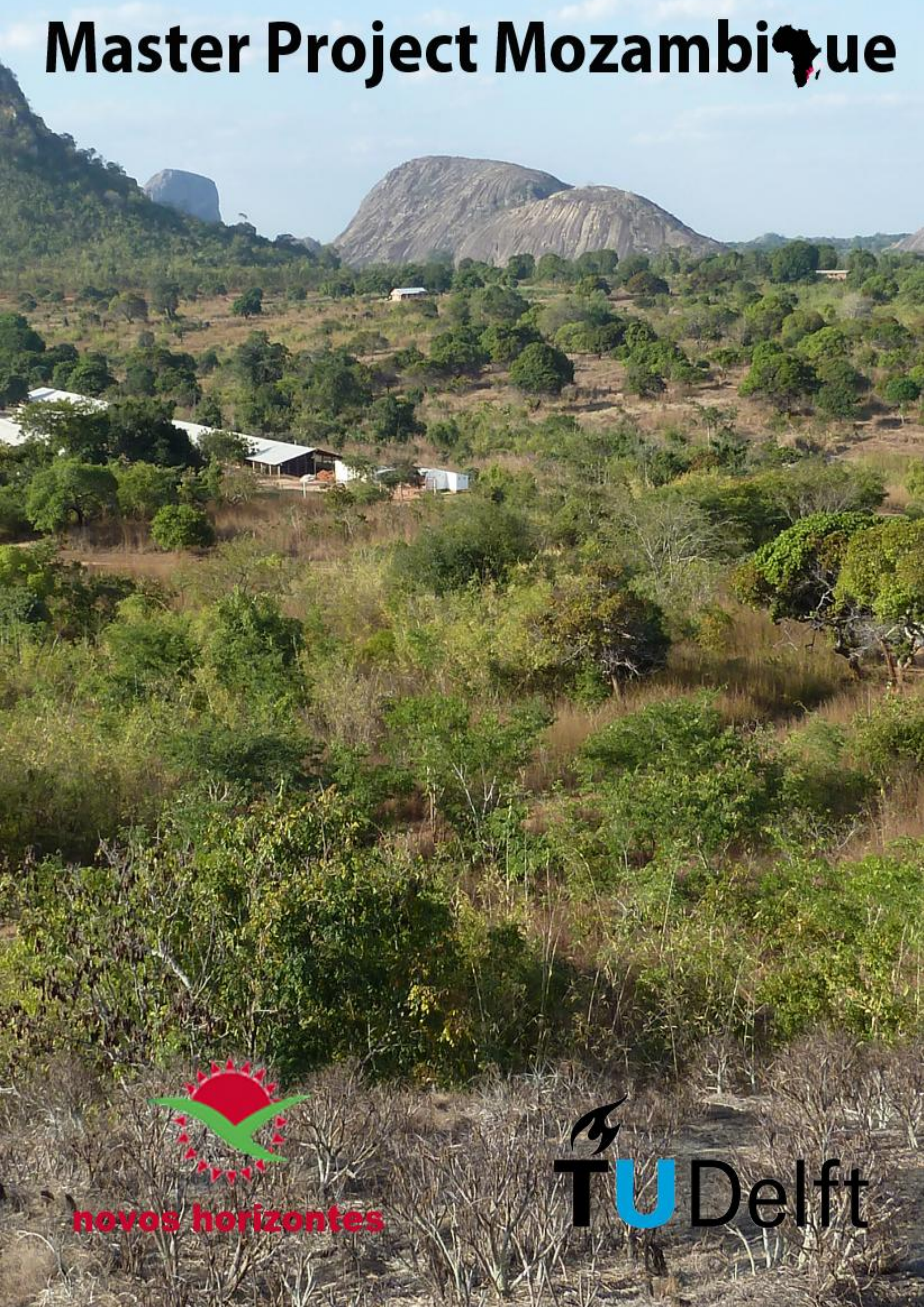
Master Project Mozambique



novos horizontes

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Preface

This report is the final result of Master Project Mozambique. Master Project Mozambique started with the idea to do a project abroad. After talking with several people at the Delft University of Technology, Cees Biesheuvel came in contact with Scott Marques, a man from Zimbabwe. Cees met Scott on a Sunday morning in Redeemer International Church, The Hague. During the church service Scott shared something about the work he was doing in Mozambique and in Zimbabwe. Scott told about dams they built in Zimbabwe and that they had a wish to increase the amount of water on a farm in Mozambique. Scott brought Cees in contact with Andrew Cunningham and with Wilfred van der Kooij. Andrew is the owner of Novos Horizontes and Wilfred is a Dutchman working for Novos Horizontes. After several Skype meetings and intensive email contact the project group decided to go to Mozambique.

The project has been executed for the course CIE4061-09 Multi-disciplinary project as part of the Master Civil Engineering at the Delft University of Technology (DUT). The total amount of credits for the project is 10 European Credits (ECTS). Multidisciplinary in this context means different master specializations within the master Civil Engineering. The different disciplines involved in this project are: Coastal Engineering, Geo-Engineering, Water Management and Structural Engineering.

Throughout almost all the project we worked and lived on a building site. The new Rapale International School was being built on the farm area and we occupied one of the semi-finished classrooms. This classroom was our multifunctional room where we worked, slept and lived for 6 weeks. Although the noise, dust and workers walking around the building site were not always providing suitable working circumstances, we were satisfied with the situation.

An open-air toilet and shower (with magnificent view), the sometimes poor internet connection and problems with the power supply made us often use the term TIA (This is Africa). We also experienced the dark side of TIA. We were surprised one night by men who were after our money. Fortunately we were unharmed and most of our belongings were still in our possession. However, part of the work for this project (and almost all laptops) were stolen during the robbery. We all decided, after the robbery, to stay in Mozambique and we would not back up for a couple of men with machete knives. Because of the robbery we were not able to finish the report as we had hoped, simply because of the time limitation. As a consequence not all parts of this report could be elaborated in such detail as was anticipated beforehand. But we were all very motivated to make this project useful for Novos Horizontes and we therefore hope that the results of this project will inspire the responsible people during the planning of the future developments of Novos Horizontes. During our stay, our trips to the city and further into Mozambique we also discovered the other side of TIA; beautiful landscapes and friendly people. Despite the huge language barrier we tried to communicate a little with the local people. Unfortunately most of us did not come much further than ‘bom dia’ and ‘tudo bem’ and attempts to speak with the use a dictionary were often met with a big smile showing neither of us understood each other.

Word of thanks

We are thankful for the opportunity to work on Master Project Mozambique. We found our time in Mozambique as a good and most of all practical addition to the theory taught at the university. We also learned a little bit more about working in a group with different people with different interests and in our opinion that will be very fruitful for our future professional work.

First of all, we would like to thank Wilfred van der Kooij, Riemer te Velde and Andrew Cunningham for their great support, their advice and help during the project. They were always there for us if we needed information, translation or a lift into the city. Their openness to new ideas and discussions on how things work in Mozambique have been very useful in realizing this report.

A special word of thanks we would like to give to Carola van der Kooij and Jennifer te Velde for the warm welcome, the very big hospitality throughout our stay in Nampula and especially for being there for us when we needed it.

We also would like to thank the Greens, Mike and Dilys, for letting us stay at the new Rapale International School. We also would like to thank Frank Dekker from DHV Mozambique for his contribution to the project.

Furthermore we would like to thank our sponsors, the supervisors of the Delft University of Technology and other persons who contributed to realizing this report.

Enjoy reading this report!

September 2012, Nampula Mozambique

The Dutch Dam Boys

Cees Biesheuvel
Jesper van Es
Richard Geerling
Hans-Peter van den Heuvel
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Rolf van Rijn.

Summary

Novos Horizontes started seven years ago in Mozambique and is part of Communities of Fusion. The Communities of Fusion, in this report, includes: Novos Horizontes, Eggs for Africa, Rapale International School, Ebenezer College and Arcapula. All these organizations are located in one area (farm) and work together. The main activity of Novos Horizontes is a vertical integrated poultry operation. The core of the business is to get the local community involved in the complete production process by providing them chicks and feed on credit, so they can grow the chickens until they are ready for slaughter. Novos Horizontes is currently planning to expand their activities. This expansion will stress the already critical state of the water availability even more. This Master Project Mozambique is aimed at finding a solution for the water problem of Novos Horizontes. The main objective of the project is stated below:

'Contribute to a structural improvement of the water system for the companies and organizations that are part of Communities of Fusion'

Part A: Current and future situation

Almost all companies and organizations belonging to Communities of Fusion are located on one farm, which is the project area of this report. The farm has a surface area of approximately 650 hectares (ha). The average annual temperature in the region is around 26°C and the average annual rainfall is 1,100 mm/year (based on a model of NASA). Almost all of this rain falls during the wet season (October to May), which means that the other months are very dry.

In the current situation there are three main consumers of water on the project area. These include chicken operations, the hatchery and the abattoir. Smaller users of water include residential buildings and office buildings. The abattoir is the main consumer of water on the farm. In the current situation it uses 48 m^3/day, which is 42% of the total amount of water (112.5 m^3/day) that is used on the farm. The water demand of different consumers is based on estimations made by the consumers themselves. In order to verify these estimations, a rough check on the order of magnitude of the used water by the abattoir (main user) was performed.

The total current water demand of 112.5 m^3/day is supplied by nine different boreholes. Seven of these boreholes are owned by Novos Horizontes and are supplying the abattoir, the hatchery, the chicken operations and some residential houses. The other two are owned by Eggs for Africa. At this moment, the water supply by the boreholes is critical, as especially at the end of the dry season there can be a shortage of water. The water quality of the boreholes is not critical, this meets the water quality requirements.

Novos Horizontes is currently planning to expand their activities. For this expansion, they formulated a demand of 1,551 m^3 of water per day for various purposes. This is almost 15 times the current water demand. In addition, Novos Horizontes wants to meet the water quality standards, which are included in the Mozambican law. Essentially this means that the water of the abattoir needs to be clean, canalised drinking water, free from any floating particles and treated with chlorine. Besides these water quantity and quality requirements, which are the boundary conditions for a possible solution, Novos Horizontes has asked to examine the reliability and sustainability of the different solutions.

Part B: Study of possible solutions

Beforehand there were four possible solutions: reuse of water, boreholes, rainwater harvesting and reservoirs. Three of these possible solutions are elaborated in the study of possibilities. The possibility 'reuse of water' is excluded from this study due to the limited amount of knowledge on this subject.

Because the slaughter process only pollutes the water (there is no water loss), water reuse has a great potential to give a significant contribution in solving the water problem. It is therefore recommended to elaborate this solution in a further study.

Another solution that can help to meet the future demand is creating additional boreholes. By making use of the results of the current boreholes and geological information, the prospected yield of the boreholes is estimated. The locations of the current boreholes are determined without any geological survey. Especially when boreholes are used on large scale, these surveys are costs efficient. An extensive geologic survey will give drilling locations with high yield potential, which will reduce the total costs. For the total solution of the water demand, the costs will be around $ 1,095,000. A big advantage of boreholes is that the water quality already meets the future quality demands. A well-known disadvantage of boreholes is the reliability, especially when they are used on a large scale. The chance that more boreholes will pump from the same source will increase, which means that they can run dry sooner. Another disadvantage is the use of power by the pumps, which has a negative effect on the operating costs and sustainability of the solution.

There are multiple buildings located on the project site. This gives the possibility to collect water from the roofs: domestic rainwater harvesting. The total amount of water that potentially can be captured per building depends on the total roof area, the average monthly rainfall and a runoff factor. In this way for each building it is determined if domestic rainwater harvesting can meet the future water demand. It seems that a domestic rain water harvesting system could be an option, as individual source, for relative small water demand sites including residential buildings, offices and schools. However, because of the long dry season, big storage facilities are required for most locations. The investment costs consist mainly of costs for storage tanks. A first estimation on the total investment costs for domestic rainwater harvesting systems are around 50 $/m^3$ of storage. For an average house, with a demand of 0.25 m^3/day, this implies an investment of $ 1500. A big advantage of domestic rainwater harvesting is that the water quality already meets the future water quality demands.

Besides domestic rainwater harvesting, harvesting runoff from rocks is also considered. This is an interesting option if reservoirs have difficulties to recharge. On the project area no problems are expected regarding this. Furthermore, the performance of rainwater harvesting from rocks is questionable in combination with a reservoir. Large storage tanks are also an option but more insight on the location of storage tanks in relation to water demanding sites and storage capacity is needed.

Building reservoirs is the third solution that is considered in the study of possibilities. With the use of Google Maps twelve possible reservoir locations are determined on the project area. For all these reservoirs, the maximum monthly volume that can be subtracted, the elevation differences, distances to water users and the costs are determined. These results have shown that reservoirs have a great potential to meet the future water demand. In consultation with Novos Horizontes it is decided to elaborate on the reservoirs that are in line with the wishes of Novos Horizontes in more detail in Part C. In total six out of the twelve reservoirs are elaborated on in more detail.

Part C: Reservoirs
The aim of this part is to give a good insight into the possibilities of the most appropriate reservoirs to achieve a phased solving of the future water demand. Therefore six reservoirs are elaborated on in more detail in this part. This elaboration consists of the determination of the optimum dam height, costs and design of the spillway.

The design of the spillway is, after consultation with a local specialist, based on a normative precipitation event with a return period of 250 years. With an economic design lifetime of 25 years, this results in a probability of 9.5% that this extreme precipitation event occurs during the lifetime of the dam.

Per reservoir, the water surface is given at a maximum dam height (based on a detailed topographic survey). This way it becomes clear which objects possibly have to move in order to give space for the corresponding reservoir, what the maximum dam height is and what the main characteristics of the reservoir are.

Subsequently, the dam height is varied with an interval of one meter. For each dam height the maximum amount of water that can be subtracted per month throughout the year without the reservoir running dry is calculated. This amount of subtracted water is the result of an established water balance for each reservoir. The inflow depends on the rainfall, the catchment area and runoff coefficient. The outflow is the sum of the infiltration and seepage, water use on the project area, constant discharge for local people and the evaporation. Together with the buffer volume of the reservoir, the maximum amount of water that can be subtracted is calculated. It can be concluded that each reservoir has a dam height that gives a maximum amount of water that can be subtracted and that only three of the six reservoirs can fulfill the future water demand.

The wish of Novos Horizontes is to maximize the transport of water by means of gravity forced flow. Therefore, for each reservoir and the main users the elevation differences and the horizontal distances are determined. The result of this is an overview for every reservoir, in which one can see if there is a pump needed to supply water for the abattoir, which is the main user.

The costs of a reservoir are mainly based on the volume of the dam. The costs are calculated per dam height, which gives an option to plot the costs against the maximum amount of water that can be subtracted. This gives an economically optimal dam height for each reservoir. The costs ($) for fulfilling a certain percentage of the future water demand are given in Table 0.1. It is clear that three reservoirs can meet the total future water demand. Reservoir 9 is the cheapest one, with total investment costs of around $ 460,000.

	Fulfilling of the future water demand, in percentage of 1,551 m^3/day									
nr.	**10 %**	**20 %**	**30 %**	**40 %**	**50 %**	**60 %**	**70 %**	**80 %**	**90 %**	**100 %**
1.1	226,986	329,931	421,481	503,450	577,651	645,895	709,997	771,767	833,019	895,566
3	359,967	601,656	818,862	966,877	1,061,605	1,179,554	1,457,845	2,094,205	-	-
8	223,843	309,645	387,919	462,123	535,713	-	-	-	-	-
9	142,158	180,253	217,523	254,028	289,828	324,983	359,555	393,603	427,189	460,371
10	149,986	284,384	396,115	493,227	583,768	675,789	-	-	-	-
12.2	77,497	145,889	210,305	271,214	329,079	384,368	437,547	489,081	539,436	589,079

Table 0.1 Costs of the reservoir (in US dollars)

The costs together with the other reservoir characteristics form a good basis to come up to an optimal design for solving the water demand in several phases. A first recommendation for a phased solution of the total water demand is given in Part D.

Part D: Phasing and recommendations

In order to meet the future water demand, two options are possible: boreholes and reservoirs. However, the costs of reservoirs are half of the costs of boreholes. In addition, the reliability of boreholes is considerably lower than that of the reservoirs. Both variants are able to meet the water quality demands. The disadvantage of a reservoir is that there are few opportunities for a phased total solution, so there may be investments made that in hindsight were unnecessary.

In order to limit this risk, it is possible to choose a combination of solutions: boreholes, rainwater harvesting, reuse of water, the use of different reservoir and / or a phased increasing of the height of a dam. In order to find a total water solution that meets best the demands and wishes of Novos Horizontes, it is important to consider all aspects of the solutions offered in this report.

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Introduction

1. Introduction

Project Mozambique was initiated by Novos Horizontes. Novos Horizontes is an organization which started its business in Mozambique seven years ago. It all started with the idea to start a vertical integrated poultry operation. The core of the business was to get the local community involved in the complete production process. Local farmers are given chicks and feed on credit and grow the chickens until they are ready for slaughter. At the moment around 180 farms are working together with Novos Horizontes of which 90% is able to get sufficient profit. Novos Horizontes is currently planning to expand their activities. This expansion will stress the already poor state of the water availability even more.

For Novos Horizontes, water is a big limitation for an expansion of their activities. The objective of this report is based on an expansion of 18 times the current amount of chicken slaughtered. To achieve that expansion, the feed mill, chicken operations, hatchery and outgrowers have to expand as well. With the current 300 employees, these big expansions will lead to a big increase in employment in the region. For a region like Nampula, this economic impulse is very important and it has a large positive impact.

Project Mozambique is aimed at finding a solution for the water problem of Novos Horizontes. Objectives and a research question are defined in order to find this solution in a structural way.

1.1 Main objective and research questions

The problem faced in this project is divided in a main objective and research questions. The objective and research questions are all formulated in full cooperation with Novos Horizontes and its stakeholders. After the objectives are described in an abstract way, they will be described in a more concrete way in chapter 3.

1.1.1 Main objective

The main objective of the project is formulated as follows:

'Contribute to a structural improvement of the water system for the companies and organizations that are part of the Communities of Fusion'

Contribute in this context means the elaboration and reporting of the problem statement and finding a suitable solution for this problem. Structural improvement of the water system here means the long term water solutions that will make expansion possible. The Communities of Fusion, in this report, includes Novos Horizontes, Eggs for Africa, Rapale International School, Ebenezer College and Arcapula. Fresh Eggs Mozambique is neglected because it lies outside the project area (see 2.3)

1.1.2 Research questions

The following research questions have been formulated. The answers of all these questions together should lead to the achievement of the main objective.

1. *How does the current situation look like?*
2. *What is needed in the future, with regard to the quantity and quality of water?*
3. *What are the possible solutions to meet this quantity and quality of water?*
4. *What is the recommended strategy to supply all the water that is demanded in the future situation?*

1.2 Approach

The approach of the project is a combination of research, design and advice. The report consists of 4 main parts.

The first part, part A, will elaborate on the current situation and the requirements that will provide enough water in the future situation. The second part, part B, will discuss the possible solutions. All possible solutions will be checked on the defined boundary conditions: water quantity and water quality. Also criteria, set by the client, will be taken into account while assessing the possible solutions. These include reliability, sustainability and costs. Part A and B form the research section of this report.

The design part of the project will be covered in part C. In this part, a more detailed design of a reservoir will be described. The last part, part D, will give the planned phasing of the water demand and final recommendations.

The final product will be a report that provides a good overview of the current situation, the possible solutions that are available, more detailed design of a reservoir and recommendations which can be used to make a water plan to improve the water system on the farm of the Communities of Fusion.

Part A

Current and future situation

2. Current situation

This chapter will deal with the current situation of the project area. Geography and climate will first be elaborated as the general description of the project area. More detailed information about the farm area, the current water demand and current water system will be elaborated as well.

2.1 Geography

The area of interest in this report is the farm of the Communities of Fusion. The farm lies in the province Nampula, about 15 km North-West of the city Nampula and close to the small town Rapale, Figure 2.1. Rapale has around 15,000 inhabitants and has limited facilities compared to the bigger city Nampula. Nampula is the third biggest city of Mozambique and has about 500,000 inhabitants.

The farm of the Communities of Fusion is located at a rural area of approximately 650 ha. Rural area in this case means that there are no paved roads on and around the farm and that availability of water, electricity and internet is limited.

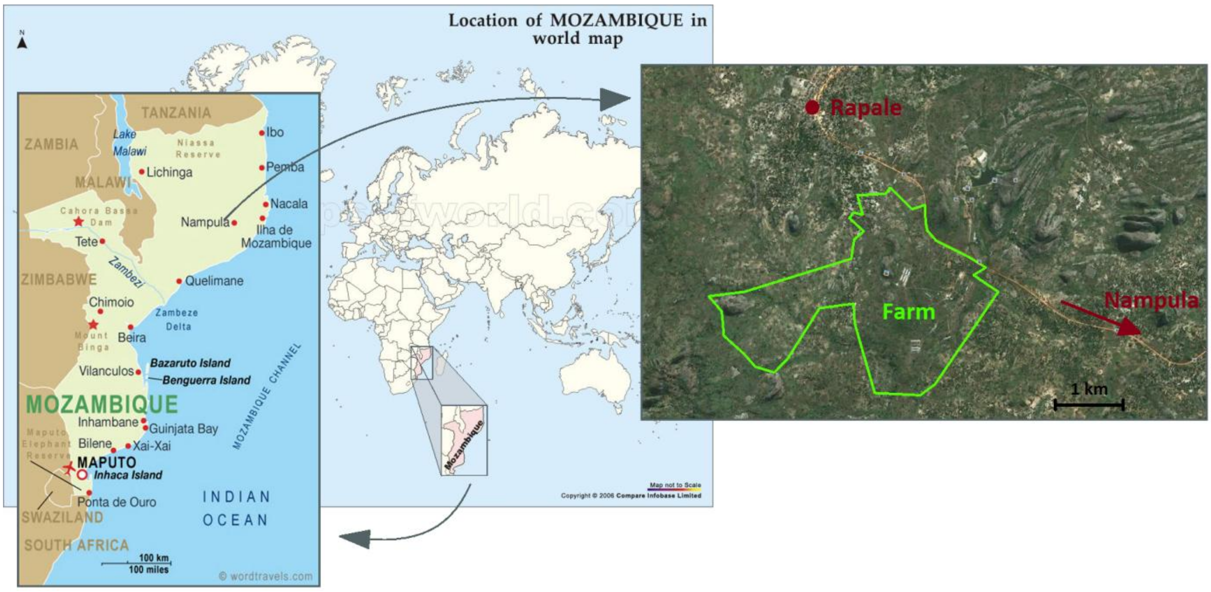


Figure 2.1 General geography of the project area

In Figure 2.1 the farm of the Communities of Fusion is shown by using three different maps. It is good to remember that the country of Mozambique is a relatively long country (north to south). Mozambique extends for 2,500 km along the east coast of Africa. The distance from Maputo to Nampula is about 2,050 km by car.
According to these distances the farm, and thus project area, is relatively small. The farm area from north to south is about 3 km long.

