Flood Management Lower Moshi

Final report

Delft University of Technology
FT Kilimanjaro

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GENERAL NOTICE TO THE READER

In the academic programme for Hydraulic Engineering at the TU Delft there is an opportunity in the fourth year (i.e. in the first year of the Master Programme) to do a project in a group of four to six students, called "Master Project". The work should be integral, starting with terms of reference, and ending with the real design. This can be a structure, but also it can be a harbour lay-out, a policy plan design, etc. The total time available for the project is in the order of two months and will provide 10 European Credits. It has to be practical and applied.

It is certainly not a M.Sc. thesis assignment (the thesis work is individual, 6 months and more focused on research or advanced design work on details). But it is also not an apprenticeship, internship or traineeship where the student has to work together with a group of experienced people. For this group work, the group has to solve the problem on their own (of course with guidance).

This report is the result of such a Master Project. This report has been assessed by staff of TU Delft. It has been provided with a passing mark (i.e. a mark between 6 and 10 on a scale of 10), and consequently considered sufficient for publication.

However, this work has not been fully corrected by TU Delft staff and therefore should be considered as a product made in the framework of education, and not as a consultancy report made by TU Delft.

The opinions presented in this report are neither the opinions of TU Delft, neither of the other sponsoring organisations.

Department of Hydraulic Engineering
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COLOFON

This report is written by Jaap Borghans, Tom van Eijk, Anke Luijben, Cornel van Zaal, Sophie van Zanten and Wessel van der Zee (all Master Civil Engineering, Delft University of Technology). Together we form the Project Group of Flood Management Lower Moshi.

Flood Management Lower Moshi

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Disclaimer: This report contains the final result of a Master Project performed by six master students from Delft University of Technology. The information is provided by the Project Group of Lower Moshi Flood Management. It includes general statements based on fieldwork, scientific research, different literature and interviews. The information contained in this report is intended for general use, to assist public knowledge and discussion and to help find a suitable solution to manage the flooding in the lower Moshi area. Readers are advised and need to be aware that this information may be incomplete or unsuitable for use in specific situations. The authors do not assume liability of any kind whatsoever resulting from any person's use or reliance upon the contents of this document.

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Date: January 2015, Moshi

PREFACE

In our master's program at the faculty of Civil Engineering of Delft University of Technology we have the great opportunity to do a so called multidisciplinary project. The purpose of this project is to integrate several specialisations and use the gained knowledge to solve a civil engineering related problem.

This report is the result of such a multidisciplinary project. In the beginning of 2014 we joined as a group to find a suitable project. With the help of Ir. H.J. Verhagen we came in contact with FT Kilimanjaro, an NGO in Tanzania that helps develop communities south of Moshi.

The report that is in front of you could not have been achieved without the invitation and support of our hosting organisation FT Kilimanjaro. Special thanks go to Gerbert Rieks for welcoming us and helping us with arranging all practical issues. In addition we would like to thank James Ashire for organising and supporting our fieldwork trips and Joris de Vries for his suggestions and feedback on our research.

Secondly, we would like to thank our supervisors from Delft University of Technology. As main supervisors we got a lot of feedback from Ir. H.J. Verhagen and Ir. W.M.J. Luxemburg. Especially considering fieldwork, their experience was really helpful to obtain the needed data. We also would like to thank Prof.dr.ir. van der Zaag for bringing us in contact with Jeremiah Kiptala and Hans Komakech of UNESCO-IHE. They were very helpful in providing us discharge data and bringing us in contact with the Pangani Basin Water Board.

From the Pangani Basin Water Board we would like to thank mr. Basso and mr. Philipo for their involvement in our research. Also we would like to thank mr. Riwa and mr. Stanley of the Pangani Basin Water Office for assisting us during our project with data and knowledge.

Furthermore, special thanks go to Yann Hardi of TPC. Yann has provided us with useful (and also frequently used) data, showed us around in the area and was involved throughout the project. For the involvement in our project and the fruitful discussions that we had we would also like to thank Joseph Gadek, an engineering advisor for FT Kilimanjaro. Also, for the support and involvement throughout the project we thank Albane Gaudissart as project manager of the TATU project.

A last big word of thanks goes out to the different sponsoring organisations for the financial support they provided us with.

Moshi, 15 January 2015,

Project group Flood Management Lower Moshi

PARTNERS

Host:

FT Kilimanjaro
http://www.ftkilimanjaro.org

Sponsoring organisations:

Mobilis
www.mobilis.nl

IHC Merwede Foundation | Royal IHC
www.ihcmerwede.com

Delft Infrastructures & Mobility Initiative (DIMI)
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Nederlandse Hydrologische Vereniging
www.nhv.nu

BT Geoconsult BV
www.btgeoconsult.nl

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THE PROJECT GROUP

As six master students of Civil Engineering with different specialisations we form the project group of Flood Management Lower Moshi. From November 2014 until January 2015 we worked on this project in Tanzania. The goal was to understand the flooding problems that arise in the rainy seasons and to come up with a solution on Flood Management.

Figure 1: Project group in front of the Kikuletwa River. From left to right: Cornel van Zaal, Wessel van der Zee, Sophie van Zanten, Tom van Eijk, Anke Luijben, Jaap Borghans.

Within the project group master tracks and specialisations differ:

Jaap Borghans	Structural Engineering – *Hydraulic Structures*
Tom van Eijk	Hydraulic Engineering and Water Resources Management – *Hydraulic Structures*
Anke Luijben	Water management – *Hydrology*
Cornel van Zaal	Hydraulic Engineering – *Hydraulic Structures*
Sophie van Zanten	Hydraulic Engineering – *Coastal Engineering*
Wessel van der Zee	Hydraulic Engineering – *Coastal Engineering*

STRUCTURE OF THE REPORT

This report is the result of a work of research done to understand the problem of floodings in the Lower Moshi area and a search for an adequate solution. This study was a cyclic process of refinement, consisting of two successive phases: the analysis and the synthesis. Both are freestanding parts and can therefore be read individually without the need of additional information. The report is finalised with a conclusion and recommendation. Appendices are written for a detailed insight into different subjects concerning the analysis and solutions.

Before the actual analysis starts, the reader will get a short introduction in what the problem, research goals and the project area are.

Part A, the first part of this report, comprises the analysis phase, which is characterised by the understanding of the flooding problem. Fieldwork was an important source of input for this phase. This part starts with a description of the system within the project area. Here, a description of the different elements in the problem area is given. In the following section the stakeholders that have their interest in this area and influence on the solution are described. This is followed by a chapter that elaborates on the flood extent. In this chapter the yearly occurring floods are mapped and investigated. In order to understand what enters the project area and how it evolves in the area of interest, an analysis on discharges has been done in the next chapter. This chapter also presents the current capacities of the system and the design discharges on which the solution will be elaborated on. Next, the influence of the water use of TPC on the system will be discussed. The last chapter describes the Nyumba ya Mungu reservoir, and treats the influence of the reservoir on the system.

Part A: Analysis is specifically interesting for readers that have a hydraulic background or are interested in the cause of the flooding problem.

In part B, the second part of this report, the actual integral solution is formed and described. Readers that are interested in the actual final solution are advised to skip the first three chapters of part B. In these chapters the alternatives are discussed and evaluated, leading to possible solutions for the problem. The final product is one final integral solution that comprises different clusters of solutions. The chapter on the integral solution starts with a short introduction in which the head scenario is described and the clusters it comprises of. Based on these clusters, the design of the proposed solution is presented. The chapter concludes with an advice on how to phase the implementation of the solutions.

To conclude all the above parts, part C: Conclusions & Recommendations has been written. First, this chapter clarifies the defined project goals and evaluates them. This part consists also of limitations of this research which have to be taken into account. At last, an advice for further research is given.

The final part D of this report consists of the appendices made in all stages of the project. These appendices are a supplement to the report, and contain more detail on specific subjects.

For readers with a limited amount of time, the authors advise to read the introduction followed by the summary and at last the conclusions and recommendations.

SUMMARY

In 2014, FT Kilimanjaro (FTK) extended their area of interest from the eastern part of Lower Moshi to the southern Lower Moshi area in order to void poverty and despair in this place. This southern Lower Moshi area is situated south of TPC; a large sugarcane plantation in the North of Tanzania, south of Mt. Kilimanjaro. After the exploratory interviews with the villagers, conducted by FTK, it appeared that their biggest troubles are the result of the yearly floods. In order to solve their main troubles, the cause of the problem had to be further investigated. This is the main reason why this research has been conducted and this report has been written. The goal of this study is to understand the flooding problem and to come up with practical solutions for this problem.

The problem area of lower Moshi is bounded by TPC in the North, the Kikuletwa River in the West and the Nyumba ya Mungu reservoir in the South. The Kikuletwa River that is adjacent to TPC, enters the project area in the North. Afterwards, it splits up into two branches: the Ronga River and the Kikuletwa River. The problems with flooding are most severe along the Ronga River. East of the Ronga River, the villages are located on higher ground and do not suffer from the floods.

Analysis:

During the analysis phase, the problems were investigated more thorough. Data was gathered, fieldtrips were made and interviews were held. All information was used to analyse different fields of study, which resulted in an analysis on the system, the stakeholders, the flood extent, the river discharges and capacities, and the influence of the Nyumba ya Mungu (N.y.M.) reservoir.

The system analysis includes both the general problem and the different elements the problem area consists of. The general problem are the floods which occur during the rainy seasons. In this region two rainy seasons are known, a short rainy season and a long rainy season. The short rains occur from October to January and can be very unpredictable. The long rains occur during March, April and May and keep the area inundated for weeks. However, due to their unpredictability, short rains are the main problem to farmers. Besides the farming land, houses and communities are affected by the floods as well. In the problem area several (sub) villages are located that belong to two main villages, namely Mikocheni and Chem Chem. Next to the settled communities, Maasai are also living in this area.

The stakeholder analysis evaluates all the interests of the several parties involved. Most important to the project are the villagers, since most of them are farmers and are willing to save their crops. Furthermore, Maasai move their cattle on all kinds of land, looking for fresh vegetation and water they also pass over farmers land. This can lead to conflicts with local farmers.

TANESCO is the Tanzania Electric Supply Company and is responsible for the power plant downstream of the Nyumba ya Mungu reservoir. Since the dam is owned by TANESCO and their interest is to supply as much electricity as possible, no interventions can be done at the dam for water management purposes. Proposed measures should not lead to a decrease of water flow into the reservoir, because water output should be maintained.

Since the Pangani Basin Water Board is in charge of all rivers of the Pangani Basin, they are an important stakeholder. Every implementation of a solution has to be acknowledged by the board.

By fieldwork and interviews with village elders, the extent of flooding was determined. It has been found that every year during the long rains the area along the Ronga River is flooded. The villages themselves are not affected by river floods, but suffer from rainfall that is not drained. Also, the

area west of the Kikuletwa and the area of Majengo-Samanga is flooded, due to overflow of the northern part of the Kikuletwa.

During the short rains, mainly the farming land of Mikocheni and Chambogo is affected. The flood starts around the point where the Ronga River starts braiding. This specifically happens at points where the river capacity is the lowest.

As a result of the discharge capacity analysis of the different sections of the river system, it was found that about 95 % of the water of the (Northern) Kikuletwa flows eastwards into the Ronga River. The other 5% continues southwards in a small channel: the Southern Kikuletwa. The capacity of the Ronga River just after the bifurcation is lower than the capacity of the (Northern) Kikuletwa River. At the point where the Ronga River starts braiding, the discharge capacity decreases even more.

The design discharge that was used in order to come up with a solution, was derived after analysing the yearly maxima of discharges. A design discharge has been calculated for both the short and long rains. During the long rains, the Kikuletwa River will already overflow before entering the problem area. Therefore, the normative discharge of the long rains is altered due to this phenomenon.

In order to understand the flooding problem, the influence of the reservoir on the floods was investigated. Given the fact that equilibrium depths are much higher than the possible water depths in the rivers (and thus the half-length of the backwater curve are very short), it can be concluded that the reservoir will not influence the water levels in the rivers.

A large part of the project area is owned by the Ministry of Water of Tanzania and managed by TANESCO. This land is used for flooding in case of high reservoir levels. While some farmers tend to grow crops in this area, no real villages are present here. It is known that the maximum reservoir levels are only reached once in the 10 years, due to a sequence of extreme rainy seasons.

Synthesis

The synthesis entails the solution for the different problems. The main problem during this phase was the fact that the floods needed to be prevented during the short rains, while the rivers should be overflowing during the long rains. A brainstorm was conducted which resulted in 18 possible solutions. The solutions were ranked according to 6 criteria; Reducing negative effects of flooding, Enhancing positive effects of flooding, Tangibility and Support, Durability, Constructability and Costs. Based on the weight of these criteria a list of best solutions was formed. A combination of the best scoring solutions resulted in the integral solution which was further elaborated. This combination of solutions is necessary because one single solution could not solve the problem as a whole.

The integral solution can be divided into core measures and additional measures. The core measures are measures that are definitely needed and should be implemented. The additional measures can be conducted if the core measures seem to be inadequate or to increase the effectiveness of the total solution.

The first core measure is to open the Chem Chem river bed to increase the discharge capacity for a large part of the Ronga. A new channel has to be constructed in between the old river bed and the Ronga river to avoid the newly built road and a school. A control structure is constructed at the bifurcation point between the Ronga and the new Chem Chem channel to control the river discharge. A tube ensures year round water flow and a heightened spillway ensures minimum water flow in the Ronga while diverting enough water in the Chem Chem river.

The second core measure is to widen the narrow part of the Southern Kikuletwa for a distance of 3.45 km and connect it to the wider part of the Kikuletwa south. This increases the capacity of the Kikuletwa South, which again increases the total river capacity from the main bifurcation point; where the Kikuletwa North splits into the Ronga and the Kikuletwa South. A control structure is proposed at this location to control the water inflow throughout the year. It is based on the same principle as the Chem Chem river control structure, but is somewhat larger. The widened channel will have a width of 15 meter.

The third core measure is to construct a dike along the Northern Kikuletwa. In order to do so, the old dike breach should be restored and the dike will be extended to the main bifurcation. The dike will prevent water from flowing into the Samanga area during the short rainy season. A spillway overflow structure will ensure water flowing into this area during the long rainy season. This will ensure that the salts in the soil are flushed away and new sediment is deposited in this area.

All control structures will be adjustable by adding large concrete blocks which can only be moved by heavy machinery. This way of constructing ensures that the villagers cannot adjust the structure, but it is adjustable by FTK when it is found necessary to do so.

The first additional measure is to construct short rain dikes along the Ronga river in order to prevent floods during the short rains. This solution can assure no flooding during the short rain, but needs heavy maintenance and cooperation from all the farmers in the area.

The second additional measure is to construct drainage channels in between the farmland to release the inundated area from the surplus of water. This is a relatively easy mitigating solution, but does not solve the problem of flooding.

It is advised to execute the measures in the presented order. Following the prescribed order, lessons can be learned from the relative low labour-intensive opening of the Chem Chem River bed, and applied to the tough job of widening the Kikuletwa South. The effect of the first two measures can then be taken into account when making the final design of the dike and the overflow structure at Samanga.

TABLE OF CONTENTS

1 INTRODUCTION

The project is located in Lower Moshi, Tanzania. Lower Moshi refers to the area comprising the TPC sugar estate and surrounding villages south of Moshi, and is part of the Moshi Rural District. More specifically, this report focuses on the villages Mikocheni and Chem Chem. An extensive river system runs through the project area, eventually feeding the Nyumba ya Mungu reservoir. This river system is mainly fed by the Kikuletwa River that displays two distinctive discharge peaks: during the short rainy season (November – January) and the long rainy season (March – May). The area is prone to annual flooding. The capacity of the river system is not big enough to discharge the precipitation fallen in the rainy seasons in the catchment, mainly on Mt. Kilimanjaro and Mt. Meru.

In the past, the river used to have different trajectories. The biggest branch of the current river system in the area, the Ronga, was formed in 1991 after a major flood. The discharge capacity of the old trajectory had been reduced in the previous years due to accumulation of debris in the cross-section.

The floods have both positive and negative effects. On one hand it destroys the crops and makes large parts of the area inaccessible for months, on the other hand it brings fertile sediment and reduces the salinity of the soil that would otherwise make farming impossible. Due to their unpredictability, the floods caused by the short rains are the main concern of the farmers.

In this report the flooding problems of the Mikocheni and Chem Chem areas are studied. A solution for these difficulties will be developed in terms of flood management. The main focus is on both the positive and negative effects the floods have on agriculture. Paragraph 1.1 provides the reader with background information on the project and problem area. This will lead to a problem definition and a problem goal defined in paragraphs 1.2 and 1.3. The structure of the report has been described on page viii.

1.1 PROJECT AREA

The project location is situated in Tanzania. Tanzania is situated in the East of Africa, visualised in the overview in Figure 2.

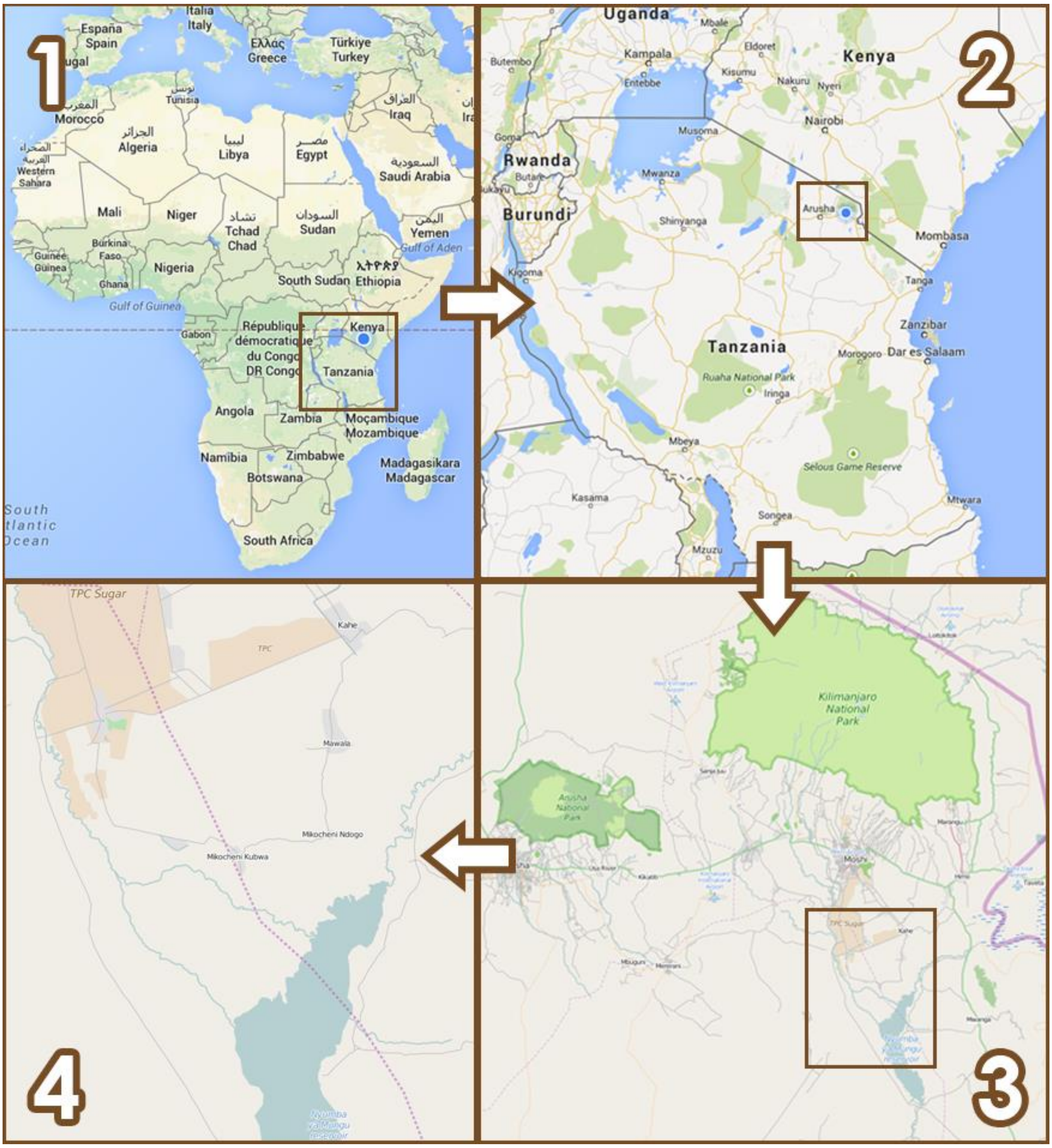

Figure 2: The project location

Tanzania borders the famous Lake Victoria in the North West, the Indian Ocean in the East, and is also home to the Mt. Kilimanjaro, the highest mountain on the African continent. Mt. Kilimanjaro is situated just north of the town Moshi and is very close, a rough 50 kilometres, to our project area. Mt. Kilimanjaro is indicated in Figure 2.3 (bottom right) in light green. The project area is located south of Moshi. This area is called Lower Moshi. A distinction should be made between the project area and the problem area:

- The project area is the area that is of influence to the problem area and the proposed solutions. This area is shown in Figure 3 as a green line.
- The problem area, which suffers from the floods and for which changes can be proposed. This area is shown in Figure 3 in red.

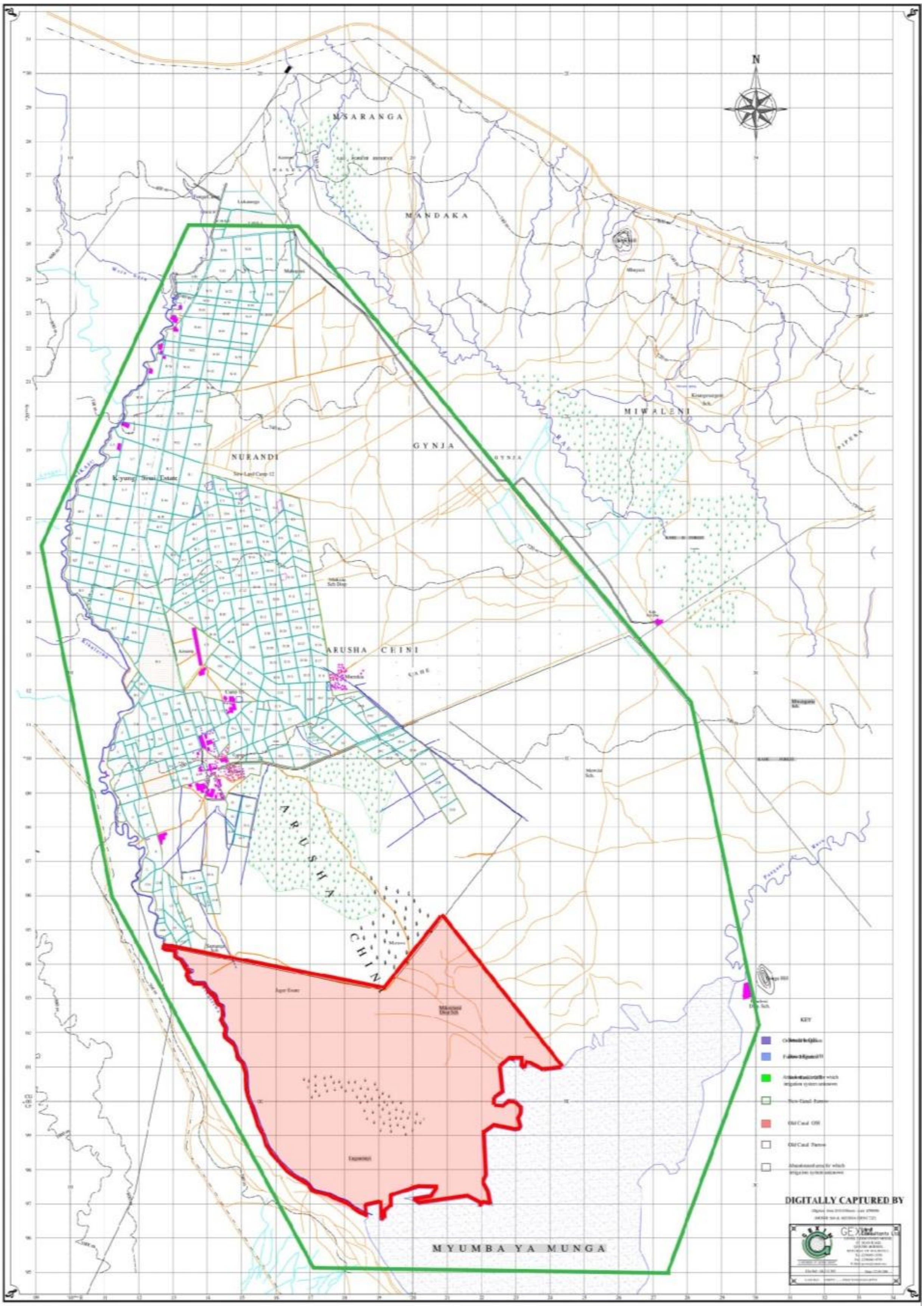

Figure 3: The project area including the problem area (red)

In Figure 4 the problem area is shown in more detail. This figure shows the different villages and sub villages. For clarification of this report some background on the administrative units in Tanzania and the project area is provided in 0. There are two villages in the area; Mikocheni and Chem Chem. Villages are subdivided in sub villages. Chem Chem consists of the sub villages Majengo, Kijijini, Miswakini and Chambogo. Mikocheni consists of the sub villages Kirungu, Mikocheni Kubwa (Mikocheni A), Mikocheni Ndogo (Mikocheni B) and Masaini.

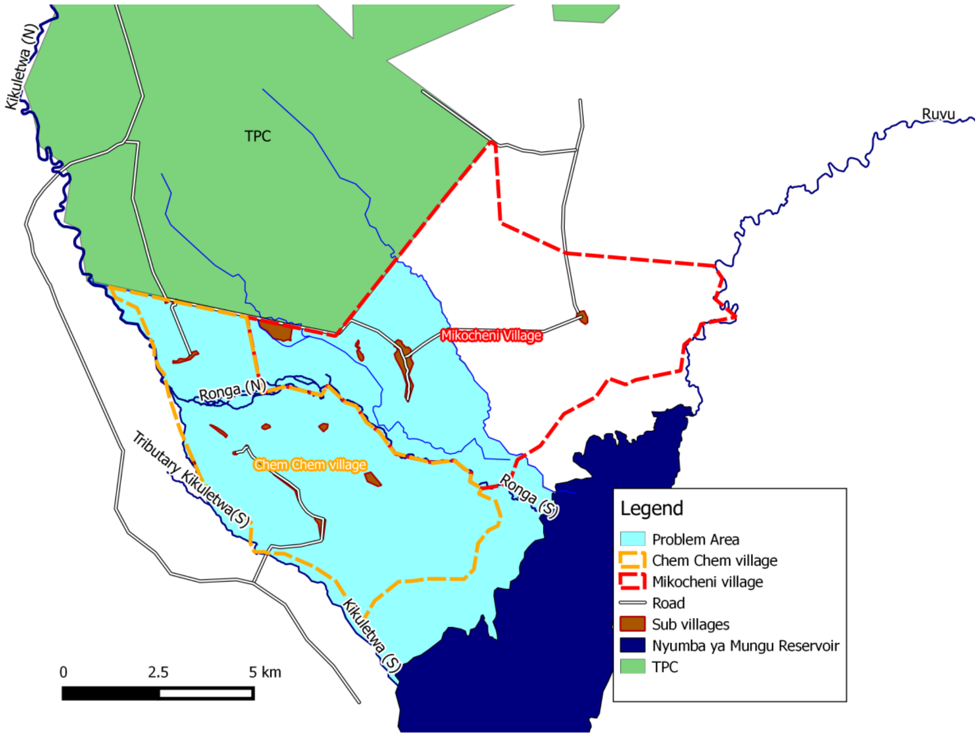

Figure 4: The problem area and its surroundings (light blue)

1.2 Problem Definition

The problem has been introduced in the previous paragraphs. In short, the problem can be described as follows:

> *"The yearly flooding of the land has negative consequences on farming activities specifically and generally on community infrastructure and livelihoods. The severe long rains make farming during this season impossible, cause damage to the infrastructure of the villages and hinder the development of the area. The unpredictability of the short rains leads to destruction of crops."*

1.3 Project Goal

From the problem definition a goal for the project has been defined:

> *"To understand the flooding problem in the problem area and find a durable, inexpensive, constructible and socially acceptable solution, which enlarges the positive and diminishes the negative consequences of the river floods."*

To achieve the goal, different phases have been executed. First an analysis on the problem, the elements in the environment and the stakeholders has been performed. The results of the analysis have been used to form an integral solution to the problem. Finally a conclusion is drawn and further recommendations are given.

Part A: Analysis

Figure 5: Aerial picture of dry river bed and Ronga, flowing towards the reservoir

2 SYSTEM ANALYSIS

In this chapter the system analysis is presented. First, the general problem is discussed, followed by the description of the different elements the problem area consists of. Roughly the system consists of the following elements:

- The reservoir;
- The rivers;
- The villages;
- TPC and its drains;
- The soil.

2.1 GENERAL PROBLEM

The main problem of the floods is the loss of harvest. Next to that, houses and communities are occasionally affected due to the floods. Sanitation problems and damaged infrastructure are not considered to be the main consequences of the floodings. However, results of a base survey [1] conducted in the summer 2013 showed that health problems arise due to still standing water and debris floating around.

There are multiple causes for the floodings. Part of the project area is flooded due to a rise of the reservoir. This will be elaborated later. It is also suspected that the high water table might have an influence on the river floodings. The cause and consequence flowchart is shown in Figure 6.

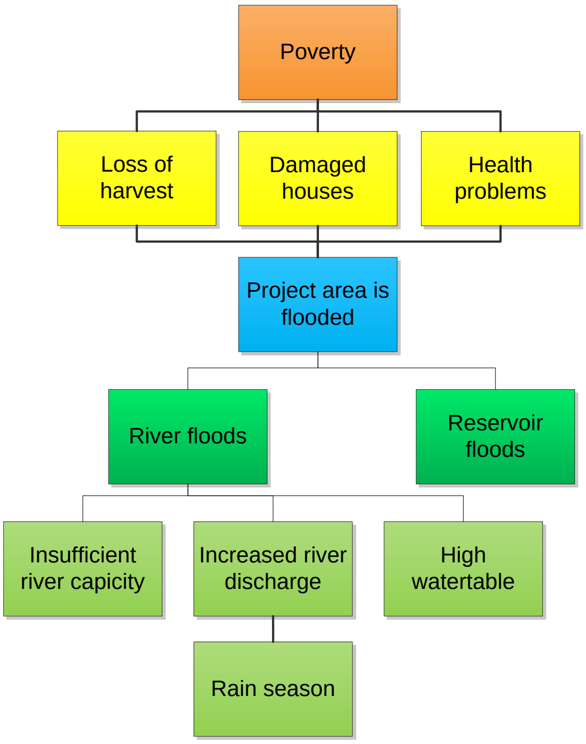

Figure 6: Cause and consequence flowchart

The flooding starts with heavy rains in the rain season. The rain that is gathered in the rivers originates from a large catchment, leading to high river discharges in the rivers near the project area. The rivers have insufficient capacity to bear these large discharges, leading to floods in the project area.

The project area has a water table very close to the surface. When the water level in the river is lower than the ground level, the soil layer is still unconfined. The precipitation can then reach the river by groundwater flow. In case of water levels close to ground level or even higher than ground level, the soil becomes saturated. At this moment there is no lower water table nearby to discharge the water via groundwater flow. Therefore it will run-off over land towards the reservoir or remain on the surface area until it evaporates or infiltrates. As a result of the high water table only a bit of water can be stored in the subsurface.

As a result of the enormous catchment in combination with heavy rains, the most important causes for the river floods are the increased river discharges and the insufficient capacity of the river system. Discharges and high river floods will be further discussed in Chapter 5.

The study will not elaborate further on the influence of the geohydrology and water table in the area. This is due to the fact that such a study can only be performed in detail and it is impossible to do it in the time scheduled for the project.

The reservoir floods are caused by an increased water level in the Nyumba ya Mungu reservoir. The reservoir floods will be treated in detail in Chapter 7.

The harvest of crops is the main activity in the surrounding areas of the rivers. An important part of the problem is that the water of the rivers is also used for irrigation, especially during the dry season. Irrigation is most often done by blocking the rivers and leading water in to small ditches dug through the natural banks. Several problems arise due to irrigation, river capacities are reduced and irrigation channels form weak spots in the banks for water to enter surrounding farming areas.

Short and long rains

The long rains occur during the months March, April and May. The short rains are more unpredictable and might occur from October to January. The farmers active nearby the Ronga have made clear to the client that the main problem of the floods is the unpredictability of them. If there would only be one flood a year, farmers could anticipate on this phenomenon. However, floods often, but not always, occur more than once a year: up to three times a year is the conclusion of a survey conducted by FT Kilimanjaro in 2013.

The main problem are thus the short rains which are very unpredictable. The result is that farmers do not know when to start planting their crops. At the moment, farmers tend to replant after a flood, as the soil is moist and fertile at that time. Damage occurs when these young plants are flushed away in the next flood of that year. It is important to realise that all villages are inundated during the long rains. Regarding the short rains, some areas of the villages are inundated during this rain season and some are not. This will be elaborated in Chapter 4.

2.2 Reservoir

The problem area is bordered in the south by the Nyumba ya Mungu reservoir. It is indicated in Figure 7. This reservoir facilitates the Nyumba ya Mungu Hydropower Plant. Two organisational bodies are responsible for the operation of this dam [2]:

- The Pangani Basin Water Office, which is responsible for the water management of the reservoir;
- TANESCO, which is responsible for the operation and maintenance of the Hydropower Plant.

The interests of both organisations is further explained in the stakeholder analysis, Chapter 3.

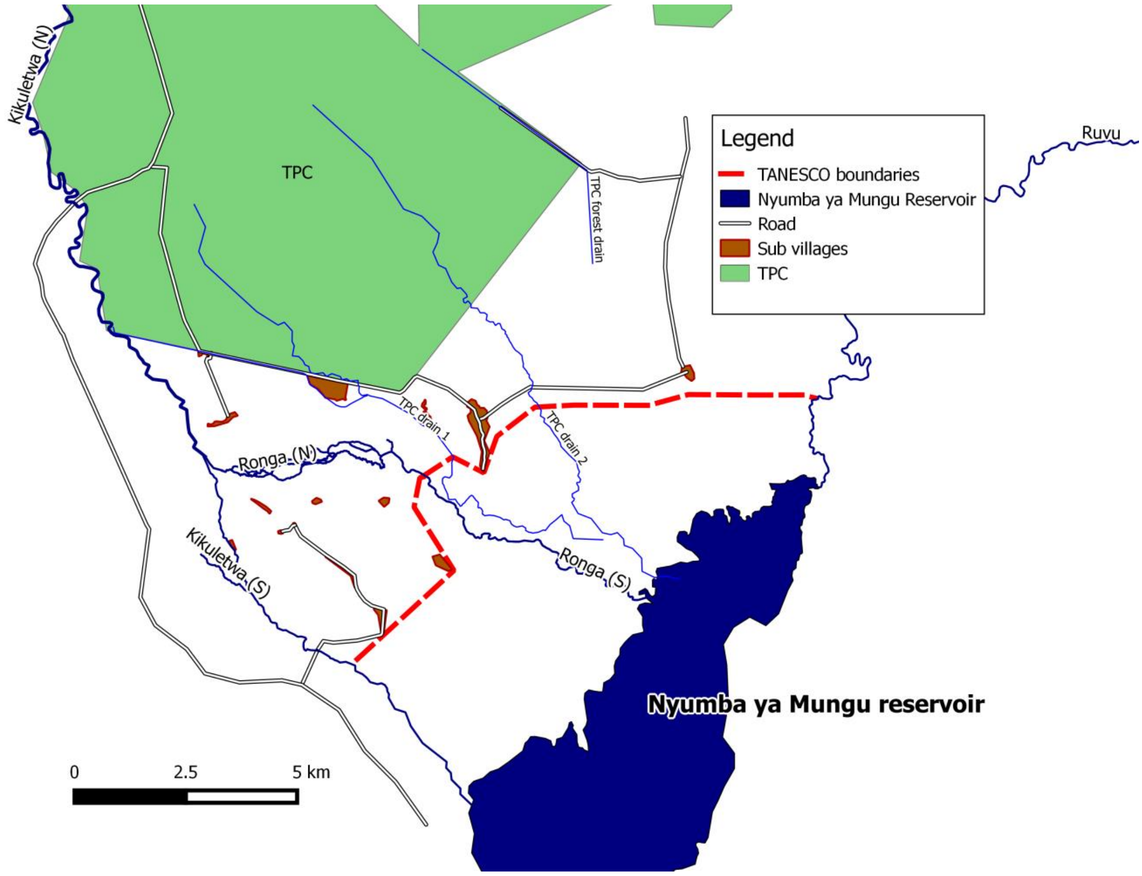

Figure 7: The Nyumba ya Mungu reservoir and the TANESCO boundaries

TANESCO (Tanzania Electric Supply Company Limited) is a power supplier fully owned by Tanzania. It also operates two other hydropower plants in the Pangani Basin. TANESCO is the owner of a lot of land in the south of our project area, the border is shown in Figure 7. This land is inundated from the reservoir side in case of high water levels of the Nyumba ya Mungu reservoir, which is the reason why it is owned by TANESCO.

The TANESCO area is prone to floods, which is logical as this land is meant for flooding. It is therefore not the aim of this project to find a solution for the flooding of this area. However, a higher water level in the reservoir may lead to higher water levels in the river upstream of the TANESCO border, due to backwater curves. This will be elaborated in paragraph 7.2.

2.3 RIVERS

The river system plays an important role in the flooding problem. The transport of water to the problem area and the insufficient capacity in the problem area lead to the floodings. In the paragraphs below, the rivers are shortly described. An overview can be found in Figure 8. The analysed system is part of the Pangani basin. This basin is illustrated in Figure 9, the analysed system is indicated in red.

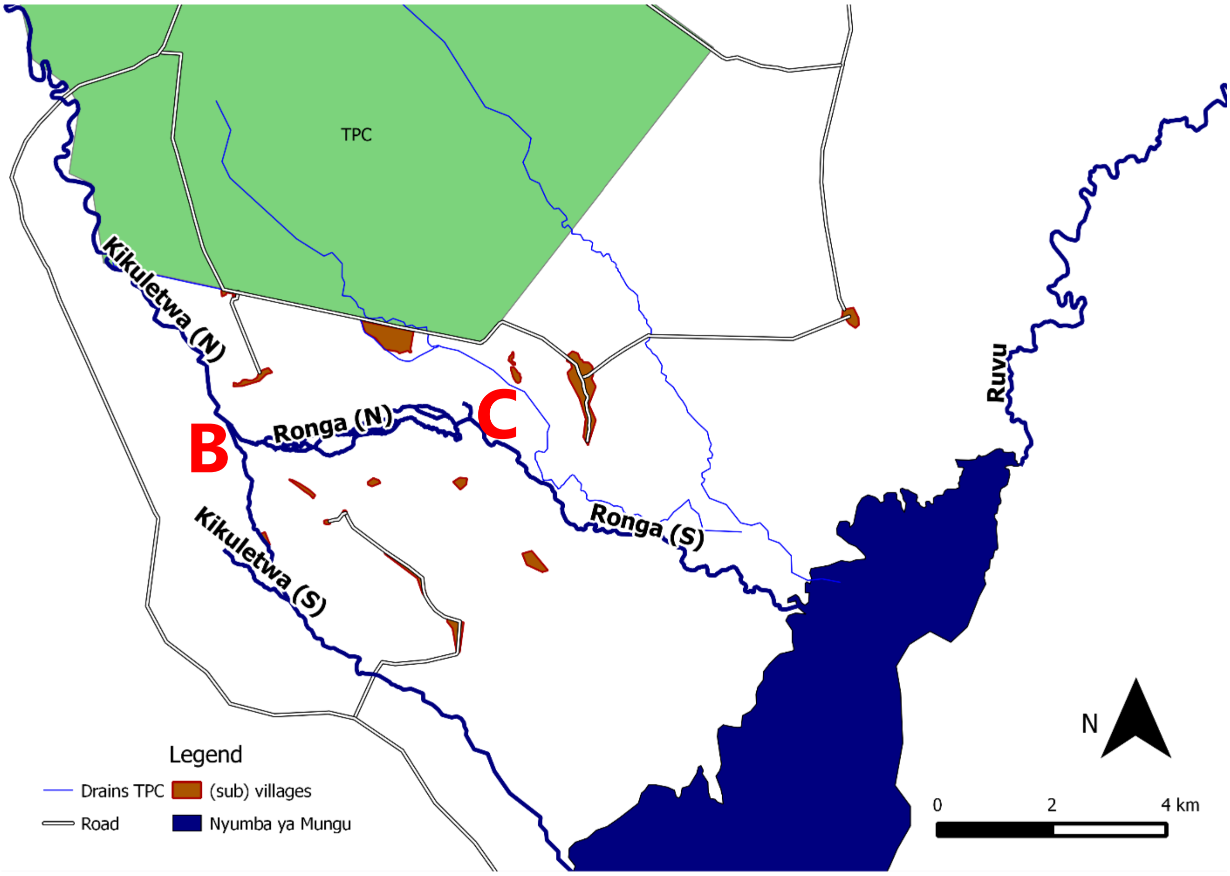

Figure 8: The river system, B=bifurcation, C = confluence

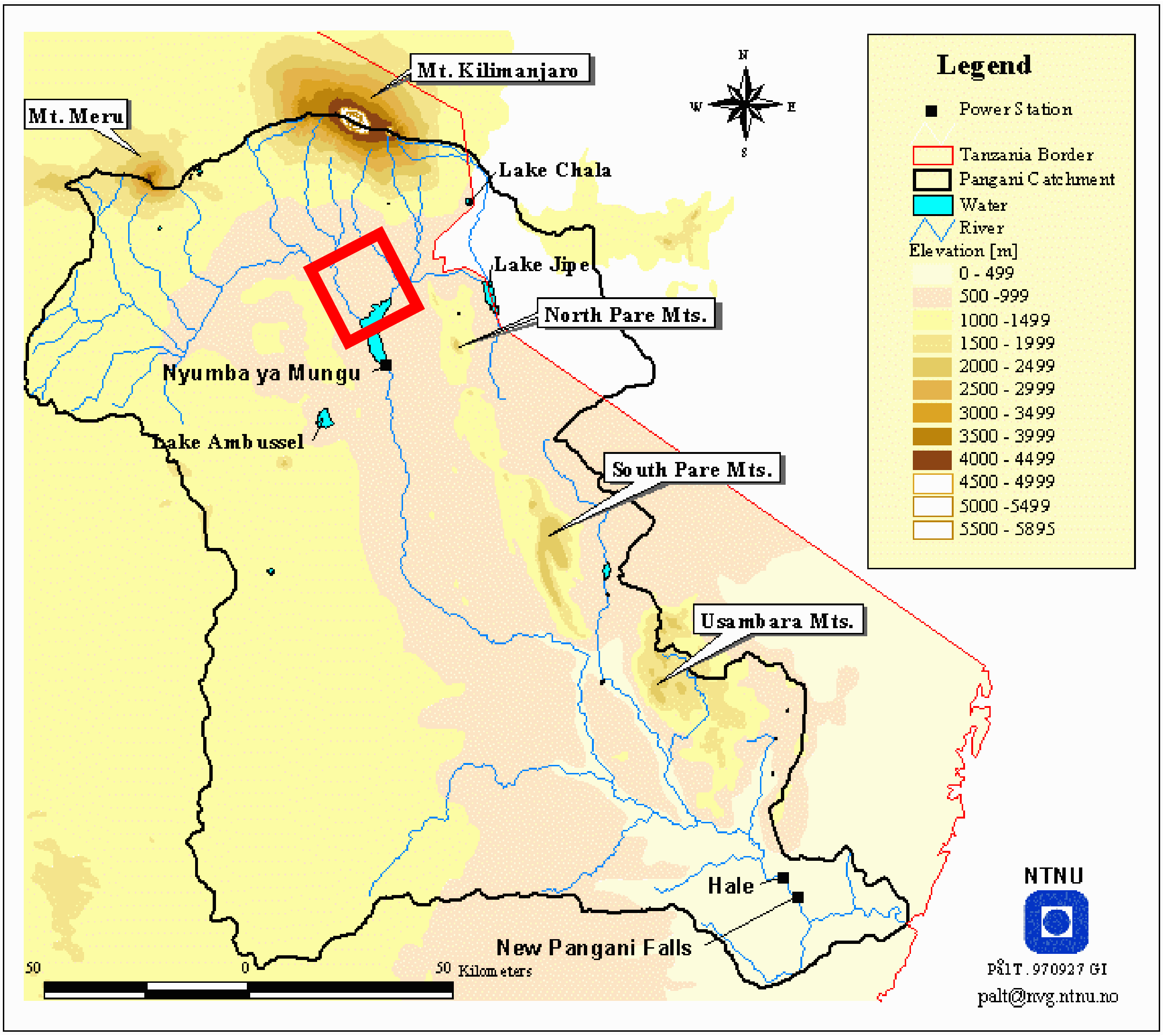

Figure 9: The Pangani basin with the analysed river system in red (source: ntnu.no)

2.3.1 Kikuletwa

The Kikuletwa is the river that conveys most water from the North into the problem area. Its catchment reaches until Arusha about 80 kilometres away from the project area. Chapter 5 (Discharge analysis) describes the catchment in more detail. In the past, the river had different trajectories which have been further elaborated in Appendix B. Earlier studies show that the Kikuletwa used to have a trajectory more eastern through current TPC-land. Its monthly averaged discharges can be seen in Figure 10. It can be seen that the base flow increases significantly from March to June.

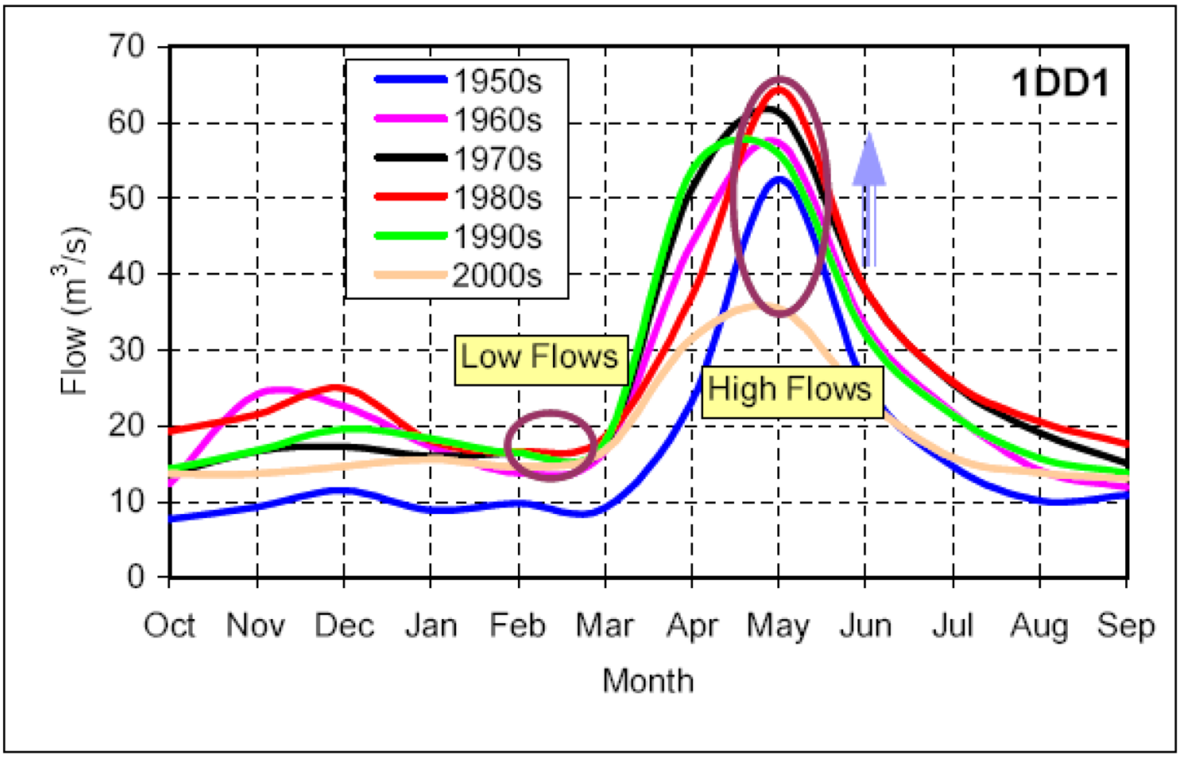

Figure 10: The monthly averaged discharges of the Kikuletwa measured upstream of the problem area [3]

2.3.1.1 Kikuletwa (N)

The Kikuletwa North runs from the north of the problem area to the bifurcation, indicated with a 'B' in Figure 8. Within the problem area it has a length of 4.45 km. The capacity of this stretch is calculated in Chapter 5 (Discharge analysis). A point of interest is the dike breach present at the east side of the river near Samanga-Majengo. Begin 2014 the newly constructed failed at the point where flood gates are present.

2.3.1.2 Kikuletwa (S)

The Kikuletwa South runs from the bifurcation 'B' in southwards direction to the reservoir. It conveys the minority of the water to the reservoir. It can be divided into two parts: the Kikuletwa Small (3.45 km) starting at 'B' and the Kikuletwa Wide (6.2 km). The capacity of these stretches is calculated in Chapter 5 (Discharge analysis).

2.3.2 Ronga

The Ronga, was formed in 1991 when a big flood occurred. The Kikuletwa was jammed with debris, which made the river change its path. It conveys the majority of the discharge towards the reservoir, see Chapter 5 (Discharge analysis).

2.3.2.1 Ronga (N)

The Ronga North runs from the bifurcation 'B' to the confluence 'C' in Figure 8. The first 0.8 km it has one river bed. From then on different branches are present. This continues for 5.65 km up to point 'C'. The capacity of this stretch is calculated in Chapter 5 (Discharge analysis).

2.3.2.2 Ronga (S)

From point 'C' in Figure 8, the river continues to have one river bed for another 5.7 km. It then reaches the reservoir. The capacity of this stretch is calculated in Chapter 5 (Discharge analysis).

2.3.2.3 Local measures

Along the Ronga, a local farmer took initiative to build a small embankment over a stretch of approximately 70 m, to protect his own plot. Figure 11 shows an image of it. For irrigation purposes manmade weirs, see Figure 12, made of local available materials, have been constructed as well in the same area. To reduce erosion during flooding, the farmers in Mikocheni cover the soil with grass. This is done during the long rains, when the farmers temporarily stop planting crops.

Figure 11: Manmade embankment along the Ronga

Figure 12: Manmade weir along the Ronga

2.3.3 Ruvu

The Ruvu River transports water from the North Pare Mountains east of the project/problem area towards the Nyumba Ya Mungu reservoir. When comparing the Kikuletwa and Ruvu river in discharge and location (horizontal and vertical), it showed that the influence of the Ruvu to the floods in the villages is negligible.

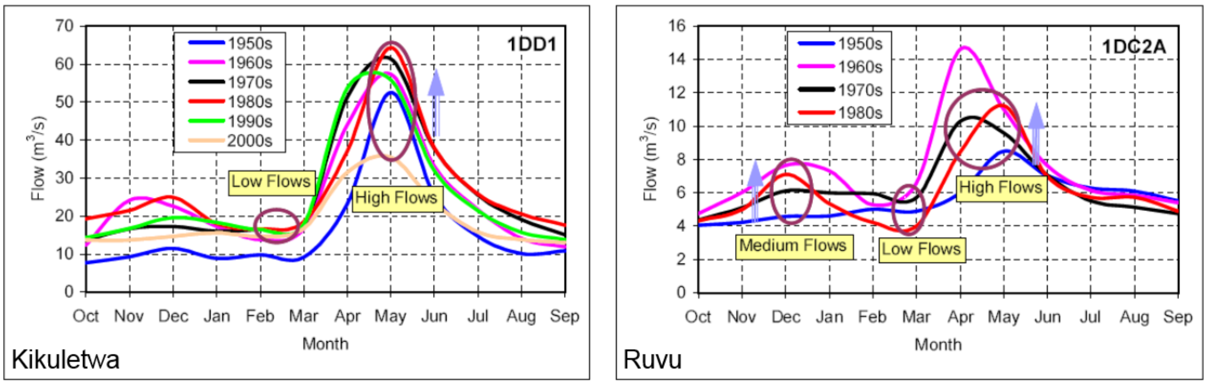

Figure 13: Monthly averaged discharges Kikuletwa (left) compared to Ruvu (right) [3]

Figure 13 shows the difference in discharge; the average monthly discharge in the rain season is 4-5 times higher in the Kikuletwa. Note that the discharges in the '2000s' are based on 5 years of measurements and no trend has been observed of lower discharges in the last years.

Apart from the difference in discharge, the Ruvu has less effect on the communities in our project area due to its location. The elevation map in Figure 14 shows the project area together with the local communities. The Ruvu River, which has its mouth in the east of the Nyumba ya Mungu reservoir, has a greater distance to the communities than the Kikuletwa River, which flows right next to the villages in the area. As one can see clearly in Figure 14, the Ruvu River enters the project area in a lower lying bed than its surrounding area.

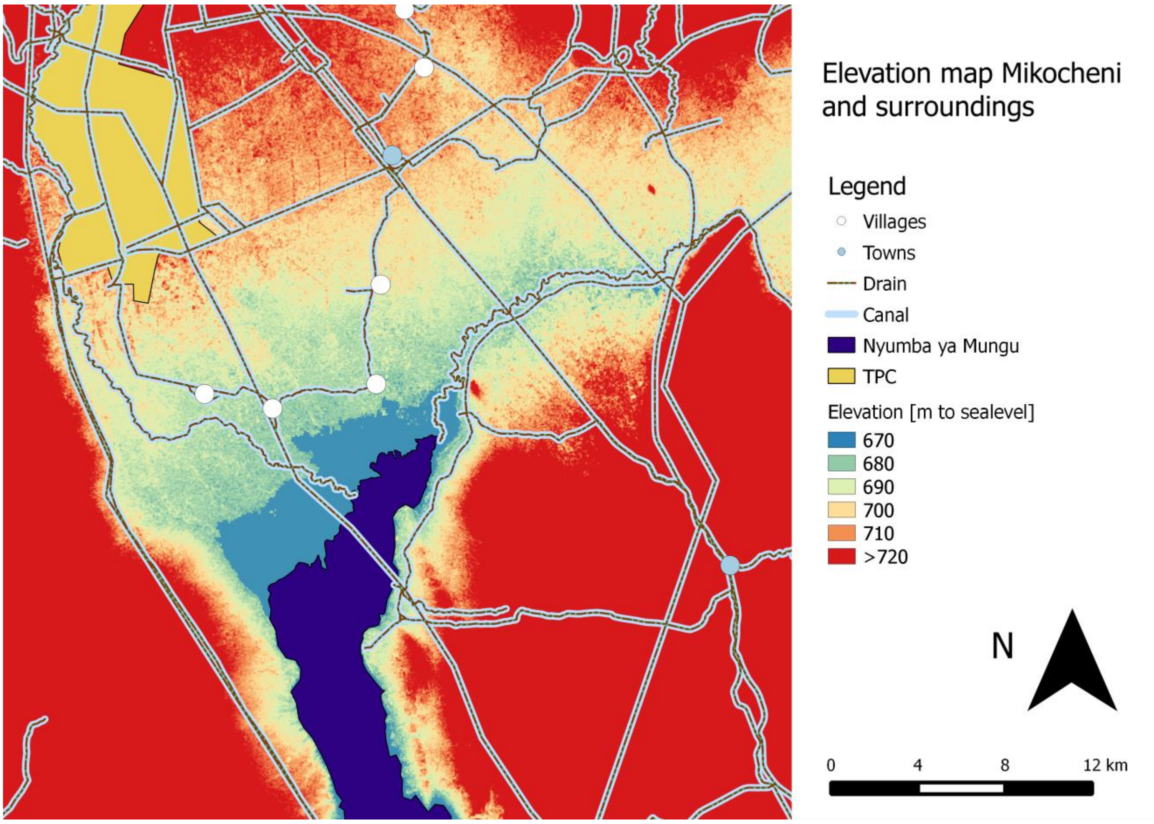

Figure 14: Elevation map of project area [4]

If the capacity of the Ruvu is insufficient, only a small area of land around the river is flooded. The water from the Ruvu will never reach the communities of Mikocheni as only land in a close proximity of the river will be flooded and these communities are further away from the Ruvu. In contrast to this, the Kikuletwa flows right next to these communities and does not have this lower bed. This has been visualised in Figure 15.

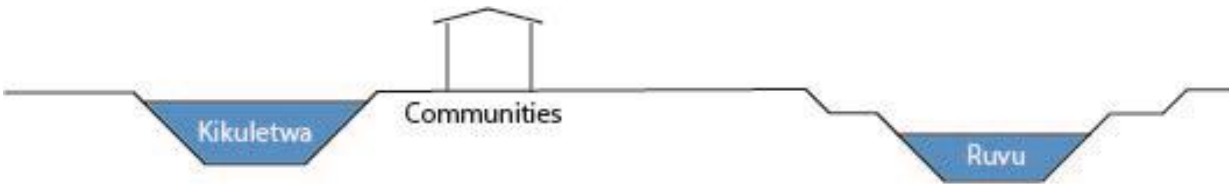

Figure 15: Qualitative comparison of the Kikuletwa and Ruvu location with respect to the communities.

2.4 VILLAGES

In this paragraph the two villages are shortly described. Their location is indicated in Figure 16. Also Maasai are living in the problem area which could involve water conflicts between local farmers and Maasai. All affected people and organisations are elaborated in the stakeholder analysis, in Chapter 3.

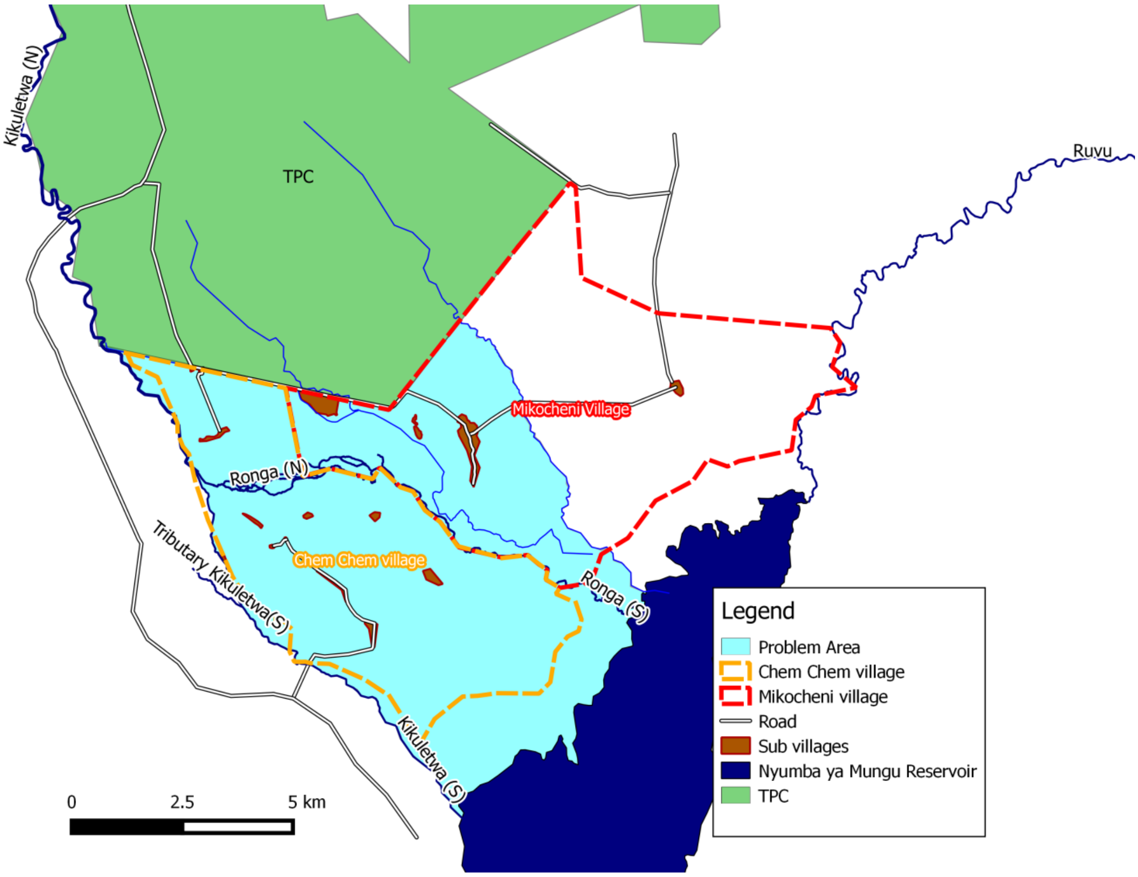

Figure 16: The villages indicated in the problem area

2.4.1 Mikocheni

Mikocheni is the village which is situated North and East of the Ronga River. It has 4460 inhabitants [5] and the area belonging to this village covers 50 km^2. The population has different occupations: fisher men, crop farmers and pastoralists. Since they are not exposed to the annual floods, the sub villages Mikocheni Ndogo and Masaini are outside problem area.

2.4.2 Chem Chem

Most of the village of Chem Chem is situated between the Kikuletwa South and the Ronga. One sub village is located north of the Ronga: Samanga-Majengo. The village has 1779 inhabitants and the area belonging to this village covers 65 km^2. Both crop farmers as pastoralists use the farming land.

2.4.3 Msitu Wa Tembo

On the West side of the Kikuletwa, outside the problem area, the village Msitu Wa Tembo is situated. This village suffers from drought, as rain that falls on the mountains in the west runs off very quickly and ends up in the Kikuletwa River. This also leads to erosion of land, clearly visible by the gullies that run from the mountains to the river, see Figure 17.

Figure 17: Dry gullies in Msitu Wa Tembo

2.5 TPC LIMITED

TPC ltd. owns a large share of land north of the problem area. For their sugar cane plantation they use a large amount of water, which is extracted from different sources in the project area. The company uses drains to lower their water table, which is beneficial for their sugar cane crops. Because of their influence on the water system in the area, it is included in the project area. Their involvement in this project, as part of FT Kilimanjaro, also shows that possible solutions might be implemented on their area. They are however not a part of the problem area, as their area is not flooded. TPC has constructed their own levee along the Weru Weru (upstream of the Kikuletwa River) and the Kikuletwa River on the eastern river bank (TPC side) as protection against high water levels and flooding. This embankment is higher than the west side of the river, preventing flooding on TPC terrain.

The influence of TPC is discussed in more detail in the stakeholder analysis, Chapter 3.

2.5.1 TPC drains

As mentioned before, TPC uses drains to lower their water table. Sugar cane does not yield well in a high water table and that is why TPC uses drains to lower the water table. The water is carried mostly southwards, into the problem area. Figure 18 shows the location of the three drains.

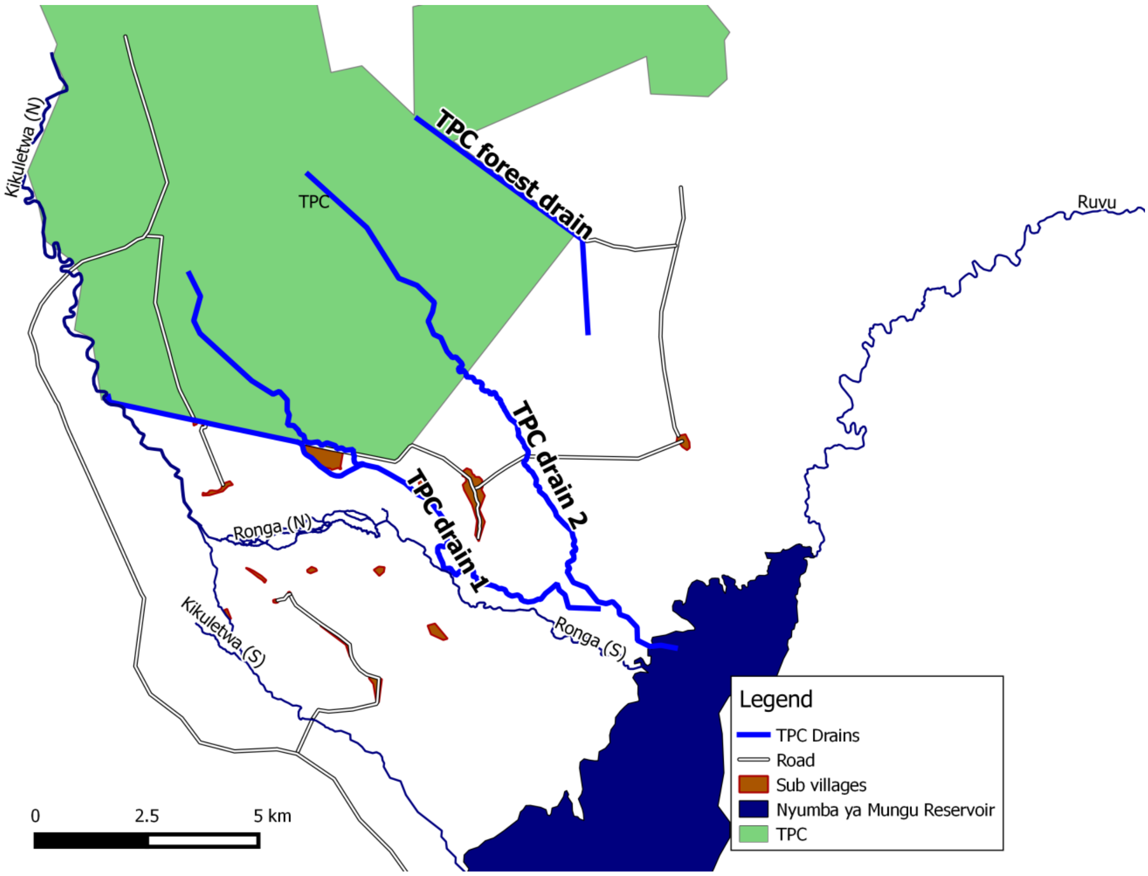

Figure 18: Location of the TPC drains

The water from the drains is reused for irrigation by the villages, but some is drained to the Nyumba ya Mungu reservoir. The problem area contains two drains flowing from TPC to the reservoir. According to the villagers, these drains currently do not contribute to the floods. TPC drain 1 forms the boundary until where the flood reaches. The drain is built around Kirungu and the bank on the Northern side is high, therefore protecting Kirungu against the river floods.

TPC does have problems with blocking of the drains by the villagers for irrigation and drinking water purposes. This is treated in Chapter 6.

Figure 19: Blockage of TPC drain 1 near Samanga

2.6 SOIL

The soil in the project area is very saline. This is a result of the saline Kikuletwa that picks up materials in its large catchment area. TPC data also made clear that there is a brackish aquifer underneath the project area. The groundwater table is close to the surface and is subject to evaporation.[6]

The local farmers use the floods to flush away salts that are present on their lands due to the evaporation. Concerns have been expressed about reducing flooding as this might increase the salinity of the farmers' lands. An optimal solution would therefore be to have controlled floods.

3 STAKEHOLDER ANALYSIS

The purpose of the stakeholder analysis is to get an overview of the activities and interests within the project area. The different stakeholders operate or live in the same or adjacent areas. Their individual activities may affect one another. An overview of these positive but also negative relations is necessary to find an optimal solution.

3.1 APPROACH

The ultimate goal, when solving a problem that affects a larger area and a large number of stakeholders, is to take into account all the different stakes. To diminish negative effects of a solution an integrated approach will be used.

There are some pitfalls in the development of a less developed area. In a larger context, Africa is a continent that is acquainted with development projects in the public area. It is not uncommon that new-implemented development works of Non-Governmental Organisations (NGO's) experience a negative output or relapse of their work. This has happened also in the area of Rural Moshi along the Ruvu River. The improvements by the Japanese International Cooperation Agency (JICA) in 1977 of the rice irrigation schemes ended up in exclusion of a part of the farmers of that area. "*Since the scheduled area was too small to be used by farmers from all villages, many villagers had to be excluded from irrigated rice farming."[7]* Sociologically, this has a negative influence on the community.

Another common problem of hydraulic related problems is the way these problems are analysed by engineers that try to solve them. Most of the attention goes to the water quantities and qualities, without taking social or cultural aspects into account: "*The second reason for failure has been poor planning, which includes failure to contextualise irrigation technology in terms of its local environment, specifically the physical and the social aspects. Part of this is because of a lack of knowledge about how the system is defined and used within its environment by local people, due to the fact that designers focus on technological models developed around quantitative approaches to hydrological and other physical data. Key social and cultural issues are nearly always missed. These include in particular gender tensions, labour constraints, cultural obstacles, agrarian institutional relations (especially land tenure) and awareness of what crops are considered as food by local people. According to Guijt and Thomson (1994), irrigation development interventions have taken on a social dynamic of their own, creating or disrupting certain relations of power among local and outside farmers, and between family members in households."[7]* The social and cultural aspects that will bind the solution should therefore be investigated and analysed.

3.2 STAKEHOLDERS

3.2.1 Villagers

There are nine distinct settlements inside the project area. Four of these are all sub villages of Mikocheni. Five of them are sub villages of Chem Chem. In the next section in Table 1: Inhabitants and Area, the different villages with their area are described. The regional borders and hierarchy are explained in the Appendix: *Administrative units in Tanzania*.

3.2.1.1 Figures

Table 1: Inhabitants and Area

Name village	Inhabitants [-]	Area [km^2]
Mikocheni	4 460 [5]	50
Chem Chem	1 779	65

3.2.1.2 Activities

After construction of the Nyumba Ya Mungu dam (1966), fishermen started to settle on the large dry plains in the village Mikocheni, originally only used by the Maasai with their cattle.. Due to decreasing fish catch, part of the fishermen started to farm the land along the Ronga River. Consequently with these developments, the available land for the Maasai and their livestock decreased. This process of retreat is still going on.

Table 2: Main activities by (sub) village [5]

Name	Fishing	Farming	Trading	Cattle breeding	Salaried job
Mikocheni					3%
- **Mikocheni (A)**	X	X	X	/	
- **Mikocheni Ndogo (B)***	X	/	/	/	
- **Kirungu**	/	/	/	X	
- **Masaini**	/	X	X	/	

X : widely practised.
/ : little practised.
**** : Mainly Maasai people***

In Table 2 the main activities per sub village are shown. These results were extracted from a population survey conducted in 2013 by FT Kilimanjaro. This survey was only done for Mikocheni village, thus no data is available for Chem Chem village. From this survey it can be concluded that Masaini is dependent on Cattle breeding, Mikocheni B on Fishing, Kirungu on Farming and Mikocheni A on Fishing and Farming.

3.2.1.3 Interest

The inhabitants of the different villages work and live in and around the problem area. The farmers represent a large part of the inhabitants of Mikocheni A and Kirungu. With the yearly flooding the harvest and therefore the main source of food is at stake. Also for the villagers it is of primary importance to solve the flooding. A conclusion of the survey of FT Kilimajaro says:

"The recurring floodings are generally recognized as the top issue facing the community, this is in line with the feedback we received from the Village Leadership. The survey team experienced the impact of and inconvenience caused by the floods in March/April when the floods turned large parts of the village into an unsightful pool of water with floating trash and debris."[8]

3.2.1.4 Power

Within the village there are several committees. Individuals of the village who participate in such committees have a large say regarding the aim of that committee, such as the food committee and fishermen's committee. [5].

3.2.2 TPC sugar estate

TPC is one of the stakeholders on the northern boundary of our problem area. It is an important water consumer in the project area. On the west side of TPC they have multiple water-extraction points in the Weru Weru, which flows in the Kikuletwa. At the northern boundary of the problem area TPC drains redundant water into the problem area.

A short description of TPC: *"The Estate measures 16,000 hectares, of which 8,000 hectares is under cultivation with sugar cane. The estate offers employment, some of it seasonally for 9 months out of the year, directly to nearly 3,000 people. In addition TPC indirectly supports another 800 jobs. TPC runs its own high efficiency boiler and turbo generator with 17.5 MW capacity to produce electricity,* *not only to provide in the company's own energy needs, but also to export excess capacity to the national grid." [9]*

As a large employer in the project area and next to the problem area, rationally a lot of the household in the problem area should work at the TPC, it's the other way around. *The small number of people working at TPC (3%) confirms the limited links that exists between the community and TPC[8]*

3.2.2.1 Interest

As a company their main focus is profit maximisation. To produce a maximum amount of sugar out of sugarcane they need a high quantity of water. About 40% of the water is extracted from boreholes and 60% is extracted from rivers.

3.2.2.2 Power

As a large company, with a lot of employees, TPC forms an important player and stakeholder within the region. To take social responsibility, it is a large shareholder in the NGO FT Kilimanjaro. Problems that occurred due to drainage of TPC water along Kirungu have been solved by TPC with construction of a bypass and embankment around Kirungu. Also, TPC helps in the form of equipment and manpower. They, for instance, helped constructing roads in the problem area as part of their donation to FT Kilimanjaro

3.2.3 Farmers

A large part of the people living in the problem area relies on agriculture. A survey done in Mikocheni by FT Kilimanjaro says 57% of the households have cultivated crop in the past years. [8] On both sides along the Ronga River maize, beans, watermelons and tomatoes are the main products. A large part of the cultivated product is used for personal consumption. In Table 3 the purpose per cultivated crop is depicted.

Table 3: Cultivated crop and purpose [8]

Type of crop	Number	From total	For sale	Personal consumption	Both
Maize	98	83%	1%	57%	42%
Beans	36	31%	6%	44%	50%
Watermelons	18	15%	22%	6%	72%
Tomatoes	14	12%	36%	7%	57%

The reasons for not growing any crop are: no capital, no farm and floods. Almost half of the interviewees gave the absence of accessible land as a main reason for not cultivating land. Inaccessibility gave part of the households enough reason to not use their own land, but TANESCO property. The farmers illegally use TANESCO area for agriculture. The fear for floods is so significant that a part of the households even chose to stop with cultivating their land.[8] In the following Table 4 the reasons for not growing any crops are indicated, as percentage of households not growing crop.

Table 4: Reasons for not growing crop

Reason	[%] *
No access to land	44*
No capital to invest (in land, inputs, etc.)	31
(Fear of) Floods	13

3.2.3.1 Interest

There are two main parameters that are important for the farmers to be able to secure a better production out of their land.

First of all, the availability of water. During the dry season there is a lack of water. To be able to irrigate as much as possible, farmers use furrows. These furrows are manmade canals from the river onto the land. Small weirs/dams are used to manage the amount of the water.

Secondly, soil improvement by bringing in nutrient rich sediments during flooding of the flood plains along the river. Important to note is that there are areas flooded only during the long rains, and other areas are both flooded during the short and long rains.

3.2.3.2 Power

Although the agricultural sector as a whole forms a large part of the working activities and society; their overall power is marginal. The farmers are all individually operating on small areas and this results in low scale productions. The management of the water through irrigation is also very local.

Furthermore, there are two large water using neighbouring stakeholders in the problem area. TPC and TANESCO, both have more power than the individual farmers.

3.2.4 Fishery

Originally Mikocheni A is a fishery village. Short after the construction of the Nyumba ya Mungu dam the reservoir contained a lot of fish and was therefore a very important source of food. During the years the amount of fish the reservoir contains decreased. *Bailey (1996) and Nhwani (1988) provide comprehensive overviews on the changes to the fishery, describing the change from prolific catches in the early years after impoundment, to progressive reduction in catches, based on government fisheries data. The reservoir is the single most important source of fish in the entire Pangani basin, though numbers of fishers have varied, as have catches, from 28,500 tonnes per year during 1970 to present-day catches of 3,000 tonnes or less in dry years. [10]* Another citation from a study done in the problem area says: *"In July 2014 a village committee of 15 persons was created to be in charge of watching over fishing practices (Mza Toa Amazani). In the 80's-90's, a good fishing day could earn 80 000 TSH. Nowadays, it is more around 10 000 TSH (MR - E8). Most of the fishermen are already farming." [10]*

Although the fishermen live and work within the problem area, they are not directly affected by the floodings and the possible implemented solutions.

3.2.4.1 Interest

The availability of fish is decreasing due to decreasing water quality. Influencing the water quality is tough and not the focus of this research.

3.2.4.2 Power

The power of the local fisherman is minimal. Their influence on decision-making is therefore marginal.

3.2.5 Livestock keepers; Maasai

"Most rural households in the Pangani River Basin keep livestock. The most common types of livestock are chickens, cattle, goats, and sheep. The average number of cattle and goats is highest in the central areas of the basin, which include a significant number of Maasai households who tend to keep larger herds of cattle and goats"

There are about 300 Maasai keeping their livestock within the project area.[5] These pastoralists live for a big part in Masaini and are spread out over the project area. With their livestock they migrate to areas of potential food.

3.2.5.1 Interest

The interest on the area of the Maasai is high. Access to the scarce but free food sources is crucial for their existence.

3.2.5.2 Power

The influence on decision making is low. This is due to the governmental policies to stimulate the agricultural sector of Tanzania, especially farming.

3.2.6 TANESCO; Nyumba Ya Mungu dam

On the southern side of the project area, downstream of the Kikuletwa River and Ronga River is the Nyumba Ya Mungu reservoir situated. This reservoir created by the dam is of primary importance for the availability of energy of Tanzania. The Pangani Basin Water Board is responsible for the management of the availability of water. TANESCO on the other hand is responsible for the operation and maintenance of the power plant.[2]

3.2.6.1 Interest

For TANESCO, the most important aim is to generate as much power as possible by the power plant. The amount of energy that TANESCO has to generate, is regulated by the government.

3.2.6.2 Power

The influence of TANESCO on the area is large. Although direct consequences of an increased reservoir level stay within their property; indirect consequences of their work can be spread far downstream or upstream.

During the rainy season, when discharges are relatively high, the power plant can have a reduced outflow:

- *"Less water is released from NyM during the wet season when enough flow is available between NyM and Hale for power generation at both Hale and New Pangani Falls.*
- *If water for power generation at Hale and New Pangani Falls is available between NyM and Hale, release from NyM reservoir during the wet season may be made for environmental reasons and also in the event of requirement for spilling.*

The energy contribution from the Pangani hydro system to the National Grid depends on the water TANESCO is allowed to use from time to time by the Pangani Basin Water Office."[2]

3.2.7 Pangani Basin Water Board

The aim of the PBWB lies on basin wide management and disaster control. They are active on locations within the basin where many people live. Their main focus is to warn people and evacuate. In Lower Moshi they are not active because the population is relatively sparse and in the area people illegally make use of land which is TANESCO property (the reservoir).

3.2.7.1 Interest

In the project area the most important aim of the Board is to make sure the reservoir level is at all times high enough to generate electricity. All measures implemented may not lead to a decreasing discharge flowing into the reservoir. The sediment transport into the reservoir is also an important issue. *"Water management is done in such a manner as to try and ensure that unnecessary spill is avoided at both Nyumba ya Mungu and the downstream power stations. It is also done in such a manner as to try and store as much water as possible during the rainy season and ensure there is water for over year use for hydropower generation and other activities"* [2].

Furthermore they have the responsibility to act when there are water management related problems within the basin; flooding is one of these. However, the focus of the PBWB lies on areas which are more densely populated.

3.2.7.2 Power

In decision-making hierarchy PBWB is on the highest level. Every implementation of a solution has to be acknowledged by the board.

3.2.8 NGO's

Two NGO's are working within the boundaries of the project area: the Tatu Project on the west side of the Kikuletwa River and our client FT Kilimanjaro around Mikocheni and Chem Chem village.

3.2.8.1 Tatu Project

They improve living conditions in Msitu wa Tembo. This village is also affected by flooding and the Tatu project is interested in the solution for Chem Chem and Mikocheni.

3.2.8.2 FT Kilimanjaro

FT Kilimanjaro is working on the overall development of Lower Moshi.

3.2.9 Interest

The interest of the Tatu project is to find a solution for the floods on the west side of the Kikuletwa. However, the villagers of Msitu wa Tembo do consider the floodings as a blessing as well. The west side of the Kikuletwa lies inside the project area but outside the defined problem area. A solution for the problem area must not negatively influence the area of the Tatu project.

As the client, the interest of FT Kilimanjaro is of most importance. With their main objective to improve the overall development in the problem area, their interest in a solution for the flooding is high.

3.2.10 Power

The experience and donations from FEMI, together with the local power and money that TPC has, make that FT Kilimanjaro is an organisation with substantial influence in the area. This became very clear during fieldwork, when the network of FT Kilimanjaro was very helpful in visiting places. There is a close link between the village managers of FT Kilimanjaro and the village officers in the area.

3.3 POWER/INTEREST MATRIX

All stakeholders have been defined. The next step is to identify their relative power and interest to each other in relation to the project. By combining these properties a power/interest matrix can be constructed. In Figure 20 the different stakeholder are mapped. Underneath identification in the end helps to identify with which stakeholders need a close relation and who need less attention, during the process of solution building. The managing action is in Figure 21 depicted.

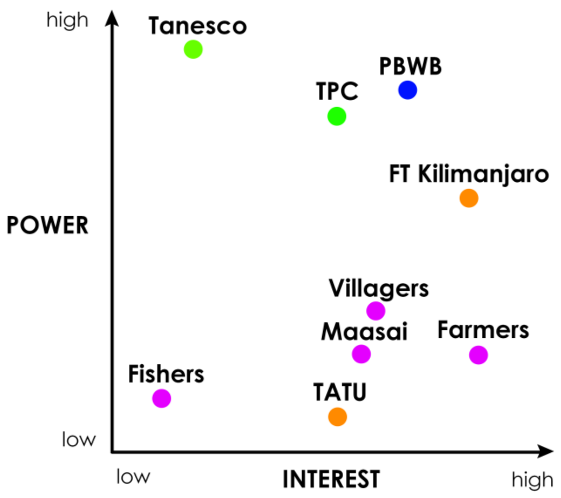

Figure 20: Power/interest matrix; mapping stakeholders

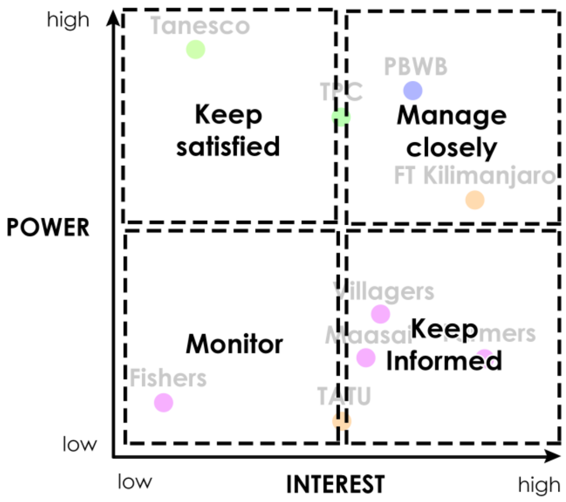

Figure 21: Power/interest matrix; management action

3.3.1 Management action:

- Manage closely: PBWB, TPC, FT Kilimanjaro
- Keep satisfied: TANESCO, TPC
- Keep informed: Villagers, Maasai, farmers, TATU
- Monitor: TATU, Fishermen

4 FLOOD EXTENT

Within the project area it is of great importance to know what part of the area is flooded. In this chapter the flood extent and the phasing of the river floods is analysed, where does the flooding begin and what area comes next. Presented are the areas that are inundated, differentiating between the long and short rains. The flood extent has been analysed using data gathered with GPS-tracks and waypoints, together with information gathered in interviews with villagers and stakeholders.