2.2 Climate

Mozambique can roughly be divided into three maim climatic zones including dry savannah climate, tropical rain savannah climate and humid temperate climate. The Nampula region is located in the tropical rain savannah climate region. The average annual temperatures in the region are around 26°C and average wind speeds vary between 5 and 8 km/hr. Solar radiation in Mozambique is on average between 18 and 20 MJ/m^2/day (Ferro and Bouman 1987).

2.2.1 Rainfall

Annual averages of rainfall vary from 300-400 mm/year in the south-west of Mozambique to 1,200-1,400 mm/year in the north east. Rainfall over 2,000 mm/year can be found in mountainous area around Gurué.

The average annual rainfall for the Nampula area is between 1,000-1,200 mm/year (Hipólito and Vaz 2011). Monthly rainfall data from two sources were available during this project. One data set is acquired from observations while the other data set is acquired by the GLDAS-1 CLM Model of NASA. The observed data covers 14 years of monthly recorded rainfall data. The model covers 32 years of monthly rainfall data. More detail on the observed and modeled data is given in Appendix A1.

The annual observed data and the annual data from the model are quite consistent concerning the average annual rainfall. The difference in average annual rainfall between the observed data and the modeled data is just 18.5 mm/year which is considered to be small. This gives reason to assume that the average annual data is accurate enough for first order estimations. The average annual rainfall in this study is set at 1,100 mm/year.

Figure 2.2 shows the annual rainfall and the average rainfall per year based on the model.

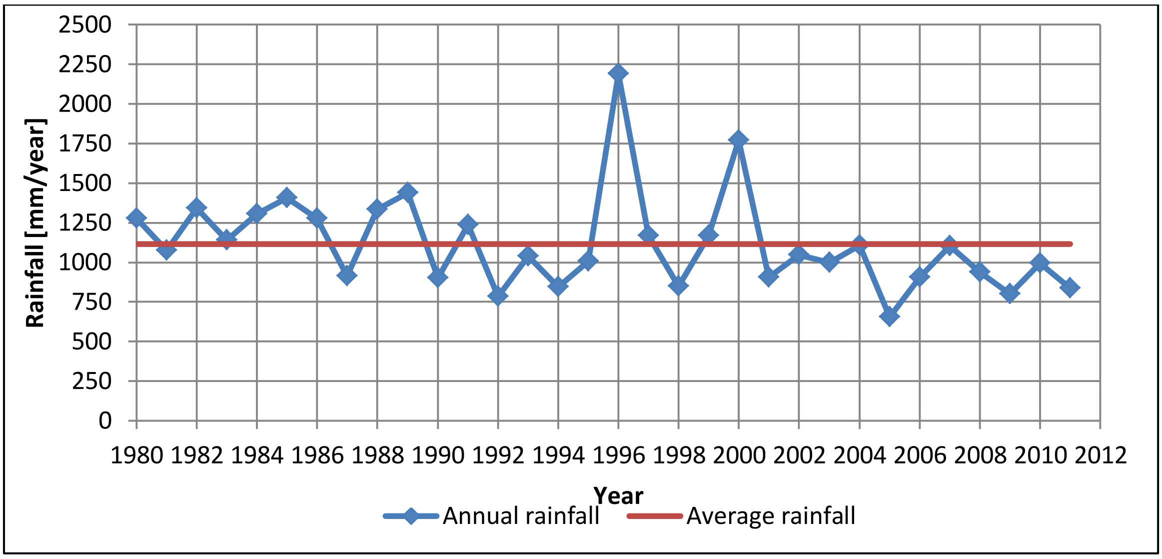


Figure 2.2 Annual rainfall data from GLDAS-1 CLM Model

The distribution of the average monthly rainfall from both sources is shown in Figure 2.3. The dry season clearly starts in May and ends in October. The other months are relative wet and are considered as the wet period.

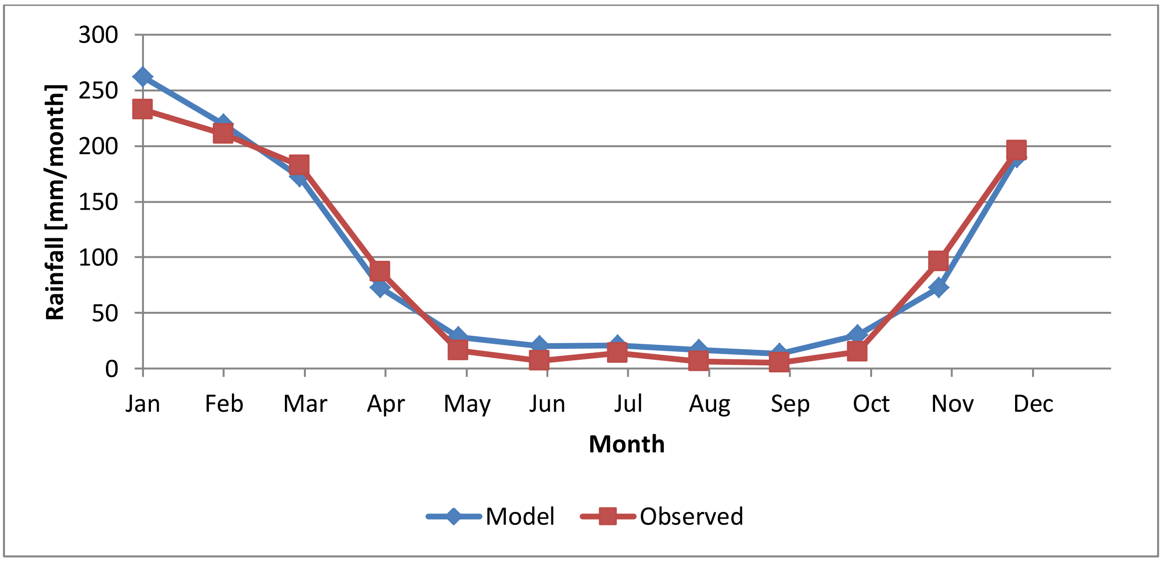


Figure 2.3 Monthly distribution of rainfall from GLDAS-1 CLM Model and from observations

Figure 2.3 also shows that the data of the model differ a little with the observed data. In the wet period the observed rainfall is clearly lower than the modeled data suggest. In this study it is decided that the monthly data, in water balances, is used from the modeled data set because evaporation will also use this model. The accuracy and the spatial domain of the used data will be consistent. In this way the accuracy in a water balance is more secure than in case of using the observed data.

2.2.2 Evapotranspiration and evaporation

Annual averages of actual evapotranspiration vary from 300-400 mm/year in the south-west of Mozambique to 1,000-1,200 mm/year in the north east. The average annual actual evapotranspiration for the Nampula area is between 600-700 mm/year (Hipólito and Vaz 2011). Monthly total evapotranspiration data was available from one source, the GLDAS-1 CLM Model of NASA. The model covers 32 years of monthly evapotranspiration data. More detail on the data is given in (Appendix A1).

Evapotranspiration is defined as the sum of evaporation and transpiration. Because of the lack of evaporation data the values for evaporation in this report will be based on the modeled values of the total evapotranspiration.

Figure 2.4 shows the modeled total annual evapotranspiration. The average annual total evapotranspiration is around 750 mm/year.

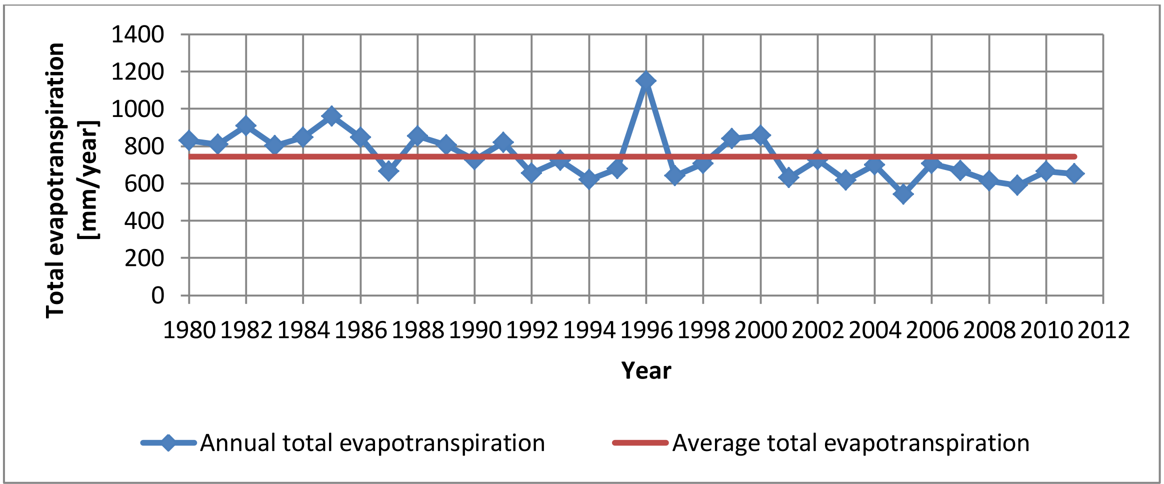


Figure 2.4 Total annual evapotranspiration data from GLDAS-1 CLM Model

Monthly distribution of total evapotranspiration is shown in Figure 2.5.

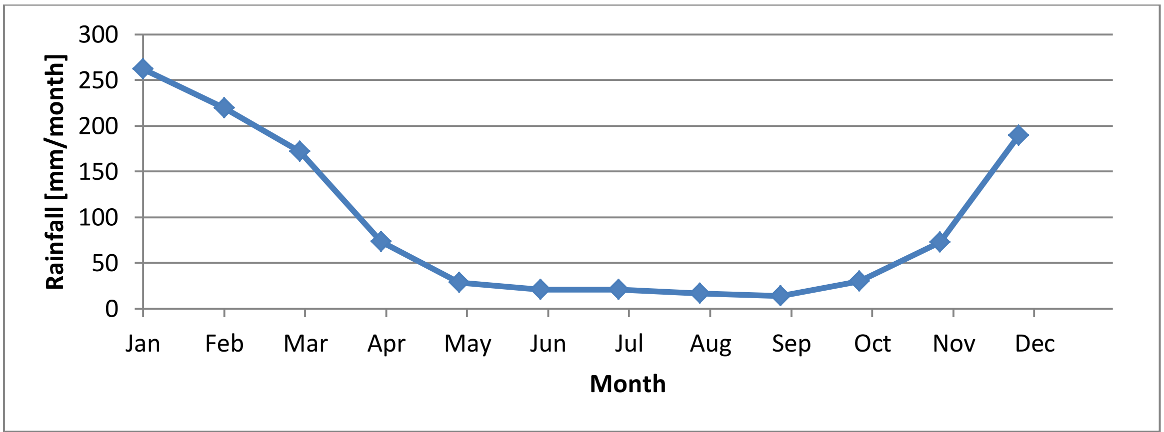


Figure 2.5 Monthly distribution of total evapotranspiration from GLDAS-1 CLM Model

2.3 Project area

The project area is defined as the land belonging to the Communities of Fusion (the farm), excluding Fresh Eggs Mozambique. The project area is shown in Figure 2.7.The main part of the project area is occupied by Novos Horizontes.

To be able to run operation Novos Horizontes has the following business units:

- *Breeder Chicken operation* are divided over 4 locations, together these locations have 8 chicken houses that store 56,000 chickens. These chickens produce the eggs for the hatchery. These special breed chickens live on a diet to increase their egg ratio.
- At the *hatchery* the eggs are being breed in special hatching machines. Approximately 90,000 eggs per week are being hatched. From the chickens that come out of the eggs, half of the eggs will be sold to the public, the other half is going to the outgrowers.
- *Outgrowers* are small scale farmers that are located within in a region of 0-15 km of the farm. Hatched chicks are being raised in 5 weeks to fully grown chickens. Novos Horizontes works closely together with these outgrowers.
- At the *abattoir* the chickens from the outgrowers are processed and frozen to be sold to the public in Nampula and to the surrounding areas.
- The *feed mill* supports almost all activities of Novos Horizontes. Here they produce all the food for the outgrowers, breeder chicken operations and Eggs for Africa. They also sell food in their local shops in Nampula to the public.

In Figure 2.6 the position of each business unit within the total organization is shown. The red squares are business units that are part of Novos Horizontes. The blue squares are not part of Novos Horizontes but are included in their business process.

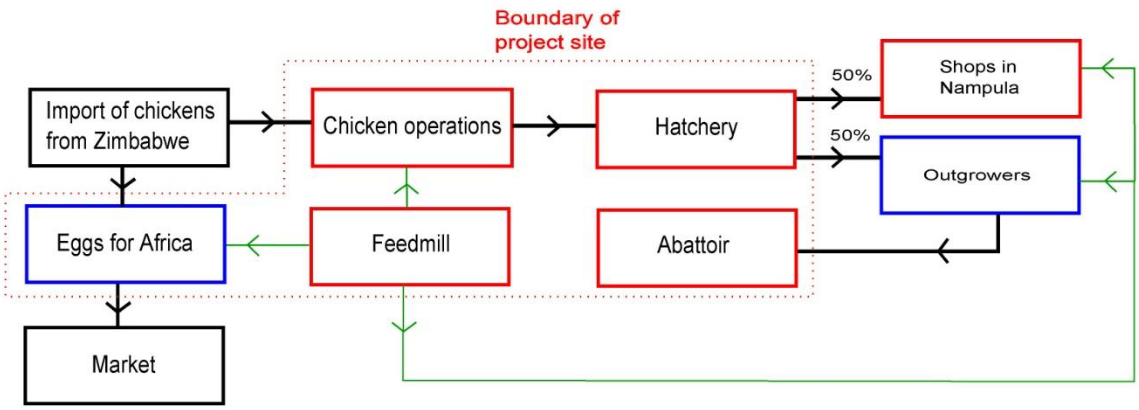


Figure 2.6 Organization Novos Horizontes

Besides Novos Horizontes there are several other organizations/companies which are part of the Communities of Fusion. All these organizations perform different activities, have different interests and strategies of working. The main goal is the same: inspiring people to develop their selves and create their own future.

Figure 2.7 shows the locations of the different business units of Novos Horizontes and the other organizations on located within the project area.

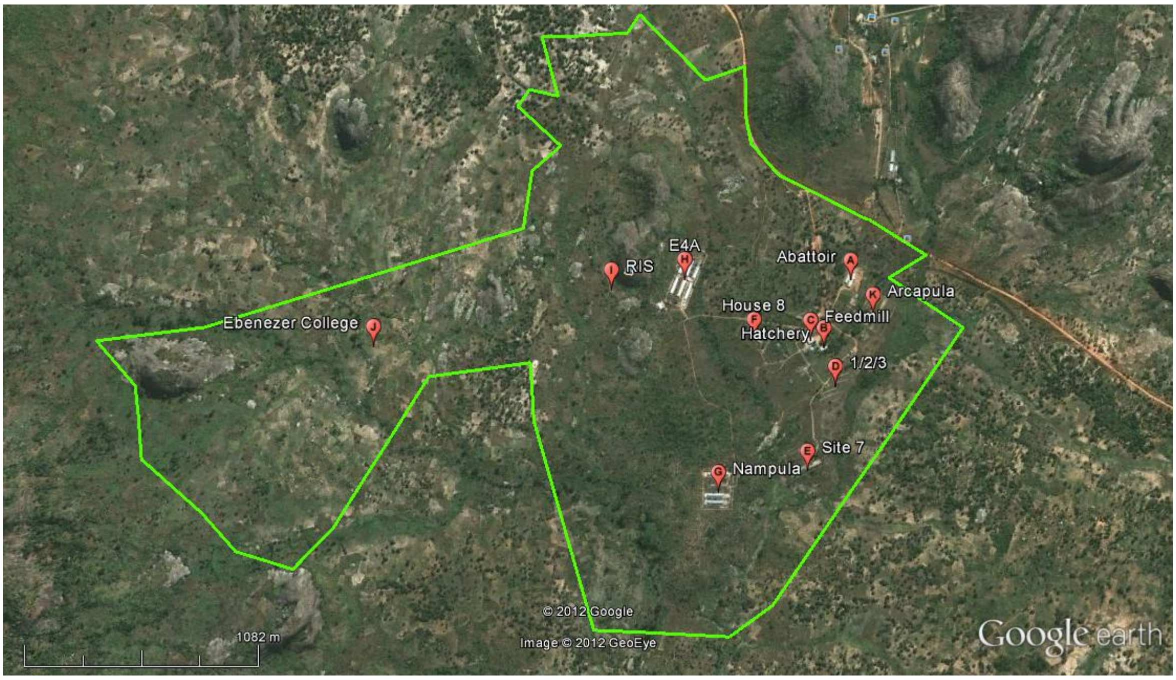


Figure 2.7 Different business units on the farm

The locations that belong to Novos Horizontes:

A. Abattoir
B. Hatchery
C. Feed mill
D. Chicken operations : 1/2/3
E. Chicken operations : Site 7
F. Chicken operations : House 8
G. Chicken operations : Nampula

Other organizations located on the farm:

H. Eggs For Africa (E4A)
I. Rapale International School (RIS)
J. Ebenezer College
K. Arcapula

All the organizations that Novos Horizontes is cooperating with are summarized below.

2.3.1 Eggs for Africa

Eggs for Africa (E4A) is founded by Scott Marques about four years ago. He started the company with the aim of setting up a small model company that can support a few families that are involved in church planting. At the moment the manager of the farm and a few of his colleagues are involved in church planting in the area of Nampula.

The company produces table eggs for the local market. At the moment Eggs for Africa has 6 chicken houses which give shelter to 25,000 chickens. On a daily basis the company produces about 21,000 eggs. There is also another company involved with table eggs called Mozambique Fresh Eggs. This is a joint venture between Eggs for Africa, some local business men and investors from the USA.

The cooperation with Novos Horizontes includes the free use of electricity and water supply to different houses on the farm.

2.3.2 Rapale International School

Currently the Rapale International School (RIS) is situated in Nampula. The school is developing at the moment. This school year 30 students were attending classes and next year there will be about 60-70 students. Next year the school will move to a new building that is being built at the farm.

2.3.3 Ebenezer College

A recent start-up activity is Ebenezer College. This is a leadership training program that will equip young Mozambicans with appropriate business, agricultural and life skills.

2.3.4 Arcapula

This company is a joint venture between Novos Horizontes and American investors. It is 50% owned by Novos and 50% by the investors. Arcapula has three chicken houses were they raise about 21,000 chicken from hatchery in 5 weeks to fully grown chickens. The company is a quality check and backup for the outgrowers.

2.4 Current water demand

In the current situation there are four main consumers of water on the project area. These include chicken operations, the hatchery, the abattoir and Eggs for Africa. Smaller users of water include private houses and office buildings.

The exact amount of water that is used for the different operations is unknown because it is simply never measured. Flow- and/or discharge measurement tools are not installed and also the turning hours of the pumps are unknown. There is a big fluctuation in the amount of water that is supplied by the boreholes, In this way it is difficult to do exact measurements.

To get the best possible insight in the current water demand, the following strategy is detained:

1. Determination of the use of water per consumer based on estimations made by the consumers themselves;
2. Rough check of the order of magnitude of the used water by the abattoir (main user) with some in- and outflow measurement.

2.4.1 Estimations on water use per consumer

The mentioned values below are based on the knowledge of the persons involved in the production process of the different locations/companies on the project area.

Abattoir

The abattoir is the main consumer on the farm. Water is used for electrocution, plucking, washing of chickens and cleaning the abattoir. The average water demand per slaughtered chicken is about 12 liters of water. During the year, on average 500 chickens per hour are being slaughtered. This means 4,000 chickens for a working day of eight hours. The total amount of water that is needed in the abattoir is therefore **48** m^3/day.

Hatchery

At the hatchery water is used to control the humidity level, this is done by nozzles that spray water over the eggs during the hatching process. Besides this, water is used to clean the crates in which the eggs are transported. The total amount of water that is needed for these two aspects is approximately **10** m^3/day.

Chicken operations

On the farm there are four locations of chicken houses. In total there are eight chicken houses that all together store 56,000 chickens. Each chicken eats 120 grams of food a day and drinks five times the weight of the food, this means 0.6 liter of water per chicken per day.The total amount of water that is needed for chicken operations is therefore **33.6** m^3/day.

Eggs for Africa

At the chicken houses of Eggs for Africa water is mainly used as drinking water for the chickens. Because these chickens are laying consumable eggs instead of breeding eggs they need less food and therefore drink less water. A chicken drinks about 0.5 liter of water a day.

During the year Eggs for Africa has an average of 25,000 chickens divided over six houses. This means that the total water demand of Eggs for Africa is **12.5** m^3/day.

Rapale International School

Rapale International School (RIS) is being built at the moment. Therefore the amount of water that is used at this location is mainly for construction operations. The amount of water needed when the RIS is open is **1.4** m^3/day, which is explained in the chapter 3.1.1.

Private houses

The recommended basic water requirements for human domestic needs are summarized in Table 2.1. (Gleick 1999).

Purpose	Recommended volume per person per day (lpcd[1])
Drinking water	5
Sanitation	20
Bathing	15
Food preparation	10
Total	50

Table 2.1 Recommended basic water requirements for human domestic needs

The water demand of the houses on the Novos Horizontes area is estimated for an average 5 persons per house. The total water use would then be 250 l per day. This means that in total **2** m^3/day of water is used by the 8 households on the farm.

Other water users

Besides the above mentioned water users there is also water used by workers for washing and by people from the neighborhood. Novos Horizontes stimulates this use by creating different water points all over the farm. The exact amount of water that is used by other users is unknown and very difficult to determine. Therefore an amount of **5** m^3/day is estimated.

2.4.2 In- and outflow measurements

As mentioned before, all values given in the previous paragraph are based on estimations made by the consumers themselves. In order to check the estimations, order of magnitude checks were performed. In order to do so, the water use of the abattoir, which is the main consumer of water, has been evaluated. To achieve this, the total in- and outflow of the reception tank close to the abattoir has been measured.

Because the inflow of the tank can never be stopped in order to guarantee enough water for the slaughtering process, first the inflow of the tank has been measured. During 24 hours, every 30 minutes the water level of the tank has been measured (this means a total of 48 measurements). During the measurements the outflow was stopped completely, this means that no operations were possible. In this way it was possible to calculate the total inflow and the average discharge of 6 boreholes together. By including the numbers of the boreholes that were working at the time of the measurements, also the average amount of working boreholes is calculated. The full results of the measurements can be found in appendix A2. A summary of the results is given in Table 2.2.

[1] Liter per person per day

Description	Value	
Water supplied by boreholes	63.1	m3/day
Total number of boreholes	6	
Average number of boreholes running during measurement	3.05	
Percentage of total boreholes that were running	51	%
Average discharge of the running boreholes	2.63	m3/h

Table 2.2 Results of the inflow measurement

Another day, the outflow (amount of water used by the abattoir) is measured by using the average inflow calculated from the first measurements. This is done by measuring the water level in the tank before the abattoir started and by measuring the water level after the abattoir closed. These two measurements together with the average discharge of the boreholes made it possible to calculate the amount of water that is used by the abattoir. By dividing the used amount of water by the amount of chicken slaughtered, the used amount of water per slaughtered chicken is calculated. The results are included in Table 2.3.