4.1 FLOODING AREAS

Two different flooding areas can be distinguished: the area that is flooded during the long rains (March-May) and the area that is flooded during the short rains. The short rains are rather variable, both in time and intensity, but can start in November and end in January.

4.1.1 Long rains

A large area is flooded during the long rains. The area stretches out from west of the Kikuletwa towards the reservoir in the south (east), shown in Figure 22. On the northern side of the Ronga; the northern boundary is formed by the TPC drain that is on the boundary of TPC and the project area and the TPC dike. The drain passes Kirungu on the south and the dike of this drain protects Kirungu from flooding. The flooded area continues southeast to the reservoir from Kirungu on, leaving the settlements of Mikocheni Kubwa untouched.

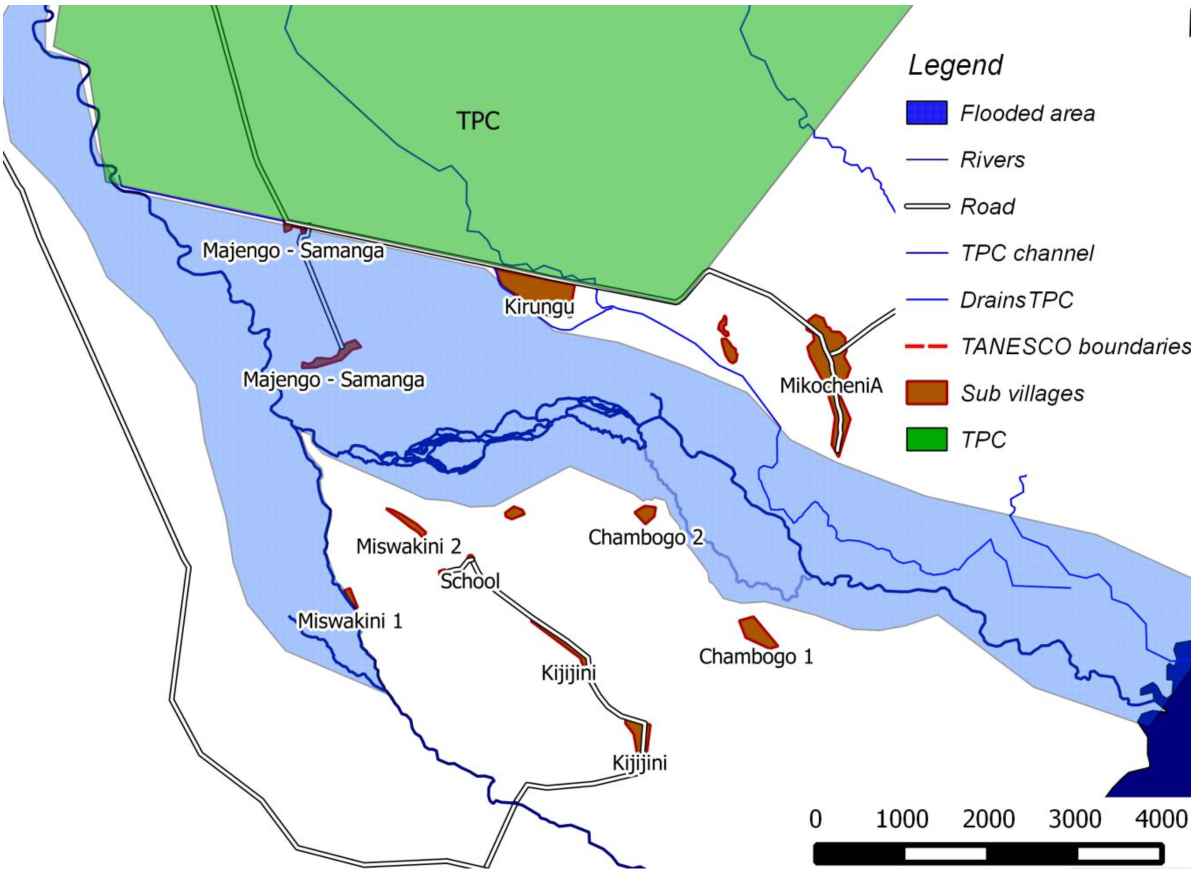

Figure 22: Flooding extent during the long rains

The northern drain used to follow the TPC border from the Kikuletwa to east of Kirungu. The drain was effective as a flood defence due to the high embankment. Therefore it was relocated to the south of Kirungu, as Kirungu was flooded initially. The TPC drain is a small man-made drain with a higher dike on the TPC side. Local villagers in Kirungu tell us that the TPC drain is not a cause of the floods, in its simplicity it keeps the floods away from Kirungu. A schematisation of the drain is shown in Figure 23.

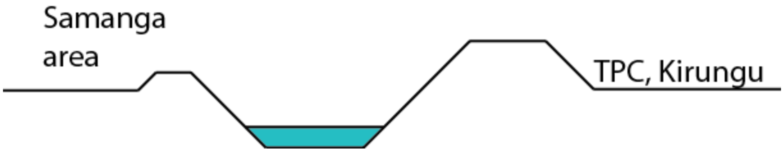

Figure 23: Schematisation of the TPC drain

The eastern boundary of the flooded area is formed by higher lying ground. It depends on the magnitude of the rains to what extent the floods reach, but in general the area that is depicted in Figure 22 is flooded yearly. This means that the sub village Mikocheni Kubwa is not flooded, as it is situated on higher ground compared to the surrounding areas.

The area around Samanga is also completely flooded during the long rains. Only the houses and communities are built on elevated areas, keeping them dry during the rain seasons.

On the southern side of the Ronga, the Chem Chem area, only the area around the Ronga is flooded. The Kikuletwa does not cause any floods on its eastern side. No communities south of the Ronga are flooded, as the floods do not reach this far.

4.1.2 Short rains

The short rains are not as severe as the long rains. They are however a big part of the problem in the area. The long rains are predictable, both in magnitude and in time. The villagers are known with the results of the long rain floods and have adapted their farming to it.

As has been mentioned in the problem analysis, the short rains are both unpredictable in time and magnitude. This unpredictability is the reason why they are a big problem for the farmers around Mikocheni A and south of the Ronga near the sub village Chambogo. Interviews with the local farmers gave a good view to what extent the floods reach yearly, this has been visualised in Figure 24.

Most important fact of the short rains is that they mainly affect the sub villages Mikocheni and Chambogo. At the point where the Ronga River starts braiding, also the flooding starts. However, this does not mean that the river overflows everywhere, the low lying areas are most sensitive to flooding. The extent of the flooding is less than the flooding during the long rains; as a result no settlements are affected by the short rains.

Due to its higher laying ground, the area around Samanga is less vulnerable to floods during the short rains than the Mikocheni area. The same holds for the south side of the Ronga; the farming land of Miswakini is not affected by floods during the short rains, while the farming land around Chambogo is.

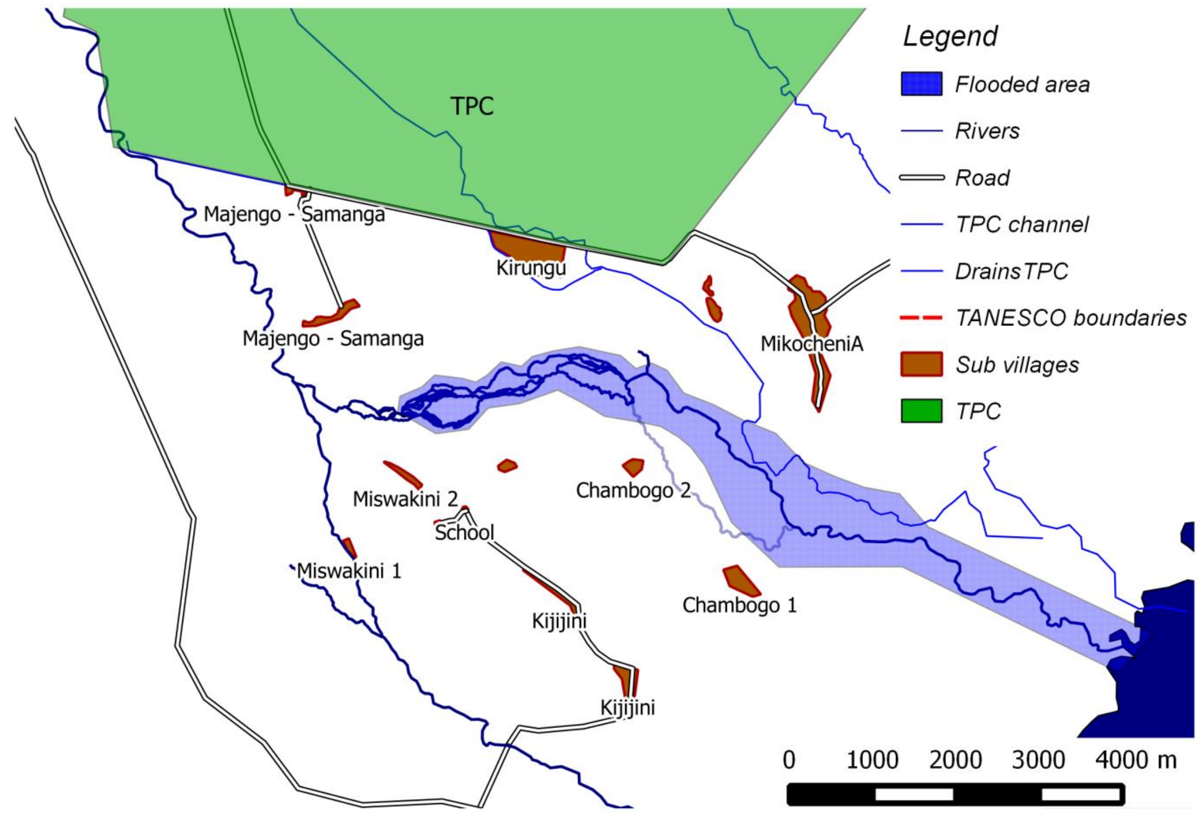

Figure 24: Flood extent during the short rains

4.2 PHASING

In this section the phasing of the floods is discussed: which parts are flooded first and how does the flood develop over time.

4.2.1 Short rains

First, the floods due to the short rains are discussed. The short rains are not as intense as the long rains, causing fewer areas to be flooded. The main area flooded is the area that surrounds the Ronga. There are two main reasons for this:

- Insufficient capacity of the Ronga;
- Low lying land next to the Ronga.

South of Mikocheni A the difference between the water level in the Ronga and the ground level of the surrounding area is small; therefore the area is prone to floods. Together with a low capacity of the Ronga, this area is flooded often. Besides that, this area is very flat and the water is not able to flow away.

More upstream the difference between ground level and water level is larger: south of Kirungu only small areas are flooded. Here, the water finds weak points in the banks, causing some areas to be flooded. Near Samanga and Miswakini the banks are much higher, therefore these areas are not flooded during the short rains.

A qualitative comparison between the Ronga in these different sections is shown in Figure 25.

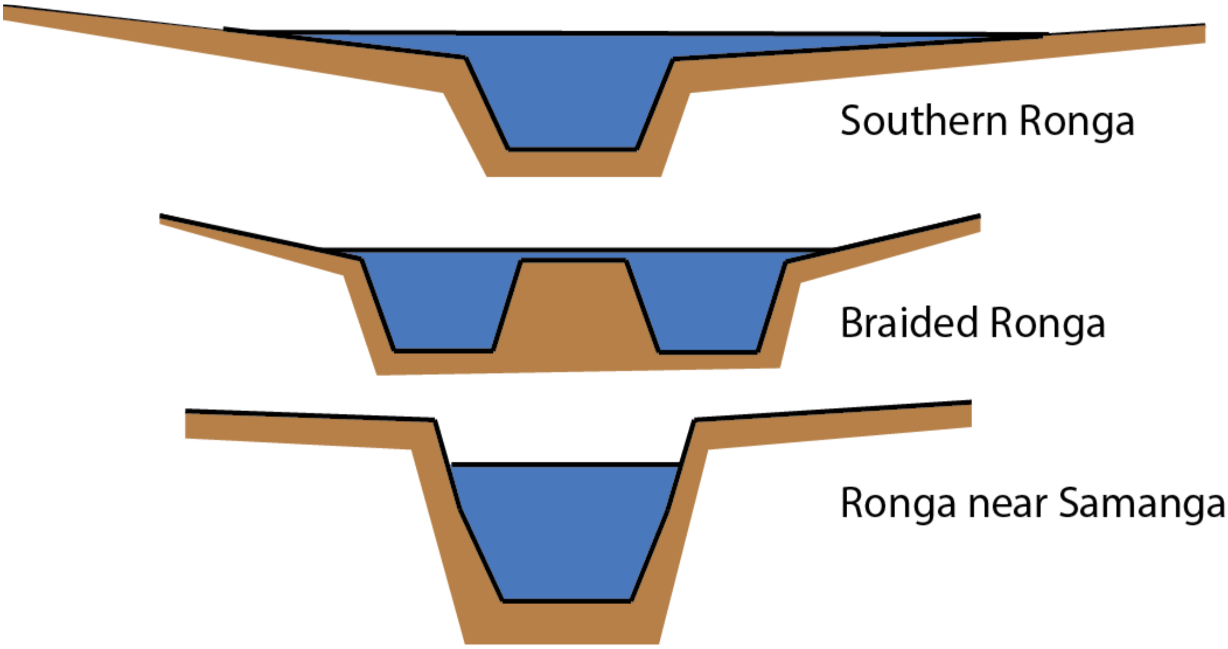

Figure 25: Qualitative comparison Ronga river

4.2.2 Long rains

The development of the flood due to the long rains can be divided in three phases. The first phase is similar to the floods during the short rains: first some low-lying areas around the Ronga are flooded (see Figure 24). Afterwards, when the water level of the Kikuletwa (N) rises, water can exit near the dike breach (Figure 27). In the last phase the area is filled up due to the swell of the rivers and saturation of the flooded area (Figure 28).

The long rains are more severe than the short rains, both in time and magnitude, resulting in higher discharges in the Kikuletwa. Figure 26 shows this clearly for the year 2013. During the short rains; November to January, discharges sometimes reach above the capacity of the Ronga (about 25 m^3/s) leading to small floods. During the long rains discharges are higher and stay high for a long period.

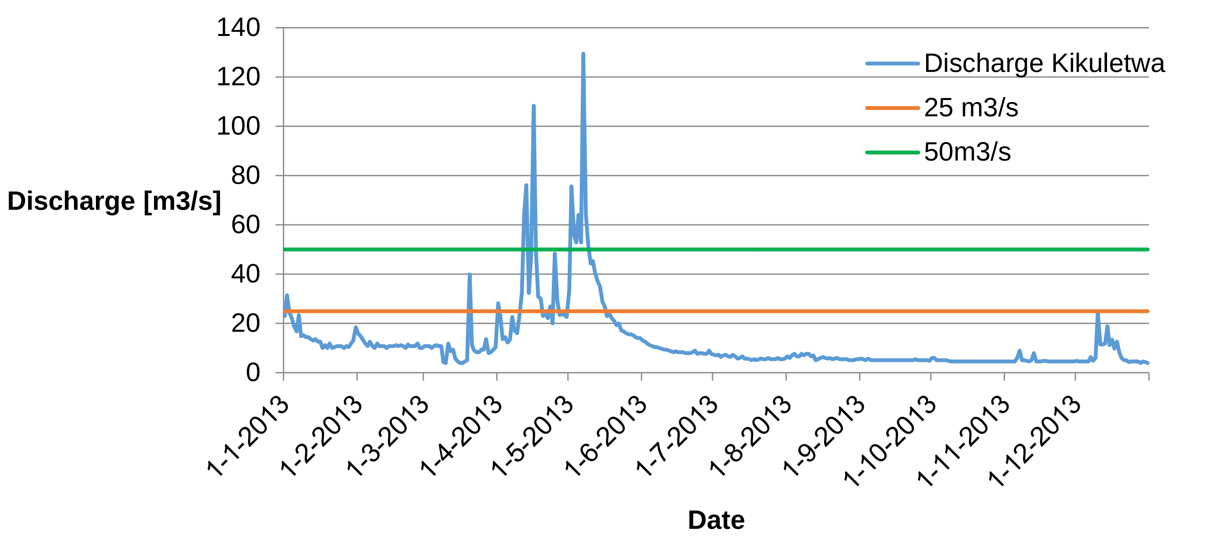

Figure 26: Daily discharges in the Kikuletwa for the year 2013.

The northern Kikuletwa has a higher capacity than the Ronga, but it has one weak point. In the northern part of the Kikuletwa, near TPC, a dike has breached, that was built by the district. This dike breach forms an entry for the water of the Kikuletwa to the area of Samanga, when discharges are high during the long rains. A large water volume enters the area through this breach, causing a flow of water from the dike breach to the reservoir. This is the second phase of the flood; flooding the area north of the Ronga in Figure 27. Important to note is that the water is flowing over this part of land, it is not stagnant. The flowing water causes more destruction than still standing water. In 24 hours the water passing through the dike breach reaches the sub village of Mikocheni A.

The last phase is the flooding of the remaining areas from Figure 22. Three different areas can be distinguished; the southern part of Samanga, the farmland in Chem Chem that was not yet flooded during phase 1 and the area west of the Kikuletwa.

Due to rising water levels and insufficient capacity in the southern Ronga the water levels in the northern Ronga rise too. Eventually this leads to overflowing of the Northern Ronga; flooding the southern Samanga area. This water is stagnant, unlike the water that flows from the northern part of Samanga to Kirungu and the reservoir.

Around Chambogo and Miswakini the higher water levels in the Ronga make that the flooded area is increased. This water does not move south to the reservoir but moves east along with the Ronga. As a result, only a small part of the Chem Chem is flooded due to the rivers, in contrast with what was first expected due to its location.

The area west of Kikuletwa is flooded due to overflowing of the Kikuletwa to this side. Due to the slope of the area, the water slowly flows to the south, alongside the Kikuletwa. This flow returns to the Kikuletwa when a stream is formed due to the geography of the area. This increases the discharge of the Kikuletwa.

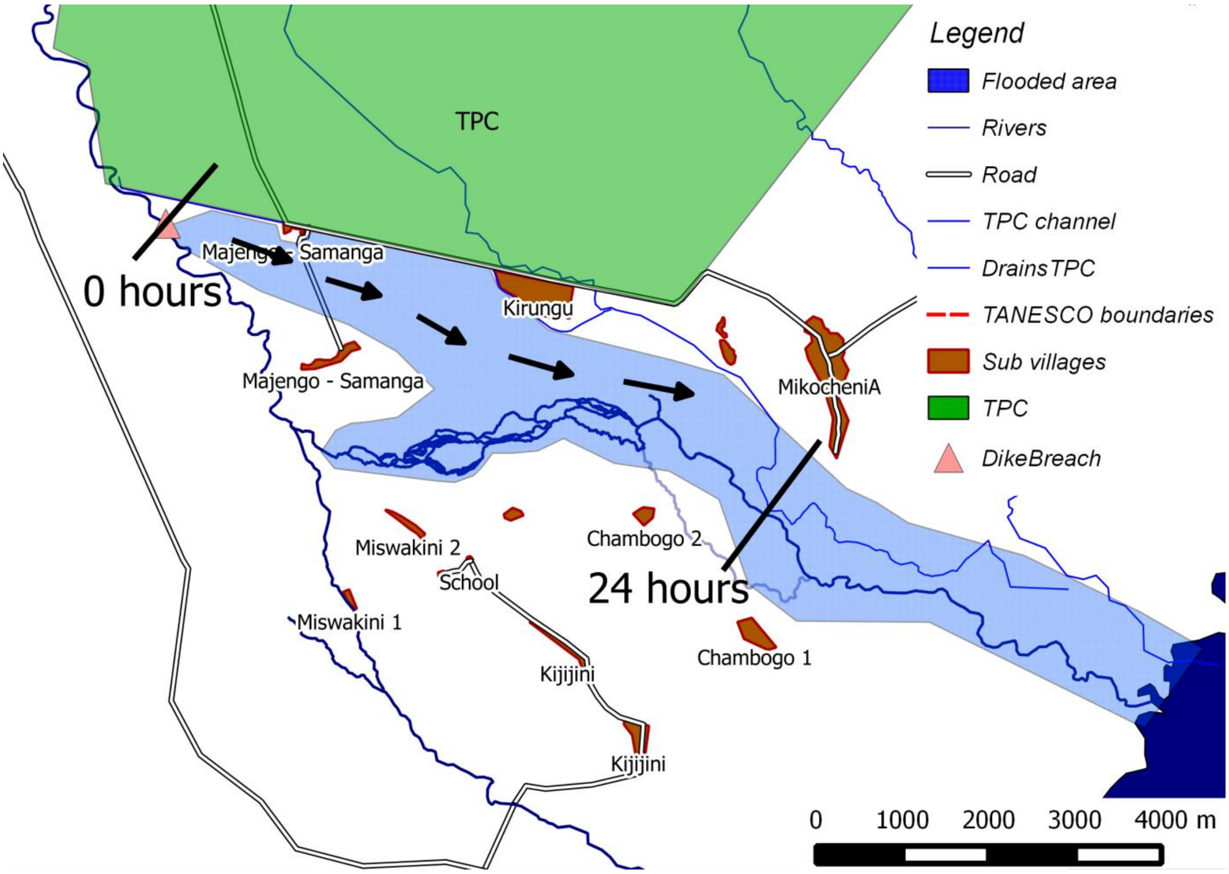

Figure 27: Second phase of flooding during the long rains

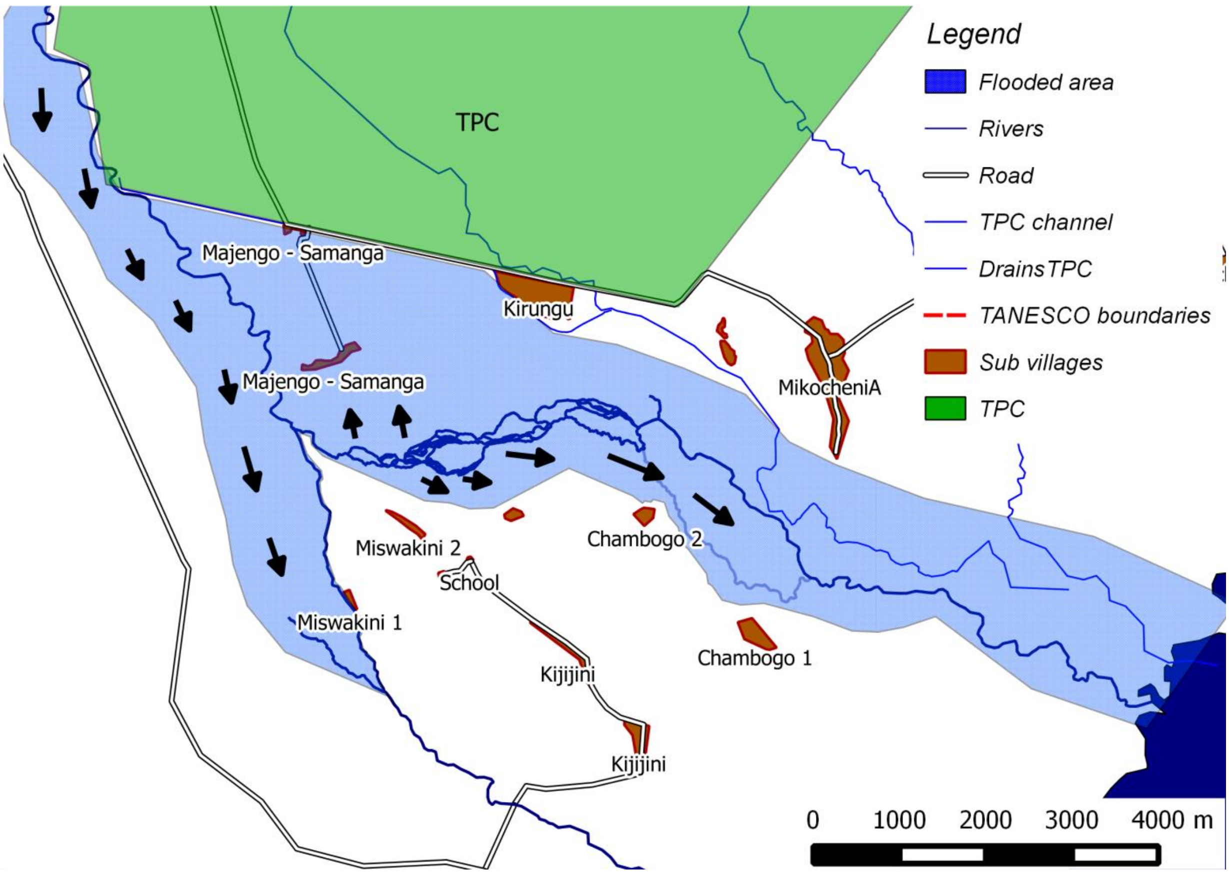

Figure 28: Third phase of flooding during large rains

5 DISCHARGE ANALYSIS

This chapter focuses on the discharges in the problem area. Roughly, this chapter will discuss the discharge coming in, discharge capacities and discharges probabilities. In the end of this chapter a design discharge will be determined which is the starting point of the solution.

The discharge that comes in can be divided into rainfall in the catchment discharged into the problem area by Kikuletwa North (section 5.1.1), and rainfall that falls west of the problem area (section 5.1.2). When the discharge enters the problem area, the river capacities are decisive for the flooding volumes. Therefore capacities of certain stretches are determined and converted to bankfull discharges (section 5.2). After a couple of kilometres the Kikuletwa (N) splits up into the Ronga River and the Kikuletwa (S). Most flooding problems are located along the Ronga. The bifurcation point is important to understand the distribution of discharges (section 5.3). In the dry season, water conflicts arise and rivers and drains get blocked. Those blockages influence the river system and are therefore of importance (section 5.4). As a result of the changing courses of the Ronga River, a few dry beds can be found in the problem area. Those beds can be of importance for the solution and are therefore discussed in this chapter (section 5.5). Thanks to the long data series that have been measured at 1DD1, an analysis on these discharges could be done (section 5.6). This gives insight in the normative annual discharges. In the end, the discharge probabilities and measured cross-sections are used to determine the design discharge (section 5.7.35.7).

5.1 RAINFALL – RUN-OFF RELATIONS

The floods are caused by increased river discharges which mainly occur during the rainy seasons. Therefore it is of importance to get insight in the hydrological processes in the catchment. However finding a relation between rainfall and run-off covers an entire research and is therefore beyond the scope of this project. To get an understanding of the origin of the Kikuletwa River and its discharges, research on the catchment and precipitation is done and described in section 5.1.1. In section 5.1.2 the rational method is used to analyse the significance of the discharge related to the run-off from the mountains west of the project area.

5.1.1 Rainfall in the Kikuletwa catchment

In this paragraph the Kikuletwa catchment is analysed. This is done to understand the volume of discharge that flows into the Kikuletwa (N) and the problem area. In Figure 29 the catchment is illustrated. This map gives more insight in the area. It can be seen that the two large volcanoes, Mt. Meru (4566m) and Mt. Kilimanjaro (5895m), both discharge to the Kikuletwa River. The streams that can be seen in the picture are based on the digital elevation map (DEM, [4]) and can differ from the original river beds.

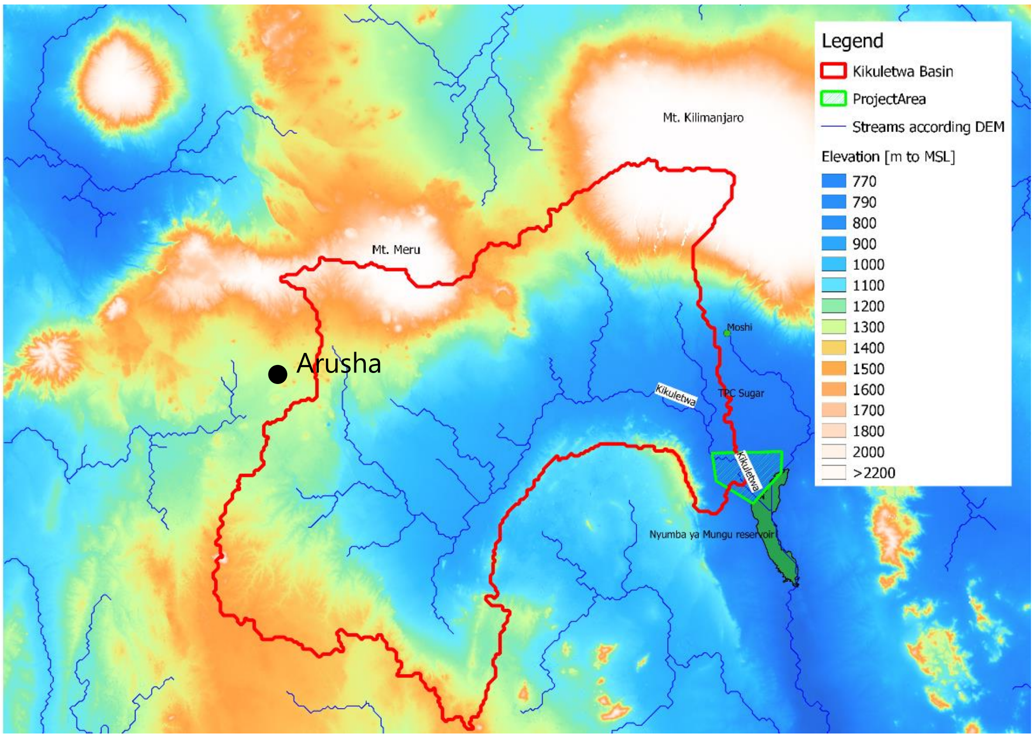

Figure 29: Elevation map and Kikuletwa catchment

In mountainous areas there can be huge rains, especially during the rainy season. The monthly rainfall of April 2008 is illustrated in Figure 30. Large differences can be seen between the high and low lying areas. It can be concluded that the rain events at Mt. Kilimanjaro and Mt. Meru can cause significant peak discharges.

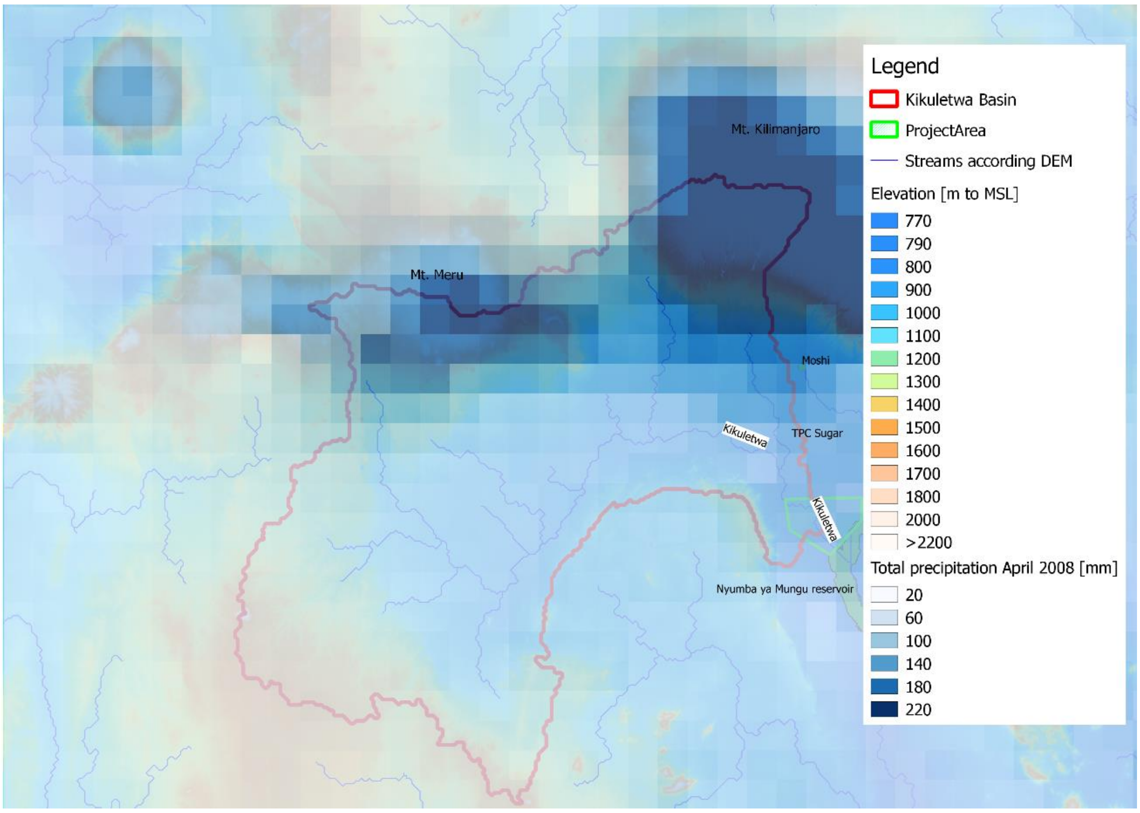

Figure 30: Monthly precipitation April 2008 [11]

5.1.2 Rainfall and run-off in the Kikuletwa (S)

During first field observations it was noticed that the river capacity of the Kikuletwa (S) increases in downstream direction. There is a significant difference in capacity between the Kikuletwa (S) just after the bifurcation point and 5 km downstream of that point. Pictures of both cross-sections can be seen in Figure 31. On the western side of the Kikuletwa (S) lots of dry gullies coming from the mountains are present. This could indicate water flows from these mountains, adding up to the Kikuletwa (S) discharge and thus requiring more discharge capacity. In this section it is investigated whether the increasing discharge capacity can be explained by rainfall in the mountain. If the capacity is not used the whole time, it would also be interesting to find out if those river beds can be used to compensate the large peak flows from the Kikuletwa River to relieve the Ronga River.

Figure 31: Kikuletwa (S), upstream (left picture) downstream (right picture)

First the Digital Elevation Model (DEM) [4] has been used to define the area that contributes to the discharge in the Kikuletwa (S). In Figure 32 the flow accumulation map is presented. This gives an indication about the magnitude of the streams and the drainage directions. The catchment has been determined by following all the streams that discharge to the Kikuletwa (S). After defining the contributing area it was investigated which area is responsible for the peak flow. The flow from this certain area enters the river via one large tributary. The discharge that enters the Kikuletwa (S) via this tributary is approached by the rational method and is described in Appendix C.

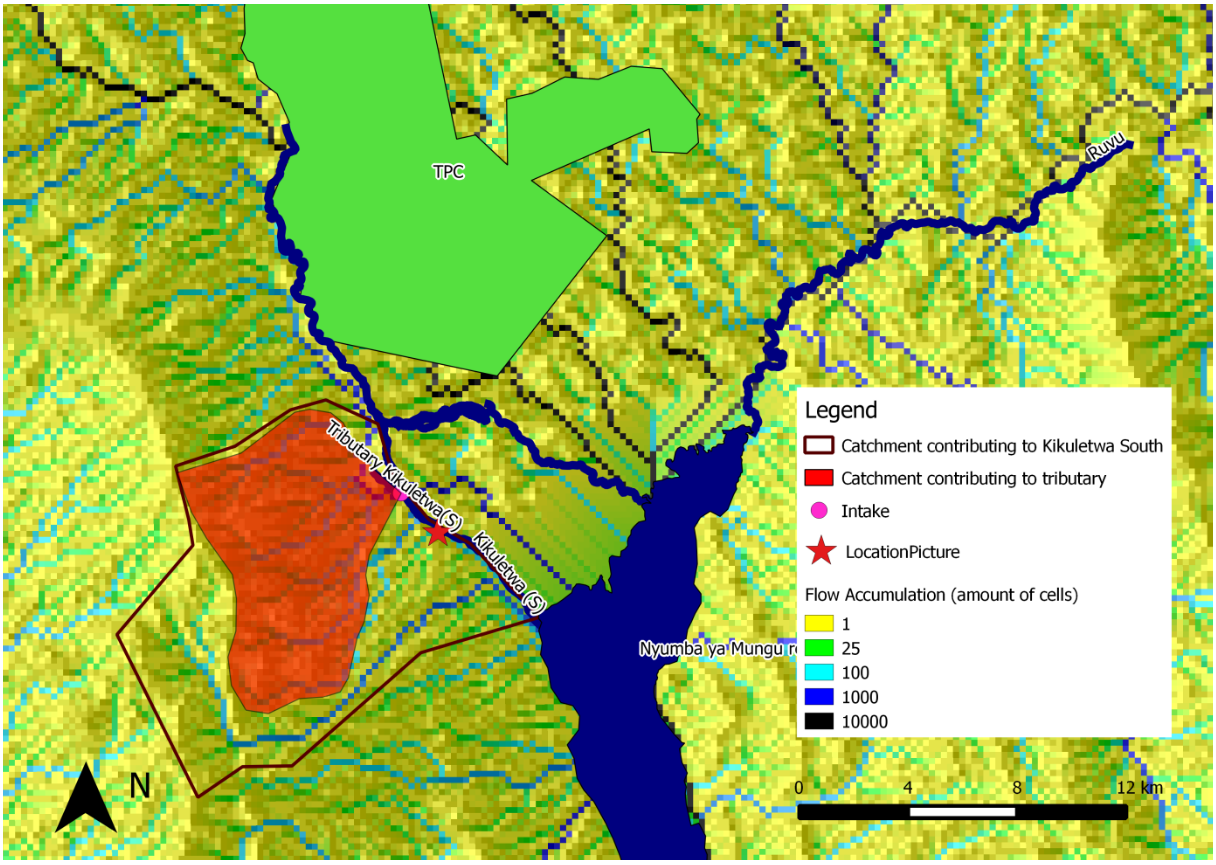

Figure 32: Catchment contributing to discharge Kikuletwa (S)

From this analysis it followed that after a common rain event of 25 mm with a duration of 3 hours, the peak flow can reach a discharge of 39 m^3/s. For an extreme rain event of 100 mm with a duration of 6 hours the peak flow can reach 117 m^3/s.

According to Appendix F, the maximum discharge capacity at the location of the right picture in Figure 31 amounts 230 m^3/s. However this seems to be one of the largest cross-sections along the Kikuletwa (S). It can be concluded that during extreme conditions the river capacity is mostly used by water flowing from the catchment west of Kikuletwa (S). However, during a common rain event of the rainy season the river is not full and still has capacity.

After the above analysis it can be concluded that the peak flows from the mountains can be of such magnitude that the capacity of the Kikuletwa (S) is needed. A logical next question would be whether the peak flow from the western mountains arrives simultaneously with the peak flow of the Kikuletwa at the point of the tributary. For March and April 2008 the precipitation is plotted in Figure 33 together with the discharge at 1DD1 and the expected peak flow after the rain event of 100 mm. It has to be noted that the time of the peak discharge of the western mountains is uncertain because the time and duration of the rain event is unknown. In this graph it is assumed that the rain event started at 26-03-2008 at 0.00 hour. It can also be that this rain event occurred later that day what would shift the peak a bit to the right.

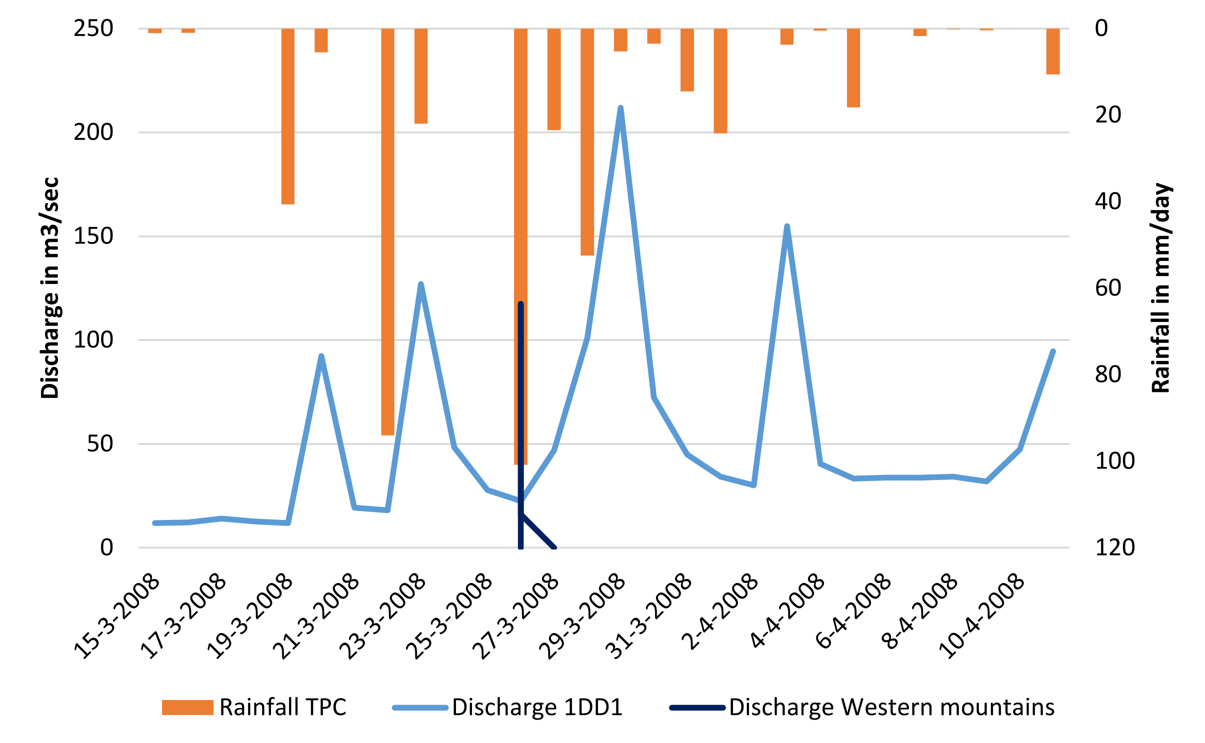

Figure 33: Delay in discharge peaks compared to rain event

In Figure 33 it can be seen that both peak discharges do not occur at the same time, even though the exact time of rain event is not known. A shift of the rain event with one day does not influence this result. The discharge from the western mountains will probably already have reached the reservoir at the time the peak flow of the Kikuletwa River enters the intake point of the tributary of Kikuletwa (S).

Obviously the results of this analysis do not guarantee that it could never happen that both peak flows add up. This analysis is namely based on one certain rain event. Besides, the rainfall can vary over the catchment. When for example two days before a big rain event in the western mountains also a big rain took place on the Kilimanjaro Mountain, it is possible that the discharges accumulate and would cause flooding. However, occasional floods in this area (Msitu wa Tembo) are not undesirable according to the local villagers.

5.2 Discharge capacities current beds

In this paragraph the river system in the problem area is elaborated. This river system is mainly analysed by data gathered from the field during fieldtrips. The locations at which the cross-sections were measured are depicted with a letter in Figure 34 . Based on the measured cross-sections, the River system is split into different sections with roughly the same properties. The different sections can be distinguished in Figure 35. In this figure the river system is subdivided into 6 river reaches. Each river reach is numbered and is assumed to have a uniform cross-section, constant Manning roughness parameter and bed slope. The properties of the river reaches have been determined in Appendix F, based on the cross-sections measured in the field, summarised in Appendix E.

The discharge at the time of the fieldwork is determined by the Strickler-Manning Formula and the Velocity Area Method. It has to be noted that both methods surely have an uncertainty. In the Strickler-Manning formula, the mean flow velocity is determined by the roughness and the bed slope. Both parameters cannot be measured in the field and therefore have to be estimated. When using the Velocity Area method, the discharges is based on the measured flow velocity and the cross-section. As a result of unreachable river parts, most measured flow velocities are not representative for the river stretch. Furthermore only one measurement has been done, on the surface and in the middle of the cross-section. To deduce the mean flow velocity from the measured flow velocity, correction factors are needed. Despite the fact that the bed slope and friction coefficient could not be verified in the field, it is believed that the discharge according to the Strickler-Manning Formula is more reliable than the discharge calculated with the Velocity Area method. The bankfull discharge is therefore determined by Strickler-Manning.

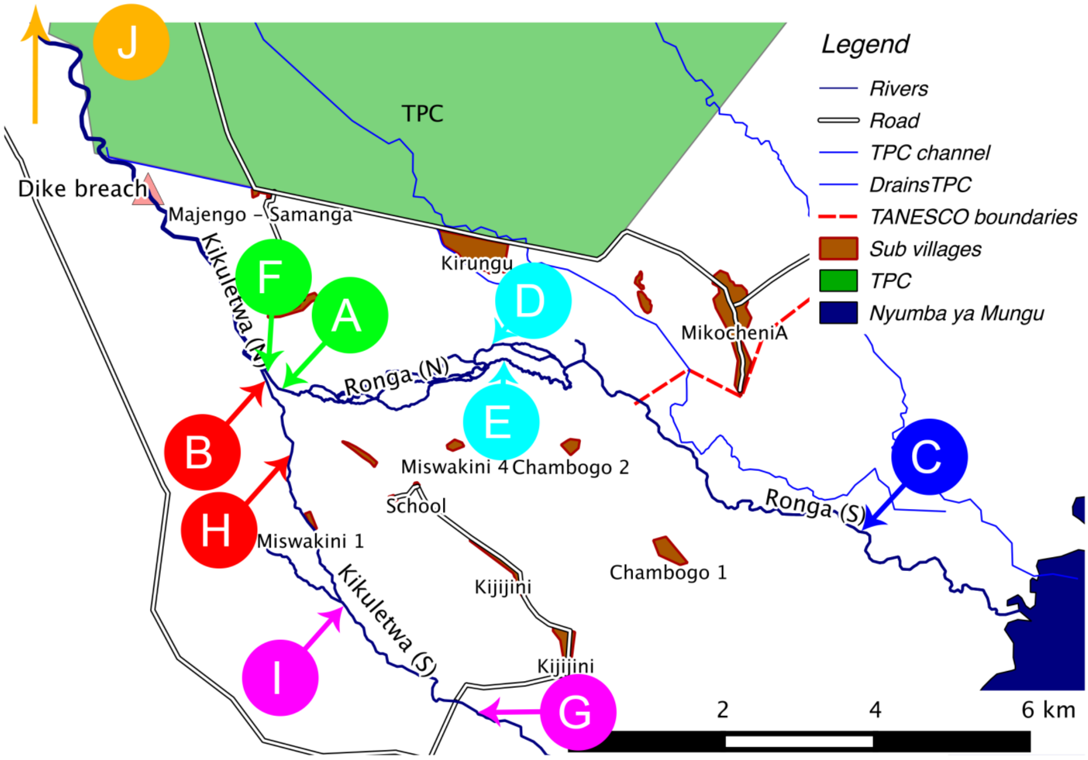

Figure 34: Project area with locations of measured cross-sections

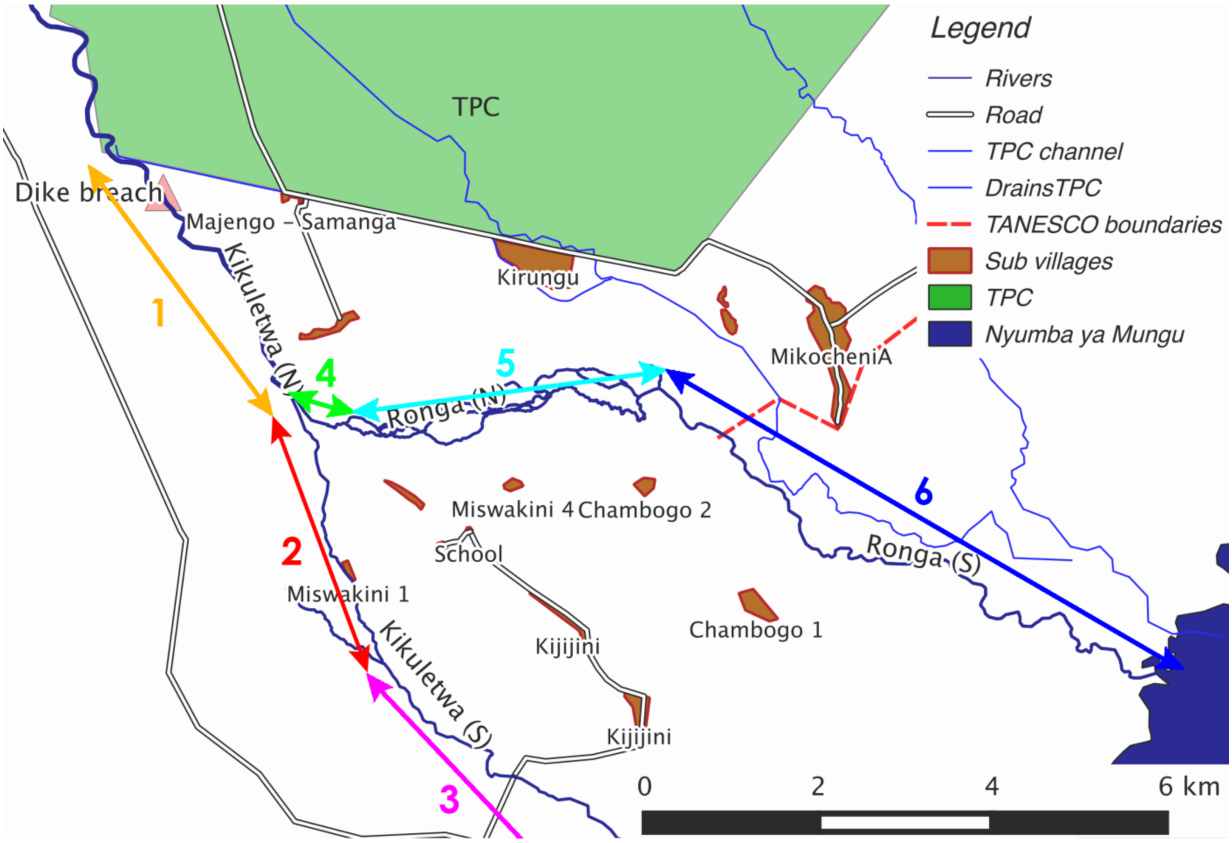

Figure 35: Project area with river reaches

5.2.1 Assumptions

In order to determine the discharge capacities, several assumptions have been made. The assumptions are shortly described in the list below.

- The river system is divided into 6 river reaches. Along each river reach the conveyance area, the discharge, the bed level gradient and the roughness parameter are assumed to stay constant.
- It is assumed that there are no accelerations and decelerations along the river stretch; there is uniform flow along each river stretch. For each section, its relevant parameters are determined. Due to the assumed uniformity, these parameters are constant in each river stretch and the bed level gradient can be used instead of the energy head difference.
- Manning's roughness parameter '*n*' is used as Chézy's '*C*' since it is independent of the water depth and determined by properties of the river such as the river bed, vegetation and shape of the cross-section. Depth, width and velocity measurements have been executed at the different river sections.
- Based on the observations done in the field, a *n* of 0.050 is used for all reaches.
- To calculate discharges, the average velocity is needed. However, the surface velocity was measured in the field. To transform the surface velocity to average velocity, a K-value is used. The derivation of the K value for different '*n*' can be found in Appendix D.
- The flow velocity varies over the width (*W*) of the river because of resistance of the banks. Therefore a factor has been used to compensate for this friction loss. This is explained in Appendix F.

- In the discharge calculation by the velocity-area method (Appendix F), the river cross-section has been divided into parts of 1.0 meter.
- If it has not been possible to measure the depth of a river stretch for different depths, one normative depth (*h*) is used.

5.2.2 Resulting discharges

The results for each river stretch, regarding the cross-section and the discharge capacity, are can be found in Table 5. These cross-sections are based on cross-sections obtained in the field, see Appendix E. The discharge capacities are calculated in Appendix F.

Table 5: Results of the discharge analysis

Stretch	Length [km]	Description	Discharge according to Manning [m3/s]	Discharge according to measured flow velocity [m3/s]	Maximum Discharge Capacity (Manning) [m3/s]
1	4.45	Kikuletwa (N)	14.3	20.0	159
2	3.45	Kikuletwa (S); small river bed	0.62	0.28	1.7
3	6.20	Kikuletwa (S); large river bed	4.26	3.51	184
4	0.8	Ronga (N); before braiding	10.3	5.6	34.4
5	5.65	Ronga (N); braided (north/south)	5.22 / 9.12	2.0 / 3.16	10.2/16.0
6	5.70	Ronga (S)	12.1	14.0	26.7

5.2.3 Conclusions resulting discharges

Based on Table 5, the following conclusions may be drawn:

- Almost all discharge of the Kikuletwa River flows into the Ronga (N)
- Stretch 1 and stretch 3 have a large capacity and therefore less sensitive to flooding. It will only flood at weak points and extreme discharges.
- The capacity of stretch 4 is a bit higher than stretch 3, 5 and 6. It is known that this stretch is not flooded during long rains. This can possibly be explained by the larger discharge capacity.
- For Ronga (N) the discharge calculation according to the velocity area method is probably not reliable because it is much lower than what would be expected.

5.3 Discharge distribution of the river system

The 1DD1 gauging station has been measuring the discharges since 1976. To use this data for the Ronga River, the discharge distribution at the bifurcation point of the Kikuletwa and the Ronga must be known. Furthermore, there is an inflow along the river system due to local rainfall and outflow due to water extraction of the farmers.

Inflow due to local rainfall in the area is neglected, because the volume of water is negligible in comparison to the discharge through the river system. However, rainfall in the west of the the Pangani Basin, which adds significantly to the discharge of the Kikuletwa South, is taken into account(see paragraph 2: 'rainfall in the catchment' of this chapter). Outflow due to water extraction is neglected as well. This is because the rainy season is the normative period, and during the rainy season TPC and farmers do not extract water for irrigation.

Two methods can be used to calculate the division. The first method is to calculate the backwater curves of the Kikuletwa and the Ronga, starting at the reservoir. The boundary condition that states that the water levels of the rivers at the bifurcation point must be equal, leads to the discharge flowing in each river. However, due to the large error in parameters necessary for this calculation, this method is not used.

The second method is to compare the discharge at 1DD1 to the measured discharge at the Kikuletwa and the Ronga, just after the bifurcation. A distribution can be deduced if either the discharge at the Ronga or Kikuletwa is known. Unfortunately, there is no discharge data available of November 2014 of the Kikuletwa. To overcome this problem, the cross-section of the area of the flowing part is used as an indication for the present distribution and properties of the river.

By measuring the maximum available cross-section, including the dry banks, the present discharge can be extrapolated to the maximum discharge capacity of the different river branches.

5.3.1 Bifurcation point

The bifurcation of the Kikuletwa North into Ronga and the Kikuletwa South is an important point in the analysis of the distribution of the river system. Important to note is the location of this bifurcation point in relation to the different phases the process of flooding is divided. The bifurcation is located nearby the starting point of inflowing water over land; flooding phase 2. This is in detail described in Chapter 4: flooding extent.

The downstream sections and their distributions can give an indication for the maximum capacities. For different locations the dimensions and discharges are illustrated in Table 6 and Table 7.

Table 6: Dimensions and discharges of Kikuletwa South; stretch 2

Description	Symbol	Value	Dimension
Cross-sectional area	A	1.5	[m^2]
Maximum Cross-sectional area	A_{max}	2.9	[m^2]
Discharge (Manning)	$Q_{Manning}$	0.62	[m^3/s]
Discharge (Measured)	$Q_{Measured}$	0.28	[m^3/s]
Maximum discharge	Q_{Max}	1.7	[m^3/s]

Table 7: Dimensions and discharges of Ronga North; stretch 4

Description	Symbol	Value	Dimension
Cross-sectional area	A	15.1	[m^2]
Maximum Cross-sectional area	A_{max}	32.5	[m^2]
Discharge (Manning)	$Q_{Manning}$	10.3	[m^3/s]
Discharge (Measured)	$Q_{Measured}$	5.6	[m^3/s]
Maximum discharge	Q_{Max}	34.4	[m^3/s]

5.3.2 Comparison

The cross-sectional dimensions and discharges before and after the bifurcation are compared in Table 8. It can be concluded that the largest part of the incoming discharge from upstream, flows into the Ronga. Based on the cross-sections and discharges of both branches, it can be concluded that more than 90% of the discharge in the Kikuletwa (N) flows into the Ronga.

Table 8: Comparison

Stretch Nr.	Name	Conveyance Area; [m^2]	Maximum Area; [m^2]	$Q_{Measured}$; [m^3/s]	Q_{max}; [m^3/s]
2	Kikuletwa South	1.5 10%	2.9 8%	0.28 5%	1.7 5%
4	Ronga North	15.1 90%	32.5 92%	5.6 95%	34.4 95%

5.4 RIVER-BLOCKINGS

In both rivers, the Ronga North and Kikuletwa South, are manmade blockings present. These blockings have been identified during the different fieldwork moments. These blockings lower the discharge capacity within the river stretch. Upstream of such an intervention the water level will have a higher equilibrium depth, but a lower average velocity. The obstructions result in lower discharges. Due to higher water levels, the farmers are able to irrigate in the dry periods. In Figure 36 one of the obstructions is depicted. This is an obstruction that diverts the river into an irrigation channel.

In the rain season on the other hand, obstructions have an enforcing effect on the flooding. Another additional problem is the self-regulating feature of the river in finding its path. Due to river obstructions the river is forced in doing this, which can result in an increased eroding of the riverbed. The eroding process is demonstrated in Figure 37.

Figure 36: river blockage; gully Ronga - fieldwork 20141117

Figure 37: river blockage; Kikuletwa (S) – eroding process

5.5 DRY/OLD RIVER BEDS

Using Google Earth [12], different dry and old branches have been identified and these were confirmed in the field. Different branches either give an inflow to the system or might create extra outflow capacity. Some of these branches contain stationary or flowing water during the flood season. Figure 38 shows the main branches that have been identified.

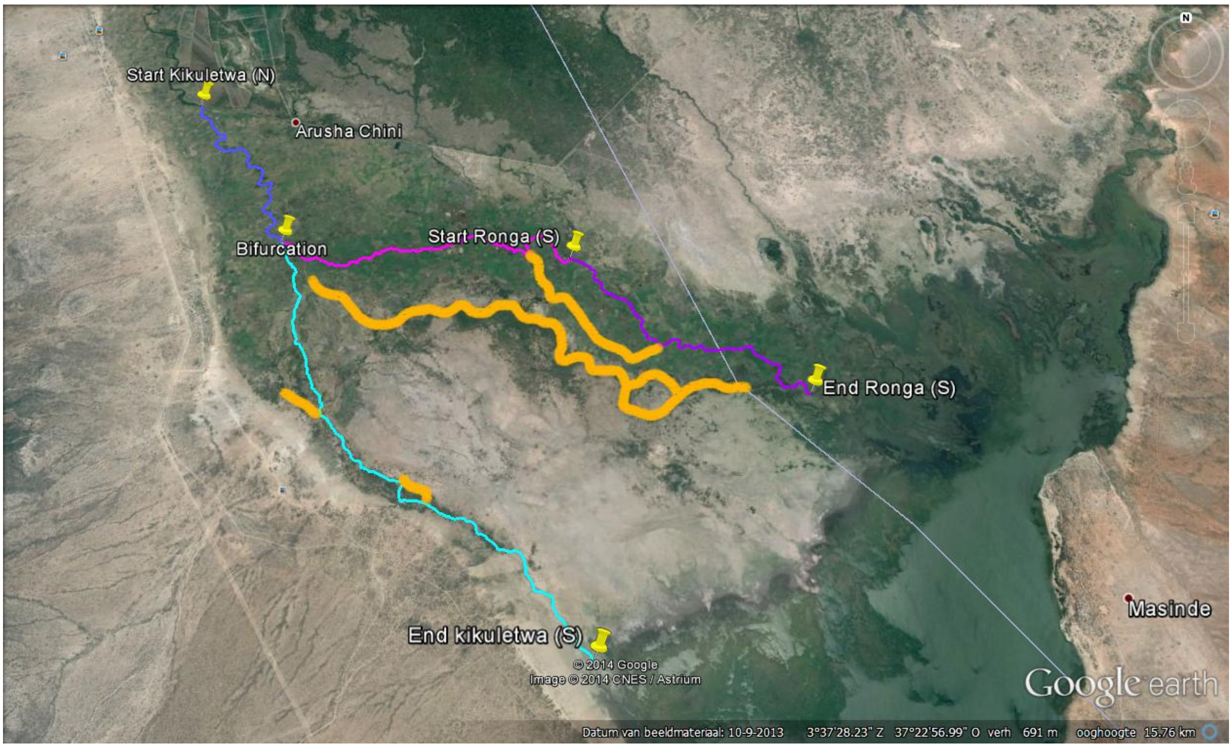

Figure 38: The river system with the dry tributaries in orange [12]

5.6 DISCHARGE PROBABILITIES

To gain insight into the significant values of the discharge of Kikuletwa North, the data has been analysed and graphically represented with a return period and probability of exceedance.

5.6.1 Annual Maxima Approach

For the years 1978 – 2010, the maximum discharge of each year is plotted against the return period, see Figure 39. The return period is the time it statistically is expected that a certain discharge is reached. There are 33 years of data; the highest measured discharge is 238 m^3/s in 1980. Statistically this means that once in 33 years, a discharge with this value is to be expected. It has to be noted that if this year a higher discharge is reached; the discharge of 238 m^3/s suddenly has a statistical return period of 17 years.

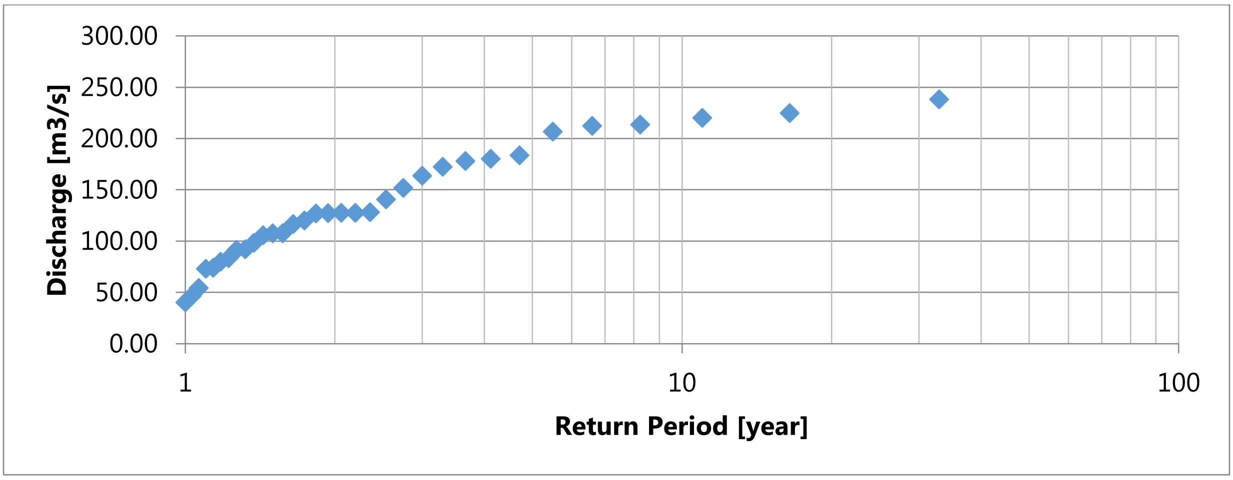

Figure 39: Return period of the annual maxima plotted on semi-log axes.

From the graph in Figure 39 it can be deducted that a discharge of 220 m^3/s will return once every 10 years. Note that by only using the maximum discharge of a year, a lot of data is lost. For instance, the discharge of 50 m^3/s has a return period of once a year. However, this discharge might occur multiple times a year.

FT Kilimanjaro its main interest is to find a quick solution to decrease the damage done by the yearly floods. Solutions for once in ten year floods do not have the priority, but positive effects on these are very welcome.

5.6.2 Probability of exceedance (flow duration)

The flow duration curve is relationship between any given discharge and the percentage of time that the discharge is exceeded. [13] For the flow duration curve, the discharge measured every day, for the period 1978 – 2010 was used. 1986, 1997, 1998, 1999 and 2006 have not been taken into account, because the data was corrupted. Thus the daily measurements of 28 years were used.

For instance, a discharge of 100 m^3/s is exceeded 1% of the time in those 28 years. On average, for 3-4 days a year the discharge is larger than 100 m^3/s. According to the flow duration curve, a discharge of 50 m^3/s (which has a return period of once a year) is exceeded for 6.3% of the time, which corresponds to approximately 23 days per year.

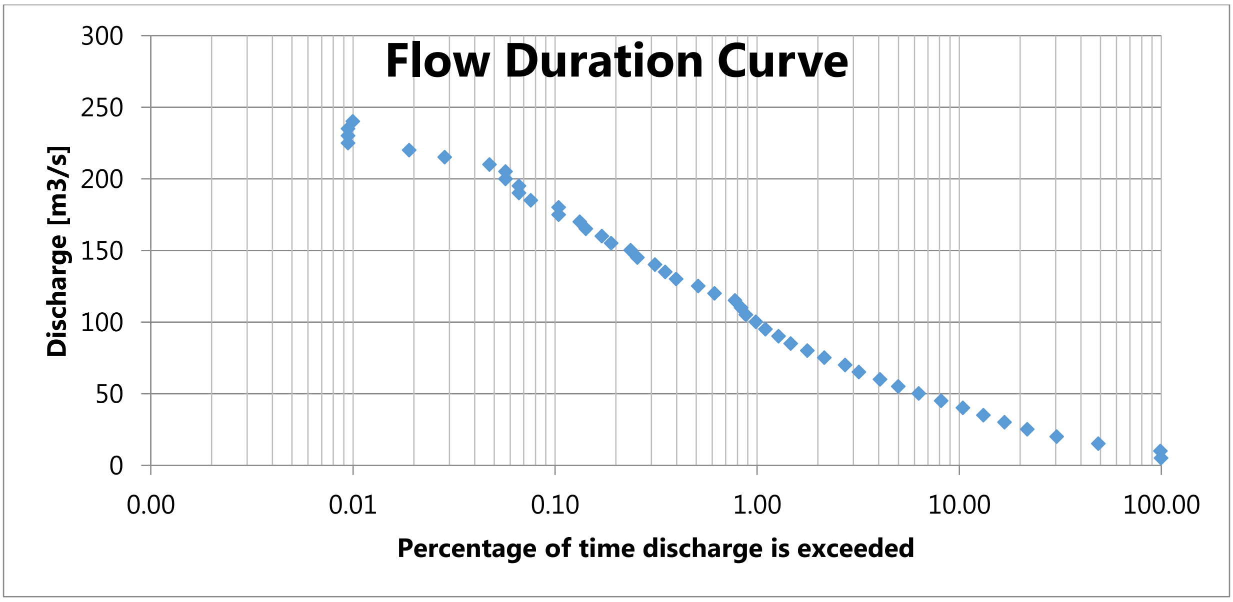

Figure 40: Flow duration curve

5.7 Estimating the design discharge

In this section the reasoning for assuming a normative discharge for the river system in the problem area is explained. This will be done by two methods. First the data of the 1DD1 gauging station is analysed. Secondly, the bankfull discharge of the Kikuletwa just upstream of the dike breach is determined. The two methods are compared and a design discharge is chosen.

5.7.1 1DD1

The daily measurements of the 1DD1 from 1978 up to 2014 are analysed, excluding 1998 because the data was corrupted. The annual maxima of the long and the short rains are compared and visualised in a histogram. From the 1DD1 data analysis a normative discharge is found, and this has to be linked to the discharge flowing into the river system of the problem area. This point of inflow will be just upstream of the dike breach south west of TPC. The discharge, during the short and long rain season, flowing into the problem area is smaller than the discharge at the 1DD1. This is because during high discharges the banks on the west side of the Kikuletwa overflow, decreasing the volume of water significantly. An estimation of the remaining discharge through the banks is elaborated in section 5.7.3. The aim of the client is to relieve the area of the problems of the floods for most years. It is not the aim to design a solution which is focussed on a nearly zero percent probability of flooding. Extreme flood years do not have to be taken into account. Therefore it is assumed that in 80% of the time, the design must be able to prevent flooding.

Short rains

In Figure 41 the histogram of the short rains is depicted. The annual maxima are distributed into bins of 5 m^3/s. Six times in 36 years, the annual maxima of the short rains were in the range of 20 – 25 m^3/s. It can be seen that there are a couple of outliers. In 1997 a discharge of 93.9 m^3/s was measured. In 1982, 2006 and 2012 discharges of 70 – 80 m^3/s occurred. Taking into account that 80% of the annual maxima must be below the design discharge, a normative discharge of 55 m^3/s is chosen. This discharge is exceeded six times in the last 36 years.

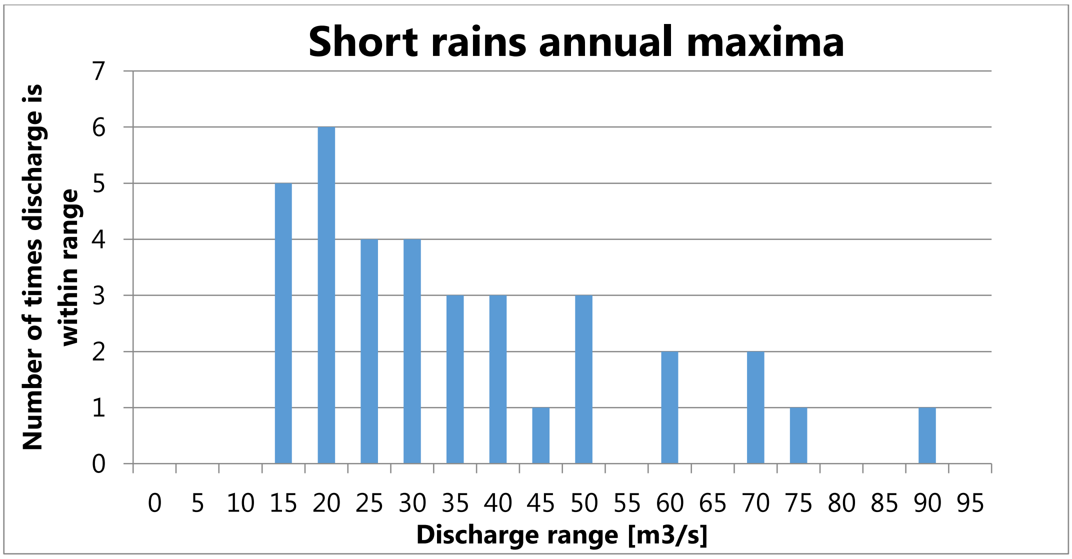

Figure 41: Histogram short rains. Bins have a range of 5 m^3/s

Long rains

In Figure 42 the histogram of the short rains is depicted. The annual maxima are distributed into bins of 5 m^3/s. Six times in 36 years, the annual maxima were in the range of 125 - 130 m^3/s. Assuming the same 80% of the time the design must be able to prevent flooding, a discharge of 185 m^3/s is normative. This discharge is exceeded seven times in the last 36 years.

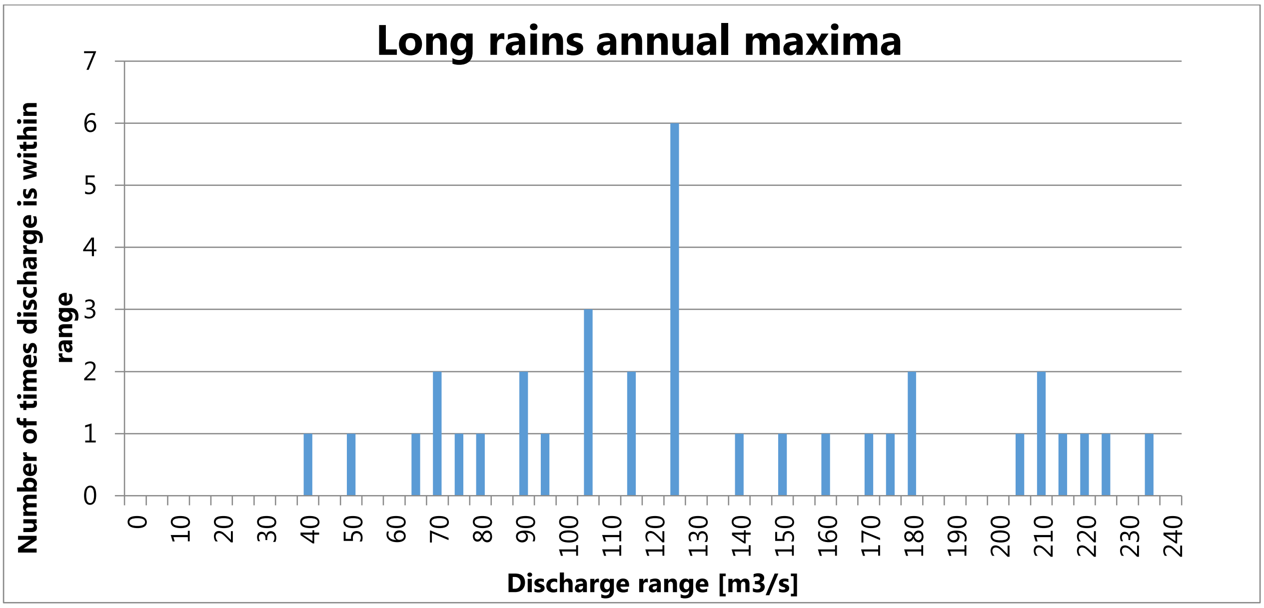

Figure 42: Histogram long rains. Bins have a range of 5 m^3/s

5.7.2 Bank-full discharge Kikuletwa (N) near dike breach

In order to determine a discharge that enters the problem area the cross-sectional profile near the dike breach has been considered in section5.7.2.1. For this cross-section an estimate of the bankfull capacity is derived using the Strickler-Manning Formula[14] in section 5.7.2.2. Since the river could not be crossed, the cross-section could not be measured. So the dimensions have be determined by the experiences that are gathered from the fieldwork. This gives a lot of uncertainty, which is discussed in section 5.7.2.3.

5.7.2.1 Cross-sectional profile

Figure 43: Kikuletwa (N) at the location of the dike breach

The cross-sectional area near the dike breach has not been measured and is therefore very uncertain. The banks on the other side of the river are lower than the banks from the side where the picture is taken. At the time of the picture approximately 1 meter was left between the water level and the surface.

At 1DD1 the width at the water level 32 meters. At the location of the dike breach the width is smaller than at 1DD1. From Figure 43 it can be seen that the width is still more than 20 meter. So the width at this point is assumed to be 25 meters.

According to the depth measurements taken at 1DD1, the cross-section can be schematized as a rectangular box. The measured depths at 1DD1 are around 1.0 meter. In lack of better data it is assumed that the depth of the Kikuletwa (N) at the time of the picture (Figure 43) was 1.0 meter. Together with the assumed width of 25 meters and the remains of the banks the bankfull cross-sectional area amounts 50 m^2. The schematisation of this profile is shown in Figure 44.

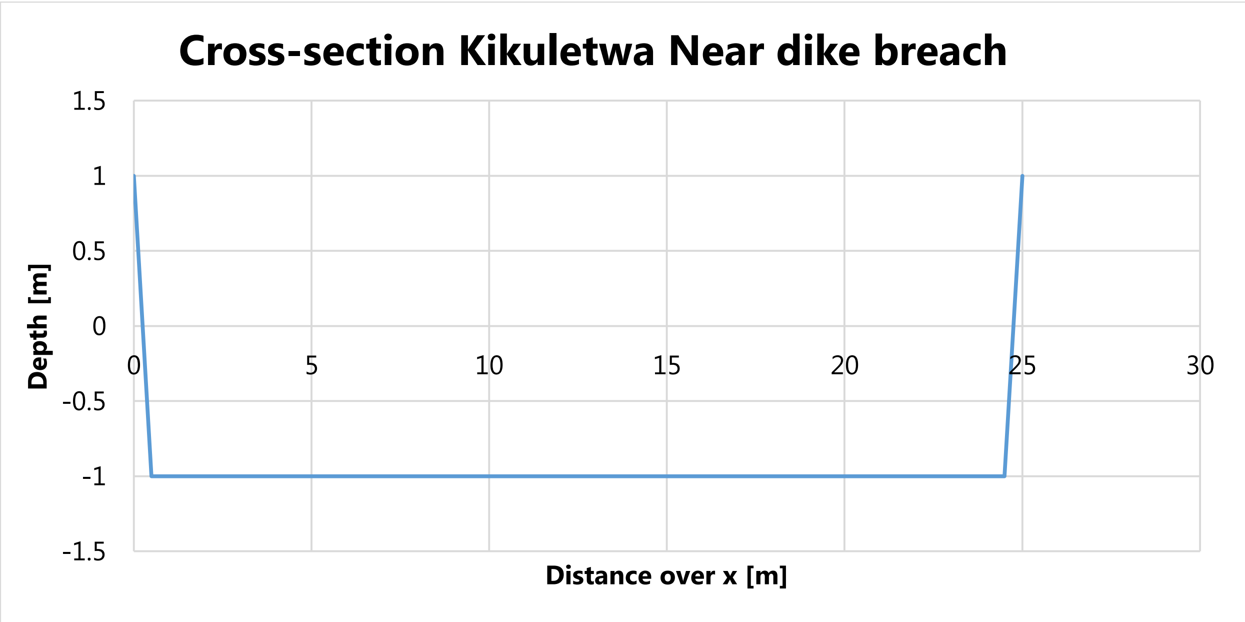

Figure 44: Assumed cross-section of the Kikuletwa River near the dike breach

5.7.2.2 Bankfull discharge

In the analysis report all bankfull discharges are computed for different stretches using the Strickler-Manning Formula [14]:

$$Q = A * \frac{R^{\frac{2}{3}} * i^{\frac{1}{2}}}{n}$$

Q = Discharge [m^3/s]
A = Cross-sectional area [m^2]
n = Roughness coefficient [m$^{1/3}$/s]
R = Hydraulic radius [m]
i = Bed slope [-]

It is assumed that the roughness and bed slope are constant for each stretch as defined in Appendix F. The parameters are equal to:

i = 0.0011 [-]
n = 0.050 [$m^{1/3}$/s]

Other parameters follow from the assumed cross-section:

A = 50 m^2
R = 1.72 m

When filling in the formula, the bankfull discharge is derived and amounts 48 m^3/s.

5.7.2.3 Uncertainty in bankfull discharge

In the previous paragraphs a lot of assumptions have been made. All those assumptions make the derived bankfull discharge more uncertain. In this paragraph the effect of possible deviations on the assumptions will be discussed.

Table 9: Uncertainty of the bank-full discharge at the dike breach

	Assumed value	Expected maximum deviation (-/+)	Effect deviation on calculated discharge [m^3/s]
Width [m]	25	5	37 - 58
Depth [m]	2.0	0.5	30 - 68
Friction [$m^{1/3}$/s]	0.05	0.005	43 - 53
Slope [-]	0.0014	0.001	14 - 66

As can be seen in Table 9 there are many assumptions to determine the discharge. As a consequence the computed discharge cannot be taken as the normative discharge. When all parameters are assumed to be the lowest extreme of the reach, so the assumed value minus the deviation, the discharge can even amount 13 m^3/s. Though downstream in the Ronga River discharges of 26 m^3/s are measured so this extremely low discharge will be very unlikely. If all parameters are taken to be the highest extreme of the reach, the discharge can amount 104 m^3/s. Since both extreme discharges are very unlikely the range between the discharges can be chosen smaller.

Another consideration is the shape of the cross-section. It is assumed that this cross-section is rectangular but this is not proven. A different profile also influences the resulting discharge.

5.7.3 Design discharge

As can be read in section 5.7.1, the normative discharge for the short rains amounts 55 m^3/s. The bankfull discharge has been calculated at 48 m^3/s. Local farmers have been interviewed near the Kikuletwa. From these interviews it became clear that the Kikuletwa does not overflow during the short rain season. Given the uncertainty of the parameters above, it is therefore concluded that the Kikuletwa must be able to discharge at least 55 m^3/s. Therefore the normative discharge that flows towards the bifurcation Kikuletwa Ronga is still 55 m^3/s.

However, during the long rains the capacity of the river section is insufficient and the surrounding area will be flooded. In times of discharges that are higher than the bankfull discharge, the water will be spread over a large area, see Figure 45. This makes it difficult to approximate the flow that is still discharged by the Kikuletwa River.

Figure 45: Flattening of the Kikuletwa discharge peak due to flooding at Msitu wa Tembo

To simplify the situation, the flow profile is schematized as illustrated in Figure 46. The schematization is illustrated for the view in downstream direction. On the left side of the river, TPC is located. This side is not flooded due to the constructed dike of approximately 1 meter high. When the water level rises above the right banks, Msitu wa Tembo will get flooded. On Google Earth [12] it can be seen that the banks on the Msitu wa Tembo side are higher than the hinterland. It is also striking that the elevation first decreases and then increases, causing a kind of pit of about 0.5 meter deep in the floodplain. The width of the floodplain will probably differ a lot along the river depending on the elevation. An approximated width of 300 meter for the flood plain seems reasonable.

As described in section 5.7.1 the normative discharge for the long rainy season is 185 m^3/s at the location of 1DD1. Due to the overflowing water the discharge that flows through the river will be lower than 185 m^3/s. However, because of the water level rise it will be more than the bankfull discharge of 48 m^3/s. To approach the discharge that still flows through the Kikuletwa (N), the cross section is divided in two segments. For both the floodplain and the river, the discharge is computed by the Strickler-Manning formula. When the sum of these discharges is equal to the normative discharge of 185 m^3/s, the leading discharge through the Kikuletwa River has been found. This is the discharge that should be used in the design of the solution.

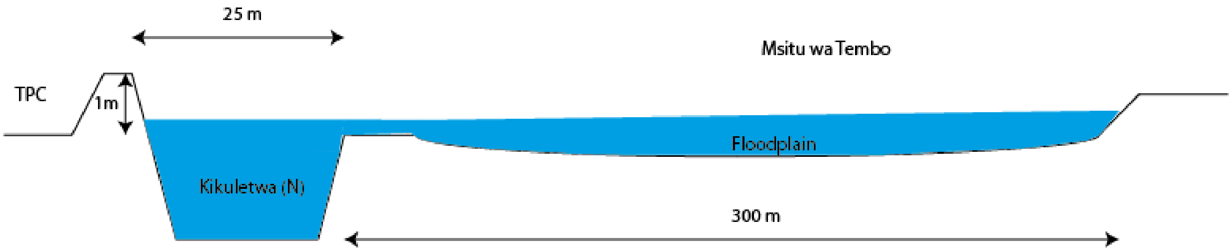

Figure 46: schematisation of the flow profile upstream of the dike breach

Table 10 shows the results of these calculations. It is assumed that there is more friction on the floodplain than in the river. The roughness coefficient *n* is assumed to amount 0.07 $m^{1/3}/s$ for the floodplain and 0.05 $m^{1/3}/s$ for the river. According to these assumptions the flooding depth will be 0.46 meter for the normative discharge of 185 m^3/s. The discharge through the river banks is 67.4 m^3/s, which is 36% of the total discharge.