Description	Value	
Water in tank before measurement	67.26	m^3
Water in tank after measurement	21.46	m^3
Added water by the boreholes	23.44	m^3
Water used by the abattoir	69.24	m^3
Chicken slaughtered	5808	
Used amount of water per slaughtered chicken	11.92	liter

Table 2.3 Results of the outflow measurement

The measured 11.9 liters per chicken gives no reason to doubt about the estimated 12 liter per chicken. However, there is an important note that needs to be considered. The real inflow on the day of slaughtering can differ from the inflow calculated by the average discharge based on the first measurements. Furthermore, some of the water could be used by 2 houses connected to the tank as well during measuring the water use of the abattoir. This is not included in the results. Therefore is chosen to keep the values as given in paragraph 2.4.1. as most reliable estimations of the currently used amount of water.

2.4.3 Total current demand of water

The total current demand of water on the farm, based on the information mentioned before, is 112.5 m^3/day divided over 7 different users.

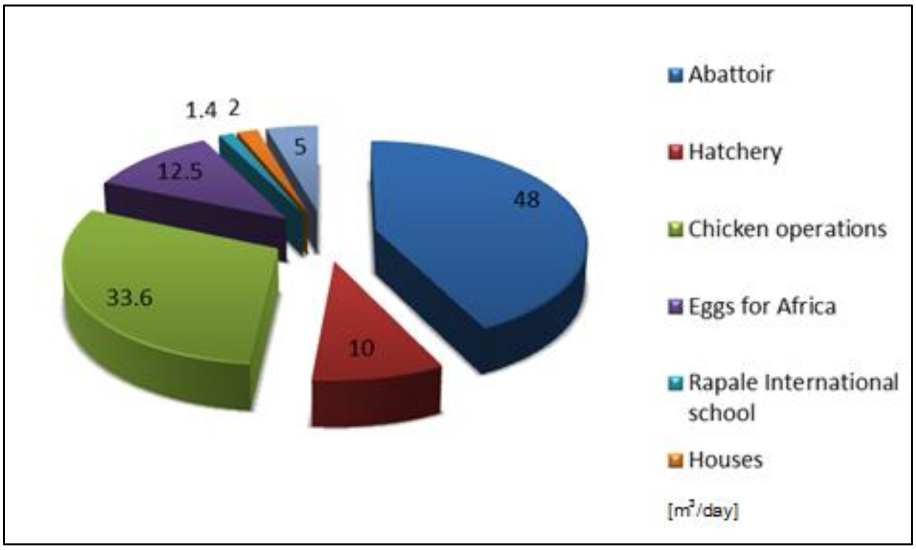


Figure 2.8 Current water demand

Figure 2.8 shows clearly that the abattoir is the main consumer of water on the farm. In the current situation it uses 48 m^3/day, which is 42% of all the water that is used on the farm.

Beside the amount of water that is used, it is also important to know where the water is used. Figure 2.9 shows the different locations on the farm which uses water. The red dots indicate the different water users. The size of the dots is representative for the amount of water that they use.

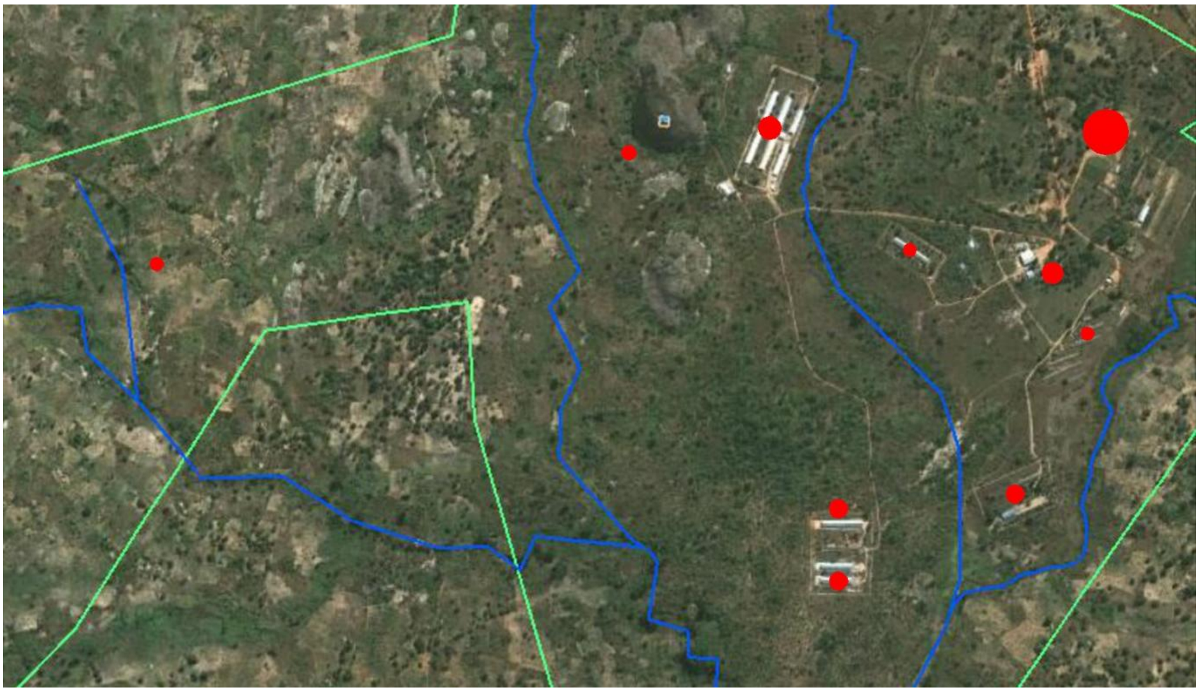


Figure 2.9 Location of the current water users

2.5 Current water system

All the water that is used on the farm is supplied by 9 different boreholes. Seven of these boreholes are owned by Novos Horizontes and two are owned by Eggs for Africa. With the two boreholes, Eggs for Africa can supply their own needs, Rapale International School and some households with water.
The seven boreholes of Novos Horizontes supply the abattoir, the hatchery, the chicken operations and some houses.

2.5.1 System of boreholes and ducts

The locations of the different boreholes are measured by using a GPS and are shown in Figure 2.10. The green indicators are the boreholes of Novos Horizontes and the orange indicators are the two boreholes that belong to Eggs for Africa.

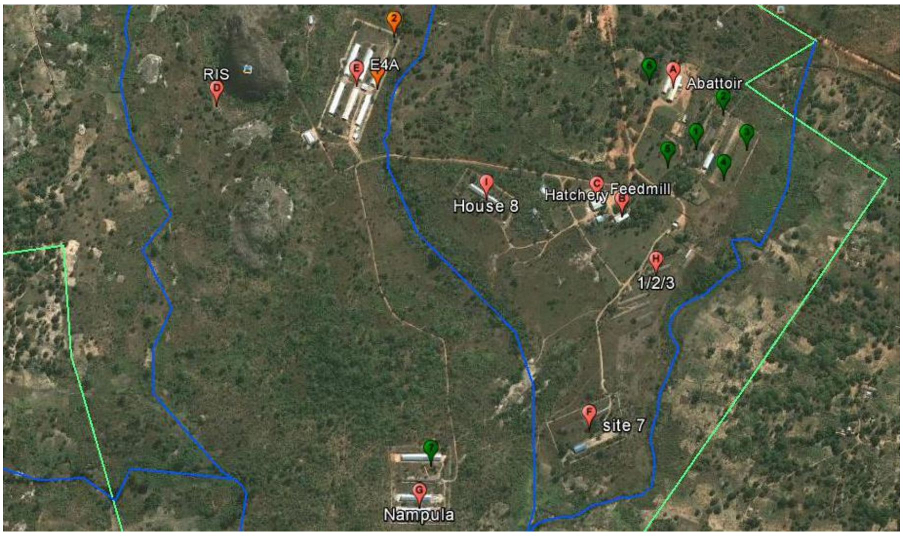


Figure 2.10 Location of the boreholes

A schematic representation of the total water system is given in Figure 2.11. All the water of boreholes (green dots) 1 till 6 come together in one reception tank close to the abattoir. From here, the water is pumped to the different locations (red squares) that need water. Borehole 7 delivers directly to different locations on the farm.

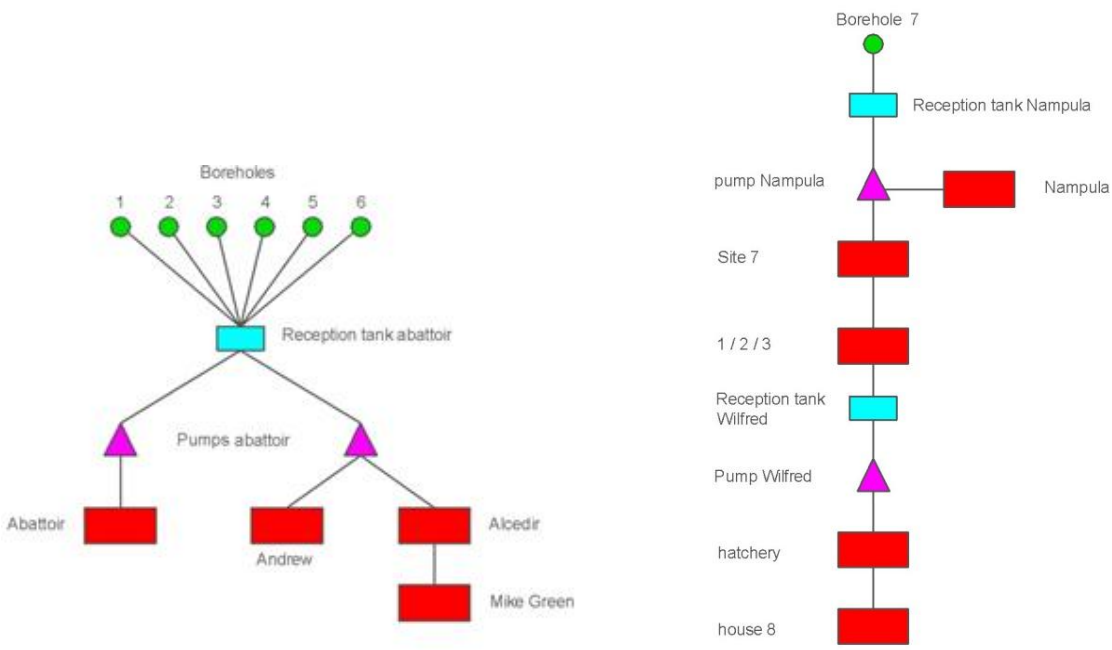


Figure 2.11 Schematic representation of the water system

In the Figure 2.11, the purple triangles are pumps at ground level that are used to pump water to the different locations. These are small pumps that run on 380 V / 50 Hz and have three phases. Figure 2.12 shows a picture of a pump that is installed at borehole 7. In total there are four of these pumps installed on the farm.

Figure 2.12 Borehole number 7 of Novos Horizontes and the pump used for water transport

On the farm is limited information available about the boreholes, the pumps inside the boreholes and the exact discharge of the boreholes. Information is gathered by interviewing employees of Novos Horizontes and by performing measurements.

Discharge

There are no discharge measurements installed on the boreholes. Therefore Novos Horizontes delivered a rough estimation for the amount of water that is provided by their seven boreholes. Based on the water that is used and stored during a working day on full capacity they estimated the total discharge. Because no water will be stored, the total supply by the 7 boreholes of Novos Horizontes has to be equal to the connected users: the abattoir, hatchery, chicken houses, workshop and 3 houses. The boreholes of Eggs for Africa will supply the other users. This means that in total 91.75 m^3/day should be delivered by the seven boreholes of Novos Horizontes.

To check this discharge and to get insight in the individual discharge of the different boreholes, simple measurements are performed. During 5 weeks the discharge of boreholes 1, 2 and 3 are measured by using a bucket and a stopwatch. The discharge is measured for these boreholes because these three are running most time of the day. Pumps switch automatically off when the water level inside the borehole is insufficient and switch back on after one hour. Therefore snapshot measurements on other boreholes do not give reliable results for the discharge during a whole day.

The results are shown in Table 2.4, for a total overview of the results see appendix A3.

Borehole	Number of measurement and discharge in [m^3/day]										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Average**
1	38	35	37	37	35	34	39	36	37	35	36
2	18	18	22	19	19	18	20	21	19	18	19
3	16	16	15	14	14	16	12	17	16	14	15

Table 2.4 Discharge measurements on borehole 1, 2 and 3

As shown in Table 2.1, there is a big variation in the capacity of the boreholes. Borehole 1 is the ‘best’ borehole. The amount of water that can be extracted in a day is estimated around 35 m^3.

Based on information from Novos Horizontes and the measurements on borehole 1, the discharge of borehole 7 is also estimated at 35 m^3/day, which is a conservative assumption because if the discharge is calculated based on the water use of the connected buildings, the discharge should be even higher.

Borehole 2 and 3 are relatively good boreholes, based on measurements they deliver between 14-19 m^3/day each. The discharge of boreholes 4 and 6, when running, can be estimated to be equal to boreholes 2 and 3. To be conservative, the average discharge of boreholes 2, 3, 4 and 6 are assumed to be 15 m^3/day. Borehole number 5 is definitely the worst borehole. It runs dry all the time. At the moment, borehole 5 is even out of use.

The average discharge per borehole is calculated by using the measured and estimated numbers above. The calculation is shown in Table 2.5.

Borehole [-]	**Discharge [m^3/day]**	**Determination**
1	36	Measured
2	19	Measured
3	15	Measured
4	15	Estimated
5	0	Measured
6	15	Estimated
7	35	Estimated
average	**19.1**	**Calculated**

Table 2.5 Average discharge per borehole

According to the results of the discharge measurements, there is an important note that needs to be considered, the discharge of the boreholes will fluctuate during the year. The measurements are all performed in July, which is in the middle of the dry season. In the wet season, apparently the boreholes will supply more water. Therefore it is likely that the estimated discharges are lower boundary values.

Depths

The real depths of the different boreholes are unknown. Local drilling contractors do not always give reliable information about the depth of the drilled borehole and they are never checked after drilling. A possibility would be to measure the depth by using a rope with a little weight at the end but unfortunately it was impossible to shut down a borehole only for measuring the depth.

The estimated depths of the different boreholes (based on knowledge of local people) are shown in Table 2.6.

Borehole number	**Depth**	**Accuracy**
1	100 m.	Pretty sure
2	40 m.	Rough estimation
3	65 m.	Estimation
4	65 m.	Estimation
5	40 m.	Pretty sure
6	40 m.	Rough estimation
7	85 m.	Pretty sure

Table 2.6 Estimated depths of the boreholes

Drill locations

The drill locations for the boreholes were determined in the past by the contractors that drilled them. To determine the drill location, very basic methods that are not common in Europe are used. There is no relation between the used methods and the quality of the borehole. For example: borehole number 7 is working properly while it is drilled after investigation with a bottle of water.

The contractor walked around the site with a bottle of water on his hand, when it felt of his hand he said he crossed a “water vein” and started drilling.

2.5.2 Water quality

At the moment, the water extracted from the boreholes 1 till 6 is collected in a big reception tank. From here the water is pumped to the abattoir and treated with chlorine before it will be used for the production process. There is no systematic check on the water quality, only sporadic samples are taken and tested, but there is no quality requirement to compare the results with.

Water from borehole 7 is directly distributed to different locations on the farm. Most of this water is used for chicken operations. The required quality for chicken operation is drinking water, but no systematic checks on quality are performed.

To get insight in the current water quality, laboratory tests were performed on water from the reception tank and water directly from a borehole. The water is tested on basic parameters. The full results of the tests can be found in Appendix A4. A summary is given in Table 2.7.

Quality parameter	Abattoir inside	Abattoir outflow	Borehole	Storage tank	Reservoir
Color	Colorless	Red	Colorless	Colorless	Light brown
Smell	No smell	Very bad	No smell	No smell	No smell
Turbidity	Very low	high	Very low	Very low	Very low
pH	7.2	8.9	7.1	7	6.5
Comments*	S	NS	S	S	S

Table 2.7 Summary of the results of the laboratory tests

* S = suitable for human consumption NS = not suitable for human consumption

2.5.3 Challenges in the current water system

In the current situation, with a water demand of 112.5 m^3 per day, the 7 boreholes of Novos Horizontes can fulfill the need for water during the wet months. During the dry months, May till October, there are sometimes problems related to the availability of water. In the dry period all the boreholes give less water and some even become dry. There were years that the production had to be lowered because of the lack of water.

The quality of the water will always be a point of attention. Water out of boreholes can be infected by pit latrines for example. Because people the water that directly comes out of the boreholes (so without any treatment), an infection of the water could lead to big health problems.

3. Future water system

In this chapter, the main objective and research questions, given in Chapter 1.1, are elaborated with more detail. In this way they will lead to boundary conditions and criteria for the future water system.

3.1 Boundary conditions

The boundary conditions exist of quantity and quality of water needed in the future. The demands about water quantity and quality in the future are provided by Novos Horizontes and based on the expansion they would like to implement in the future.

3.1.1 Quantity of water

In Table 3.1 the required amount of water in the future is shown. To get an idea of the expansion the relation to the current water demand (see paragraph 2.4.1) is visible.

Consumer	Current demand [m^3/day]	Demand in future [m^3/day]	Expansion [%]
Abattoir	48	864	1800
Hatchery	10	30	303
Chicken operations	33.6	100	300
Eggs for Arica	12.5	20	160
Schools	1.4	2.8	200
Houses	2	3.75	188
Other water users	5	30	600
Irrigation	0	500	-
Total	112.5	1551	1386

Table 3.1 Current water demand vs. future demand of water

The total amount of water that is demanded in the future is 1,551 m³/day, which is almost 14 times the current demand (112.5 m^3/day).

The abattoir is by far the biggest user of water. The amount of 864 m³/day is based on a maximum capacity of the production line of 4,500 chickens per hour. Two shifts of eight hours, Novos Horizontes will not work with 3 shifts, because this is not feasible with the current culture in Mozambique, yield in a production of 72,000 chickens per day. Every slaughtered bird uses 12 liters of water, which means a total of **864** m³/day. The wish is to continue having, as in the current situation, 6 production days per week.

The amount of water for chicken operations is based on a maximum expansion of the current facilities. This means a maximum of 24 houses each containing 7,000 birds. Each bird is drinking 0.6 liter[2], which results in a total amount of **100** m³/day. This is not in relation with the expansion of the abattoir. The plan is to build extra chicken houses outside the farm. These chicken houses are outside the scope of the project.

The maximum capacity of the hatchery is about 500,000 chickens a week, which is sufficient for the expansion of the abattoir. The amount of water needed for the hatchery is estimated at **30** m^3 / day.

The wish of Novos Horizontes is to plant 150 ha of fruit trees on the farm. The amount of water needed for irrigation of these trees in this climate is 1200 m^3/year/ha, which is based on figures of the International commission on irrigation and drainage, country profile – South Africa.

[2] 5 times the weight of the food they eat a day, based on experiences of the farmer

This means a 493 m³/day for 150 ha, which is rounded off to **500** m³/day (because of the uncertainty of the size of the area).

Currently there are eight private houses on the farm. With an expansion of the farm, also an expansion of the houses on the farm is expected. It is assumed that in the future situation a total of 15 houses is needed, which uses each 0.25 m³/day (see paragraph 2.4.1). This results in a total water use of **3.75** m^3/day.

Besides the houses, there will be two schools on the farm: Rapale International School (2012) and Ebenezer College (2013). The amount of water needed for both schools is calculated by making use of 7 l/p/d, which is following the WHO[3] guideline. With an estimation of 200 persons per school, the total amount of water needed for both schools is **2.8** m³/day.

Eggs of Africa has the idea to expand to 40,000 chickens per day. Each using 0.5 liters a day results in a total use of **20** m³/day.

Besides the above mentioned water users there is also water used by workers for washing and by people from the neighborhood. The current amount is estimated at 5 m^3/day. For the future situation, **30** m^3/day is reserved based on a big increase of the amount of employees.

In Figure 3.1, the final amount of water needed in the future is visible.

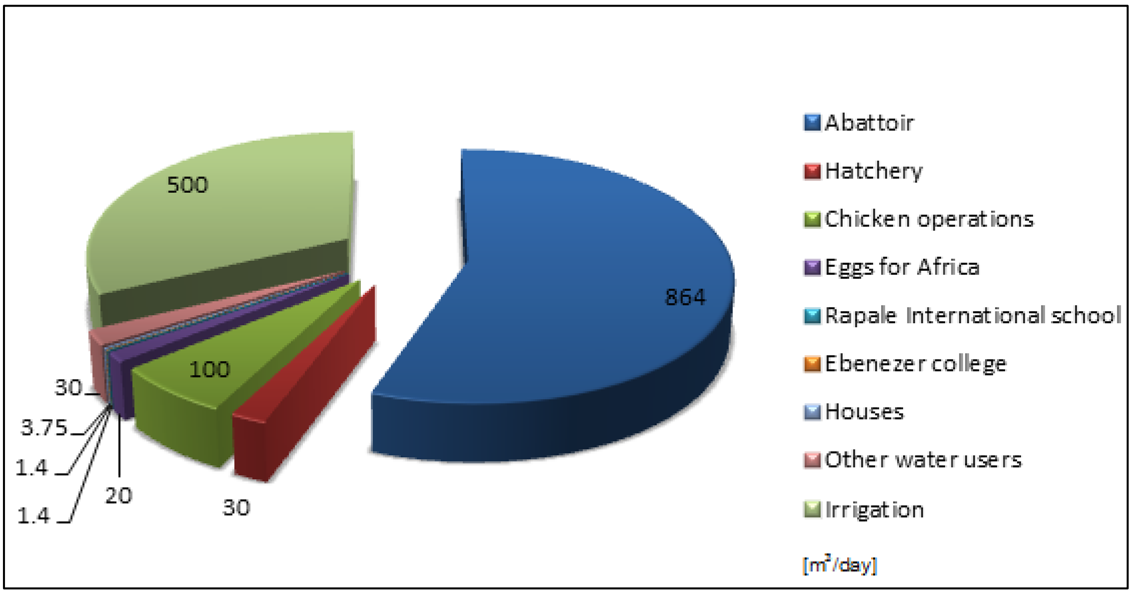


Figure 3.1 Water usage in future

To come to a structural improvement of the water system of the project area, it is important to know where the water is demanded in the current situation and future. In Figure 3.2, the dark red dots indicate the current water demand and the light red the future demand. The size of the dot is representative for the water that is demanded in the current situation and in the future.