Table 10: Discharge calculation of the flow profile during flooding

	River	**Floodplain**
Width [m]	25	300
Water depth [m]	2.46	0.46 – 0.96
Wet perimeter [m]	29.4	300
Cross sectional area [m^2]	59.6	243.5
Hydraulic radius [m]	2.09	0.89
Roughness coefficient [$m^{1/3}/s$]	0.05	0.07
Bed slope [-]	0.0011	0.0011
Discharge [m^3/s]	67.4 (36%)	117.7 (64%)

To conclude this chapter, quantifying discharges has proven to be very difficult. However, to create a solution, a design discharge is necessary. Using Google Earth and the experiences gathered by fieldwork, which comply with the observations of villagers, all parameters are estimated. This gives a design discharge of 67.4 m^3/s that flows through the banks of the Kikuletwa (N) into the problem area during the long rain season. In the short rains the design discharge will be 55 m^3/s.

6 WATER USAGE TPC

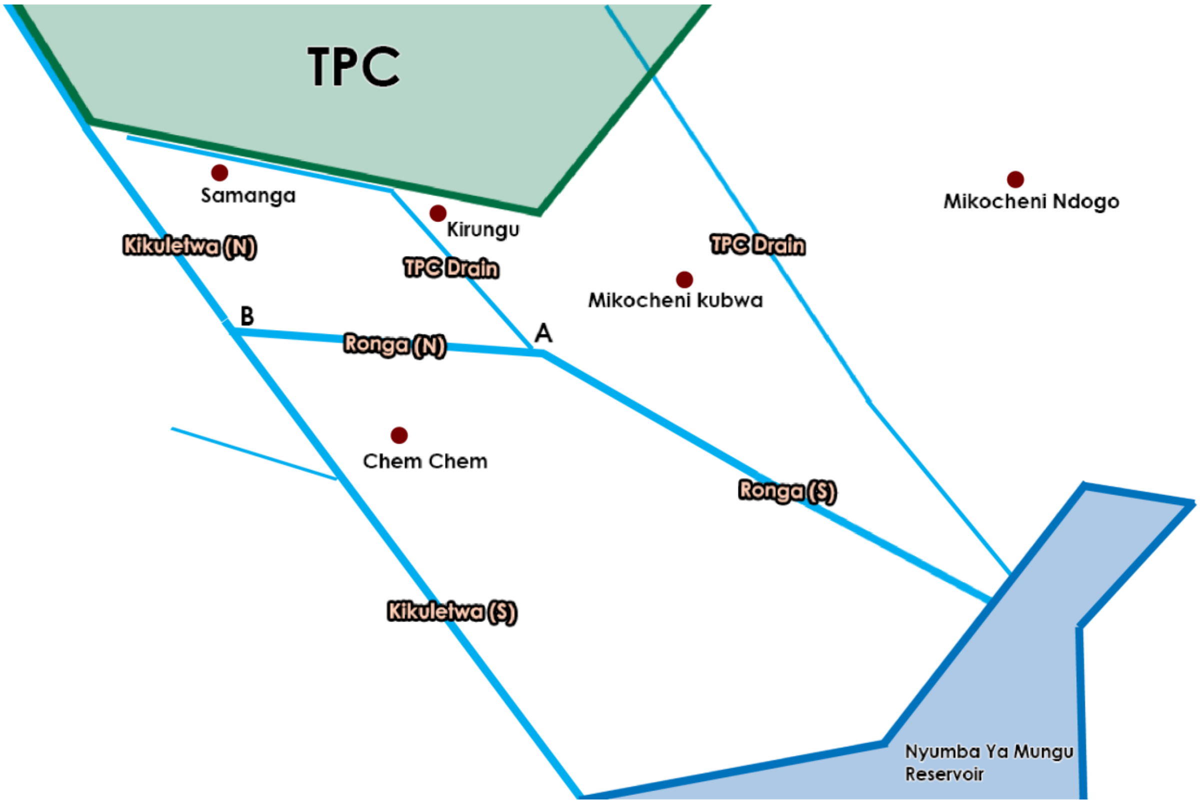

Figure 47: Schematisation of the project area and its components

The water usage of TPC for sugar cane production can influence the problem area, see TPC drains in Figure 47. An exact determination of water balance is not necessary, but the order input and output of water is needed. Subsequently the influence of TPC on the problem area and stakeholders concerning water is essential. There are three different subjects that will be discussed:

- Input by:
  - River extraction
  - Water from boreholes
  - Springs
- Output by
  - Drainage canals

6.1 RIVER EXTRACTION

There are two extraction points along the Weru Weru on the north side of TPC. The average water volume TPC extracts in between July and March approximately is 3.6 m^3/s. [6] So, if the base flow is assumed to be equal to 15 m^3/s, TPC extract about 24% of the river discharge outside the rainy season. In the rainy seasons TPC stops extracting water and profits from rainfall, this is sufficient to provide their fields of enough water.

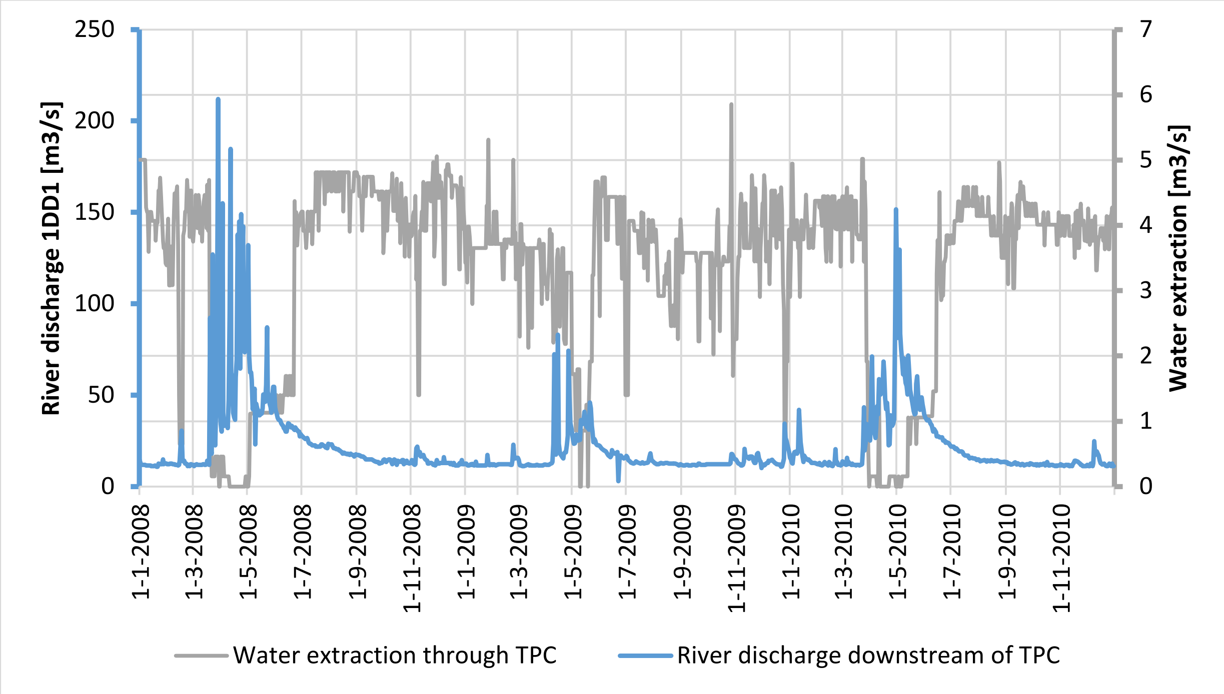

Figure 48: Discharge and extraction of Weru Weru (Data source: TPC)

6.2 Boreholes

Extra sources for water are 14 boreholes across TPC fields. During previous years boreholes supply about 1.7 m^3/s.[6]

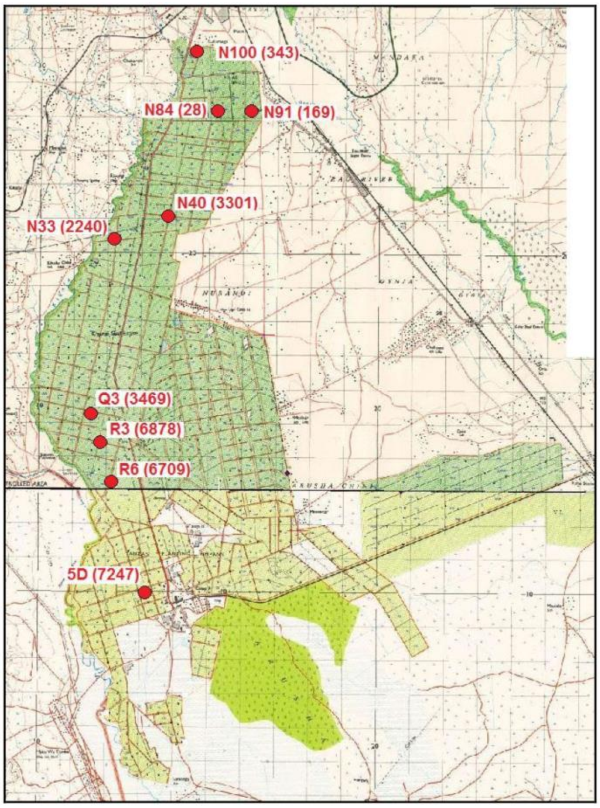

Figure 49: Boreholes TPC

6.3 Springs

Other sources of water for TPC are the Miwaleni Springs. By use of a drain the water flows into TPC area. The discharge of this spring is about 1.7 m^3/s. [6]

6.4 Drains

On the TPC area a system of drainage channels is used to irrigate the water over the total agricultural land. Two drains are used for outflow of dispensable water out of TPC area on the southern side of TPC. The drainage quantities for both drains are variable and not known.

For the villages Samanga and Kirungu the northern drain is a source of water for irrigation and domestic purposes. To make sure that the villagers have enough water at all time, they block the water by use of self-made weirs, see also Appendix P: Field Reports.

Figure 50: Blockage northern TPC drain near Samanga

Figure 51: Blockage northern TPC drain near Kirungu

6.5 Salinity problem

A special feature the Kikuletwa River and therefore also of the TPC area is the high salinity content in the topsoil. The salinity brought in by Kikuletwa River as result of Saline debris from the Arusha area. Underneath intermezzo comprises extra info about the origin:

"Sodicity is the presence of excess 'exchangeable sodium' (sodium salts capable of alkaline hydrolysis) and results in poor soil permeability and tilth. Salinity is common in arid/semi-arid areas because there is not enough water to flush accumulated salts from the crop root zone. Salinization may occur when the supply of salts exceeds their removal by flooding or leaching. Amongst many problems associated with salinization is its impact on soil absorption and moisture retention. The breakdown of the soil's physical properties causes its top layer to compact, ensuring that water infiltration from the surface layers to the root zone is restricted. In the Pangani River Basin, the problem of salinity has been reported in some irrigation schemes, including Musa Mwijanga, Kikafu Chini (both in Hai District) and Mawala (Moshi Rural District) (Misana and Makoi, 2001), as well as on some of the Basin's large private irrigation schemes (Sahib, 2002)". [15]

As a method to lower the saline content in the top layer of the agricultural land, TPC uses the method of high drainage quantities to drain the so called 'exchangeable soda' out of the aquifer. The extra need for drainage due to the infiltration is possibly hindered by blockages in the northern drain, depicted in Figure 140.

Important to note is that the boundary of this saline soil is at the confluence of the Kikuletwa and the Weru Weru. South and South East of the confluence the soil is saline at TPC. Upstream of the confluence, so east of the Weru Weru, this is not a problem.

7 NYUMBA YA MUNGU RESERVOIR

The Nyumba ya Mungu ("House of God") reservoir is the reservoir used to facilitate the Nyumba ya Mungu hydropower dam. The rivers in the project area, Kikuletwa and Ronga (and also the Ruvu), end up in the reservoir and it is therefore of our interest to analyse the influence of the reservoir on the upstream water system. In this chapter this analysis is presented, treating water levels, backwater curves and flooding areas.

7.1 GENERAL CHARACTERISTICS

The reservoir is owned by the Tanzanian government and managed by the Pangani Basin Water Board (PBWO). It was created in 1965 because of the construction of a hydroelectric dam. The dam is an inclined rock fill type of dam. It was mainly built for storing flood flow and regulating discharge for the Hale hydropower plant further downstream. Besides producing electricity power the reservoir also has a fishing industry. The people from sub village Mikocheni Ndogo are mainly fisherman fishing in the reservoir.

The dam provides a maximum head of 29 m and has an installed capacity of 8 MW. Downstream of the Nyumba Ya Mungu (NYM) dam two other power plants are located at Hale (22 MW) and New Pangani Falls (66 MW). On average the estimated inflow of the reservoir is 35.8 m^3/s of which 21.3 m^3/s is released through the turbines [16]. The maximum depth of the reservoir is 29 m and the maximum live storage capacity is 871.5 Mm^3.

Physical characteristics of Nyumba Ya Mungu reservoir:

Table 11: Physical characteristics of Nyumba ya Mungu reservoir

Property	Value
Length of crest	400 m
Length of spillway	400 m
Width of the spillway crest	183 m
Highest water level	688.91 m.a.s.l.(at Tanga)
Lowest operation water level	679.15 m.a.s.l. (at Tanga)
Max. design flood capacity of spillway	920 m^3/s
Storage at HWL	$871*10^6$ m^3
Minimum statutory release	21.3 m^3/s

The amount of hydropower that is generated depends on different parameters. These are the water discharge Q that flows from one water height to another, the head H. The general formula for power then is:

$P = \rho * g * Q * H$ (in Watt) [17]

It can be concluded that more power is generated when the reservoir has a higher water level. However, it should be avoided that water is spilled when the highest water level is reached. This trade-off is shown in Figure 52, where a high water level in the reservoir is maintained but in 1998 that led to reaching the maximum water level in the rain season. This led to spilling through the spillway, shown in Figure 52 as the difference between a discharge gauging station downstream of the dam and the discharge through the machine.

The last years in the graph show a lower water level than usual. These were years with less rainfall and as a result; less water in the reservoir.

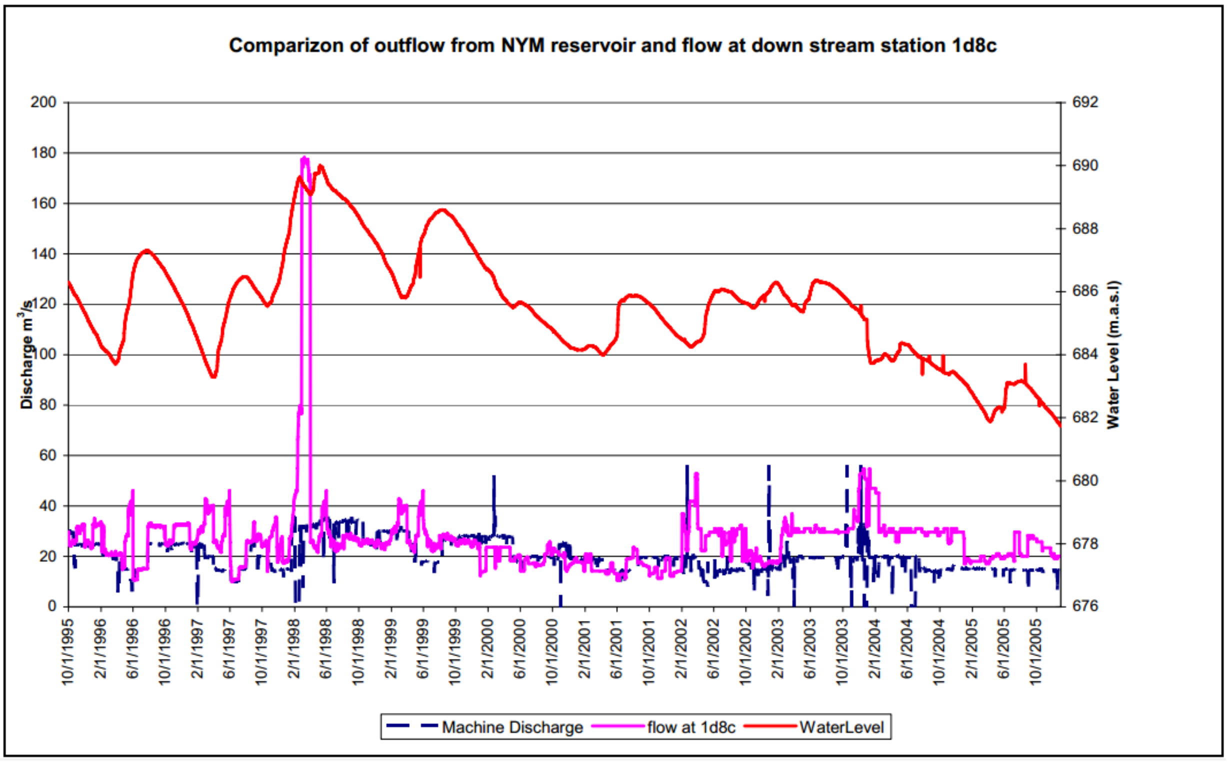

Figure 52: Reservoir levels from 1995 – 2005, note the spilling of water through spillway in N.y.M. reservoir in 1998 [16]

7.1.1 Operating rules

Unfortunately, the operating rules for the Nyumba Ya Mungu reservoir are not very consistent. In general the reservoir operates to optimise power generation in the total Pangani Hydropower System. This means that it serves the two lower lying hydropower stations by flattening the flood waves throughout the year, but at the mean time there is a trade-off between the maintenance of a high head to generate power.

S.A. Moges has proposed to include the concept of probability of failure in the operating rules of the reservoir [18]. He defined the minimum conservation level for each month by analysing historical data of the reservoir. In Figure 53 the water levels are shown for two different confidence levels above which failure cannot occur within the next year. However, there is no information present in which it is proven that TANESCO has adjusted to this policy.

Month	95% reliability		99% reliability	
	CRC as levels (m.a.s.l)	CRC as Storage (Mm^3)	CRC as levels (m.a.s.l)	CRC as storage (Mm^3)
January	680.86	88.27	681.35	116.22
February	680.37	61.75	680.86	88.27
March	680.37	61.75	681.80	143.33
April	680.37	61.75	682.91	217.27
May	682.32	176.64	684.27	324.26
June	683.30	245.96	684.27	324.26
July	682.81	210.16	684.27	324.26
August	682.81	210.16	684.27	324.26
September	682.32	176.64	683.79	284.22
October	681.80	143.33	683.30	245.96
November	681.35	116.22	682.81	210.16
December	680.36	88.27	681.80	143.33

Figure 53: Minimum reservoir levels to ensure reliability of Nyumba ya Mungu reservoir

7.1.2 Reservoir floods

As has been treated in section 2.2 a lot of land in the project area is owned by the Ministry of Water of Tanzania. However, TANESCO is the (governmental) company that uses the dam and the reservoir. TANESCO is the Tanzanian power supplier owned by the government. The "TANESCO" land is used for flooding in case of high water. To what extent the reservoir yearly reaches has been analysed.

Data has been provided by TPC on the weekly water levels of the reservoir in the last five years. This data has been analysed, reservoir levels are shown in Figure 54 and a summary is shown in Table 12.

Table 12: Minimum and maximum reservoir levels

	2009	*2010*	*2011*	*2012*	*2013*	*2014*	**2009-2014**
MAX	688,11	687,28	685,79	684,21	685,15	685,86	688,11
MIN	685,01	684,65	682,96	682,19	682,32	683,60	682,19

Using the information from Figure 52 and Figure 54, insight can be gained on what area is yearly flooded. The yearly highest reached water level is on average 685 – 686 meters above sea level (m.a.s.l.) and is shown as a light blue line in Figure 55.

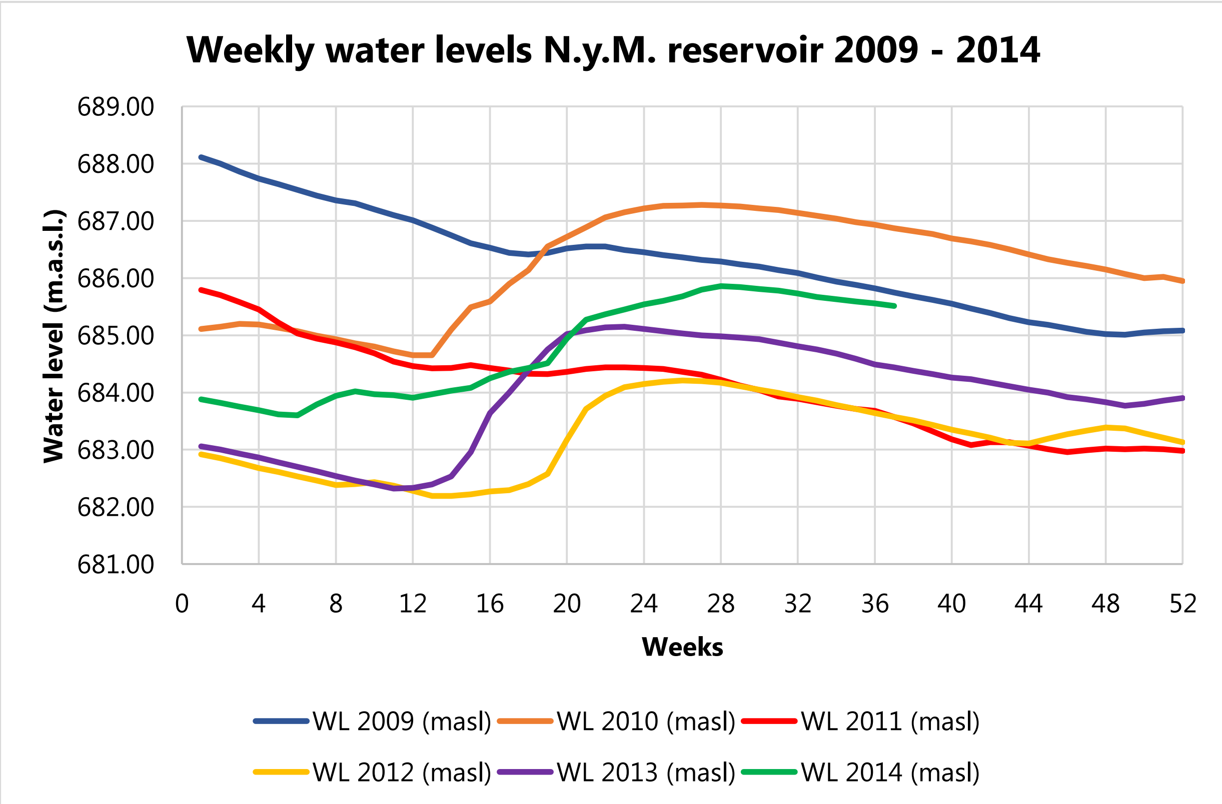

Figure 54: Water levels reservoir 2009-2014

7.1.3 Extreme reservoir floods

In interviews with the villagers and other stakeholders, people regularly talked about extreme reservoir floods. Further questioning made clear that these floods occur about once in 10 years. This coincides with the data from the figures; in 1998 and 2008 maximum reservoir levels were reached.

A study was conducted by use of a Digital Elevation Map to what horizontal extent the reservoir floods would reach when this vertical reservoir level is reached. This study is shown in Appendix G, the results however did not coincide with local observations and what the villagers said was the extreme flood reach. The cause of this mismatch was likely to be the inaccuracy of the DEM. Therefore other sources were used to investigate the extent of these extreme floods. The elevation used in Google Earth gave results that correspond with anecdotes from villagers and stakeholders. The extent to where the extreme floods reach is shown in Figure 55 by the dark blue line, visualised using Google Earth and their elevation levels.

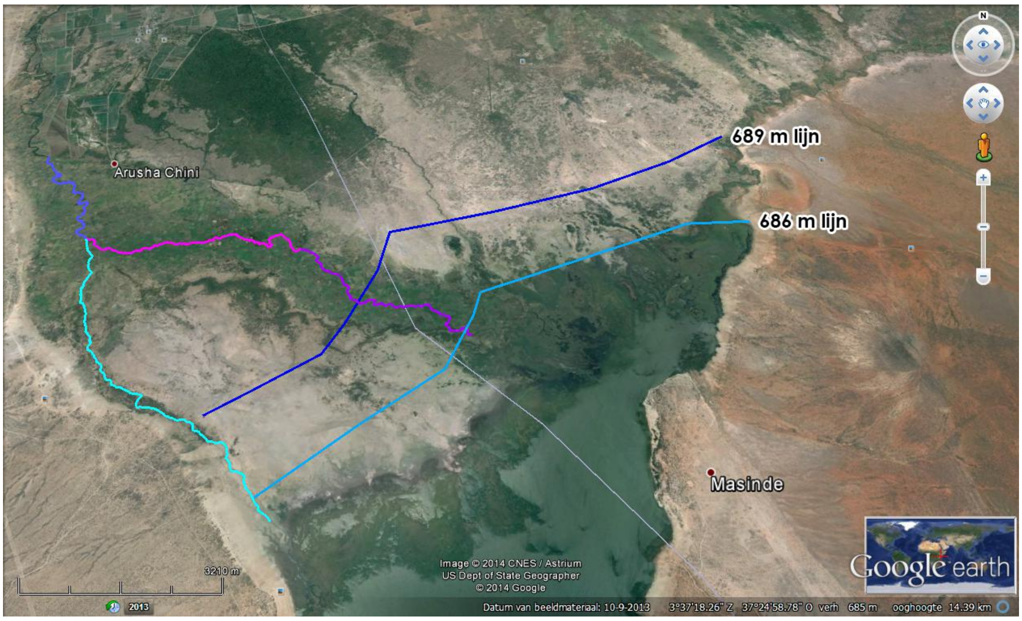

Figure 55: Extreme and average flood line (source: Google earth)

When the highest possible reservoir level is reached, large parts of the sub villages are flooded. Still a lot of land is not drowned by the reservoir floods, which is flooded by the rivers.

7.2 RELATION RESERVOIR LEVELS AND THE WATER SYSTEM

The reservoir is thought of to have a big influence on the local water system. In this section this influence is analysed.

7.2.1 Relation of reservoir levels and discharge in the Kikuletwa

TPC provided data for the analysis of the water system. This data included weekly levels of the reservoir since 2009 and daily discharges of the Kikuletwa up to 2010. Therefore two years of measurements are available to relate reservoir levels and discharges in the Kikuletwa.

Both have been plotted to get a quick view on the system, see Figure 56 and Figure 57. The daily discharges were changed to weekly averages in order to relate discharges and water levels. It has to be noted that 2008 was a year with a lot of rainfall and high discharges in the Kikuletwa. This led to high reservoir levels, starting with 688.1 m.a.s.l.[1] in January 2009. These reservoir levels were brought down later that year as 2009 was a year that had not much rainfall and therefore small discharges. Figure 57 shows a more representative year with a clear increase in the reservoir level as a result of the increased discharge in Kikuletwa (and probably Ruvu too).

[1] Meter above sea level

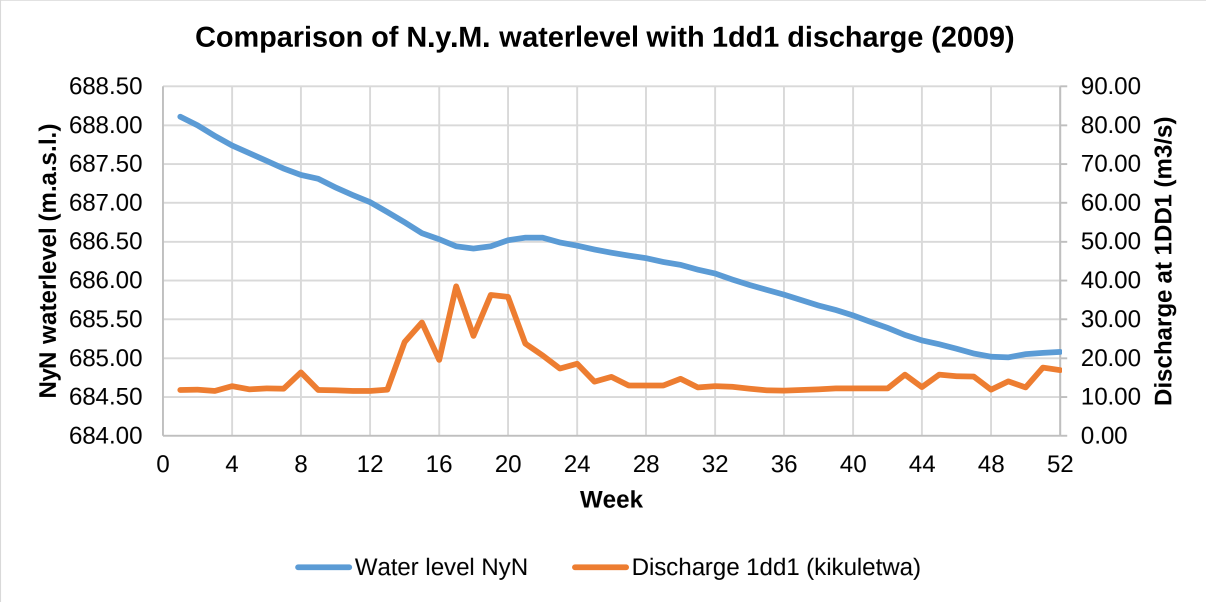

Figure 56: Comparison of reservoir level and Kikuletwa discharges (2009)

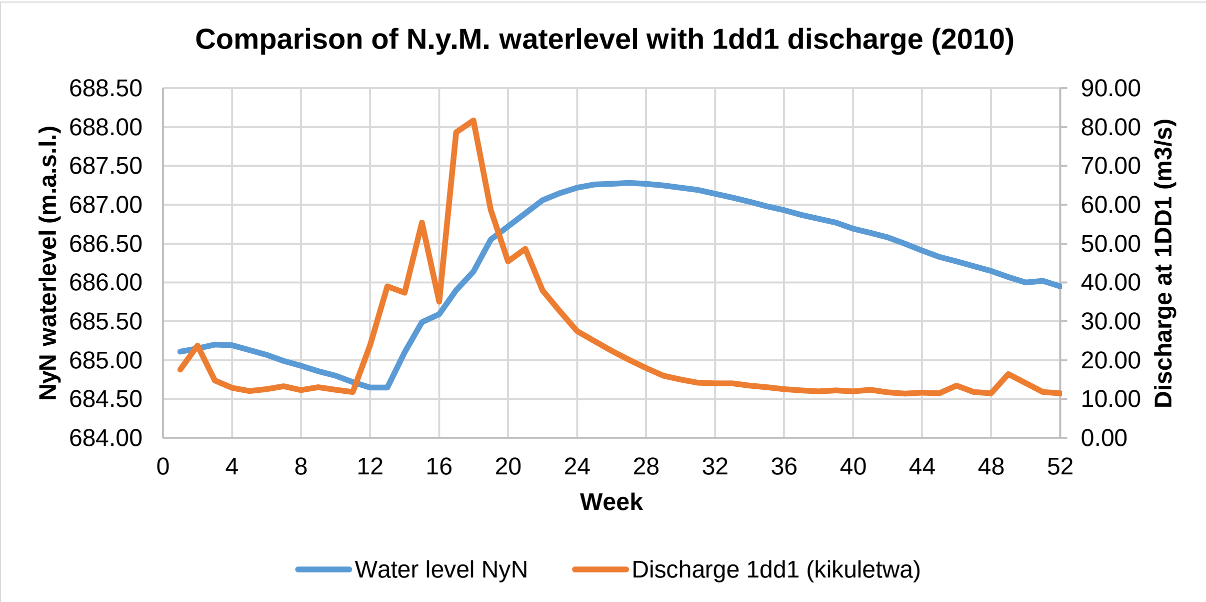

Figure 57: Comparison of reservoir level and Kikuletwa discharges (2010)

It is clear that due to the long rains, from March to May, the reservoir increases significantly. As stated before, the reservoir is used to flatten the flood waves for the next hydropower dams in the Pangani Basin. A high water level during the long rains would probably negatively influence the river floods. This works two ways;

- Backwater curve;
- Increase of the water table.

The backwater curve is elaborated later in this chapter. A higher reservoir level would decrease the gradient in Darcy's Law:

$$Q = -K \cdot i$$

In which K is a parameter for the permeability of the ground and i is the slope or gradient in the groundwater. If the reservoir levels rises, the gradient decreases and less water flows through the ground towards the reservoir. This leads to a higher water table, with the result that the rivers cannot lose water through the ground.

7.2.2 Backwater curve

It is clear that the rainy season is of great importance to the reservoir levels. The next question is whether the reservoir level influences the water system. One way to assess this influence is by looking at the backwater curve.

The backwater curve is the result of a water level downstream (for example in a lake or at the sea) that is not in accordance with the natural, equilibrium depth of the waterway upstream. This has been visualised in Figure 154 for the Nyumba ya Mungu reservoir and the Ronga or the Kikuletwa.

If the water level of the Nyumba ya Mungu reservoir is lower at the mouth of the river (in purple, h_{low}), then for a certain distance upstream the water level will be lower than the equilibrium depth h_{eq}. This also works the other way around, for a water level in the waterway, at the mouth of the river, which is higher than the equilibrium depth the water level is higher upstream. How fast a waterway returns to its equilibrium depth upstream depends on the characteristics of the waterway. If this takes a long distance, the water level near the villages just upstream of the lake (Mikocheni Kubwa, Chem Chem, etc.) is more distorted (case B in Figure 154) than if the distance to equilibrium is short (case A). A measure for this distance is the half-length.

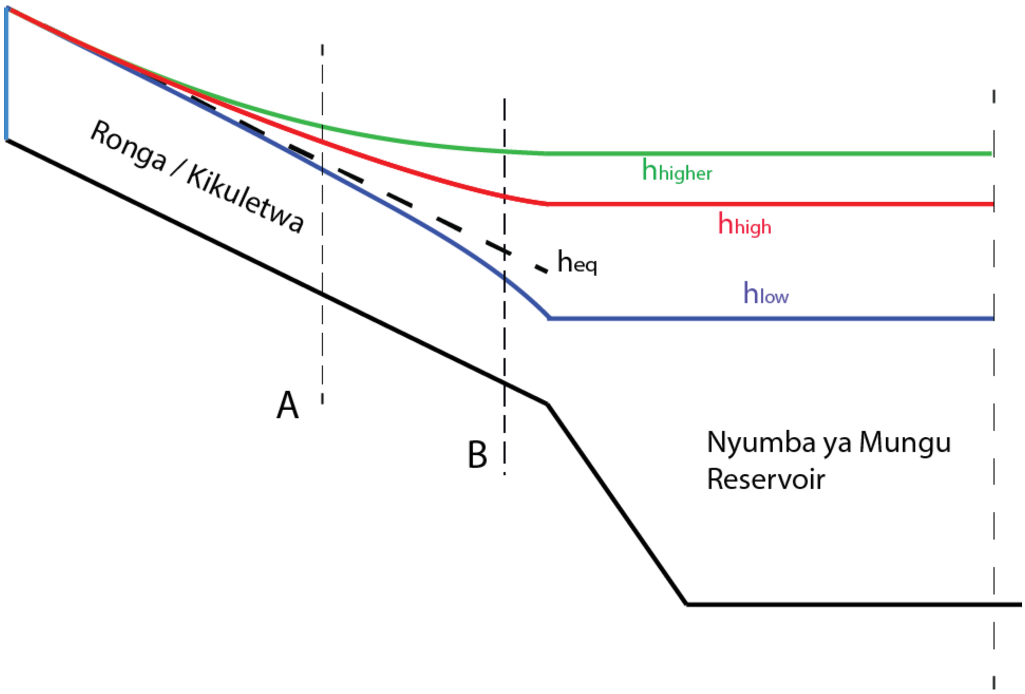

Figure 58: Visualisation of the backwater curve

In Appendix H calculations for backwater curves are presented for both the Ronga and the Kikuletwa River in order to determine the influence of the Nyumba ya Mungu reservoir on the water system. Input parameters for the calculations were the characteristics of the waterway and the discharge that was going through the waterway. Two cases have been considered, one case for discharges in the dry season and one for high discharges during the rainy season.

Especially the case for high discharges yielded surprising results. Given the high discharges passing through the waterways, equilibrium depths are much higher than the possible depths in the rivers. Together with very short half-lengths it can be said that the reservoir does not have much influence on the water levels in the river. The half-lengths are so short that the rivers will reach the height of the banks not far from the reservoir, not influencing the rivers levels around the communities.

7.3 FLOODING VOLUME

Both the Kikuletwa and the Ruvu have a steady base flow and yearly occurring high discharges (because of the rainy seasons). The level of the reservoir is of course partly related to these inflows and thus differs throughout the year. This paragraph focuses on the consequences to the reservoir of the higher discharges of these rivers.

7.3.1 Filling speed of the reservoir

As stated before, the maximum live storage of the reservoir is $871*10^6$ m^3. This is the amount of water which, if the reservoir has reached the maximum level of 688.91 meters above sea level (m.a.s.l.), can be used to generate power[2]. The water below the minimum water level of 679.15 m.a.s.l. cannot be used to generate power, and thus does not account to the live storage. The relation between the water level (h) of the reservoir and the live storage (S) is given by [18]:

$$S = 49.24 \cdot h + (h - 679.15)^{2.62} - 33441.35$$

In which S is given in million cubic meter (Mm^3) and h in meters above sea level (m.a.s.l.). The relation is shown in Figure 59 below:

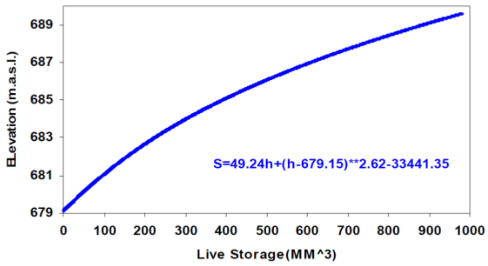

Figure 59: Live storage elevation curve [18]

Besides the storage elevation curve, Moges also derived a relation between the waterlevel (h) and the area (A) of the reservoir:

$$A = 1.2442 \cdot (h - 672.132)^{1.62} + 17.6$$

In which A is given in square kilometres (km^2) and h in m.a.s.l. The area elevation curve is shown in Figure 60.

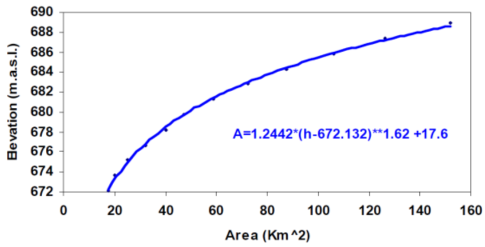

Figure 60: Area elevation curve [18]

This curve shows that at a higher starting level, a little water level increase causes a relatively larger area increase.

D.M.M. Mulungu et al. [19] simulated the Nyumba Ya Mungu reservoir by using a hec-ressim model. In this study it was found that the yearly inflow is 824 Mm^3/y, the yearly evaporation is 240.08 Mm^3/yr and the yearly rainfall in the reservoir is 84.5 Mm^3/yr. After analysing flow data from 1991 to 2005 they extracted the parameters shown in Table 13.

[2] If all in- and outtake, except for the flow through the turbines, is neglected.

Table 13: Mean discharges at 1DD1 and 1DC1 for the period 1991-2005 [19]

River	Mean (m^3/s)	Std.dev. (m^3/s)	Max. (m^3/s)	Min. (m^3/s)
1DD1-Kikuletwa	24.00	21.50	220.89	8.20
1DC1-Ruvu	11.80	6.80	64.40	3.74
Inflow expected at NyM	35.80	25.40	243.60	16.70

The maximum inflow from both the Kikuletwa and the Ruvu is 243.60 m^3/s. The average outflow through the turbines is 21.3 m^3/s. The maximum net inflow is then 222.3 m^3/s. Using this value (ignoring evaporation and rainfall), the minimum time needed to fill the total live storage of the reservoir is:

$$\frac{871 \cdot 10^6}{222.30} = 3918129\,\text{sec} = 45.35\ days$$

This is an unrealistic calculation, because the maximum discharge never occurs 46 days in a row and the water level of the basin almost never reaches the minimum level. It only gives an indication that it would at least take 46 days to fill.

The average water level of the Nyumba Ya Mungu reservoir is 684.75 m.a.s.l, this is a more realistic level to start calculations. If a flood starts at this level it would take 26.3 days to fill the whole reservoir. Thus it would at least take 4 weeks. It is impossible that the maximum discharge occurs for such a long time. If a realistic discharge were used, the time to fill the reservoir will even take longer. It can be concluded that it takes a very long time to raise reservoir water levels as a consequence of the long rain season.

The next thing to consider is the daily influence of the flood wave. The water level and area or storage relations were used to perform a sensitivity analysis. The results are shown in Figure 61.

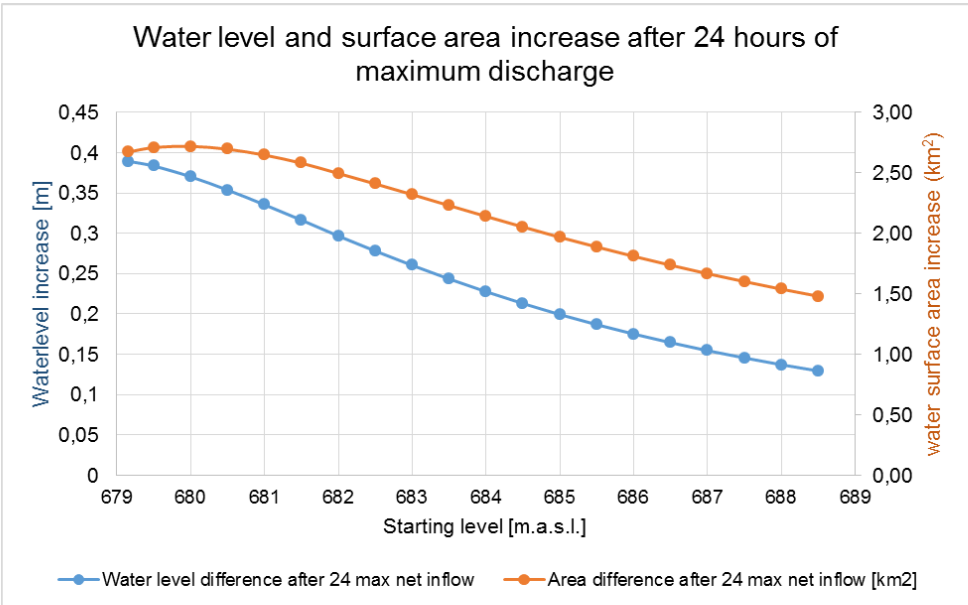

Figure 61: W.L. and area increase after 24 hours max net inflow

The figure shows the increase of water level and the increase of surface area for different starting water levels. In this analysis the maximum net inflow of 222.3 m^3/s was used. The volume that enters the reservoir after one day then is:

$$222.3 \cdot 3600 \cdot 24 = 19.6\ Mm^3$$

From this graph it can be deducted that at higher starting levels the water level and surface area is relatively smaller due to a maximum flood wave of a day.

7.3.2 Importance of the flood volume

In subparagraph 7.2.1 it already was concluded that the higher discharges during the rainy season do influence the reservoir and let the water level rise. In this subparagraph the importance of the flood volume relative to the total volume will be analysed.

In 5.2it was deducted that the maximum discharge capacity of the Ronga is 26.2 m^3/s. It is assumed that the Kikuletwa(S) only accounts for 5% of the total discharge capacity. Thus a maximum total discharge capacity for both the Ronga and the Kikuletwa(S) is ~25 m^3/s. In the next calculations, 25 m^3/s is used as boundary between normal flow and flood flow. Everything above this boundary, is accounted as flood discharge.

Ruvu discharge data was not available, thus only the flood volume from the Kikuletwa was considered. The discharge data of 1DD1-Kikuletwa from 1978 – 2010 has been used to calculate the total water volume and the total flood volume per year. The result is shown in Figure 62.

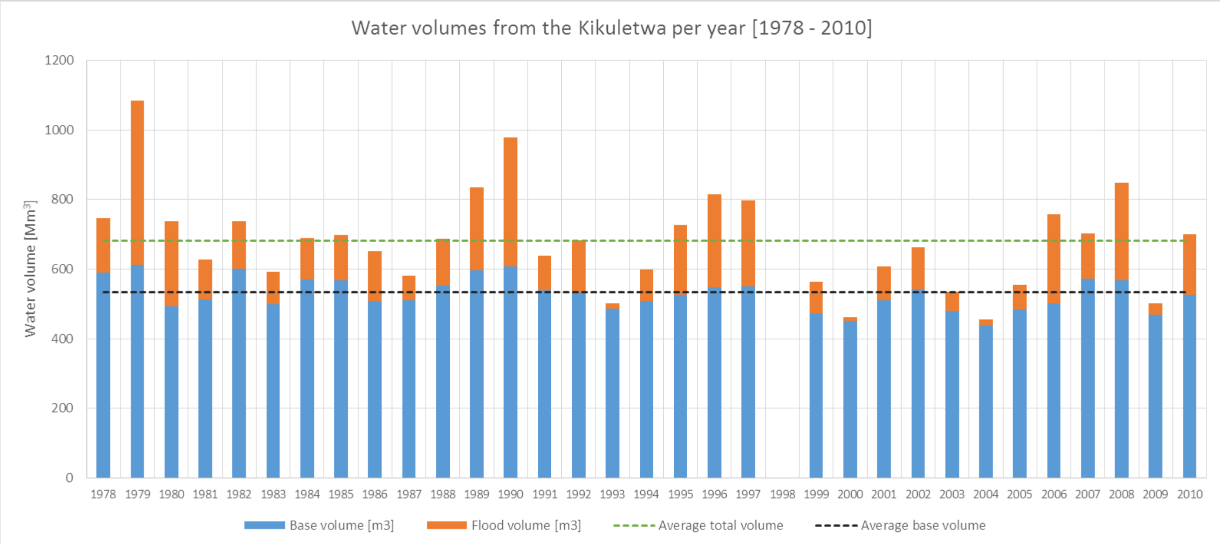

Figure 62: Total and flood volume from the Kikuletwa per year

The average total volume inflow from the Kikuletwa is 681 Mm^3 and is showed in Figure 62 by the green dotted line. The black dotted line shows the average base volume (no flood) which has a value of 533 Mm^3. The average flood volume is the difference between those, which is 148 Mm^3 per year. This is 22% of the total volume that yearly flows in the reservoir. In Figure 63 the percentage of the flood volume compared with the total water volume is shown per year. The average percentage (of 22%) is also shown in orange.

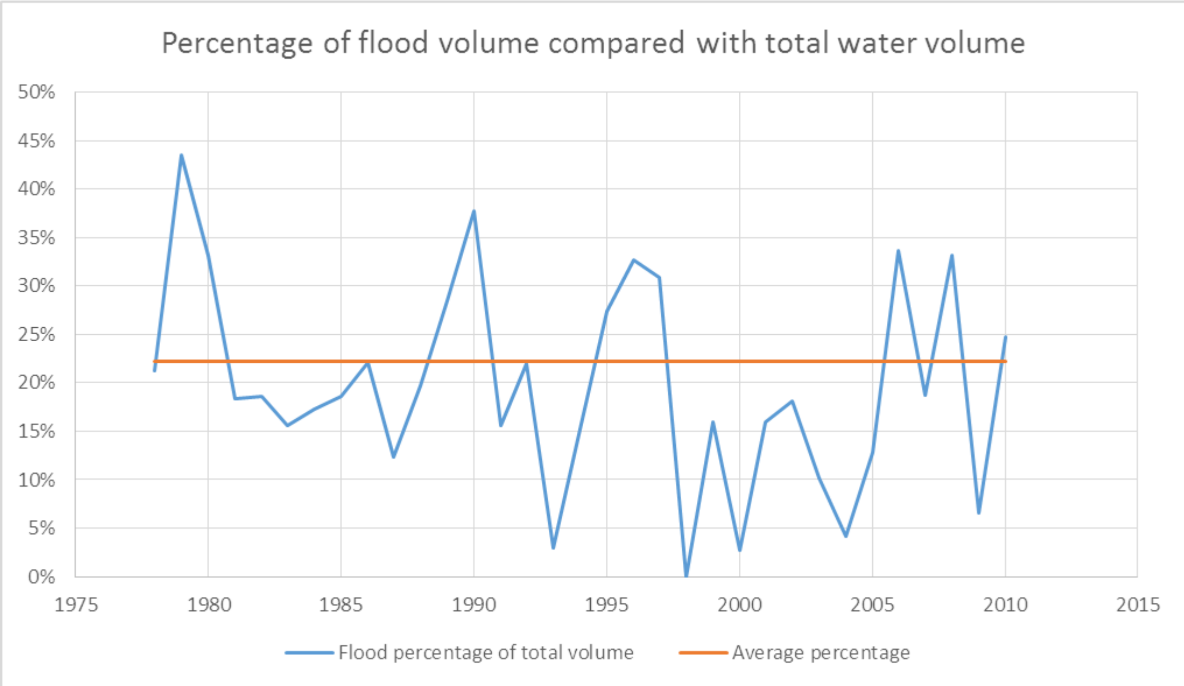

Figure 63: Percentage of flood volume of total

22% is a fair amount and thus it can be concluded that the flood volume of the Kikuletwa is of big importance to maintain water levels and energy production in the Nyumba ya Mungu reservoir.

Part B: Synthesis

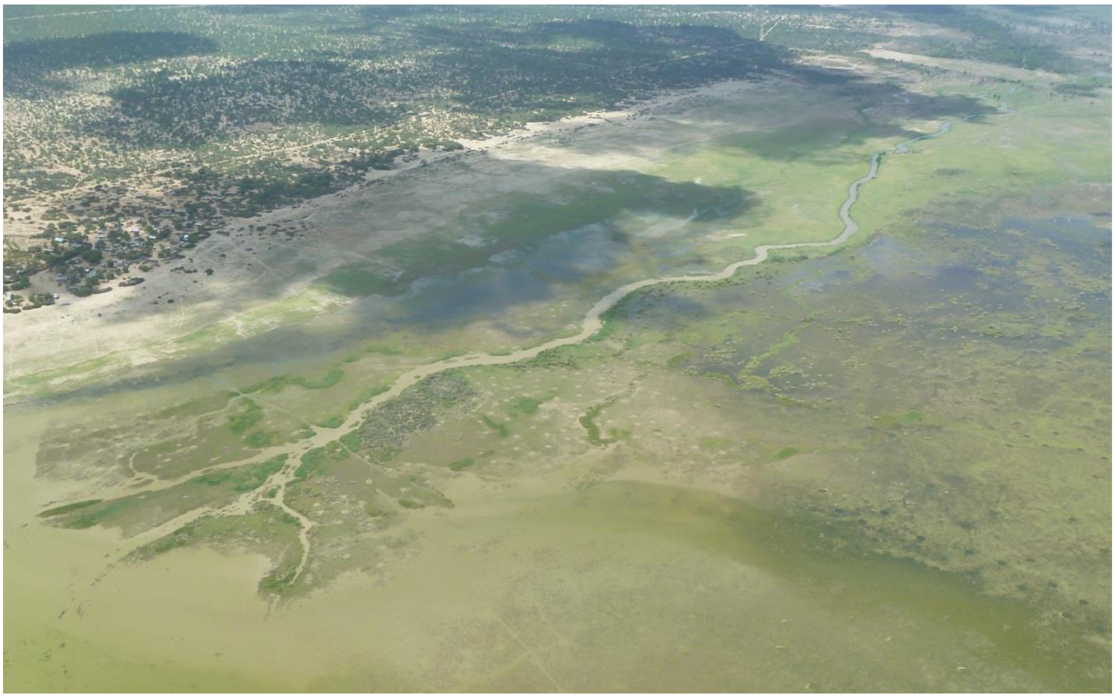

Figure 64: Aerial picture of Kikuletwa ending in Nyumba ya Mungu reservoir

8 REQUIREMENTS TO THE SOLUTION

In this chapter the requirements and conditions of this project are described. The requirements laid down by FT Kilimanjaro (FTK) are the minimum a solution should comply to. In the section of preferences, the wishes of some of the stakeholders and FTK are included. The boundary conditions define the framework of the project.

8.1 REQUIREMENTS:

Together with FT Kilimanjaro the following requirements for this research project are defined:

- The solution has to reduce the negative consequences of the yearly floods on farming activities, specifically, and generally on community infrastructure and livelihoods;
- Aspects of the solution must be tangible or visible on short term to gain trust of the villagers;
- The solution may not enhance the problem of saline soil in the problem area;
- Solution should not evoke water conflicts between farmers and livestock keepers.

8.2 PREFERENCES

Some stakeholders have expressed their preferences, which they wish will be included in the solution. Also FTK has some wishes they would include. Those desired conditions are:

- Farming land should be protected from flooding during the short rain season;
- The flooding depth should be lowered during the large rain season;
- The breached dike needs to be repaired;
- Some of the flood volume should be captured and stored for irrigation purposes during the dry season;
- Farmers would like to be able to open the gate near the dike breach to provide their farming land with water;
- The solution should not negatively influence the current infrastructure and other social facilities;
- Water conflicts between crop farmers and livestock keepers could be diminished by increasing the grazing land;
- The solution should be executable with local equipment and labour. This includes the equipment and experience of TPC;
- The project area (problem area including western side of Kikuletwa, TPC and Mikocheni Ndogo) should preferably not be influenced negatively;
- Solve the issue of the TPC drain blockages.

8.3 BOUNDARY CONDITIONS

These conditions follow from the surroundings and involved parties:

8.3.1 Environmental/natural conditions:

- When the solution entails changing river beds, the consequences of these changes on sedimentation should be evaluated.
- The amount of sediments that enter the reservoir should be kept to a minimum
- Adjusting reservoir levels are not within the solution framework

8.3.2 Legal conditions:

- When (a part of) the solution lies in the TANESCO area, permission has to be asked and received from the responsible organisation;
- Each measure on the river system must be announced to, and approved by the Pangani Basin Water Board;
- The solution has to comply with Tanzanian law.

8.3.3 Societal conditions:

- The solution must be supported by local villagers;
- Current farmers' irrigation access levels must be maintained;
- The district should be in favour of the solution.

8.3.4 Financial / economic conditions:

- The solution should be economical feasible and realistic in relation to the FTK budget;
- The cost of the solution should be proportional to the added value.

9 ALTERNATIVES STUDY

Based on the program of requirements and the analysis, a study towards possible solutions has been conducted. Six different solution orientations have been identified, that will be discussed in this chapter. These different solution orientations have led to different final solutions that are discussed in this chapter too.

9.1 SOLUTION ORIENTATIONS

In order to derive final solutions that can be implemented in the project area, different solution orientations were investigated. A brainstorm yielded six orientations that could lead to final solutions. The research conducted towards each orientation is discussed in Appendix I: Alternatives study, the different orientations are presented here shortly.

9.1.1 Dikes

Building dikes is a measure that increases the capacity of waterways or secures one side of the waterway against flooding. When built on both sides on a waterway, the water level can increase to a higher level, thus increasing the capacity of the river. When a dike is built on one side of the river to a level that is higher than on the other banks, the side of the higher bank will not get flooded as the other side is flooded first.

Different locations and types of dikes have been researched in this orientation, these are:

- A dike along the northern Kikuletwa near the Samanga area;
- Short rain dikes along the Ronga;
- High dikes on both sides of the Ronga.

9.1.2 Afforestation

A more general measure to reduce discharge peaks is to flatten these peaks by means of afforestation. More vegetation in the catchment of the Kikuletwa, be it forests, agriculture or grass, retains more moisture and thereby increases the retention time of rainfall. This flattens the sharp peaks in the discharge of the Kikuletwa.

It has been researched whether afforestation can be implemented in the project area, and what the best location would be. The location Msitu wa Tembo could yield positive results in delaying run-off from the mountains towards the southern Kikuletwa. However, effects of afforestation in Msitu wa Tembo are hard to quantify and will probably be marginal. Afforestation is often part of a larger masterplan in restoring landscapes. Reducing and flattening discharge peaks is therefore more a positive side-effect of afforestation than an actual solution to the problem.

9.1.3 Capacity increase

The capacity of waterways can be increased in several ways. A general formula to calculate discharge capacity is the Chezy-formula:

$$Q = A \cdot C \cdot \sqrt{R \cdot i}$$

The capacity can be increased by increasing the cross-section A and hydraulic radius R by means of:

- Deepening the waterway;
- Widening the waterway.

The slope i of the river can be increased by straightening the river path. Increasing the smoothness coefficient C could also lead to a higher capacity, it has been researched how the resistance/friction can be reduced. These four effects have been researched and possible locations have been identified.

9.1.4 Control structures

Control structures are structures that can regulate water flow in the project area. Different types of control structures have been looked into. The goals of the structures differ; these can be to divert water at a bifurcation or to irrigate farmland. The different structures discussed are:

- Sill (overflow);
- Division structure;
- Weir (underflow);
- Siphons;
- Pumps.

The operation of these structures and possible locations have been explained in detail in I.4.

9.1.5 Storage and basins

The storage of water in reservoirs of basins could help with the problems faced in the lower Moshi area. Not only is there an abundance of water during the rain seasons, there is also a shortage of water during dry seasons. Multiple storage purposes can be identified:

1. Storage for irrigation during dry seasons;
2. Storage to reduce peak discharges;
3. Storage for controlled flooding.

9.1.6 Increase the number of discharge routes

Increasing the number of discharge routes increases the discharge capacity of the river system: more water can be discharged at the same time. It is likely that the flood volume and flood extent in the problem area will decrease by using more routes. Multiple new routes have been discussed, that can be divided in two main types of new routes:

- Restoring and using old river beds;
    - Chem Chem river bed;
    - Ronga Ndogo;
- New discharging channels;
    - Eastern old river bed (channel through TPC);
    - Channel west of the Kikuletwa (bypassing the bifurcation);
    - Drainage channels in the problem area.

9.2 Optional solutions

In this section, eighteen possible solutions are briefly explained. The solutions follow from the previous paragraph, where six different approaches were defined. A more elaborate, detailed explanation of these optional solutions can be found in Appendix I. In Figure 65 the eighteen solutions are shown. The solutions which are related to each other or to a specific measure type are allocated in the same column.

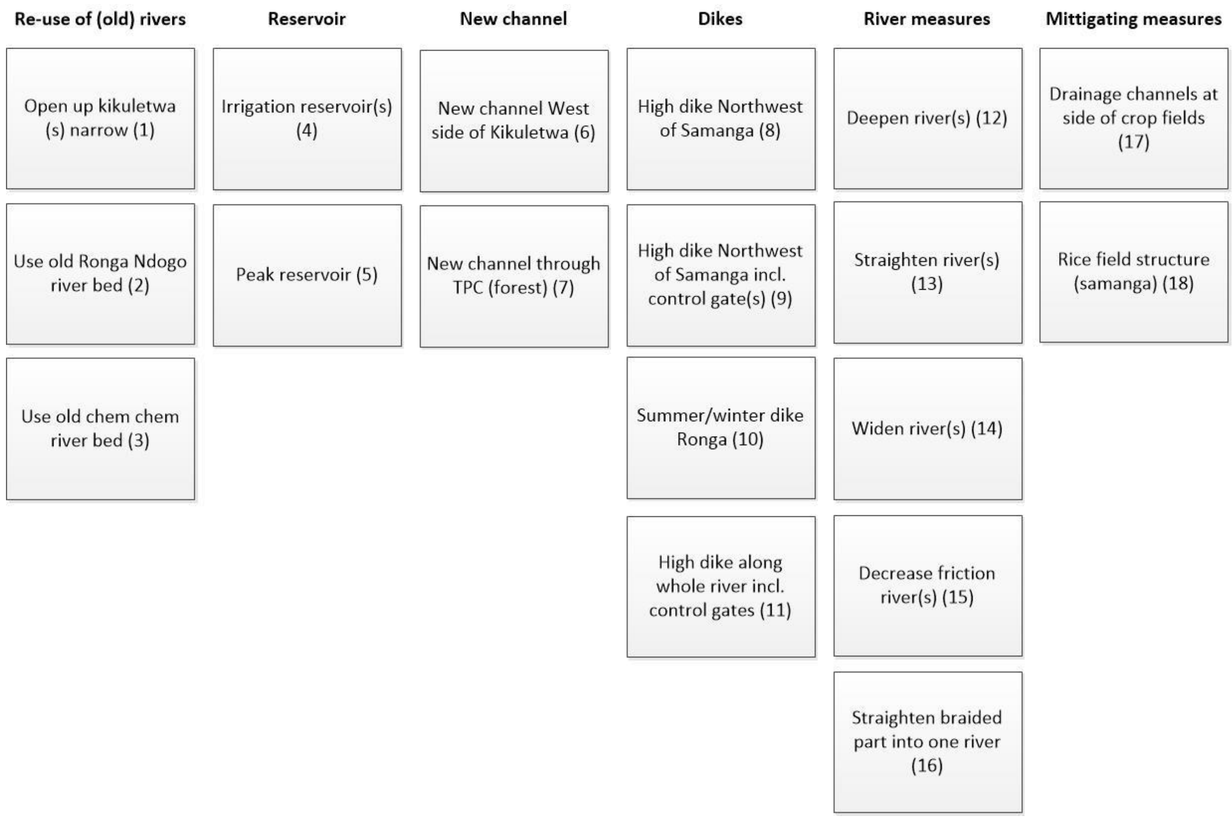

Figure 65: Six approaches to finding a solution

1. **Open up Kikuletwa South:** This solution entails widening the narrow part of Kikuletwa South to release extra discharge through this river. A control structure will be placed to manage the inflow of water into the Kikuletwa.

2. **Use old river bed – Ronga Ndogo:** The Ronga Ndogo will be excavated to make the gully able to discharge water again. This will enlarge the discharge capacity of the Ronga South.

3. **Use dry river bed - Chem Chem river bed:** This solution entails using the dry Chem Chem river bed, which will enlarge the discharge capacity of the water system. The Chem Chem river bed will be connected at the upstream part with the existing river system, either the Ronga or the Kikuletwa. The excavation of the gully will go around the school, to prevent soil instability near this school.

4. **Irrigation reservoirs:** Water is stored on multiple locations along the Ronga in reservoirs to provide water throughout the year. The Ronga is located on lower lying ground, therefore pumps are needed to store the water in the higher lying reservoirs.

5. **Peak reservoir:** A reservoir will be created to cut off the peak of the flood wave. During discharges higher than 80 m^3/s, the water is allowed to flow into the reservoir to remove the yearly extreme discharges, this will dissolve a big part of the floods in the area. The area that needs to be reserved for the reservoir is 13 km^2. The problem area is not able to accommodate this reservoir, therefore it should be placed elsewhere in the project area.

6. **New channel West Kikuletwa:** A bypass will be created on the western side of the Kikuletwa to relieve the Ronga. The bypass will start upstream of the bifurcation point at Kikuletwa North, and will connect downstream of the bifurcation point with the Kikuletwa South again.

7. **Channel through TPC:** In this option the existing infrastructure of TPC will be used. In the wet season the extraction from the Weru Weru will continue, and the water is brought to the east of TPC with a drain and led to the eastern part of the forest where it is discharged into the TPC drain on the east of the forest. The water will run in between Mikocheni A and B towards the reservoir. On TPC ground, partly a new channel must be constructed to connect the current infrastructure with the eastern drain.

8. **Dike Samanga area:** The breached dike at Samanga will be restored and lengthened until higher ground, to prevent floods in Samanga. There is no control structure present.

9. **Dike Samanga including control structure:** The breached dike at Samanga will be restored and lengthened until higher ground. In the dike a control structure will be placed, which allows control of the amount and duration of the flooding. This option decreases the amount of water and speed of the water flowing over the Samanga area.

10. **Short rain dike Ronga:** This solution entails the concept of the short rain dike, applied to the short rains and long rains. Along the Ronga the embankment will be heightened to form a 'short rain' dike, which has the capacity to discharge the water during the short rain season. During the long rains, this 'short rain' dike will overflow, flooding the farmland. The winter dike will be placed behind the farmland to protect the villages during the long rains. This dike is already present, it is the TPC drain around Kirungu.

11. **High dikes along Ronga, including control gates:** Along the Ronga, dikes are built. The crest of the dike is high enough to prevent overtopping during the long rains. To make sure the farmers are able to irrigate, control gates are incorporated to discharge water to the farm land.

12. **Deepen river sections Ronga:** The Ronga river is deepened and thus the discharge capacity is increased.

13. **Straighten river sections:** The Ronga South and/or the Kikuletwa North are straightened to increase the slope and thus the discharge capacity increases.

14. **Widen river sections Ronga:** The Ronga river is widened and thus the discharge capacity is increased.

15. **Decrease friction river sections:** The vegetation is removed from the river bed, to decrease the friction and increase the maximum discharge capacity of the river.

16. **Straighten "Ronga braided reach", one channel:** This solution entails straightening the river, to make the slope steeper and thus the discharge capacity larger. During the straightening the multiple branches will be filled up and one cross section will be excavated. This will reduce the friction as well, as the hydraulic radius becomes larger.

17. **Drainage channels:** This solution is focussed on shortening the duration of the flooding. Along the boundaries of the flooded area, a gully will be excavated on each side of the Ronga, parallel to the Ronga, flowing to the reservoir. A network of channels on the farm land, flowing to the larger gully, help to drain the flooded area more quickly. This solution does not solve the flooding itself, but mitigates the consequences of the flooding.

18. **"Rice field" structure, including control structure:** This solution prevents high velocities of the run-off over land, concerning the area between the dike breach and Kirungu (North of Samanga). Terraced fields are created by low levees. This leads to the farm land being separated into compartments for flooding.

10 EVALUATION

This chapter describes the decision procedure and the actual decision of which solution is going to be elaborated on further. The outcome is a combination of solutions leading to one integral solution.

10.1 GOAL AND PROCESS

As a result of the analysis, different important criteria for the solution are identified. A solution can be described in added value and required cost. A reasonable ratio between these quantities is essential. To be able to quantify the added value, for the different alternatives, a Multi Criteria Evaluation method (MCE) is used. In this method, several criteria are evaluated. Each criterion is deduced from the analysis and its importance is taken into account by a given weight factor. A score is given to each alternative solution. The result is the summation of all the products of the weight factors and the scores per alternative. So each alternative solution can be ranked. For example: the best scoring alternative gets 18 points (nr. Alternatives). If the first criterion has a weight factor of 5 the sub score for criterion 'a' for this alternative has a value 90. For each criterion the alternative gets a value; the sub score. The summation of sub scores gives an end score for each alternative. Ranking these scores results in a hierarchy of the alternative solutions.

The costs are an important aspect of the project. Therefore they are incorporated in the Multi Criteria Evaluation, which normally only evaluates the added value of the different alternatives. In the following paragraphs the different criteria and prescribed weight factors are given.

10.2 CRITERIA

The criteria 'A' to 'F' are enlisted below. Each criterion is shortly described and clarified by suitable questions to evaluate each alternative solution. These questions can help to allocate a score. The weight factors are defined by an evaluation meeting in which, with the client, the criteria and their significance is discussed.

A. Reducing negative effects of flooding

To what extent does the solution succeed in mitigating the negative effects of flooding? Useful questions are:

- Are the possible floods in the short rain season prevented?
- Is the inundation of floods reduced during the long rain season?

B. Enhancing positive effects of flooding

To what extent does the solution succeed in enhancing the positive effects of flooding? Useful questions are:

- Is fertile soil transported by the river system still able to settle in the problem area?
- Is the land still flooded in order to wash out the salts?

C. Tangibility and support (short term)

To what extent will the solution be tangible and therefore have a positive effect on the support? Useful questions are:

- Will the measure be tangible on a short time scale?
- Do locals support the implementation of the alternative, or do they not cooperate?

D. Durability

Will the solution last over time?? Useful questions are:

- Is the implementation durable? Will it last on the long term?
- Can it survive peak floods?
- Is a lot of maintenance needed after the measure is implemented?

E. Constructability

Is the solution difficult to construct? Emphasising on the technical complexity or simplicity. Useful questions are:

- Does the solution consist of many elements?
- Is special equipment required for the implementation or construction?
- Are local farmers or contractors able to construct the structure?

F. Costs

Do the estimated costs have a negative influence on the feasibility of the possible implementation of the alternative? A useful question is:

- What are the costs of the implementation of this measure?

10.3 Multi Criteria Evaluation

This paragraph shortly describes the evaluation process. The different alternative solutions have been tested on the above mentioned criteria. The criteria have been given a certain weight, both by FTK and by the project group. A total of 30 points was divided over the six different criteria. The results of the weight per criterion can be found in the table below.

Table 14: Weight of the different criteria

	Criterion	Group	FTK
A	Reducing negative effects of flooding	8.33	6.50
B	Enhancing positive effects of flooding	4.67	3.00
C	Tangibility and support	4.50	7.00
D	Durability	4.33	7.00
E	Constructability	4.83	2.50
F	Costs	3.33	4.00

It can clearly be seen that the project group came with the intention to solve the flooding problem. This is the reason for the high score on criterion A. However, FTK proposes that more attention should be paid to the tangibility and support and durability. It has experienced that measures should be understandable and have direct effect on the local villagers. Moreover, it is of no use to come up with measures that need to be maintained a lot and/or are not robust. The villagers tend to forget about the function of a measure over time.

The following step in the process is evaluating the 18 different solutions, see paragraph 9.2, on the six different criteria. A table with the results per criterion can be found in Appendix J: Scores of the different solutions.

10.3.1 Results of the evaluation

In Table 15 the results of the evaluation can be found. As can be seen in Table 15, alternative solutions 1, 3, 6 and 9 score the highest.

Table 15: Resulting scores of the evaluation

	Description	Group	FTK	Average
1	Open up Kikuletwa South	446	458	452
2	Use old river bed – Ronga Ndogo	288	317	303
3	Use dry river bed - Chem Chem river bed	437	438	438
4	Irrigation reservoirs	224	239	232
5	Peak reservoir	293	274	284
6	New channel West Kikuletwa	417	405	411
7	Channel through TPC	279	285	282
8	Dike Samanga area	333	365	349
9	Dike Samanga including control structure	360	371	367
10	Short rain dike Ronga	356	319	338
11	High dikes along Ronga, including control gates	274	296	285
12	Deepen river sections Ronga	130	136	133
13	Straighten river sections	159	161	160
14	Widen river sections Ronga	220	236	228
15	Decrease friction river sections	119	129	124
16	Straighten “Ronga braided reach”, one channel	143	156	150
17	Drainage channels	263	246	255
18	“Rice field” structure, including control structure	260	218	239

The client made it clear that for 7 of 18 possible measures it is not needed to look into it further. The measures and reason for rejection can be found in the text below.

Irrigation reservoirs (4)
It is not possible to retain the flood wave with small scale reservoirs. It would however help the farmers irrigate their land, but this is not a solution for the problem.

Peak reservoir (5)
The reservoir has to be build outside the project area which is difficult to accomplish. The possible location for the reservoir is in another region and involves relocation of people including their farm land. The impact of this solution in a relatively unknown area is to big and thus this solution is defined unsuitable.

New channel West of Kikuletwa (6)
The channel has to be build outside the problem area which is difficult to accomplish. Its location is in another province which slows down decision-making and execution.

High dikes along Ronga including control gates (11)
This measure is considered too expensive. Moreover it would mean that a very long dike has to be built which may be very sensitive to failure if not built in a decent way.

Deepen river sections Ronga (12)
It is not possible to reach the river with cranes that would have to deepen the river. Deepening is a continuous process, requires a lot of maintenance and is therefore not durable.

Straighten river sections (13)
Straightening the rivers would involve a difficult operation in closing off the old bends and creating the straight river bed. A lot of sediment would be transported to the reservoir which is not desirable.

Decrease friction river sections (15)
This measure entails taking the vegetation out of the river system on a regular (yearly) basis. Not enough equipment is available to do this. Moreover, it is not durable.

Consultation of the important stakeholders led to leaving out the following measure:

Channel through TPC (7)
TPC mentioned that the canal should be dry in the rain season in order to perform maintenance. Therefore it cannot be used as an extra discharge route. Moreover, the risk of canal overflowing would be too high: factory and residential areas are located downstream of the canal. The amount of water flowing into the canal would be difficult to control as well.

Other remarks regarding possible solutions:

Applying flexible control structures (1 and 9)
To prevent the water level of decreasing too much during the dry season, it is needed to implement a control structure which regulates the distribution of water during the dry season and the rain seasons. However, the client has made clear that this might lead to conflicts among the villages. Their stakes are not completely in line and they will want to control the water in a way which benefits their village most. This should carefully be considered when designing any control structure.

10.4 Conclusions

In the previous chapter the alternative solutions were evaluated. To form an integral solution for the flooding, a combination of the highest scoring solutions is made.

The basis of the solution is a combination of:

- Alternative 1: Open up Kikuletwa South
- Alternative 3: Use dry river bed – Chem Chem river bed
- Alternative 9: Dike at Samanga, including control structure

These three alternatives are the core of the solution. Several other alternatives that may contribute and fit the basic solution will be taken into account when necessary, to gain the optimum result. The alternatives that may be added are:

- Alternative 10: "Short rain" dike Ronga
  If the capacity of the Ronga is insufficient after the implantation of alternative 1, 3 and 9, this alternative can be executed to increase the bankfull capacity of the Ronga.

- Alternative 17: Drainage channels
  This alternative will be implemented to decrease the retention time of the flooding and to relieve the consequences. It can be implemented simultaneously to the basic solution.

An elaboration and synthesis of the integral solution can be found in the following Chapter 11.

11 INTEGRAL SOLUTION

In this chapter the final, integral solution is presented. The integral solution is a combination of solutions that were positively evaluated in the preceding Chapter 10. First, the integral solution as a whole is presented, including locations, design discharges and possible additional measures. Four clusters of solutions have been identified, based on locations, that form the integral solution. These clusters are explained in detail in this chapter; discussing the design, location and other remarks. The chapter ends with a section on phasing of the solutions.

11.1 HEAD SCENARIO

In the last chapter, three alternatives showed to be the basis of the solution, these were:

- Opening the Kikuletwa South to increase the bankfull discharge capacity;
- Use the old Chem Chem river bed;
- Reconstruct dike at Samanga, including a control structure.

Two alternatives were considered that could be added to this basis. These are:

- “Summer/winter” dikes at the Ronga; to increase the bankfull discharge capacity;
- Drainage channels parallel to the Ronga, to decrease the retention time of the flooding.

An integral solution has combined these alternatives. The core of the solution is extended with a short rain dike along part of the braided Ronga. These alternatives were combined based on design discharges, which will be elaborated later in 11.1.2. Next to this integral solution, additional measures are possible, including the two alternatives that can be added to the basis.

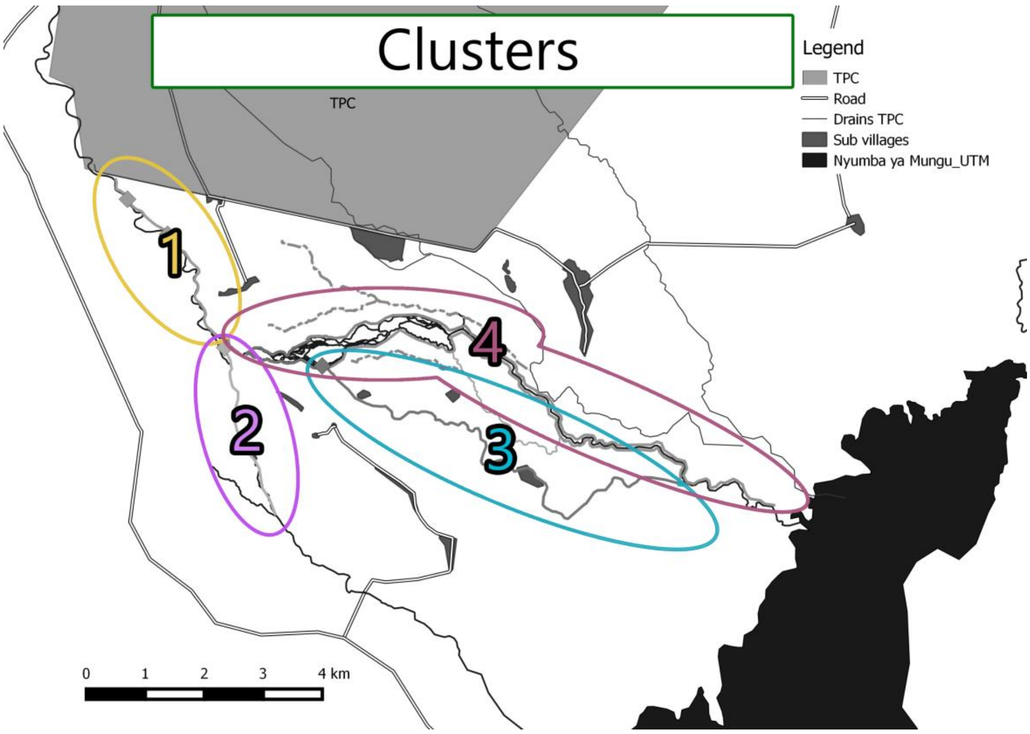

Figure 66: Clusters of solutions

Figure 66 shows the map of the project area including four clusters of solutions. These clusters are, including their solutions:

- Cluster 1: Samanga (paragraph 11.2)
    - Samanga dike along the Kikuletwa North
    - Control structure in the dike to discharge water in the Samanga-Majengo farming area.
- Cluster 2: Bifurcation Kikuletwa – Ronga (paragraph 11.3)
    - Opening the northern part of the Kikuletwa South
    - Control structure to control flow in Ronga and Kikuletwa
- Cluster 3: Chem Chem river bed (paragraph 11.4)
    - New channel between Ronga and old river bed Chem Chem
    - Control structure to control flow in Ronga and Chem Chem river bed
- Cluster 4: Ronga (paragraph 11.5)
    - Short rain dikes upstream of the Chem Chem river bed connection

11.1.1 Additional measures

Next to the main scenario there are other measures possible that could be an extension of the main scenario. These include the earlier mentioned alternatives 'drainage channels', 'short rain dikes' and the re-opening of the Ronga Ndogo. These additional measures are situated along the Ronga and are therefore treated in Cluster 4.

11.1.2 Discharges through system

The integral solution was put together using design discharges. These discharges were used to gain insight in what combination and dimensions of solutions could solve (part of) the problem. The resulting discharges are also used to design the different control structures and river beds of the solutions.

Different situations are considered; discharges during the dry season, the short rain season and the long rain season. From these different situations the short rain season is normative, as it is the period in which the most problems arise. First, the situation during the short rains is presented, followed by the situation during the long rains.

Short rains

The flow chart with the water flow through the river system during the short rains is shown in Figure 68.

The discharges start with incoming discharges from the northern Kikuletwa upstream of Samanga. In the analysis, paragraph 5.7.3, it has been calculated what the design discharges are that enter the water system in the project area, based on 1dd1 data. For the short rains the incoming design discharge is: 55 m^3/s. This value is the discharge that is exceeded in only 20% of the years, 80% of the years do not reach this discharge. This discharge flows through the Kikuletwa North towards the bifurcation Kikuletwa – Ronga.

In order to stop the floods during the short rain season; the maximum bankfull discharge capacity of the Ronga and the Chem Chem river bed will be used. The remaining incoming discharge has to be discharged through the opened Kikuletwa South. The bankfull discharge capacities have been calculated in Chapter 5; discharge analysis, these are:

- Ronga South: 26.7 m^3/s
- Ronga braided: 26.2 m^3/s
- Ronga North: 34.3 m^3/s
- Chem Chem River bed: 6.8 m^3/s

Downstream of the bifurcation Ronga – Chem Chem River bed, the braided Ronga has the lowest capacity and is therefore normative (*Maximum discharge in Ronga (2)*). Together with the Chem Chem River bed (*Maximum discharge in Chem Chem river*), the total capacity is 33.0 m^3/s. The Ronga North, upstream of Ronga braided, has the capacity to discharge this amount of water (34.3 m^3/s), the braided Ronga has not (26.2 m^3/s). The bankfull discharge capacity of the braided Ronga, upstream of the Chem Chem River bed bifurcation, therefore has to be increased. (*Maximum discharge in Ronga (1)*) This will be done using "short rain" dikes.

As a result; during the short rains the Kikuletwa South must be able to discharge at least 22.0 m^3/s, which is what is left of the incoming discharge (55 m^3/s) minus Ronga discharge (33 m^3/s). This is lower than the maximum discharge of the current Kikuletwa South (*Maximum discharge in Kikuletwa*), which was determined in paragraph 5.2 as 184 m^3/s.

The discharges to which the solutions must be designed are shown in Figure 67.