[3] World Health Organization

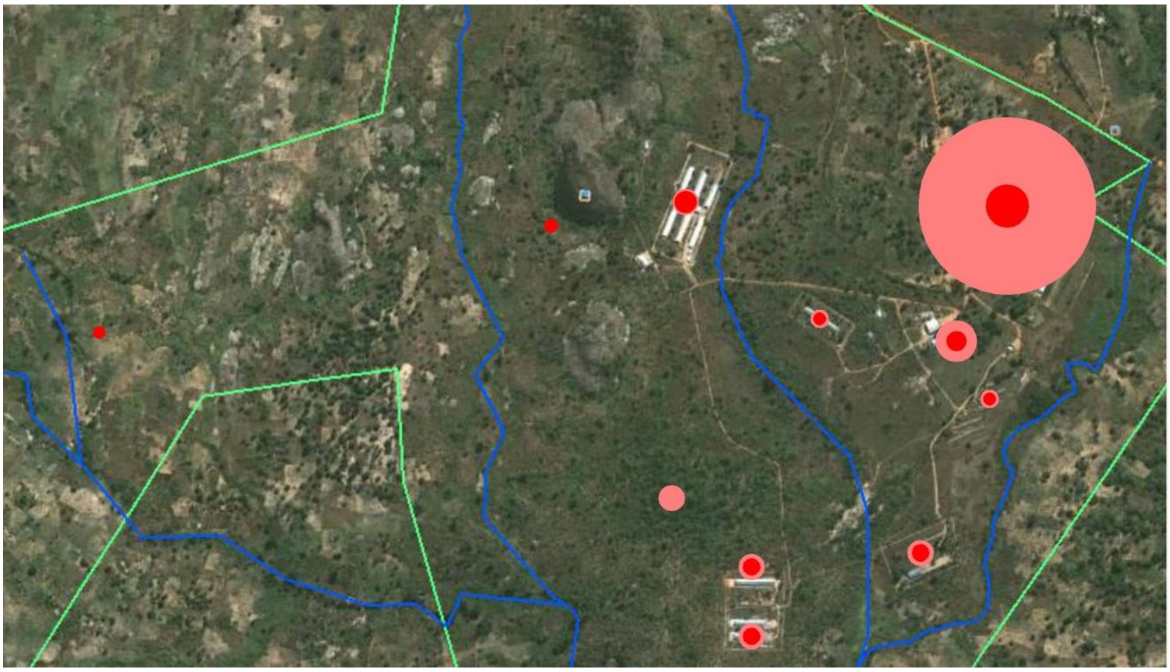


Figure 3.2 Current water demand and future water demand on the farm

3.1.2 Quality of water

In the future, Novos Horizontes wants to standardize the water quality. Regulations on abattoirs for poultry and other farm animals exist and were released by the Mozambican Ministry of Agriculture (2011). The following requirements with respect to water quality are included:

Article 18.1:	The water of the abattoir needs to be clean, canalized drinking water, free from any floating particles and treated with chlorine.
Article 18.2:	The water needs to be tested every month by a certified lab to assure the turbidity of the water.
Article 18.3:	The water tanks used for the abattoir needs to be closed. Furthermore the tanks needs to be disinfected every 6 months.

This means that the water for the abattoir (864 m³/day) needs to meet the demands described above. The water needed for other purposes, needs to stay at the same quality as the current (borehole quality).

3.2 Criteria

Besides the demands, there are also important criteria with respect to the solution of the water problem. The criteria are determined in cooperation with Novos Horizontes and explained below.

3.2.1 Reliability

Every possible solution divers in way of delivering water and therefore there are different failure mechanisms for each solution. The reliability of possible solutions depends on the failure mechanisms and the probability of occurrence of those failure mechanisms. In this context failure also means that a solution cannot meet the demand.

3.2.2 Sustainability

The definition of sustainability is given by the VN-commission Brundtland, 1987: ‘Sustainability meets the needs of the present without compromising the ability for future generations to meet in their own needs’. Sustainability is the long-term maintenance of responsibility, which has environmental, economic, and social dimensions.

Environmental impact
It is important to assess the effects on the environment. For example: Some solutions need a lot of space and therefore some agriculture areas used by the local people needs to be moved. Another example: blocking a water stream by a dam will have an impact on the people downstream.

Furthermore environmental issues will deal with the use of scarce resources. The use of power, sustainable products and equipment will be taken into account while assessing the possible solutions.

Economic impact
The economic aspects of sustainability include creation of employment and other aspects that have direct impact on the local economy.

Social impact
All the people in Mozambique are strongly dependent on water. The aim of Novos Horizontes is to share the water with the local people. Solutions which enable it to share water with others have a positive impact on the social aspect of sustainability.

4. Review and follow-up

The current water system on the project area consists of, in total, 7 boreholes. The water is pumped to the several water demand sites on the farm: the abattoir, the hatchery, chicken operation buildings, Eggs for Africa, houses and Rapale International School. The current water demand on the farm is 112.5 m^3/day. At the moment the 7 boreholes can fulfill this demand, only during very dry periods there are some problems. Further there are no problems related to the quality of the water.

Planned expansions of the activity on the farm will increase the water demand to 1,551 m^3/day. Besides this quantity demand, the quality of the water is preferred to be standardized in the future. This means that the water should meet the requirements set in the regulations on abattoirs for poultry and other farm animal. These are governmental requirements that were released by the Mozambican Ministry of Agriculture. Besides this, reliability and sustainability are important criteria which will be included in the assessment of the different solutions for the future water demand.

Based on the boundary conditions and criteria defined in this part, possible solutions will be elaborated in the next part.

Part B

Possible solutions

5. Possible solutions

Part B includes an elaboration of possible solutions to create more water on the farm. The final objective is to come up with a good view of the possible solutions for the demands described in Chapter? Therefore the reachable amount of water (quantity), the expected water quality and the expected costs per solution are determined. Furthermore, every solution is judged on the advantages and disadvantages related to reliability and sustainability. In this way, the demands and criteria for a future water system (determined in chapter 3) can be assessed.

In a previous stage, a list of six different possible solutions was defined: moving the farm, using an existing reservoir, reuse of water, boreholes, rainwater harvesting and reservoirs. These solutions were shortly described in the project plan. In a later stage it was chosen to skip the option of moving of the farm. This option seemed not in line with the philosophy of Novos Horizontes. Also the use of an existing reservoir near to the farm is in this report ignored as a possible solution. To be dependent on a reservoir of another owner is considered to be very undesirable. Besides this, is the possible reservoir owned by a competitor of Novos Horizontes.

Reuse of water could be a possible solution, but could not be elaborated in full detail. Therefore first a short notice will be given on reuse of water. Afterwards, the following possible solutions will be elaborated into more detail: boreholes, rainwater harvesting and reservoirs.

5.1 Reuse of water

The main activity for Novos Horizontes is the sale of frozen chickens for consumption. The process of preparing the final products is done in the abattoir. As mentioned before, the abattoir is the main user of water and reuse of used water is a serious solution to meet the requirements in the future. Unfortunately the knowledge was not available during the project to give a good and well supported judgment on the reuse of water from the abattoir. Therefore only a brief overview of the process and possible treatment installations will be given.

5.1.1 Process

The process of producing frozen chicken products includes slaughtering, intestines removal and cleaning before the chickens are frozen in and sold. The process is very water consuming. It is assumed that the loss of water is limited during the process. The inflow is almost equal to the outflow. This makes the abattoir in basis a good option for the reuse of water. However the used water is contaminated with detergents, blood, grease, possible deceases (dead chickens have a direct contact with the discharge gutter), intestines and feathers.

The process, based on visual inspection, is schematically shown in Figure 5.1.

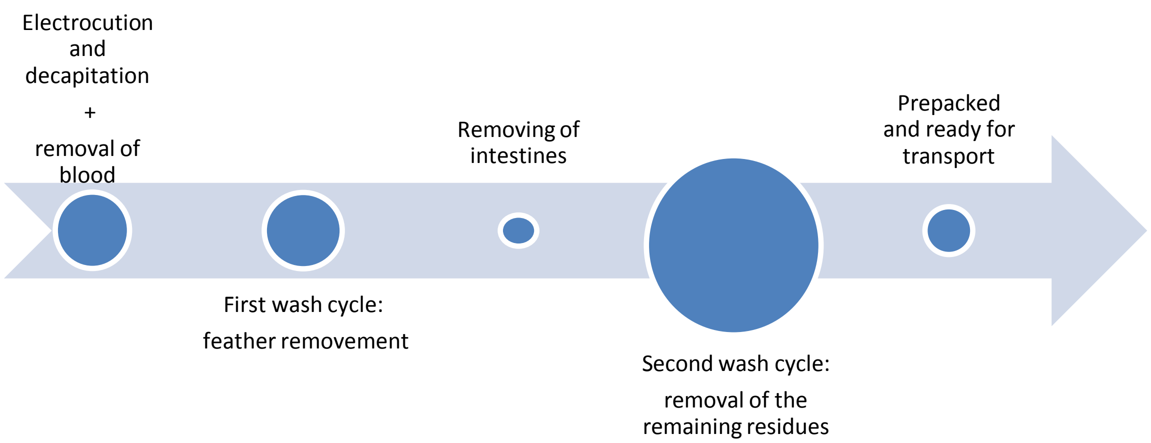


Figure 5.1 The process of the abattoir

The circles in Figure 5.1 give an estimation of the amount of water that is being used in the different part in the process. The ratios are estimations based on visual inspection in combination with local knowledge. As can be seen the second wash cycle is the biggest water consumer.

Cleaning of the floors inside the abattoir is done by means of chemical cleaning with Vet Range, a liquid detergent for cleaning abattoirs. In case this detergent is not available simple kitchen detergent is used instead.

5.1.2 Streams of water

All the waste water is collected in one discharge gutter and transported outside the abattoir before it is discharged into the environment. The discharge gutter has a course filter system to remove feathers, bones and intestines. Blood is collected and transported out of the abattoir separately before it is disposed into the ground. However it is possible that some of the blood will end up in the discharge gutter because of the blood that remains in the chicken until the first wash cycle and also cleaning the floor of the first room (where the blood is removed) will discharge blood into the discharge gutter.

At present time a total of 48 m^3 per day of water is being used. Prospects on developments estimate the total water use of the abattoir in the future at 864 m^3 per day. It is assumed that the outflow of the abattoir will also be around 864 m^3 per day.

Simple tests on the inflow and outflow show no big differences in quality. However, very important features as nitrogen content, COD (Chemical Oxygen Demand) values and FOG (Fat Oil Grease) values were not tested and thus it is impossible to say something about the quality of the effluent. Based on experience of a DUT professor it is assumed that COD and FOG values of abattoirs are high.

5.1.3 Possible treatment installations

Because of the high levels of COD and FOG the following treatment technologies are recommended (by a DUT) to study.

- Dissolved Air Flotation (DAF) technology
- Upflow Anaerobic Sludge Blanket (USAB) technology

The elaboration of these processes, with advantage, disadvantages and costs falls out of the scope of this project.

5.1.4 Conclusions and recommendations

Reuse of water is a very interesting possible solution because of the high ratio between inflow and outflow. However further research into water quality and treatment technologies are necessary to make a good and well supported judgment on reuse of water as a possible solution. Possible treatment technologies include DAF and USAB technologies.

5.2 Boreholes

One of the solutions for the water problem could be to make more boreholes. It is difficult to assess the potential of using boreholes to provide more water because it is almost fully dependent on the subsurface. Despite the fact that insufficient data about the subsurface is available, a first assessment is made on the possibilities of using boreholes. This first assessment is based on the available geological-, hydrological- and current borehole data (SADC 1997).

5.2.1 General principle

Boreholes are specifically suitable for regions where a lot of water is stored in deep aquifers. Groundwater in the basement formations are generally encountered in the overburden, weathered rock or in fractured rock. An illustration of the presence of aquifers in the basement formations is shown in Figure 5.2.

The weathered rock in general has a good transitivity and storage capacity to provide some yield. However the better aquifers are found in the contact zone between the overburden and the bedrock. In most cases these zones are less disintegrated with secondary clay minerals and have therefore a higher transitivity. Ultimately, the highest yielding aquifers can be expected in the fractured bedrock. Boreholes are usually drilled into the fractured bedrock where the permeability is rather high and storage can be provided by the overburden. Large and deep fractured aquifers are recharged through connected systems of fractured zones. The recharge of shallow aquifers (found in overburden or in fractured upper part of bedrock) generally dependent on rainwater recharge and the lithological character of the overburden.

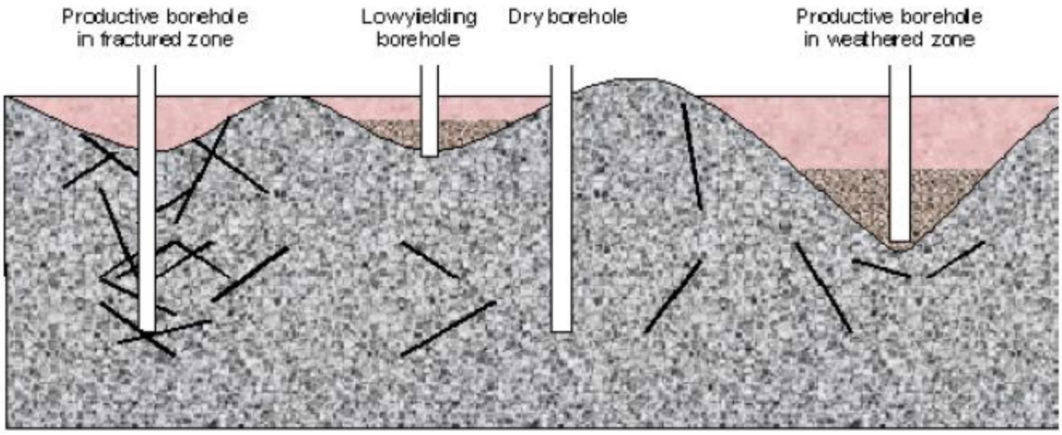


Figure 5.2 Illustration of the presence of aquifers in basement formations

5.2.2 Quantity

The water quantity that can be pumped from boreholes is depending on the size of the source, it is catchment area (in combination with rainfall) and the yield. If sufficient boreholes are used it is likely that the demand of 1,551 m^3/day can be fulfilled.

In the current situations boreholes are placed randomly without any geophysical investigation and/or field measurements. In this case the average discharge of a borehole can be estimated as 19.1 m^3/day, which is measured and described in chapter 2.5.1 For the future demand, this means that, if boreholes are placed randomly, 82 boreholes are needed.

A proper geophysical investigation can increase the discharge/yield per borehole and therefore reduce the amount of boreholes that are needed. In weathered hard rock areas, geo-electrical surveys are particularly appropriate. Geo-electrical surveys consist of vertical resistivity measurements and Vertical Electrical Sounding (VES). The aim of a vertical resistivity measurement is to identify lower resistivity values caused by the presence of a fractured zone and/or a deeper weathering profile which may be favorable for groundwater abstraction.

The VES will be carried out to get an insight in the differences in depth and type of the overburden. In this way it is possible to predict the drilling depth of the boreholes.

It is assumed that it is not feasible to do VES measurements on the entire project area. An often used approach is to first carry out a couple of horizontal lines, based on the desk study and analyses of current boreholes. Along these lines, vertical resistivity measurements will be performed. Finally, a VES is performed on promising sites of the lines.

Following Appendix B1, the project area belongs to the Geological Class C2. Experience in that Class shows that the use of adequate geophysical techniques can result in an increase of the discharge from 30% to 80% in the weathered hard-rock areas.

Another property of Class C2 is that boreholes usually will have a maximum yield of 24 m^3/day (8 hours times 3 m^3/hour). This means that the current yield of 19.1 m^3/day is already relatively high compared to the maximum yield. Because of this high value the maximum increase of discharge, due to a geophysical survey, is estimated at 30%. The estimated average yield will therefore be 24.8 m^3/day, which results in 63 boreholes. An overview of the calculation is given in Table 5.1.

Subject	Value	
Demand	1,551	m^3/day
Average discharge current boreholes	19.14	m^3/day
Needed amount of boreholes without field survey	82	
Increase of discharge with field survey	30	%
Average discharge boreholes with field survey	24.89	m^3/day
Needed amount of boreholes with field survey	63	

Table 5.1 Needed amount of boreholes

5.2.3 Quality

In the future, Novos Horizontes wants to standardize the water quality. The quality must comply with the regulations on abattoirs for poultry and other farm animals (see chapter 3.1.2). The main requirement is defined as follows:

“The water of the abattoir needs to be clean, canalized drinking water, free from any floating particles and treated with chlorine”.

Test performed in the laboratory of the Nampula Hospital (see Chapter 2.5.2) proved that the water, from the boreholes and the reception tank is clean, free from any floating particles and from drinking water quality. This means that the water from the boreholes only needs to be treated with chlorine to use it for the abattoir, which is the main user.

5.2.4 Reliability

The only problem, related to reliability, is that boreholes can run dry. This means that the water level inside the borehole becomes lower than the level of the pump. When this happens, is unfortunately not easy to determine. It depends on the groundwater level and therefore on the size of the source, it is catchment area (in combination with rainfall) and the yield. Most boreholes in this region are drilled in a productive fractured zone, which makes it even more difficult to determine the source and it is catchment area.

In the current situation only a few boreholes are running dry during the dry periods. Especially when boreholes are used on a large scale, it can be a significant problem.

It will be very important to collect data about the boreholes that run dry (pump levels, turning hours). In this way the ideal pump level can be found and it is probably possible to say something about the size of the source and catchment area. In this way conflicted boreholes can be prevented and the reliability can be improved.

5.2.5 Sustainability

For sustainability different aspect needs to be reviewed, namely the three pillars of sustainability: social, environmental impact and economic. These aspects can be reviewed in the following context in order to define the sustainability of using boreholes.

Social

The idea of Novos Horizontes is to install water tabs on each borehole. In this way people from the surrounding are free to extract and use water from the boreholes. Especially water with such a quality as borehole water is very scarce. Therefore this will have a significant positive effect on people that live on and around the farm.

Environmental impact

Boreholes will not result in direct danger for the environment. The holes are relatively small (5 inch in diameter) and will be covered after drilling.
On the other hand, extracting water out of the subsurface could lead to a reduction of the yield of boreholes around the farm. It is difficult to quantify this effect, because it fully depends on the properties of the subsurface hydrology.

Furthermore, the pumps of the boreholes will use a lot of power. At this time, the used power is environmentally friendly power, which is supplied by a big hydropower station in Mozambique. However, in the future it is possible that, due to several reasons, the used power is created with use of scarce sources.

Economic

The boreholes will be drilled by specialized companies. Only a few workers are needed for the drilling process, which means that this will not lead to a temporary increase of the local employment. On the other hand, boreholes will supply more water and give Novos Horizontes big opportunities to expand, which is explained in Chapter 1.

5.2.6 Costs

The costs for boreholes are split up into investment costs, maintenance costs and electricity costs.
The investment costs are based on the number of boreholes that are needed and the price for a single borehole. In general local drilling contractors are asking $15,000 for a borehole including a pump. The costs are independent on the depth. Contractors just drill until they find water. Only really deep boreholes (> 100 meter) will lead to higher investment cost.

The calculation of the investment costs is based on a 5 inch hole. The pumps that are used in the calculation are CRI deep well submersible pumps (C.R.I-Pumps 2012). This 4” pump is chosen because Novos Horizontes has good experiences with this brand and type. The costs for a single pump are $1000.-
Last part of the calculation is the geological survey, cost for the survey are estimated on $100,000.- These cost are determined by information from the company WE consult. To give an insight in when a field survey is profitable, the costs are calculated with and without a field survey (Table 5.2)

General:

Type of cost		Costs [$]
1	Borehole	14,000
1	Pump	1,000
1	**Borehole + Pump**	**15,000**

Without field survey:

Type of cost		Costs [$]
0	Geotechnical survey	
82	Boreholes + Pumps	1,230,000
1	Electricity supply	50,000
Total investment		**1,280,000**

With field survey:

Type of cost		Costs [$]
1	Geotechnical survey	100,000
63	Boreholes + Pumps	945,000
1	Electricity supply	50,000
Total investment		**1,095,000**

Table 5.2 Investment costs with and without geotechnical survey

Table 5.2 shows clearly that an extensive field survey will lead to a reduction of $ 265,000 in investment costs.

The maintenance costs include reparation and replacement. The costs for these two aspects are based on the experiences in the current situation. At the moment there are 7 boreholes with 7 pumps, every year 1 or 2 pumps needs to be replaced. This means that an average of 20% of the pumps must be replaced during the year. The costs for maintenance differs per pump. Three phase pumps are considered in this report. In general three phase pumps are more reliable and require less maintenance. Maintenance costs are shown in Table 5.3.

Without field survey:

Type of cost		Costs [$/year]
17	Replaced pumps	17,000
1	General maintenance	1,300
Total maintenance		**18,300**

With field survey:

Type of cost		Costs [$/year]
13	Replaced pumps	13,000
1	General maintenance	1,300
Total maintenance		**14,300**

Table 5.3 Maintenance costs

Electricity costs are based on the CRI deep well submersible pump. This pump uses 3.50 kWh. In general a pump operates 8 hours per day, therefore the following costs for electricity are calculated during the year (Table 5.4)

Without field survey:

Type of cost		Power [kW]	Costs [$/kWh]	Costs [$/year]
82	Pumps	3.50	0.05	41,902
Total energy costs				**41,902**

With field survey:

Type of cost		Power [kW]	Costs [$/kWh]	Costs [$/year]
63	Pumps	3.50	0.05	32,193
Total energy costs				32,193

Table 5.4 Energy costs

5.2.7 Conclusions and recommendations

Based on the aspects quantity, quality, reliability, sustainability and costs it is possible to use boreholes to fulfill the water demand of 1,551 m^3/day.

A big advantage of boreholes is the water quality. Water from boreholes can almost directly be used for the production process of the abattoir, which is the main user. Furthermore, with water tabs installed on all boreholes the solution gives opportunities for people in the surrounding.

An important disadvantage of boreholes is the reliability, especially when they are used on a large scale. The chance that boreholes will pump from the same source will increase, which means that they can run dry sooner. This aspect can partially be compensated by performing a geophysical investigation. A proper geophysical investigation can lead to an increase of the discharge/yield per borehole and therefore reduce the amount of boreholes that is needed. Another disadvantage is the use of power by the pumps, which has a negative effect on the sustainability of the solution.

The costs of boreholes consist of investment, maintenance and electricity costs. Based on local knowledge, the cost of a single borehole is $ 15,000. The amount of boreholes needed for a certain demanded amount of water depends on the execution of a geophysical investigation. For the final demand of water, the investment costs vary between $ 1,095,000 and $ 1,200,000.

If more boreholes are chosen as a solution for the water plan it is recommend to perform an extensive geological survey. In this way there will be a better insight in the applicability of boreholes and the possible drill locations.

It is possible to drill the boreholes in several stages. In this way information from already drilled boreholes can be used in deciding the drilling strategy of the next boreholes. This probably will decrease the number of boreholes that will fail and/or give insufficient water.

It is also recommended that power facilities on the farm are improved. In this way the turning hours will increase and technical problems can be prevented. Also a detailed maintenance plan will most certainly reduce technical problems and therefore increase the turning hours of the pumps.

Recommended is also the setting up of a system that includes all needed specification of the different boreholes. This could help in getting a better insight in the subsurface hydrology which is important to decide locations and depths of new boreholes.

5.3 Rainwater harvesting

Rainwater harvesting or water harvesting can be defined in different ways. Boers and Ben-Asher (1982) summarizes three definitions of water harvesting. In line of this report the definition of Currier fits the best: 'The process of collecting natural rainfall from prepared watersheds for beneficial use.' Boers (1994) states that all water harvesting systems have in common that in terms of catchment area, volume, needed storage and capital investment rainwater harvesting is a relative small-scale operation. Also the variation of surface runoff and subsurface flow in arid and sub-arid regions during the year and the local character of water resources are common characteristics of water harvesting.