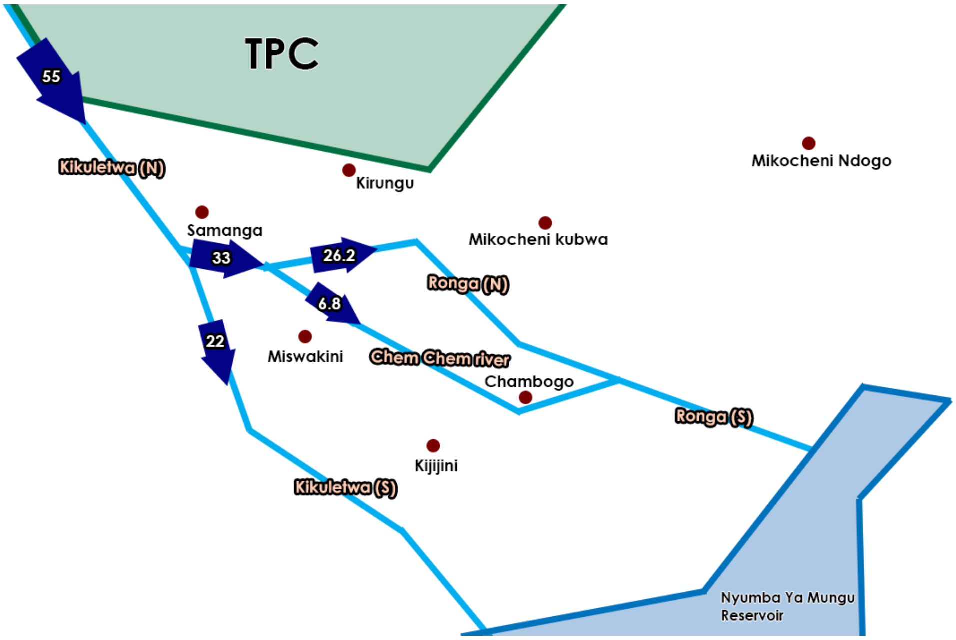

Figure 67: Discharges to be designed for during short rains period

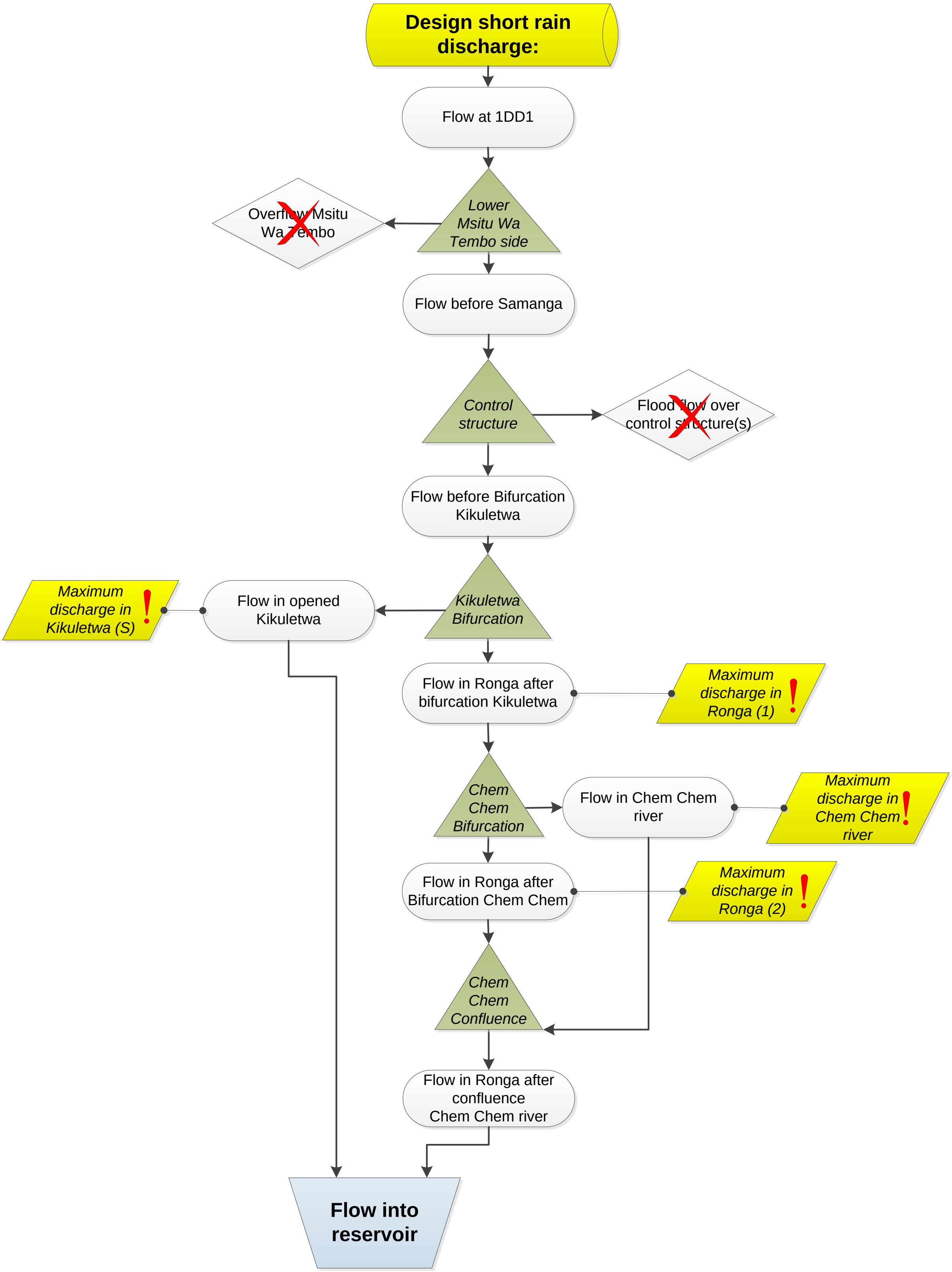

Figure 68: Flowchart on water flows through the river system during short rains.

Long rains
The flow chart with the water flow through the river system during the long rains is shown in Figure 69. It is similar to that of the short rains, but includes some losses near Samanga.

Again, the water system starts with an incoming design discharge in the northern Kikuletwa. In the analysis, paragraph 5.7, it has been calculated what the design discharges are that enter the water system in the project area, based on 1dd1 data. For the long rains the incoming design discharge is: 67.4 m^3/s. The long rains discharge is the flow between the banks of the Kikuletwa North, as part of a total discharge of 185 m^3/s. The rest of the discharge flows in the floodplains, see Figure 44. 185 m^3/s is the value that is not exceeded by 80% of the yearly maxima.

During the long rain season also floods occur, but these are a blessing instead of a problem. However, less severe floods are desired in terms of water height and retention time. To flood the current farming areas; situated along the Ronga and between Samanga and Kirungu, a control structure will need to be made in the Samanga dike and more water needs to be discharged through the Ronga than its bankfull discharge capacity.

In Appendix K it has been calculated that about 5 m^3/s (*Flood flow over control structure)* is desired of the peak discharges to sufficiently flood the Samanga – Kirungu farming area. The incoming design discharge is 67.4 m^3/s, as part of a total 185 m^3/s in the Kikuletwa and its floodplains. The 5 m^3/s is deducted from the total discharge, leaving 180 m^3/s in the Kikuletwa and its floodplains.

Using the same calculation as in 5.7.3 it is calculated that the flow in the Kikuletwa North, between its banks (Figure 46), is 66.8 m^3/s. The remaining 118.2 m^3/s flows over the floodplains on the Msitu wa Tembo side of the Kikuletwa (*Overflow Msitu wa Tembo*) towards the southern Kikuletwa and the reservoir. It has to be noted that the calculations with floodplains have a high uncertainty, due to the presence of several parameters which are hard to define exactly.

This leaves 66.8 m^3/s in the Kikuletwa towards the bifurcation Kikuletwa – Ronga (*Flow before bifurcation Kikuletwa*). This is only 11.8 m^3/s more than the discharge in the short rains. During the long rains the farming areas surrounding the Ronga should be flooded, therefore a discharge higher than the bankfull discharge is required. During the short rains this maximum bankfull discharge capacity is used. Therefore part of the 11.8 m^3/s extra discharge in the water system must be discharged through the Ronga, yielding flooding of this river.

Due to the high capacity of the Kikuletwa South (184 m^3/s), downstream of the reopened part, no problems are expected in this river, not even when the water from the Msitu wa Tembo mountains and floodplains enter this part of the Kikuletwa.

Dry season
During the dry season it is desired that the water that enters the project area is not lost through the Kikuletwa South and Chem Chem River bed, but flows through the Ronga as it does now. However, as is the case now, it is also desired that both river beds discharge some water in order to stop clogging of the rivers and to remind local villagers that the rivers should be open. Therefore a design discharge of 1 m^3/s is desired in both rivers during the dry season. This will have to be realised using control structures, which will be discussed later in this chapter.

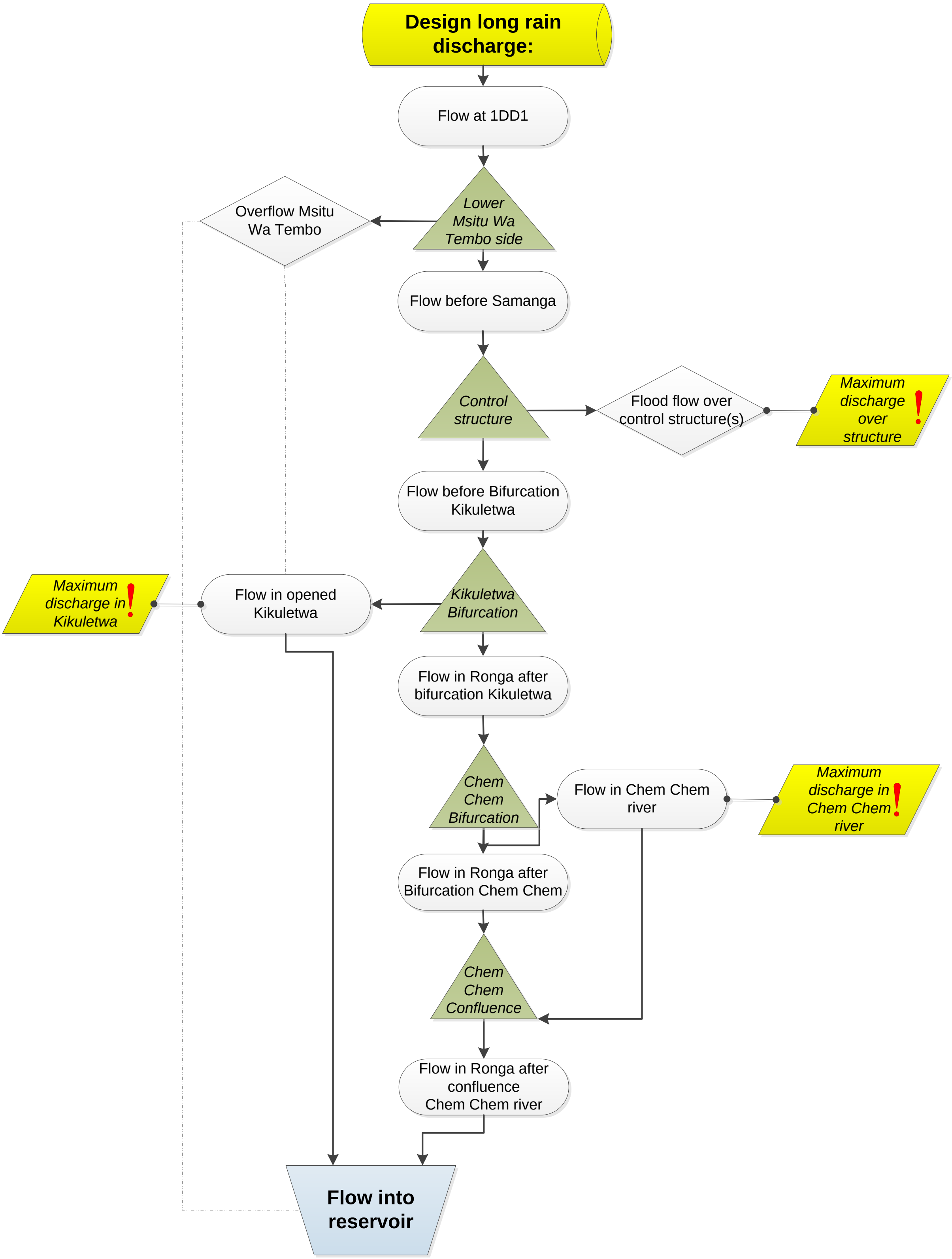

Figure 69: Flowchart on water flows through the river system during long rains.

11.2 Samanga dike and control structure

The Kikuletwa River enters the northern part of the project area just downstream of TPC. In the analysis this river stretch has been identified as stretch number one. This forms the basis for the design of the Samanga dike and the control structures, also named cluster 1, see Figure 70. In the following parts of this paragraph the design of the dike and control structure(s) are described and illustrated. After the dike has been discussed the control structure will be treated. For each part the location, the design and some remarks will be stated.

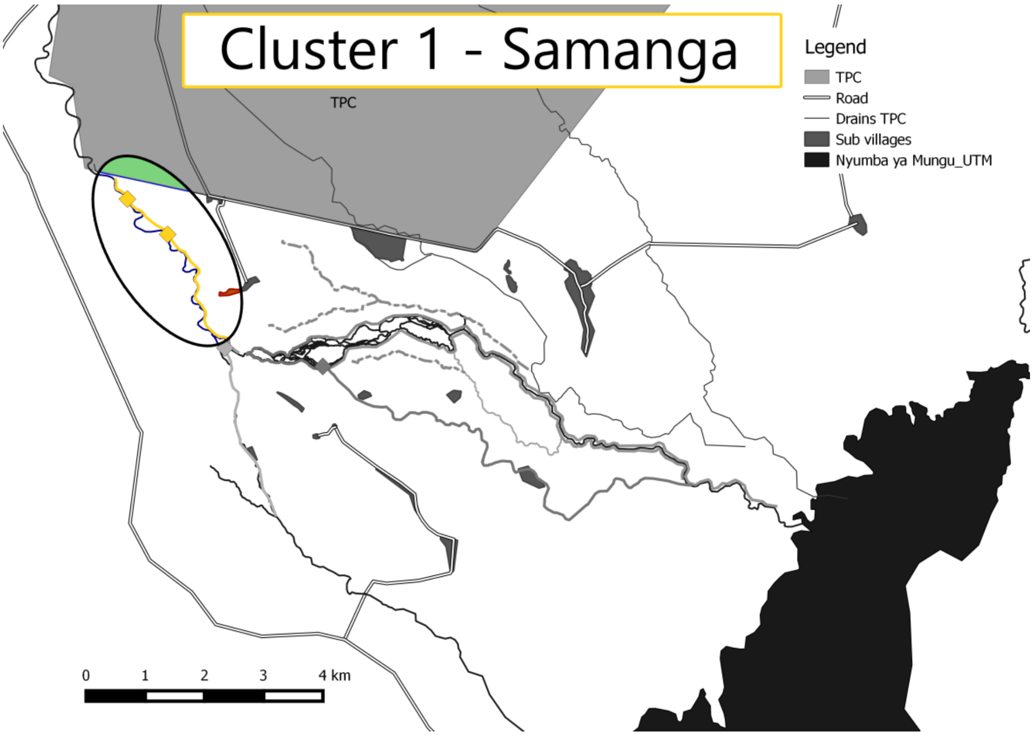

Figure 70: Location of cluster 1

11.2.1 Dike

During the long rain season it is important to prevent extreme water amounts flowing into the Samanga area. Therefore the dike has to be restored at the location of the dike breach. This is essential because of the destructive force and associated effects of the flowing water on the Samanga farmland. In Figure 71 the principle of the dike illustrated.

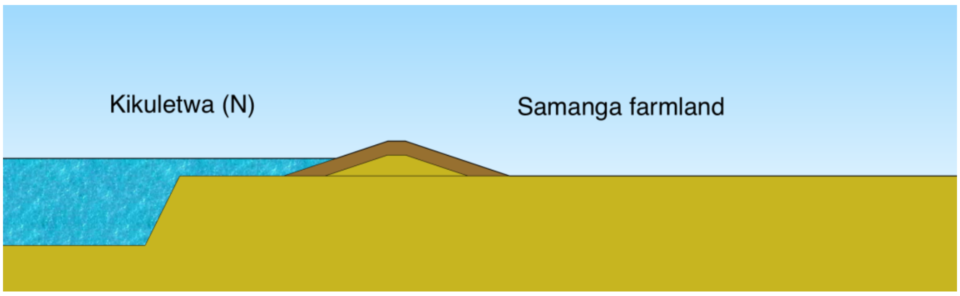

Figure 71: dike principle at maximum discharge

Assumptions

Construction of the dike and control structure will be done in and by use of materials that are available in the vicinity of the project area. Exact values of the properties of these materials are not known. Therefore this design has a more descriptive and qualitative approach. Exact dimensions and material properties are not the aim of this design.

11.2.1.1 Location

The aim of this solution is to restore the dike at the location of the breach and to extent the dike in southern direction along the Kikuletwa. In this way the Samanga area will be protected against extreme floods.

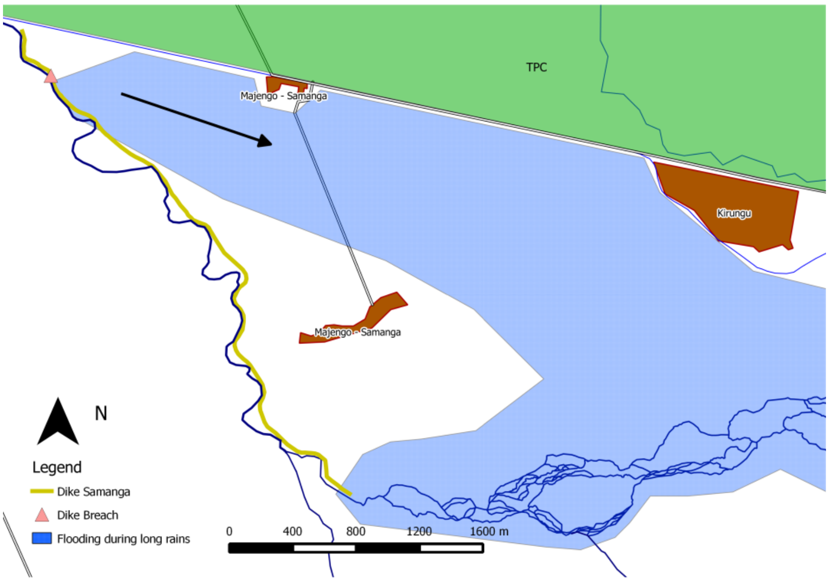

Figure 72: Flooding extent and dike location

In Figure 72 the location of the dike restoration and extension is shown. The dike does not follow the exact course of the river. This design takes into account the following:

- Meandering belt: to make sure the river trajectory will not intersect with the dike it is advisable to locate the dike outside the river meandering belt, see Figure 73.
- Length: a reduction of the length of the dike will reduce the amount of labour and material
- Ownership: due to local owned farming land the exact alignment is a point for discussion. Consultation with the farmers is essential for the local acceptability.
- Straightness: bends in a dike are prone to forces due to turbulent current. These currents can increase the chance on erosion of the dikes. Therefore it is advisable to straighten the dike as much as possible.

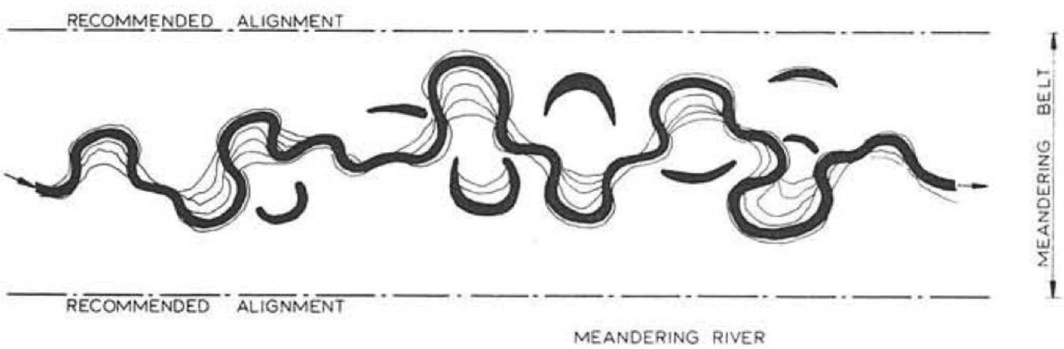

Figure 73: recommended alignment; meandering belt

11.2.1.2 Design

A dike is a very common structure to retain water along a river. It is a relative uncomplicated and cheap solution, which requires only a small amount of maintenance. The core of the dike is made out of sand. No classifications are required. Because of the presence of water on one side of the dike a new phreatic line will arise within the dike. This phreatic line (water head) will result in instability of the dike body. To retain the water in combination with reducing the phreatic line, a drain can be used, illustrated in Figure 71. Another possibility is to add an impervious layer, usually made out of clay, at the outer side of the dike, illustrated in Figure 75. The retained water will not infiltrate into the dike itself and therefore no instability problems due to horizontal flows will occur.

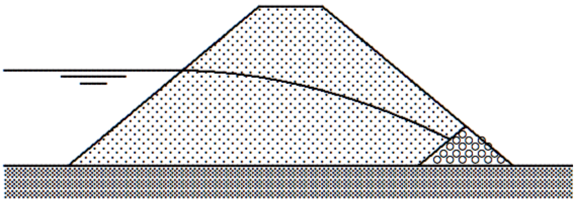

Figure 74: Dike with drain in lower-toe [20]

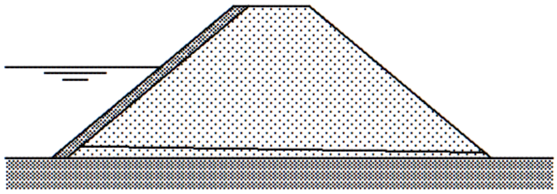

Figure 75: Impervious layer on outer layer [20]

A negative property of the drain is that there is a small flow of water within the body of the dike. These flows can cause instability of the dike. When using an impervious layer, reducing the phreatic line is not necessary. Therefore a dike with an impervious layer is preferred. In the following sections a dike with impervious layer is assumed. Overall dimensions of the dike are determined by the combination of water levels and the overall stability of the dike during high water levels in the Kikuletwa in combination with a low inner water level. In the following sections the design will be discussed. A detailed description of the failure mechanisms and materials can be found in Appendix L.

Crest height

During the long rainy season the defined normative discharge for stretch number one will partly discharge in the river and partly on the floodplains. Therefore, the water levels will be dependent on these floodplain discharges as well. Besides this, part of the discharge can flow into the Samanga area. This is described in Appendix K. The overall design discharge in the river that is the result of these processes is described in the paragraph 5.7.3.

The design discharge entering the area is 185 m^3/s, of which 67 m^3/s flows in the river section (conveyance area) and 118 m^3/s over the floodplains. The associated water level in the river will be about 0.5 m above the level of the river embankments (Msitu wa Tembo side). At the TPC side the dike has a height of 1 m ([3]). On the Msitu wa Tembo side there is no dike and therefore this side is flooded frequently.

The minimum crest height has to be at least as high as the rest of the dike. The dike section at the breach therefore has to be restored to a height of 1 m. This results in a freeboard of 0.5 m. This is sufficient for the stability of the dike.

Conclusion: H = 1 m.

Width

The width of the dike is dependent on stability considerations. The dike has to be a stable structure on its own. For this reason the slopes of the dike cannot be too steep. A conservative value for the slopes is: 1:3 (vertical : horizontal). The crest has to be a minimal value of 0.5m. This results in a total width of 6.5 m

Conclusion: W = 6.5 m.

[3] Relative to surface level at Msitu Wa Tembo side

Clay layers
To prevent that the dike will erode due to river currents the dike can be implemented with an impervious layer in combination with a grass cover; the clay layer has been mentioned before. By using such a clay layer, there are some restrictions that have to be taken into account:

- Clayey soil is from itself erosion resistant, when it has a high content of clay particles instead of sand. It is known that soil with a larger content of sand particles than 40% will erode relatively easy at low currents. [21] Without laboratory tests, an indication can be given by rolling. Therefore, it is advised that clay with a high content of clay will be used. This can be easily determined by the fact that clay has a cohesive force. One can test this cohesive force by adding water to a clay sample. The larger the amount of water sticking to the clay, the stickier the clay. By rolling the clay through the hands the stickiness can be indicated as well.
- Soil with a low plasticity index (Atterberg Limit) , lower than 18 %, will erode rapidly as well. To prevent that the dike will erode, the content of clay and plasticity has to be taken into account [21]. This is although it is a restriction, not measurable in without laboratory tests. Therefore, it is not taken into account.
- To reduce the probability of erosion it is advisable to cover the slopes with a grass top layer, see Figure 76. Especially Vetiver Grass is suitable for this purpose [22]: it grows fast, has long roots, is useable in saline environment, endures 7 months of drought and is available in Tanzania.

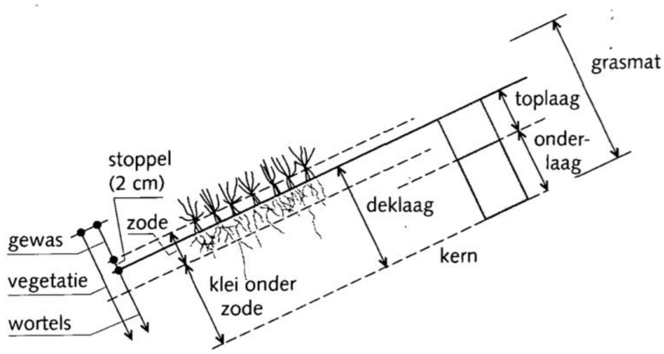

Figure 76: Clay-layer components(text is in Dutch) [21]

Conclusion: Clay layers of 0.4 m thick should be placed as an impervious layer and covered by Vetiver grass.

Dimension sketch
The end result of the considerations and dimensions stated above is summarised in the sketch below; Figure 77. These values are the minimum values. On the left the low water line (L.W.L.) and high water line (H.W.L.) are shown as reference levels for the design.

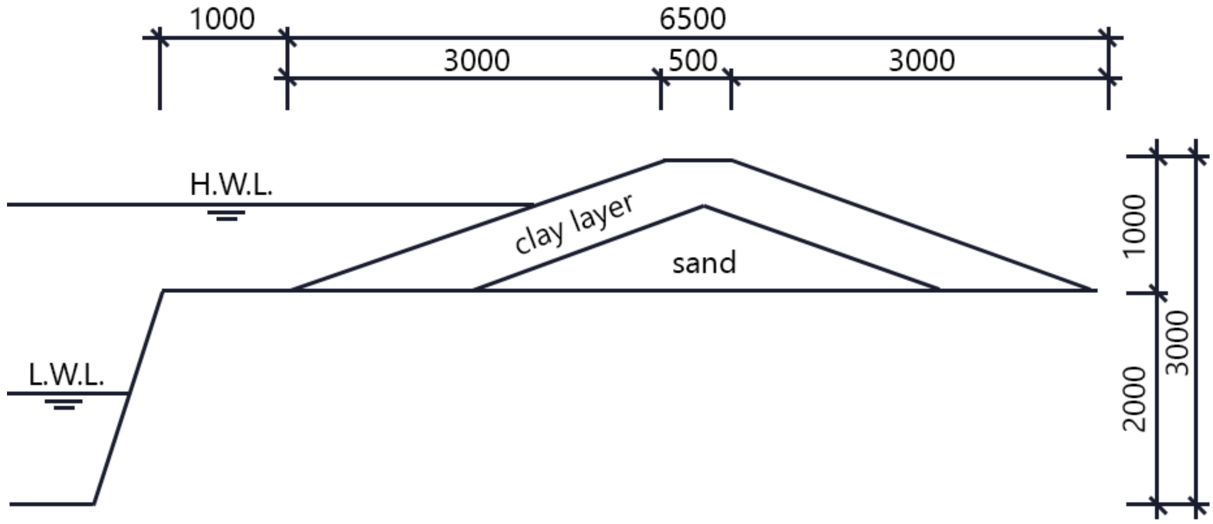

Figure 77: Sketch with dimensions

Phasing

A proper execution is essential for the reliability and durability of the dike. The construction of the dike is explained in the following 8 steps:

1. Levelling of the subsoil. No drains or furrows are allowed in the direct vicinity (couple of meters) of the location. Make sure that the subsoil of the location of the dike is from clay. This can be checked by the cohesiveness. If the sample has some cohesive properties, then it is clay;
2. Heightening of the core. Compact the sand after each added 0.3 m. This can be done with pressure by a heavy roll or by vibration with a drilling device;
3. Levelling the slopes of the dike 1:3 (vertical : horizontal) on both sides. The geometry of the sand core does not have to be exact;
4. Add the first clay layer of 0.2 m. add some extra centimetres of clay so that the end thickness of 0.2 m will be reached;
5. Compact the first clay layer. Use the same equipment as for the sand layer;
6. Add the second clay layer. Also for this layer add some extra thickness;
7. Compact the second clay layer. Use the same equipment as used before;
8. Sow the grass. A high concentration of grass seeds is necessary, for the density of the roots and final eroding resistance.

The phasing mentioned above can be executed over the full range of the dike location or step by step over a shorter distance. It does not matter which section is built first. It is thus dependent on the preferences of the contractor.

11.2.1.3 Remarks

As already mentioned in the clay layer and phase section, a proper compaction is desired. For more details, see Appendix L: Materials.

To check and discuss the possible failure mechanisms of the dike, the design of the dike has been checked. The following failure mechanisms have been checked:

- *Macro instability - Slope instability;*
- *Macro instability - Horizontal instability;*
- *Micro instability;*
- *Piping;*
- *Length-effect.*

For further details on these mechanisms can be found in Appendix L: Failure mechanisms.

11.2.2 Control structure(s)

During the long rainy season, the Samanga area needs to be flooded to provide water and sediment for the farmland. In the current situation the floods are uncontrollable and excessive. To provide the Samanga area with the required floods during the long rainy season, but prevent it from flooding during the short rainy season the previously explained dike in combination with a control structure(s) can be built. This paragraph states a layout of where and in what way such a control structure should be built.

11.2.2.1 Location

In order to spread the flood wave over the complete farmland in the Samanga area, it is best to place multiple control structures along the dike. However, one structure would be the cheapest solution because less material and man-hours are needed. As a compromise to reduce cost and to optimize spreading of the flow, two control structures are suggested, which would best be placed at the locations depicted in Figure 78.

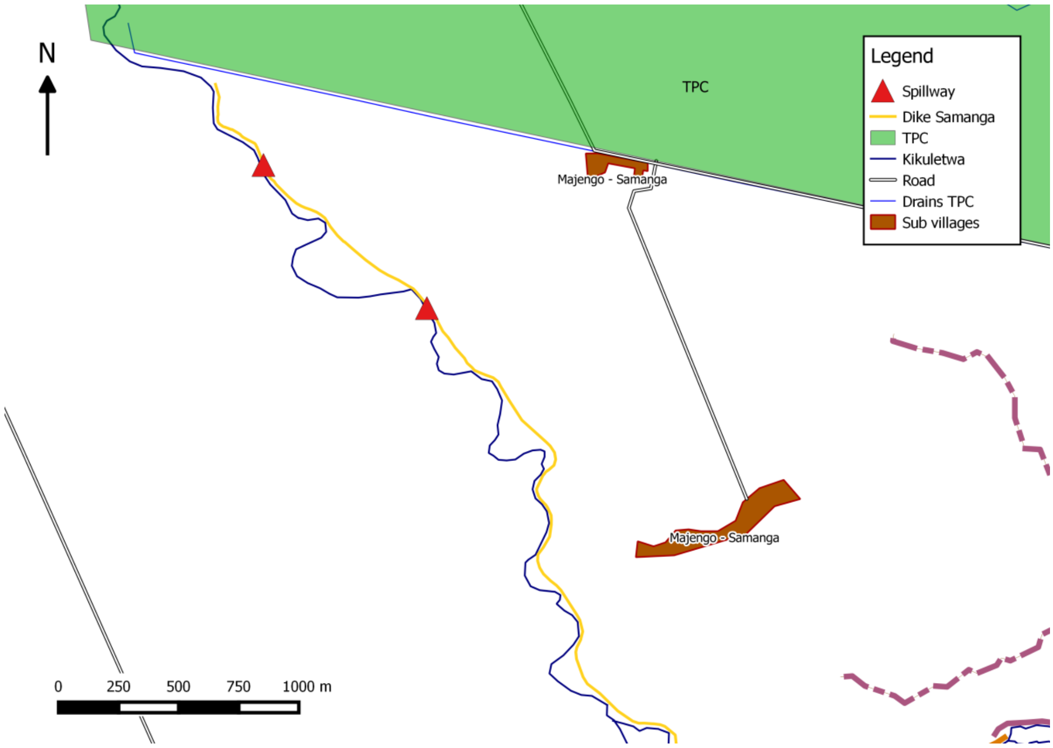

Figure 78: locations of the spillways

11.2.2.2 Design

For the design of a control structure several options are possible, which are set out in Appendix M. The two options that qualify best for this location are the weir (which functions as an overflow at a certain water level in the Kikuletwa) and the flow gate (which can be opened and closed by hand and thus can be adjusted to the water needs at Samanga). However, the disadvantage of this last option is that local farmers are able to operate the control structure themselves. It may be possible that the farmers close to the control gate have other priorities and may shut off the flow gate prematurely, while it is better to open the gate for a longer time to provide farmers downstream too. Hence, it is advisable to construct a spillway, which overflows annually and is not adjustable by local villagers. The only down side of this construction is that during an extreme year also an extreme flood occurs in the Samanga area. The spillway is shown in Figure 79.

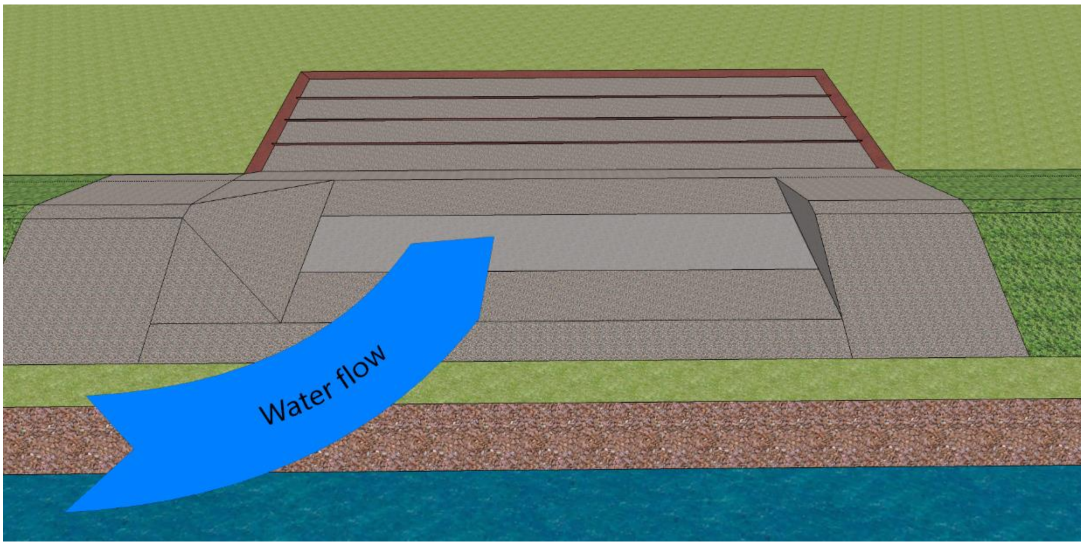

Figure 79: Spillway control structure

The construction is designed in such a way that it can be adjusted later if it appears that the amount of water overflowing is too much. The construction will be made out of boulders, which are founded in a layer of concrete. These boulders are placed at the surface and stick out to roughen the spillway to slow down the water flowing over it. If it appears that the spillway is too low, an extra layer of boulders can be added to heighten the structure. In Figure 80 the mixture of boulders and concrete is explained. The middle 2 meters of the weir will be made out of flat concrete (without boulders). On this layer Legioblocks® or other (interlocking) concrete blocks can be placed to make the weir smaller in its length. This is explained in Appendix N.

Figure 80: Concrete and boulder mixture

The average amount of water that should be overflowing the spillway to get the right amount of water in the Samanga area was estimated to be 5 m^3/s, see Appendix K for an explanation. Thus, the two constructions should be designed in such a way that each of them overflows 2.5 m^3/s. The spillway constructed in the dike is of a type called a side weir. This is a weir, which is located at the side of the main river/channel. Unfortunately it is impossible to calculate the amount of discharge overflowing such a structure analytically, because the flow varies spatially over the considered structure. The amount of discharge can only be calculated by use of numerical methods, which is not possible in the time frame of this project. Therefore, it is difficult to give a specific height, which the spillway should have to overflow 2.5 m^3/s.

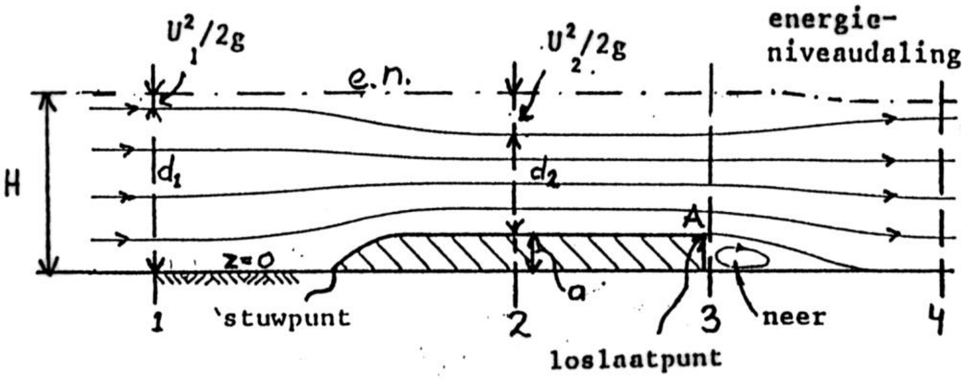

Figure 81: Flow over a long weir (text is in Dutch)[23]

Therefore, a simplified calculation is done to determine the spillway dimensions. This calculation assumes uniform flow in one direction over a long weir and neglects energy losses, as shown in Figure 81 [23]. It assumes that the flow over the weir is not dependant on the water level downstream; the flow on top of the weir is critical. The specific discharge (q) over the weir is then given by:

$$q = d_2 \cdot u_2 = \frac{2}{3} \cdot E_k \cdot \sqrt{g \cdot \frac{2}{3} \cdot E_k} \, (\approx 1.70 \frac{m^{\frac{1}{2}}}{s} \cdot E_k^{\frac{3}{2}})$$

In which the q is the specific discharge (m^2/s), d is the water height (m), u is the flow speed (m/s), g is the gravitational acceleration (= 9,81 m/s^2) and E_k is the specific energy height on top of the weir. The specific energy height E_k is given by:

$$E_k = H - a$$

In which H is the energy height (m) and a is the height of the weir (m). Energy losses are not taken into account, thus the Energy height is given by:

$$H = d_1 + \frac{u_1^2}{2 \cdot g}$$

For this calculation it is assumed that the flow speed right before the weir (u_1) has an average speed of 0.5 m/s in the direction of the weir. If the height of the weir (a) is 0.25 m, the water level in the Kikuletwa (d_1) is 0.5 m, the calculated specific discharge is 0.23 m^2/s. To obtain a discharge of 5 m^3/s the weirs should have a total length of 22 m. According to this calculation in which the weir is 0.25 m high compared to ground level, each weir should have a width of 11 m.

The previous calculation is based on a continuous channel with long weir in it, while the reality is that the weir is on the side of the channel and bifurcates the water. Therefore, the dimensions will be based on the previous gathered result, but it must be stated that there is a high uncertainty in it.

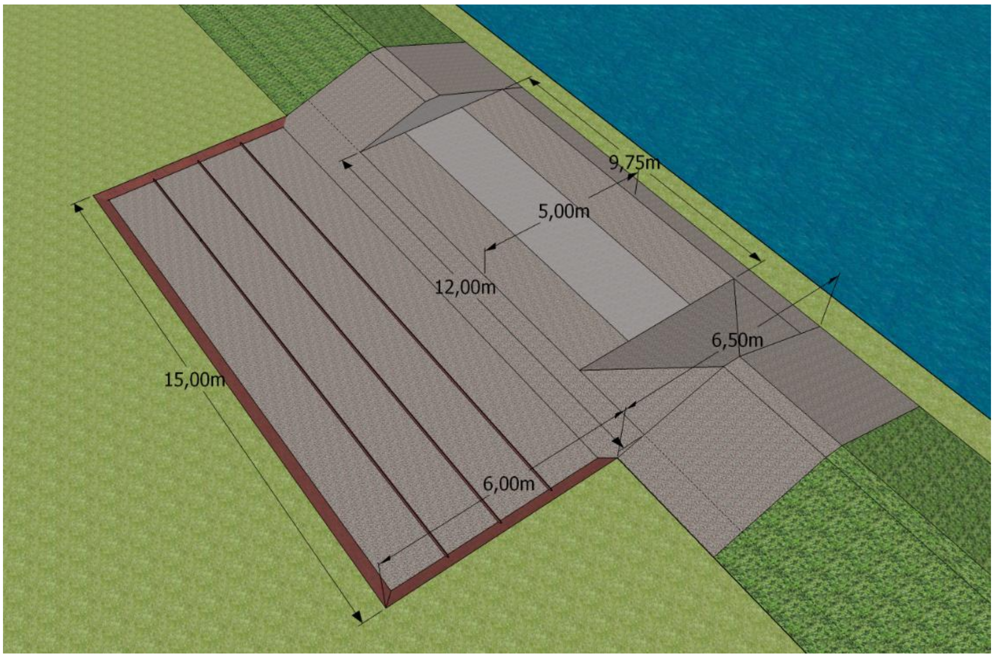

Figure 82: Spillway overview

A total overview of the spillway design is showed in Figure 82. The total length of the construction is 18 meters. In the middle of this construction there is a part of 12 meters which is deepened by 0.75 meter compared to the top level of the dike. Thus the weir level is 0.25 meter high compared to ground level. The crest length of the weir is 5 meter, while the total width of the dike is 6.5 meter. Behind the weir is a dissipation chamber which breaks the overflowing water. This is necessary to slow down the water before it enters the field to prevent erosion and instability of the dike and control structure. It is a concrete slab which is filled extensively with boulders. Also, boulders can be placed disjointed on this layer to increase the dissipation of the water. The dissipation chamber is 15 meter long and 6 meter wide. It extents more to the downstream direction of the Kikuletwa flow because water is flowing in that direction and thus will also flow over the weir in that direction. The concrete/boulder layer should have a thickness of 40 cm over the full structure.

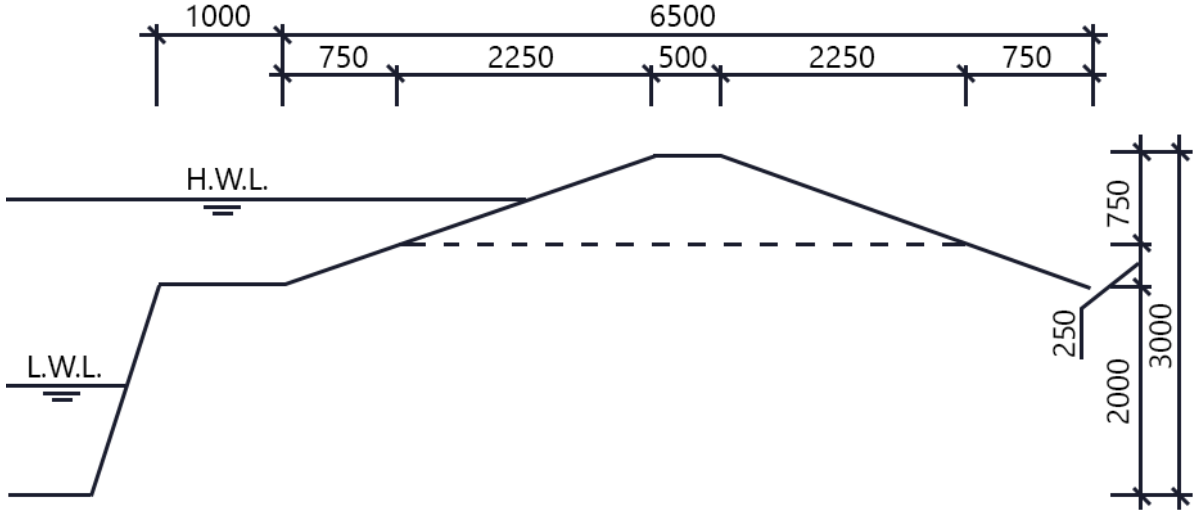

Figure 83: Cross-section dike and spillway Samanga

In Figure 83 a cross-section of the dike and the spillway is shown. The spillway is shown as a dotted line. Also high water level (H.W.L.) and low water level (L.W.L.) in the Kikuletwa are shown.

Implementation

It is best to construct both spillways at the same time as when the dike is being constructed, because then the total system will be functioning exactly at the same time. Underneath the structure a small layer of dense sand should be placed to pour the concrete on. This can be done at the same time that the dike is being built. If the dike is already there, the dike should be dug to the appropriate height to place the dense sand layer.

After the sand layout is complete, the boulders should be placed and the concrete can be poured. In the middle part of the crest 2 meters of normal concrete should be placed (without boulders!) to allow additional blocks to be placed here. It is important that the dike should be poured in concrete and completed with boulders. This should be done for an extra 3 meters to both sides to assure the stability of the structure. The dissipation chamber should be made 10 cm lower than the ground level. After completion of the dissipation chamber, extra boulders can be placed on top of this layer to increase the dissipation of the water.

11.2.2.3 Remarks

The design of a control structure within the dike needs lots of attention. A well-designed transition from the dike to the control structure is essential. Therefore it is important that the boulders are placed at the surface to roughen the structure. A transition should be made between the concrete part and the clay/dike part. This should be done by laying boulders on both sides, as if it is one layer, except that one half is founded in concrete and the other half is founded in clay.

The control structure should be monitored after completion to look if the structure still fulfils its function. Also, if possible, it should be checked if the amount of water overflowing the structure during the long rain season is sufficient for the farmland. If water is abundant during the long rains, the control structure should be adjusted by adding extra concrete layers or by adding Legioblocks® or other (interlocking) concrete blocks.

It is important to place the spillway/side weir along a straight part of the Kikuletwa. If the structure is placed in the in- or outside of a bend it is vulnerable to erosion and extreme overflows.

The structure should be built in one dry season. If the structure is not fully complete before the long rain season start the structure is a vulnerability to the hinterland and it can cause extreme floods when this specific part of the dike fails.

11.3 Bifurcation Kikuletwa – Ronga

In this section the adjustments to the bifurcation point of the Kikuletwa and the Ronga are explained. In section 11.3.1 the opening of Kikuletwa Small is discussed and in section 11.3.2 the control structure at the bifurcation point is described. In Figure 84 the location of the control structure and the widening of the Kikuletwa South are indicated.

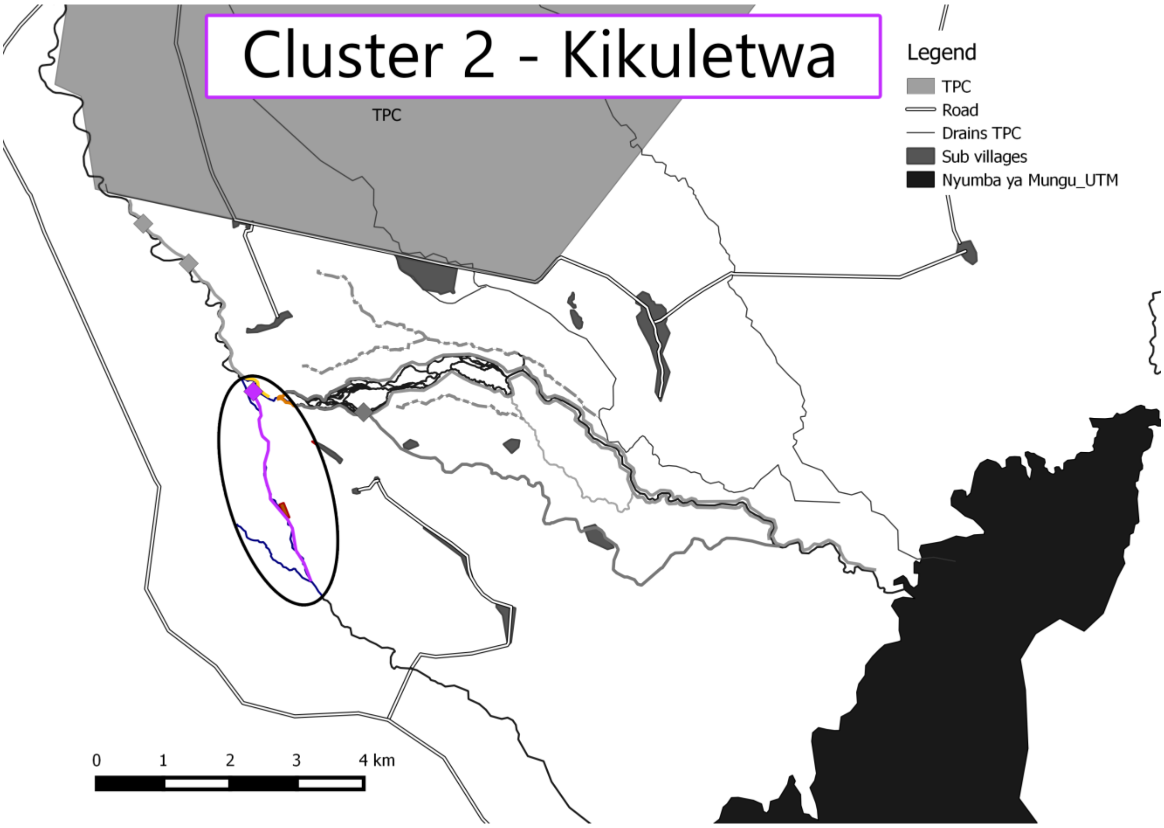

Figure 84: Cluster 2: location control structure (purple square) and widening of Kikuletwa South

As is explained at the beginning of this chapter, during the short rains a discharge of 55 m^3/s reaches the bifurcation point. Approximately 33 m^3/s can be discharged through the Ronga. This means the capacity of the Kikuletwa South needs to be at least 22 m^3/s to prevent flooding of the Ronga.

During the long rains, it is calculated that 66.8 m^3/s reaches the bifurcation point. The farmland needs to flood during the long rains to flush the salts out of the soil and to deposit fertile sediments. This means that the volume of water flowing into the Ronga needs to be significantly higher than the capacity of the Ronga plus the Chem Chem river bed of 33 m^3/s. The area of farmland of Mikocheni and Chem Chem that needs to be flooded is approximately 9.4 km^2. If a water depth of 10 cm is assumed during the flood, this amounts to a flood volume of $0.9*10^6$ m^3. An extreme peak during the long rains lasts approximately one day. This means a discharge of 10.9 m^3/s, on top of the bankfull discharge, is necessary to obtain such a volume. In other words, during the long rains a minimum discharge of 43.9 m^3/s needs to flow into the Ronga. During the scenario that a discharge of 66.8 m^3/s reaches the bifurcation point, 22.9 m^3/s will flow into the Kikuletwa South.

In the Kikuletwa a minimum discharge of 1 m^3/s needs to be assured to keep a velocity high enough to prevent silting up of the channel.

11.3.1 Opening Kikuletwa South

To enlarge the discharge capacity the river will be widened and deepened. The first part of the Kikuletwa South has a small discharge capacity and is therefore called Kikuletwa Small. Enlarging Kikuletwa Small will lead to a larger conveyance area. At the bifurcation point, this will lead to an increase in discharge flowing through Kikuletwa South. The increase in discharge depends, among others, on the new conveyance area. As was mentioned in the analysis, see Chapter 5, currently more than 90% of the water flows into the Ronga.

11.3.1.1 Location

The length of the river stretch that needs to be widened and deepened is 3.45 km. The trajectory of the widened river is indicated in Figure 85.

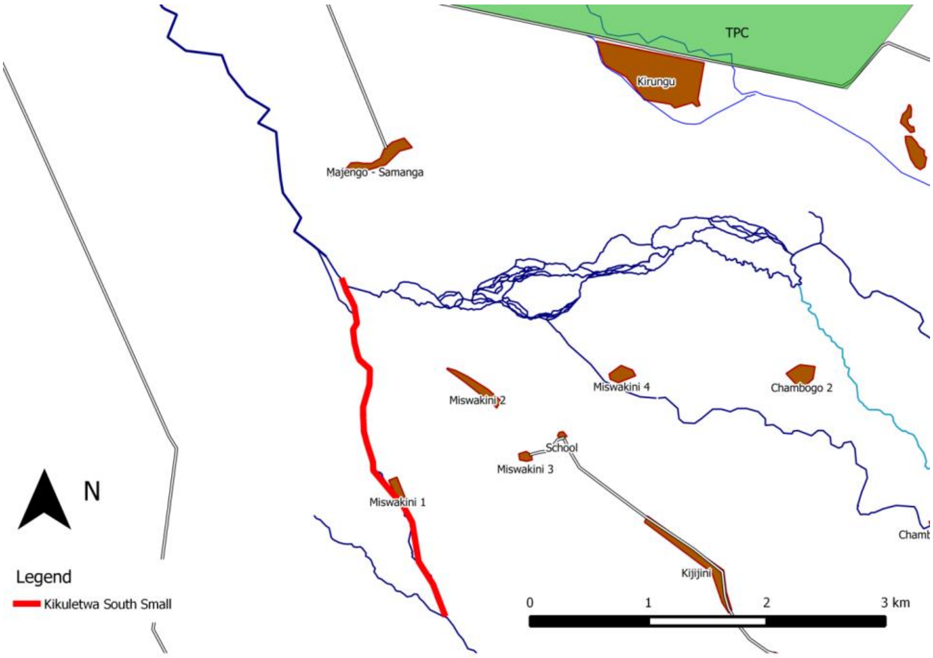

Figure 85: To be widened stretch of the Kikuletwa South

11.3.1.2 Design

The new cross-section of the Ronga must be such that it can discharge at least 23 m^3/s. The current capacity of the Kikuletwa Small is 1.7 m^3/s. The current cross section is presented in Figure 86.

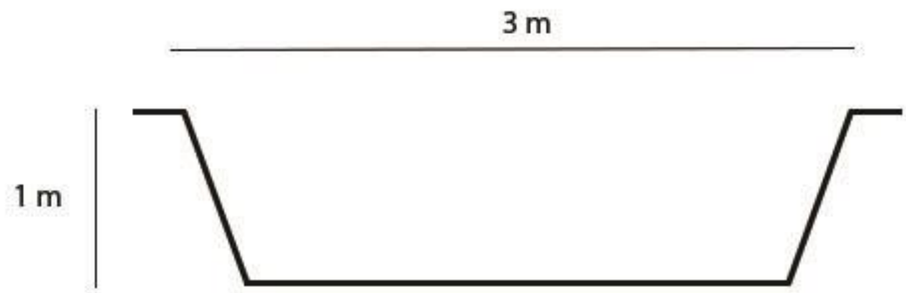

Figure 86: Current cross section at bifurcation point at way point 34

The new cross-section is depicted in Figure 87:

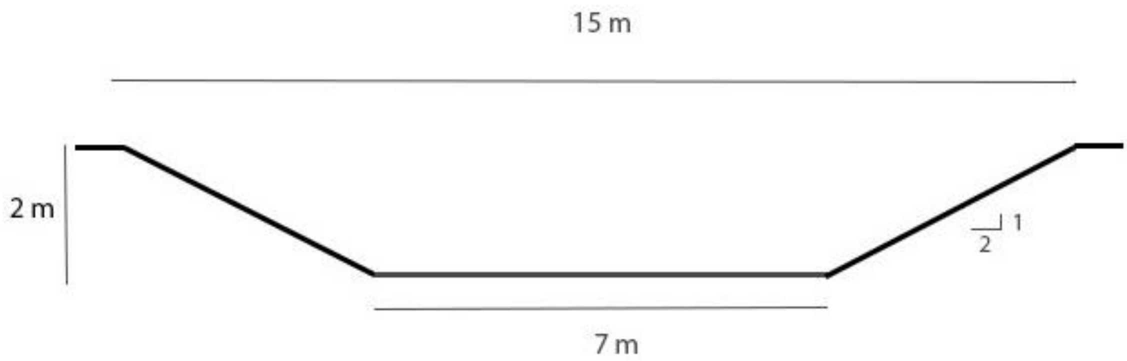

Figure 87: New cross section Kikuletwa South

The side slopes will be 1:2. The Kikuletwa Small will be widened to 15 m and deepened to 2 m. The parameters of the new cross section are summarised in Table 16.

Table 16: Parameters new cross section

Parameter	
Cross section A	22 m^2
Perimeter P	15.94 m
Hydraulic radius R	1.38 m
i_b	0.0016
Manning's n	0.030 – 0.040

A range for Manning's n from 0.030 – 0.040 is chosen, because it might vary due to maintenance of the channel. This leads to a range of $U_{manning}$:

$$U_{manning} = \frac{R^{\frac{2}{3}} i_b^{\frac{1}{2}}}{n} = 1.24 - 1.65\ m/s$$

With:

$$R = \frac{A}{P}$$

In which:

R: Hydraulic Radius
A: Cross sectional area
P: Wet Perimeter
i_b: Bottom gradient
n: Manning roughness coefficient

$$Q_{manning} = U_{Manning} * A = 27 - 36\ m^3/s$$

The bankfull capacity of the Kikuletwa South will be somewhat larger than the necessary discharge of 23 m^3/s. This will make the design more flexible, as it is difficult and expensive to alter the channel dimensions in the future. It will be able to handle a sudden increase in discharge.

Vegetation
To strengthen the slopes of the channel, vegetation needs to grow on the side slopes and the bottom. This will diminish the sediment transport due to the flow speed and it will strengthen the slope to prevent micro instability and collapse. The vegetation needs to be short, like grass or small

plants. The vegetation needs to be well maintained and kept short, otherwise it will increase the value of Manning's n and decrease the discharge capacity. By letting grass grow by itself, without using fertilizer, the roots are longer and stronger and functions better as slope protection.

Excavation
The river can be widened either on the Moshi Rural side, the Simanjiro side or partially on both sides. Those three options are explained below:

1. *Widening on the Moshi Rural side*
   The widening of the river will take place entirely on the Chem Chem side. Arranging the execution of the works on this side is easier because of the existing contact with this district. However, along this stretch some houses are present which need to be removed. The location of these houses are indicated in Figure 88. It is also possible to partially widen the channel on both sides at the location of the houses, in order to leave them untouched. This is the preferred option as the execution of the project can be started more quickly.

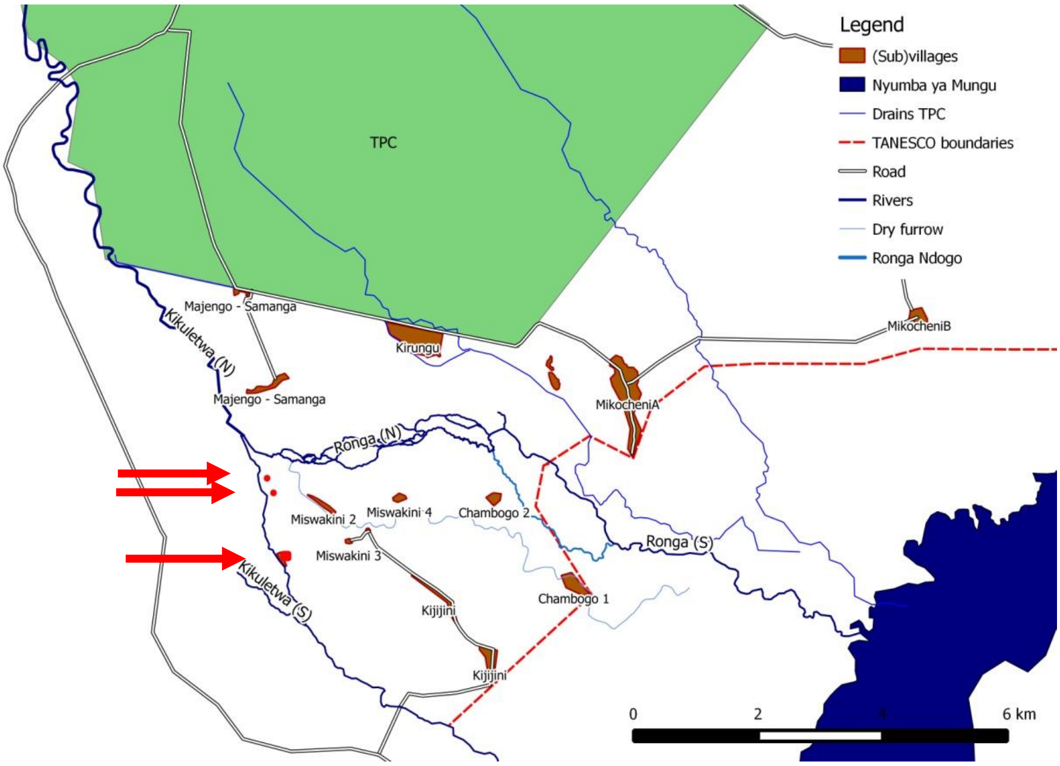

Figure 88: Three dots indicating the possible location of houses based on satellite images that need to be relocated

2. *Widening on the Simanjiro side*
   The widening of the river takes place entirely on the Msitu wa Tembo side. On the western side along Kikuletwa South no houses are located near to the river. However, there is no contact with this district yet, which would make the process more difficult.

3. *Partially widening on both sides*
   This option would equally divide the loss of land to both sides. However both districts would be involved which could lead to difficulties in decision making.

11.3.1.3 Remarks

The increase in discharge in the Kikuletwa leads to a decrease in the Ronga. If the volume of water flowing into the Ronga becomes too small, adjustments to the control structure must be made. See the next paragraph for more information.

Because the hydraulic radius increases, in comparison to the old situation, the velocity in the channel will increase. This could lead to an increase in sediment bed load transport. If the new slopes and bottom are covered in vegetation, this effect will diminish.

The river will be 12 m wider than in the original situation, which means about 4 hectares of land will be sacrificed. The consequences of the loss of land should be discussed with the village committee of Chem Chem. Along the Kikuletwa Narrow several houses are situated from the village Chem Chem. These might have to be relocated in case the widening is executed entirely on the Moshi Rural side.

At this moment, the only way to reach Chem Chem by car is driving through the river bed of the wide part of Kikuletwa South. There are plans to construct a bridge over the Ronga, but until that is built Chem Chem is inaccessible during high water. Widening the narrow part of Kikuletwa South will not make this problem worse. Only during peaks due to heavy rains, the water will be too high to cross. This would have been the case anyway, even if the Kikuletwa would remain in its current state, as a discharge peak would flow in from the west as well.

When the river is widened, it will be hard to define river flow during the dry season. The water will spread over the entire width. Therefore it is advised that a small deepened section is created in order to channel the water instead of spreading it across the entire width. An example of such a cross section is given in Figure 89.

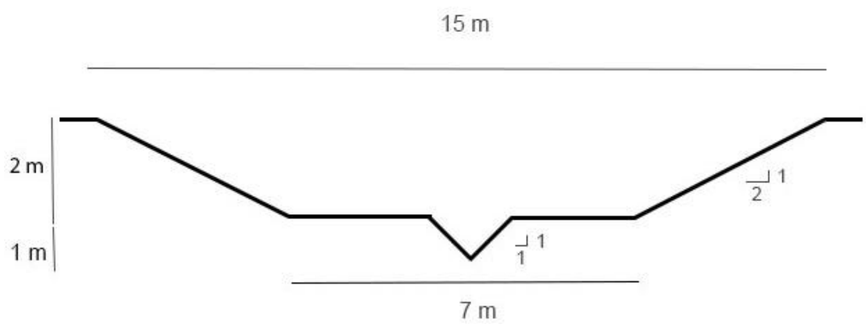

Figure 89: Adjusted cross section

11.3.2 Control structure

In order to regulate the amount of discharge flowing in to the Kikuletwa South a control structure has to be designed. As can be seen in Appendix M, different designs are possible. All have their benefits and trade-offs, also indicated in Appendix M. The main point of the control structure is that it discharges at least 1 m^3/s during dry periods and approximately 23 m^3/s during the rainy seasons.

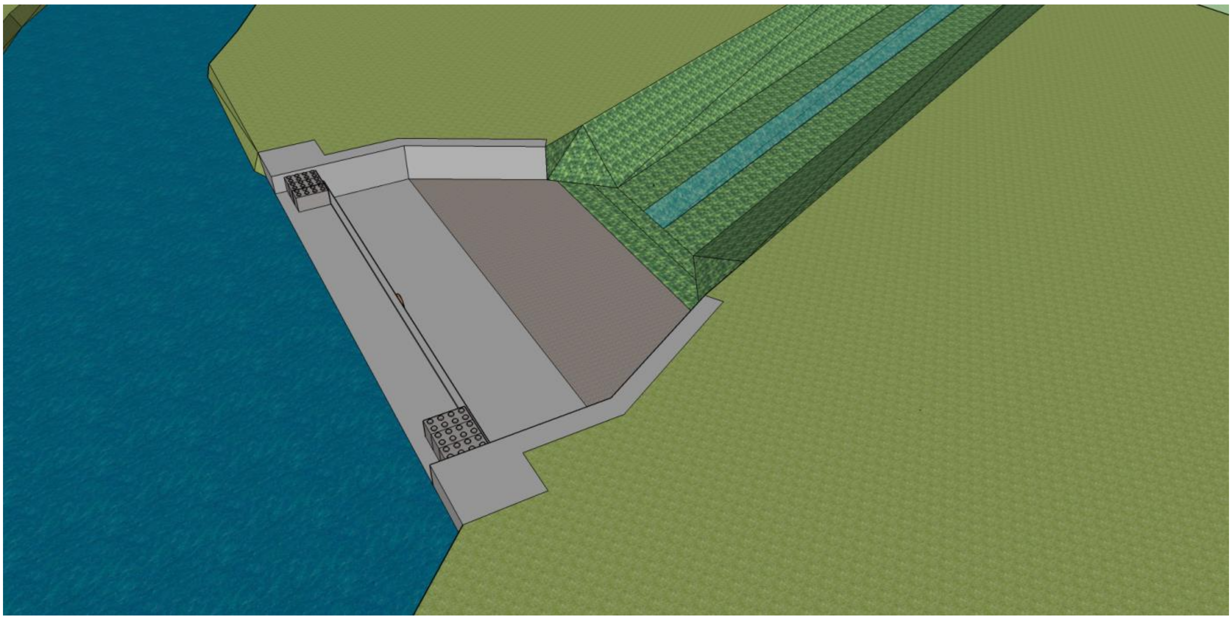

Figure 90: Visualisation of the control structure

11.3.2.1 Location

The control structure is located in the Kikuletwa South, directly after the bifurcation. Its location is shown in Figure 91.

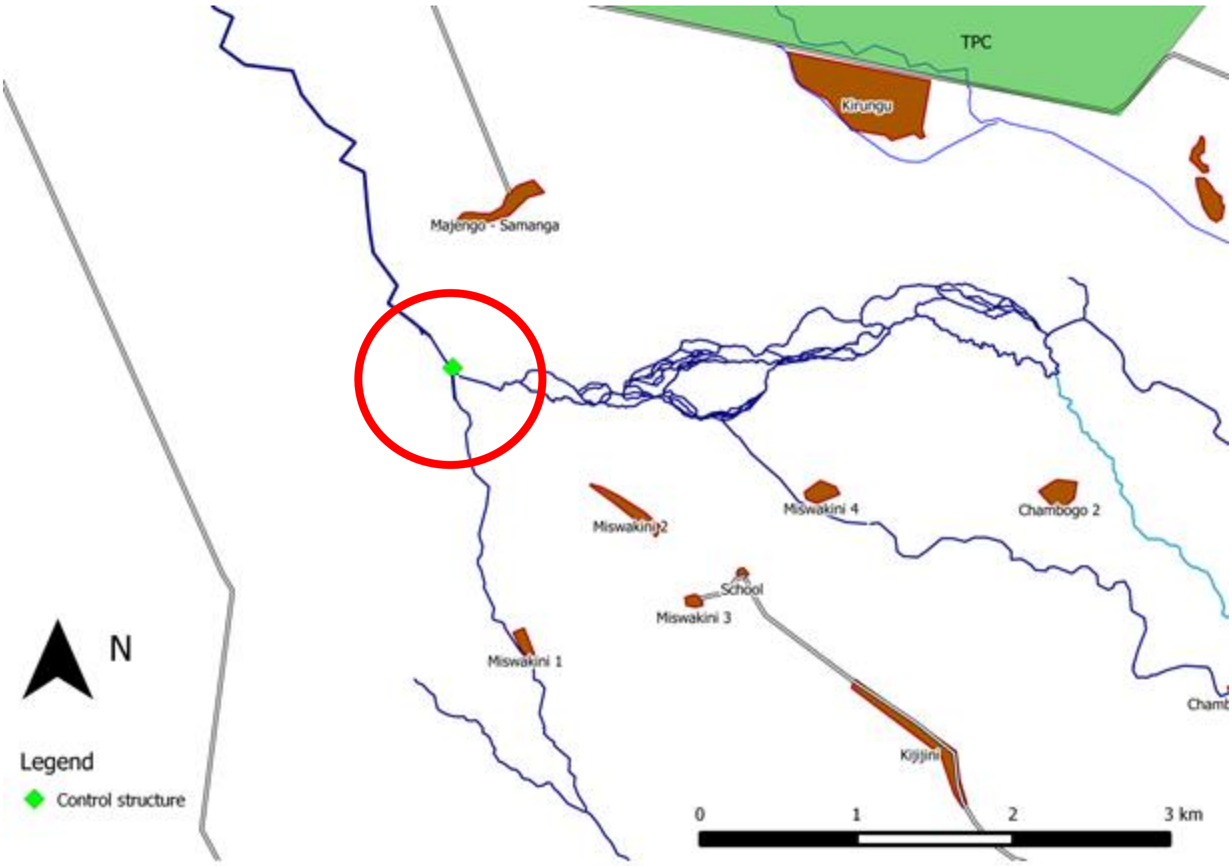

Figure 91: Location of the control structure

11.3.2.2 Design

The exact amount of discharge flowing through each branch of the river system is not known. Creating an exact and solid design based on the values calculated in the Analysis would not be wise since it would lack flexibility. Therefore, a design has been chosen that can be adjusted after the construction has finished. The discharge can be altered afterwards. The main dimensions of the structure can be found in Table 17. A visualisation can be found in Figure 90 – Figure 96. The design checks and assumptions can be found in Appendix N.

Table 17: Main dimensions control structure

Width structure	29	m
Width sill	23	m
Length sill	3	m
Total length	7	m
Total height	2.5	m
Height foundation slab	0.5	m
Height top of sill[4]	0	m
Diameter pipe	0.8	m
Length scour protection back	7	m
Length scour protection front	3	m

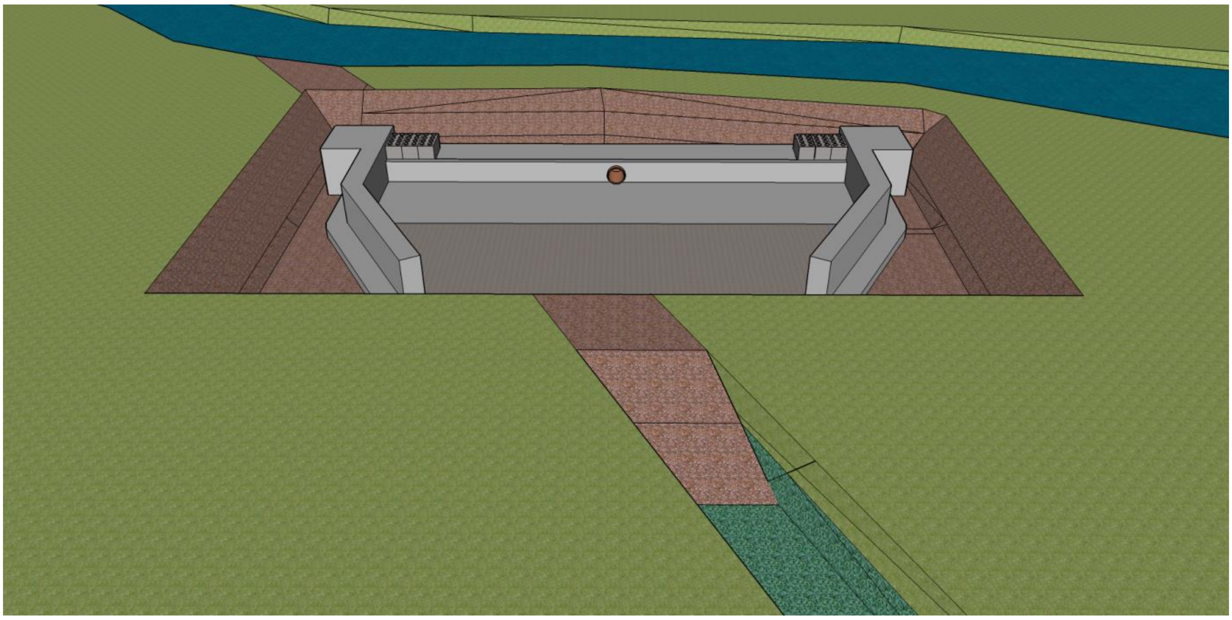

Figure 92: Control structure in the building pit

[4] Relative to current surface level

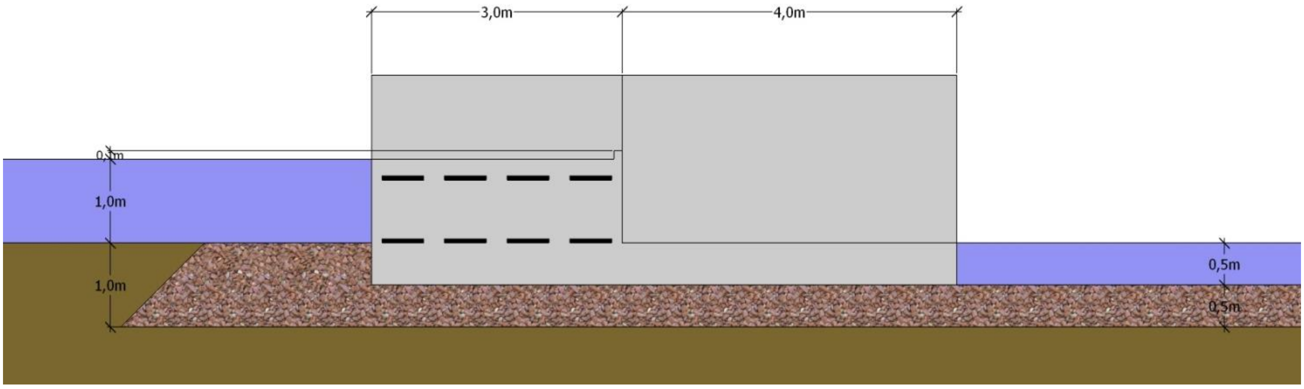

Figure 93: Side view control structure, with the tube's location marked in black

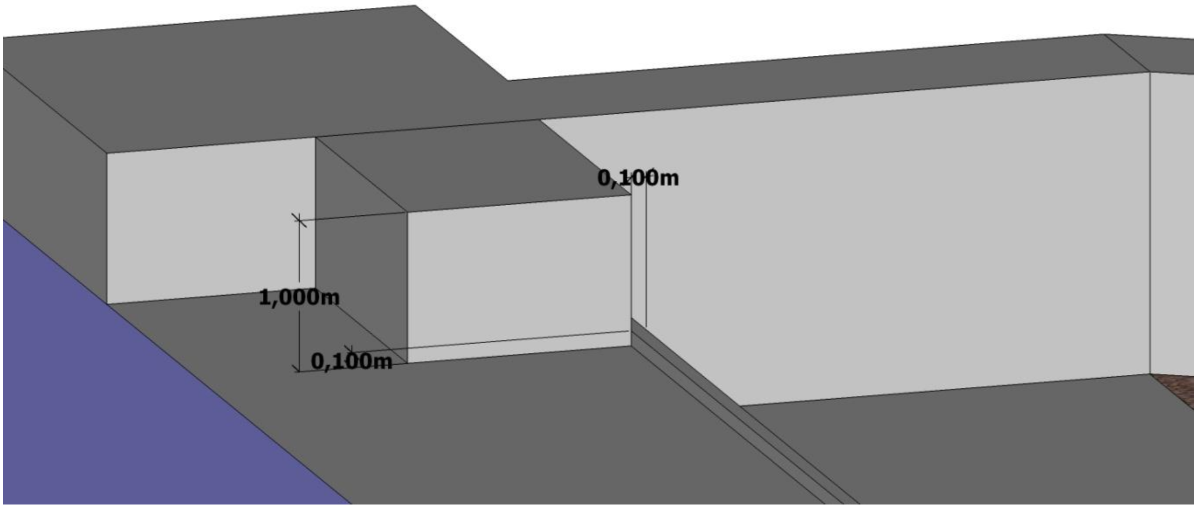

Figure 94: Block on the sill

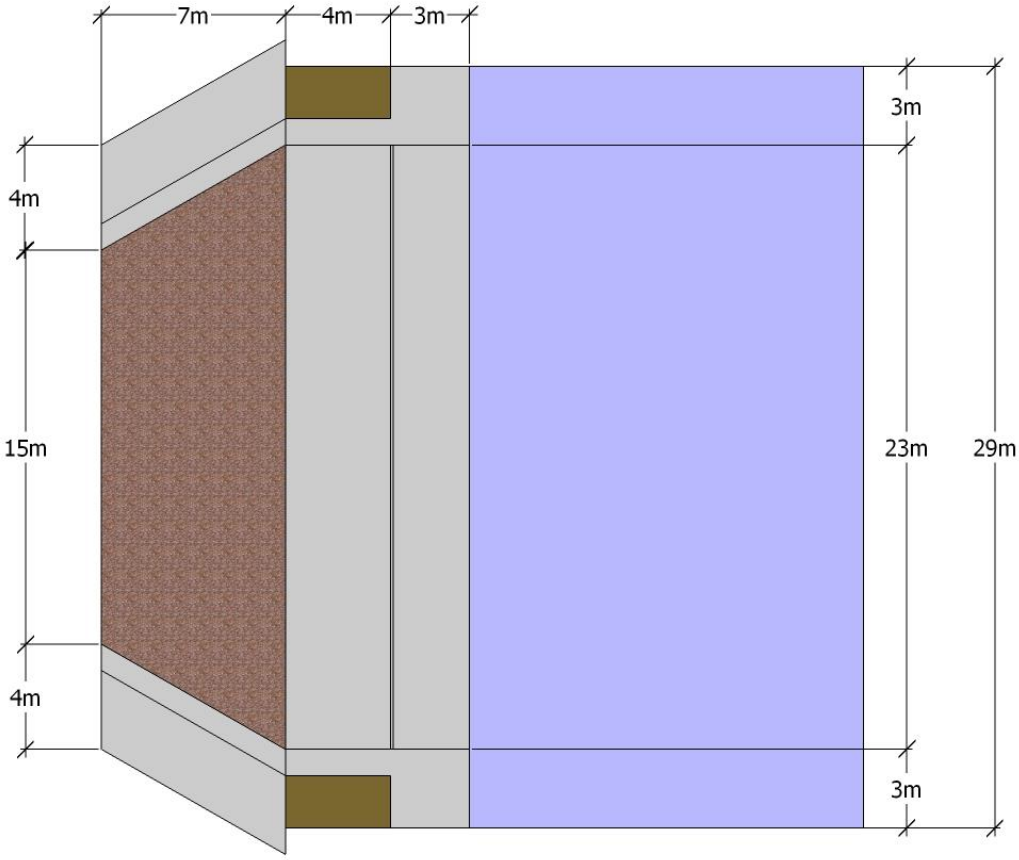

Figure 95: Top view control structure

The pipe is constructed in the middle of the control structure. It is placed directly on top of the bottom slab, as can be seen in Figure 96.

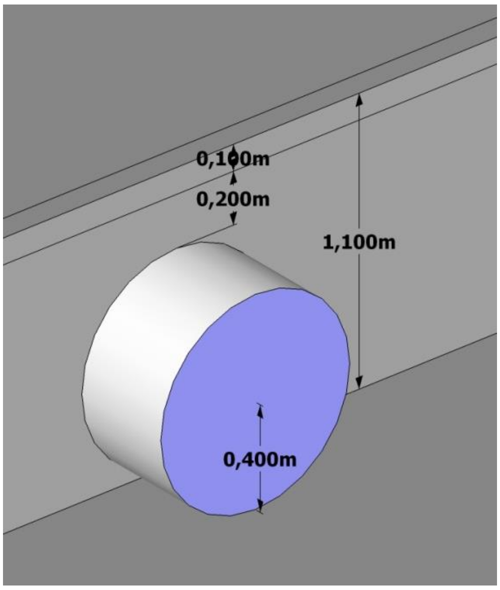

Figure 96: Details of the pipe

At the side of the sill, abutments are constructed. Their function is to prevent water from flowing around the sill. The abutments are made wider than the sill to prevent flooding of the land neighbouring the control structure and channel the water into the widened Kikuletwa. These guiding walls are L-walls to prevent them from tumbling over.

11.3.3 Implementation

The execution of this phase can be divided into 3 steps. The phasing is represented in Figure 97.

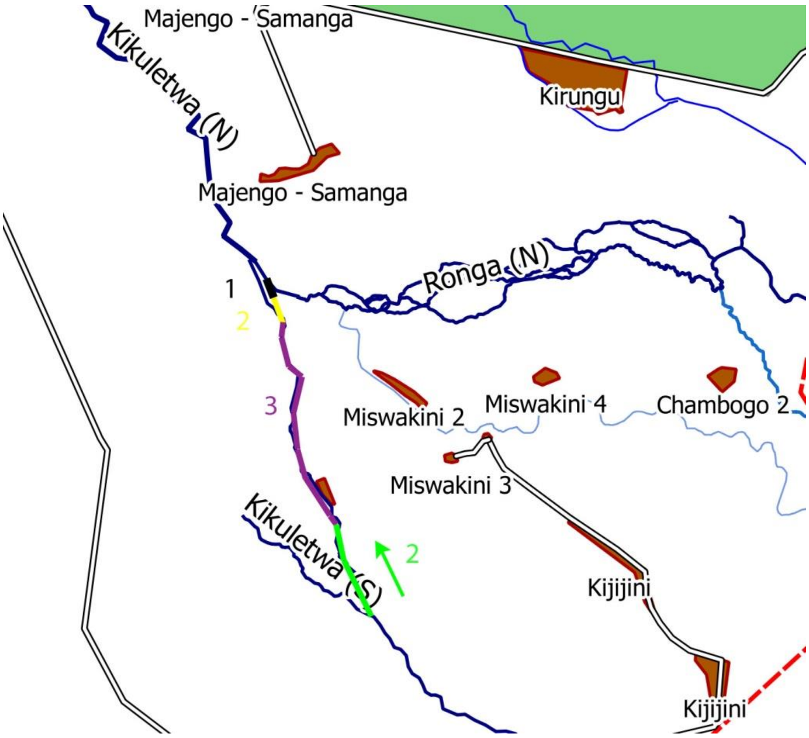

Figure 97: Three phases excavation

Step 1: Construct the control structure

First construct the control structure at the bifurcation point. While this step is executed the Kikuletwa Small is not obstructed yet. The water is still flowing as usual. The control structure is built next to the current channel, on the eastern side.

In order to construct the control structure, a building pit should be excavated at first. In order to do so, the old Kikuletwa South has to be dammed, see Figure 92. Since this pit is located very close to the river, extra measures to retain soil and water are recommended. Due to the soil's permeability and the low level of the pit is expected to fill with water. To keep the pit dry, there should be enough pumping capacity available. Another risk is the instability of the earth separating the pit from the river. To prevent this it is advised to install sheet piles. This would also reduce permeability of the soil.

After the excavation of the building pit, the foundation of is constructed. To prevent piping, it is advised to have a gravel bed foundation. This bed has thickness of 0.5 m. Additionally, to prevent failure due to scour, it is advised to lengthen the foundation another 3 m into the Ronga direction and 7 m into the Chem Chem river bed direction. The reasoning behind this is further elaborated in Appendix N. The construction of the gravel bed is followed by the construction of the bottom slab, the sill and the sides of the structure. The top of the concrete of the bottom slab is advised to be made with large boulders in order to slow down the water, see paragraph 11.2.2 (Samanga spillway). To create a rigid structure, the concrete has to be reinforced with steel. Special attention should be paid to the area around the pipe, the bottom slab and the concrete edge preventing the blocks from sliding (see Figure 94).

Step 2: Excavate the channel

Start at the northern top of the new channel, so the channel is linked perfectly to the control structure. This stretch is indicated with yellow in Figure 97. The excavation of the first part, approximately 300 m, will be dry. The newly excavated channel will not be linked to the Kikuletwa South yet.

Simultaneously the river is widened from downstream. This part is indicated with green in Figure 97. The exact trail of the current river does not need to be followed. Straight sections are easier to excavate and positively influence the Manning roughness n. The channel needs to be connected to the start of the Kikuletwa South Large.

Step 3: Excavate the middle of the stretch

Working in upstream direction, the new channel is further excavated. On the location of the houses the excavation is preferably done on the western side of the river. If this is not possible three or four houses need to be relocated.

At the end the point will be reached where the new channel should be linked to the excavated part behind the control structure (in Figure 97 this is the point between the yellow and purple reach). Once this connection is made, the water can flow through the control structure into the channel and the old Kikuletwa Small next to the control structure can be filled up with soil. The volume of soil necessary for this is approximately 1200 m^3.

Approximately a volume of 85,000 m^3 soil is dug up over the entire channel and needs to be stored somewhere. The 1200 m^3 necessary to fill up the old Kikuletwa Small next to the control structure can be taken from this storage. A suitable location, nearby the project area, needs to be found to store the large amount of soil.

11.4 Chem Chem river bed

The reopening of the Chem Chem River bed consists of three parts. These are the connecting channels with the current river system, both in the north and in the south, and the upstream inlet of the Chem Chem River bed. First the channels will be discussed, afterwards the water inlet. The location of the Chem Chem River bed, see Figure 98 below.

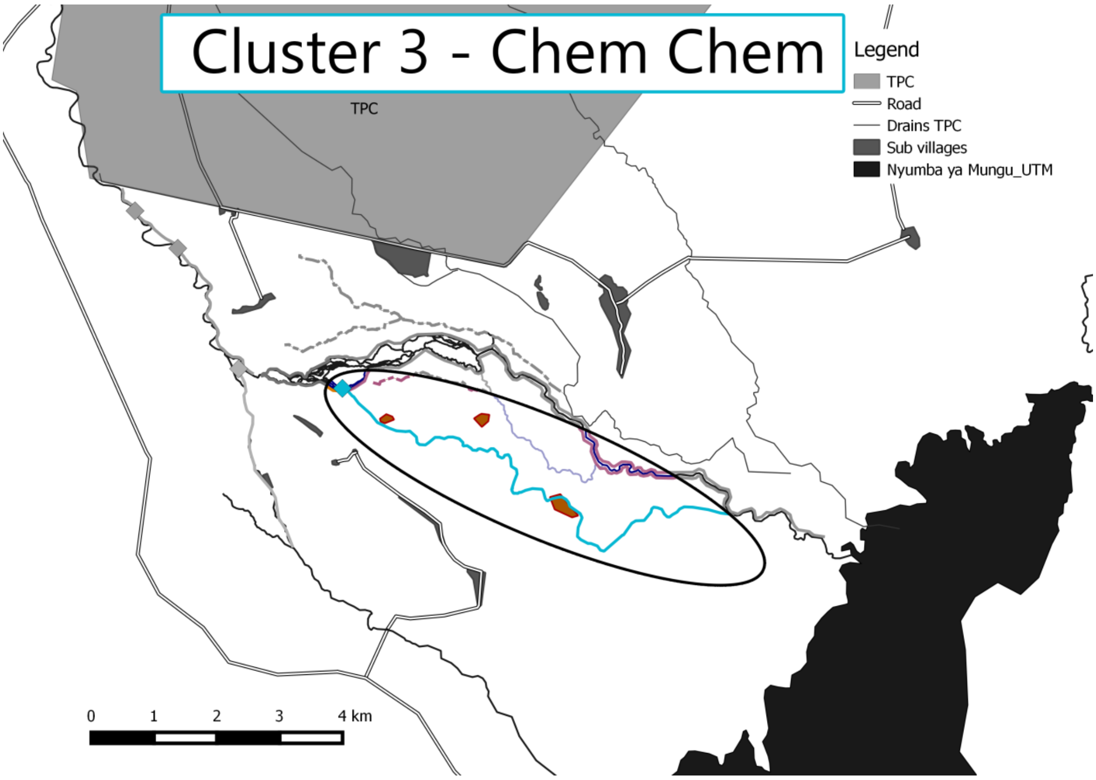

Figure 98: Cluster 3 - Chem Chem River bed

11.4.1 Chem Chem River bed connections and design

The Chem Chem river bed will have to be reconnected with the river system, either at the Kikuletwa or Ronga in the north and at the Ronga in the south. In this section the channels that connect the water system and the Chem Chem River bed will be elaborated. First the location of the channels, next the cross-section designs.

11.4.1.1 Location

Two connections are discussed; the northern connection and the southern connection.

Northern connection

Figure 99 shows the northern end of the Chem Chem River bed. It also shows the new road constructed by FT Kilimanjaro. The Chem Chem River bed is currently not in use, as it was blocked some years ago. The reason for this blocking was that the river destabilised a school that is situated near the river bed, see Figure 99. Reopening the river close to the school could destabilise it again. This is undesirable; a diverting channel would have to be built.

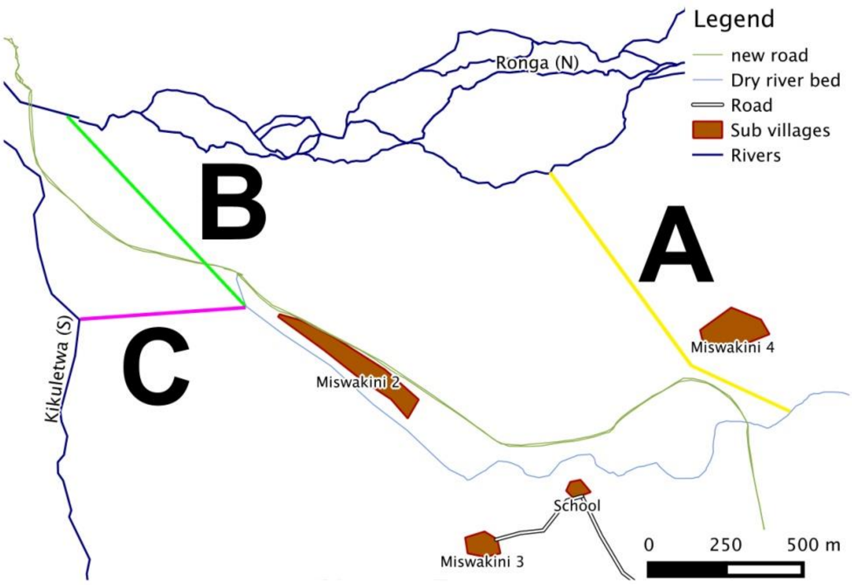

Figure 99: Different trajectories at the northern side of the Chem Chem river bed

In order to connect the Chem Chem river bed to the river system, different trajectories are possible:

A. A connection at location 'A' connects the bed eastwards of the school to the Ronga (N). It is connected to the most southern branch of the braided Ronga. An advantage is that the channel is not crossing the newly constructed road and does not influence the school its foundation. A disadvantage is the relatively long channel that needs to be built: 1.2 km. Another disadvantage is that the braided part of the Ronga has a low bankfull discharge capacity, and short rain dikes are necessary to increase the capacity.
B. Connection 'B' uses the full length of the old river bed and connects it to Ronga (N) close to the planned bridge of FT Kilimanjaro. It is connected to the Ronga North where the Ronga only has one channel, because this part of the Ronga has a higher discharge capacity than the braided part. The short length of the newly created channel (0.7 km) is an advantage. However, the newly constructed road has to be crossed twice (requires big culverts) and a channel around the school has to be built.
C. Option 'C' links the old river bed to the Kikuletwa (S). The short length of the newly created channel (0.5 km) is an advantage. However, the newly constructed road has to be crossed and a channel around the school has to be built. Also, problems are expected with the slope of this channel, as the height difference between the inlet at the Kikuletwa and the connection with the old river bed will be very small.

After reviewing the three options, it is advised that option A is built as it influences existing structures (school and road) the least. Crossing the road would require enormous culverts to be built, which will become bottlenecks and diminish the effects of reopening the river bed. Another consequence could be that the new road is affected and loses its function. When channel A is constructed, possible flooding of the adjacent Miswakini 4, see Figure 99, should be monitored and negative consequences should be mitigated.

An exact route for the northern connection is yet to be determined; the proposed connection, visible in Figure 100, has four advantages:

1. It avoids the new road made by FT Kilimanjaro;
2. It bypasses the village of Miswakini;
3. Current drainage/irrigation channels near the Ronga are used;
4. It uses an outer bend in the Ronga to ensure water flow in Chem Chem River bed.

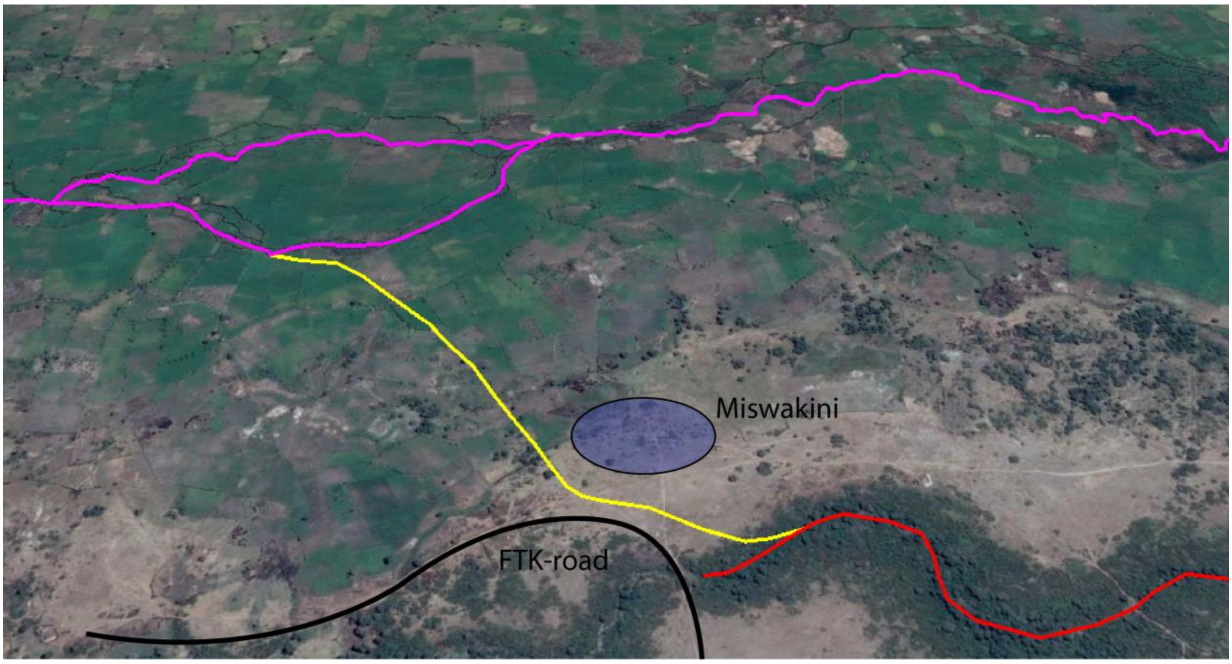

Figure 100: Exact trajectory of northern connection in yellow.

Southern connection
At the southern end of the river bed, see Figure 101, another 0.7 km of water way is missing in order to connect the Chem Chem River bed to the Ronga (S). There are traces of the old river bed, it is however not as suitable for discharging water as the rest of the Chem Chem River bed. Two options are considered:

A. Connecting the river bed to the Ronga with a channel;
B. Letting the water flow over the land.

Option 'A' involves a 0.7 km connection with the Ronga (S). A possible trajectory is indicated in Figure 101 in yellow. Figure 101 shows the Ronga South in purple and the river bed of Chem Chem in red. The advantage is that the water is drained away and cannot damage crops, its disadvantage is that it requires machinery and possibly money to be realised. Option 'B' lets the water run off land, a cheap solution that requires no labour. This has no initial costs; it can however damage crops. Given the fact that the goal of this project is to reduce the negative effects of floods, option A is advised to realise. However, option B could suffice to start with, after which option A can be realised.

The trajectory in Figure 101 follows parts where the old river bed used to be. It also avoids large trees, in order to ensure good constructability of the channel.

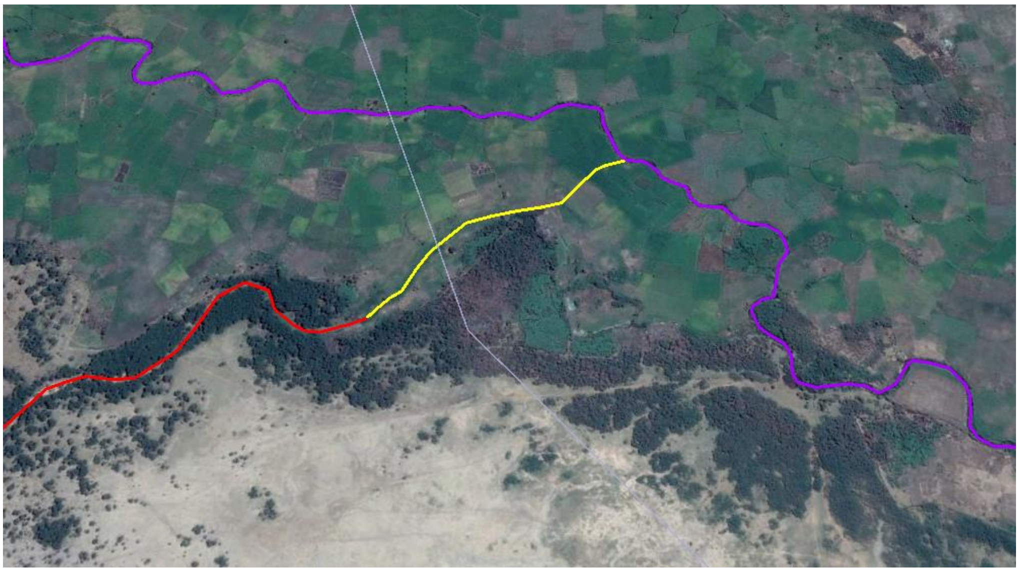

Figure 101: The 'Southern Connection' with a possible trajectory of option 'A', adapted from

11.4.1.2 Design

To create a similar discharge capacity as the existing river bed, similar dimensions as the bed are proposed for the connecting channels. During fieldwork the dimensions of the Chem Chem river bed were determined as shown in Figure 102.

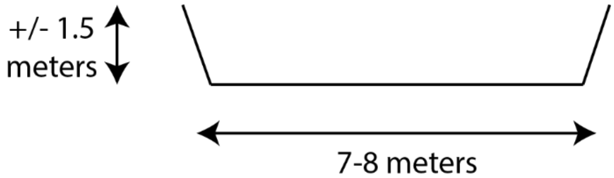

Figure 102: Dimensions Chem Chem river bed

For the channels the same dimensions are advised, using a bottom width of 7 meters with very gentle slopes, 1:2 (vertical:horizontal). Observed slopes in the area are quite steep, up to 2:1 (vertical:horizontal), also for the Chem Chem River bed. These slopes are however fully vegetated, thereby increasing the strength of the slopes. Gentle slopes are chosen to ensure the stability of the slopes when there is no vegetation present yet. The proposed vegetation type for the banks is Vetiver Grass. This grass has proven to be able to withstand large periods of drought and salinity [22]. Most important is that it is present in the area and already used as dike strengthening on TPC grounds and in the project area, see Figure 103.

Figure 103: Vetiver grass on banks of TPC channel.

The proposed dimensions for the Chem Chem River channels are shown in Figure 104.

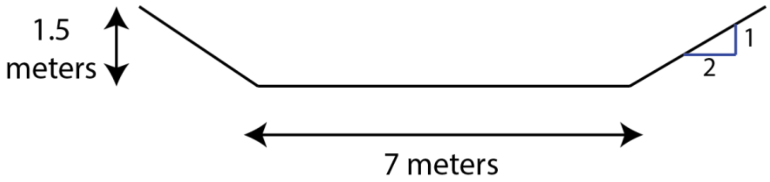

Figure 104: Dimensions Chem Chem channels

The construction of such a canal will take quite some time as 15 m^2 needs to be excavated per running meter. It is advised to use the excavated ground for small dikes on the side of the river, for extra safety of the surrounding areas. At locations where towns are located on one side of the river, the banks at this side should be higher than on the side where no town or houses are located. During fieldwork it became clear that the ground in the Chem Chem area is quite clayey, not much problems are therefore expected with soil erosion. As mentioned, Vetiver Grass can be used to strengthen the banks of the river.

It is advised to start the construction of the northern connection at the south side, where it connects with the Chem Chem River bed. There are two main reasons to start excavating in the south. Firstly, the TPC road reaches to this point, so materiel can be transported. Secondly, groundwater and rain entering the excavated channel can be discharged via the Chem Chem River bed. In this way, no water will fill up the channel, obstructing construction. After realizing the northern connection it can be decided whether to excavate a channel to connect the Chem Chem River bed to the Ronga South.

11.4.1.3 Points of notice

Next to the design and location of the channels, other points of notice have to be addressed.

The Chem Chem area has been visited and local villagers have been interviewed. It became clear that the people in the area welcome the idea of reopening the Chem Chem River bed. Small attempts were already going on to connect the Ronga with the Chem Chem River bed. The efforts of local people can therefore be used to speed up the construction of the channels. This also ensures the support of the local villagers.

Besides the extra discharge capacity of the water system, other positive effects are realised with the reopening. As more water enters the, relatively dry, area of Chem Chem, more farming can be realised, thereby increasing the welfare. However, problems may arise due to farming in the area; the Chem Chem River bed might be blocked or dammed by local farmers to benefit irrigation. This can be in conflict with the main function of the reopening; increasing the discharge capacity of the water system.

The channels that need to be constructed between the current bed and the Ronga might cause problems on a local scale between farmers. The current trajectories follow (visible) farming land boundaries as much as possible, but conflicts may still arise. Good coordination, together with the local farmers, on where the actual trajectory will be is therefore required.

A point of concern to the reopening of the Chem Chem River bed is the accessibility of the area in between the Ronga and the Chem Chem River bed. The current old river bed is crossed a few times by (dirt)roads. During the long rains these crossings will be temporarily unavailable due to high water in the river. One crossing in Chambogo crosses the river at a point where it has a sudden widening. Due to this widening the water depth will be lower at this location; this crossing might therefore still function during the long rains.

11.4.2 Inlet Ronga

In order to regulate the amount of discharge flowing in to the Chem Chem river bed a control structure has to be designed. As can be seen in Appendix M, different designs are possible. All have their benefits and trade-offs, which have been indicated in Appendix M as well. The main point of the control structure is that it discharges at least 1 m^3/s during dry periods and approximately 6.8 m^3/s during the rainy seasons.

11.4.2.1 Location

The control structure is located in the newly dug channel to the Chem Chem river bed, close to Miswakini. Its location is shown in Figure 105.

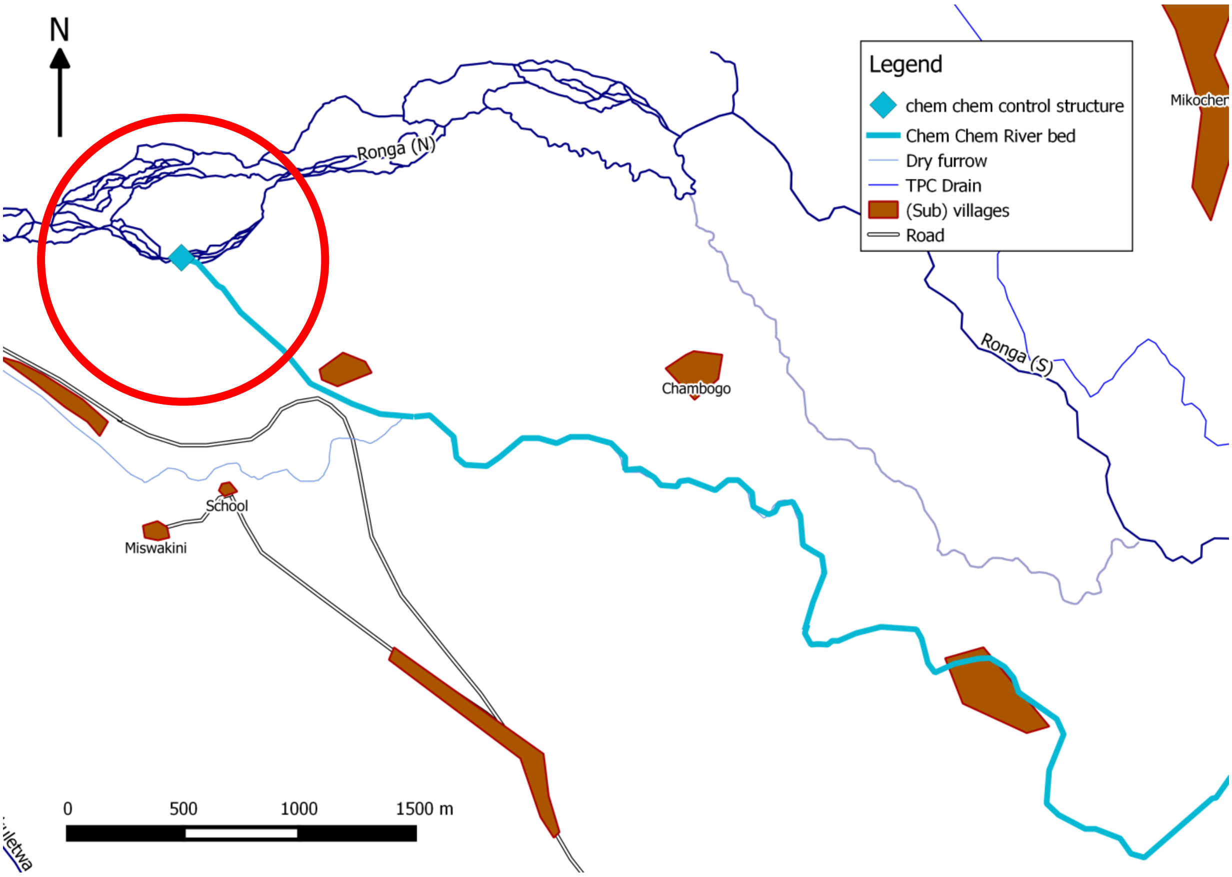

Figure 105: Location of the control structure

11.4.2.2 Design

The exact amount of discharge flowing through each branch of the river system is not known. Creating an exact and solid design based on the values calculated in the Analysis would not be wise since it would lack flexibility. Therefore, a design has been chosen that can be adjusted after the construction has finished. The discharge can be altered afterwards. The main dimensions of the structure can be found in Table 17. A visualisation can be found in Figure 90 – Figure 96. The design checks and assumptions can be found in Appendix N.

Table 18: Main dimensions control structure

Width structure	11.5	m
Width sill	5.5	m
Length sill	3	m
Total length	7	m
Total height	2.5	m
Height foundation slab	0.5	m
Height top of sill[5]	0	m
Diameter pipe	0.8	m
Length scour protection back	7	m
Length scour protection front	3	m

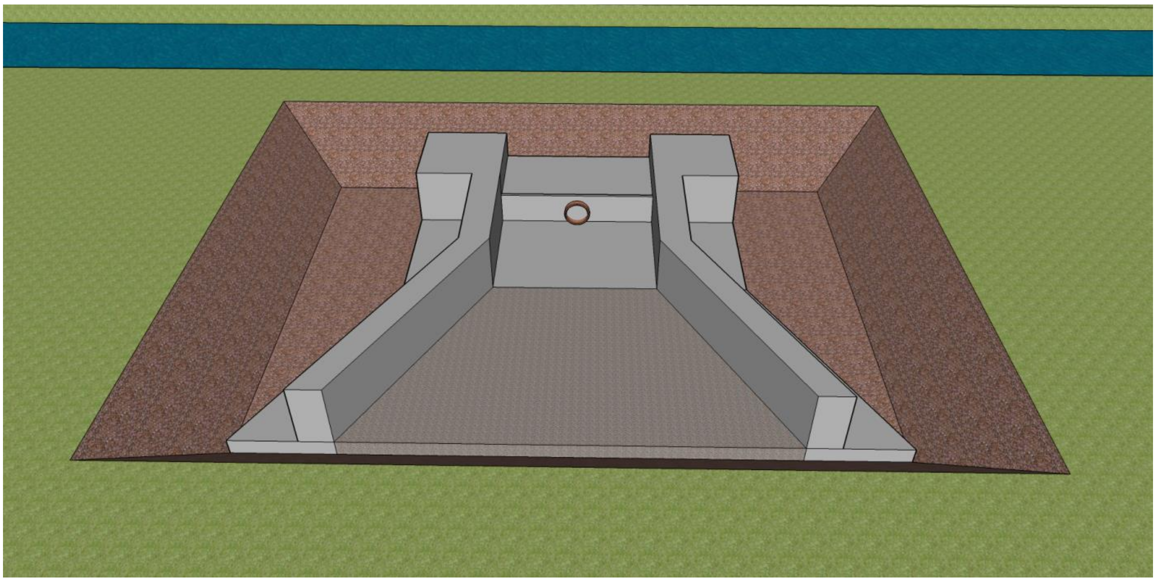

Figure 106: Control structure in the building pit

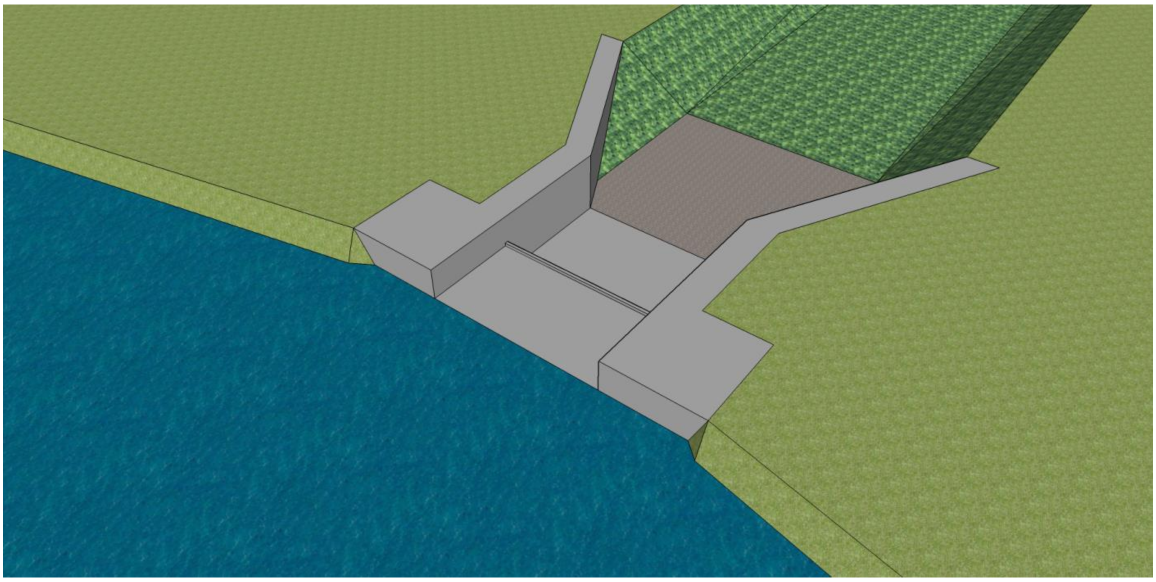

Figure 107: Visualisation of the control structure

[5] Relative to current surface level

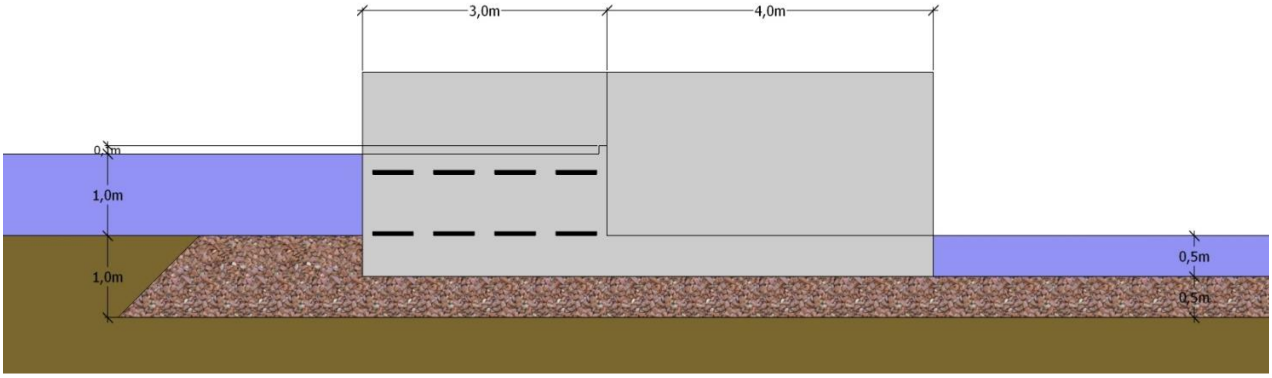

Figure 108: Side view control structure, with the tube's location marked in black

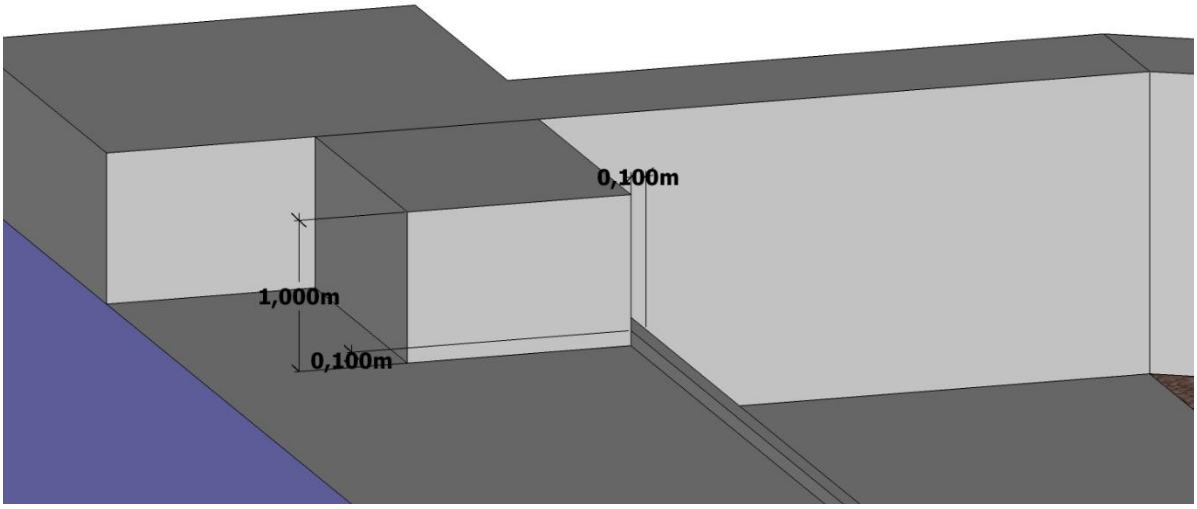

Figure 109: Block on the sil

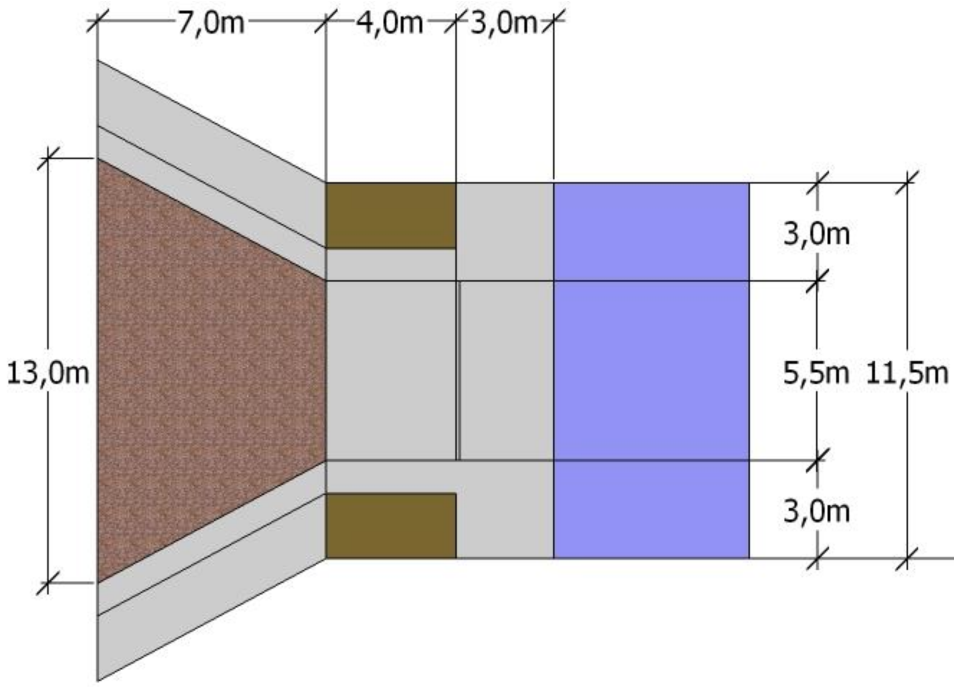

Figure 110: Top view control structure

The pipe is constructed in the middle of the control structure. It is placed directly on top of the bottom slab, as can be seen in Figure 96.

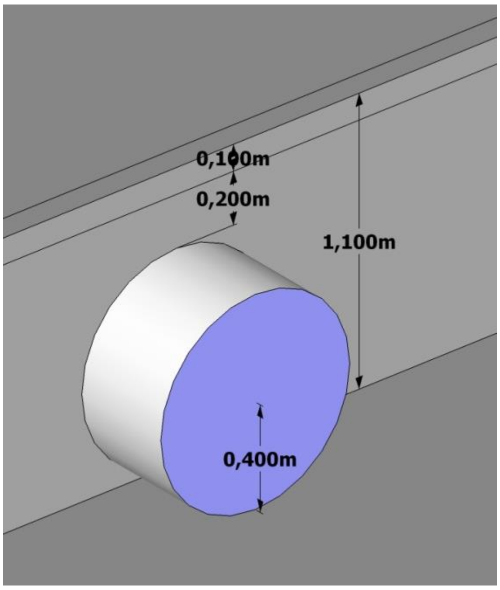

Figure 111: Details of the pipe

At the side of the sill, abutments are constructed. Their function is to prevent water from flowing around the sill. The abutments are made wider than the sill to prevent flooding of the land neighbouring the control structure and channel the water into the newly dug channel. These guiding walls are L-walls to prevent them from tumbling over.

Construction

In order to construct the control structure, a building pit should be excavated at first. Since this pit is located very close to the river, extra measures to retain soil and water are recommended. Due to the soil's permeability and the low level of the pit it is expected to fill with water. To keep the pit dry, there should be enough pumping capacity available. Another risk is the instability of the earth separating the pit from the river. To prevent this it is advised to install sheet piles. This would also reduce permeability of the soil.

After the excavation of the building pit, the foundation of is constructed. To prevent piping, it is advised to have a gravel bed foundation. This bed has thickness of 0.5 m. Additionally, to prevent failure due to scour, it is advised to lengthen the foundation another 3 m into the Ronga direction and 7 m into the Chem Chem river bed direction. The reasoning behind this is further elaborated in Appendix N. The construction of the gravel bed is followed by the construction of the bottom slab, the sill and the sides of the structure. The top of the concrete of the bottom slab is advised to be made with large boulders in order to slow down the water, see paragraph 11.2.2 (Samanga spillway). To create a rigid structure, the concrete has to be reinforced with steel. Special attention should be paid to the area around the pipe, the bottom slab and the concrete edge preventing the blocks from sliding (see Figure 94).

11.5 RONGA

In this paragraph all measures along the Ronga are elaborated and further explained, see Figure 112 for the location of this cluster. Short rain dikes at the start of the braiding are part of the head scenario and will be discussed in paragraph 11.5.1. To reduce the negative effects of flooding also additional measures are introduced. They will be discussed in paragraph 11.5.2.

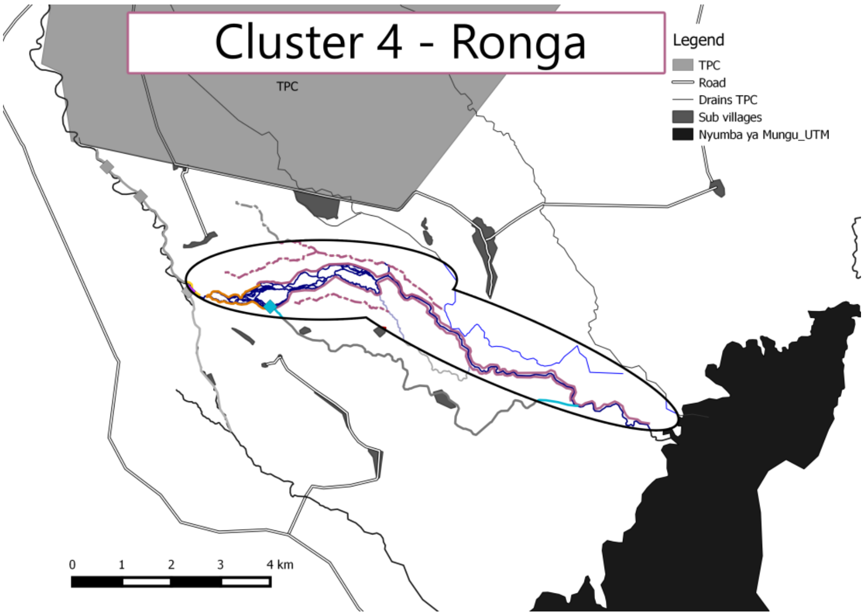

Figure 112: Location of cluster 4 - Ronga

11.5.1 Short rain dikes

Two kilometres after the bifurcation point, the Chem Chem River bed splits off from the Ronga. This section before the splitting must therefore be able to carry off higher discharges than the rest of the Ronga River. The normative discharge that enters the Ronga during the short rains is determined in paragraph 11.1.2. After the bifurcation, the Ronga River should be able to discharge up to 33.0 m^3/s. Before the braiding, the bankfull river capacity has proven to be sufficient. However, for the braided part this is not the case. The bankfull river capacity of the braided part amounts 26.2 m^3/s. To overcome this extra discharge of 6.8 m^3/s, short rain dikes are required. The concerning area for those dikes is illustrated in Figure 113.

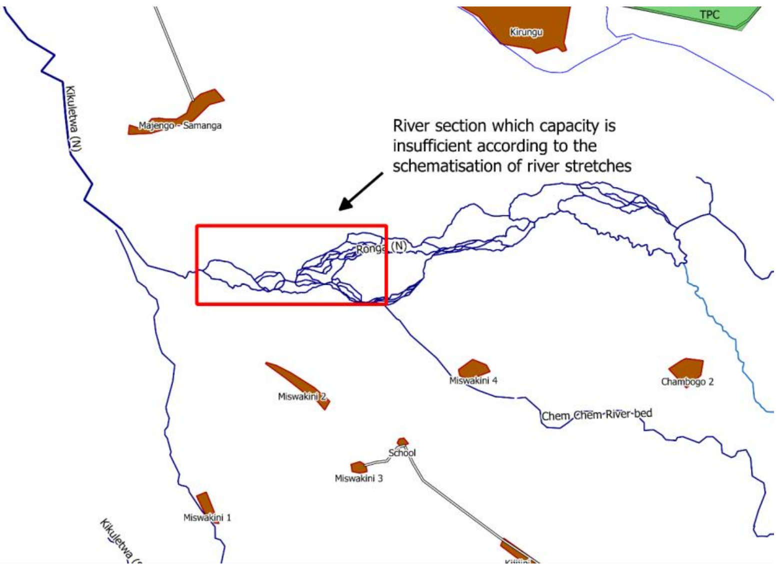

Figure 113: River capacity of the marked region is insufficient

11.5.1.1 Location

In Figure 114 the location of the summer dikes are presented. The dikes start at the point where the Ronga starts braiding. The dike south of the Ronga must be constructed until the beginning of the Chem Chem River bed. Afterwards the discharge of the Ronga is decreased and the current river capacity will be sufficient. For the northern dike it is more uncertain until where the dike is neccesary. It is known that the northern region is more prone to floods, therefore it is important that the length of the dike is sufficient.

Only the outside streams of the braided part must be embanked. Then floods in the hinterland can be prevented and the area in between can be used as floodplains. The floodplains can be seen as an extra buffer for high discharges.

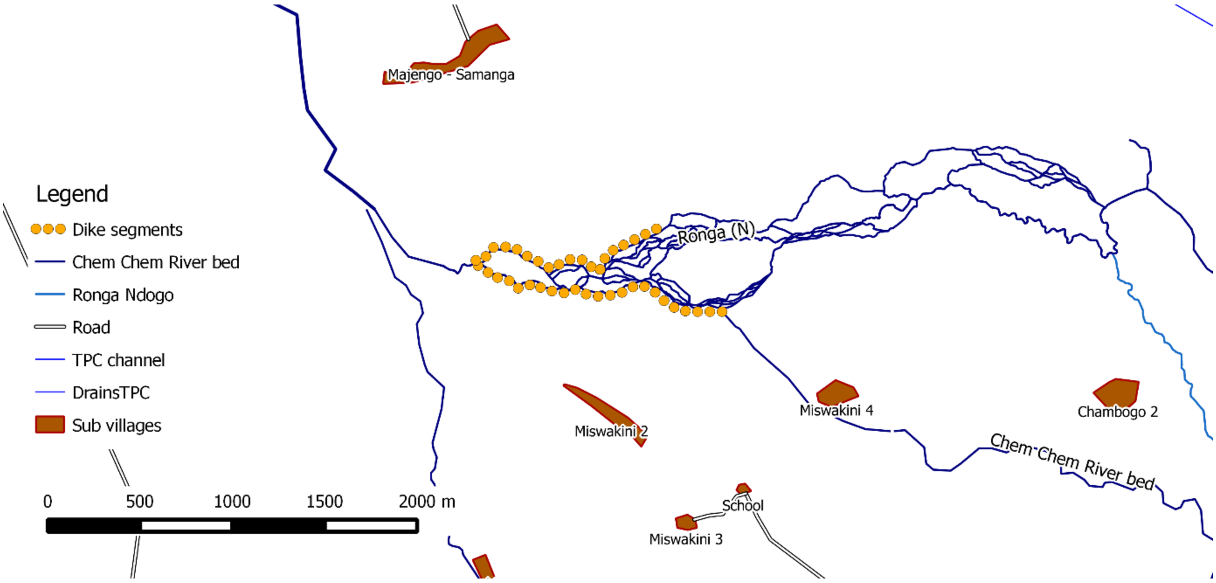

Figure 114: Location of short rain dikes

11.5.1.2 Design

The river capacity of the braided part is based on the measurements that have been done during fieldwork. These measurements were executed on a location where the Ronga exists of only two streams. The total river capacity is equal to the sum of the bankfull river capacity of both streams. In those calculations it was assumed that the banks were full when the water level rises 40 cm. The discharge is computed with the Strickler-Manning equation:

$$Q = A\frac{R^{\frac{2}{3}}i^{\frac{1}{2}}}{n}$$

In which:

A	Cross-sectional area [m2]
R	Hydraulic radius [m]
i	Bed slope [-]
n	Roughness coefficient [$m^{1/2}/s$]

Implementing short rain dikes can be seen as enlarging the banks. An increase in the height of the banks changes the hydraulic radius and the cross-sectional area. As a consequence the bankfull river capacity increases. In Table 19 can be seen what the effect is on building short rain dikes. Dikes of 25 cm height seem to be sufficient to prevent flooding during the short rains.

Table 19: Influence of short rain dikes on the bank full river capacity

Height of the banks [m]	Bankfull discharge capacity in Ronga braided [m3/s]
0.10	29.0
0.15	30.4
0.20	31.9
0.25	33.3
0.30	34.8
0.35	36.3
0.40	37.9

In Figure 115 the schematisation of the Ronga River including the short rain dikes is presented. Also the dimensions of the dike are given. It is of importance that the dike will be covered by vegetation or geotextile. During the long rains the short rain dikes will overflow and the dike gets saturated. The dike can therefore fail by micro instability or be washed away due to overtopping. Those phenomena are further explained in lxxxiiAppendix L: failure mechanisms. A grass cover or geotextile prevents erosion. Furthermore, it is preferable to cover the dike with clay. If it is possible to acquire clayey soil, this should be used to protect the dike. A clay cover can prevent water flowing into the dike, which makes the dike more stable.

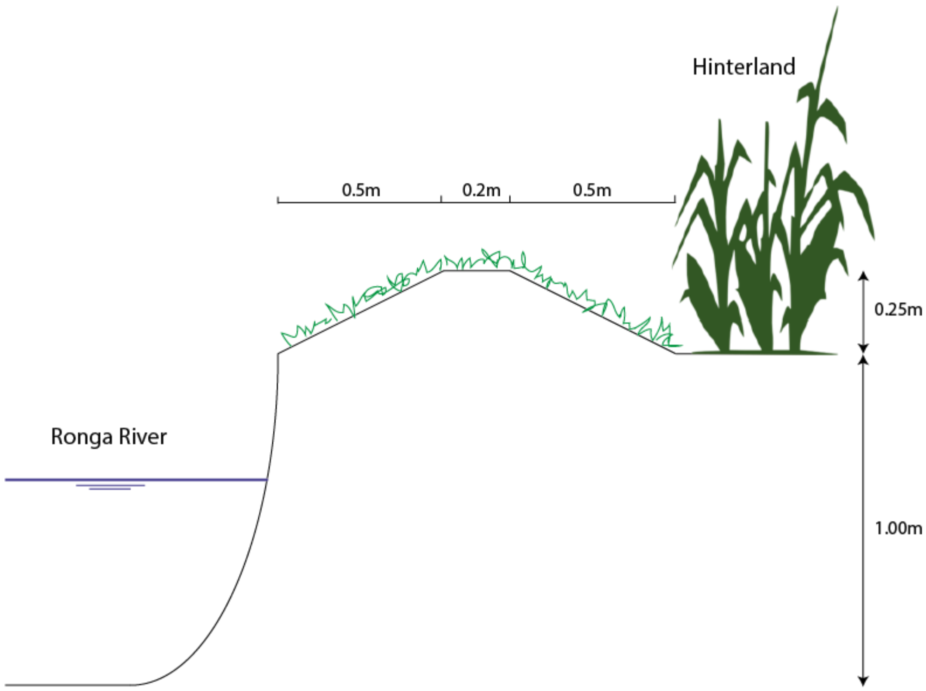

Figure 115: Designed cross-section of the short rain dikes

11.5.1.3 Execution/implementation

To construct 2.7 kilometres of small dikes about 273 cubic metres of soil are needed. It is expected that a lot of soil becomes available when digging the Chem Chem River bed and widening the Kikuletwa South. This soil can be used for the construction of dikes.

The dike system can be built by local farmers. On both sides the Ronga River is bounded by farming land. If all owners of the adjacent farming land construct their own dikes. The job will be less intensive. Though, farmers have to collaborate with their neighbours. Dike sections must be connected well to make good/strong dikes.

When building a dike, the theory applies that the dike section is as strong as the weakest link. Therefore it is of importance that the farmers maintain their dikes well and monitor the condition of the dikes of their neighbours. This must also be told to the farmers. Farmers have to realize that their farming land can also be flooded due to the bad condition of their neighbours' dikes. If they are aware, it is assumed that the control system will work.

11.5.1.4 Remarks

The discharge capacity for the region that is shown in Figure 113 is assumed to be similar for the whole stretch of the braiding Ronga River. This discharge is derived in the analysis report, in the chapter of discharges. Another chapter of the analysis report describes the flood extent as how it is experienced in the fields. An illustration of the flood extent during the short rains is shown in Figure 116. When observing this picture, the necessity of the small rain dikes in the region of Figure 113 can be doubted. This region is according to Figure 116 less sensitive to flooding.

In between the bifurcation point and the start of the braiding, it has been seen that the banks are high compared to the water level of the Ronga River. The elevation map (Figure 116) shows in the discussed region similar elevation levels as in the Samanga region. It has to be considered that it can also be that the discharge capacity for this section is larger than assumed in the analysis report.

When the Kikuletwa (S) and the Chem Chem River bed are opened. The following short rain season would reveal whether short rain dikes are necessary. This decision is included in the paragraph on phasing, paragraph 11.6. If the dikes are indeed needed, it is wise to reconsider the dike height based on the observations during the flood.

After the construction of small dikes the irrigation channels will lose their connection to the Ronga River. To solve this problem several methods can be applied. All methods are discussed in Appendix O.

To make the dike system successful farmers have to collaborate. Therefore some attention and supervision is needed for this collaboration. Especially at the locations where farmers currently tap off their irrigation water. It is probable that farmers would like to break through the short rain dike instead of implementing the supposed measures.

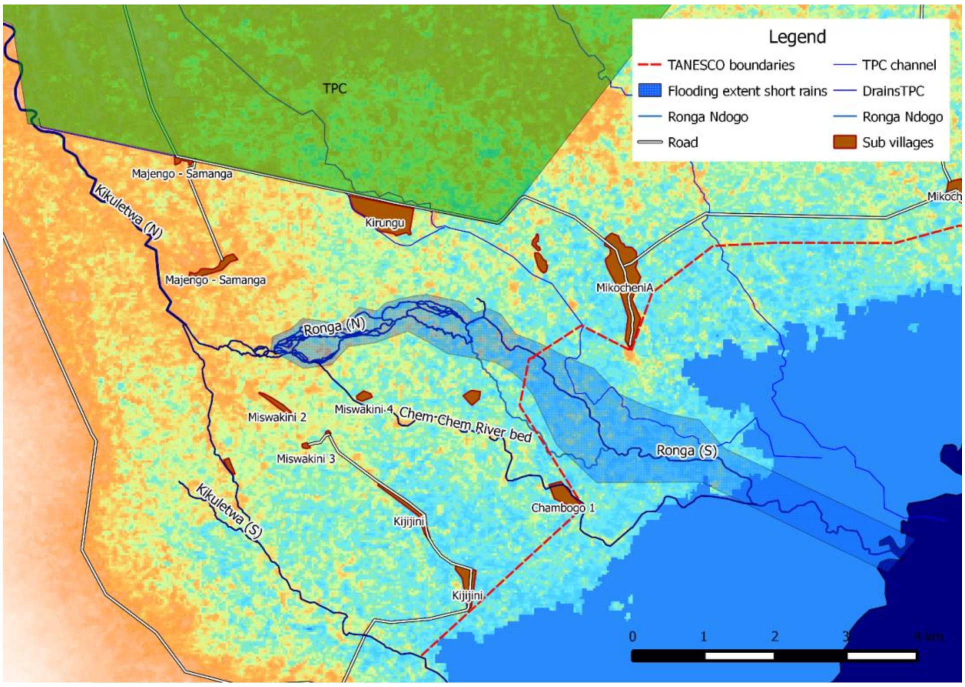

Figure 116: Elevation map and flood extent during short rains

11.5.2 Additional measures

Due to unpredictable river flows and uncertainty of the impact of the implemented measures, it cannot be guaranteed that the negative effects of flooding will be taken away. In order to reduce negative effects of flooding. two additional measures can be implemented along the Ronga River:

- Constructing short rain dikes to prevent farming land from flooding during the short rains.
- Ditching new drainage channels to reduce the flooding depth.

In this paragraph for both measures the location will be identified, also the design will be dimensioned and the method is further explained.

11.5.2.1 Short rain dikes

So far, only dikes in the first kilometres of the Ronga River are discussed. It has been seen that the river capacity of the Ronga River can be very small. It is therefore uncertain what exactly will happen during high flows, even after the increase of the capacity of the river system by opening up the Kikuleta and the Ronga River. It cannot be guaranteed that the Ronga River after the outflow to the Chem Chem river bed will not overflow during the short rains. To protect farming land along the Ronga River from the unpredictable floods in the short rains, constructing small dikes is a logical additional consequence.

Location

The Samanga area does not suffer from the short rains. For the braided part, the section until the Chem Chem River bed, is discussed in paragraph 11.5.1. Therefore the additional short rain dikes will be needed along the resulting part of the Ronga River. This section is illustrated in Figure 117. The dikes end there where the farming land stops. The point where the dikes end is approximately the extent of the yearly maximum reservoir level. The dotted lines indicate the dikes in the TANESCO area. Farmers decided by themselves to grow crops in that region, therefore also the choice of implementation of short rain dikes is upon them.

The lengths of the dikes are:

North: 9.2 km (3.9 km on non-TANESCO ground)
South: 8.1 km (3.8 km on non-TANESCO ground)

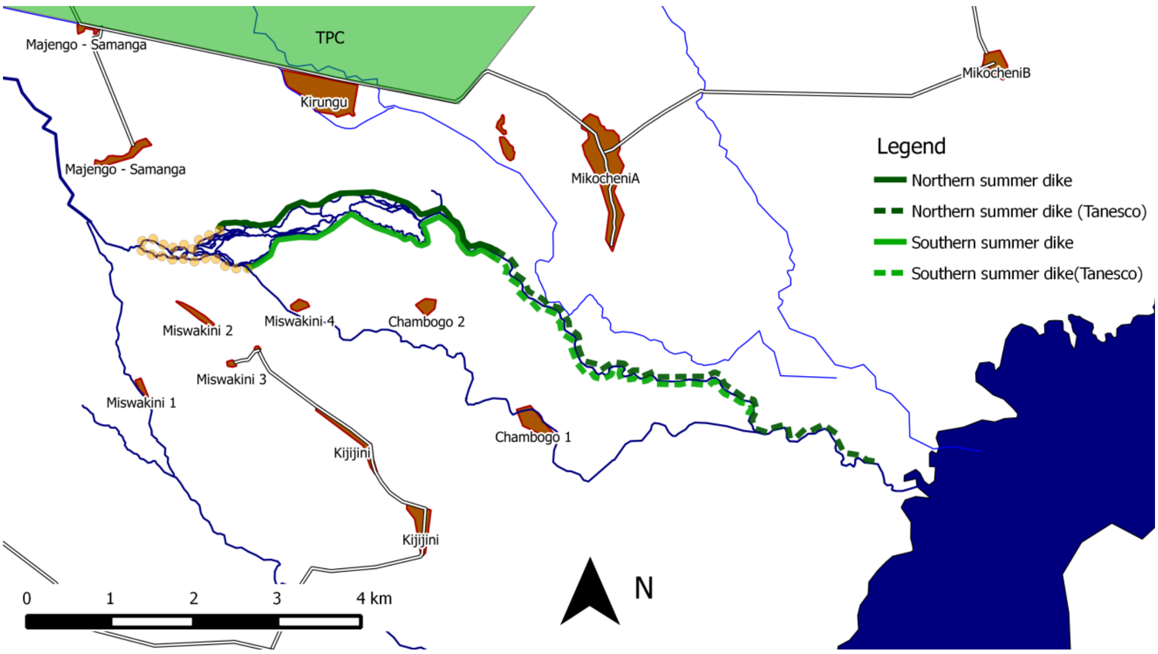

Figure 117: location of the short rain dikes

Design
During the large rain season all farming land is supposed to be flooded. This flooding effects the state of the short rain dikes. Large flow velocities can lead to strong erosion and thereby destroy those dikes. Also if the dike gets saturated, it can become instable. Then the dike can be shifted away or just collapse. To account for this, it can be decided to construct yearly/temporary dikes or to place permanent dikes and take good care of them.

For the permanent dikes the design can be based on the design as described in section 11.5.1.2. The height of the dike should be adapted to the flooding depth after implementing the head scenario. The result will probably be found after some trial and error.

Temporary dikes can be easily implemented when the floods are very local. Dead vegetation as dry grass, straw, maize stalks and dead leaves can be an outcome to protect an area from small floods.

Remarks
In case of permanent dikes farmers have to find access to the river for their irrigation channels. This is also noted in section 11.5.1 and mitigating measures are presented in Appendix O. Those intake points are a weak point for the dike section and tangible to manmade interventions.

In order to let the whole dike section function well, farmers have to collaborate. Dikes have to be connected properly. Especially when the dike section is long and the whole area is sensible to flooding. When only one point is weak the flood will enter via that point. So it is important for farmers to check other dike parts.

The durability of the intervention can be discussed. A yearly flood during the large rains has to show what is left after a flood. If the dike is totally flushed away it will not be worth it to build permanent dikes.

11.5.2.2 Drainage channels
According to the villagers the floods lasts for a couple of weeks. To reduce the flooding depth and to lower the water table, drainage channels can be used. The design of those drainage channels includes several main channels. It is supposed that farmers construct their own connection to the drainage channels.

Location
In Figure 118 it is shown where the drainage channels have to be constructed. If the drains are placed as presented in this figure, all farming land is at most 500 meter away from a drain. The drains are placed in between the river and the boundary of the farming land. In this way, farming land on both sides of the drain can be connected and the distances are minimised. There is also a drain depicted in between Samanga and Kirungu. This drain can discharge water that enters the area via the Samanga dike and control structure.

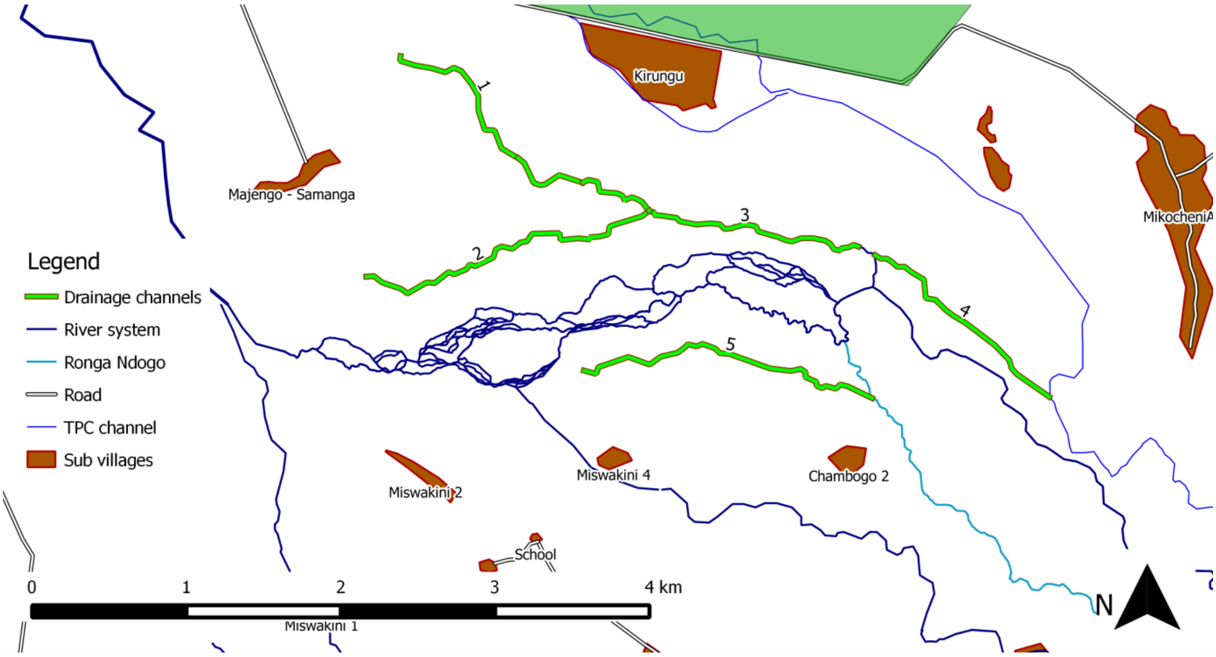

Figure 118: location of drainage channels

The drains are bounded by the TANESCO border. On the northern side, the drain will be connected to the TPC drain. South of the Ronga River the drainage channel can be connected to the Ronga Ndogo. The Ronga Ndogo is an old river bed and can therefore easily be used as a drain. Downstream the connection of Ronga Ndogo with the Ronga River has to be restored.

Design

As can be seen in Figure 118 the drainage channels consists of several stretches. For each of those stretches the characteristics are presented in Table 20. For each stretch, the natural slope is sufficient to discharge the water of the yearly floods.

Table 20: Characteristics of the drainage channels

Stretch	Location	Distance [km]	Elevation upstream [m m.a.s.l.]	Elevation Downstream	Slope [-]
1	Samanga North	2.26	696-697	692-693	0.00177
2	Samanga South	2.14	697	692-693	0.00210
3	Kirungu	1.48	692-693	691-692	0.00068
4	Mikocheni A	1.52	691-692	690	0.00099
5	Chem Chem ps	2.10	694	692	0.00095
		9.50			

To give farmers the opportunity to connect their farming land to the drainage channels, the depth of the drains is chosen to be 1.0 meter deep. By doing so, also farming land at a larger distance can drain their water under gravity to the drainage channel. Due to the high ground water table, the drains will also have effect on the ground water flow. In Figure 119 the groundwater flow into the drainage channel can be seen. Also the dimension of these channels are presented. For the banks a slope of 1:2 is assumed. The banks have to be covered by small vegetation, preferably grass, to prevent erosion.

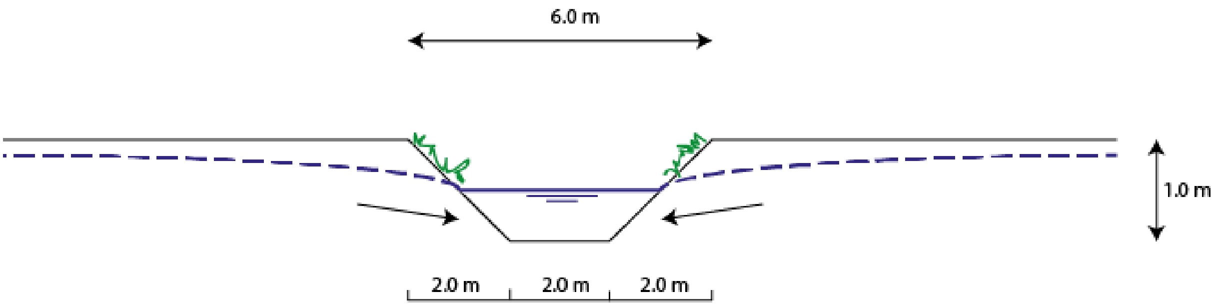

Figure 119: schematisation of the cross-section of the drainage channel

The deep bottom of the designed drain disturbs the current system of the less deep irrigation channels. Farming land behind the drains normally get their water for irrigation from the river. The construction of a drainage channel would destroy those irrigation channels. To account for this the design as presented in Figure 120 is proposed for all locations where the drainage channels cross an irrigation channel. In this design it is assumed that an irrigation channel is 0.5 meter deep and has a width of 1.0 meter. One or more pipes connect the drainage channels and cross the irrigation channels. Those pipes are assumed to have a diameter of 0.3 meter. The material proposed for those pipes is PVC.

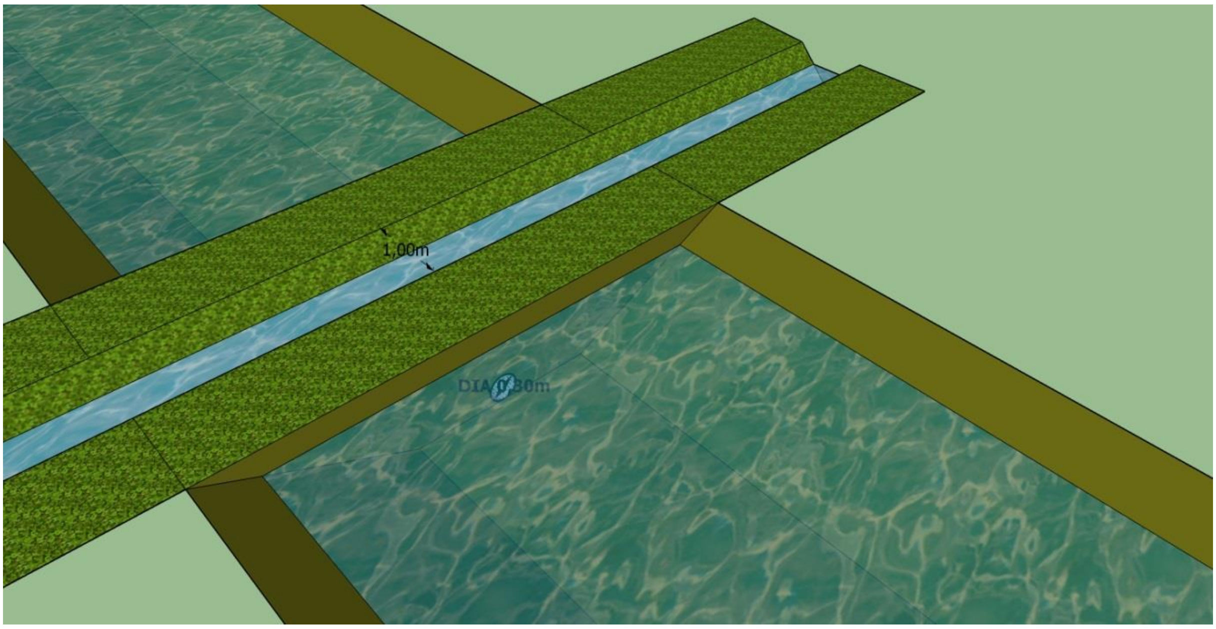

Figure 120: Connection of a drain and an irrigation channel

Implementation

First of all the connection between the Ronga Ndogo and the Ronga River has to be restored. When excavating the drainage system, it is wise to start excavating downstream. This means at the Ronga Ndogo and the TPC channel. It is possible to start at the same time with digging the northern and the southern drain. This way, when the drain fills itself with groundwater, the water can be discharged.

When the design of the drainage system crosses an irrigation channel that is needed to foresee the hinterland of irrigation water, a couple of meters have to be skipped. When the cross-section of the drainage channel on the other side of the irrigation channel is excavated, the connection can be made. This can be done by pushing and rotating a pipe or excavate if needed. After realizing the connection the drainage channel can be dug out in upstream direction.

After finishing the excavation the bed of the drain has to be covered with grass. It will take a while before the slopes have a good, strong grass cover. Therefore the construction of those channels must be done in time for the rainy season.

To make those channels durable, good maintenance is necessary. In fact, a distinction can be made between the drain south of the Ronga River and the drain north of the Ronga River. Both drains are situated in another village. Therefore the village can be held responsible for the maintenance of the drain. Most important is that the depth of the drain has to be sustained and all parts have to stay connected. Only then the water can run-off fast during the yearly floods.

Remarks
A drainage channel over almost the whole stretch of the project area has consequences for the accessibility. The other side of the drainage channel can only be reached by walking through the drain. It should be wise to make some locations where people can easily pass.

11.6 PHASING

In this section an advice is presented on how to phase the different solutions for the flooding problem. Some measures depend on the effect of others. Also the rainy seasons have to be taken into account. Ideally the measures are implemented during the dry season. The phasing as illustrated in Figure 121 is proposed. In the last paragraphs the measures are clustered per location. Those clusters have a different colour in the chart. Roughly the following phases are proposed:

1. Chem Chem River bed;
2. Opening of the Kikuletwa;
3. Monitoring
4. Samanga dike;
5. Decide on small rain dikes;
6. Additional measures;
7. Evaluation.

In the following sections those phases are further explained.

11.6.1 Chem Chem River bed

The Chem Chem River bed is ideal to start with as it requires the least amount of work to increase the discharge capacity of the river system. Compared to the Kikuletwa only a relative small length has to be reopened (1.2 kilometres vs. 3.4 kilometres). Next to the length, also a smaller amount of ground needs to be excavated per running meter.

Excavation of the channel needs to be started in the south at the Chem Chem River bed. This allows incoming water to be drained. Before both rivers are connected, the control structure will need to be built first. The control structure needs to be built just outside of the Ronga, to ensure a dry construction area. This benefits construction time and quality. When the control structure is finished the excavated channel needs to be connected. After that, a connection with the Ronga can be made.

The southern connection between the Chem Chem River bed and the Ronga can be realised in a later stage. To start with, the water can run off over land for the small length between both rivers. This will also encourage local farmers to dig channels that can lead the water to the desired location.

In paragraph 11.4 a decision has been made on the connection of the Chem Chem River bed to the northern Ronga. As a result, the first part of the braiding of the Ronga will be probably unsufficient for the normative discharge during the short rains. In phase 4, after the capacity of the river system is increased, it will be decided whether those dikes are necessary.

During the construction, floods are undesirable. Therefore the proceedings should start just after the end of the long rains.

11.6.2 Opening of the Kikuletwa South

As said, the opening of the Kikuletwa requires more effort than the reopening of the Chem Chem River bed. It does however benefit the river system significantly, as this measure results in quite an increase in the discharge capacity of the river system. As said, this intervention is of a larger scale than the opening of the Chem Chem River bed. This is the reason that Chem Chem River bed should be opened first. The working experiences of phase 1 can then be used by the opening of the Kikuletwa South.

It is believed that there is only a marginal extra inaccessibility of Chem Chem due to the opening of the Kikuletwa South. When it rains the opening of the Kikuletwa S will be used, in those periods the access route is most often already blocked. However, this is hard to predict. Therefore it is advised to first construct the bridge over the Ronga to give the people of Chem Chem a guaranteed access to the surrounding areas.

First the control structure of the bifurcation must be realised. From that point on a new channel can be excavated. Afterwards, starting downstream the Kikuletwa (S) can be widened. In the end the channel can be connected to the widened Kikuletwa.

If it turns out that the activities to restore the Chem Chem River take longer than expected. It is advised to wait until the next dry season before starting the project. It is important that the construction is finished before the coming rain seasons.

11.6.3 Monitoring water levels

After the opening of the Ronga River and the Kikuletwa South, the river capacity should be increased a lot. It is expected that the water levels during the floods decrease. For the following phases, it is very important to know the magnitude of the floods. Therefore the flooding depths should be monitored. Important locations to measure are the Kikuletwa North, the braided part of the Ronga River and the Ronga South. For the Ronga the water level or flooding depth should be accounted as well in the short rains as during the long rains.

In order to stimulate this monitoring process, gauging rods can be placed on the important locations. If one person is kept responsible for the measurements, the results will be more consequent and reliable.

11.6.4 Samanga dike

The Samanga dike does not solve the problem of flooding during the short rain period. It decreases the negative effects of the flooding during the long rain period. The opening of the Chem Chem River bed and the Kikuletwa take away negative consequences in both rain periods, and therefore the Samanga dike is advised to be constructed later.

To build the dike construction on a dry basis, the execution should be done in the dry season. First thing to start with would be the restoration of the current dike breach. Afterwards the dike has to be extended so that the control structure can be implemented.

When the realisation of the Samanga dike starts in the dry season, this means that already a rainy season has passed. The findings of this period are very useful for the design of the dike. Until now it is unknown whether the dike is needed for the whole stretch of the Kikuletwa (N). Also the height of the dike is approximated. These can be evaluated with the data that is derived in phase 3.

11.6.5 Decide on small rain dikes

Before building the small rain dikes, it is important that the river capacity increasing measures are already realised. Only then it can be proved during the short rains whether small rain dikes are still necessary. If the first part of the braiding of the Ronga has flooded during the short rains and phase 3 is executed properly, the height of the small rain dikes can be easily determined. Constructing those dikes can be done fast if a lot of farmers want to cooperate.

11.6.6 Additional measures Ronga

The additional measures in the Ronga do not have priority as they do not solve the problem, but counteract on the consequences. After all the measures of the integral solution are implemented, it can be decided whether additional measures are still needed. If so, it might be possible to realise the additional measures with cooperation of the local farmers. If that is the case, implementation can start as soon as the farmers

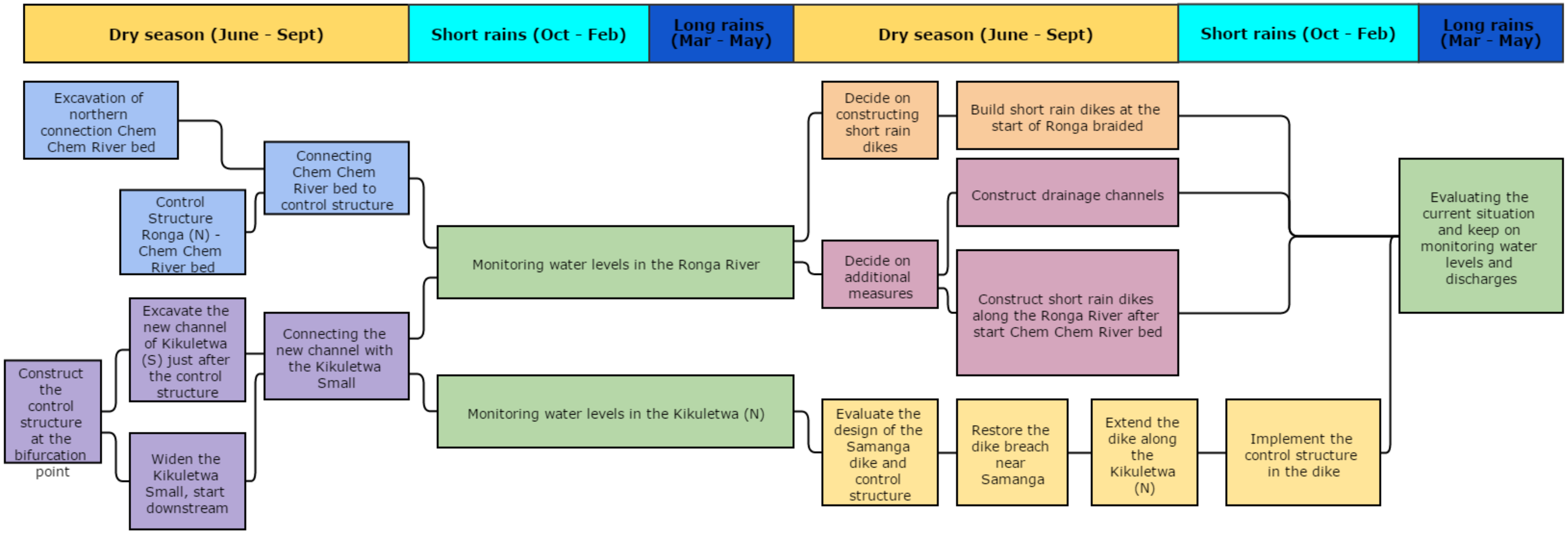

Figure 121: Phasing of the clustered solution. In blue the Chem Chem river bed, in purple the bifurcation point, in orange the summer dikes, in yellow the Samanga dike and control structure and in pink the additional measures.

Part C: Conclusions & Recommendations

Figure 122: Aerial picture of meandering Ronga and dryer Chem Chem area

12 CONCLUSIONS AND RECOMMENDATIONS

This report was set out to explore the yearly flooding issues along the southern Kikuletwa in the North of Tanzania. The floods have negative consequences on farming activities specifically, and generally on community infrastructure and livelihoods. On the other hand, the floods have positive effects on the salinity and the fertility of the soil. Due to inundations that last for weeks, health problems arise and areas become inaccessible. To overcome those problems, a durable, inexpensive, constructible, socially acceptable and short term tangible solution is proposed. This solution should diminish the negative consequences of the river floods and possibly enlarge the positive.

In this chapter first the defined project goals are discussed. The two main goals are:

- Understand and clarify the flooding problem;
- Find a solution to the flooding problem that fits the requirements.

After the project goals the social implications are argued. In the recommendation section, topics or subjects are mentioned that are relevant but are beyond the scope of this study. Also the limitations of this study are given. The chapter is ended with final conclusions.

12.1 UNDERSTANDING OF THE FLOODING PROBLEM

The yearly floods can be explained by the sudden increase in discharge during the rainy seasons. As a result of the large flood that occurred in 1991, a new course of the Kikuletwa River was formed. This new course is called the Ronga River. The Ronga River has a discharge capacity which is insufficient during the short and long rain season. A couple of times during the short rains and for a longer period during the long rains, the discharge in the Ronga River is larger than the river capacity and the area gets flooded. Due to the high water table in the area the flood volume cannot infiltrate and the flooding depth cannot decrease.

About a year ago, the district built an inlet in the dike, south of TPC, near Samanga. The purpose of this dike was to let the farmers behind the dike control the amount of irrigation water. Unfortunately, the design of the dike did not suffice and the dike failed at the location of the inlet. This location is currently the weakest point of this dike section. During the long rains water enters the area of Samanga and Kirungu. When the long rainy season starts, the discharge increases drastically. Discharge peaks exceed 15 up to 20 times their dry season values. As a result, the water level and flow velocities increase considerably. If the water level becomes larger than the height of the bank at the dike breach, the dike at this point will overflow. Due to the high flow velocities, the run-off will destroy crops on the farmland. It has been found that the main cause of the inundation is the overflowing of the Ronga River. The dike breach contributes to the flooding, but is not the main cause. However, to solve the flooding issues a restoration of the dike at the breach should be included in the solution.

Theoretically, high water levels in the Nyumba ya Mungu reservoir could influence the water levels in the river system. However, it was found that the equilibrium depths of the rivers are much higher than the water levels that are reached throughout the year. Moreover, the half-lengths of the backwater curves were calculated to be very short. Therefore it can be concluded that the reservoir levels do not significantly influence the water levels in the rivers.

12.2 FIND A SOLUTION THAT COMPLIES WITH ALL REQUIREMENTS

Preventing the area from flooding during the short rains is challenging. To overcome these floods, the Ronga will be relieved by increasing the capacity of the river system. This includes:

- Reconnecting and restoring the Chem Chem River bed;
- Enlarging the narrow part of the Kikuletwa South and connecting it to the wide section of the Kikuletwa South.

During the dry season, farmers need to supply their farming land with irrigation water from the Ronga River. In other words, a minimum water level in the Ronga must be assured. To control the water running into the widened Kikuletwa and the reconnected Chem Chem River bed, a control structure has been designed. Using an adaptable weir, the appropriate water levels in the Ronga River during the dry season can be guaranteed. When the water level increases due to the rainy seasons, the water can flow over the weir and will find access to these new channels. Due to this increase of river capacity, the water level will be reduced and the floods are prevented during the short rain season.

Local people are accustomed to the inundation of their land and the floods are desired during the long rains. Considering the outliers on discharges that occur yearly, even after increasing the discharge capacity, it can still be expected that the area will get flooded. In order to minimise the problem of flooding, the flooding depth needs to be reduced and the time of inundation can be shortened. By increasing the capacity of the river system, the flood volume will be reduced. To shorten the retention time of the inundation, drainage channels can be implemented to discharge the flooding volume to the reservoir. Next to that, small dikes can be constructed to minimise the probability of a flood during the short rainy season.

The area behind the dike breach is affected by large flow velocities that damage the fields. In order to solve this problem, the dike needs to be repaired and possibly extended. To comply with the desire to have controlled floods between Samanga and Kirungu, a weir is integrated into the dike design at two locations.

Tangibility, constructability and durability of the solution are important aspects to be considered. Firstly, other projects of FT Kilimanjaro have proven that in order to make a project successful, trust and support of the local villagers is needed. All measures of the integral solution can therefore be implemented on the short term and will directly have effect after construction. Therefore, the measures are considered to be tangible. This is important because, as long as they can see the effort of it, they will want to cooperate and will support the project.

Secondly, the measures taken should be durable: the solution should last for the upcoming years. Therefore river beds have to be well maintained. To prevent that the vegetation in the river beds of the new channels is growing freely, it is important to have a base flow in the channels. Next to that, it also prevents clogging of the river beds. The base flow is achieved by low lying pipes in the sill. In this way there will always be flow through the Kikuletwa South and the Chem Chem River bed. The measures have been designed in such way that they are rigid and need little maintenance.

Thirdly, the constructability of the measures are considered. TPC has a lot of machinery and other equipment that can be used for the implementation of the solution. By making use of local available materials, the constructability can be improved. A large part of the solution consists of excavation work. TPC has experience in excavating channels on their own premises, so no difficulties are expected in terms of constructability. The control structures are probably more challenging. However, TPC has experience concerning control structures and can assist at the construction site. Furthermore, concrete structures are common in the district. Using the knowledge that is present in this area, the proposed structures should be achievable.

Social implications
The fastest solution to relieve the area of the flooding problem would be to increase the capacity of the Kikuletwa drastically. This would be short sighted since the positive effects of the flooding cannot be neglected. The area around the Ronga is considered to be valuable agricultural land. Depriving this area of river water would not be supported by the local stakeholders. The solution proposed does take into account the beneficiary points of the floods.

12.3 LIMITATIONS

While looking at the integral solution, a couple of issues and uncertainties need to be addressed. To start with, for a couple of locations the cross-sections are approximated. If the cross-section in reality deviates from the assumed cross-section, this has consequences for the discharges. Approximated discharges are used as the starting point of the design of the solution. However, the results of all calculations are compared with our experiences and impressions from the fieldwork.

Secondly, this project took place during the short rains. It is therefore still uncertain what happens during the long rains. Findings as presented in the report are based on interviews in the field and might be biased. Misunderstanding in the flooding extent as described in the analysis, should be taken into account.

Thirdly, also the non-uniformity of river stretches should be considered. In order to make the project manageable, characteristics within a stretch are assumed to be the same. For each stretch the characteristics have been measured at one location. Due to the river's natural course, it is plausible that the cross-sections deviate from the assumed dimensions, especially regarding the braided part. For the cross-sections that are measured, a representative cross-section at that location is chosen.

Fourthly, the elevation map that was available for this study has a relative large error and large grid. Therefore it could not be used to identify height differences on a small scale. Discharges of all stretches depend on bed slopes. Those bed slopes could not be measured by the elevation map and are therefore approximated by using Google Earth. On Google Earth, heights can differ every meter due to vegetation, trees or other obstacles. Thereby the inaccuracy of Google Earth is not defined. It appeared during this study that it is difficult to get an understanding of local height differences and it can therefore be that the assumed slopes differ from the real slopes. Since this influences the assumed discharges, uncertainty on these values increases.

Fifthly, the study was limited by a lack of information on soil types. As a result, a final design cannot be made. Both the dikes and the slopes of the new channels can therefore be wrongly dimensioned. In addition, the safety check on instability cannot be quantified for the dikes and banks.

Sixthly, it was beyond the scope of this study to define the distribution of discharges at a bifurcation. This can only be determined after complex calculations wherefore it could be very useful to make use of modelling tools. Therefore, in this design all control structures are adjustable and the rainy seasons have to prove what the actual distributions are.

Finally, it should be noted that the design of the solution is based on the knowledge that has been gained in the Netherlands. Local engineering knowledge was not obtained. As a result it could be that the design is a bit more complex than local engineers are used to. Therefore coordination of the execution of the solution is very important.