The African Development Bank has developed a water harvesting handbook which elaborated different rainwater harvesting systems. This study will mainly focus on domestic rainwater harvesting (DRWH) systems. Also Surface Catchment Harvesting (SCH) will be elaborated. Finally groundwater recharge in combination rainwater harvesting systems will be elaborate shortly.

5.3.1 General principle

DRHW is defined as the collection of water from roof areas. DRHW system (Figure 5.3) consists of different components including roof, transport system (gutters and downpipes) and a storage facility. The system can be applied to all buildings with a roof and DRHW systems provide local availability of water and there is no need for a head difference or pumps for the transport of water.

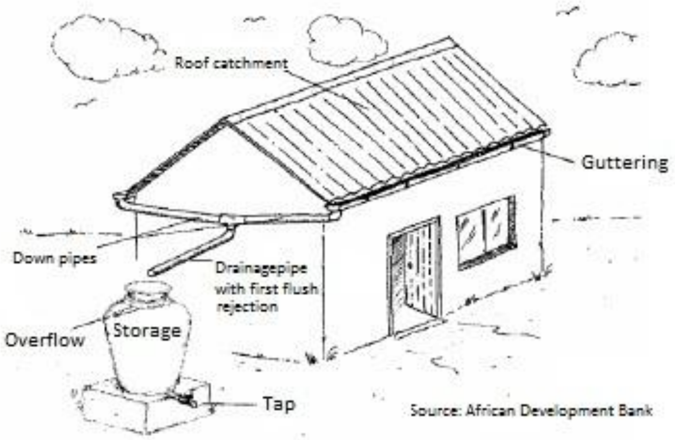


Figure 5.3 Domestic Rainwater Harvesting System

Another option for rainwater harvesting is Surface Catchment Harvesting (SCH). This is the collection of surface runoff in small reservoirs or established water retaining structures. Because the Novos Horizontes area consists of a number of Inselberg rock formations that rise above the surface level the SCH systems can be applied. The idea is to collect the runoff from the rocks and transport it in channels to storage facilities like a reservoir or storage tanks.

5.3.2 Quantity

Water quantity will be checked on the basis of the performance of the rainwater harvesting systems. The performance of rainwater harvesting systems is mainly depended on rainfall and area of roof or footprint of an Inselberg rock formation. The total amount of water that potentially can be captured per building or rock can be calculated with equation (5.1) :

$$V_{captured} = A \cdot i_{year} \cdot \alpha \qquad \textbf{(5.1)}$$

With:

$V_{captured}$:	Total available volume of water through rainwater harvesting [m^3/year]
A:	Total roof or rock footprint area [m^2]
i_{year}:	Average annual rainfall [m/year]
α:	Runoff factor [-]

The area of roofs and the footprint of the Inselberg are estimated based on Google Earth aerial pictures.

Annual rainfall

From the Giovanni GLDAS-1 CLM Model the average rainfall (i_{year}) in the area has been calculated and is around 1,100 mm per year, Figure 5.4 (see Appendix A1).

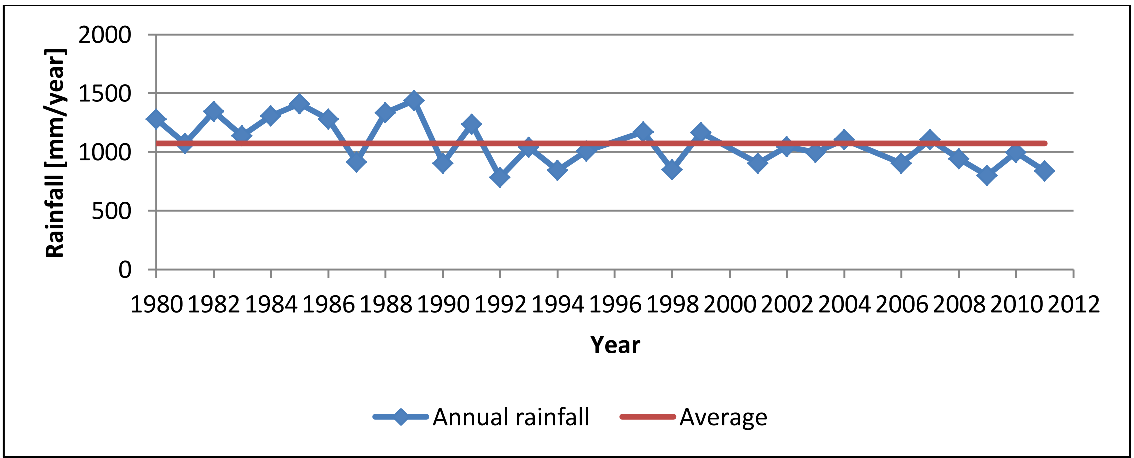


Figure 5.4 Annual rainfall (GLDAS-1 CLM Model)

Runoff factor

The roof runoff factor (α_{roof}) is used in order to deal with the water losses that occur on a roof and are based on GI sheets, which are equivalent to the roofs at Novos Horizontes. Here the value is set at 0.9. Outgrowers mostly have thatched roofs on their chicken buildings. The roof runoff factor for thatched roofed buildings is 0.2. The values are obtained from the Rainwater Harvesting Handbook of the African Development Bank.

The rock runoff factor is used in order to deal with the water losses that occur and are based on the value given by African Development Bank. Here the value is set at 0.6.

The Novos Horizontes area consists also of some poorly maintained thatched roofed buildings (Site 1/2/3). These buildings are not considered in this study because they will be out of use in the future and are considered not to be efficient for DRWH systems because of the low runoff factor of thatched roofs (0.2) and the poor quality of the roofs.

Performance and demand

The area (A_{roof} and A_{rock}) and the average potential total volume of water captured by the buildings and rocks ($V_{captured}$) located on the Novos Horizontes area is summarized in Table 5.5. The table does not include all future developments.

	A_{roof} , A_{rock} [m^2]	$V_{captured}$ [m^3/year]	$V_{captured,min}$ [m^3/year]	$V_{captured,max}$ [m^3/year]	V_{demand} [m^3/year]
Process buildings					
Abattoir	990	980	648	2,146	328,725
Hatchery	480	475	314	1,041	10,958
Feed mill	700	693	458	1,518	-
Chicken operations					
Eggs for Africa	5,975	5,915	3,909	12,954	7,305
Nampula	9,000	8,910	5,888	19,512	9,205
Chicken building (Mike)	1,300	1,287	850	2,818	1,535
Site 7	5,175	5,123	3,386	11,219	4,600
Residential buildings					
Scott's	420	416	275	911	90
Wilfred's	300	297	196	650	90
Andrew's	140	139	92	304	90
Alcedir's	80	79	52	173	90
Riemer's	150	149	98	325	90
Mike's	200	198	131	434	90
Doc's	150	149	98	325	90
Other buildings					
Novos Horizontes office	420	416	275	911	16
Eggs for Africa office	195	193	128	423	16
Rapale International School	600	594	393	1,301	308
Ebenezer College	600	594	393	1,301	308
Workshop	225	223	147	488	-
Rocks					
Scotts rock	26,000	17,160	10,206	34,162	-
Easter rock	19,200	12,672	7,537	25,228	-
Rock in the west of the farm area	45,000	29,700	17,664	59,127	-
Outgrowers	200-245	44-132	131-160	438-537	275-550

Table 5.5 Roof area, captured water and water demand

Figure 5.5 shows the average ($V_{captured}$), the minimum ($V_{captured,min}$) and the maximum ($V_{captured,max}$) captured volume of water. These values are based on the roof area and the average annual rainfall of 1,100 mm/year, the minimum annual rainfall of 654 mm/year and the maximum annual rainfall of 2,190 mm/year (Appendix A1).

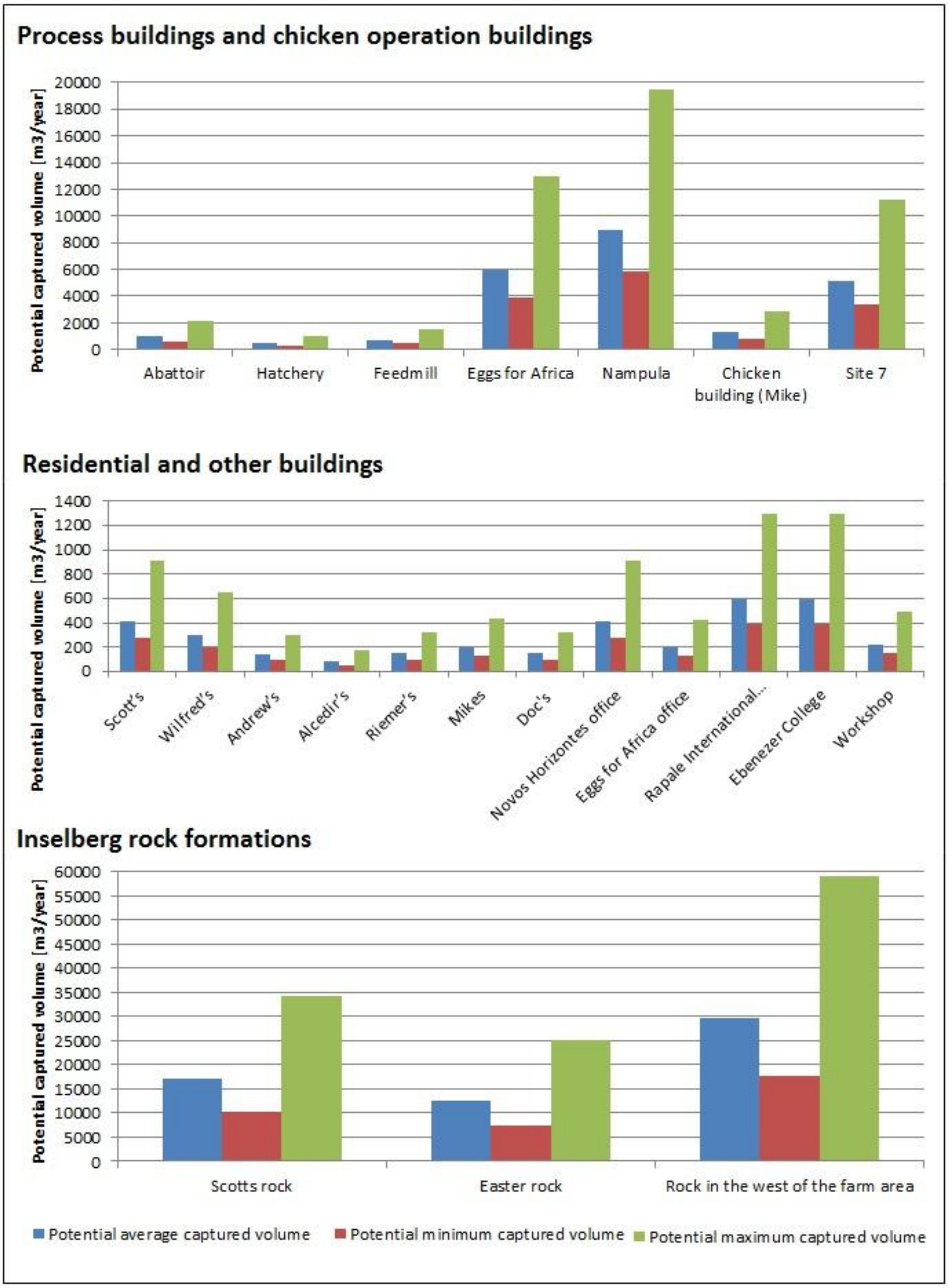


Figure 5.5 Captured volume of water by rainwater harvesting systems

The water demand per year of each building (V_{demand}) is also shown in Table 5.5. The total daily water demand for the different buildings was calculated in Chapter 2.4.1. Eggs for Africa will use, including an expansion to 40,000 chickens, around 7,305 m^3 per year. The water demand of the other chicken operation sites, where the water use is equal to 0.6 l per chicken per day, is also shown in Table 5.5.

The table includes the planned expansion plans except the construction of completely new chicken buildings on the farm.

The residential water demand sums up to 91.25 m^3 of water per year. In this study 90 m^3 per year will be used.

The water use for offices is estimated based on 5 people using water for drinking (5 lcpd[4]) and washing hands, flushing and cleaning toilets (4 lpcd). This yields in a water demand of 16 m^3 per year.

Aalbers, Arkesteijn et al. (2011) estimated water consumption for schools between 6 and 7 liter per day per student (including teachers). This amount includes drinking water, preparing of food, washing faces and hands, cleaning of latrines and classrooms and a lunch program. Based on this, this study will use 7 liter per day per student for the water use at a school. For a 44 weeks (5 days per week) school year and 200 students and staff, a total of around 308 m^3 of water per year will be used. Here it is assumed that Rapale International School and Ebenezer College will be equally large and will use both 308 m^3 of water per year.

Outgrowers are located outside the project area and the average water use per day per chicken is around 0.5 l. The water use per average outgrower, depending on the size (1,500-3,000 chickens), is between 44 - 132 m^3 per year.

Table 5.5 shows that DRWH systems are not suitable as an individual source for the demands of the abattoir, hatchery and all chicken operation buildings. The roof area is just not sufficient for the big demand of these buildings. As a supplementary source the DRWH systems are suitable for these buildings.

DRWH in this form is also not a solution for outgrowers, Table 5.5. Improving the DRWH system by combination with groundwater recharge (paragraph 5.3.8) can be a solution for outgrowers. Investment in groundwater recharge facilities, pump capacity and roof material is however required. Further exploration of the outgrowers falls out of the scope of this report.

Runoff from rocks is relative large in total volume. Captured water can be transported to specific demand sites by use of pumps and pipes. Transport of water by gravity is also possible.

Elaboration of domestic rainwater harvesting for individual buildings will only focus on all residential buildings (except Alcedir's), offices and both schools.

Because of the lack of daily rainfall data the required storage capacity will be based on the monthly distribution of the rainfall that has been analyzed. For the storage, the observed monthly rainfall data will be used because of the pessimistic values compared to the modeled data. Figure 5.6 shows this monthly distribution in rainfall. The dry season can be assumed to be from May until October.

[4] Liter per person per day

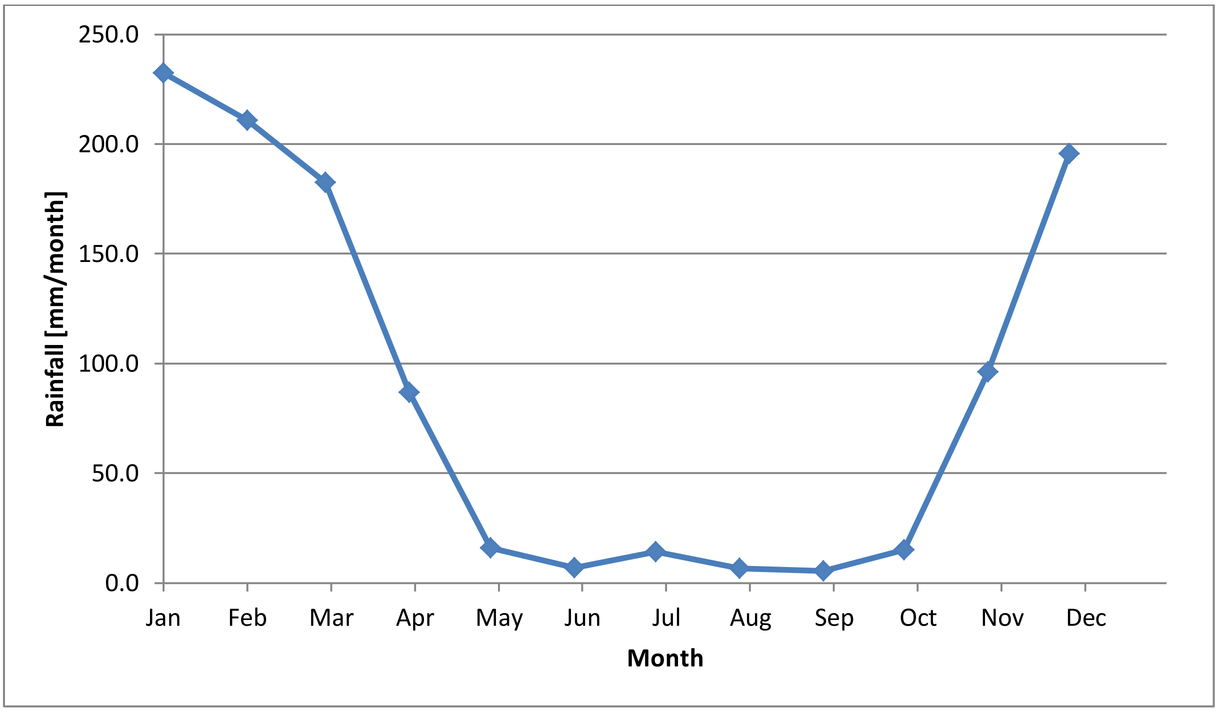


Figure 5.6 Average monthly rainfall distribution

Figure 5.7 shows the monthly water balance of the different buildings.

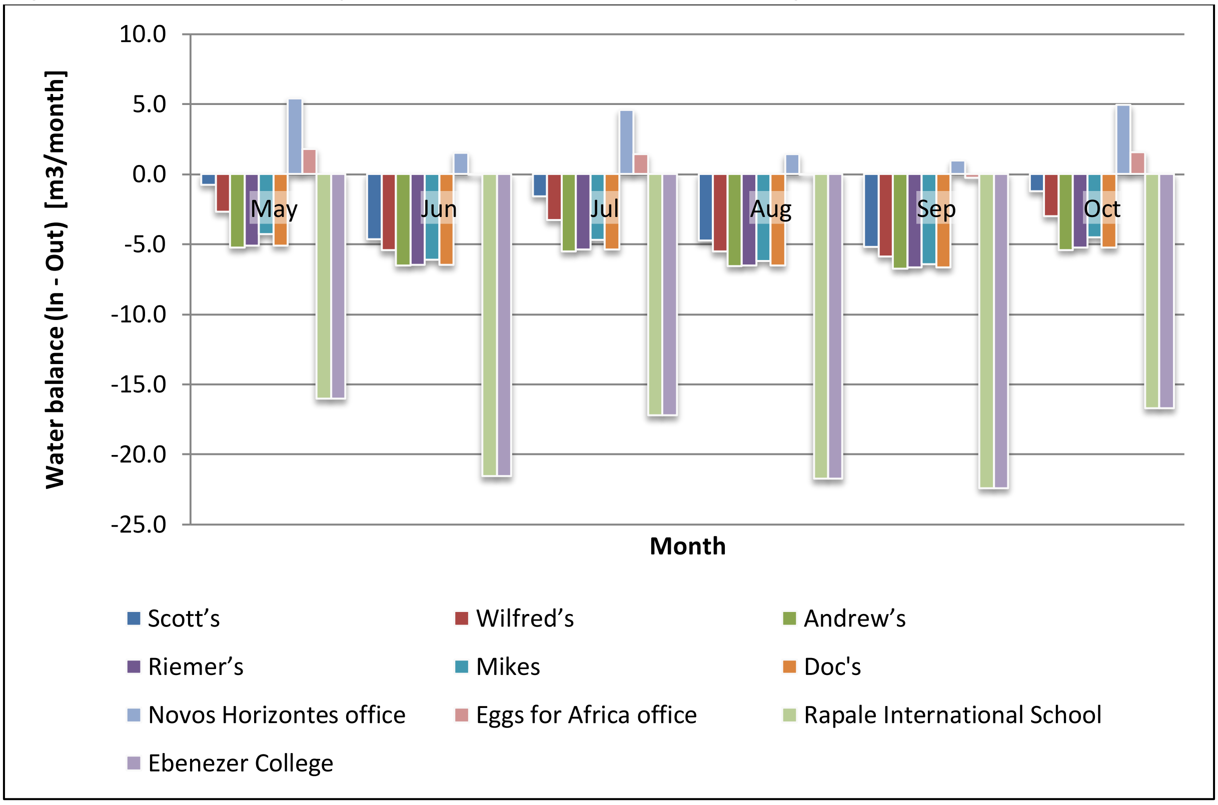


Figure 5.7 Monthly water balance per building

The minimum required storage capacity is set at 1 m^3. Taken this minimum required storage into account, the office building of Novos Horizontes and Eggs for Africa are the only locations that do not need extra storage in order to coop with the dry months. The water supply exceeds the demand in all months for the office of Novos Horizontes. The office of Eggs for Africa need some additional storage during 3 months but the volume of storage that is needed is less than the minimum required volume.

The monthly water balance for the other buildings show that storage is required in order to supply throughout the year. As a supplementary source of water DRWH and SCH systems will function. The total volume of water that comes available by rainwater harvesting per month is shown in Appendix B5.

5.3.3 Storage

The 6 months of the dry period will prove to be decisive for the storage, in case rainwater harvesting is used as individual source. Some residential buildings and both schools need considerable storage facilities. The total storage capacity is based on the sum of all shortages during the dry months. Table 5.7 shows the total required storage per building.

Building	Required storage [m^3]
Residential buildings	
Scott's	18
Wilfred's	26
Andrew's	36
Riemer's	35
Mike's	32
Doc's	35
Other buildings	
Novos Horizontes office	1
Eggs for Africa office	1
Rapale International School	116
Ebenezer College	116

Table 5.6 Required storage capacity per building

Storage facilities can consist of above- or underground facilities. Type of tanks include plastic tanks, ferro-cement tanks and cement block storage basins. Plastic tanks and cement block basins are very suitable for smaller volumes of storage. Plastic tanks are at least available in 1000 l, 2500 l, 5000 l and 10,000 l. In this report it is considered that 10,000 l is the biggest available plastic tank. Cement block basins have to be constructed and thus can vary in size. This is also the case for ferro-cement tanks, which range at least up to 100,000 l (REFERENCE UNHCR) .This means that the storage volume that is required can be provided by the type or facilities described above.

Reservoirs as storage facilities for SCH systems are considered to be too expensive. Reservoirs on the project area can be filled by discharge from the streams. Furthermore, the performance of SCH system is questionable because it is not certain that more water is made available for use. Runoff from the rocks will eventually end up in streams and thus end up in a downstream reservoir. The process of water transport to the reservoir will be faster and probably less evaporation will take place. But it is unclear if that is worth the investment of transport pipes or channels. Rainwater harvesting in combination with reservoirs as storage are therefore not taken into account in this possible solution study.

5.3.4 Quality

Quality issues related to DRWH can be found in contamination on the roof and in the storage tank. This contamination consists mainly of dust, leaves, chemical deposits, and bird droppings. Cleaning of the roof and the storage tank on regular basis can reduce the probability of contamination. Also a first flush rejection system can be installed (Figure 5.8).

This system will provide that the first millimeters of roof runoff containing contamination will be separated from the cleaner subsequent water flow. This is established with a downpipe with a drain. The drain can be opened after a rainfall event and the dirt can be flushed out (Mwenge Kahinda, Taigbenu et al. 2007).