12.4 RECOMMENDATIONS

It should be noted that there are several issues that are beyond the scope of this study but still important to consider. Firstly it should be noted that the proposed solution is a preliminary design. To go on with this design, first an implementation plan has to be set up. Preferably this will be done by a local engineer.

Secondly it is known that also other areas suffer from floods. Probably it is more efficient to approach the problem on a larger scale. It is advised to investigate this in the near future. This is consistent with the third point, namely the return period of the floods. The current design only covers the yearly floods. In order to solve for larger floods, probably more measures are needed.

Thirdly, this study has shown how worthy it is to have a good set of data. Therefore it is advised to set up a monitoring system for the defined river stretches. When additional measures in the future are needed, designing would be easier using sufficient and reliable data. In order to do so, for each stretch a representative cross-section has to be found. For the selection of this site, an important criterion is that the river must be stable. Therefore it is preferred to avoid river bends for those measurements.

For the found location, the cross-sectional area has to be measured exactly. Then the flow velocities have to be measured at a representative depth on an equal interval of the width of the river. In this way, the discharge can be computed for the current water level by the velocity-area method. If these measurements are done at the same location during other stages, a relation between water levels and discharges can be derived by means of a regression line. This relation is also known as the stage-discharge relation. By means of this relation, the discharge can be directly derived by reading the water level by a staff gauge. When this staff gauge is permanently installed and a responsible villager is elected, all means are available to collect discharge data on a frequently basis. For literature on this subject the authors advise the lecture notes of W.M.J. Luxemburg [24].

Fourthly, in the phasing of the solution, monitoring of water levels in the rainy seasons is included. In order to derive the right conclusions from these water levels, the discharges at 1DD1 should be taken into account. In the discharge data from 1978 until now it can been seen that the yearly maxima can be very different. When the maximum discharge of the coming years are compared to this data series, it can be seen whether it was a moderate, average or extreme year.

Fifthly, drainage channels are proposed as additional measure to the head scenario. Until now it is still unknown what time a flood should last in order to make the soil fertile for a new farming season or to reduce the salinity of the soil. This should therefore be investigated before deciding on the necessity of those channels.

Sixthly, as is mentioned before, the influences of geohydrology are excluded from this study. Recently, TPC published an aquifer study of this region. The present high water table and saline areas, are however related to the problem. This relation is still open for further research.

Seventhly, it is recommended to educate the inhabitants of the villages on the measures that will be taken and what their effect is. In order to get the full support of the villagers, it is assumed that some basic understanding on water management is needed.

Lastly, the design only focuses on the water system since the knowledge on irrigation is limited. However, for the farmers this is very important. Therefore more research should be done on the link between the irrigation system and the water system.

12.5 Final words of the authors

As is argued in this chapter, a solution has been found that fits all requirements. In its design most conditions or wishes are included as well. In order to fulfil all requirements, innovation was the key to success. With the current design of the control structures, social conflicts are avoided, a base flow in each stream is guaranteed and the main problems of flooding are solved.

In this report an area is studied and mapped where until recently the river system was unknown. An analysis of the water system as a whole was made in order to clearly understand the problem. This knowledge is combined in the final solution to the problem. If the implementation of the solution is supported and can be carried out, better prospects for the affected people could be achieved.

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Part D: Appendices

Appendix A Public Administrative Organisation in Tanzania

Tanzania has a large public administrative organisation, with many different levels. In this appendix an insight in this organisation is given for the clarification of the report. The focus of this appendix will be on the administrative organisation in our project area, and what higher administrative units the project area is part of. A flow chart is provided in Figure 125. A document that was provided by Gerbert Rieks (FTK) has been used for this appendix, together with [25].

Tanzania is divided into 30 regions, which are clustered in 6 zones:

- Central zone
- Coastal zone
- Lake zone
- Northern zone
- Southern Highlands zone
- Zanzibar zone

Our project area is situated in the Kilimanjaro region, in the Northern zone, see Figure 123. This region is named after Mt. Kilimanjaro, which dominates the scenery of this region. A region is headed by a Regional Commissioner, who is appointed by the President of Tanzania. The Kikuletwa River, which forms the western border of our project area, is also the border between the regions Kilimanjaro and Manyara.

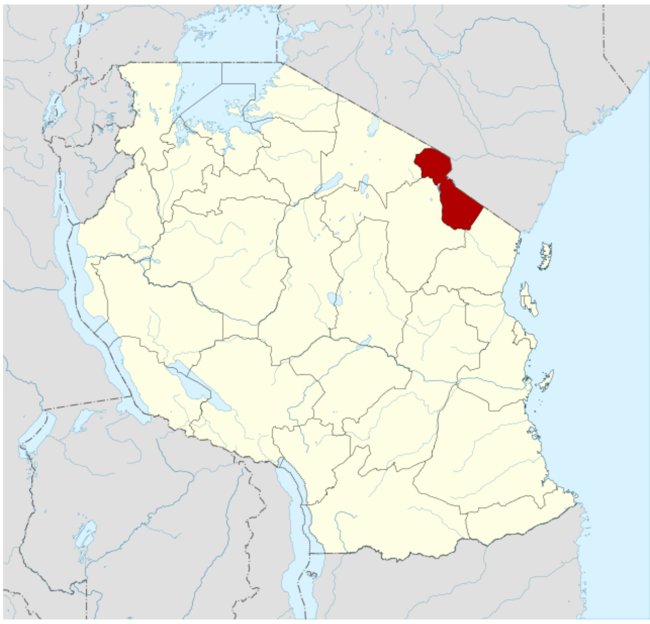


Figure 123: Kilimanjaro region in Tanzania

The next administrative unit in line is the District. The Kilimanjaro region consists of 7 districts. The project area is situated in the district Moshi Rural. Figure 124 shows the districts around the project area. The project area is bordered by the Simanjiro district in the west, part of the Manyara region. The district is the lowest administrative unit in the hierarchy that has a budget to spend. It is headed by the district commissioner and has 11 departments. The district has a districts engineer which can spend budget on infrastructural works. In the project area a dike was built east of the Kikuletwa. Unfortunately this dike has failed, probably due to a combination of an outlet sluice in the outer bend of the river and marginal cohesion due to a sandy dike.

A district is subdivided in Wards. There are 31 Wards present in Moshi Rural and the project area is part of the Ward Arusha Chini, see Figure 124. A ward has no budget and its departments and executive officer are appointed by the district. The next line in the bureaucracy is formed by the villages. Arusha Chini has 8 villages, of which TPC, Mikocheni and Chem Chem are the project area.

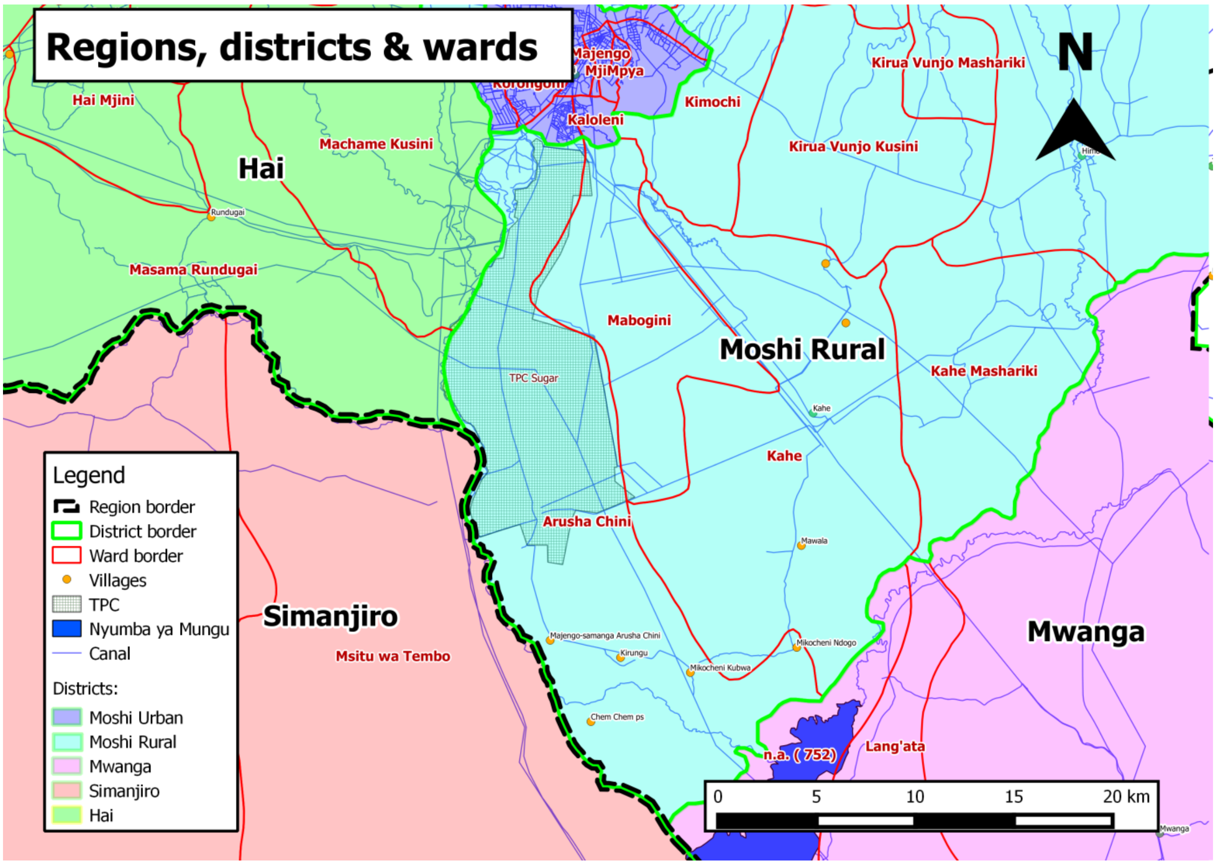


Figure 124: Regions, districts and wards around our project area. Nyumba ya Mungu reservoir in shown in the South, just above is the project area in Ward Arusha Chini.

These villages are again subdivided in sub villages, which are a main source of confusion. Often the main sub village is also the name of the village, which is the case for Mikocheni. Mikocheni and Chem Chem are part of our problem area and consist of the subvillages Kijijini, Majengo (Samanga), Chambogo and Miswakini (for village Chem Chem) and Mikocheni Kubwa(=big), Kirungu, Mikocheni Ndogo (=small) and Masaini in Mikocheni village. The last two are in higher laying parts of the village and are therefore not prone to flooding. In the different sub villages groups of 10 households are formed that have 10-cell leaders.

Interviews during fieldwork were mostly conducted with leaders of villages and sub villages. 10-cell leaders are therefore not in our interest, it is however remarkable that on such a small level democratic leaders are chosen. Besides the 10-cell leaders the sub village leaders are chosen too. The villages have no budget but occasionally some money is collected among the villagers. Measures affecting more people are often decided upon on a village level.

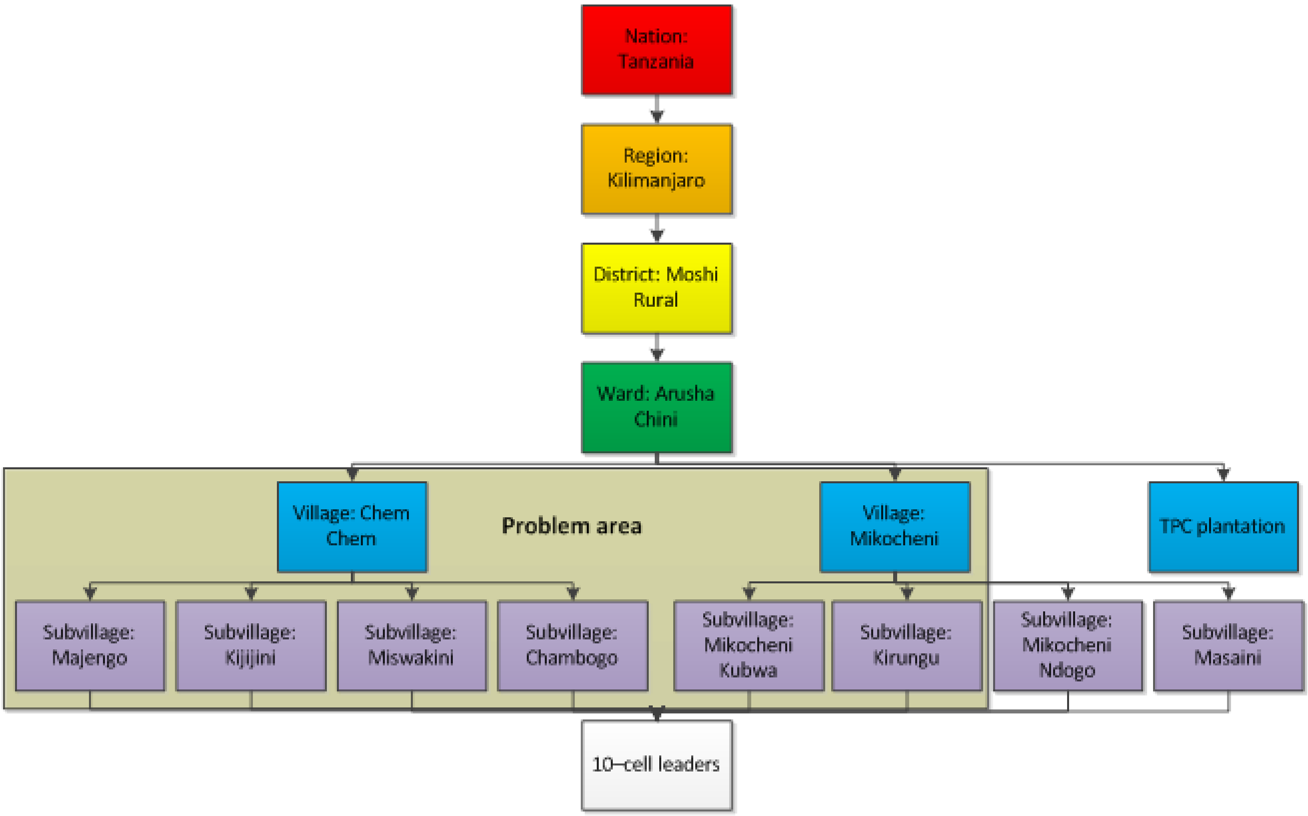


Figure 125: Administrative units relating to project area.

Appendix B HISTORY OF THE KIKULETWA AND THE RONGA

In this appendix a short history of the development of the Kikuletwa and the Ronga is described.

B.1 History of the Kikuletwa

Satellite imagery shows that the Kikuletwa flows at the most western side of the valley. Soil on the west side of the river is sandy, while the soil on the east side is clayey. Observations in the field confirm the difference in soil type, see Figure 126 and Figure 127.

This paragraph discusses the possibility of different tributaries in the past. Additionally a suggestion will be made for a solution in the (distant) future.

Figure 126: Sandy soil west of the Kikuletwa (L)

Figure 127: Clayey soil east of Kikuletwa (R)

A reason for the alluvial soils east of the Kikuletwa could be that the river has deposited them in the past by eastern branches running through the current TPC terrain. Figure 128 shows the Kikuletwa at the western border of the valley. The natural drain of TPC is encircled in red. From satellite imagery (Figure 128) it looks like as if the drain is an old river bed. An aquifer study [6] conducted by HYDRIAD for TPC strengthens this presumption.

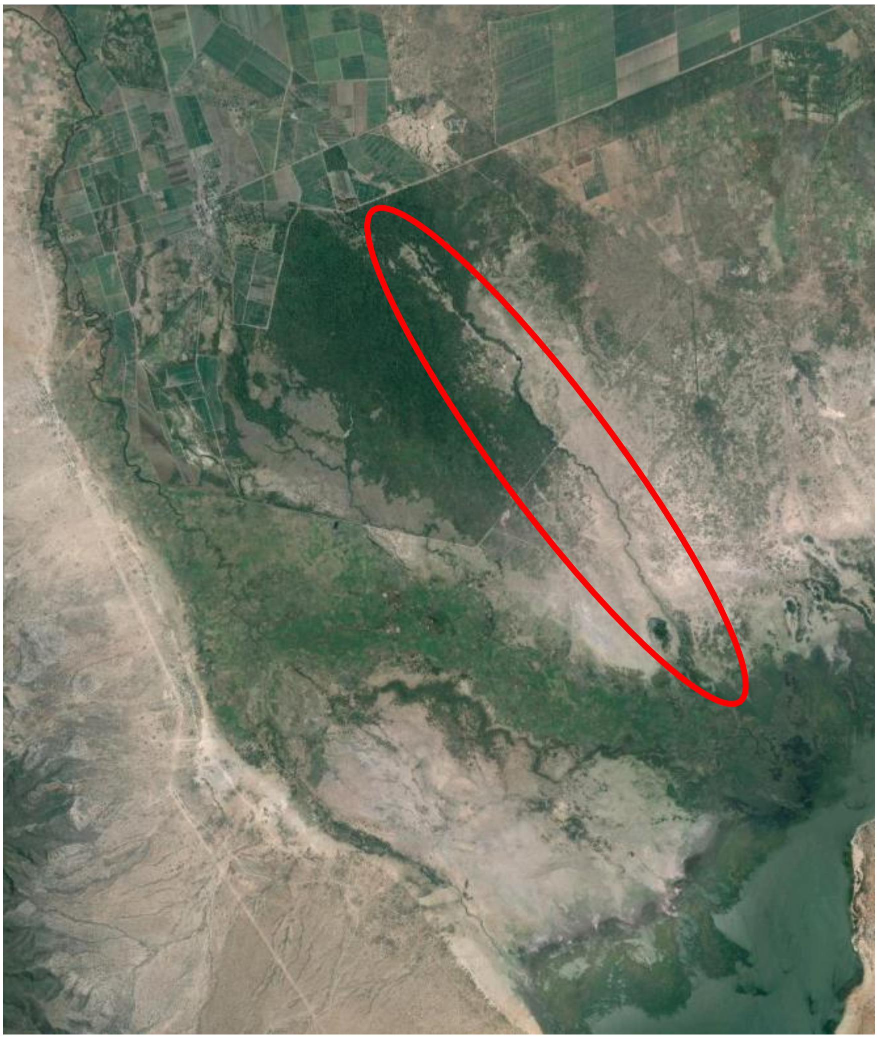


Figure 128: The Kikuletwa at the western border of the valley and the natural drain of TPC encircled. source:maps.google.com

One reason this study was conducted, was to find an explanation for the high sodium concentration in some areas at TPC. The study links the high salinity of the Kikuletwa river to the high sodium concentrations in these areas. Using these high concentrations, a past course of the Kikuletwa river is constructed, see Figure 129.

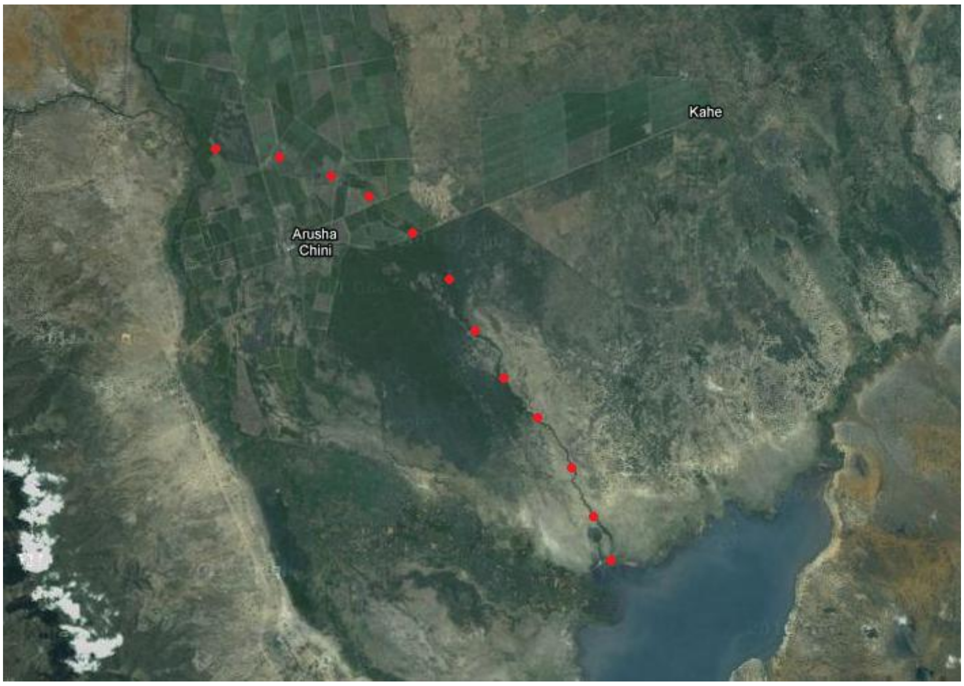


Figure 129: Possible past course of the Kikuletwa as observed on air photo [6]

The past course is constructed almost exactly over the natural drain of TPC. It is likely that the Kikuletwa river, or one of its branches, ran more eastward in the past. The river may be forced westward due to man-made interventions. If it was a branch of the river, blocking it means that the discharge is now forced through the western branch, which would miss the capacity to accommodate peak discharges. If all the discharge used to flow through the old river course, it could mean that the old river bed has a lot of unused capacity which can be used to mitigate the flooding problem in the problem area. Downstream of TPC the Kikuletwa bifurcates into the Kikuletwa and the Ronga.

B.2 History of the Ronga

During field trips, local villagers mentioned that the Ronga played a different role in the past. According to them, the Kikuletwa remained to be the largest river. This change apparently occurred not even too long ago. From interviews with village elders it became known that previous to 1991, there was no Ronga. Before 1991 the Kikuletwa South was the main river. The river was clogged throughout the past by debris and mud, which significantly decreased the discharge capacity. 1991 was an extreme flood year, and when the flood wave occurred, the Kikuletwa South was blocked too much and the force of the water created a new path: the Ronga.

When the Ronga came into existence, the area became much more appealing for farming. The fishermen and Maasai who previously lived in Lower Moshi were slowly replaced by farmers. In the beginning, the Ronga existed of one main river. Herds of hippos live in the area, which bath in the Ronga. When the hippos climb out of the river, they always use the same location. According to the villagers the hippos climbing out of the river led (and still lead) to new pathways for the river, which cause the river to develop into the braided area of Ronga North. This phenomenon is known as "Hippo Highways" [26]. There may be other reasons for the new pathways as well, such as the creation of irrigation channels.

After this development, the Kikuletwa South was no longer the main ongoing river. The Kikuletwa South partially filled up with debris. The Kikuletwa South as we know it today is dug by the villages surrounding the bifurcation point.

B.3 Development of the Ronga and the Kikuletwa

To investigate the changes of the course of the rivers, the oldest satellite images available by Google Earth are used. Some important current place marks are compared to old satellite images of the same location.

Course of the river Kikuletwa South and Ronga

From Figure 130 can be seen that the bifurcation point did not have its current form yet in 2002. Downstream of the bifurcation the Kikuletwa has the dimensions of an irrigation channel. The Kikuletwa South as we know it today, did not exist yet in 2002, see the encircled area in Figure 130. In 2002 the bifurcation point seems to be further downstream.

Figure 130: Bifurcation point. On the left Google Earth image Sep, 2013. On the right Google Earth image Apr, 2002.

In 2002, the bifurcation point was a bit further downstream, see Figure 131. The bifurcation point in 2013 is located in the top left corner of the figure. At this location the river splits up into two rivers. The western stream continues further south towards the reservoir. This river does not exist anymore, but today you can clearly see a line of trees on that exact location.

The eastern stream splits up again into a braided river towards the east and a stream towards the south east. This braided river reach is comparable to the braided reach of the Ronga River as we know it today. The other stream towards the South does not exist anymore. The image of 2013 was taken in September, during the dry season. The exact influence of the rains on the river width or creation of new streams cannot be determined.

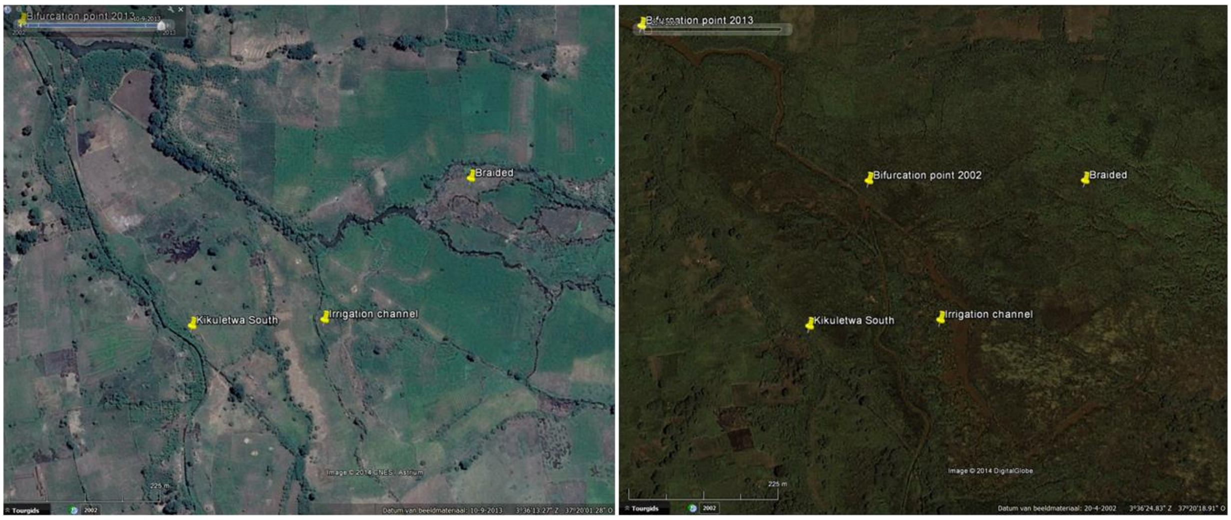


Figure 131: Downstream of bifurcation point. the left Google Earth image Sep, 2013. On the right Google Earth image Apr, 2002.

A bit further downstream of the Ronga, in the current situation the Ronga is braided and eventually joins again into one river, see Figure 132. In the satellite image of 2002, the eastern braided reach is clearly visible. The western braided reach is difficult to see, but this may be due to the poor quality of the image. Considering upstream and downstream the braided reaches are clearly visible in 2002, one may assume that the Ronga has hardly changed in 12 years time.

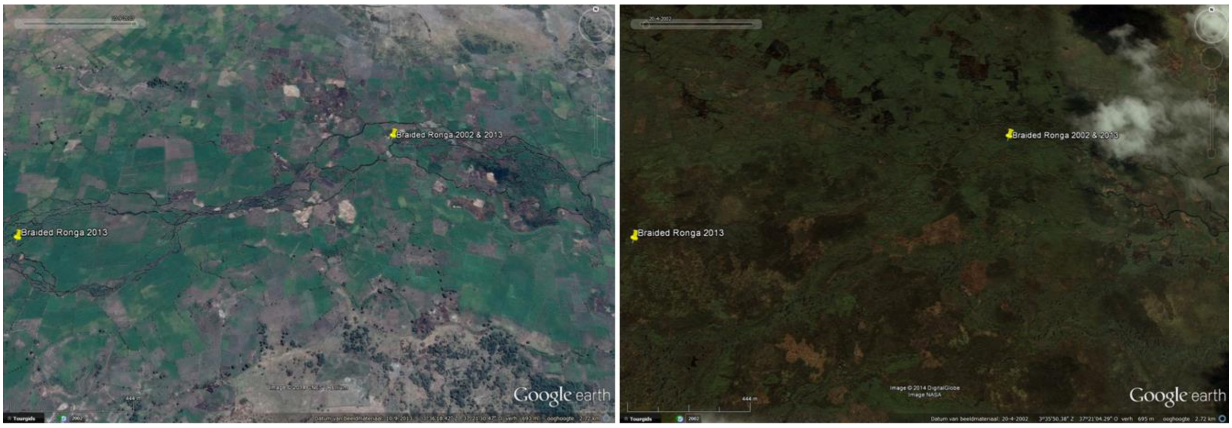


Figure 132: Ronga braided reach. On the left Google Earth image Sep, 2013. On the right Google Earth image Apr, 2002.

When comparing the reach of the Kikuletwa just upstream of the Nyumba ya Mungu reservoir, in 2001 to 2013, no changes have occurred, see Figure 133. The river going south at the bifurcation point in 2002, is probably connected to the Kikuletwa flowing into the reservoir. However, Google Earth shows a failed photograph at this location, so this is an assumption.

Overall, the location of the bifurcation point of the Kikuletwa and the Ronga has moved upstream over the years. There is no high quality satellite data available previous to 2002, therefore the only way to know that the Ronga was not a significant river in the past is by testimonials from people living in Lower Moshi.

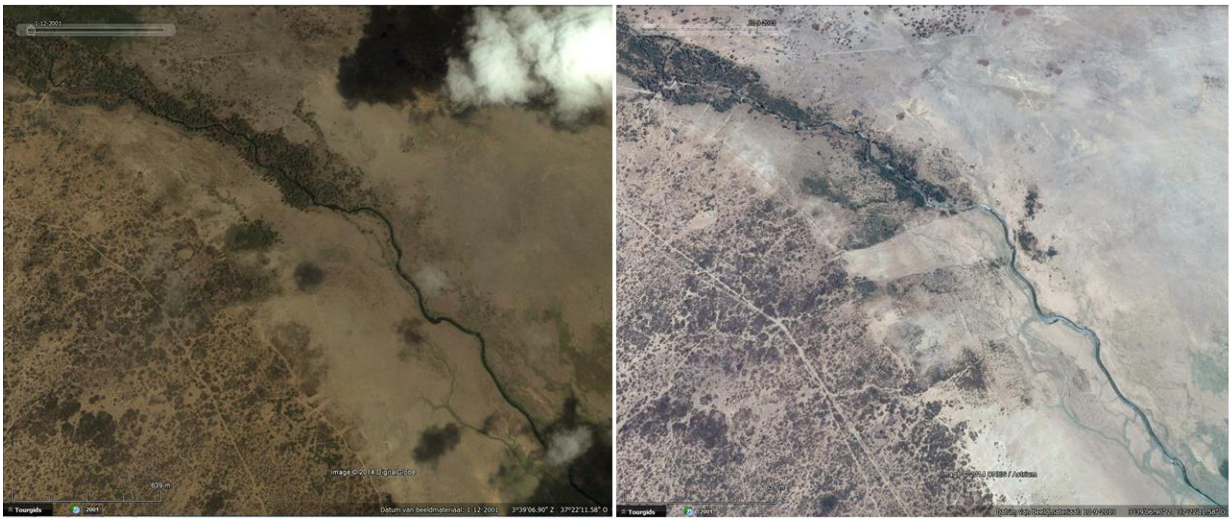


Figure 133: Kikuletwa just upstream of NyM reservoir. On the left Google Earth image Sep, 2013. On the right Google Earth image Dec, 2001.

Appendix C Rational Method Kikuletwa (S)

A Digital Elevation Map (DEM) was used to acquire a flow accumulation map, which is shown in Figure 134. In this map the catchment area that is likely to contribute to the Kikuletwa (S) is shown by a red line. The rainfall from this catchment gives a discharge that is considered separately from the discharge coming via Kikuletwa (N). The surface area of this area amounts 120 km^2. However, not all of the discharge enters the Kikuletwa (S) at the same location. The pink dot shows the entry of a tributary. From there on the river discharge of Kikuletwa (S) increases. Most of the discharge downstream of the intake point originates from the tributary. The area contributing to the tributary is identified by black lines.

The water through the tributary creates a peak flow, while the water fallen on the remaining ground directly flows (slowly) to the Kikuletwa (S). The area which does not contribute to this tributary is excluded from the following calculations. Also, the tributary most south flows into the Kikuletwa (S) just before it enters the reservoir. Therefore it thus is not in the scope of the next step of the analysis.

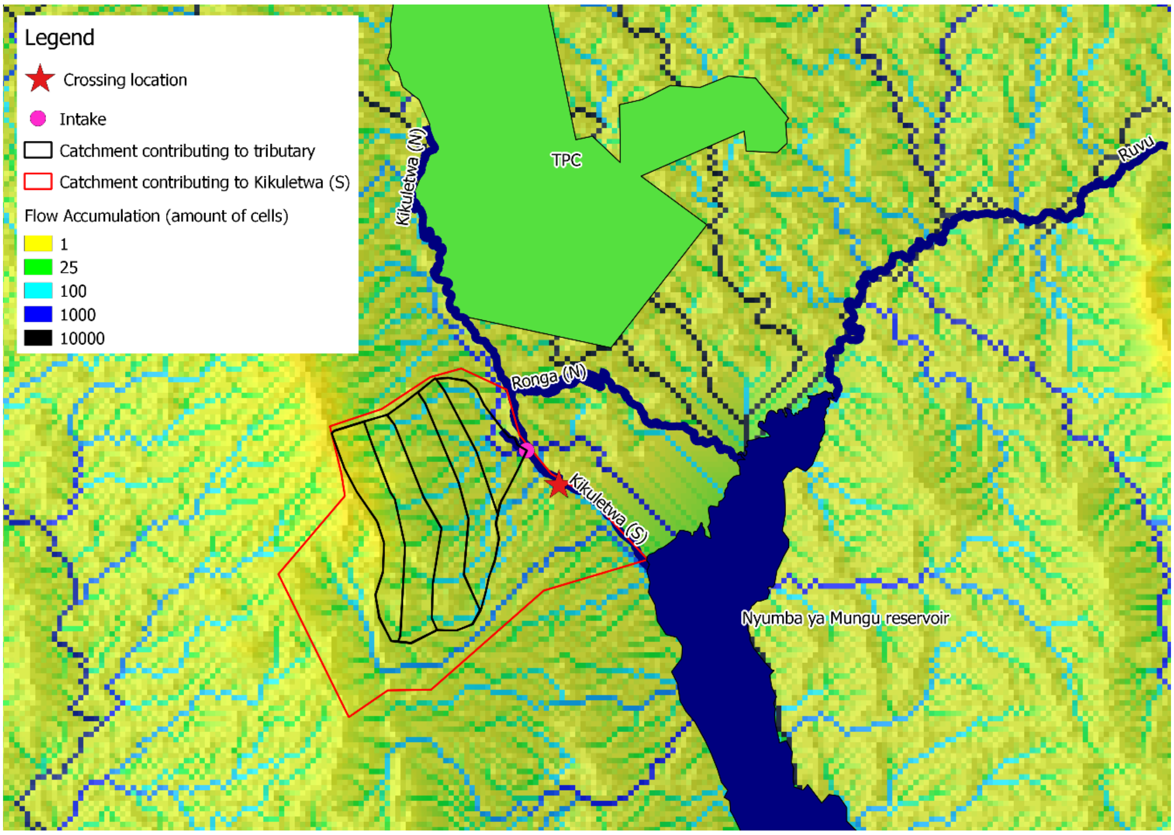


Figure 134: Contributing area western mountains on discharge Kikuletwa (S)

The catchment of the first tributary is illustrated in Figure 135 and divided into 5 subareas with an expected comparable retention time of one hour. This division has been made based on the flow accumulation map and the existing gullies that can be seen in Google Earth. The magnitude of the streams is comparable within each area and therefore the retention times can be assumed to be equal. Using the rational method [14], an approximation of the hydrograph due to rainfall can be derived.

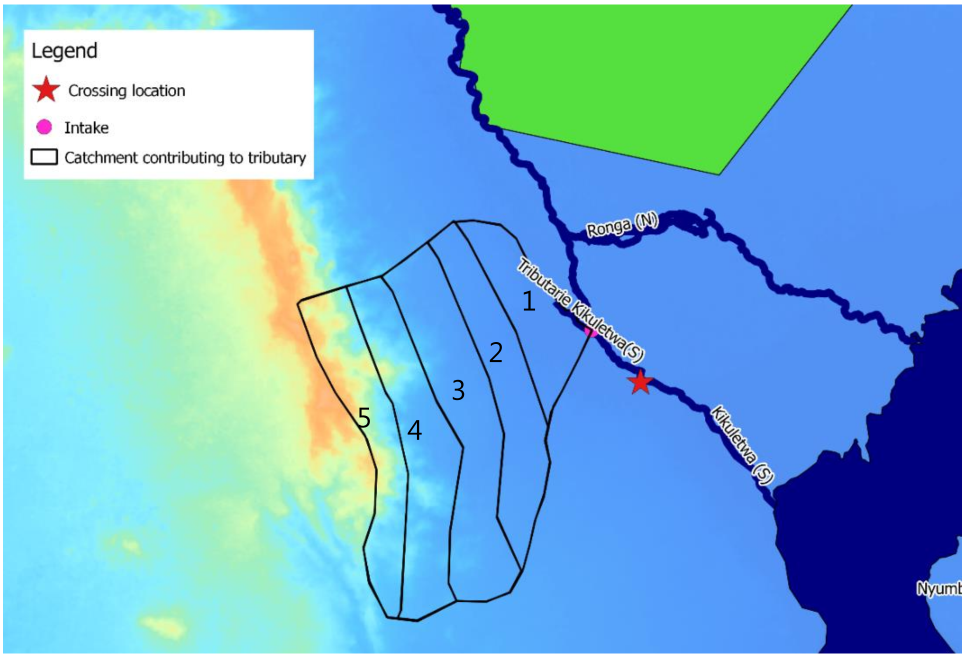


Figure 135: Contributing area and sub catchments

Surface areas of the different sub catchments are presented in Table 21. In the most downstream region, sub catchment five, the water travels maximum 4.2 kilometres. With a concentration time of one hour this results in a maximum flow velocity of 1.15 meters/second.

Table 21: Surface areas subcatchments

Subcatchment	Surface area (km2)
1	7
2	10
3	15
4	12
5	10
Total	55

The rainfall was investigated for the rainy season of 2008, according to the discharge data this was quite an extreme year. A daily rainfall of 25 mm seems common during the rainy season. Because it is expected that the rainfall after a rain event reaches the river in one day, only separate rain events are considered. This assumption is confirmed by field observations after a storm at night. During the rainy season it is expected that also the Kikuletwa (N) contributes to the discharge in the Kikuletwa (S).

The monthly rainfall at TPC in April 2008 amounted approximately 90 mm. According to [11], the rainfall at TPC is representative for the area west of the Kikuletwa (S). Only the mountainous area has more rainfall, about 30% more. The duration of the rain event is unknown and assumed to be 3 hours.

Next, the rain depth is translated to a certain rain event with an intensity that varies each hour. The intensities are presented below:

Table 22: Rainfall intensities during rain event of 26.75 mm

Time span	Rainfall intensity (mm)
$t_0 - t_1$	7
t_1-t_2	13
t_2-t_3	5

The discharge is computed for t_0 to t_8. At t_0 the rain event starts and it stops at t_3. The times in hours after the start of the rain event are presented in the table below:

Table 23: Time steps for which the discharges are computed

	Time after start rain event at t_0 in hours
t_0	0
t_1	1.0
t_2	2.0
t_3	3.0
t_4	4.0
t_5	5.0
t_6	6.0
t_7	7.0
t_8	8.0

The formula used to compute the discharge at each time step is:

$$Q_t = C * P_a * A_i$$

In which:

Q_t = Discharge at time t
C = Run-off coefficient
A_i = Contributing area
P_a = Rainfall

The run-off coefficient is determined with Budyko's empirical relation, see Figure 136.

$$\bar{E} = \bar{P}(1 - \exp\left(-\frac{\bar{E}_p}{\bar{P}}\right))$$

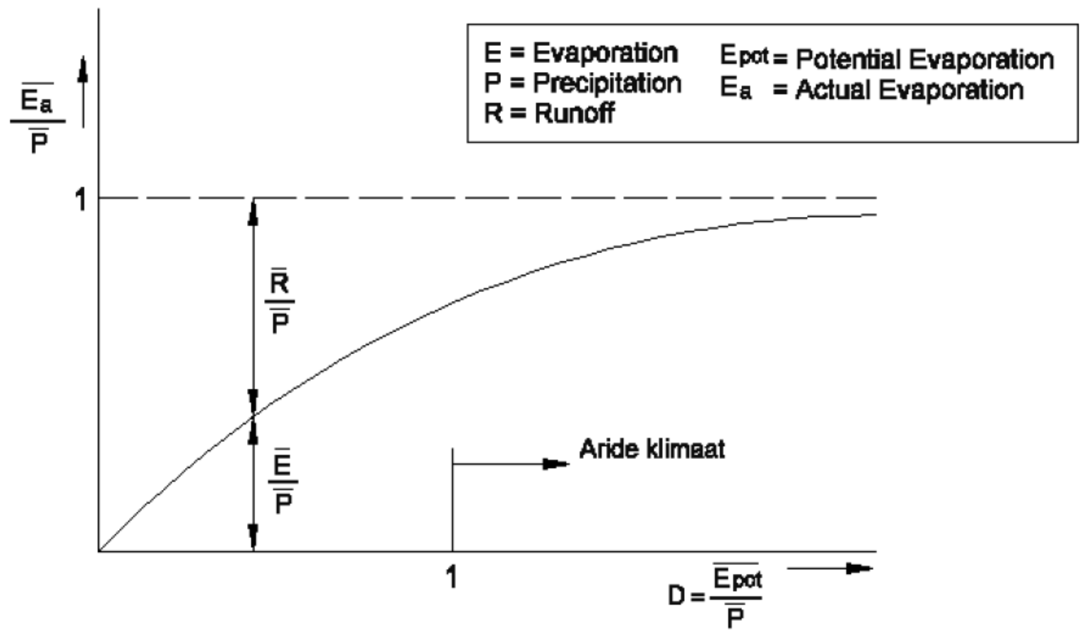


Figure 136: Budyko's curve

The higher the aridity, the more evaporation and the less run-off. To determine the evaporation rate, the mean rainfall of April 2008 is taken. It is expected that the radiation does not differ much between TPC and the contributing area. Therefore the potential evaporation measured at TPC, using a class-A evaporation pan, is assumed to be equal. Also, for the potential evaporation, the average of April 2008 is taken.

With $\overline{Epot}$ equal to 129.5 mm and monthly rainfall $\bar{P}$ equal to 92 mm (averaged over the catchment), a runoff-coefficient C (equal to $\overline{E_a}/\bar{P}$) of 0.25 was found.

The resulting discharges at the described times are presented in Figure 137.

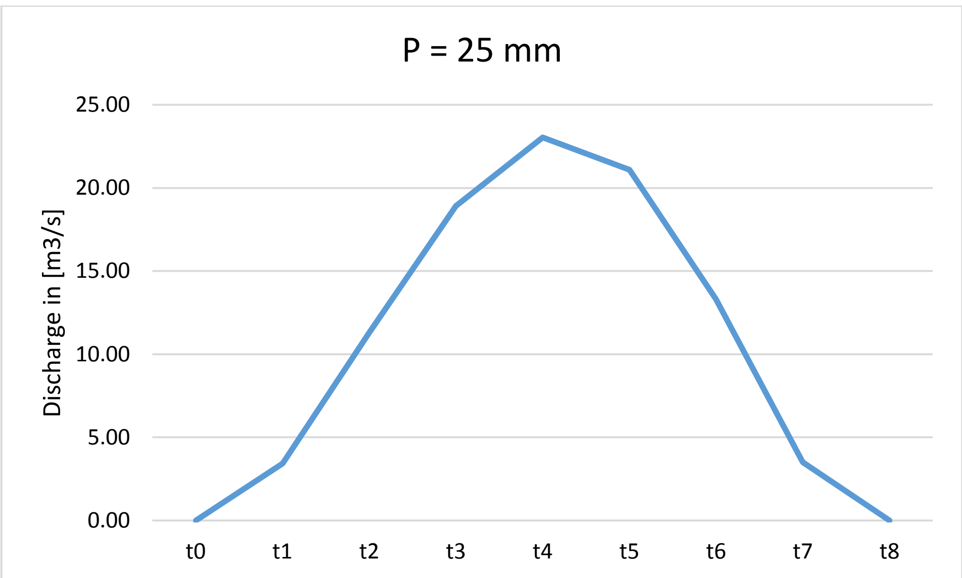


Figure 137: Hydrograph after rain event of 25mm

On March 26 in 2008 there was a rain event of 100.8 millimetres. In the records from 2000 to 2013 two more rain days with a rain depth larger than 100 millimetres were measured. With the same method this rain event has been converted to discharges. It is assumed that the duration for this rain event amounts six hours. The intensities during this event are presented in Table 24.

Table 24: Rainfall intensities during rain event of 100mm

Time span	Rainfall intensity (mm/hour)
t_0-t_1	8
t_1-t_2	13
t_2-t_3	22
t_3-t_4	40
t_4-t_5	11
t_5-t_6	6

The discharges for this specific rain event under the described assumptions are presented in Figure 138.

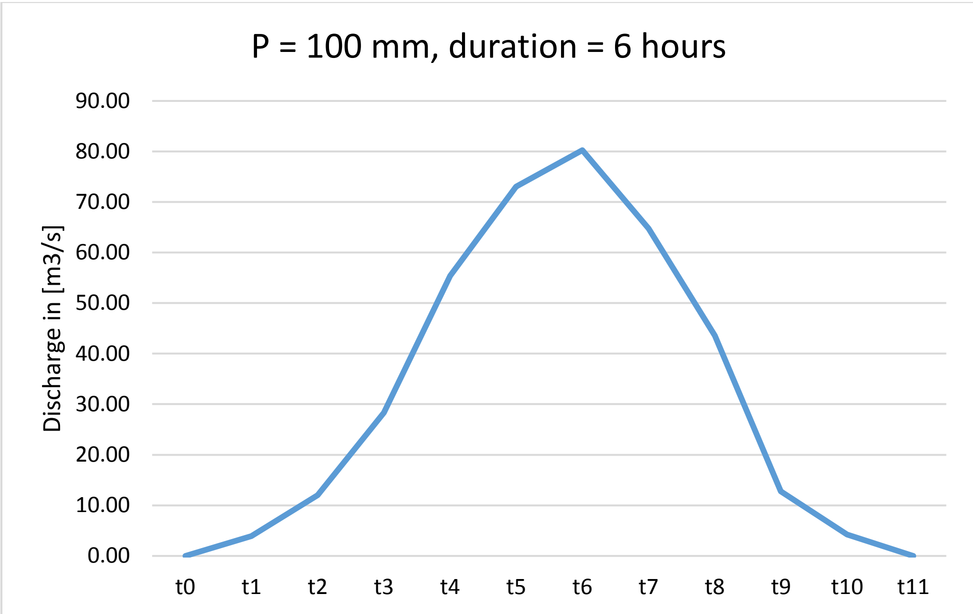


Figure 138: Hydrograph after rain event of 100mm

Appendix D Derivation of K value

In order to transform the measured surface velocities to the average velocities a K value will be used according to STOWA [27]. The values found in this hand book have been depicted in Table 25. However, the rivers analysed have a higher Manning coefficient than found in the STOWA. Therefore, the values are extrapolated in Figure 139. Notice the linear relationship between the correction factor 'K' and Manning's 'n'. Table 25 can now be extended. The result can be found in Table 26.

*Table 25: Correction factor for surface floaters[27], * for 0.5 m < hydraulic radius (R) < 2.50 m.*

N [s/m$^{1/3}$]*	K
0.029-0.037	0.78
0.021-0.028	0.84
0.017-0.022	0.87
0.014-0.019	0.89
0.012-0.016	0.90

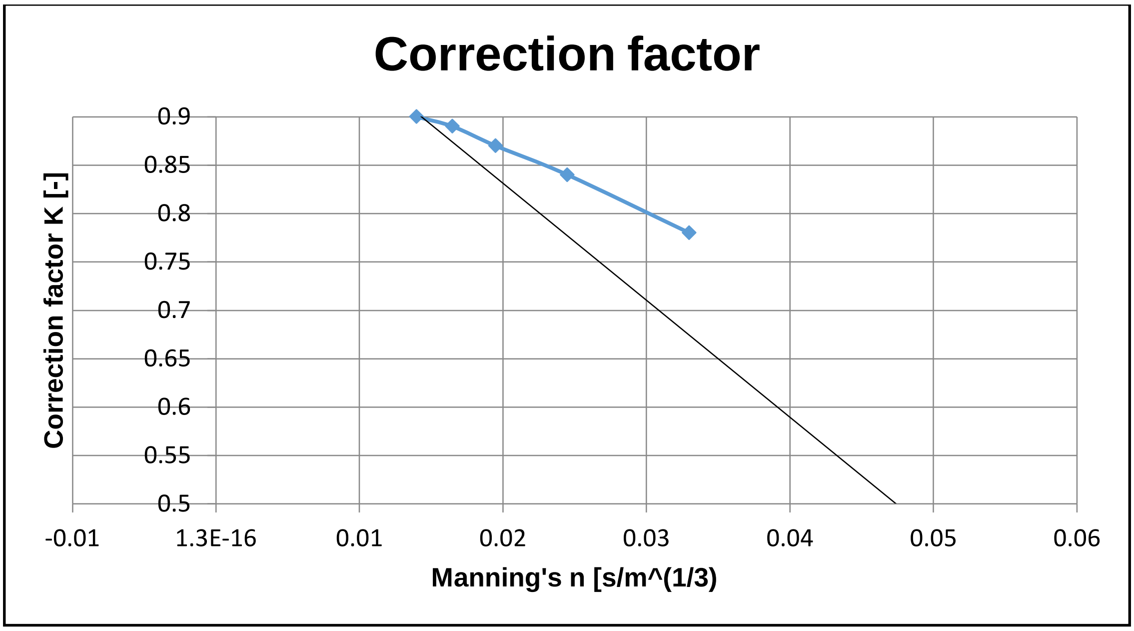


Figure 139: K-values plotted and extrapolated [27]

*Table 26: Extension of Table 25 for n-values in river system, * for 0.5 m < hydraulic radius (R) < 2.50 m.*

N [s/m$^{1/3}$]*	K
0.60	0.61
0.55	0.64
0.50	0.67
0.45	0.71
0.40	0.74

Appendix E Measured cross-sections

During the fieldtrips different cross-sections have been measured. An overview of the locations of the cross-section can be found in Figure 140.

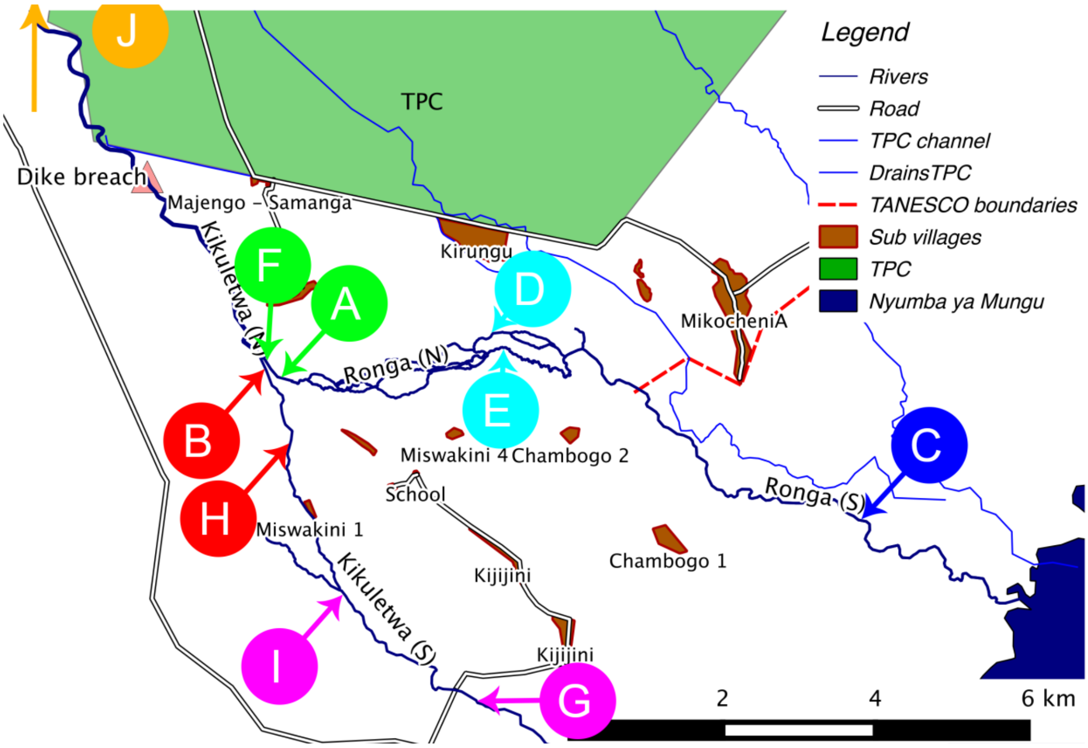


Figure 140: Measured cross-sections and their locations

Please note that in the graphs of the cross section, the water surface is at depth = 0. For every cross-section the width, the conveyance area, the hydraulic radius and the surface velocity are determined for the river at that specific moment in time. To determine the bankfull area, the area available for water level rise must be added. To determine this area the height difference between the water level and the bank is used.

E.1 Cross-section A (waypoint 37)

The cross-section shown in Figure 141 was made on 17 November 2014, see Appendix P for the report on the field work on that day. The blue line represents the measured data. The points of measurement are linearly connected.

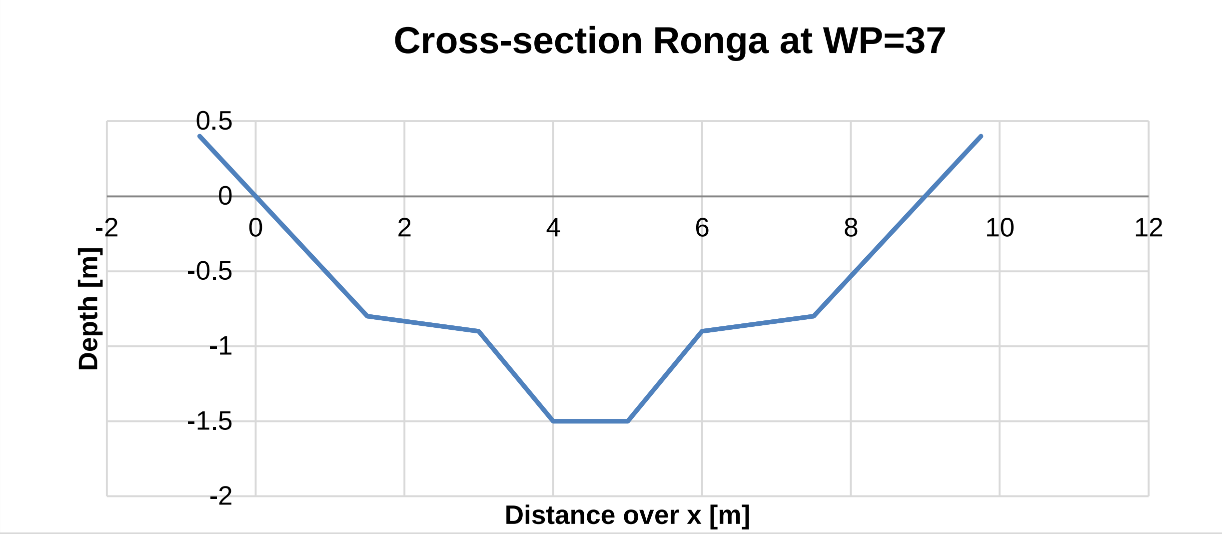


Figure 141: Cross-section at A (waypoint 037). The blue line represents the measured depth.

Table 27: Dimensions cross-section A.

Description	Symbol	Value	Dimension
Measured conveyance area:			
Width at water level	W	9	[m]
Cross-sectional area	A	7,7	[m^2]
Hydraulic radius	R	0,8	[m]
Surface velocity	$U_{surface}$	1,1	[m/s]
Bankfull area:			
Distance between banks	W_{max}	9.8	
Cross-sectional area	A_{max}	11.5	[m^2]
Hydraulic radius	R	1.07	

E.2 Cross-section B (waypoint 34)

The cross-section shown in Figure 142 was made on 17 November 2014, see Appendix P for the report on the field work on that day. The blue line represents the measured data. The points of measurement are linearly connected. At this cross-section a surface flow velocity of 0.37 m/s was measured.

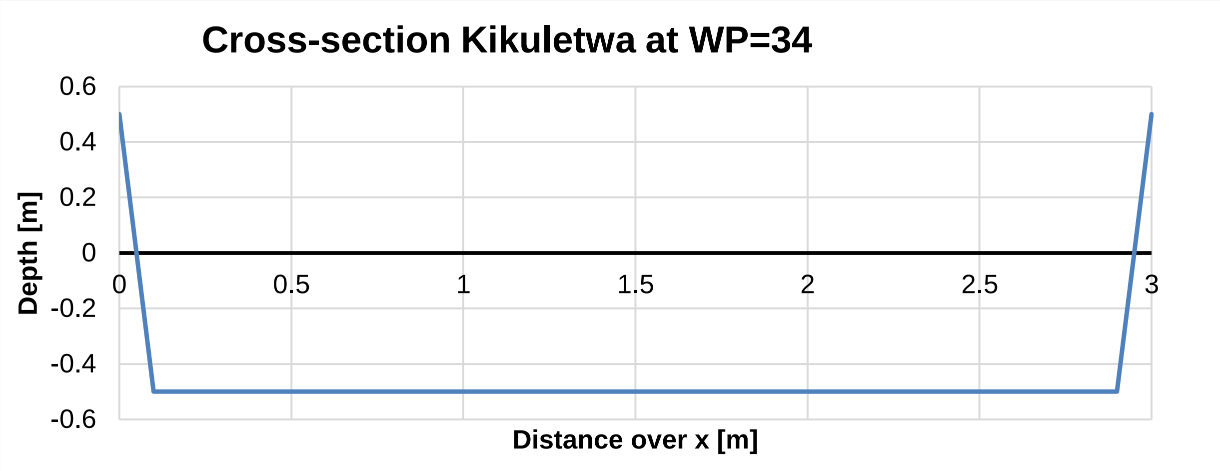


Figure 142: Cross-section at B (waypoint 034). The blue line represents the measured depth.

Table 28: Dimensions cross-section B

Description	Symbol	Value	Dimension
Measured conveyance area:			
Width at water level	W	3.0	[m]
Cross-sectional area	A	1.5	[m^2]
Hydraulic radius	R	0.375	[m]
Surface velocity	$U_{surface}$	0.4	[m/s]
Bankfull area:			
Distance between banks	W_{max}	3	[m]
Cross-sectional area	A_{max}	2.9	[m^2]
Hydraulic radius	R	0.603	[m]

E.3 Cross-section C (waypoint 646)

The cross-section shown in Figure 143 was made on 20 November 2014, see Appendix P for the report on the field work on that day. The blue line represents the measured data. The points of measurement are linearly connected. The black line is a second order polynomial trend line.

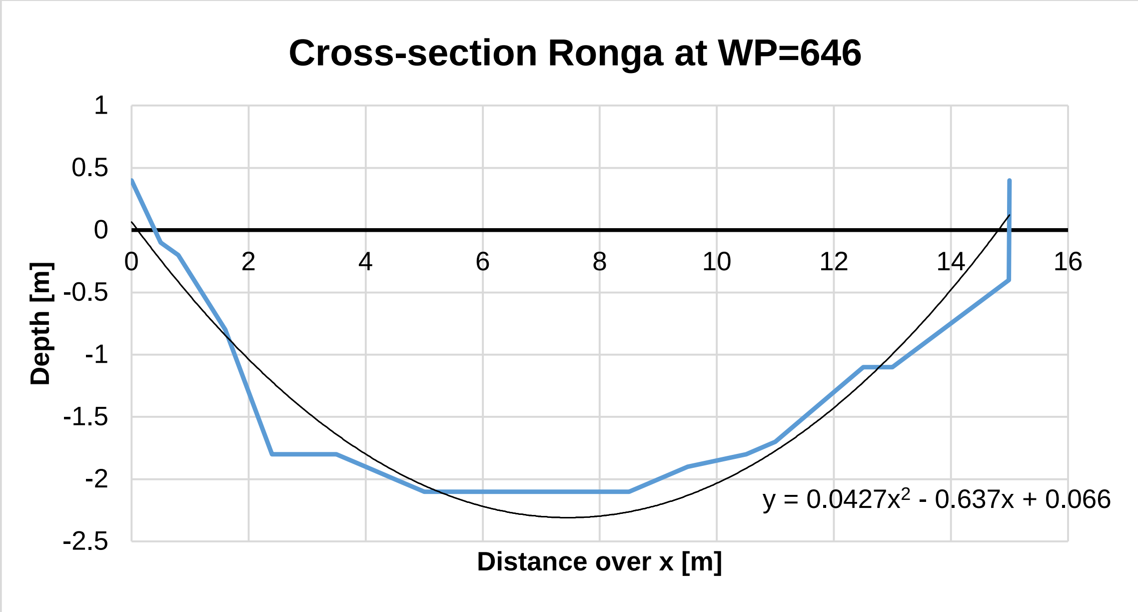


Figure 143: Cross-section at waypoint 646. The blue line represents the measured data. The black line is a trend line that approaches the measured data.

Table 29: Dimensions cross-section C

Description	Symbol	Value	Dimension
Measured conveyance area:			
Width at water level	W	15.0	[m]
Cross-sectional area	A	21.7	[m^2]
Hydraulic radius	R	0.77	[m]
Surface velocity	$U_{surface}$	1.0	[m/s]
Bankfull area:			
Distance between banks	W_{max}	15.0	[m]
Cross-sectional area	A_{max}	28.5	[m^2]
Hydraulic radius	R	1.68	[m]

E.4 Cross-section D (waypoint 053)

The cross-section shown in Figure 144 was made on 28 November 2014, see Appendix P for the report on the field work on that day. The blue line represents the measured data. The points of measurement are linearly connected.

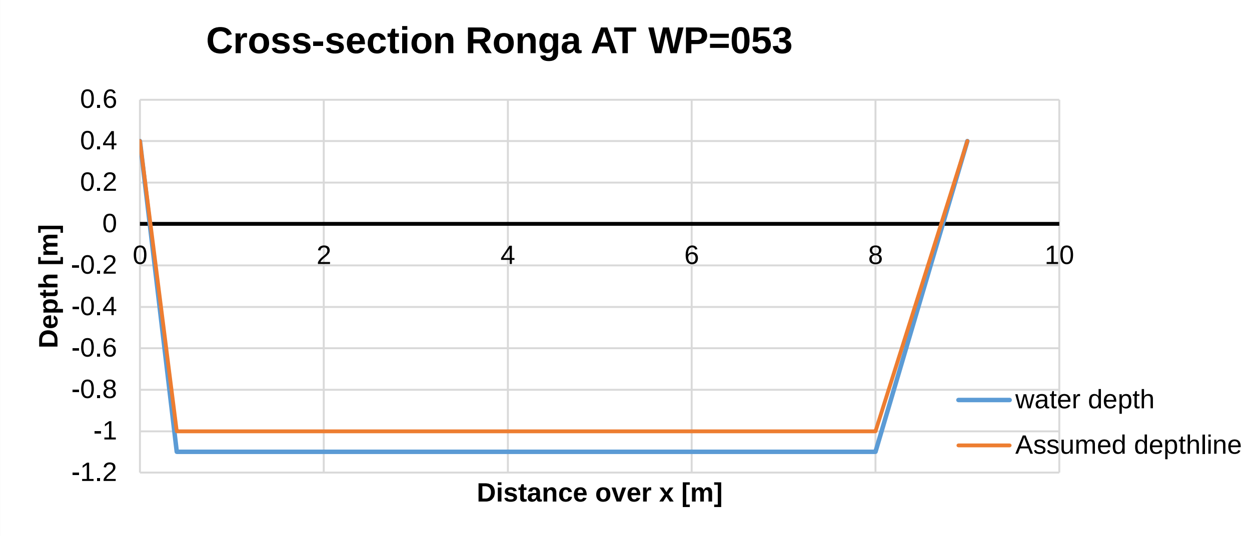


Figure 144: Cross-section at D (waypoint 053). The blue line represents the measured data.

Table 30: Dimensions cross-section D

Description	Symbol	Value	Dimension
Measured conveyance area:			
Width at water level	W	8.5	[m]
Cross-sectional area	A	8.0	[m^2]
Hydraulic radius	R	0.81	[m]
Surface velocity	$U_{surface}$	0.6	[m/s]
Bankfull area:			
Distance between banks	W_{max}	9	[m]
Cross-sectional area	A_{max}	11.9	[m^2]
Hydraulic radius	R	1.27	[m]

E.5 Cross-section E (waypoint 054)

The cross-section shown in Figure 145 was made on 28 November 2014, see Appendix P for the report on the field work on that day. The blue line represents the measured data. The points of measurement are linearly connected. The black line is second order polynomial trend line.

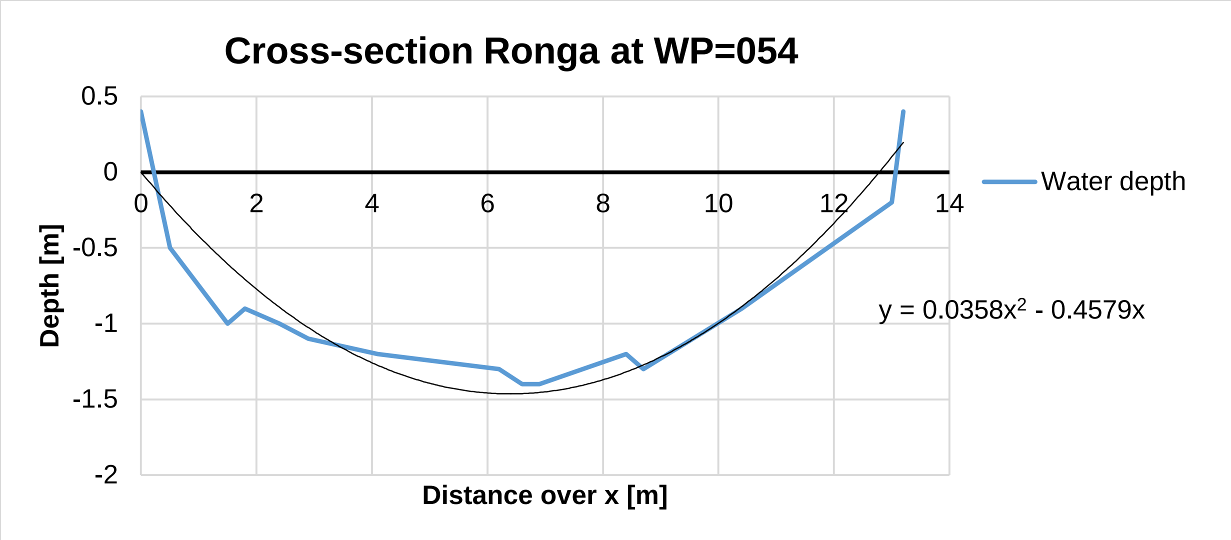


Figure 145: Cross-section at E (waypoint 054). The blue line represents the measured data. The black line is a trend line that approaches the measured data.

Table 31: Dimensions cross-section E

Description	Symbol	Value	Dimension
Measured conveyance area:			
Width at water level	W	13.0	[m]
Cross-sectional area	A	12.7	[m^2]
Hydraulic radius	R	0.9	[m]
Surface velocity	$U_{surface}$	0.5	[m/s]
Bankfull area:			
Distance between banks	W_{max}	13.0	[m]
Cross-sectional area	A_{max}	16.6	[m^2]
Hydraulic radius	R	1.30	[m]

E.6 Cross-section F (waypoint 085)

The cross-section shown in Figure 146 was made on 28 November 2014, see Appendix P for the report on the field work on that day. The blue line represents the measured data. The points of measurement are linearly connected. The black line is a fifth order polynomial trend line.

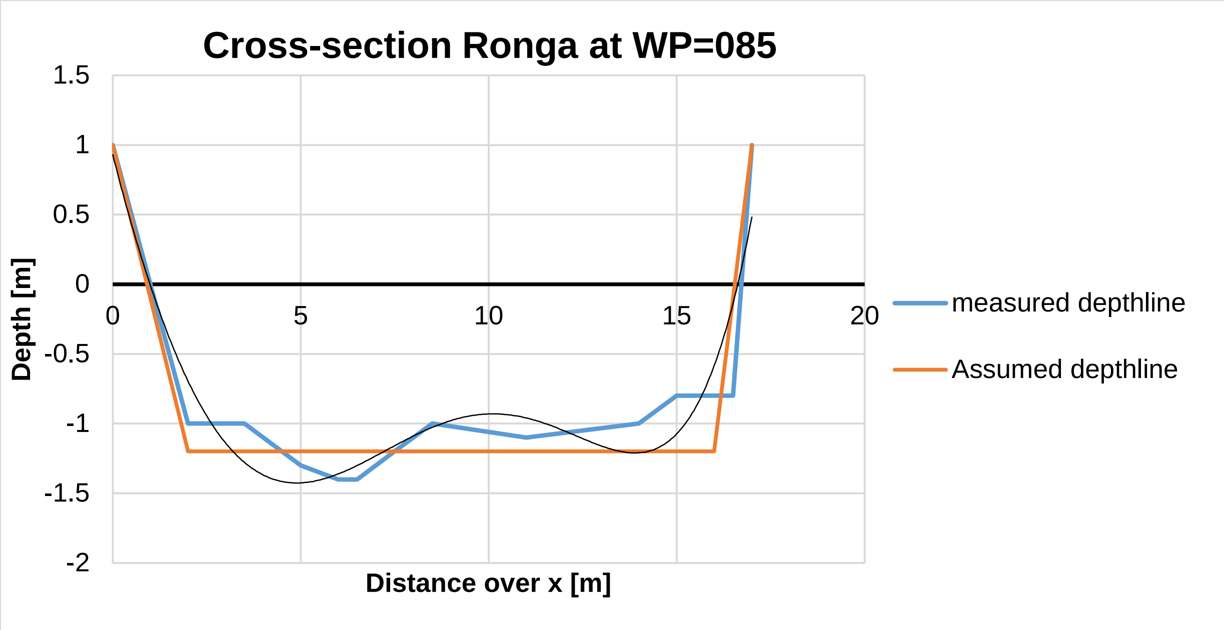


Figure 146: Cross-section at F (waypoint 085). The blue line represents the measured data. The black line is a trend line that approaches the measured data.

Table 32: Dimensions cross-section F

Description	Symbol	Value	Dimension
Measured conveyance area:			
Width at water level	W	17	[m]
Cross-sectional area	A	15.2	[m^2]
Hydraulic radius	R	0.9	[m]
Surface velocity	$U_{surface}$	0.6	[m/s]
Bankfull area:			
Distance between banks	W_{max}	17	[m]
Cross-sectional area	A_{max}	32.5	[m^2]
Hydraulic radius	R	1.68	[m]

E.7 Cross-section G (waypoint 003)

The cross-section shown in Figure 147 was made on 2 December 2014, see Appendix P for the report on the field work on that day. The blue line represents the measured data, including the adjoining banks with are depicted on the positive axis. The water level is at depth = 0. The points of measurement are linearly connected.

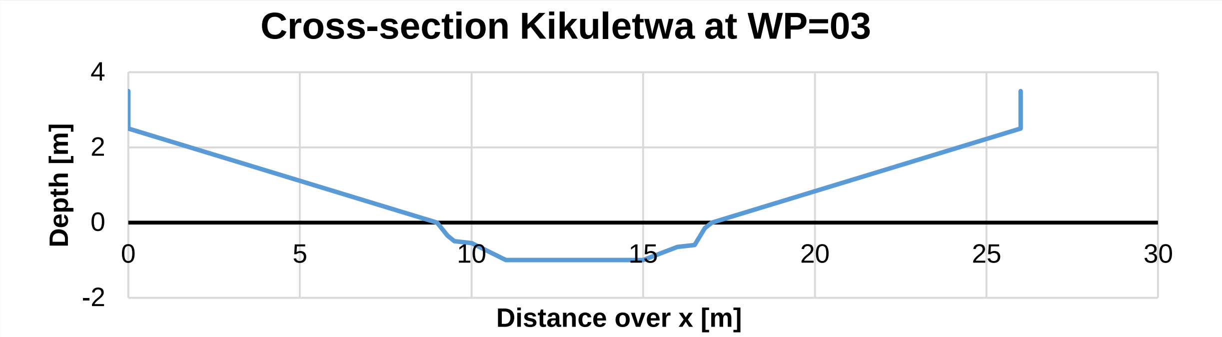


Figure 147: Cross-section at G (waypoint 003). The blue line represents the conveyance area and the flood plain. At time of measurement the water level reached up to d=0.

Table 33: Dimensions cross-section G

Description	Symbol	Value	Dimension
Measured conveyance area:			
Width at water level	W	8	[m]
Cross-sectional area	A	6.4	[m^2]
Hydraulic radius	R	0.8	[m]
Surface velocity	$U_{surface}$	0.4	[m/s]
Bankfull area:			
Distance between banks	W_{max}	27	[m]
Cross-sectional area	A_{max}	100.9	[m^2]
Hydraulic radius	R	3.44	[m]

E.8 Cross-section H (waypoint 006)

The cross-section shown in Figure 148 was made on 2 December 2014, see Appendix P for the report on the field work on that day. The blue line represents the measured data. The points of measurement are linearly connected. The heights of the adjoining banks have been incorporated as well.

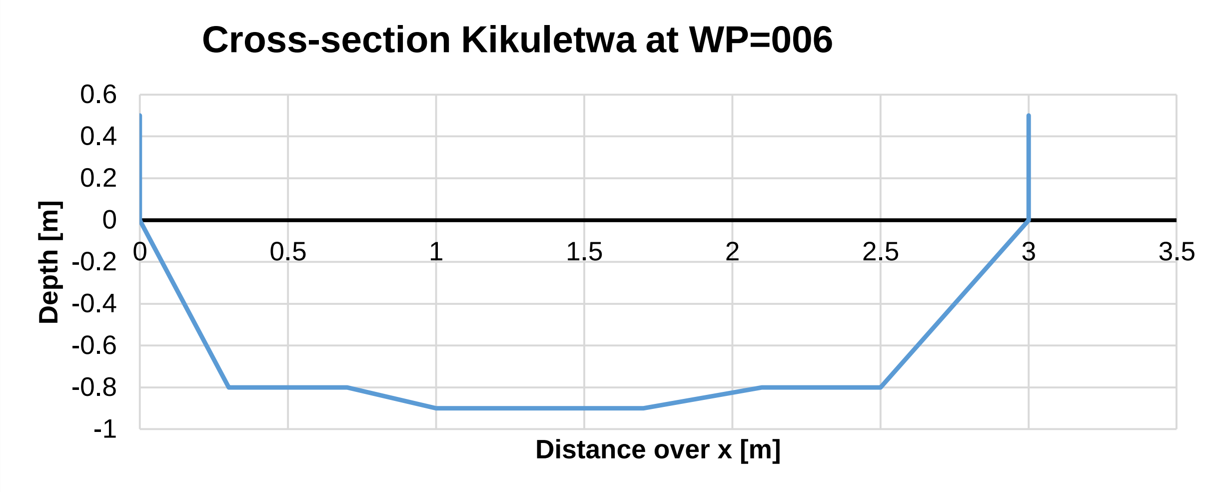


Figure 148: Cross-section at H (waypoint 006). The blue line represents the measured data.

Table 34: Dimensions cross-section H

Description	Symbol	Value	Dimension
Measured conveyance area:			
Width at water level	W	3	[m]
Cross-sectional area	A	2.2	[m^2]
Hydraulic radius	R	0.6	[m]
Surface velocity	$U_{surface}$	0.4	[m/s]
Bankfull area:			
Distance between banks	W_{max}	3	[m]
Cross-sectional area	A_{max}	3.7	[m^2]
Hydraulic radius	R	0.79	[m]

E.9 Cross-section I (waypoint 020)

The cross-section shown in Figure 149 was made on 2 December 2014, see Appendix P for the report on the field work on that day. The blue line represents the measured data. The points of measurement are linearly connected.

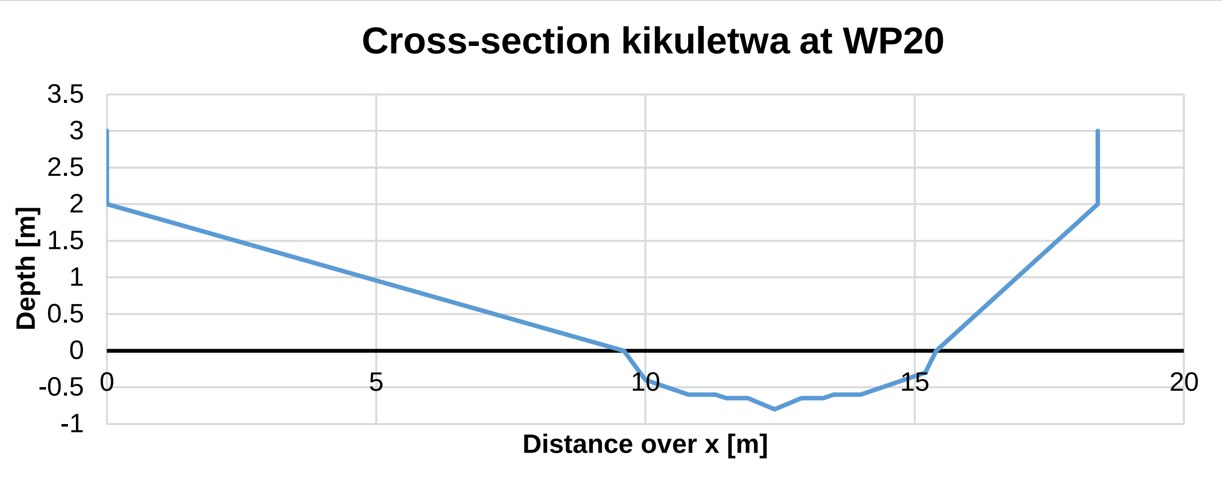


Figure 149: Cross-section at I (waypoint020). The blue line represents the measured data.

Table 35: Dimensions cross-section I

Description	Symbol	Value	Dimension
Measured conveyance area:			
Width at water level	W	5.8	[m]
Cross-sectional area	A	3.1	[m^2]
Hydraulic radius	R	1.0	[m]
Surface velocity	$U_{surface}$	0.3	[m/s]
Bankfull area:			
Distance between banks	W_{max}	18	[m]
Cross-sectional area	A_{max}	45.3	[m^2]
Hydraulic radius	R	2.64	[m]

E.10 Cross-section J (waypoint014 of 14-11 field report)

The cross-section shown in Figure 150 was made on 4 December 2014 by students or the university of Dar Es Salaam, see Appendix P for the report on the field work on that day. The blue line represents the measured data. The points of measurement are linearly connected.

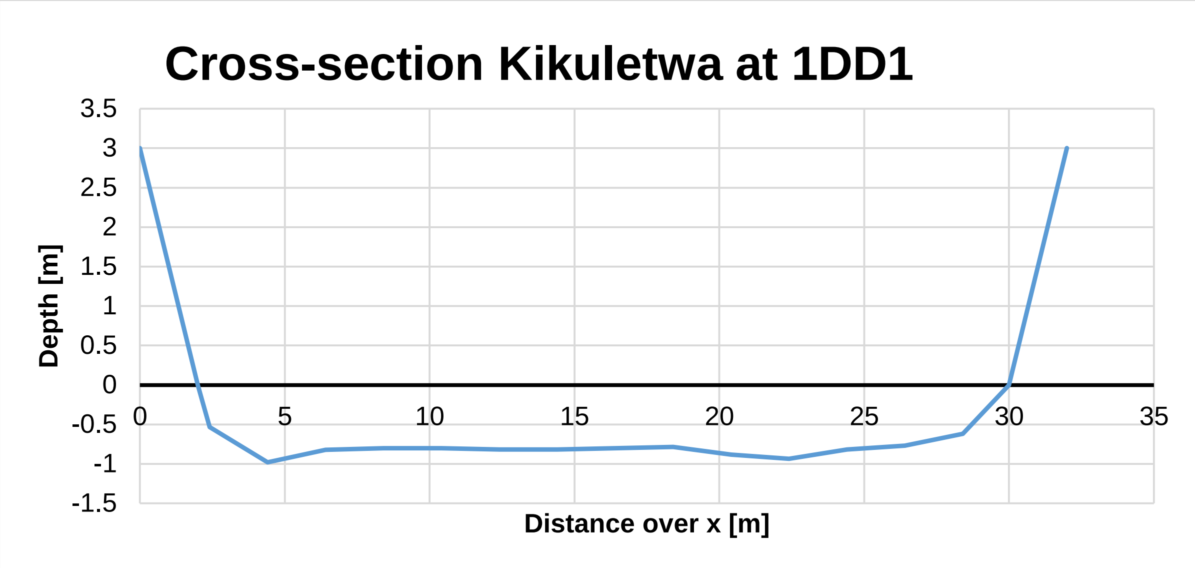


Figure 150: Cross-section at J (1DD1 gauging station). The blue line represents the measured data

Table 36: Dimensions cross-section J

Description	Symbol	Value	Dimension
Measured conveyance area:			
Width at water level	W	28	[m]
Cross-sectional area	A	27.7	[m^2]
Hydraulic radius	R	1.0	[m]
Surface velocity	$U_{surface}$	1.4	[m/s]
Bankfull area:			
Distance between banks	W_{max}	32	[m]
Cross-sectional area	A_{max}	111.7	[m^2]
Hydraulic radius	R	3.13	[m]

Appendix F DISCHARGE PER SECTION

Based on the cross-sections measured, the river section is divided into six sections, as can be seen in Figure 151. For each section, the velocity is determined based on the measured velocity (Appendix X) and on the velocity according to the Manning formula. With the cross-sections as determined in Appendix E those velocities can be translated to discharges.

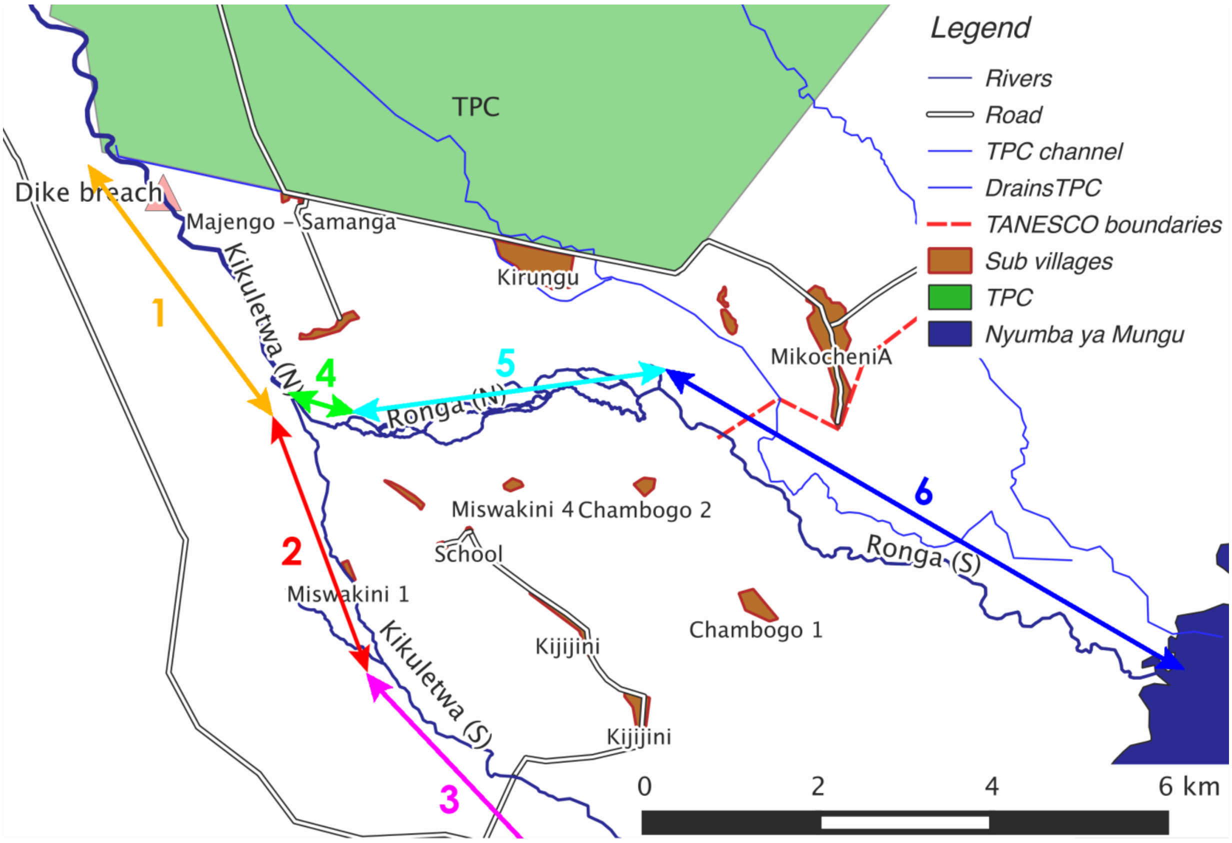


Figure 151: River sections

F.1 Discharge calculation with manning's method

For uniform flow in natural river beds several relations can be used for known water depths. One of them is the velocity calculation of Strickler Manning:

$$U_{manning} = \frac{R^{\frac{2}{3}} i_b^{\frac{1}{2}}}{n}$$

With:

$$R = \frac{A}{P}$$

In which:

R: Hydraulic Radius
A: Cross sectional area
P: Wet Perimeter
i_b: Bottom gradient
n: Strickler-Manning roughness coefficient

The bed slope has been determined using Google Earth [12], see Appendix H. Chow's values for Manning's coefficients were used as guideline to determine these coefficients [28]. A distinction has been made between stretch 3 and all other stretches because there is less vegetation in stretch 3.

Manning's velocity $U_{Manning}$ is the mean velocity of the river cross-section. Therefore it has to be multiplied by the cross-section to derive the discharge:

$$Q_{manning} = U_{Manning} * A$$

F.1.1 Maximum discharge capacity

Strickler-Manning's formula can also be used to determine the maximum discharge capacity. The same formula is used, only the cross-section is replaced by the bankfull area in the waterway. This means an increase in the cross-sectional area and an increase in the perimeter. When a depth-profile was determined in a river, also the height of the banks was measured. With these parameters the maximum cross-sectional area and corresponding perimeter are calculated.

F.2 Discharge calculation using velocity area method

During fieldwork on most locations also the velocity has been measured. By using a float the travel time over a certain distance is measured to derive the surface velocity. Mostly the velocities were measured in the middle of the river. It is assumed that the flow velocity is here at its maximum.

At the banks there will be more friction and the flow velocities will thus be lower near the banks. This has been compensated using a correction factor [29] as illustrated in Figure 152. It can be seen that when the width of the river is large compared to the depth, the influence of the banks will be lower. For each cross-section the width has been divided into parts of 1.0 meter. For each of those sections the mean velocity is determined according to the ratio of width and river depth, and the distance from the inner bank compared to the total width.

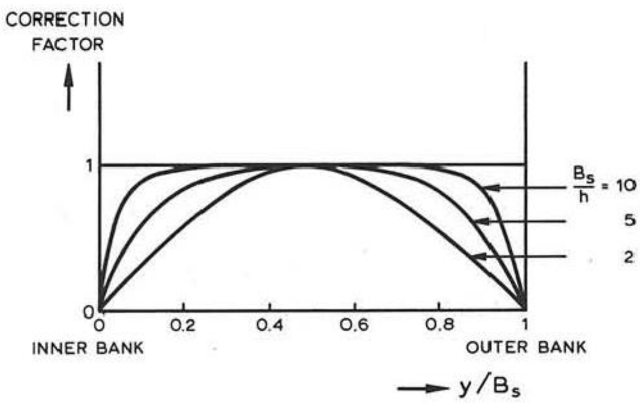


Figure 152: Correction factor for the velocities distributed among the width [29]

After correcting the velocity over the width also a correction is needed for the depth. The correction factor for this is determined in Appendix D. Each of the above parts will be multiplied by the same K-value. Afterwards the normative flow velocities for the different parts have been derived. By multiplying this with the surface area of that part the discharge can be found [24]:

$$Q = \sum(A_i * v_i)$$

F.3 Kikuletwa (N)

F.3.1 Stretch 1: Cross-section at 1DD1 measuring station

Table 37Table 37 summarises the properties of Kikuletwa (N) at 1DD1. These properties have been determined based on measurements made by a group of students of the University of Dar es Salam. Because they measured the flow velocity at a depth of 0.4 times the depth we have to divide by the k-value to derive the surface velocity.

Table 37: Dimensions and discharges of stretch 1

Description	Symbol	Value	Dimension
Measured conveyance area:			
Width	W	28	[m]
Cross-sectional area	A	24.1	[m^2]
Hydraulic radius	R	0.84	[m]
Bed slope	i_b	0.0011	[-]
Manning coefficient	n	0.05	[-]
Mean velocity (Manning)	$U_{Manning}$	0.59	[m/s]
Discharge (Manning)	$Q_{Manning}$	14.3	[m3/s]
Surface velocity (Measured)	$U_{Surface}$	1.4	[m/s]
Discharge (Measured)	$Q_{Measured}$	20.0	[m3/s]
Maximum conveyance area:			
Distance between banks	W_{max}	32	[m]
Cross-sectional area	A_{max}	111.7	[m^2]
Hydraulic radius	R	3.13	[m]
Maximum discharge	Q_{Max}	159	[m3/s]

F.4 Kikuletwa (S)

The Kikuletwa (S) exists of a small river bed and a large river bed more downstream. The small river bed only discharges from the Kikuletwa (N) and the larger bed discharges also run-off from the mountains. Therefore both are distinguished in this section.

F.4.1 Stretch 2: Small river bed

Table 38 summarises the properties of the small river bed, the most upstream part of Kikuletwa(S). These properties have been determined based on observations in the field, mainly the measurements done at WP34.

Table 38: Dimensions and discharges of stretch 2

Description	Symbol	Value	Dimension
Measured conveyance area:			
Width	W	3.0	[m]
Cross-sectional area	A	1.5	[m^2]
Hydraulic radius	R	0.38	[m]
Bed slope	i_b	0.0016	[-]
Manning coefficient	n	0.05	[-]
Mean velocity (Manning)	$U_{Manning}$	0.42	[m/s]
Discharge (Manning)	$Q_{Manning}$	0.62	[m3/s]
Surface velocity (Measured)	$U_{Surface}$	0.38	[m/s]
Discharge (Measured)	$Q_{Measured}$	0.28	[m3/s]
Maximum conveyance area:			
Distance between banks	W_{max}	3	[m]
Cross-sectional area	A_{max}	2.9	[m^2]
Hydraulic radius	R	0.603	[m]
Maximum discharge	Q_{Max}	1.7	[m3/s]

F.4.2 Stretch 3: Large river bed

Table 39 summarises the properties of the large river bed, the most downstream part of Kikuletwa(S). These properties have been determined based on observations in the field, mainly the measurements done at WP03.

Table 39: Dimensions and discharges of stretch 3

Description	Symbol	Value	Dimension
Measured conveyance area:			
Width	W	8	[m]
Cross-sectional area	A	6.4	[m^2]
Hydraulic radius	R	0.76	[m]
Bed slope	i_b	0.0016	[-]
Manning coefficient	n	0.04	[-]
Mean velocity (Manning)	$U_{Manning}$	0.83	[m/s]
Discharge (Manning)	$Q_{Manning}$	5.32	[m3/s]
Surface velocity (Measured)	$U_{Surface}$	0.38	[m/s]
Discharge (Measured)	$Q_{Measured}$	3.87	[m3/s]
Maximum conveyance area:			
Distance between banks	W_{max}	8	[m]
Cross-sectional area	A_{max}	100.9	[m^2]
Hydraulic radius	R	3.44	[m]
Maximum discharge	Q_{Max}	230	[m3/s]

F.5 Ronga (N)

F.5.1 Stretch 4: Before braiding

Table 40 summarises the properties of the Ronga River just after the bifurcation and before it starts braiding. These properties have been determined based on observations in the field, mainly the measurements done at WP85.

Table 40: Dimensions and discharges of stretch 4

Description	Symbol	Value	Dimension
Measured conveyance area:			
Width	W	17	[m]
Cross-sectional area	A	15.1	[m^2]
Hydraulic radius	R	0.87	[m]
Bed slope	i_b	0.0014	[-]
Manning coefficient	n	0.05	[-]
Mean velocity (Manning)	$U_{Manning}$	0.68	[m/s]
Discharge (Manning)	$Q_{Manning}$	10.3	[m3/s]
Surface velocity (Measured)	$U_{Surface}$	0.8	[m/s]
Discharge (Measured)	$Q_{Measured}$	5.6	[m3/s]
Maximum conveyance area:			
Distance between banks	W_{max}	17	[m]
Cross-sectional area	A_{max}	32.5	[m^2]
Hydraulic radius	R	1.68	[m]
Maximum discharge	Q_{Max}	34.4	[m3/s]

F.5.2 Stretch 5: Branches

Table 41 and Table 42 summarise the properties of the Ronga River in the braiding part at the point where the Ronga exists of two branches. These properties have been determined based on observations and measurements in the field at WP053 and WP054.

Branch 1:

Table 41: Dimensions and discharges of stretch 5, northern branch

Description	Symbol	Value	Dimension
Measured conveyance area:			
Width	W	9	[m]
Cross-sectional area	A	8.0	[m^2]
Hydraulic radius	R	0.81	[m]
Bed slope	i_b	0.0014	[-]
Manning coefficient	n	0.05	[-]
Mean velocity (Manning)	$U_{Manning}$	0.65	[m/s]
Discharge (Manning)	$Q_{Manning}$	5.22	[m3/s]
Surface velocity (Measured)	$U_{Surface}$	0.6	[m/s]
Discharge (Measured)	$Q_{Measured}$	2.0	[m3/s]
Maximum conveyance area:			
Distance between banks	W_{max}	9	[m]
Cross-sectional area	A_{max}	11.9	[m^2]
Hydraulic radius	R	1.27	[m]
Maximum discharge	Q_{Max}	10.2	[m3/s]

Branch 2:

Table 42: Dimensions and discharges of stretch 5, southern branch

Description	Symbol	Value	Dimension
Measured conveyance area:			
Width	W	13	[m]
Cross-sectional area	A	12.7	[m^2]
Hydraulic radius	R	0.95	[m]
Bed slope	i_b	0.0014	[-]
Manning coefficient	n	0.05	[-]
Mean velocity (Manning)	$U_{Manning}$	0.72	[m/s]
Discharge (Manning)	$Q_{Manning}$	9.17	[m3/s]
Surface velocity (Measured)	$U_{Surface}$	0.50	[m/s]
Discharge (Measured)	$Q_{Measured}$	3.16	[m3/s]
Maximum conveyance area:			
Distance between banks	W_{max}	13.0	[m]
Cross-sectional area	A_{max}	16.6	[m^2]
Hydraulic radius	R	1.30	[m]
Maximum discharge	Q_{Max}	16.0	[m3/s]

F.6 Ronga (S)

F.6.1 Stretch 6: Cross-section South of Mikocheni Kubwa

Table 43 summarises the properties of Ronga (S). These properties have been determined based on observations in the field, mainly the measurements done at WP646.

Table 43: Dimensions and discharges of stretch 6

Description	Symbol	Value	Dimension
Measured conveyance area:			
Width	W	15	[m]
Cross-sectional area	A	21.7	[m^2]
Hydraulic radius	R	0.77	[m]
Bed slope	i_b	0.0011	[-]
Manning coefficient	n	0.05	[-]
Mean velocity (Manning)	$U_{Manning}$	0.56	[m/s]
Discharge (Manning)	$Q_{Manning}$	12.1	[m3/s]
Surface velocity (Measured)	$U_{Surface}$	1.0	[m/s]
Discharge (Measured)	$Q_{Measured}$	14.0	[m3/s]
Maximum conveyance area:			
Distance between banks	W_{max}	15.0	[m]
Cross-sectional area	A_{max}	28.5	[m^2]
Hydraulic radius	R	1.68	[m]
Maximum discharge	Q_{Max}	26.7	[m3/s]

F.7 Overview

Stretch	Length [km]	Description	Discharge according to Manning [m3/s]	Discharge according to measured flow velocity [m3/s]	Maximum Discharge Capacity (Manning) [m3/s]
1	4.45	Kikuletwa (N)	14.3	20.0	159
2	3.45	Kikuletwa (S); small river bed	0.62	0.28	1.7
3	6.20	Kikuletwa (S); large river bed	5.32	3.87	230
4	0.8	Ronga (N); before braiding	10.3	5.6	34.4
5	5.65	Ronga (N); braided (north/south)	5.22 / 9.12	2.0 / 3.16	10.2/16.0
6	5.70	Ronga (S)	12.1	14.0	26.7

Appendix G DEM RESERVOIR FLOOD EXTENT

A study was conducted by the use of a Digital Elevation Map (DEM) [4] to what horizontal extent the reservoir floods would reach when this vertical reservoir level is reached. The DEM was loaded in to a Geographical Information System (GIS) called QGIS. Evaluating the DEM, different contour plots where derived for water levels between 682 and 689 m.a.s.l. In Figure 153 the water extent is shown in case the water level in the reservoir is at 689 m.a.s.l.

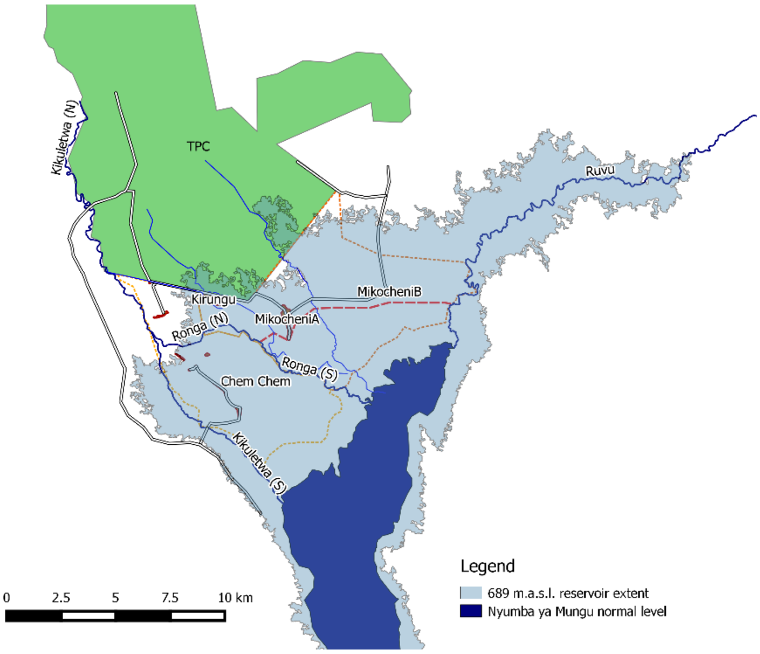


Figure 153: DEM determination of reservoir extent at 689 m.a.s.l.

According to the DEM the water would rise as high as the TPC forest and far beyond Mikocheni B, Mikocheni A, Chem Chem and Kirungu. While reservoir level records show that occasionally the level of the reservoir had this height, nobody experienced any floods in Kirungu or at TPC due to the reservoir. Also, when comparing true water area found by earlier research and the area given by the DEM in QGIS, the difference is more than 80 km^2. Thus it can be stated that the DEM gives unrealistic values. This probably is due to an inaccurate resolution of the DEM. Therefore, other sources were used to determine the extent of an extreme reservoir level.

Appendix H BACKWATER CURVE CALCULATIONS

In this appendix the backwater calculations are explained. It must be stated that these calculations are purely to get an insight in the consequences of the reservoir water level on the river. They are not accurate enough to draw exact conclusions. However, they do provide insight in the sensitivity of characteristics, which can be used as background for future solutions.

The backwater curve is the result of a water level downstream (for example in a lake or at the sea) that is not in accordance with the natural, equilibrium depth of the waterway upstream. This has been visualised in Figure 154 for the Nyumba ya Mungu reservoir and the Ronga or the Kikuletwa.

If the Nyumba ya Mungu reservoir its water level is lower at the mouth of the river (in purple, h_{low}), then for a certain distance upstream the water level will be lower than the equilibrium depth h_{eq}. This also works the other way around, for a water level in the waterway, at the mouth of the river, which is higher than the equilibrium depth the water level is higher upstream. How fast a waterway returns to its equilibrium depth upstream depends on the characteristics of the waterway. If this takes a long distance, the water level near the villages just upstream of the lake (Mikocheni Kubwa, Chem Chem, etc.) is more distorted (case B in Figure 154) than if the distance to equilibrium is short (case A). A measure for this distance is the half-length.

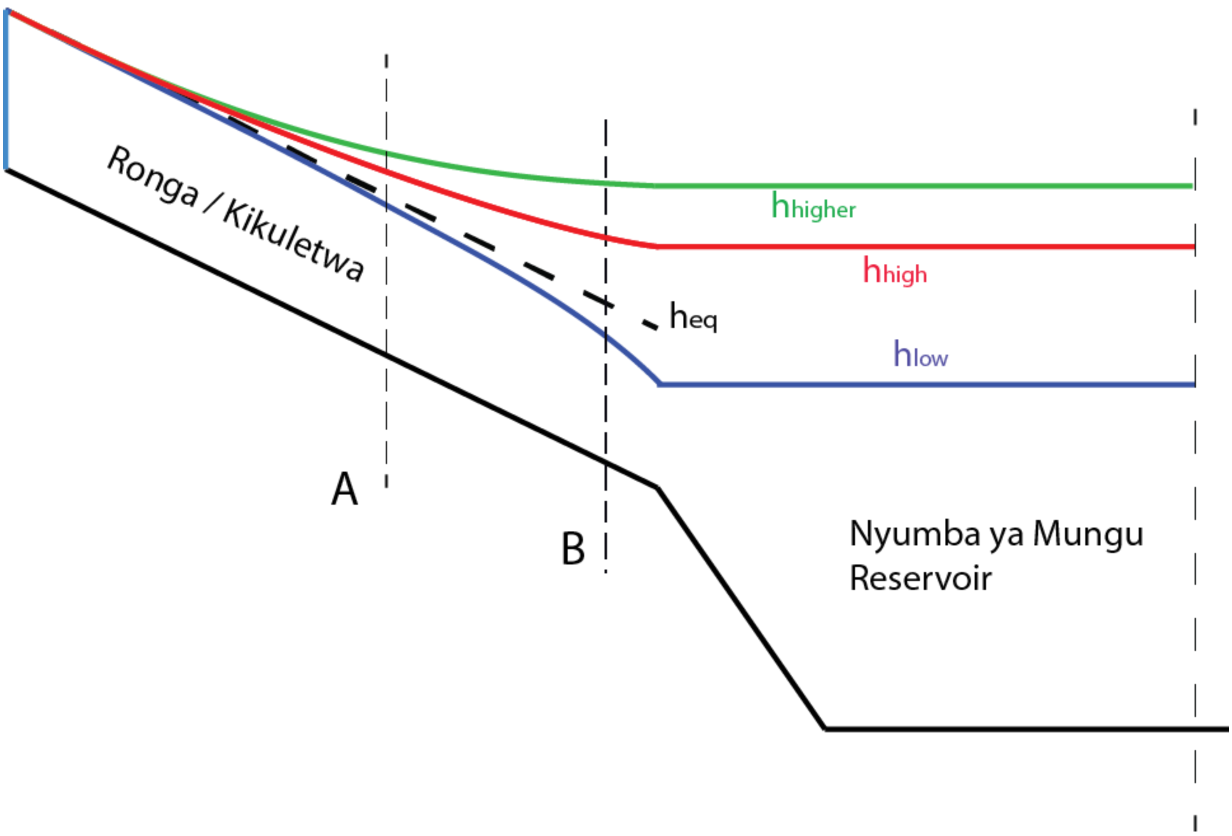


Figure 154: Visualisation of the backwater curve

H.1 Assumptions

The following general assumptions were made during the backwater calculations:

- Uniform flow: no accelerations or decelerations along each river stretch;
- Use of Manning's roughness parameter, converted to Chezy coefficient;
- Measured surfaced velocity transformed to average velocity through a K-value;
- Rectangular cross-section (converted from perimeter and width).

H.2 Schematisation

To perform the preliminary backwater calculation, the schematisation shown in Figure 155 is used. The TPC drains were not considered in these calculations. So the river system is separated in 4 parts; Kikuletwa North, Kikuletwa South, Ronga North and Ronga South.

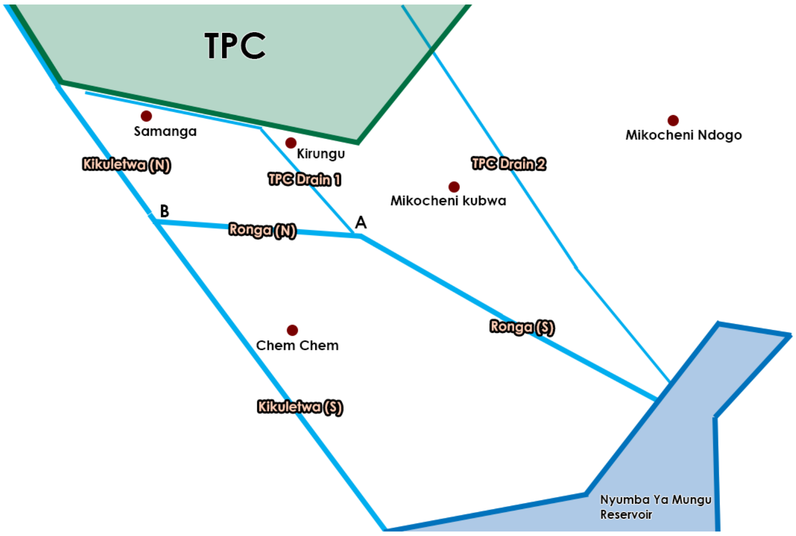


Figure 155: Schematisation river system

H.3 Backwater equations

A sound backwater calculation can only be performed if subcritical flow is present. The Froude number should be bigger than 1, only then information is carried upstream and the influence of the reservoir to the river can be calculated. This can be checked by calculating the critical and equilibrium depths of the considered river parts. In any case the equilibrium depth (h_e) should be bigger than the critical depth (h_g). It holds:

$$h_g = \left(\frac{q^2}{g}\right)^{\frac{1}{3}} = critical\ depth$$

$$h_e = \left(\frac{q^2}{C^2 i_b}\right)^{\frac{1}{3}} = equilibrium\ depth$$

$$h_e > h_g \rightarrow sub\ critical$$

In which q is the specific discharge (in m^2/s), g is the gravitational acceleration (in m/s^2), C is the Chezy coefficient (in $m^{1/2}/s$) and i_b is the bed slope.

An analytical approximation of the Bélanger equation was presented by Bresse. These formulas hold for low Froude numbers. The half-length of the backwater curve is given by:

$$L_{\frac{1}{2}} = 0.24 \cdot \frac{h_e}{i_b} \cdot \left(\frac{h_0}{h_e}\right)^{\frac{4}{3}}$$

In which $L_{1/2}$ is the half-length and h_0 is the water level at the boundary condition. The half-length is the length of the river for which half of the difference in water level between equilibrium depth and water level at the reservoir is overcome. A case: the equilibrium depth of a waterway is 4 meters, and at its mouth (for example at the sea) the water level is 6 meters. If the half-length is 20 km, then at 20 km upstream half of the difference is gone, so the water depth is 5 meters at that point.

The water depth at a distance x then can be calculated by:

$$h(x) = h_e + (h_0 - h_e) \cdot \frac{1}{2}^{-\frac{x-x_0}{L_{\frac{1}{2}}}}$$

With these formulas the water levels at different locations can be calculated, using the reservoir level as a boundary condition.

H.4 Input parameters

To perform correct backwater calculations, specific input parameters are needed. In this paragraph these parameters are explained and elaborated. For each parameter it is explained how the necessary data for this parameter was gathered. This could be existing data, fieldwork data or rough estimates.

In the previous paragraph the backwater equations were given. To perform calculations with these equations, the following input parameters are needed per considered river stretch:

- Width (W);
- Average depth (h);
- Bed-Slope (i_b);
- Chezy coefficient (C);
- Average specific discharge (q).

These 5 parameters can be used to acquire the parameters necessary to perform the calculations.

H.4.1 Width (W)

If possible, the width was measured by use of a measuring tape. If not, the width was guessed by field observation. In a river section the width may vary, one average width over the river section was used as input for the calculation.

H.4.2 Average depth (h)

The average depth was measured by crossing the river parts with a boat and the use of a depth sounder. This gave a cross-sectional area of the river part. The total cross-sectional area was divided by the width to get the average depth.

H.4.3 Bed-Slope (i_b)

Google Earth [12] was used to calculate the slope per river stretch. The start and ending points per stretch where marked and the height level was gained per marking point. Then, the total length of the river stretches was determined by drawing a path over the river. In Figure 156 the four river stretches as drawn in Google Earth are shown.

The height difference divided by the river stretch gives the slope. In this calculation, it is assumed that the average bed slope is the same as the average surface slope.

Figure 156: Calculation of river stretch lengths by use of Google Earth [12]

Table 44: Slope calculations

Slope calculations [source: Google Earth]					
River:	**River distance [km]**	**Begin height [m.a.s.l.]**	**End height [m.a.s.l.]**	**(difference) [m]**	**slope [m/m]**
Kikuletwa (N)	4.45	705	700	5	0.0011
Kikuletwa (S)	9.65	700	685	15	0.0016
Ronga (N)	6.45	700	691	9	0.0014
Ronga (S)	5.7	691	685	6	0.0011

H.4.4 Chezy coefficient (C)

The Chezy coefficient is obtained by rewriting the Manning's roughness parameter n. Manning is used because it is independent of the water depth and determined by properties of the river such as vegetation and shape. The formula is:

$$C = \frac{R^{\frac{1}{6}}}{n}$$

In which R is the hydraulic radius and n is the Manning roughness parameter. The hydraulic radius is given by:

$$R = \frac{A}{P}$$

In which R is the hydraulic radius (m), A is the area (m^2) and P is the wet perimeter (m). P is in this case given by: $2 \cdot h + W$.

The Manning roughness parameter is assumed to be 0.045, as the considered river parts are vegetated and meandering.

H.4.5 Specific discharge (q)

The specific discharge can be obtained by dividing the average discharge by the width of the considered part. The average discharge is calculated via the formula of Strickler-Manning. Combining these two the specific discharge is given by:

$$q = \frac{h \cdot R^{\frac{2}{3}} i_b^{\frac{1}{2}}}{n}$$

In which q is the specific discharge (m^2/s), h is the average depth (m), R is the hydraulic radius (m), i_b is the slope (-) and n is the Manning roughness parameter (-).

The Strickler-Manning formula considers what a 'natural' discharge is, given the water depth and physical characteristics of the river bed. Apart from the natural discharge, actual discharges can be used as input for the calculations. The discharge of the Kikuletwa is known over many years, which has been used in the calculations.

H.5 Output

The desired output is an insight in the equilibrium depth and half-lengths of the waterways in the project area. Two cases have been considered; one case with discharge 20 m^3/s for low discharges and one high discharge case with 80 m^3/s. Discharges were also determined with the use of the Strickler-Manning discharge, as a check for the observed discharges.

H.5.1 Low discharge case

The low discharge case was based on field observations. In the field characteristics as discharge, width and water depth were determined. Hereby assumed is that the Ronga has equal discharges in the northern and the southern part. Manning's constant has been set at 0.045 (vegetated natural waterways).

Table 45: Output results for low discharge case

What?	Observed discharge: (m^3/s)	Strickler Manning discharge	Width (m)	Average depth (m)	Peri-meter (m)	Hydraulic Radius (m)	Chezy coefficient	Slope	Critical depth	Equil. depth	Lhalf (m)
Kikuletwa (n)	20.4	19.25	15	2	19	1.578947	23.98	0.0011	0.063	0.954	546.7115
Kikuletwa (s)	0.6	0.68	3	0.5	4	0.38	18.87	0.0016	0.001	0.024	534.6269
Ronga (n)	19.8	18.56	9	2	13	1.38	23.46	0.0014	0.165	2.101	338.415
Ronga (s)	19.8	18.82	15	1.5	18	1.25	23.06	0.0011	0.059	1.037	567.5675

Table 45 shows the results and calculations for the low discharge case. Very interesting to see is that the observed discharges are in good accordance with the Strickler-Manning discharges. What can be concluded is that the used slopes and Manning coefficient have the right order of magnitude.

What surprises is that the equilibrium depth of the Kikuletwa is half of what is observed. The half-length of all the river sections are quite short (+/- 500 meter), so it is to be expected that the equilibrium depth and observed depth (several times the half-length upstream) of the Kikuletwa are close to each other. The same holds for the southern part of the Ronga.

Most striking is the equilibrium depth of the Kikuletwa, which would be two centimetres. It is not strange that the observed depth is not in accordance with the equilibrium depth. It was assumed that there was uniform flow and a uniform river bed. Both are quite variable for the southern Kikuletwa, therefore corrupting the calculation.

H.5.2 High discharge case

Apart from the low discharge case, which is used as a reference to the observed data, also a high discharge case is considered. This case could represent a year with very high discharges during the long rain season. A discharge of 80 m^3/s is used in the Kikuletwa. It is assumed that 95% of this discharge continues to the Ronga, given the small capacity of the Kikuletwa at the bifurcation. The results and calculations are shown in Table 46.

Table 46: Output results for high discharge case

What?	**High discharges (m^3/s)**	**Strickler Manning discharge**	**Width (m)**	**Average depth (m)**	**Peri-meter (m)**	**Hydraulic Radius (m)**	**Chezy coefficient**	**Slope**	**Critical depth**	**Equil. depth**	**Lhalf (m)**
Kikuletwa (n)	80	35.03	15	4	23	2.61	26.07	0.0011	0.97	12.41	232.5
Kikuletwa (s)	4	1.87	3	1	5	0.60	20.41	0.0016	0.06	0.92	159.0
Ronga (n)	76	33.16	9	3	15	1.80	24.51	0.0014	2.43	28.36	142.1
Ronga (s)	76	33.16	15	3	21	2.14	25.23	0.0011	0.87	12.77	245.8

For this extreme case some interesting results are obtained. As was mentioned earlier, these calculations are merely to provide insight in the acting parameters. For the high discharge case, the bankfull capacity of the river beds was used.

The first notable result is the Strickler-Manning discharge. For the different river sections it is less than half of the high discharges historically recorded in the 1DD1 gauging station. What this says is that the discharge capacity of these rivers is not sufficient for the high discharge, leading to pushing up of the rivers and overflowing.

The second indication that the rivers will overflow is the equilibrium depth of the river sections in combination with the half-length. The equilibrium depth of the river sections is very high, while the half-length is very short. This does not mean that this equilibrium depth is physically reached; the only meaning is that it is higher than the river banks. As a result, the rivers will overflow.

What can be said from these equilibrium depths and half-lengths is that the reservoir does not have much influence on the water levels in the river. The half-lengths are so short that the river levels will reach the height of the banks not far from the reservoir, not influencing the river levels around the communities.

Appendix I ALTERNATIVES STUDY

Several orientations of solutions have been identified. These solutions are presented here, after which a combination of solutions will be used to form an integral solution.

I.1 Dikes

I.1.1 Dike Samanga area

In the northern stretch of the Kikuletwa a weak spot in the water system is present, which causes floods during the long rain season. In December 2013, a water retaining control structure was constructed to regulate the water from the river into the farming area, for irrigation purposes. The structure failed during the last long rain season. For a stretch of 5 kilometres the water can easily flow eastwards into the Majengo area, see Figure 157.

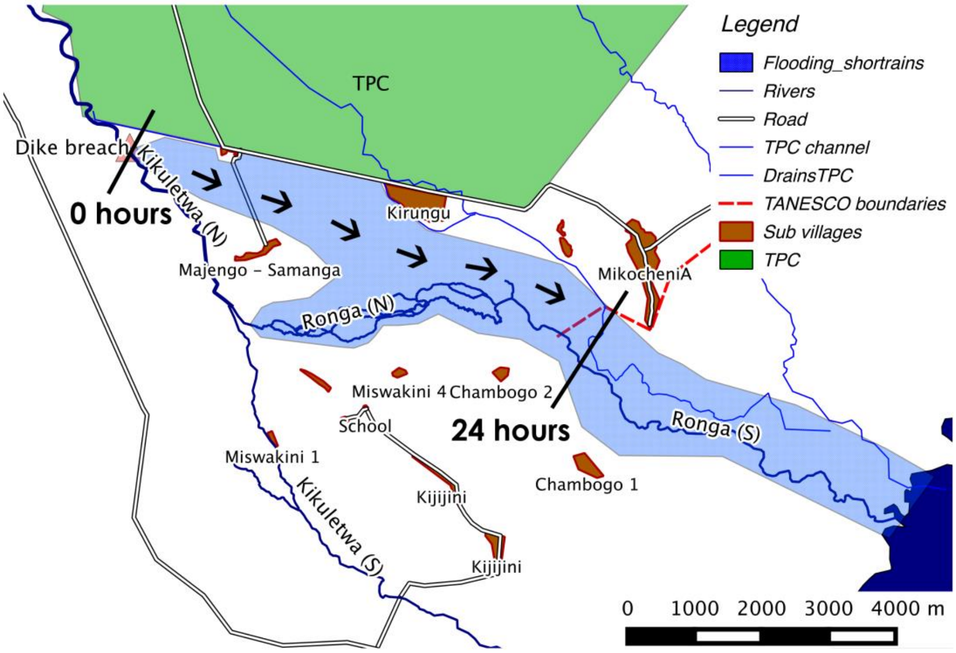


Figure 157: Map project area with location breach

The dike to be constructed consists of two parts; the restoration of the breached dike and the continuation of the built dike to where the banks are higher along the Kikuletwa. The dike is currently breached over a length of 20 meters, and the restoration is therefore not a big operation. The breached control structure will need to be removed too. The dike will be constructed with locally available material: the core of the dike can be constructed of sand and the outer layer with a water-retaining clay layer. The dike could also totally be made out of clay. Assuming the dike will have a height of 1.5 m, with slopes of 45°, and a crest width of 0.5 m, the dike contains about 3 m^3/m.

Figure 158: Cross - section dike principal

The second part is the lengthening of the current dike towards higher banks. When visiting the dike breach it became clear that the dike is only present over a small length. To secure the Samanga area the dike will need to be continued to where the banks are higher.

Impact dike Samanga area

This solution will have a positive effect against the flooding; phase two of the flooding during the long rains, will not occur anymore. Another effect, be it negative, is that the sedimentation as a result of the floods will not occur. For the feasibility of this solution it is therefore essential to implement it with a water controlling structure to irrigate the area, the location of this regulating structure and the type of structure will still need to be determined. Point of attention is the possibility of scouring around these structures.

The support by the local villagers depends on whether the dike will be implemented in combination with a water controlling structure. The costs of the dike might be substantial, depending on the length of the dike.

I.1.2 Short rain dike Ronga

This dike structure is partly based on the Po-system principal, see Figure 159. This system consists of a small dike (short rain dike) along the embankments of the river and a secondary dike (winter dike) on the floodplain further away from the river. The short rain dike retains the water during the short rain season and the winter dike retains the flood within the farming area during the long rains floods.

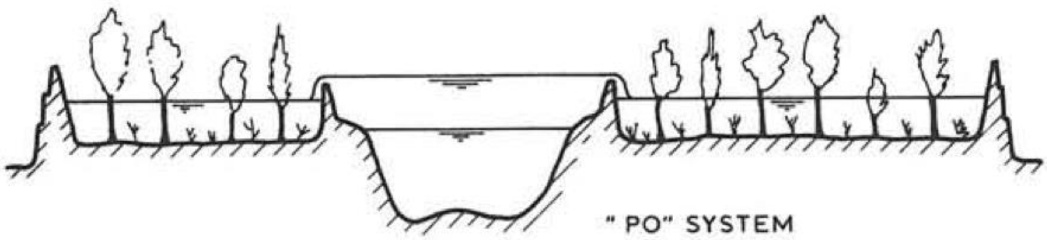


Figure 159: Schematic view of a Po-system [29]

The principal works in the following way: during small floodings (short rains) the secondary dike will not overflow. During larger flooding of the long rains the water will overflow the secondary dike. Due to the sudden inflow of water into the floodplains, the water will be partly stored by the primary dike created floodplains. The storage is called a non-uniform storage, which is because the water level on the floodplains are not the everywhere the same. This is because of the roughness differences on the floodplains due vegetation; the inflow into the floodplains is delayed. Important to note is that the presence of the secondary dike and the delayed inflow result in an inundated floodplain. In the situation without a secondary dike, the floodplains are part of the conveying cross-section; the cross-section that contribute to the discharge. This results in destruction of crops due to the presents of currents. [29]

The total amount of dike is as follows: a dike along the northern side of the Kikuletwa of 9 km length and on the southern side a dike with a length of about 5 km.

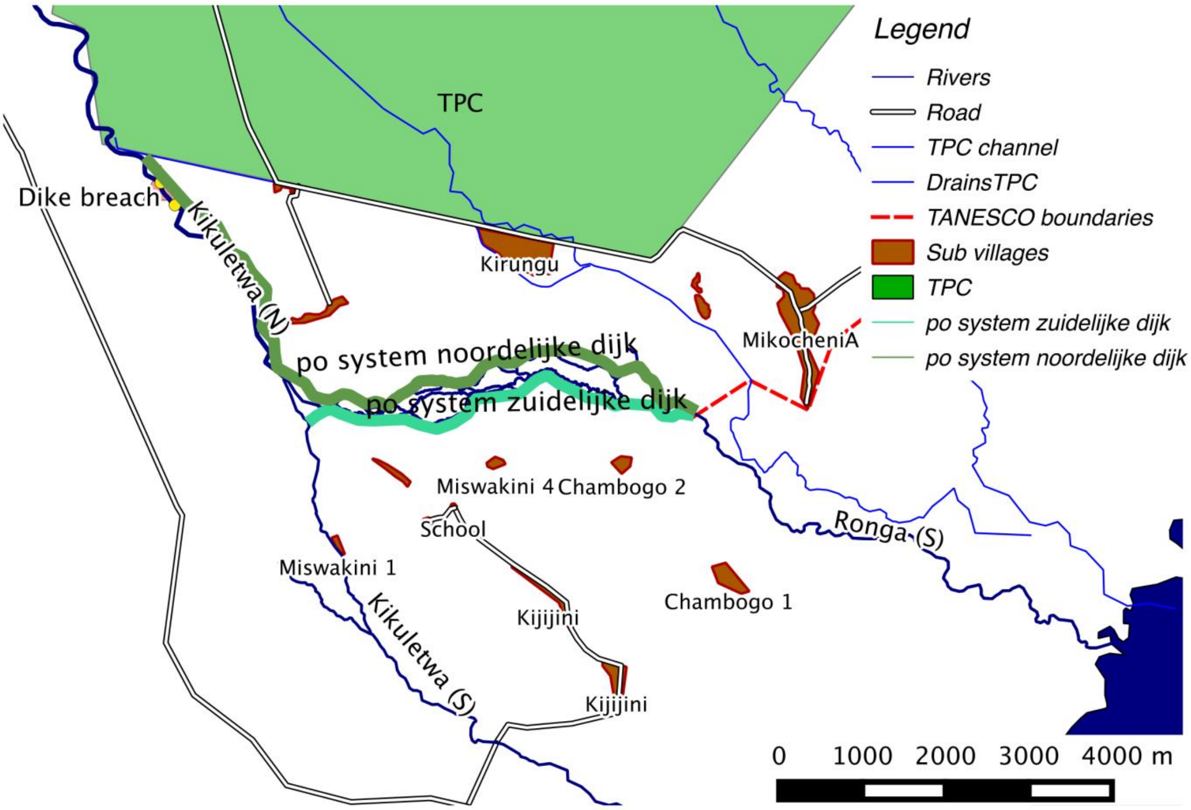


Figure 160: Map overview dike alignment; Po-system northern dike, southern dike

The alignment of the dike has to be outside of the path of the meandering river; called the migrating belt, as depicted in Figure 161 below.

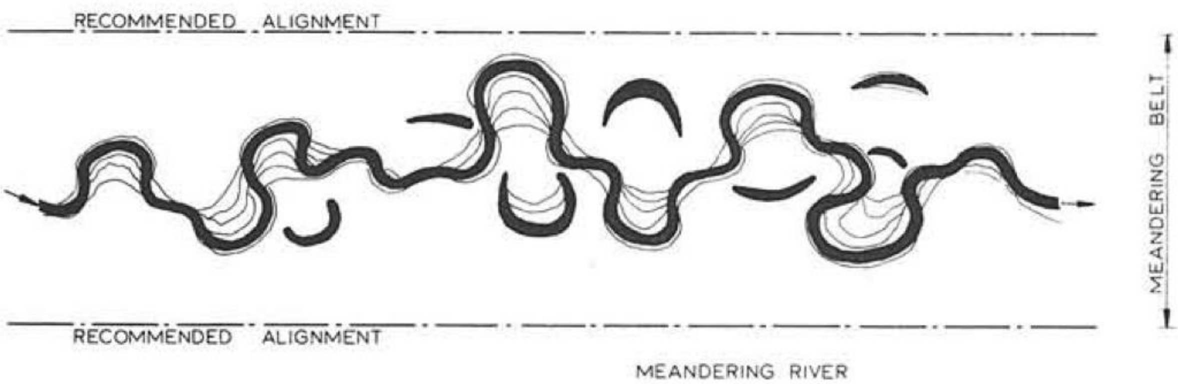


Figure 161: Recommended alignment of the dike. [29]

Impact short rain dike Ronga

This solution will have a reduction in the consequences of the flood wave. As result of the reduced flood area, due to the construction of the dikes, the flood wave will not be reduced. However, the frequency of flooding and the consequences of flooding are reduced. Besides, the celerity of the flood wave is, due to it restricted floodplains, larger. The water rises and drops also faster.

A drawback is that farmers have to do more for irrigating their land. The river is more restricted and flowing between its banks. A method to counteract this is by using siphons. The water can be relocated by gravity without the need of fuels.

The construction of the solution along the whole length of the river is an immense task. To ensure the support of the villagers and farmers a phased implementation is needed. The timespan of the implementation is therefore both short and long term.

Durability of the intervention is a point for discussion. During the floods of the long rains season the river dikes will partly be scoured and might fall down, to have a flood-reduction effect. It is therefore possible that they have to be rebuilt once a while.

Due to the large amount of dike that has to be placed, costs might be high, depending on the height of both the dikes. The first defence, the short rain dike, does not need to be very high. The short rain dike can be constructed using the villagers, every farmer is responsible for its own dike. Village committees can overlook these dikes and care for a secure system.

I.1.3 High dikes along Ronga, including control gates

Another possible dike solution can be a high dike along the Ronga (N) & (S). This dike has such a height that the flooding, during both the short and long rain, can be retained. This dike will have a height of 1.5 meter above ground level. The volume of the dike will be about 3 m^3/m. With a total length of 12 km, including both sides of the river, the total volume is about 36.000 m^3. The dike has the same alignment as the secondary dike of the Po-system of paragraph I.1.2. The large dike will be directly along the river and therefore retain all rising water of the river. See for an overview of the location paragraph I.1.2.

Impact high dikes along the Ronga

The high dike has a positive effect on the floodings. Due to the new dike there is now a high level of security. The farmers can be sure that they can farm the whole year round and destruction of the land is not happening anymore.

However, a negative effect is the absence of new fertile soils due to the floodings. To overcome this problem it is essential to implement this solution in combination with a controlling structure to inundate the land for a certain period of time and level. To regulate the outflow after inundation, using extra drain channels can be thought of.

The efficiency of the measure is not high because of the large amount of material that has to be moved. Local support by villagers can help in the supply of material and the amount of workload; resulting in a reduction of construction time. Overall, this support can lead to a reduction in costs.

The construction of such a high and long dike is very costly. Next to that, the construction will take a very long time and can possibly not be executed within one year. The rain seasons may therefore be an extra challenge for the construction.

A dike is a very durable solution; if it is well constructed it will last for a long time. However, a point of attention is the possibility of overflowing. If this happens, parts of the dike can be damaged. Inspection on the dike is therefore needed during the year.

I.2 Afforestation

A more general measure to reduce discharge peaks is to flatten these peaks by means of afforestation. More vegetation in the catchment of the Kikuletwa, be it forests, agriculture or grass, retains more moisture and thereby increases the retention time of rainfall. This flattens the sharp peaks in the discharge of the Kikuletwa. Besides, more vegetation also means more transpiration, which also reduces the run-off. In Figure 162 the blue line indicates the peak discharge, in this figure a red line is added to show the desired flattened hydrograph.

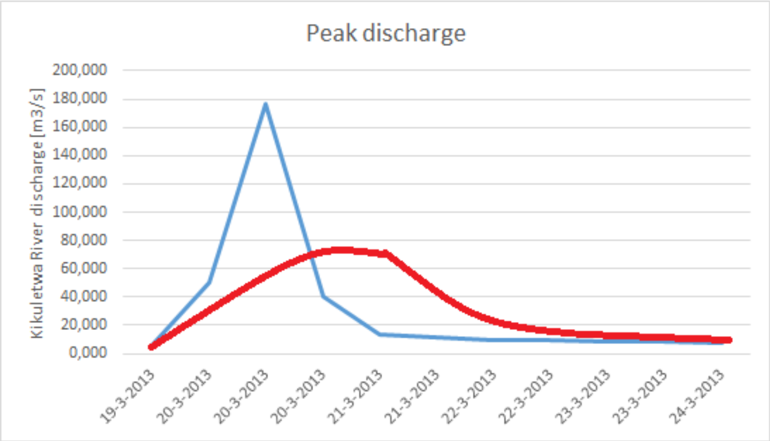


Figure 162: Impression of flattening the peak discharge

Most of the rainfall that enters the Kikuletwa falls far away from the project area. Therefore afforestation would be most beneficial if this was done upstream of the Kikuletwa, on a large scale. However, afforestation on the slopes of Mt. Kilimanjaro and Mt. Meru is not within the scope of this project.

Closer by, another area is interesting to implement afforestation. To the west of the Kikuletwa, the district of Msitu wa Tembo is situated. This area is very dry and is prone to soil erosion, as there is almost no vegetation, see Figure 163 and Figure 164. The rainfall and run-off in this area have been discussed in Chapter 3: discharges. The rainfall in this area can lead to high discharges in the southern part of the Kikuletwa. Afforestation in the Msitu wa Tembo area could lead to more continuous flow in this part of the Kikuletwa and retain more moist in the area.

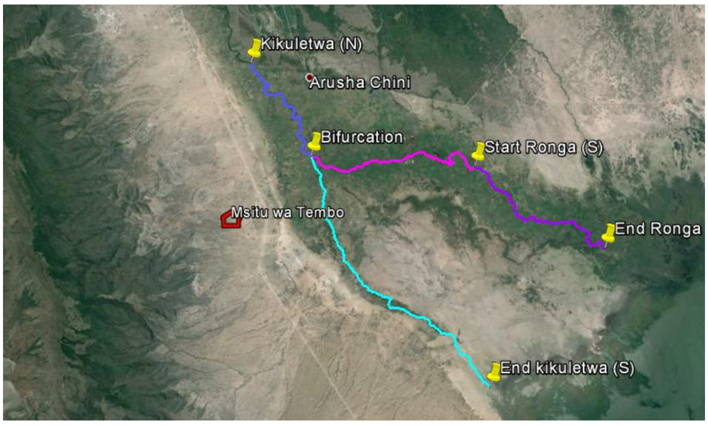


Figure 163: Location of Msitu wa Tembo in the project area, note the drought in the area.

Figure 164: Soil erosion in Msitu wa Tembo

Impact of the solution

The effects of this solution are hard to quantify. When started on a large scale upstream, the results will be big. However, this is not within the scope of this project, but is a solution to the problem. On a smaller, local scale, the Msitu wa Tembo area is interesting for afforestation. However, the afforestation in this area will not have a significant influence in reducing discharges and/or reducing discharge peaks. The main problem with discharges in the area is the discharge that enters the Kikuletwa North. Most important is that the decrease and flattening of the peak discharge in the Kikuletwa South can be seen as a very positive side-effect in landscape restoring / afforestation projects.

Another issue to consider is the support by the local villagers. Of course, restoring the dry landscape towards a vital green ecosystem is also in the villagers' best interest. There is however a societal problem that felled trees can be sold for fuel and firewood. It is therefore uncertain if trees can grow to mature trees or are felled when they are young. This societal conflict, how to prevent villagers from felling trees too early, is hard to solve. It will also be hard for the local villagers to see the effect of afforestation on the discharges in the river, therefore the local support must be generated for the restoring of the landscape/ecosystem.

Another point of attention is the time span necessary for afforestation to be effective. Young trees need time to grow and an afforestation project takes time to implement. It is therefore not a 'quick fix' but a long term solution. The solution is however durable if the local villagers are aware of the long term vision. A complete restoration of the landscape in a way that it is self-providing would not only be effective but will also last for a long time.

The last criterion to be discussed are the costs of an afforestation project. The initial investment costs for this project are quite large. Therefore a business model is needed to get this project started. Some organisations involved with afforestation have expressed their interest in the Lower Moshi region, these organisations can help in starting the project.

I.3 Capacity increase

I.3.1 Straighten river path

According to Chézy's formula, straightening the rivers increases the discharge capacity. Straightening of the rivers leads to a decrease in the river length, which increases the bed slope and therefore the discharge capacity.

$$Q = A \cdot C \cdot \sqrt{R \cdot i}$$

It is assumed that the river is currently in a steady state, meaning the river bed has adjusted such that it can transport all sediment supplied by the river from upstream in downstream direction. Without any other measures, this intervention will almost certainly lead to erosion upstream on the long term. A plus side is that this erosion will lead to a deepening of the river bed, decreasing the probability of a flood.

Kikuletwa North

In this section the option of straightening the Kikuletwa North will be elucidated. The straightened section is represented in Figure 165.

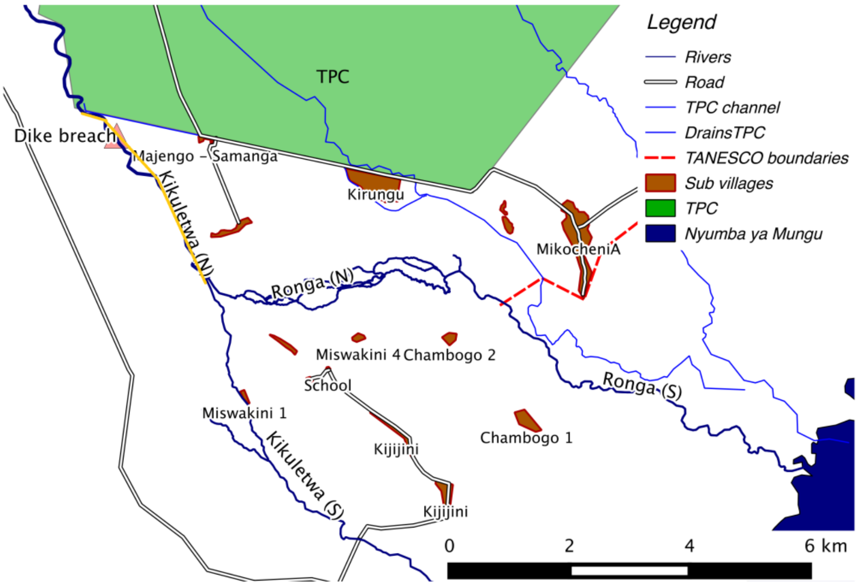


Figure 165: Straightening Kikuletwa North. The orange line is the new path way.

Impact on Kikuletwa North

By straightening the Kikuletwa North, the bed slope over this reach will increase. The erosion will start at the downstream end of the river straightening: the bifurcation point. At his point the erosion is still negligible. The erosion will increase further upstream. In Table 47 the old situation is compared with the new situation.

Table 47: Present situation compared to the new situation; Kikuletwa North

	Present situation	New situation
River length	4.5 km	3.4 km
Slope	0.0011	0.0015
Increase discharge capacity	100 %	117 % (Chezy)

On the short term, this measure will lead to an increase in discharge capacity of 17%.

On the long term, the river bed will tend to reach its equilibrium bed slope of 0.0011 again. This means the northern point of the straightened reach the river bed will tend to deepen about 1.3 m (0.0011 * 3400 = 3.74). Thus leading to decrease in the water level and a decrease in the probability of flooding. However, the original effect of an increased discharge capacity due to increased bed slope is not present anymore.

With this measure erosion will take place, the sediment will accumulate in the reservoir. The volume of this erosion must further be investigated.

Because of the new path of the river, farm land that was originally on the west side of the Kikuletwa might now be on the east side, or vice versa. This might lead to an absence of support by the villagers.

The cost of this measure lies with the excavation of 3.4 km river bed.

Ronga North

In this section the option of straightening the Ronga North will be investigated. The straightened section is represented in Figure 166.

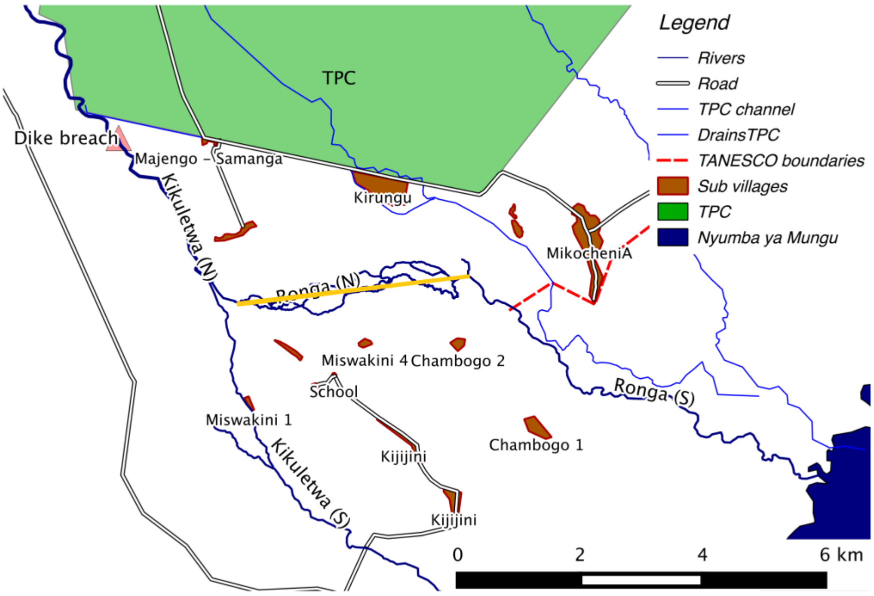


Figure 166: Straightening Ronga North. The orange line is the new path way.

Impact on Ronga North

By straightening the Ronga North, the bed slope over this reach will increase. The erosion will start at the confluence of the braided part. At his point the erosion is still negligible. The erosion will increase further upstream. In Table 48 the old situation is compared with the new situation. The impact of the reduction of the number of channels, see I.6.5, at this stretch, and therefore increase in discharge capacity due to the friction reduction has not been taken into account.

Table 48: Present situation compared to new situation; Ronga North

	Present situation	New situation
River length	6.45 km	4.5 km
Slope	0.0014	0.0020
Increase discharge capacity	100 %	120 %

On the short term, this measure will lead to an increase in discharge capacity of 20%.

On the long term, the river bed will tend to reach its equilibrium bed slope of 0.0014 again. This means the northern point of the straightened reach the river bed will tend to deepen about 2.7 m (0.0014 * 4500 = 6.3). Thus leading to decrease in the water level and a decrease in the probability of flooding. However, the original effect of an increased discharge capacity due to an increased slope is not present anymore.

With this measure erosion will take place, the sediment will accumulate in the reservoir. The volume of this erosion must further be investigated.

Because of the new path of the river, farm land that was originally on the Chem Chem side of the Ronga might now be on the Mikocheni side, or vice versa. This might lead to an absence of support by the villagers.

The cost of this measure lies with the excavation of 4.3 km river bed.

Ronga South

In this section the option of straightening the Ronga South will be investigated. The straightened section is represented in Figure 167.

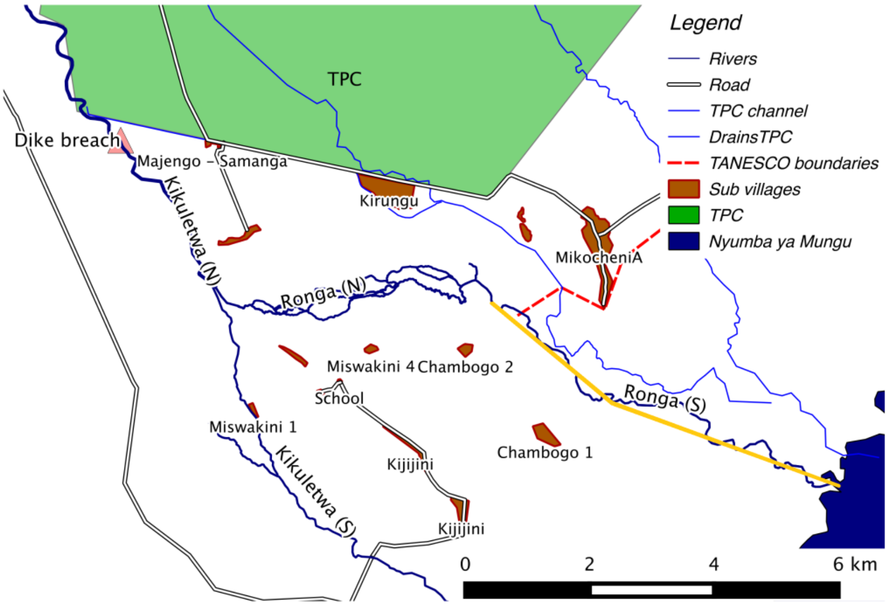


Figure 167: Straightening Ronga South. The orange line is the new path way.

Impact on Ronga South

By straightening the Ronga South, the bed slope over this reach will increase. The erosion will start at the reservoir. At his point the erosion is still negligible. The erosion will increase further upstream. In Table 48 the old situation is compared with the new situation.

Table 49: Present situation compared to new situation; Ronga South

	Present situation	New situation
River length	5.7 km	4.4 km
Slope	0.0011	0.0014
Increase discharge capacity	100 %	113 %

On the short term, this measure will lead to an increase in discharge capacity of 13%.

On the long term, the river bed will tend to reach its equilibrium bed slope of 0.0011 again. This means the northern point of the straightened reach the river bed will tend to deepen about 1.4 m (0.0011 * 4400 = 4.84). Thus leading to decrease in the water level and a decrease in the probability of flooding. However, the original effect of an increased discharge capacity, due to an increased slope is not present anymore.

With this measure erosion will take place, the sediment will accumulate in the reservoir. The volume of this erosion must further be investigated.

Because of the new path of the river, farm land that was originally on the Chem Chem side of the Ronga might now be on the Mikocheni side, or vice versa. This might lead to an absence of support by the villagers.

The cost of this measure lies with the excavation of 4.4 km river bed.

I.3.2 Decrease resistance

Less vegetation in river leads to a lower friction coefficient, and thus a higher discharge capacity.

$$Q = A \cdot C \cdot \sqrt{R \cdot i}$$

$$C = \frac{R^{\frac{1}{6}}}{n}$$

By decreasing the Manning coefficient n, the Chezy coefficient increases. This is done by removing vegetation from the wet area of the river bed. By removing vegetation, the discharge capacity is increased.

Impact

Table 50: Indication roughness values for Strickler-Manning equation

Tabel 9.1 - Indicatie van ruwheidswaarden voor de Strickler-Manning vergelijking (bron: 'Open-channel hydraulics' – Ven te Chow, International Student Edition, 1959, blz. 111-113 (gemiddelde waarde))

Type waterloop	Manning ruwheidswaarde n
Gebouwde waterlopen:	
- Hout	0,012
- Beton	0,013
- Grind	0,020
Gebaggerde waterlopen:	
- Aarde, recht en uniform	0,018
- Rotspunten	0,035
- Niet onderhouden	0.080
Natuurlijke waterlopen:	
- Goed onderhouden, recht	0,030
- Goed onderhouden, slingerend	0,040
- Slingerend, met vegetatie	0,045
- Met stenen en vegetatie	0,050
Uiterwaarden:	
- Grasland, kort gras	0,030
- Akkerbouw	0,040
- Struikgewas	0,050
- Dicht struikgewas	0,070
- Dichte bebossing	0,100

Currently a Manning coefficient of n = 0.05 is assumed in the river reaches, see Table 50. By removing the vegetation en large rocks the Manning coefficient can be decreased to n = 0.040. If straightening of the river is combined with smoothening the bed, the Manning coefficient will be n = 0.030. A summary is given in Table 51.

Table 51: Comparison present situation and new situation

Alternatives	Present	New
Smoothening the bed	n=0.050	n=0.040
Smoothening the bed and straightening the river	n=0.050	n=0.030

This will lead to an increase in discharge capacity, summarised in Table 52.

Table 52: Increase in discharge capacity

Alternatives	Present	New
Smoothening the bed	Q=100%	Q=125%
Smoothening the bed and straightening the river	Q=100%	Q=167%

By smoothening the bed, a theoretically large gain in discharge capacity is reached. This measure might lead to an increase in erosion of the river bed. To quantify the increase in erosion, the sediment transport relation of Engelund-Hansen is used.

$$s = mu^n = m\left(\frac{R^{\frac{2}{3}} i_b^{\frac{1}{2}}}{n_{Manning}}\right)^n$$

In which

$s = sediment\ transport\ pe\ runit\ width\ \left[\frac{m^2}{s}\right]$

$m\ and\ n = Engelund\ Hansen\ coefficients$

$R = hydraulic\ radius\ [m]$

$i_b = bed\ level\ gradient\ [-]$

$n_{Manning} = Manning\ coefficient$

When changing the Manning coefficient, the Engelund Hansen parameter n changes as well. Keeping all other parameters constant, this leads to:

$$m = \frac{0.05\ n_{Manning}^3}{\sqrt{g}\ \Delta^2\ D_{50}\ \sqrt{R}} \sim n_{Manning}^3$$

In which

$$g = Gravitational\ acceleration$$

$$\Delta = relative\ density$$

$$D_{50} = median\ grain\ size$$

Using n = 5 for Engelund Hansen and keeping all parameters constant this leads to:

$$s \sim \frac{1}{n_{Manning}^2}$$

The results are summarised in Table 53.

Table 53: Increase in sediment transport

Alternatives	Present situation	New situation
Smoothening the bed	s=100%	s=156%
Smoothening the bed and straightening the river	s=100%	s=278%

So per unit width, the sediment transport increases significantly. This will certainly lead to erosion at the location where the vegetation is removed. It will probably lead to deposition at the location where the vegetation can grow freely again, for example in the reservoir.

The measure does not have an effect on the land of the farmers. However, the measure leads to a temporary increase of sedimentation in the reservoir. Therefore the Pangani Basin Water Office might not support this solution.

To prevent the vegetation from growing back, regular maintenance has to be executed. The maintenance costs add up to the costs of the initial removal of the vegetation.

I.3.3 Widening the river

By widening the river, the hydraulic radius R and the conveyance area A increase, resulting in a larger discharge capacity.

$$Q = A \cdot \frac{R^{\frac{1}{6}}}{n} \cdot \sqrt{R \cdot i}$$

The width of the river can be adjusted such that the once in a year discharge fits the profile, and no flooding occurs.

Widening the river influences the flow velocity of the water. Generally, when the discharge stays constant, after widening the water will flow slower than before, leading to sedimentation in the widened reach.

Kikuletwa South

Widening Kikuletwa Small will lead to a larger conveyance area. At the bifurcation point, this will lead to an increase in discharge flowing through Kikuletwa South. The increase in discharge depends, among others, on the new conveyance area. Further research on this effect must be done.

The increase in discharge in the Kikuletwa leads to a decrease in the Ronga. The exact division of the discharges is dependent on many factors.

The increase in the hydraulic radius leads to an increase in the flow velocity through the river. This will lead to an increase in the sediment transport rate.

It is expected that this measure has the support of the villages. Widening the Kikuletwa Small does not have a large impact on the farm land en will lead to more water being available for the villages along the river. It will lead to a decrease in discharge in the Ronga, decreasing the probability of a flooding.

The costs lie with the excavating of 3.45 km river bed.

Ronga North and Ronga South

When the Ronga North is widened, this will lead to an increase of the conveyance area at the bifurcation point. However, this will not lead to a significant increase of the discharge, as 95% of the water from upstream already flows through the Ronga. When assuming the discharge stays constant, the flow velocity will decrease and sedimentation occurs. Due to this sedimentation, maintenance must be done to keep the desired effect of an increased discharge capacity. The river bed must be dredged to prevent it from silting up.

A solution for this would be to widen the river by floodplains. During base flow, the river profile does not change and the flow velocity does not decrease. While during peak flow, the flood plains are in use and the river has extra capacity.

Widening the Ronga might lead to a negative Environmental Impact Assessment, because flora and fauna like hippo's and crocodiles live along the banks of the Ronga.

The costs lie with the excavating of 12.2 km river bed.

I.3.4 Deepen the river

When deepening the river bed, the water level drops. Because the water level needs space to adjust, a backwater curve is formed. Because of the backwater effect, the deepening does not have an effect immediately. The effect of the deepening starts at the river mouth and increases in the upstream direction.

It is important that the deepened river bed has the same slope as the original bed, to prevent other effects like a change in flow velocity and erosion/sedimentation.

Impact deepening Ronga South and North

In this section the effect of deepening the Ronga North and South is treated. The water level in the mouth and the equilibrium water depths do not change. Therefore lowering of the bed level will result in a lowering of the water level of the Ronga North and South. Due to the backwater effect, the effect is smallest close to the river mouth and largest far upstream of the mouth. See Figure 168 for an illustration of the backwater curve.

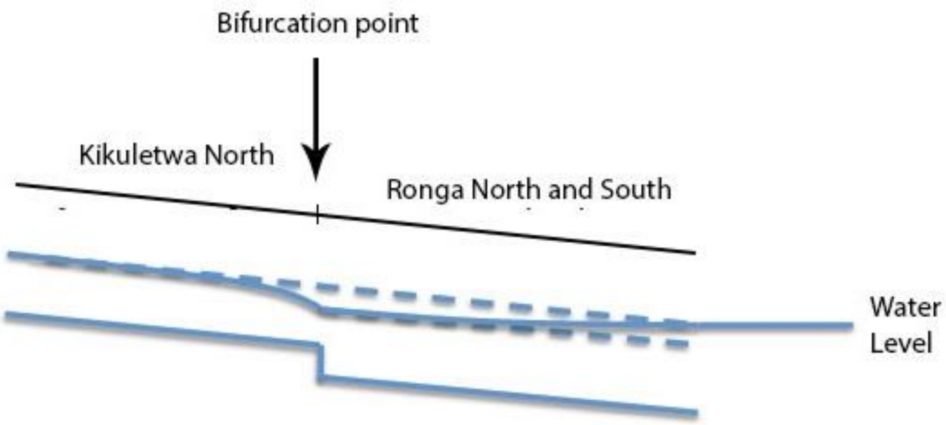


Figure 168: Backwater curve due to deepening Ronga

The measure is effective for flood risk during periods of peak discharges from the river floods. The effectiveness increases towards the bifurcation point.

On the long term, deposition of sediment will take place at the deepened stretch and the Ronga will fill up again. To keep the measure effective, continuous dredging must take place. This will add up to the maintenance costs.

Because the measure is executed locally, it is expected that the villages support this solution.

I.4 Control structures

I.4.1 Sill (overflow)

A sill is a barrier in or across a river that is built to adjust its flow characteristics. It is a (mostly permanent) construction which is placed inside the river. The sill could be adjustable, to alter the flow characteristics during different flow regimes. However, such an adjustable structure is more expensive than a solid one.

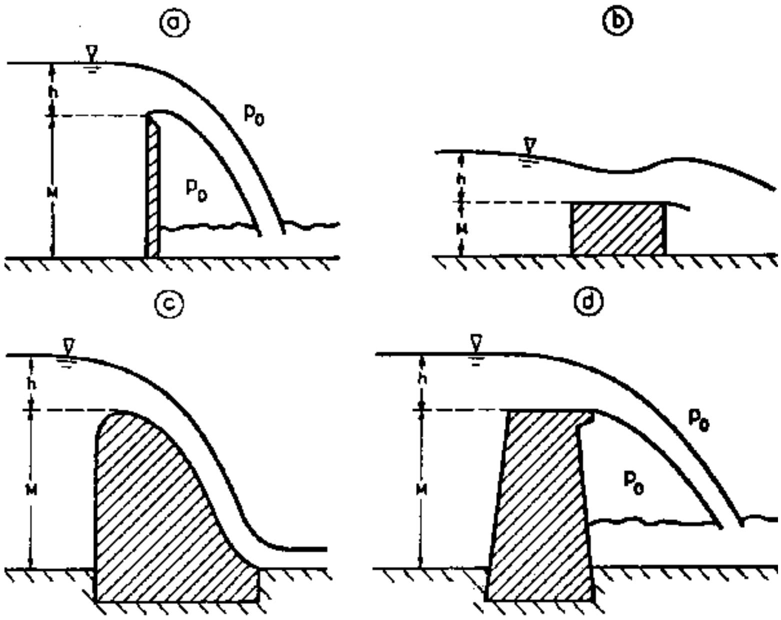


Figure 169: Different type of sill shapes (source: www.fao.org)

An option is to place a sill in or around the bifurcation point between the Kikuletwa and the Ronga, to control the amount of water flowing in these two rivers. A sill could be constructed at the entrance of the Kikuletwa South to create base flow through the Ronga during the dry season, while diverting extra water into the Kikuletwa during the long Rain season. Another option would be to construct a sill in the Ronga downstream of the bifurcation point. This would raise the water level upstream of the sill and thus increase the discharge through the Kikuletwa South.

General impact

The geometry of the bifurcation point is of great importance to the flow characteristics of the different rivers. If a sill were to be built along the whole bifurcation point, water levels upstream may rise because of backwater effects. In general, flow speed decreases, which is directly related to an increase of sediment deposition upstream and erosion downstream of the sill. If water levels raise to high, levees should be built along the upstream part, to protect the area upstream from not being flooded year round.

When built effectively, a sill could divert just the right amount of water into the Kikuletwa to lower water levels in the Ronga. However, such an adjustment should also be related to the option of widening the narrow part of the Kikuletwa South.

A sill is a local structure, which on itself does not have a big impact, because the construction area is limited. However, because of changing flow and sediment characteristics, such a structure may have an influence on the reservoir downstream. Sedimentation in the reservoir may decrease because it is blocked by the sill. The sill decreases water flow speeds and thus extra sedimentation occurs in the river, which is beneficial to the reservoir. Also, the sill is built to decrease water levels in the Ronga, thus probably less flooding occur, which is positive for the local farmers. But, as mentioned before, the sill may increase water levels upstream, which may increase floods over there. This can be countered by building levees.

A sill could be constructed relatively easy and fast because it is only very local. However, a good design which alters the water level in the right way may be time costly. A sill can be constructed in concrete, which is relatively expensive, but also a rock filled sill can be used. The last type is easy to construct, but has a downside that the construction has a larger error compared to the design.

A sill design is a durable construction which in general lasts for years. However, the construction must be designed in a proper way, otherwise it may fail.

Sill at entrance Kikuletwa South

A sill could be constructed in the entrance of the Kikuletwa South. The sill blocks water from flowing into the Kikuletwa during the dry season, to keep water levels high enough in the Ronga. However, it should be kept in mind that this solution does not solve the floods during the short rains.

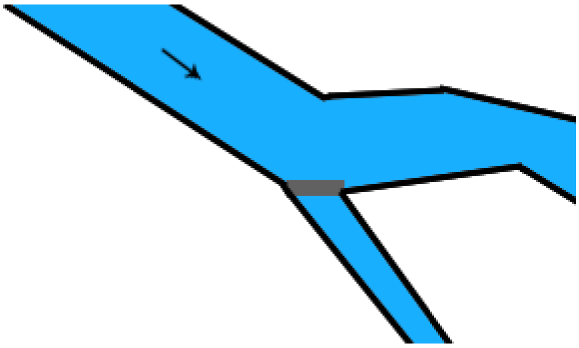


Figure 170: Sill at Kikuletwa South entrance

The sill is shown in Figure 170 as a side sill. To divert more water into the Kikuletwa, the sill could also be constructed more into the remaining river part.

One of the consequences of building the sill in this way is that during the dry season all sediment is released through the Ronga. Thus probably more sediment reaches the reservoir. However, most sediment transport happens during the long rain season, in which also the Kikuletwa is used, but maybe sediment is then blocked by the sill.

Sill in Ronga downstream of bifurcation point

Another option is to construct a sill downstream of the bifurcation point. This options will raise the water level at the bifurcation point, and thus more water will flow into the Kikuletwa South. This water flow can be enlarged by widening the Kikuletwa South.

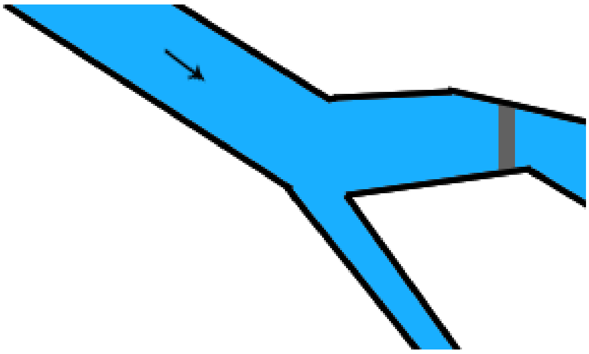


Figure 171: Sill in Ronga downstream of bifurcation point

Building this sill probably has a major impact on the upstream water levels, because most water flows through the Ronga. This may be limited, because more water starts flowing through the Kikuletwa South, but still should be accounted for. Also, during the dry season, the division between water in the Kikuletwa South and the Ronga is probably somewhat the same because the Kikuletwa is open, and the Ronga is blocked. This blocking, may also decrease the water inflow into the reservoir, because more evaporation occurs.

I.4.2 Division structure

A division structure could be built to divert water at a bifurcation point. Such a structure could be placed at the bifurcation point between the Kikuletwa and the Ronga to adjust the amount of discharge into the two remaining rivers. In the current situation the diversion point is to the side. This point could be adjusted to the middle by a manmade structure as shown in Figure 172. This would permanently divide the water flow between the two rivers and may decrease water levels in the Ronga, while increasing water levels and flows in the Kikuletwa South. However, such a structure should be built in combination with a widening of the smaller part of the Kikuletwa South.

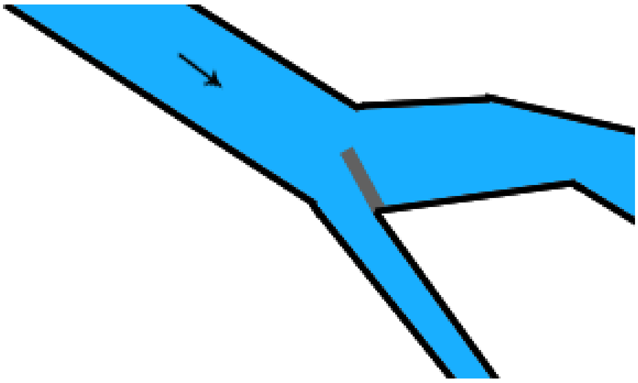


Figure 172: Division structure

Impact

A division structure would permanently increase discharge and sediment in the Kikuletwa, while permanently decreasing this in the Ronga. Also, because of less water flowing through the Ronga, the water level and probability of flooding will decrease for the part after the bifurcation point. The decrease in water flow may cause water levels to be not high enough during the dry season, which can give problems to the farmers who cannot divert water into their irrigation channels. This totally depends on the size of the division structure.

I.4.3 Weir (underflow)

A movable weir is a control structure often used to manually adjust the amount of water flowing through. An example of a movable weir is shown in Figure 173. This weir is used to divert water into irrigation channels.

Figure 173: Weir at TPC

On a larger scale, weirs could also be used to control water flow from the rivers into basins or as a flood control structure. A bad example is the weir constructed in the recently built dike Northwest of Samanga. A picture of the failed weir is shown in Figure 174. This weir probably became instable because his foundation was not secure enough. Also, the weir was placed in the outside corner of a bend, which is prone to erosion and thus fails earlier.

Figure 174: Failed weir at Samanga Dike

If a weir is constructed that should be operable all year long, the gate should be at the right height to be adjustable to lower and higher water levels of the river.

When the weir is only used for controlled flood waves over agricultural land, the total operable gate area should be large enough to let through enough water and sediment. The sedimentation aspect is important because it is necessary to fertilize the land and flush out salts. Also, such a structure should be operable for local villagers. The construction should be able to be controlled with manpower.

Impact

A big pro of such a structure is the possibility to control the floods. However, this is only the case when combined with a sufficient dike system. Also, proper irrigation channels are advisable. If combined with a dike system, a flood control weir has a very positive effect on the area. However, it should be taken in to account that damming only a certain part and controlling the floods over there may have an impact of the size of the floods downstream. Also, if not enough sediment is brought into the area, the sediment may flow to the reservoir, which is not in favour of TANESCO. This also has bad consequences on the fertility of the ground.

A controllable weir mainly is effective against flooding when it is placed in formerly used drainage channels. A controllable weir then can be opened during low water, to flow water into the farmland. And then, if floods occur, the weir could be closed, protecting the flood wave from flowing through irrigation channels and increasing the flooded area. If proper weirs are built, this is in favour of local villagers, because the water than can be tamed.

The construction of a proper movable weir could take some time, especially when it needs to combined with other solutions like irrigation channels and/or dikes. Also, a movable weir is a relatively complex structure to construct and thus will cost a lot compared to other structures. The durability of a movable weir should be lifelong, but as seen in the example of the Samanga dike this is not true for a badly designed one. A weir is thus only durable when designed and constructed in a proper manner.

I.4.4 Siphon

A siphon is a (u-inverted shaped) tube which flows water from a high reservoir over a hill into a lower lying reservoir. The siphon principle works by the under pressure created through the tube. The water is brought upward by the gravitational pull of the water on the lower side of the tube. A siphon is not a solution to the flooding problem, but may help bringing water from the river into irrigation channels or crop fields. A condition for the siphon is that the water level of the river or channel is higher than the water level in the to be pumped area. In Figure 175 siphons are shown which bring water from an irrigation channel to the furrows. A siphon is relatively cheap and easy to use, but it is limited to the previous stated situations.

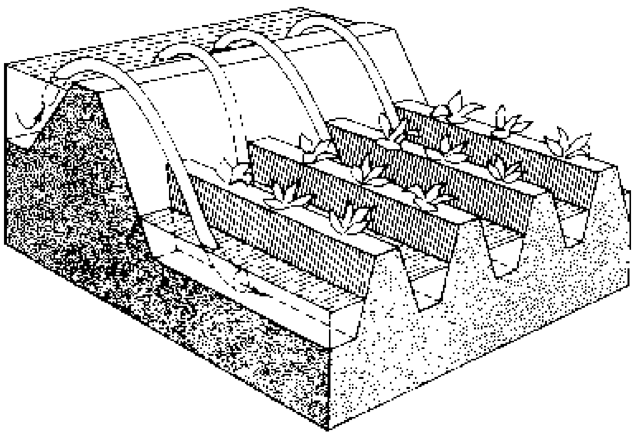


Figure 175: Siphons (source: www.fao.org)

I.4.5 Pumps

Pumps can be of the same use as siphons, but then in places where the water level of the river or channel is lower than the to be transported to area or channel. A pump requires a form of energy. Also, a small investment is needed, because pumps are not that cheap. Pumps are no solution to the flooding problem in Lower Moshi, because the flood volume is too large to be pumped away. However, pumps could be used to solve the problem of blocking of the rivers and TPC drains. If pumps would be in use, the drains should not be blocked to get the water into the fields.

I.5 Storage and basins

There are multiple problems in the lower Moshi area. Not only are there the floods during the rain seasons, there is also drought during the dry seasons. A way farmers battle the drought is by use of irrigation. The storage of water in reservoirs of basins could help with one or both problems. Multiple storage purposes can be identified:

1. Storage for irrigation during dry seasons
2. Storage to reduce peak discharges
3. Storage for controlled flooding

I.5.1 Storage for irrigation during dry season

Along the Ronga River there is a lot of farming land. Farming is therefore an important source of income for the problem area. When the floods are finished, farmers are able to harvest from the moisture in the ground, as a result of the flood. When the area is dried up, there is too little water available for the farmers to grow their crops. Therefore it is preferable to store some of the plenty amount of water during the rainy season and use this during the dry season for irrigation.

On Google Earth [12] the farming area can be clearly distinguished from the living and dryer area. By approximation this total farming area along the Ronga River amounts 15 km^2. When it is assumed that effectively on half of this area crops are growing, the total surface area for crops amounts 7.5 km^2. When the crops need 700 mm/m^2 to grow, this would result in a preferable storage of 5.250.000 m^3. This is an enormous amount of water to store in the area. Hardly any farm land would remain if land is sacrificed to store the amount of water.

Most farming areas get water from their drains that are connected to the Ronga River. Therefore the storages must be located on multiple locations near the Ronga River. In this way the irrigation water will be reachable for most farmers.

There are multiple possibilities to store water, most common solutions are water tanks and reservoirs. Because the Ronga River is located lower than the ground level, gravity cannot be used to fill the reservoir. As a result, farmers should pump to get the water in the storage basin. Unfortunately, if they have to pump water to store for irrigation purposes, it would be more logical to directly pump the water out of the river during the dry season.

Another possibility is to fill the reservoir by means of flooding. For this purpose low lying areas are preferable. However again to use the water, pumps are needed. Also evaporation, infiltration and other losses have to be taken into account. The irrigation water has to be stored for a couple of months so losses are not negligible. Altogether it will be unlikely to realize a storage area for irrigation purposes.