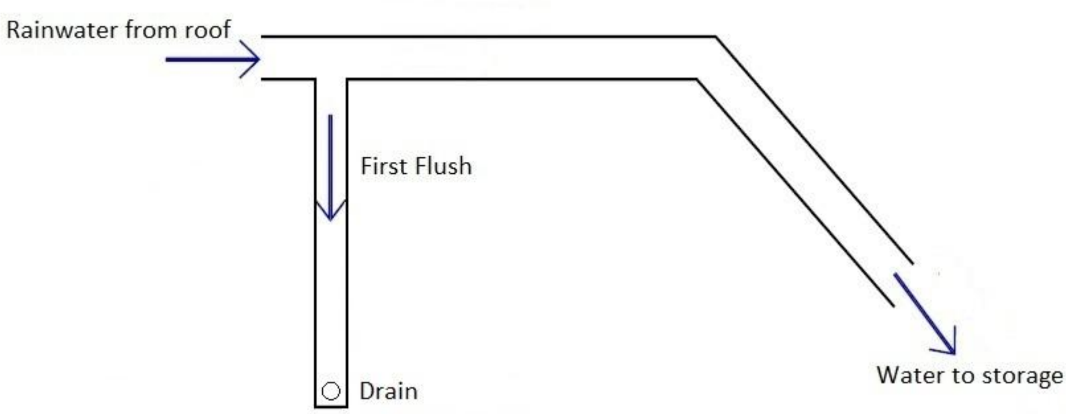


Figure 5.8 First flush principle

The roofs at the Novos Horizontes area consists mainly of zinc roof sheets. Zinc is a heavy metal and can be a quality issue if present in large densities. No data is available on the quality of roof runoff.

Another quality issue is water related diseases. These diseases are caused by insects that breed in water. Examples of these diseases are malaria and yellow fever. Prevention measures for mosquito breeding around on DRWH facilities (at tank level) include good closure of the tank, mosquito screens and the prevention of (longtime) stagnant water in gutters, down pipes and first flush pipes (Mwenge Kahinda, Taigbenu et al. 2007)

Finally, treatment after storage can include solar disinfection, addition of a disinfectant such as chlorine, boiling of the water before use and filtering. Also measures against mosquito bites can limit the effects of poor water quality (Mwenge Kahinda, Taigbenu et al. 2007)

Runoff from Inselberg rock formations has the same quality issues as reservoirs, see paragraph 5.4.

5.3.5 Reliability

Reliability for domestic rainwater harvesting systems mainly relies on the volume of rainfall. Dry years can make rainwater harvesting systems less effective which means less water can be captured and used. In the modeled rainfall data (32 years of data , appendix A1) the rainfall was less than 700 mm in 1 year, less than 800 mm in 2 years and less than 900 mm in 6 years. In the observed rainfall data (14 years of data , appendix A1) the rainfall was less than 700 mm in 1 year, less than 800 mm in 3 years and less than 900 mm in 5 years. Domestic rainfall harvesting is according to (Source Rainwater Harvesting Handbook) not effective when less than 200 mm of rainfall per year is present. This makes the domestic rainwater harvesting a reliable system for this area. Large storage tanks can also reduce the effects of a year with less rainfall.

Climate change is a factor that could have an influence on the total volume of precipitation. Also changing rainfall distribution and rainfall intensities are common effects of climate change and have an influence on the performance of especially domestic rainwater harvesting systems. Study on the long term effects of climate change are outside the scope of this study.

5.3.6 Sustainability

Sustainabilty will be jugded on three basic factors including impact on the environment, society and economical impact.

Impact on the environment

Domestic rainwater harvesting systems have almost no impact on the environment. Storage tanks can claim some space but this is considered to be negligable. Underground storage tanks can even require no usuable space at all. SCH systems require transport pipes or channels. Pipes can be put underground and will have no impact. Channels will require space but this is relative small compared to for example a reservoir.

Economic impact

Rainwater harvesting systems will be good for the employment of the local people. However construction time is relative short (days to weeks) and the effects will therefore be short term. Maintenance costs are relative low which suggest that no extra people will be hired for maintenance activities.

Impact on society

Water captured by rainwater harvesting can be made available for more people. This can be established by extra taps on transport facilities. However, individual storage tanks will mostly be placed on private terrain and sharing of the water there will probably not be aprreciated by the owner. SCH systems in combination with channels are very suitable for water sharing, people can easily fetch water from the channels. Large central storage tanks can also be provided with a tap so that local people can get water from it.

5.3.7 Costs

Maintenance and installation of a DRWH system is relative easy and cheap. Gutters and down pipes are easily accessible and do not need extensive maintenance or special equipment. Removal of leaves and debris from the gutter is sufficient. The tank needs to be cleaned before and after the first rain.

Storage for individual houses can include plastic, ferro-cement or cement block tanks. For a plastic storage tank investment costs vary between 120-240 $\$/m^3$ storage depending on the size. Here 150 $\$/m^3$ storage is adopted for a first estimate of costs. For cement block basins, cement blocks can be made onside. Based on experience of the construction of a 6.5 m^3 storage basin, the first estimate of investment costs for cement block basins is 25 $\$/m^3$ storage. Ferro-cement tanks will costs, based on experience of people of Novos Horizontes, around 35 $\$/m^3$.The storage tank is considered to be the most expensive part of the investment costs. Therefore other costs including costs of gutters, downpipes and connections (transport system) are set around 15 $\$/m^3$ stored water as a first estimation. The total investment costs are between 40-165 $\$/m^3$ storage.

An overview of the investment costs per building is shown in Table 5.7.

Building	Costs plastic tank [$]	Costs cement block basin [$]	Ferro-cement tank [$]	Costs transport system [$]
Residential buildings				
Scott's	2,729	455	637	273
Wilfred's	3,878	646	905	388
Andrew's	5,410	902	1,262	541
Riemer's	5,314	886	1,240	531
Mike's	4,835	806	1,128	484
Doc's	5,314	886	1,240	531
Other buildings				
Novos Horizontes office	150	25	35	15
Eggs for Africa office	150	25	35	15
Rapale International School	17,356	2,893	4,050	1,736
Ebenezer College	17,356	2,893	4,050	1,736

Table 5.7 Investment costs

Investment costs for the SCH system mainly depend on the distance that needs to be covered between the rock formation and the demand site or storage facility. Because in this is unknown in this stage, no detailed information about SCH system can be provided.

Ferro-cement storage tanks and concrete storage basins are good in combination with SCH systems as well because the large storage capacity of such tanks.

5.3.8 Groundwater recharge

Groundwater recharge can be used in combination with domestic rainwater harvesting. The fluctuation in the groundwater level is the equivalent of a storage facility. Groundwater recharge facilities will increase infiltration and therefore prevents that this water will evaporate. Local soil properties and groundwater levels have a great influence on the performance of recharge facilities. Figure 5.9 shows an example of a roof water infiltration system in combination with a filter bed.

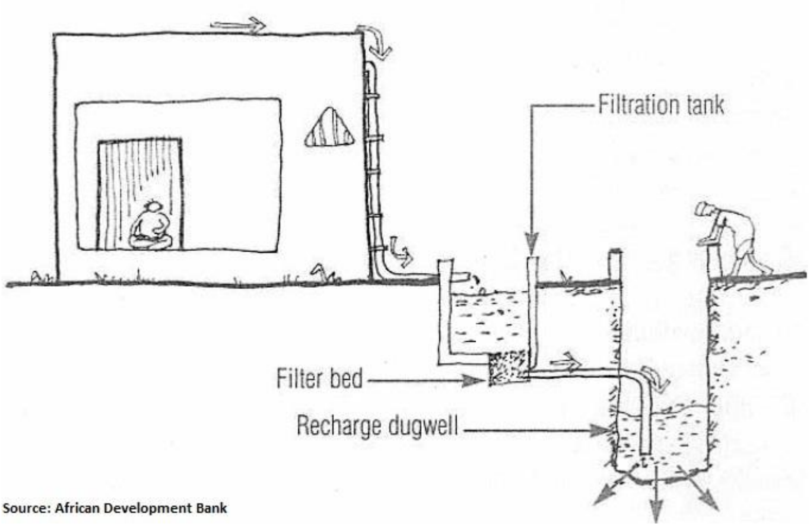


Figure 5.9 Roof water infiltration principle

Groundwater recharge can be applied with an individual abstraction point (on building level) or in combinations with boreholes. In the latter case the rainwater harvesting can be an extra source of water, which can lead to a larger capacity of the borehole.

On building level, abstraction facilities should be created (or should be present) in order to make groundwater recharge a source of water for households. Abstraction of water from the aquifer can be done by a hand pump, a mechanical pump or an open well. The technique is relative simple and can be applied without extensive experience or knowledge. This makes it also suitable for outgrowers. Research on the effectiveness of groundwater recharge falls outside the scope of this study.

5.3.9 Conclusions and recommendations

Domestic rain water harvesting system can be an option, as individual source, for relative small water demand sites including residential buildings, offices and both schools. However, because of the long dry season, big storage facilities are required for most buildings. First estimation of the total investment costs for domestic rainwater harvesting systems are between 40-165 $\$/m^3$ storage.

On the first site domestic rainwater harvesting systems cannot be applied by outgrowers. Investment in roof material and groundwater recharge facilities can make DRHW system a good option. Further elaboration on rainwater harvesting for outgrowers is recommend in order to study the feasibility.

Harvesting runoff from rocks is an interesting option if reservoirs have difficulties with the recharge of water. On the project area no problems are expected with regard to this and performance of rainwater harvesting from rocks is questionable in combination with a reservoir. Large storage tanks are also an option but more inside on the location of storage tanks in relation to water demand sites and storage capacity is needed.

Further research on performance of DRWH systems should include analysis of rainfall intensity and transport capacity of gutter and downpipes. Performance of the transport system (gutters and downpipes) is highly depended on rainfall intensities.

The influence of zinc roof sheets should also be examined. Zinc is a heavy metal and can have severe negative influence on the quality of the roof runoff.

5.4 Reservoirs

In this chapter a brief introduction of the reservoirs is given and the possibilities of reservoirs at several locations at the project site are discussed. With the aid of Google Earth a first impression about the possible locations for reservoirs are found and the storage capacity of these reservoirs is determined. The results obtained by Google Earth give a rough estimation on the characteristics of each reservoir.

5.4.1 General principle

The purpose of the reservoirs discussed below is to store water for agriculture purposes, operational use for Novos Horizontes and for drinking purposes after filtering. All the possible locations for a reservoir are locations near a river in a small valley. This implies that only one dam is needed in order to create a reservoir. This dam will block the river, so the river will fill the reservoir together with water which is running off from the land to the reservoir. This type of reservoir is called a valley reservoir, which has the advantage that it is cheap to construct and easy to store water in. Figure 5.10 shows this type of reservoir.

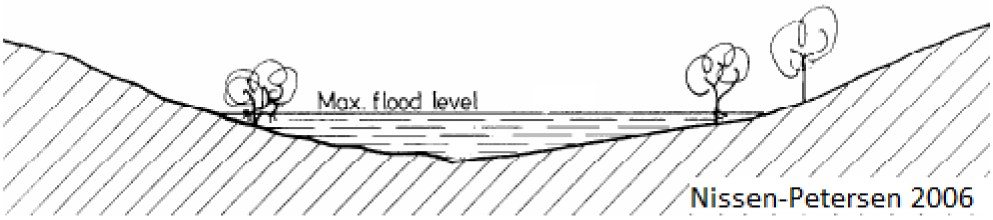


Figure 5.10 Sketch of a valley reservoir

General concept

Figure 5.11 shows the cross section of a reservoir in which several definitions are shown. The definitions are briefly discussed below. The dead storage can be used for the storage of sediments. The difference between the normal pool level and the minimum pool elevation is called the useful storage. The volume of water that is stored here can be released by the sluiceway or via a pipe as shown in Figure 5.11. The storage above the useful storage is called the surcharge storage. This volume of water depends on the amount of water discharged from the catchment area to the reservoir and will be discharged by the spillway. Spillways are permanent structures which releases the surcharge of water which cannot be kept in the reservoir. The dam will probably be an earth-fill dam because of the availability of soil and the skills of the local contractors. Earth-fill and rock-fill dams are very sensitive for failure when they are overtopped by water. Therefore it is important to design a spillway which has sufficient capacity to discharge the surcharge of water, see Figure 5.12.

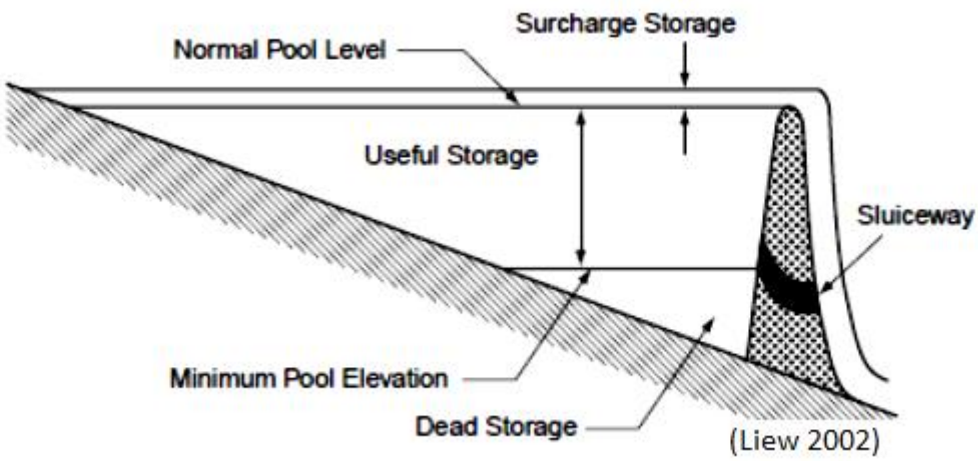


Figure 5.11 Storage pools of a typical reservoir

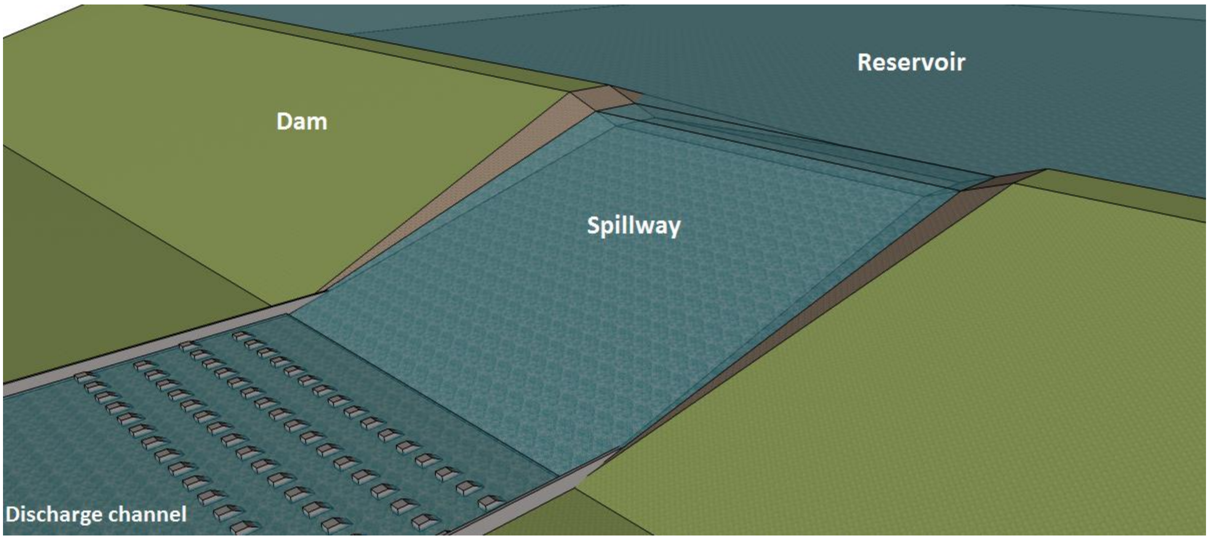


Figure 5.12 Reservoir with spillway

5.4.1 Reservoir identification

In the project area there are several locations where reservoirs are possible. To get an indication at which location reservoirs are suitable, a site investigation for the possibilities of reservoirs on the Novos Horizontes land has been carried out. In this investigation the focus lays on appropriate places where the natural differences in elevation will require only one dam to create a reservoir (valley reservoir) and the presence of a river/water stream. With this site investigation twelve suitable reservoir locations are found. In Figure 5.13 an overview of all possible reservoir locations is shown. Reservoir 5 cannot be seen on Google Earth and is added to the list of reservoirs based on visual observations. Recently a 3D survey at the project area was conducted. However, this data was not available in time and Google Earth data will be used in this part, part B. The results of this 3D survey will be used for further detailed calculations which are presented in part C of this report.

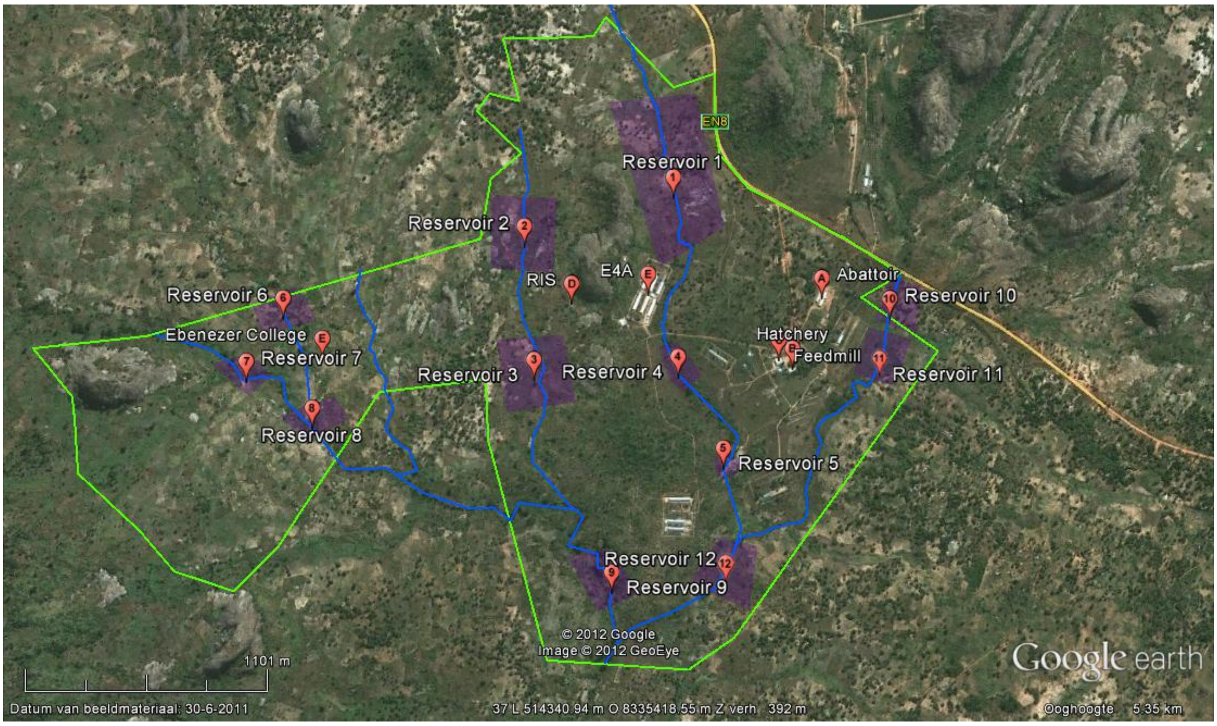


Figure 5.13 Locations of reservoirs and water users

Except for reservoir 10 all the reservoirs are located on the land of Novos Horizontes. This implies that when reservoir 10 would be implemented the land should be bought, which increases the costs.

5.4.2 Quantity

In order to determine the quantity of water which will fill the reservoirs the catchment area for every reservoir is determined. The catchment area is the area which receives the rainwater and transfers this towards the reservoir. If the catchment area is too large for the reservoir and the spillway has insufficient discharge capacity, too much water comes in and the dam risks being washed away. Therefore it is important to determine the catchment area as accurate as possible.

The amount of water received from the catchment area depends on the runoff. The annual runoff of the catchment area can be calculated by Equation (5.2).

$$V = P \cdot A \cdot C_r \qquad \textbf{(5.2)}$$

In which:

- V= Volume of runoff from catchment area [m^3]
- P= Annual rainfall for the catchment area [m]
- A= Catchment area [m^2]
- C_r= Runoff coefficient [-]

The catchment areas are determined with Google Earth. The rivers are followed as much as possible and the elevations of the surroundings are mapped in order to gain insight if the water flows to the rivers. The catchment areas are used to create a water balance for each reservoir. A schematic view of the above is shown in Figure 5.14. This figure also shows that the topographic divide is not always the right way to define boundaries of the catchment area. During further analysis the phreatic divide is not taken into account because of the lack of data. This means that the total runoff can be smaller.

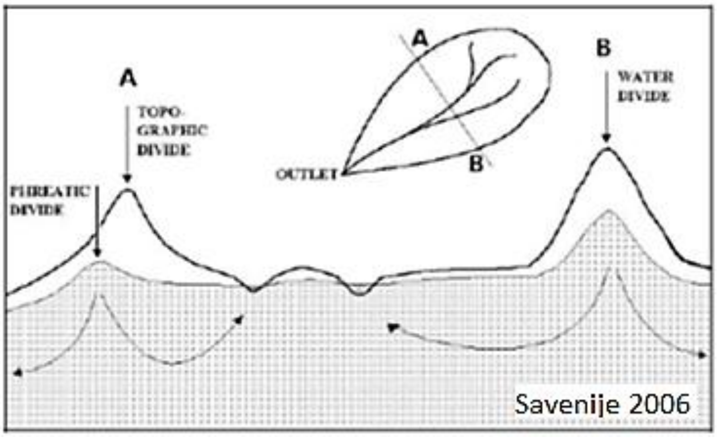
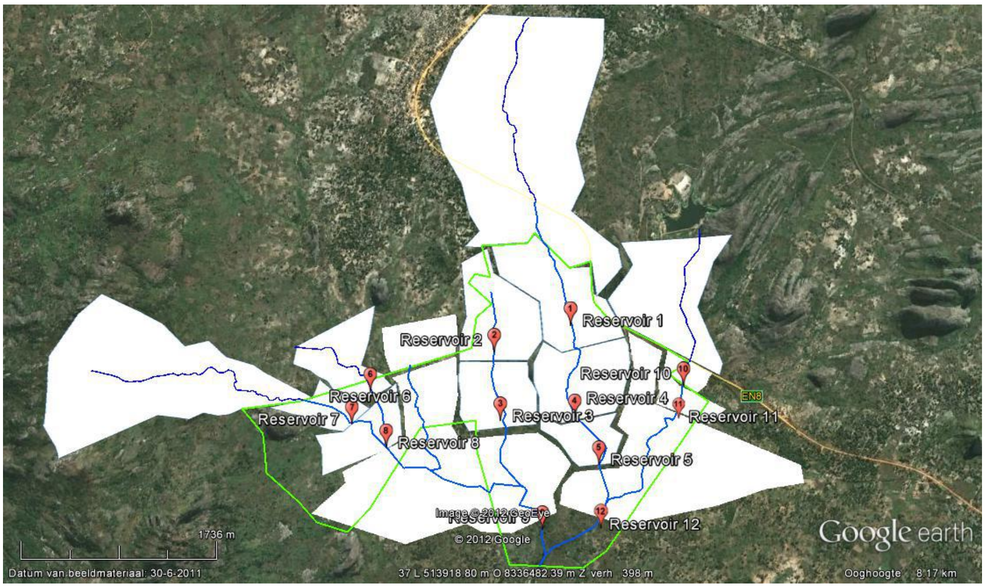


Figure 5.14 Schematic view of catchment area

The catchment areas for the reservoirs are shown in Figure 5.15. The size of the catchment areas are given next to the figure.



Reservoir	Estimated Catchment area [m²]
1	2,925,608
2	1,085,667
3	2,160,479
4	3,401,696
5	3,602,867
6	339,992
7	1,763,461
8	2,034,425
9	4,407,854
10	810,892
11	936,130
12	5,902,130

Figure 5.15 Catchment areas

Storage capacity

The elevation profiles of Google Earth have been transferred to Excel where a formula of the ground surface is obtained. With this formula and the use of Maple (a mathematical software program) the storage capacity of each reservoir is obtained. As an example a cross section of reservoir 3 is inserted in Figure 5.16. Here it can be seen that the red dots represent the dam height and the blue dots the ground level. The blue area between the red and blue dots is the cross section of the reservoir. The detailed calculations of each reservoir are enclosed as Appendix B6, B7 and B8.

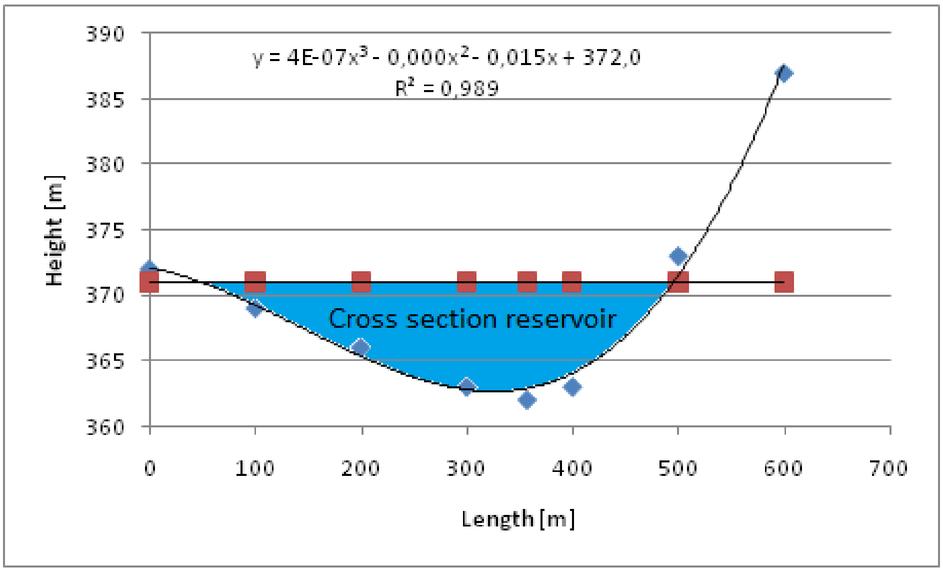


Figure 5.16 Cross section reservoir 3

In the figure above the R^2 indicates the accuracy of the formula y. This formula belongs to the line through the blue dots.

Remark: In these calculations the maximum dam height is used in order to get an indication of the storage capacity. In part C of this report more detailed calculations are made and the most economical dam height is determined. This implies that for several reservoirs the dam height will be lower than the maximum dam height, which results in a lower storage capacity.

Reservoir	Storage capacity [m^3]
1	960,000
2	800,000
3	710,000
4	38,000
5	16,000
6	30,000
7	38,000
8	145,000
9	24,000
10	110,000
11	22,000
12	275,000

Table 5.8 Storage capacities of the reservoirs

5.4.3 Reservoir characteristics

The possible reservoirs showed in Figure 5.13 are compared to each other in which the following aspects are taken into account:

- Dam dimensions;
- Distance to demand site;
- Elevation difference between reservoir and location of water usage;

Dam dimensions

The dam volumes are determined in the same way as the reservoir volumes are determined. For the dam height the maximum possible height is taken into account. However the dam height and the used materials do not vary linear over the dam length, but are dependent on the cross-section (A) of the dam with respect to the dam height.

$$Section\ volume\ [m^3] = \int_{x1}^{x2} A(h(x))dx \qquad \textbf{(5.3)}$$

Where $x1$ and $x2$ are the length boundaries of the dam. The total volume calculation for each dam height for reservoir 1 can be seen in Appendix B8. The volumes of every material used for the dam can be described with Equation (5.3). The table below summarizes the characteristics of the dams for each reservoir.

Reservoir	Dam height [m]	Dam length [m]	Approximated dam volume [m^3]
1	405	12	106,920
2	470	16	218,121
3	490	11	101,162
4	244	5	11,569
5	90	4	11,077
6	354	4	10,907
7	350	6	14,690
8	350	7	32,745
9	365	5	12,623
10	345	7	19,215
11	235	4	7,395
12	420	7	38,919

Table 5.9 Dam dimensions per reservoir

Elevation differences and distances to water users

The reservoirs and different water users are located at different elevations at the project site, which implies that not every reservoir is able to supply water without the use of a pump.

Table 5.10 shows the distance between the reservoir and water demand site. It also shows which reservoir is able to supply water by means of gravity. The red numbers indicates that a pump is necessary and the black numbers indicates that no pump is necessary to supply water.

Reservoir	Abattoir [m]	Eggs for Africa [m]	Ebenezer College [m]	Hatchery [m]	Closest chicken house [m]
1	750	450	2,000	850	700
2	1,500	1,000	1,000	1,300	1,000
3	1,500	750	1,000	1,200	900
4	780	400	1,800	450	200
5	950	900	2,000	560	240
6	2,600	1,800	250	2,400	2,100
7	2,800	1,900	350	2,500	2,200
8	2,500	1,700	330	2,300	2,000
9	1,700	1,400	1,750	1,400	450
10	350	1,150	2,700	500	200
11	450	1,150	2,600	400	240
12	1,450	1,400	2,150	1,100	300

Table 5.10 Distance between reservoirs and demand sites

5.4.4 Reliability

A water balance is made in order to determine the amount of water which can be subtracted every month without getting a dry reservoir. The water balance is determined over a simulation period of 36 months. Every month a certain amount of rain enters the reservoir and at the same time water is subtracted from the reservoir. The subtracted water can be used at the project site for all kind of purposes. Table 5.11 shows the input data used for the water balance per reservoir. The runoff coefficient changes per month, this is because of the fact that during the rain period the ground is saturated and that during the dry month the ground is not saturated.

The water which is subtracted from the reservoir consists of:

- Evapotranspiration, see chapter 2.2.2 and table Table 5.11.;
- Rainfall, see chapter 2.2.2. and table Table 5.11;
- Constant release of water for local people, 1 l/s;
- Seepage + infiltration into the ground, 10% of the maximum reservoir capacity per year;
- Amount of water which can be subtracted throughout the year without getting a dry reservoir, this amount is determined by trial and error, see Table 5.12 for these volumes.

For the water balance of reservoirs the evaporation data should be used instead of the evapotranspiration. Unfortunately data about evaporation is not available, because of this evapotranspiration data is used. With the use of this date the results of the water balance are conservative, because the evapotranspiration is larger than the evaporation.

Month	Rainfall [mm]	Evapotranspiration [mm]	Runoff coefficient
January	261.8	131.8	0.35
February	219.1	112.6	0.35
March	171.9	111.7	0.30
April	72.9	75.8	0.20
May	28.1	41.7	0.15
June	20.5	26.4	0.10
July	20.8	22.9	0.10
August	16.6	17.7	0.10
September	13.5	13.7	0.10
October	30.0	26.3	0.15
November	72.7	56.0	0.20
December	189.2	108.1	0.30

Table 5.11 Input data for the water balance.

The rainfall data and the evapotranspiration data in the table above is used from the GLDAS-1 CLM Model, this model data is shown in Figure 2.3.

To make sure that a reservoir never becomes dry, a limited amount of water can be subtracted for use at the project site. This amount of water is determined by trial and error during the calculation for the water balances. In Table 5.12 this maximum amount of water which can be subtracted throughout the year is presented. This subtracted volume of water is constant over a year.

Reservoir	Maximum volume that can be subtracted [m^3/month]
1	40,000
2	6,500
3	27,000
4	11,000
5	7,000
6	3,500
7	7,000
8	18,000
9	10,500
10	8,000
11	2,000
12	45,000

Table 5.12 Maximum volume of water that can be subtracted per reservoir

For the water balance it is assumed that when a reservoir is full the spillway discharges the amount of surcharge water. This amount of water discharged by the spillway may fill reservoirs downstream, if any is presented. This effect is not taken into account for the water balances for the downstream located reservoirs. The filling of reservoirs is solely based on catchment areas.

The results of the water balances are shown in Figure 5.17 and in Figure 5.18. The peaks presents the situation in which the reservoirs are full (rain season) and the troughs present the situation during the dry season.

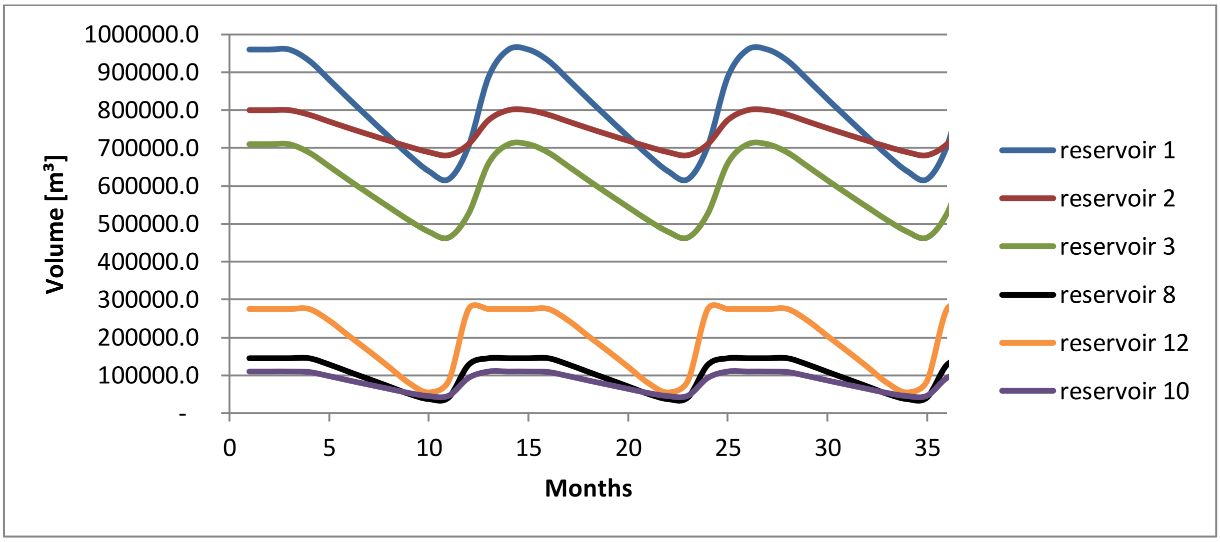


Figure 5.17 Volume of water of the larger reservoirs simulated over a period of 36 months

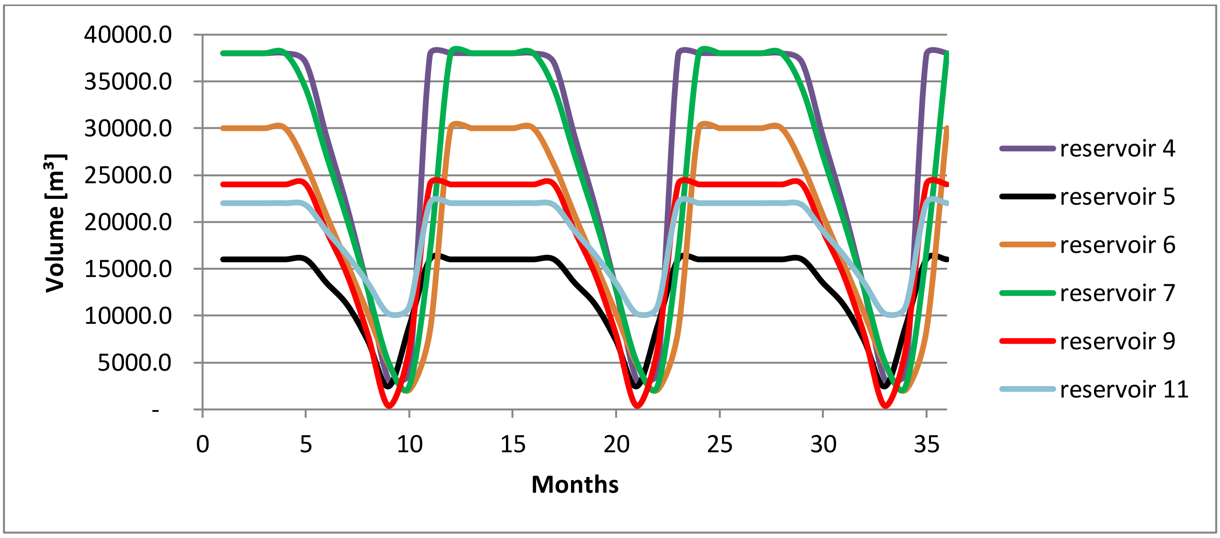


Figure 5.18 Volume of water of the smaller reservoirs simulated over a period of 36 months

From the graphs above it can be concluded that there is a cyclic behavior of the amount of water in the reservoirs and that there always will be water presented in the reservoirs. The cyclic behavior of the graphs is due to the amount of rain and evaporation that differs throughout the year. In Figure 5.18 it looks that reservoir 9 is empty around month 8 (August), this is not the case. In fact the minimum amount of water during a year in reservoir 9 is approximately 1000 m^3.

In Figure 5.19 the daily amount of water which can be subtracted per reservoir without getting a dry reservoir and the demand for water for the different users is shown. With the aid of this figure several combinations can be made between water supplier (reservoir) and water user. From this figure it can be concluded that reservoir 1, 3 and 12 are able to supply water to the abattoir, which is the largest water user at the farm. Besides this combination, several other combinations of water supplier and water user can be made.

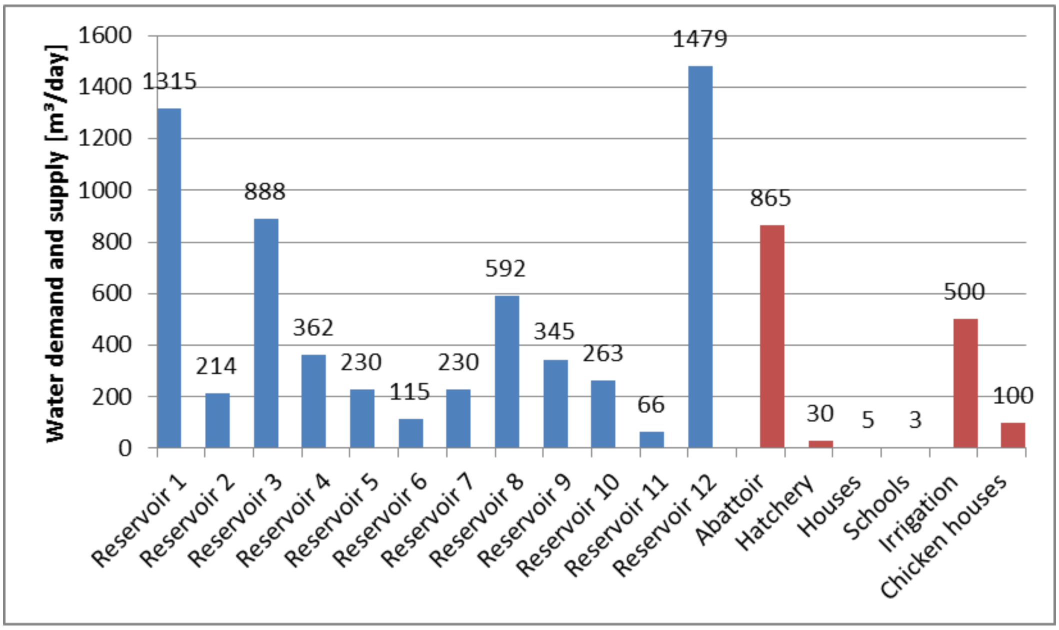


Figure 5.19 Maximum subtracted water volumes per reservoir and demand of the water users

5.4.5 Water quality

In the future, Novos Horizontes wants to standardize the water quality. The quality must meet the regulations on abattoirs for poultry and other farm animals (see chapter 3.1.2). The main requirement is defined as follows:

"The water of the abattoir needs to be clean, canalized drinking water, free from any floating particles and treated with chloride".

Reservoirs are sensitive for diseases like cholera and other bacteria, especially when the water is not in motion. Therefore additional measurements are necessary in order to meet the requirement stated above. Some suitable measurements for large subtracted volumes of water (water demand abattoir) may be as follows:

- The floating particles can be removed by a sand filter, Figure 5.20;
- Adding chloride to kill bacteria and viruses.

When smaller volumes of water are subtracted, for instance by the local people who live around the reservoir the following measurements may be suitable:

- The floating particles can be removed by a sand filter, Figure 5.20;
- Chloride tablets or boiling the water to kill viruses and bacteria;
- Ultra Violet (UV) radiation to kill bacteria. This method becomes effective after an exposure of 6 hours at 40°C.

Close to the farm a reservoir is presented which is part of a restaurant and camping. Tests are performed related to the water quality of this reservoir. The main results are as follows:

- Light brown color;
- No smell;
- Very low turbidity;
- PH level of 6.5;
- Appropriate for human consumption.

The full report on these test results are enclosed as appendix A4.

From these results it can be concluded that this water has sufficient quality for the abattoir and for drinking purposes without any measurements. But it is not sure if these results will be the same for the reservoirs being built in the future. Therefore it is advised to perform tests on a regular basis when using a reservoir as water source.

When a filter system is implemented, it is advised to consult experts on water quality in order to design an appropriate filter system.

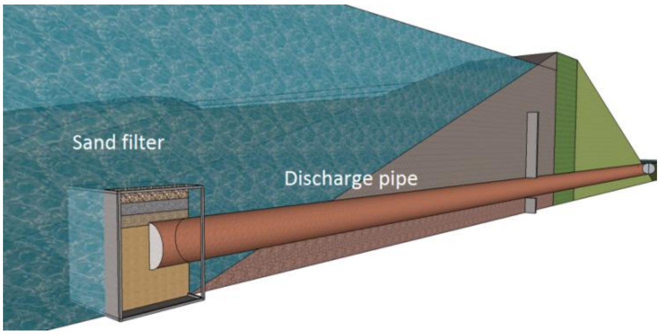


Figure 5.20 Discharge of water from the reservoir with sand filter

5.4.6 Sustainability

For this concept different stages are reviewed, namely the three pillars of sustainability (social, environmental impact, economic). This can be reviewed in the following context in order to define sustainability.

Social

With the construction of a reservoir there is no direct danger for people. If the reservoir is used properly people would get more clean water. This would result in better health conditions. Novos Horizontes restricts themselves to governmental regulations and the 3 P's principle[5] to protect the work conditions of workers, so it would not have any negative influence on local health conditions.
On the other hand when a dam fails, a few houses could be flooded by the reservoir. This could be a possible hazard.

Environmental impact

For building the reservoir some land needs to be excavated and leveled. This will decrease the local ecosystems and biodiversity. The construction of the reservoir will also include some contaminations from hydraulic equipment and workers. A filled reservoir would also decrease the local ecosystem on land. On the other hand a filled reservoir will create biodiversity with different species then before.

Another consequence when building a reservoir is a more controlled discharge of peak floods downstream. This is much better for the local villagers with gardens downstream of possible reservoirs. Some gardens needs to be removed and places elsewhere. It should be noted that the gardens are on Novos Horizontes property.

A final note regarding to the use of natural resources. Rain will be used to fulfill the demand for water. Primarily this will not have negative consequences. The rain caught by the reservoir is runoff water from the mountains. Also a continues discharge would serve as a continues water supply downstream.

[5] 3P concept refers to the responsible management in which equal weight should be given to people, planet and profit.

Economic
In order to expand and increase the profit of Novos Horizontes an increasing demand for water is required. Reservoirs would fulfill this requirement. The local economy would be stimulated, because it would create an employment for building the reservoir, but also an increase of workers for the farm. It would be economic beneficial to building a dam site.

Responsible management
If the farm give equal weight to the people, planet, profit principle this would be considered as responsible. In the current design not only profit, but also people and planet are taken into account to minimize the hazardous effects of a reservoir.

5.4.7 Dam design

In this paragraph the general design of the dam and the spillway are discussed. The reservoirs discussed above are valley reservoirs which imply that they are created by one single dam. The spillway is part of the dam and discharges the surcharge of water when the reservoir is filled.

The dams for the reservoirs are small dams and are classified as low hazard class dams and consist of earth materials. Distinction can be made between homogeneous and zoned dams.

Homogenous dams
Homogenous dams are dams which consist of one type of soil. These dams are relatively cheap to construct compared to zoned dams, because less material is needed. Excess pore pressures within the dam and seepage might be a problem, especially when water levels fluctuate rapidly. Seepage is the leakage of water through the dam and can lead to dam failure when sediments get transported. The phenomena where sediments are transported are called piping. To prevent piping granular filter layers or a permeable geotextile can be used at the downstream side of the dam.

Zoned dams
Zoned dams are dams which consist of different materials and reduce the possible seepage hazards to a minimum. The zoned dam can be divided into three sections: impermeable core, pervious to semi-pervious downstream section and semi-impervious upstream section. The impermeable core should be imbedded into impermeable subsoil layer to prevent water flow between the dam and foundation. Occurrence of piping should be checked and when necessary measurements should be taken to prevent piping. The costs are likely to be higher because of the different materials used to construct the dam. In Figure 5.21 an example of a zoned dam is shown. As appendix B9 a detailed drawing is enclosed of a zoned dam.

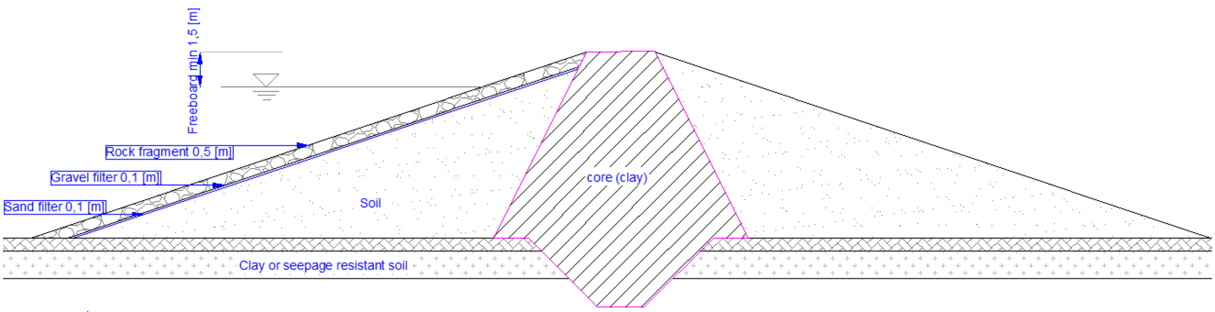


Figure 5.21 Cross section of a zoned dam

It is expected that water levels fluctuate rapidly, especially during heavy rain periods. Besides this the water level difference over the dam can be large and seepage may form a serious problem. Because of this it is advised to construct a zoned dam.