An alternative would be to make use of floodplains. Small banks must be placed along the Ronga River which overflow during high discharges. A certain area next to the Ronga River has to be reserved to store this volume. This entire floodplain area should then be embanked to retain the water volume. This principle is applied in the Netherlands where they distinguish a short rain dike Figure 176. For the application of dikes one is referred to section I.1.

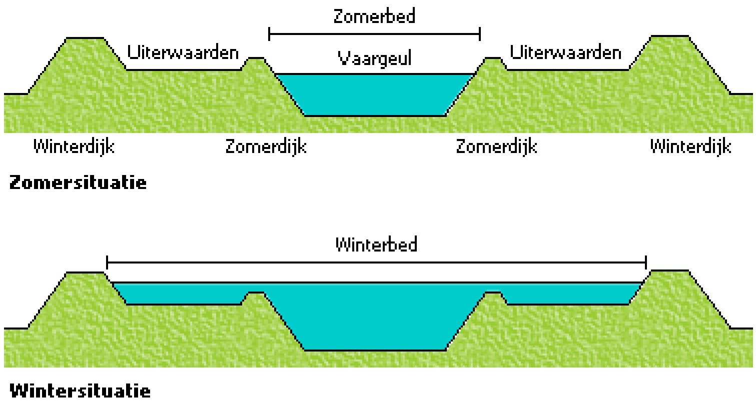


Figure 176: Illustration on floodplains (Dutch).

Impact

In this section the impact will be described of the floodplain solution. The positive effects are only partially preserved. After the rainy seasons the floodplains consists of very fertile soils when the area behind is withhold from flooding and therefore less fertile. For this solution the negative effects will be reduced. Behind the last dike the area will be mostly protected from flooding. A possible solution for farming land behind the dike should be to use siphons to flood their own farming land and thereby gain new sediments and wash away the salts.

For the farmers there will be several ways of looking at this solutions. The whole area should be redeveloped and therefore all farmers should collaborate. Therefore it is really important to convince the villagers and to make a proofed design. Also it takes a lot of effort to realize such a large extent of dikes. To get insight in the possibility of realizing dikes along the area section I.1 can be read.

I.5.2 Storage to reduce peak discharges

To limit the damage of the large peak discharges, the volumes of these peaks can be temporarily stored in a basin. It is preferable that only the large outliers are stored in a basin. In Figure 177 the river discharges in 2013, as a reference, are shown. The year 2013 is chosen because this year seems to represent the common yearly discharge. From this graph it can be concluded that the basin should be opened by a river discharge of approximately 70 m^3/s, in order to store the outliers.

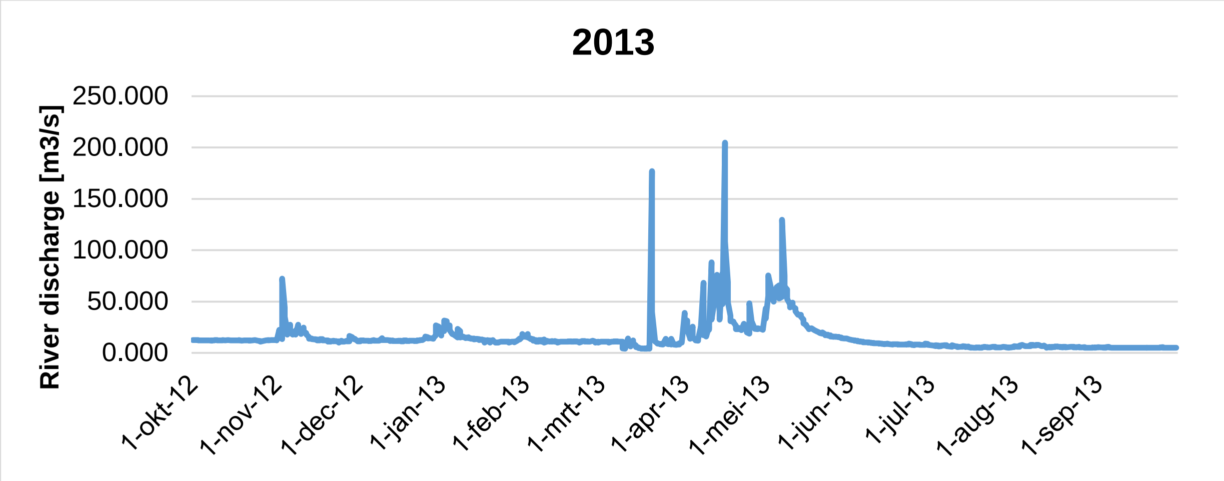


Figure 177: River discharge measured at 1DD1 [m3/s]

When all river discharges above 70 m^3/s have to be stored in 2013, the maximum volume of the reservoir should be 12,985,444 m^3.

To store this huge amount of water a large area has to be reserved. Besides that, the reservoir has to be connected with the river and water should only enter when the discharge is larger than 70 m^3/s. In the Analysis it is pointed out that 95% of the discharge of the Kikuletwa (N) enters the Ronga. Since the Ronga River cannot process discharges larger than 30 m^3/s without overflowing, a storage basin near the Ronga is reasonless. Therefore it is preferable to store the water volume of the outliers next to the Kikuletwa (N), because the river should be able to handle large discharges.

Filling of the reservoir can be done in multiple ways, for example by pumping and gravity. Since pumps need energy and can fail it is preferable to only use gravity. As the area is really flat and the banks on the TPC side are not larger than 1.0 meter, it is irrational to build a reservoir with a depth larger than 1.0 meter. The banks of the Kikuletwa are also approximately 1.0 meter high compared to the hinterland. To embank the basin it would be logical to extent the current banks, which results in a reservoir depth of 1.0 meter. Then the volume to be stored requires a reservoir area of at least 13 km^2 to facilitate the basin. Figure 178 shows the extent of such a basin near the Kikuletwa.

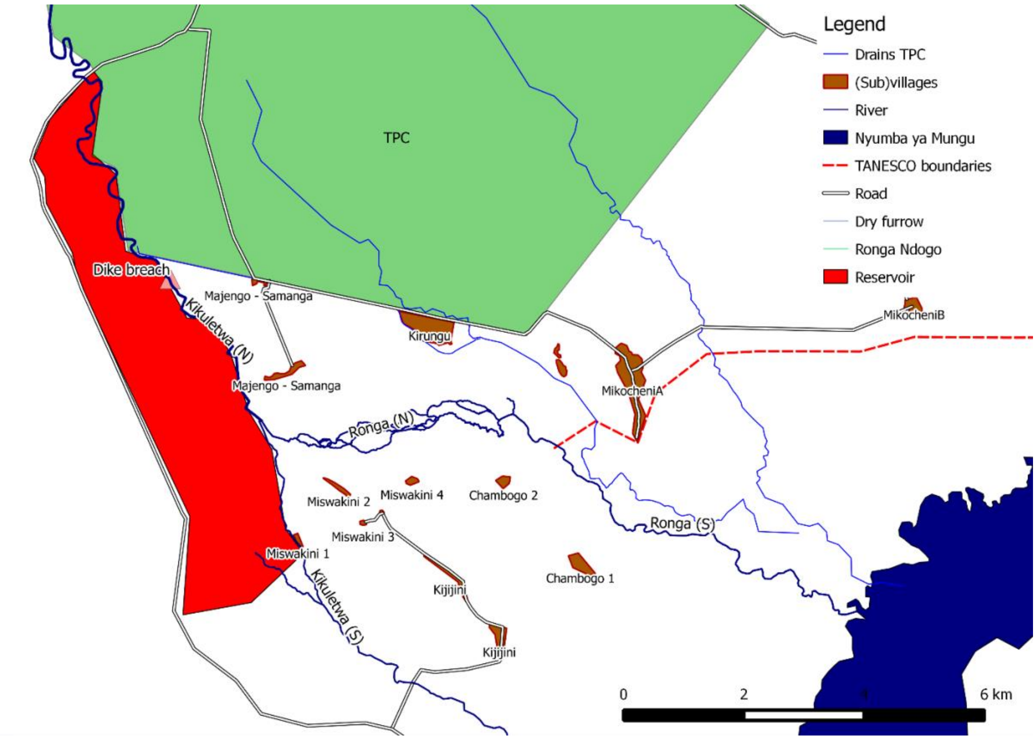


Figure 178: Example of minimum reservoir area (red)

Impact

A storage basin to reduce peak discharges has both advantages and disadvantages. A positive effect of realizing a basin is that it reduces the damage due to high flow velocities of such large peak flows. Apart from the basin the problem area still has to process discharges up to 70 m^3/s. Therefore the floods next to the Ronga River are not yet solved. On the other hand will the basin reduce the floods in the hinterland of the dike breach.

Socially the solution can be hard to implement because a large storage area is needed. It is inevitable that this storage area has to be placed on someone's property. However, it supplies a large volume of water that is available for the dry season. Therefore it also create new opportunities as new farming land of a water supply for cattle so that they have new grazing areas. If the solution is received well, a new boost can be given to the area and the future of this area can be successful.

When (soil) material and labour are not restricted the basin can be realized within a year. So the effort should be visible on short term. If the weir and banks are constructed well the solution would also be durable.

I.5.3 Storage for controlled flooding

As has been mentioned above; basins can be used to reduce the discharge peak. This function can be combined with another function; the storage of water that can be used for a controlled flooding. During the fieldwork it became clear that farmers desire controlled floods. Floods are necessary to wash away salts and to settle fertile soil. A location has been sought that would be able to store water, and later release this water gradually over farmland.

The location that was chosen for this type of storage is the Majengo-Samanga area where a dike was built at the end of 2013. This dike has breached, leaving a weak spot in the eastern banks of the northern Kikuletwa. Before this dike was built, and after it was breached, water used to flow from the Kikuletwa over the Samanga area to Kirungu, flooding an enormous area.

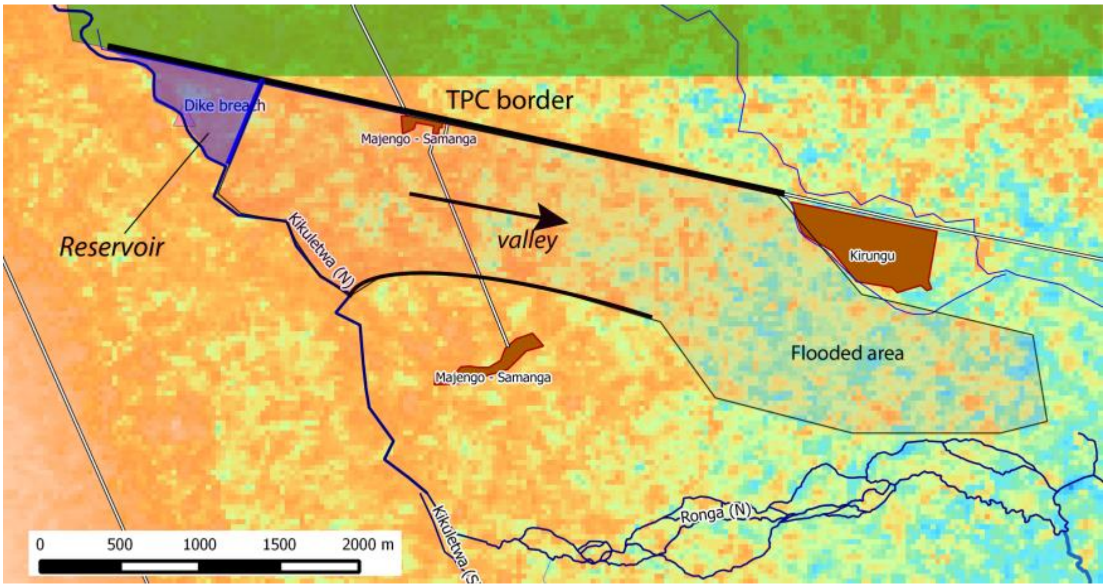


Figure 179: Location of possible reservoir and valley between Majengo-Samanga and TPC.

Near the dike breach, an area could be used to store water. This area is depicted in Figure 179, in which the different colours give an indication of the elevation. The reason why this area is chosen is that it is a low lying area: there is a kind of 'valley' between TPC and Samanga through which water runs from the dike breach towards Kirungu. Next to that; the area needs to be flooded for farming and there are already some dikes present. The dike of the Kikuletwa and the dike at the border of TPC are present dikes that can be used to create a storage reservoir/basin. Only a third dike has to be built, which is approximately 500 meters long.

There is a trade-off in the size of the reservoir. A bigger reservoir can store more water, and thus reduces the discharge peak more. However, the basin is placed on current farming land owned by local villagers. Therefore we have to be economical with the land. A larger area also leads to a longer dike to enclose the area.

It has been researched what the size of the reservoir should be in order to have a controlled flood. The area of Samanga that suffers from the dike breach, but profits from the reduction of salinity and settlement of new soil is shown in Figure 179. The surface area amounts approximately 5 km^2. It is assumed that this area needs 0.5 meter of flooding depth. Of course a large part of this volume will run-off or evaporate, so in the end only a fraction of it infiltrates into the ground. The needed flooding volume will then be in the order of 2,500,000 m^3. The area of the reservoir depicted in Figure 179 is approximately 125,000 m^2. If the reservoir has an average depth of 1 meter (difference between height of banks and land), this means that the reservoir should be filled about 20 times.

Unfortunately, it would not be possible to fill the reservoir 20 times using high water levels in the Kikuletwa, these only occur a few days a year. The only way to fill the reservoir 20 times would be to construct a complex pumping system that could pump water during lower discharges. Instead, a larger reservoir area could be used. However, using a larger reservoir area would mean that more farmers have to give up their land, and that an even longer dike needs to be built. As a result, it would be better to have a controlled flood using (large) control gates, as was the purpose of the previously built dike. For control gates, see section I.4.

The problem of current floods is that large volumes of water enter with large velocities; leading to soil erosion and destruction of remaining crops. Instead of building storage basins to control flooding, another way to control the velocities of the released water is to build terraced reservoirs. How this could work in the area north of Samanga is shown as an impression in Figure 180. The farmers have expressed their desire to have floods to the height of the ankles.

If dikes are built to ankles' height, the water level will only reach this height. When the water gets higher, water flows slowly towards the next terrace, instead of fast runoff over land. Due to the slowly flowing water, fertile soils will settle on the farming lands; which is both beneficial for the farmers as for the Pangani Basin Water Office, whose goal it is to reduce sedimentation in the Nyumba ya Mungu reservoir. A system of small furrows will be needed to reduce the runoff over land when the water starts overflowing initially from one reservoir to another.

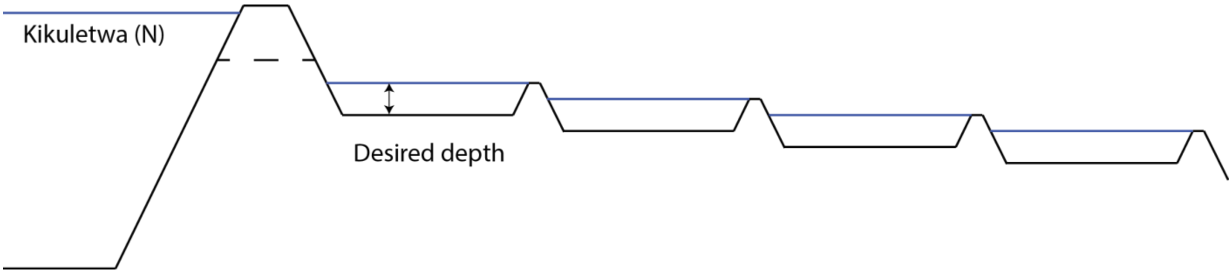


Figure 180: Impression of terraced reservoirs to have controlled flooding

Impact

The realisation of an effective reservoir near the dike breach is concluded to be impossible. Therefore the idea of terraced reservoirs has been introduced. These reservoirs, in combination with a control structure, enhance the positive effects of the floods. These are the washing away of salts and the enrichment of the soil by fertile particles in the water.

The negative effects of the floods in this area will be reduced. If the volume of water that enters the area is limited to an acceptable value; the water will only reach to the depth that is desired by the farmers. Thereby the main problem was that high flow velocities cause a lot of damage which will be reduced by using terraces.

The measure is very efficient in enhancing the positive effects and diminishing the negative effects of the floods. However, the solution of terraced reservoirs is dependent on the control structure that releases water from the Kikuletwa to the Samanga – Majengo area. As a result, the expected local support by villagers is assumed to be very positive.

The terraced reservoirs are easy to implement, only small dikes/banks are needed to construct the reservoirs. Depending on the desired depth, approximately ankles' height (10-20 cm.), it will not take a long time to build the dikes. The farmers will be able to do the work themselves, which makes it a cheap solution. However, the terraced reservoirs and dikes will not be very durable. There will probably be weak spots in the dikes where water can enter the next reservoir. Good monitoring of the reservoirs by the farmers is therefore key in this solution.

I.6 Increase number of discharge routes

Increasing the number of discharge routes increases the discharge capacity of the river system: more water can be discharged at the same time. It is likely that the flood volume and extent in the problem area will decrease. In the chapter below, different new discharge routes are discussed.

I.6.1 Chem Chem river bed

The Chem Chem river bed can clearly be identified on satellite images [12] by the trees bordering it . The Chem Chem river bed is indicated in Figure 181. Figure 182 shows the river bed during a field trip.

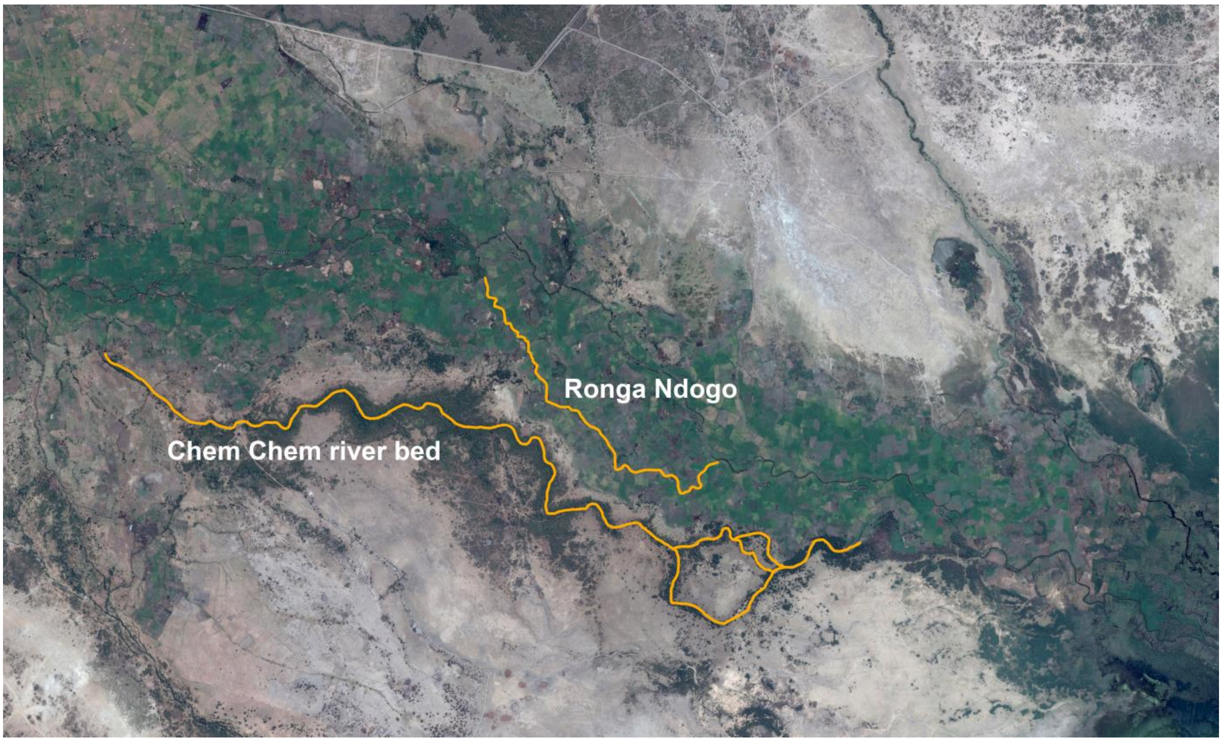


Figure 181: The Chem Chem river bed indicated. Source:maps.google.com

Figure 182: Images of the Chem Chem river bed

It can be seen that the bed is currently dry. Moreover there is vegetation growing in the bed. During the rain seasons, some water is collected in it, however there is no flow. Potential flow would be decelerated by the friction due to the vegetation. The bed can be used to reduce the flooding of farming land roughly from Majengo to Mikocheni Kubwa.

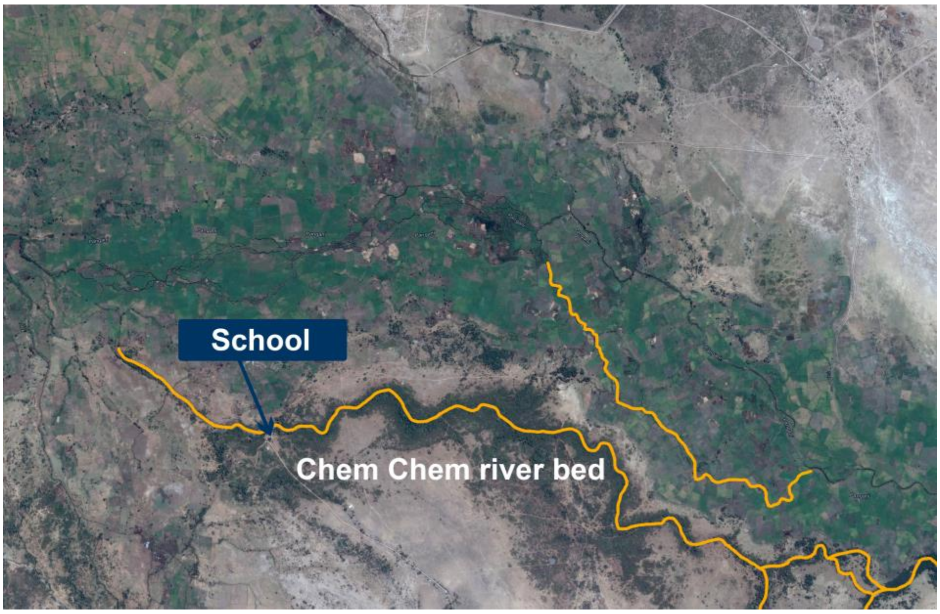
Table 54: Properties of the Chem Chem river bed

Properties			
Length	L	8.3	km
'Missing' length	$L_{channel}$	0.4	km
Width	W	6-8	m
Height	h	1.5	m
Max discharge cap.[6]	Q	8.4-12.7	m^3/s

There are two reasons the bed is not discharging water at this moment. The first reason is that the bed is not connected to the Ronga River at both ends of the bed. At the northern side approximately 400 m is missing; at the southern side 800 m. Linking the northern end of the bed to the Ronga North would create a new discharge route. If property on the southern end of the bed is of equal value, connecting the bed to the Ronga South is not needed: the water will find its way to the reservoir. The second reason is the position of the school in Chem Chem. The position is indicated in Figure 183. The school is of big importance to the villagers and is situated right next to the river bed. Allowing water to flow through this bed would lead to a destabilisation of the school's foundation. Therefore, in order to use the river bed, a diversion would have to be made around the school. The estimated length of such a channel is 400 m.

Concluding, in order to make full use of the Chem Chem river bed, the following would have to be executed:

- Connect the northern end of the bed to the Ronga North;
- Create a diversion channel around the school;
- Remove the major vegetation inside the channel.



[6] Based on maximum average velocities of WP85 and WP646

Figure 183: location of the school. Source: maps.google.com

Figure 184: The school in Chem Chem

Impact

Making use of this river bed reduces the negative effects of floods by reducing the flood volume and extent along the Ronga North and South. If the inlet of water is regulated in such way that enough flooding can still occur to fertilise the land, it also enhances the positive effects. If the diversion channel mentioned in text above is implemented as well, it is expected that this measure will have the support of the villagers. Not creating the channel would lead to damage to the school which is not desirable. Since 800 m new channel needs to be created to make this solution work, it can be implemented on the short term. Removing the major vegetation would be a more tedious job to do. Therefore, to effectively use the bed for discharge it would be a long term solution. In terms of building with nature it is a durable solution. Of course the bed has to be maintained in order to function well. From time to time, vegetation needs to be removed out of the bed. Additionally not a lot of material is needed to implement this solution.

I.6.2 Ronga Ndogo

The Ronga Ndogo (little Ronga) is a tributary west of the Ronga and is indicated in Figure 185. Figure 186 shows the southern end of the Ronga Ndogo during a field trip.

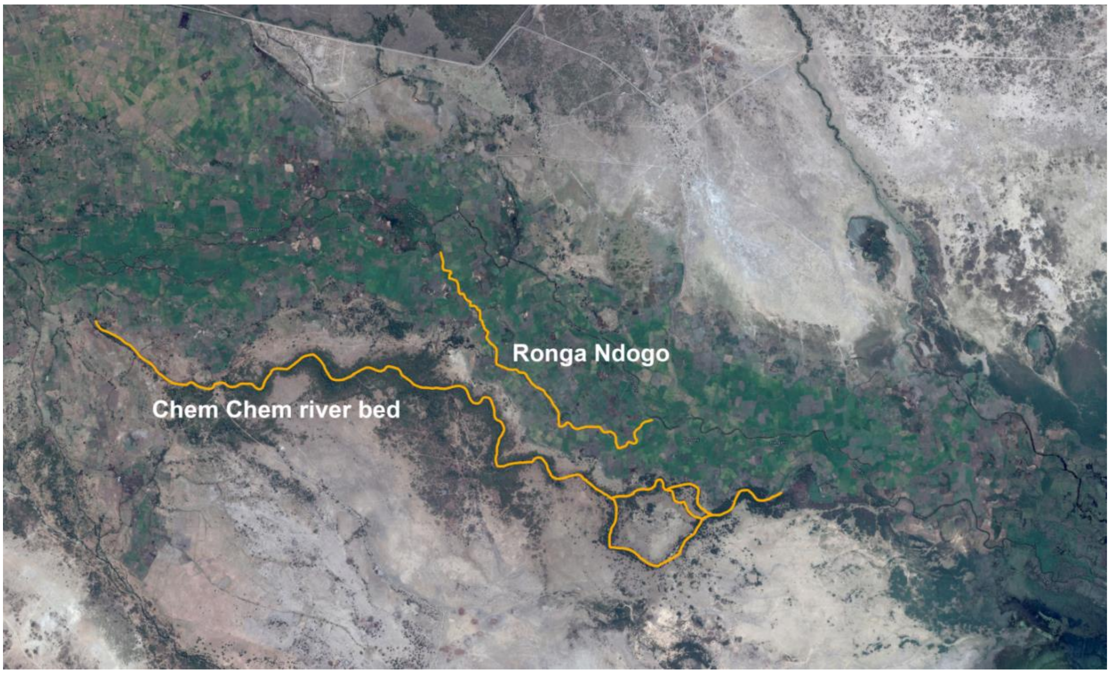


Figure 185: Location of the Ronga Ndogo Source: maps.google.com

Figure 186: Swamp at the end of Ronga Ndogo

There are two reasons why the Ronga Ndogo is not discharging water. Figure 186 shows the southern end of the Ronga Ndogo. The waterway ends in a swamp, which increases the friction enormously. This swamp is only fed by water from downstream flowing into the old bed. Upstream of this swamp the river bed is dry. Upstream of the dry river bed the Ronga Ndogo is a water way with still standing water.

Table 55: Properties of the Ronga Ndogo river bed

Properties			
Length	L	1.8	km
'Missing' length	$L_{channel}$	1.8	km
Width	W	4-6	m
Height	h	0.9-1	m
Max discharge cap.[7]	Q	~3.4-5.6	m^3/s

As can be seen in Table 55 half of the tributary is dry. Possibly the river was filled with sediment that closed down this river branch. Concluding, in order to make full use of the Ronga Ndogo, the following would have to be executed:

- Deepen the bed;
- Remove the major vegetation (swamp) inside the channel.

Impact

If implemented, the flood amount and extent around the Ronga South and for the farmers of Mikocheni Kubwa could be reduced significantly. The effectiveness of this measure is smaller than opening the Chem Chem river bed, since its cross-section is smaller. The bed is already existent: therefore local support of the villagers is expected. No agricultural land is lost. However, 1.8 km of old river bed has to be reopened. This is more than the Chem Chem river bed and will therefore be more expensive. This will take some time to execute. Although the reason for the closed Ronga Ndogo is uncertain, this may be natural. Keeping this branch open might over time cost a lot of effort.

I.6.3 Kikuletwa South tributary

The Kikuletwa South tributary is a short tributary channeling water around the place where cars can drive through the river to reach Chem Chem. Its location is pointed out in Figure 187. Figure 188 shows the tributary during fieldwork.

[7] Based on the average maximum flow velocity of WP 646

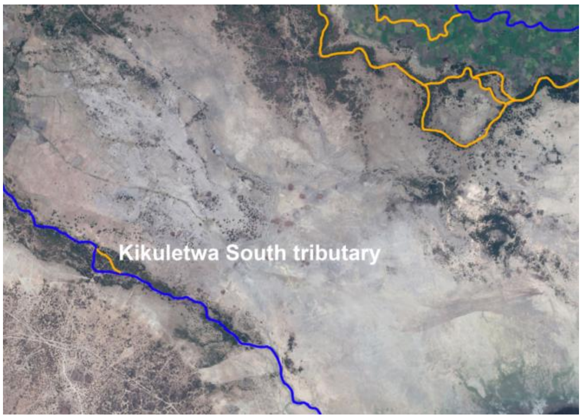


Figure 187: Location of the Kikuletwa South tributary Source: maps.google.com

Figure 188: The Kikuletwa South tributary during field work

Figure 188 shows a lot of vegetation. Therefore, to make full use of the channel, major vegetation has to be removed from the bed.

Table 56: Properties of the Kikuletwa South tributary

Properties			
Length	L	0.4	km
Width	W	7-8	m
Height	h	2.5	m
Max discharge cap.[8]	Q	~45-46	m^3/s

[8] Based on the average maximum velocity of WP03

Impact

As can be seen in Table 56, the length of this tributary is quite short: 400 m. Therefore, if full use is made of this tributary, the flooding extent will only reduce locally. Moreover, it is located on the downstream side of the problem area and will have minor impact on the Ronga river. The floods are most severe there. The effects are on a small scale, but can be implemented on a small time scale since it is a short distance. The bed is already existent: therefore local support of the villagers is expected. No agricultural land is lost. From time to time, vegetation needs to be removed out of the bed. However it is durable in a material sense, since no extra material is needed.

I.6.4 Eastern old river bed

As described by Banton [6], (a branch of) the Kikuletwa was flowing more eastwards in the past. In order to divert water from the problem area, restoring this old bed could be an option. In Figure 189 a possible trajectory can be found. It could also be possible to use the drain east of the forest for example.

Figure 189: Possible location of the eastern branch Source: maps.google.com

The figure above shows the newly created eastern branch following the natural drain running through the forest and thus making use of the existing bed. The existing infrastructure on the TPC terrain can be used to discharge the water. The bed does not have to have water running through permanently. By regulating the inlet of water, the canal could discharge water only during peak discharges.

Table 57: Properties of the East old river bed

Properties			
Length on TPC farm	L_{TPC}	7.2	km
Length in TPC forest	L_{forest}	7.1	km
Length forest – reservoir	$L_{forest\text{-}reservoir}$	9.4	km
Width	W	~6	m
Height	h	~1	m
Max discharge cap.	Q	~6	m^3/s

Impact
As can be seen in Table 57, the cross-sectional properties of the channel are estimated. This is because the exact dimensions of the trajectory are not known. When using the existing infrastructure the estimated amount of discharge possible is 6 m^3/s. The new waterway brings water to the area east of Mikocheni Kubwa, an area where currently the fertility of the land is low. Bypassing the problem area, it could reduce the flood extent and volume in the entire problem area. It is therefore expected that the villagers support this solution. As mentioned before, the channel is on TPC terrain. Therefore, TPC has a strong say if this solution will be implemented. Discharging more water over the TPC terrain may lead to a higher water table which could not be desirable. Seasonal use of such the channel (during the rain seasons) could mitigate this problem. Since decision making takes some time, it is expected this is a long term measure. The costs to create this waterway are expected to be not that high, since a lot of already existing infrastructure is used.

I.6.5 Reducing the amount of channels in Ronga North
Currently a lot of channels are present in the northern part of Ronga. Several small channels have a higher resistance than one big channel. Therefore, the discharge capacity of the river system is reduced by the several channels. Figure 190 shows an image of this pattern.

Figure 190: Several channels of Ronga North

Blocking the different channels and creating only one discharging waterway would increase the discharge capacity of the Ronga North. The estimated present and new discharge capacity is given in Table 58. If for example the profile which is existent just upstream of the braided part is used the discharge capacity increases to 34.4 m^3/s.

Table 58: Properties of one channel in the Ronga North

Properties			
Length	L	3.74	km
Width	W	17	m
Height	h	1.3	m
Max current discharge cap.	$Q_{current}$	26.2	m^3
Max new discharge cap.	Q_{new}	34.4	m^3/s

Impact
Increasing the discharge capacity has a positive effect on the flooding, since it reduces the flood volume and extent. If all the tributaries are dammed, water used for irrigation and for cattle will become less accessible. This could be mitigated if control structures are implemented in the tributaries. Without the control structures, it is believed that the solution is not supported by the villagers. It will also not be durable, since farmers would reopen the tributaries for irrigation purposes. Creating one river reduces the time the water needs to flow to the reservoir. It therefore has less time to infiltrate and evaporate. However, the sediment transported has less time to settle as well. As a result, more water will enter the reservoir taking more sediment with it. Regarding the time span, it is expected that this is a long term solution, since widening a river and blocking its tributaries over a length of almost four km is a tedious job to do with the equipment available.

I.6.6 Channel west of Kikuletwa

Another option would be to create a new channel west of the Kikuletwa running from north to south in order to discharge the run-off from the mountains west of the problem area. This has been described in the Analysis. Linking this channel to the Kikuletwa would create a by-pass around the narrow part of this river. An example of the location of the channel is given in Figure 191. Its properties are stated in Table 59.

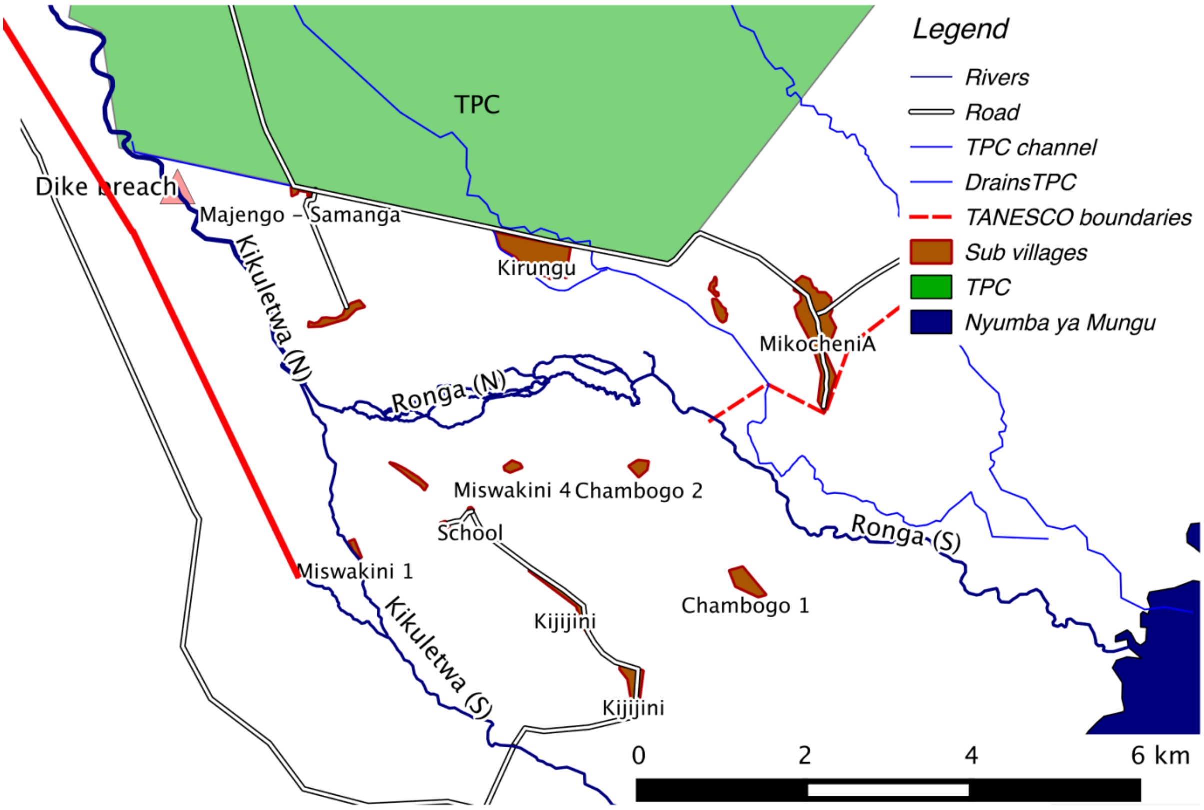


Figure 191: Possible location of channel west of Kikuletwa

Table 59: Properties of channel west of Kikuletwa

Properties			
Length	L	~6	km
Width	W	Variable	m
Height	h	Variable	m
Max current discharge cap.	$Q_{current}$	Variable	m^3
Max new discharge cap.	Q_{new}	Variable	m^3/s

Impact

Table 59 shows that a lot is variable in this solution. This is because the channel has to be created and therefore the properties can be determined and designed. It channels a part of the water away from the smaller part of the Kikuletwa (N) and therefore reduces the flooding in the problem area. During the dry seasons it does not have to be used. Creating such a long channel is a long term solution, since it takes long to build. Moreover it is expensive to build such a channel and it is situated in a different region. More water would be present west of the Kikuletwa in the rain seasons. However the water is discharged more quickly as well, which leaves less time to irrigate the water.

I.6.7 Drainage channels

A way to mitigate the long floods is to construct drainage channels which drain the flood water. The drainage channels could be build on the border of the outer farmlands, which is shown in Figure 192. To this large drain, smaller drainage channels could be built to drain the water to this larger drain. The drains are not directly connected to the river, but start halfway between the large drain and the river. When they only work if floods occur, it therefore does not solve the flooding problem. It only helps dissolve the floods in a faster way.

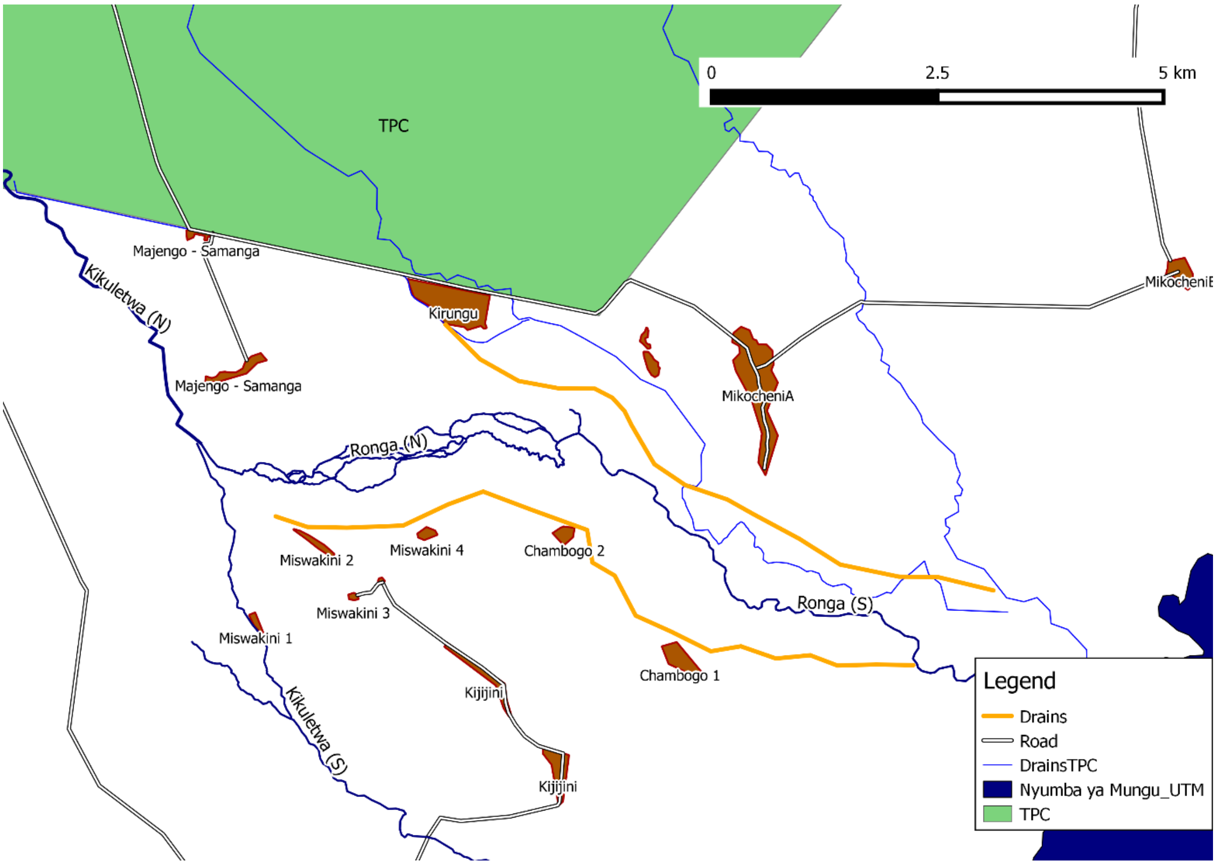


Figure 192: Drainage channels

Impact

The drains will not have a direct influence on the river system and flooding mechanism. However, the drains may reduce the total flooding time enormously. The drainage channels could maybe form an obstruction to road vehicles. A little bridge should then be build to divert the water under the road. Also, if the drainage channels are also used as irrigation channels during dry season, these should be blocked. Because otherwise water can flow away and the drainage channels do not work.

The villagers will probably react positive to this mitigating measure because the flooding volume decreases and thus the amount of water that stands still on their land decreases. This option is relatively easy to construct and only requires an excavator or a lot of manpower of local villagers. The drain however should be maintained well and should be constructed with a layer of grass. This will increase the durability of the drains.

Appendix J SCORES OF THE DIFFERENT SOLUTIONS

In Table 61 the different measures have been ranked on the different criteria. The solutions are ranked relatively; the highest score to be obtained is 18 points, the lowest score is 1. In column B it can be seen that 7 alternatives score zero points. This is because they do not enhance the positive effects in any sense. For clarification the criteria are listed in Table 60.

The six different criteria are listed below:

Table 60: Criteria for Multi Criteria Evaluation

	Criterion
A	Reducing negative effects of flooding
B	Enhancing positive effects of flooding
C	Tangibility and support
D	Durability
E	Constructability
F	Costs

The results of the Multi Criteria Evaluation are listed below.

Table 61: Ranking the different solutions on the different criteria

	Description	A	B	C	D	E	F
1	Open up Kikuletwa South	16	12	16	17	14	13
2	Use old river bed – Ronga Ndogo	4	8	12	15	12	12
3	Use dry river bed - Chem Chem river bed	11	16	15	16	18	14
4	Irrigation reservoirs	1	11	9	10	9	11
5	Peak reservoir	17	13	8	7	3	3
6	New channel West Kikuletwa	18	15	11	14	11	10
7	Channel through TPC	5	9	1	18	13	15
8	Dike Samanga area	15	0	17	13	10	8
9	Dike Samanga including control structure	14	14	18	12	8	2
10	Short rain dike Ronga	10	18	13	1	15	16
11	High dikes along Ronga, including control gates	13	10	14	11	1	1
12	Deepen river sections Ronga	8	0	5	4	2	4
13	Straighten river sections	7	0	2	8	7	7
14	Widen river sections Ronga	12	0	10	6	4	9
15	Decrease friction river sections	3	0	7	3	6	6
16	Straighten "Ronga braided reach", one channel	6	0	3	9	5	5
17	Drainage channels	9	0	6	5	17	17
18	"Rice field" structure, including control structure	2	17	4	2	16	18

Appendix K SAMANGA OVERFLOW CALCULATION

In this appendix an estimate is made on the amount of water which should flow over a control structure from the Kikuletwa into the Samanga area. This flow is illustrated in Figure 193 with the black arrows.

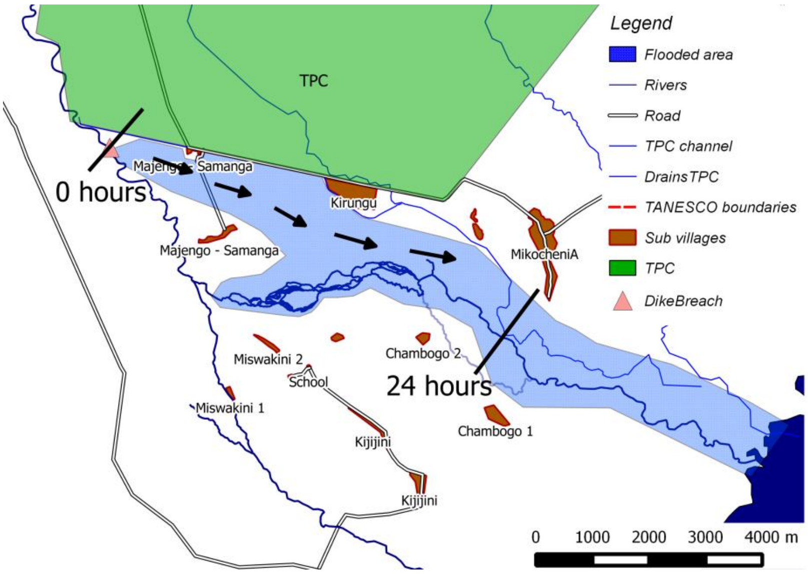


Figure 193: Samanga flow

In the current situation water flows freely and is uncontrollable during high water. During interviews it became clear that the water at Samanga is flowing and can be as high as half a meter. Also, because of high flow velocities, the land in the area starts eroding. To counteract the destructive effects of the overland runoff a maximum runoff will be determined in this section, to make an engineering approximate of the desired amount of water entering the Samanga area.

K.1 Calculations

To perform calculations over a floodplain, comprehensive and extensive calculations should be made. The whole system should be taken into account and a total analysis should be made. These calculations are not possible in the time frame of the project. That's why an estimated guess will be made which may not be completely correct, but gives a good indication to continue working with.

The maximum flow speed over the grassland is taken as a starting point. It is assumed that the average flow speed (u) of the water should have a maximum of 0.2 m/s. With higher velocities the ground starts eroding. Strickler-Manning formula is used to derive an average water height for the flood plain. The Strickler-Manning coefficient (n) for a floodplain with short grass is 0.03. The slope (i_b) over the total Samanga area is 0.002. With the assumption that the width of the plain is very large compared to the height, the average water height is:

$$h = \left(\frac{u \cdot n}{\sqrt{i_b}}\right)^{\frac{3}{2}} = \left(\frac{0.2 \cdot 0.03}{\sqrt{0.002}}\right)^{\frac{3}{2}} = 0.048\, m$$

The smallest part of the Samanga flood plain is 500 meter wide. This leads to a maximum discharge of: $500 \cdot 0.05 \cdot 0.2 = 5\ m^3/s$.

K.2 Conclusion

For the preliminary calculations regarding maximum and minimum discharge in the solution system a value of 5 m^3/s should be strived for. The control structure at Samanga next to the Kikuletwa should be designed in such a way that during high water no more than 5 m^3/s overflows.

Appendix L SAMANGA DIKE

L.1 Failure mechanisms

For the design of a river dike a number of failure mechanisms have to be taken into account. An important distinction between river dikes and sea dikes is the relatively long timeframe of higher water level along the dike. This results in a permanent rising phreatic level within the dike. This results in different failure mechanisms. The following failure mechanism and their measurements will be taken into account:

Macro instability - Slope instability

During extreme high water levels, induced by discharges higher than the design discharges, the water levels can rise as high as the dike itself. In this situation there will be water overtopping the dike. As a result there will be a flow along the inner slope of the dike. This also results in instability of the dike profile. This situation is illustrated in Figure 194. Therefore it is advisable to make use of clay on all the outside layers of the dike. This clay will reduce the infiltration of water into the core of the dike and reduce the eroding of the outer layer due to river currents. Implementing the inner slope of the dike with clay is therefore essential.

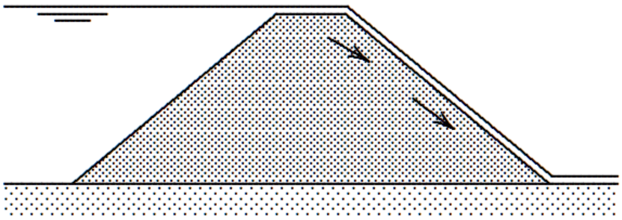


Figure 194: water flow along the inner slope. [20]

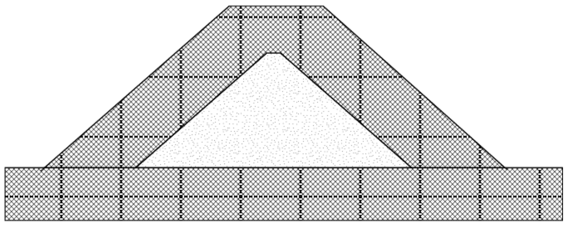


Figure 195: Dike with clay-layers on all sides.

Macro instability - Horizontal instability

Horizontal sliding of the total embankment is a failure mechanism that has to be taken into account. The forces resulting from the active water pressures are counteracted shear forces resulting from the total deadweight of soil volume of the dike. The wet volumetric weight of different soils ranges from 17 to 26 kg/m^3.

All used values are based on the Dutch standard: NEN 6740:2006 Table 1 [30]

The shear stress underneath the dike that counteracts the water pressures is given by:

$$\tau_f = c \cdot \sigma' \ \tan\phi$$

In which:

Property	Symbol	Dimension
Internal friction	ϕ	-
Effective pressure	σ'	-
Cohesion	c	kN/m^2

In this formula the most conservative situation with a total saturated dike body with the lowest volumetric weight and no cohesion is assumed.

It is assumed that the dike body is totally saturated. A wet volumetric-weight of sand of 17 kg/m3 and an angle of internal friction of 30 degrees results in a shear stress of: $\tau_f = 4$ kPa.

The total resistance force (R) against the water pressures is defined by the equation:

$$R = B \cdot \tau_f$$

With a width of the dike of 6.5 meter the total resistance force is 26 kN/m.

The active water pressure force (F_w) is given by:

$$F_w = \frac{1}{2} \cdot \rho_w \cdot g \cdot h^2$$

If the water height is 0,5 meter, the water force on the dike is 12.5 kN/m

The unity check is then given by: 26/12.5 = 2.08, which is sufficient.

Another situation is present when weak sandy clay is assumed. The dike then has a wet volumetric weight of 15 kN/m2, an internal friction of 17.5 degrees and a minimal cohesion of 2 kN/m2. The shear stress is then given by 3.6 kN/m and the resistance force is by 23.4 kN/m. The unity check is then 23.4/12.5=1.872. Therefore the construction is also sufficient in this situation.

Micro instability:
Due to local instability at the inner slope, the dike can fail. This is a result of the seepage of water through the dike, due to high water pressures in the inner core of the dike. This is depicted in Figure 196. Measures to prevent this problem are:

- Constructing the outer cover of the dike with a clay layer that is thick enough to counteract the water pressures.
- Prevent uplift of the inner slope by using an inner berm.

It is essential to implement one of the above measures to secure the safety of the dike.

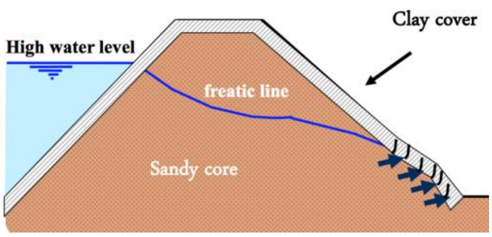


Figure 196: situation sketch micro instability

Piping
Piping is one of the most underestimated failure modes of dikes. Due to internal erosion as a result of a water head difference the dike fails. A method to control the minimum leakage length (L) of Bligh will be used. In Figure 197 this method is illustrated.

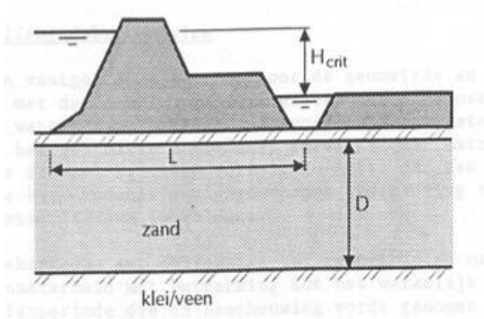


Figure 197: Bligh method; piping

The minimum required length is given by:

$$L \geq H_{crit} \cdot C_{creep}$$

The parameter C_{creep} is 12 for coarse sand and 18 for fine sand/silt. In the design situation H_{crit} has a value of 0.5 m. Assuming fine sand or silt this results in a minimum leakage length of 9 m. It is however most uncertain that the subsoil under the dike consist out of fine sand. The floodplains where the dike will be situated consist of river deposits. These deposits have a gradation between highly salty to clay. These have the property of low permeability and therefore the above leakage effect will not appear.

Length-effect
A dike is a structure that can be divided in dike sections. The strength of a dike section is as large as its weakest link. This means, the longer the dike, the larger the change of failure. It is therefore essential that the quality and homogeneity of the dike is as constant as possible.

L.2 Materials

The core of the dike consists out of sand or clayey sand. The outer layer consists of 0.4 thick clay layer/cover. As mentioned before the soil properties are hard to determine.

For a clay-layer the following properties are important:

- Presence of soil structures in the clay-layer: The presence of soil structures is of high influence to the permeability and eroding of the soil. The presence of soil structures is dependent on water content and the way of execution.
- Water content: Soil structures are formed due to climate and weather effects. Clay has the property to shrink and swell, which is dependent on the water content. To reduce the forming of structures after execution, the water content, indicated by the consistency index (I_c) of the clay, has to be lower than 0.6[21]. Determination of this value is not possible in Tanzania, because appropriate facilities are not available.
- Way of execution: Every placed clay-layer always consists out of chunks of clay called aggregates. After the initial placement of the clay pores are present between these aggregates. To reduce the porosity of the clay layer it is therefore important to roll the placed layers. By the process of compaction the porosity will reduce.

For sand core the following properties are important:

- Homogeneity: To get an equal quality of the dike, it is important that the soil that is used is homogeneous enough. Large particles such as boulders, stones, roots or branches have a negative influence on the stability of the dike.
- Compaction: for the strength of the dike, the grade of compaction is important. Sand structures are in essence small rolling interlinked stacked balls which can have different configurations. To make sure this stacking is optimal two methods are possible:
    - To saturate the soil with water: The water will drain and the particles will find the ideal configuration. A too large amount of water will result in instability. Sprinkling is therefore advisable.
    - Compaction: this method is essential for the stability of the dike. It can be done by rolling over the sand with a large weight such as a concrete roll or by the weight of machinery. Another method is drilling the layer.

  It is important to use these methods frequently enough, after each 0.3 m of added layer.

Appendix M POSSIBLE CONTROL STRUCTURES AND PROPERTIES

M.1 V-Notch weir

As its name suggests, a V-Notch weir is V-shaped. It has an increased discharge capacity as the water level rises. It can be made from different materials such as concrete, steel and wood. Figure 198 shows an example of a V-notch weir, Figure 199 shows how it can be applied as a control structure.

Figure 198: A V-Notch weir

(source: LTER Network Office)

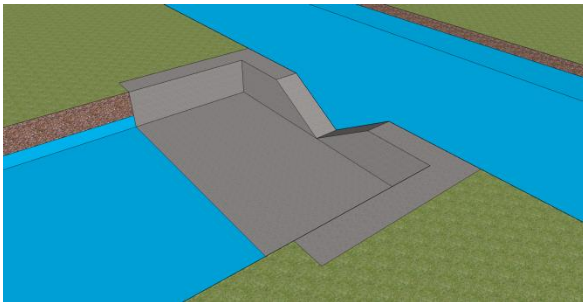


Figure 199: Visualisation of the application of a V-Notch weir

An advantage of this type of control structure is that it is rigid. If the slopes of the 'V' are right, the weir gives the tributary the right amount of water for a certain water level. The type of material used for the V-Notch weir determines how easy the structure can be adjusted. If made out of concrete it would be hard to modify, a steel or wooden weir could be modified or replaced with greater ease.

M.2 Legioblock®

The Legioblock® is an interlocking concrete block. Figure 200 shows the Legioblock®, Figure 201 shows how they can be used to make a control structure. It is produced in different sizes ranging from 0.4 m x 0.4 m x 0.4 m up to 1.6 m x 0.8 m x 0.8 m.

Figure 200: The Legioblock®

(source: www.letsrecycle.com)

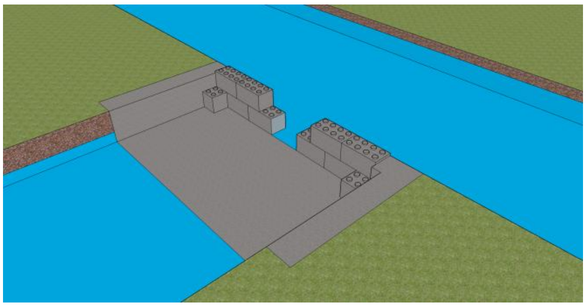


Figure 201: Visualisation of the application of Legioblocks®

An advantage is that the height of a control structure built with Legioblock® can be adjusted after construction. Blocks can be removed or added. Additionally, it is not possible to lift the blocks without heavy machinery, which ensures that FTK can only remove the block when needed. Since not all locations are easy accessible by road, the need to use heavy machinery may also be a disadvantage. Additionally, the Legioblock® may imply difficulties in producing the block in Tanzania.

M.3 Gabions

Gabions are steel cages filled with stones or rocks, see Figure 202. Figure 203 shows how gabions can be used to create a control structure.

Figure 202: Gabions

(source: nitinwirenetting.com)

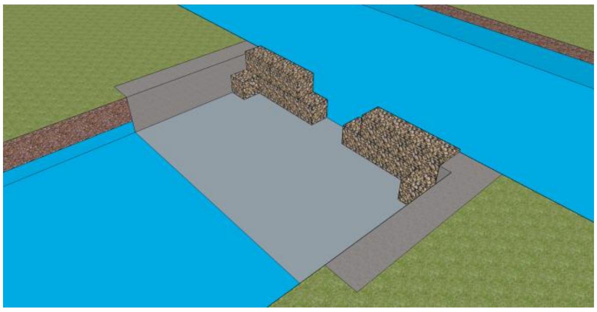


Figure 203: Visualisation of application of gabions

The advantage is that the height of the control structure built with gabions can be adjusted after construction. Cages can be removed or added. Contrary to the Legioblocks®, the cages can be installed locally without heavy machinery. This means that villagers can remove stones from the cages to adjust the control structure, which may be disadvantageous. Additionally the steel cage may rust over time and the structure may disintegrate.

M.4 Sheeting

Sheeting can be used to control the height of a structure. The steel/concrete sheets or wooden planks are placed in U-shaped sockets. An example can be seen in Figure 204. Figure 205 show a visualization of this control structure.

Figure 204: Sockets for sheeting

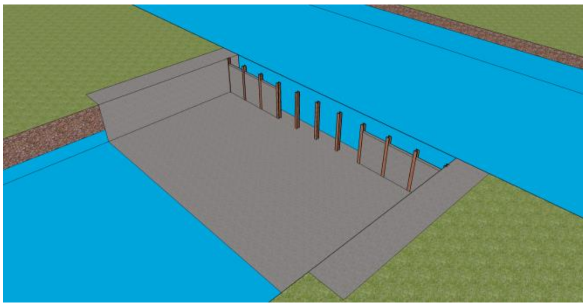


Figure 205: Visualisation of the application of sheeting

The advantage is that the height of the control structure built with sheeting can be adjusted after construction. Planks or sheets can be removed or added. However, since their weight is relatively small, everyone is able to remove or add sheets/planks. Moreover the steel may wear down over time. This can be prevented by increasing the plank size to such a size that it is not able to move by manpower.

M.5 Sill

A sill is a rigid concrete structure which diverts the water above a certain water level. As the water level increases, the amount of discharge released through the sill path is also increased. The Sill can be built in different ways, as shown in Figure 206.

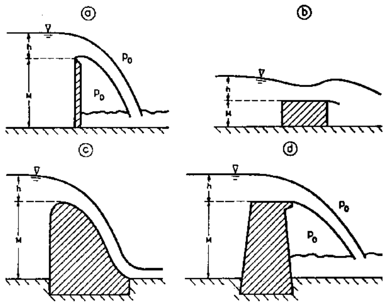


Figure 206: Different type of sill shapes

(source: http://www.fao.org)

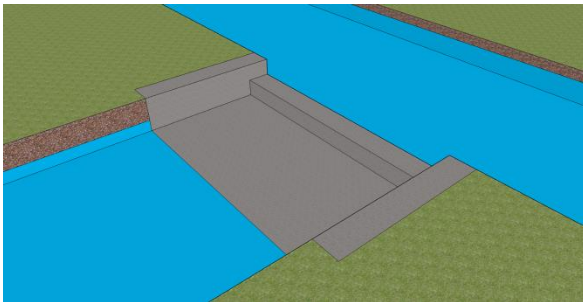


Figure 207: Visualisation of the application of a sill

The sill can be built in such a way that the water flows in a thorough manner down the sill. This can be done to prevent supercritical flow downstream of the sill, which causes erosion. This construction type is not adaptable and thus cannot be changed if it is built wrong.

M.6 Pipes

Alternatively to the sill, a water retaining wall with pipes could be built as well. The pipes are installed at such height that it ensures a certain base flow during arid times and diverts enough water away from the main waterway during rain seasons. Figure 209 illustrates this principle

Figure 208: Pipe through earth wall

(source: home.kpn.nl)

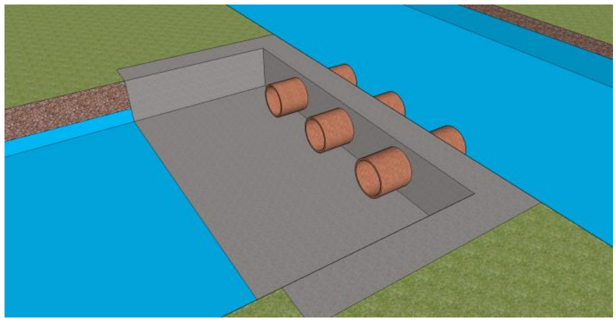


Figure 209: Pipes regulating the discharge

Since it is rigid, it is not possible to modify the structure easily. Of course one of the pipes could be blocked to reduce the discharge, but increasing the maximum discharge capacity is not possible. Constructing the pipes in a dike, see Figure 208, could lead to instability of this dike or the pipes could be flushed out. An advantage is that a rigid structure can be created without the use of heavy lifting machinery.

M.7 Diversion structure

A diversion structure fixes the division of discharge in both waterways. Figure 210 shows a real-life example, Figure 211 shows a visualisation of such a structure.

Figure 210: Diversion structure

(source: www.geocaching.com)

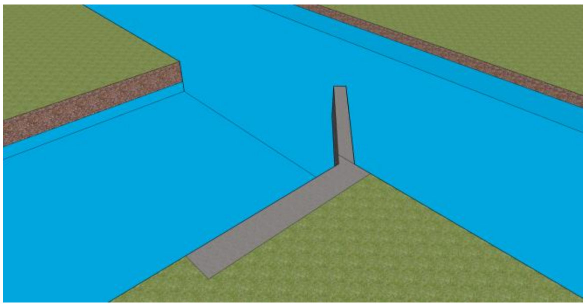


Figure 211: Visualisation of the application of a diversion structure

A diversion structure can be made out of different materials, such as rocks or concrete, and can be constructed on site, without the need of heavy lifting machinery. An advantage is that can remain for a long time. On the other hand, it is difficult to determine what the division of discharges to both branches will be. Once built, the geometry of the bifurcation changes and possibly too much water will flow to one side. This is hard to change afterwards.

M.8 Flow gate

A flow gate regulates the amount of water with doors. Figure 212 shows a flow gate in the project area (Samanga).

Figure 212: An example of a flow gate in the field

An advantage of such a structure is that it can be regulated easily. However anyone can open or close the gates, which may lead to conflicts. No heavy machinery is needed which is a plus, but on the other hand the gates could be stolen or damaged easily.

M.9 Control structures properties

In Table 62 all seven different control structures are shown with their position regarding a certain property that a control structure should or should not have. The definition of each property is explained below the table.

Table 62: Control structures properties

Property	V-notch	Legiobloc k	Gabions	Sheeting	Sill	Pipes	Diversion	Flow Gate
Constructability	0	-	++	-	++	-	0	-
Adjustability	-	+	+	++	--	-	--	++
Changeable only FTK	++	++	--	+	++	0	-	-
No Heavy machinery	++	--	+	-	++	-	-	+
Durability	+	+	-	0	++	+	+	-
Flow characteristics	+	+	+	+	-	0	--	++

Constructability
The constructability property relates to the ease and efficiency with which the control structure can be built. A structure is positively constructible if it is easy to make, because the design is easy to understand and interpret by a local contractor.

Adjustability
Adjustability relates to the ability to change and adjust the control structure over time to changing flow properties. Also, it takes into account adjusting the construction to errors that are made in the design which are changeable or not. The adjustability is positive when it is able to modify its design.

Changeable only FTK
This property relates to the societal issues related to constructing a control structure. It relates to the ability of FTK to be the only one to adjust the structure overtime. A structure's property is negative if local villagers (close to the control structure) can change the structure. They may do this because it is beneficial for them locally, but it can have negative consequence for the total system.

No Heavy machinery
The heavy machinery property takes into account whether any heavy machinery needs to be used to construct the structure. Preferably no heavy machinery should be used to construct the control structure because the location may be hard to reach with these machines. If a control structure positive on heavy machinery it means that it makes no use of these machines.

Durability
Durability takes into account whether the structure is enduring and reliable for a longer time. Also, it considers if the construction needs any maintenance overtime or not. A durable construction is positive.

Flow characteristics
The property of flow characteristics relates to the ability of the control structure to fulfil all the properties of the minimum and maximum discharges overflowing the structure. It takes into account if the structure releases little water in the dry season while discharging not too much water during the rainy season.

Appendix N Design procedure control structures

In order to create adjustable control structure that releases a minimum discharge during the dry seasons, a sill was chosen with two pipes at a lower level. If the discharge over the sill appears to be too high in the rainy season, extra concrete blocks (see Appendix M) could be placed on top. The structure has been designed using knowledge of fluid mechanics [23] and hydraulic structures [31].

N.1 Design

There are two similar control structures to be designed: one at the bifurcation of the Ronga and the Kikuletwa South, control structure 1, and one at the bifurcation of the Ronga and the Chem Chem river bed, control structure 2.

N.1.1 Assumptions

- It is assumed that the control structure makes an angle of 45 degrees with the Ronga;
- For discharge calculations, an average flow velocity in the Ronga of 0.68 m/s and 1.05 m/s are used for the dry and rainy seasons respectively;
- The water level in the Ronga is assumed to be 1 m in the dry season and 2 m in the rainy seasons;
- The banks are assumed to be 1 m above the dry season water level;
- For the pipe calculations, a μ-value of 0.8 is used;
- For the pipe calculations, a varying hydraulic head *(H)* of 0.60 m (situation 1) – 1.0 m (situation 2) is used.
- For the sill calculations, it is assumed that the water is discharged with the same flow velocity as the average flow velocity in the Ronga at that moment;
- For the scour protection calculations, the maximum distance of the reattachment point of the turbulent flow is assumed to be at 5 - 7 times the height of the sill [32].
- For the scour protection calculations, the maximum length of the scour protection is assumed to be 10 times the height of the sill [32];
- The density of concrete is assumed to be 25 kN/m^3.

N.1.2 Capacity calculation

Their load criteria are similar, however their discharge capacity differs. Both structures should allow 1 m^3/s to flow into the Kikuletwa and Chem Chem river bed during the dry season. In the wet season, control structure 1 has to discharge approximately 23 m^3/s into the Kikuletwa South. Control structure 2 has to discharge 6.8 m^3/s in the rainy season.

Pipe calculation

The discharge capacity in arid times is the same for both control structures. A pipe of with a diameter of 0.8 m is proposed. The bottom of the pipe is placed 0.9 m below current surface level. Using the theory from fluid mechanics [23], the discharge properties are calculated, see Table 63.

Table 63: pipe properties

	Situation 1		Situation 2	
Hydr. head (H)	0.60	m	1.0	m
Diameter pipe	0.80	m	0.80	m
Level bottom pipe[9]	-1.10	m	-1.10	m

[9] Relative to current surface level

Discharge capacity	1.80	m^3/s	2.31	m^3/s

Table 63 shows that this pipe diameter is large enough to discharge the proposed 1 m^3/s. Actually it is slightly over dimensioned. This is done to ensure that water is flowing into the Kikuletwa South and the Chem Chem riverbed. Moreover, the calculations done are theory based, which may differ from practise. The pipe diameter could reduce over time due to clogging of debris and vegetation. Additionally it is easier to decrease the diameter than to increase it after construction has finished. Increasing the diameter could do damage to the structure.

Sill calculation

The different discharge capacities in the rainy seasons lead to different widths of both control structures. The water level above the sill is proposed to be 0.9 m. This would imply that the height of the structure is 1.1 m, excluding the foundation. During the rainy season, a hydraulic head of 1 m can be expected. This would lead to a pipe discharge of 2.31 m^3/s, as mentioned in Table 63. Subtracting this value from the desired discharge capacity of 23 m^3/s and 6.8 m^3/s for control structures 1 and 2 respectively, gives the discharge capacity needed for the sill. The sill properties have been summarised in Table 64.

Table 64: Sill properties

	Control structure 1		Control structure 2	
Hydr. head (H)	1.0	m	1.0	m
Level top of sill[10]	+0.10	m	+0.10	m
Width sill	23.0	m	5.50	m
Capacity needed	20.7	m^3/s	4.49	m^3/s
Actual capacity	21.7	m^3/s	5.20	m^3/s

N.2 Check design

In order to test whether the designed structure can withstand the loads in reality, two prevailing cases have been checked:

- Case I: With concrete blocks;
- Case II: Without concrete blocks.

In Case I, the concrete blocks have been placed on top of the sill. This could be the case during the rainy season. There is a hydraulic head difference of 1 m. This case is been schematised in Figure 213.

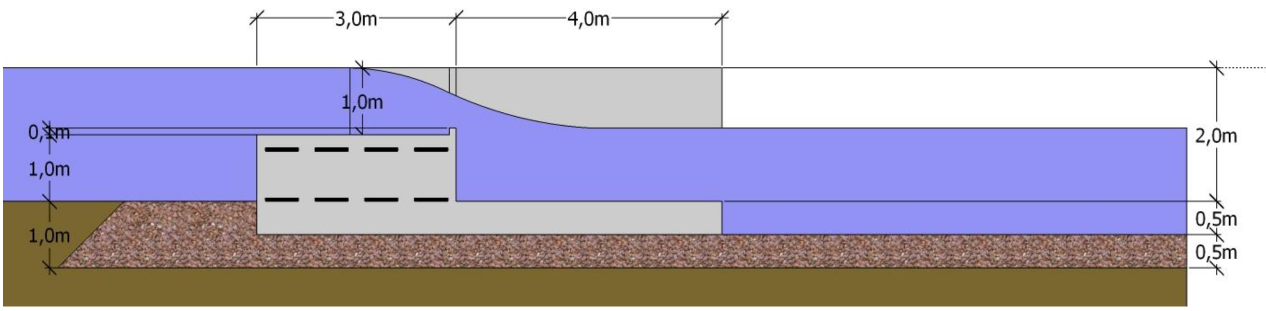


Figure 213: Hydraulic head case 1

[10] relative to current surface level

In Case II, concrete blocks have been placed on top of the sill. There is a hydraulic head difference of 1.1 m. This is the case in the dry season and is schematised in Figure 214.

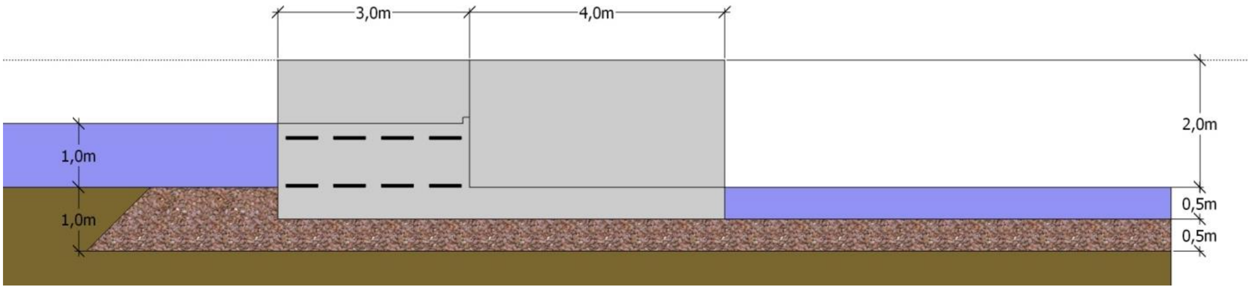


Figure 214: Hydraulic head case 2

The following checks have been performed:

- Horizontal stability: Is the structure heavy enough to withstand the horizontal (water) loads?
- Rotational stability: Has the structure a wide enough foundation in order not to topple over?
- Vertical stability: Is the bearing capacity of the soil high enough to withstand the additional pressure caused by the control structure?
- Piping: Is the width of the structure enough to prevent piping?
- Scour: Is the structure protected enough against scour that may influence the stability of the structure?

Table 65: Unity checks[11]

	Case I	Case II
Horizontal stability	1.21	1.51
Rotational stability	1.37	2.12
Vertical stability[12][33]	1.49	2.82
Piping (Bligh)	1.07	1.07
Scour (10 *1.1 m)	0.36	0.36

N.3 Additional measures

In this section additional measures and details are discussed. These measures have to be taken in order to prevent different failure mechanisms from occurring.

N.3.1 Piping

As can be seen in Table 65, the unity check on Piping results in a value only just greater than 1.00. It should be noted that this value has been achieved using a gravel bed as foundation. Therefore it is advised to place the construction on a gravel bed of at least 0.5 m.

N.3.2 Scour protection behind structure

As can be seen in Table 65, the structure itself is not long enough to be protected against scouring. Therefore protection against scour is needed. It is advised that a 7 m long bed protection is placed

[11] A value below 1.00 is considered to be an unsafe design

[12] Based on very soft clay 50 kN/m^2

behind the control structure. This could be realised by extending the gravel foundation. Extra care should be taken on the installation of the scour protection at the reattachment point where turbulence will be largest. This point is located 5 – 8 m behind the sill.

N.3.3 Scour protection in front of structure

The calculations in this appendix have been mainly focused on the hydraulic head difference over the structure. However, there are other failure mechanisms the structure can be prone to. Due to the sediment transport, the Ronga River can scour away the bed in front of the structure. To prevent this destabilisation process of the control structure, it is advised to create a protective gravel layer in front of the control structure. For example extending the gravel foundation with another 3 m could reduce the risk of scour in front of the control structure.

N.3.4 Local reinforcements

In general, a (local) contractor should be consulted on the reinforcement of the structure. More specifically, extra care should be taken to reinforce the concrete around the discharge pipe and in the bottom concrete slab.

Appendix O IRRIGATION CONTROL STRUCTURES

This paragraph has the aim to give an overview of different types of control structures for irrigation purposes along the river. The need for irrigation water is induced by the low moisture content of the farming land during the dry season. As a result of the river bed of the Ronga River that is lying lower than the surface level, it is difficult to irrigate all year long. Currently natural floodings irrigate the land. The purpose of this appendix is to propose several solutions to gain irrigation water from the river at all times. Those irrigation structures or methods have to be combined with, or situated in, the embankments of the Ronga River.

O.1 Intake methods

Below four types of intake structures are presented:

1. Small weir with changing elements; (gated intake structure), see Figure 215
   - A drawback of this type of structure is that it is labour-intensive.
   - An advantage of this is that it can be adjusted to the current water level.
2. Spiles (PVC); limited discharge depending on water level and diameter, see Figure 216
   - A drawback of this type of structure is that it can be blocked.
3. Inflow over the banks; see Figure 217
   - A drawback of this type of structure is that it is difficult to control the amount of intake through the inlets.
4. Siphon (PVC); makes use of the principal of flow by gravity, see Figure 218
   - Limited discharge depending on water level and diameter.
   - Advantage is that siphons are flexible and not locational. Also the dike section does not need to be broken.

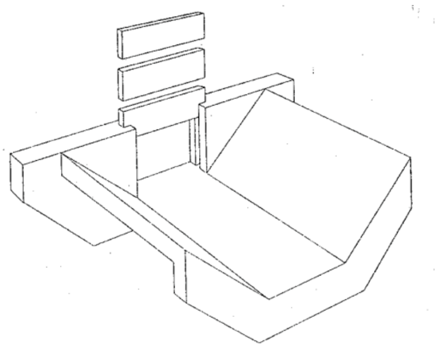


Figure 215: Simple weir structure [34]

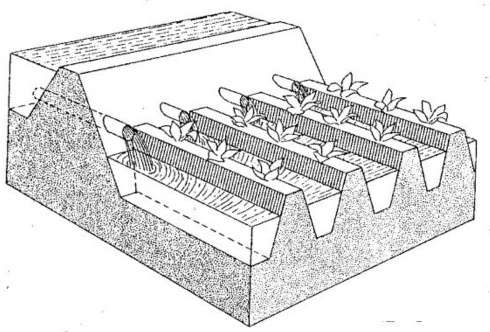


Figure 216: Spiles [34]

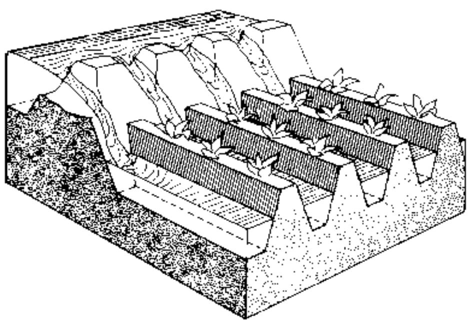


Figure 217: Inflow by open banks [34]

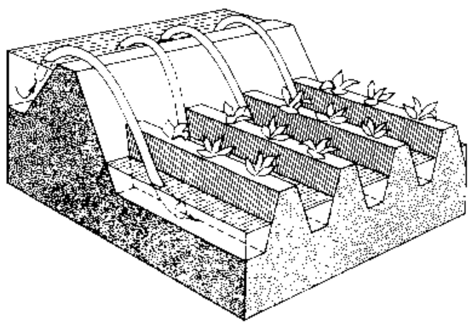


Figure 218: Siphons [34]

O.1.1 Current methods:
A current method to irrigate the land is by using manmade weirs that are self-operational and made of local materials. Examples of those weirs are presented in the field reports, Appendix P.

O.2 Implementation of the intake methods:
For above-mentioned types of structures different designs are possible. However, there are certain issues that need to be noted concerning the design. Mostly the structure will be integrated in the embankment, this can lead to instability of the embankment. The location of the structure and the resistance of the structure to overtopping during the long rain season will be elaborated below.

Location
The location is important because of the eroded capacity of the river due to the higher velocities in the outer bends. That's why the best location is between two successive river bends. At this location the highest velocities are situated in the middle of the river and the lower at the sides. The lower velocities at the sides result in less eroding of the banks and therefore less change of instability of the banks. This is illustrated in Figure 219.

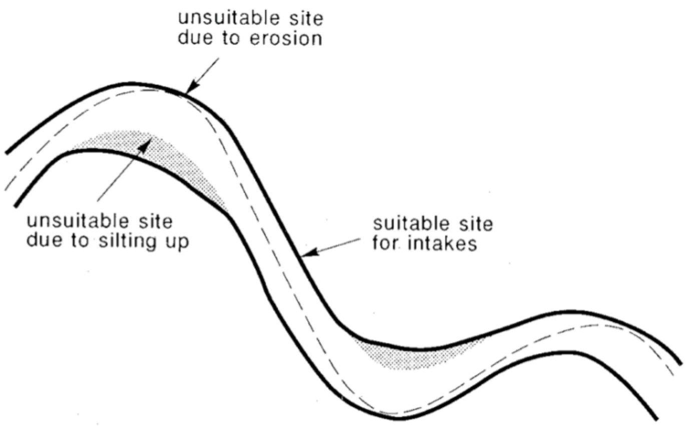


Figure 219: location irrigation intakes

Flow resistance
Along the Ronga, in case of high water levels during the long rain season, the river banks will overflow. When the height of the banks is the same for all locations there is no problem. Constructing banks with a clay layer and vegetation on top will then probably be sufficient for protection against scouring. At the inlet locations the embankment is locally lowered. The water will therefore flow in at a higher rate than at locations without an inlet construction. Measures to protect against scouring are therefore necessary.

Figure 220: concrete weir with timber elements, side extension

Figure 221: scouring protection with rocks

Possible solutions are the use of concrete structures that extent to the embankments sides and have a sufficient transition zone between the structure and the riverbed. A possible structure is Figure 220. Other possibilities are to use ‘filter layers’ between the construction and the bottom. For example by using heavy rocks, illustrated in Figure 221.

Appendix P FIELD REPORTS

During the analysis several field trips were conducted to gain insights in the water system and the floods. Measurements and observations were done, using several instruments like depth sounders and GPS-loggers. Interesting points were marked with GPS-waypoints. On the basis of the GPS-waypoints reports were made for every field trip.

These field reports are standalone reports and are not part of this report. Therefore they are added to the end of this report. The following field reports are added:

File name:	Date:	Guide:	Visited places:
20141112 Field observations v2.pdf	12-11-2014	Mr. Moshi (driver)	Mikocheni
20141114 Tour TPC v2.pdf	14-11-2014	Yann Hardy (TPC)	TPC
20141117 Field observations with Gerbert v2.pdf	17-17-2014	Gerbert Rieks (FTK)	Bifurcation, breached dike
20141120 Fieldwork with James 1 v2.pdf	20-11-2014	James Ashire (FTK)	North of Ronga River
20141128 Fieldwork with James 2 v2.pdf	28-11-2014	James Ashire (FTK)	Samanga, Kirungu and braided Ronga
20141202 Fieldwork with James 3 v2.pdf	02-12-2014	James Ashire (FTK)	Southern Kikuletwa
20141204 Fieldwork with James 4 v2.pdf	04-12-2014	James Ashire (FTK)	Chem Chem area
20141205 Aerial photographs.pdf	05-12-2014	Aat van der Wel (pilot)	Project area
20141208 Reservoir v2.pdf	08-12-2014	James Ashire (FTK)	Nyumba ya Mungu reservoir