Spillway
The main function of the spillway is to fix the maximum water level in the reservoir by discharging the surcharge of water. If the spillway has insufficient capacity overtopping occurs and material at the downstream slope can be eroded which may cause dam failure. This is why all dams must have a spillway.

The spillway can be located in the center of the dam or at the side of the dam. The advantage of the spillway located at the side of the dam is that the excavated material at the spillway location can be used for the dam and that the water discharged by the spillway is kept away from the dam. Besides this it is easier during construction, because the spillway and the dam can be constructed independent of each other. However, the type of soil next to the dam determines if the spillway can be located near the dam. For the final dam design this should be investigated into more detail for each reservoir. It is recommended to build a spillway at the edge of a dam site on rocky soil. For this very small modifications needs to be made and can be many times cheaper than a central spillway.

After the spillway a discharge channel is situated to transport the water to the river. When high velocities are reached behind the spillway an energy dissipating structure (stilling basin) should be implemented to reduce the amount of energy from the flow. This is necessary because otherwise heavy erosion occurs close to the dam which may result into instabilities of the dam.

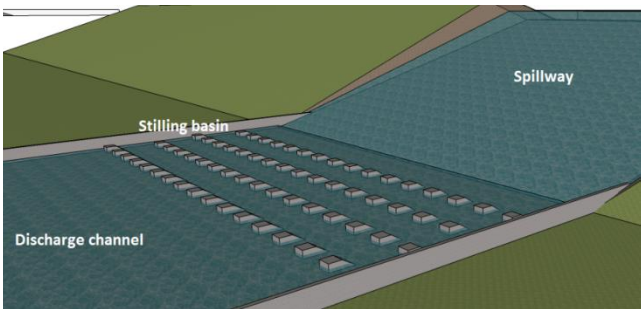


Figure 5.22 Spillway with stilling basin

Figure 5.22 shows the spillway together with the stilling basin and the discharge channel. The stilling basin consists of obstacles which subtract energy from the flow. The result is lower flow velocities which are required for the flow through the river.

5.4.8 Cost estimate

The total investment costs for construction an earth walled dam depends on several factors, namely: the capital investment (materials, construction costs and engineering fees), maintenance costs and interest. Capital investments are off-costs, where maintenance and interest are yearly costs dependent on the economic lifetime of a reservoir. To calculate the total costs some boundary conditions are applied.

Boundary conditions with respect to investment costs

- The economic lifetime of an earth walled dam is set at 25 years. This means that the total investment costs are earned back within the economic lifetime.
- Inflation has been taken into account for the maintenance costs.
- Labor is done here mostly by hand. Therefore many laborers are needed. However for large amounts of building materials hydraulic equipment is used
- All concrete is handmade casted by laborers. Less homogeneous and brittle material behavior can occur. Therefore no large constructive concrete sections will be casted. The concrete used in the calculation is used for the spillway.
- Material costs consist mostly of transportation costs. At this moment it is not certain where the materials come from. Nevertheless it is assumed that all materials are being excavated in the near area

With above boundary conditions applied it is possible to make a cost estimate. All costs have subdivisions to give an impression were the total costs are based on. Each chapter consists of the type of costs, the costs per quantity, source of these estimations and some general remarks.

Material costs

Material costs are the total costs for all materials used for an earth walled dam. The material costs consist of excavation and transportation to the construction site. The material prices are shown in Table 5.13.

	Unit costs incl. transport	**Remarks**
Soil	9 $/m^3$	In the order of $7-11/m^3. *Source: R. Buane. Engineer/planner, Nampula, August 2012*
Concrete	170 $/m^3$	Around $170/m^3 when mixed by own labors. When done by a contractor the price of concrete can rise up to $ 220/m^3. *Source: R. Buane. Engineer/planner, Nampula, August 2012*
Rock	12 $/m^3$	Around $25 for a truckload (2.2-2.3 m^3) *Source: R. Buane. Engineer/planner, Nampula, August 2012*
Clay	11 $/m^3$	Clay needs to be extracted close to river banks. Therefore special transport is required. This transport has higher costs than traditional vehicles. *Source: R. Buane. Engineer/planner, Nampula, August 2012*
Top soil	0.2 $/m^2$	Grass. *Source: Nampula shop*
Remaining	1 $/m^2$	Small layer of gravel/wire etc.

Table 5.13 Material prices

Construction costs

The capital investment consists of the construction too. Prices have been estimated with the help of local resources. This is a calculation based on unit prices confirmed by local experts.

Hydraulic equipment costs that are taken into account are shown in Table 5.14.

	Costs [$/d]	**Capacity [m^3/d]**	**Costs per quantity [$/m^3]**
Excavator	750	400	1.88
Bulldozer	750	1000	0.75
Dump truck	200	100	2.00

Table 5.14 Hydraulic equipment taken into account

Other costs that were taken in account are shown in Table 5.15.

	Unit costs	Remarks
Mobilization	2000 $	Transportation all personal and equipment to construction site. This can take up to 2 days. *Source: R. Buane. Engineer/planner, Nampula, August 2012*
Constructing road to reservoir	3.5 $/m	A bulldozer needs to clear the terrain. Assuming a capacity of 200 m/d. It would take at most 5 days. *Source: R. Buane. Engineer/planner, Nampula, August 2012*
Clearing building site	6 $/m^2	Remove all trees and plants and level the construction area. A bulldozer and excavator can level up to 500 m/d.*Source: R. Buane. Engineer/planner, Nampula, August 2012*
Excavating cut off trench	10.0 $/m^3	Depends on the dam height. Assuming an excavators capacity is the one described above. Bulldozers can move the soil. *Source: Ing P. te Velde, Dam-Engineer, Zimbabwe, September 2012*
Core construction	3.5 $/m^3	Excavated clay from river banks is placed in the core. Tractors/bulldozers will place it in the correct position. *Source: R. Buane. Engineer/planner, Nampula, August 2012*
Backfilling / frontfilling	2.5 $/m^3	A bulldozer is needed to place the soil, brought from the excavation site, in the right place *Source: R. Buane. Engineer/planner, Nampula, August 2012*
Compacting	2.8 $/m^3	Compacting of all layers to make it solid and prevent it from instabilities. *Source: R. Buane. Engineer/planner, Nampula, August 2012*
Dike protection	2.0 $/m^3	Large rocks are brought by the excavation process. At the dam site all rocks needs to be placed by hand. So it would require quite some laborers. *Source: R. Buane. Engineer/planner, Nampula, August 2012*
Spillway	100 $/m^3	The spillway needs to be made by hand. It is very expensive to construct a spillway so it needs to be done with great care. *Source: Ing P. te Velde, Dam-Engineer, Zimbabwe, September 2012*
Filter system	20,000 $	To clean the water. A rough estimation would be that the filter system would have off costs. *Source: Ing P. te Velde, Dam-Engineer, Zimbabwe, September 2012*
Topsoil return	0.1 $/m^2	One laborer can seed about 50 m^2
Labor	90 $/d	Approximate 30 extra laborers need to be hired for general purposes

Table 5.15 Other costs

Maintenance costs

Assuming an economic lifetime of 25 years a reservoir needs maintenance in order to work properly. It should be properly fenced to prevent contaminations. Also the banks needs to be maintained for its general condition. Another important and expensive maintenance is sediment removal. Without sediment removal the storage capacity of the reservoir would decrease over the years. Also the water treatment system needs maintenance in order to work properly. Maintenance costs (Table 5.16) are given in years with the duration of the economic lifetime.

	Unit costs [$/y]	Remarks
Grass cover	500	The whole waterline needs to be covered with grass as possible to prevent the bottom from eroding.
Sediment removal	250	As repressive measures every once in a while the silt traps needs to be cleaned.
General dike inspection	120	Every month by a skilled/educated worker
Fencing	100	Fencing would consist of wires/concrete, labour. And maintenance. A first approximation would give $500 building costs/maintenance a year
Tree/bush removal	144	Can be done by the 4 workers as well
Settlement restore	500	The dam will settle and shrink, so small settlements needs to be restored with extra soil/clay if not engineered/constructed properly.
Maintaining additional water treatment	500	This would only be a rough estimation
Total maintenance costs	2,114	

Table 5.16 Maintenance costs

The total maintenance costs (M) for an economic lifetime of 25 years (y) is about $52,850. With an average inflation (i) of 3.5% the average maintenance costs are approximately

$$Averaged\ maintenance\ costs\ [\$] = \frac{M * \left(1 + \frac{i}{100}\right)^{y}}{2} \quad \textbf{(5.4)}$$

The total answer is averaged, because the expenses vary linear over the years. Therefore the averaged maintenance costs are estimated at $65,000 over its economic lifetime including inflation.

Engineering fees

Engineering fees consists of the dam design, calculations and licenses. In general the engineering fees vary between the 3-10%, dependent on the total investment costs. This approximation is used in Mozambique.

Loan
When the capital investment (material costs, construction costs and engineering fees) cannot be satisfied by the company's equity, a loan has to be taken. No interest has been taken into account in this calculation. Remember that the total costs would double in its economic lifetime when interest is taken into account. It is assumed that maintenance costs can be satisfied by the equity.

Total costs
All the information above is implemented in the calculation sheets (see Appendix B10). The total costs are divided in several subdivisions to give a rough overview on how the costs are build up. The total costs are over a period of 25 years and it is assumed that Novos Horizontes has enough equity.

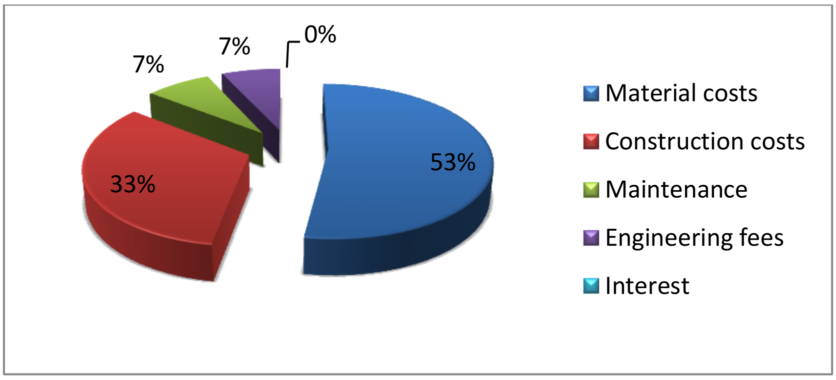


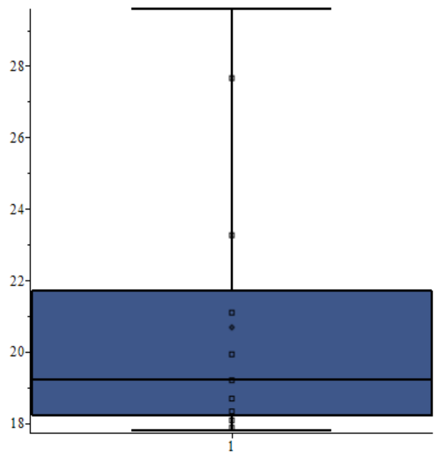
Figure 5.23 Averaged costs differentiation

Above information is extrapolated to the other reservoirs. The averaged relative costs are shown in Figure 5.23. It is interesting to see that almost half of the total costs consist of material costs. For optimizing the design and for engineering purposes this should be remembered.

To evaluate the total costs it is necessary to calculate the average costs per m^3 dam. This can be extrapolated to other reservoirs to make a comparison.
For the feasibility study the dam volume as a function of the height has been calculated for one reservoir. The average costs per cubic meter for the dam is calculated by Equation (5.5).

$$Direct\ costs\left[\frac{\$}{m^3}\right]=\frac{Investment\ costs\ [\$]}{Dam\ volume\ [m^3\ ]} \qquad \textbf{(5.5)}$$

In Figure 5.24 the direct costs per m^3 dam are plotted in a boxplot to show the diversity in costs when the dam size increases.



Dam height	Costs per m^3 dam [$]
3 m	29.6
4 m	24.3
5 m	21.7
6 m	20.3
7 m	19.5
8 m	18.9
9 m	18.5
10 m	18.2
11 m	18.0
12 m	17.8

Figure 5.24 Boxplot for costs per m³ dam

The median is 19.2 $/m³. For a dam height lower than 7 meters the costs per m³ have a rather large dispersion (18-30 $/m³). For a dam height above 7 meters there is a smaller dispersion. The preferred height for a dam would be approximate 5-6 meters. For a save direct cost estimate the third quartile ($20.1) is used.

$$Costs\ per\ dam\ [\$] = dam\ volume\ [m^3] * costs\ per\ m^3\ dam\ \left[\frac{\$}{m^3}\right] + maintenance\ costs\ [\$] \quad \textbf{(5.6)}$$

With equation (5.6) the total costs per reservoir have been calculated. A subdivision has been made between maintenance and capital investment.

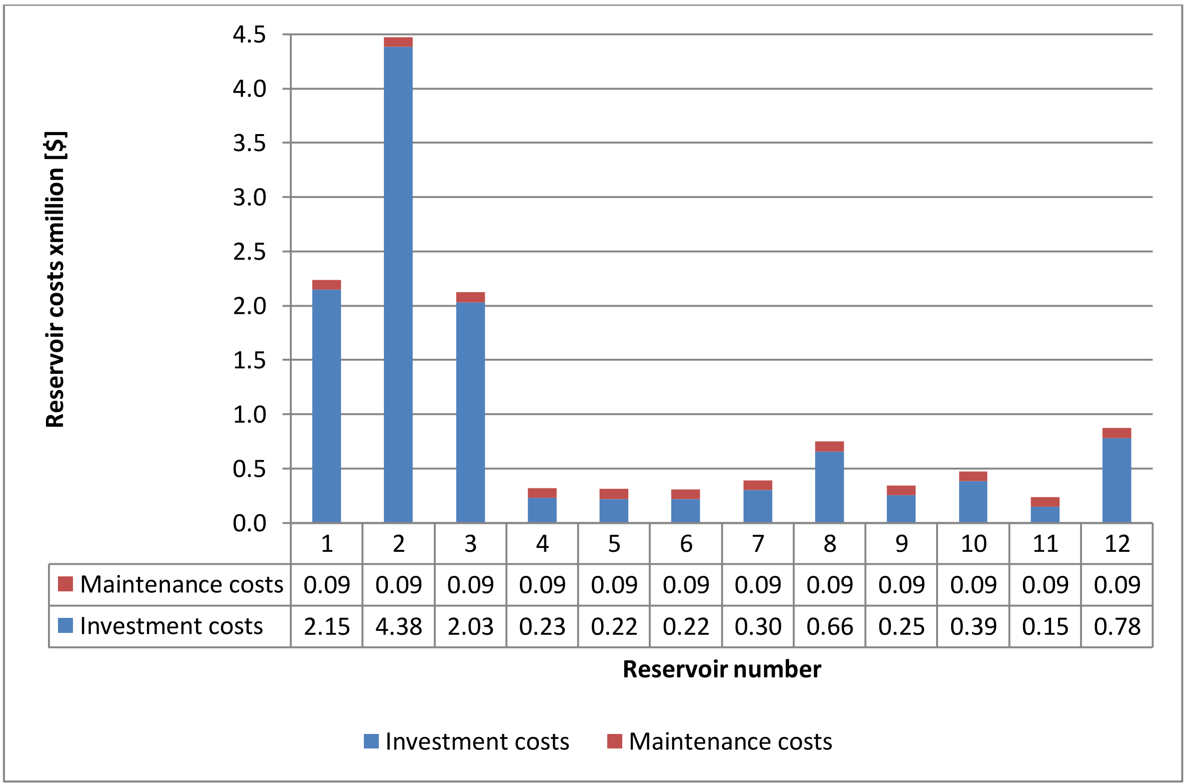


Figure 5.25 Total costs specified in investment an maintenance costs for each reservoir

Figure 5.25 gives the costs for each reservoir. However to finalize the comparison it is necessary to compute the costs per m³ discharge capacity. The necessity for this comparison is that the discharge capacity is the useable water for the farm.

$$Costs\ per\ m^3\ discharge\ \left[\frac{\$}{m^3}\right] = \frac{Dam\ costs\ [\$]}{Discharge\ capacity\ [m^3]} \quad \textbf{(5.7)}$$

It is now possible to compare all the reservoirs, according to their maximum discharge capacity and the costs per cubic meter discharge capacity per month.

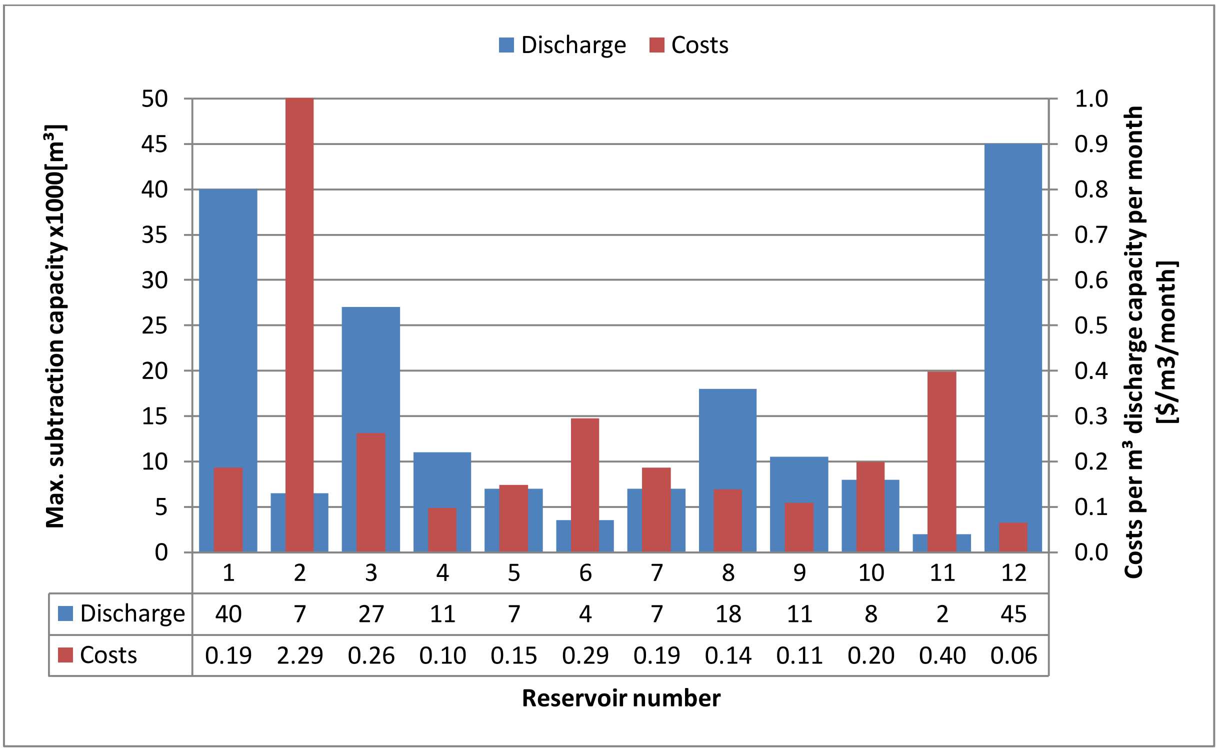


Figure 5.26 Maximum discharge capacity and costs per m^3 per lifetime

With the information described in Figure 5.26 it is possible to see which dam sites are more economical beneficial than others. In the next chapter the reservoirs are reviewed and also the financial prospects can be overseen in order to support the decision making for different possibilities.

5.4.9 Conclusions

From the chapters above it is now possible to discuss the most economical and beneficial reservoirs. Each reservoir is reviewed and conclusions are drawn for the Follow-up.

Reservoir	**Max water level [m]**	**Elevation [m]**	**Storage capacity[6] [m^3]**	**Dam length [m]**	**Dam height [m]**	**Volume dam[6] [m^3]**	**Reservoir length [m]**	**Reservoir area [m^2]**	**Max. subtraction volume [m^3/month]**	**Costs [$]**	**Costs [$/m^3/lifetime]**
1	10	375	960,000	410	12	107,000	760	206,600	40,000	2,238,526	0.19
2	14	371	800,000	470	16	218,000	370	115,900	6,500	4,473,088	2.29
3	9	362	710,000	490	11	101,000	560	182,900	27,000	2,122,830	0.26
4	3	366	38,000	244	5	12,000	190	30,100	11,000	322,473	0.10
5	2	361	16,000	90	4	11,000	80	4,800	7,000	312,588	0.15
6	2	369	30,000	350	4	11,000	160	36,600	3,500	309,181	0.29
7	4	367	38,000	350	6	15,000	110	25,700	7,000	390,627	0.19
8	5	362	145,000	350	7	33,000	260	60,700	18,000	747,995	0.14
9	3	354	24,000	370	5	13,000	100	23,100	10,500	343,647	0.11
10	5	361	110,000	350	7	19,000	320	73,600	8,000	476,111	0.20
11	2	359	22,000	240	4	7,000	190	29,000	2,000	238,601	0.40
12	5	352	275,000	420	7	39,000	360	100,800	45,000	872,070	0.06

Table 5.17 General overview for each reservoir

[6] Values are approximations

Table 5.17 shows the first results of the research for each reservoir. It should be noticed that a higher dam would not directly contribute to a higher subtraction capacity. Therefore some reservoirs will be worked out into more detail, while the first cost estimate shows little potential. As a last remark it should also be said that extra costs for pumps and pipes are not taken into account in these calculations.

The table below summarizes the reservoirs and the water users. The numbers indicate the distances of the reservoir to the water users. The colors of the numbers indicate if a pump is necessary. The cell colors indicate if the reservoir has sufficient capacity to supply the water users.

Reservoir	Abattoir [m]	Eggs for Africa [m]	Ebenezer College [m]	Hatchery [m]	Closest chicken house [m]
1	750	450	2,000	850	700
2	1,500	1,000	1,000	1,300	1,000
3	1,500	750	1,000	1,200	900
4	780	400	1,800	450	200
5	950	900	2,000	560	240
6	2,600	1,800	250	2,400	2,100
7	2,800	1,900	350	2,500	2,200
8	2,500	1,700	330	2,300	2,000
9	1,700	1,400	1,750	1,400	450
10	350	1,150	2,700	500	200
11	450	1,150	2,600	400	240
12	1,450	1,400	2,150	1,100	300

Possible to use reservoir	Not possible to use reservoir	Pump necessary	Pump not necessary

Table 5.18 Distance between reservoirs and demand sites

Reservoir 1
This reservoir shows high potential due to its low costs per cubic meter subtraction capacity and the high subtraction potential. Because of its high elevation, transportation from this reservoir can mostly be done by gravity forced flow. For some buildings with a higher elevation small pumps can be installed. Also the distance to the largest water consumer (abattoir) relatively small, namely 750 m. This reservoir *will* be worked out in more detail

Reservoir 2
This reservoir has a very small catchment area, and therefore a small subtraction capacity compared to the other reservoir. Besides this, the costs for this reservoir are very high. Even with a smaller dam size the costs would still outrun the other reservoirs. Also the distance to the abattoir (1500 m) would not contribute to work this reservoir out into more detail. Therefore this reservoir *will not* be worked out in more detail

Reservoir 3
This reservoir shows high potential due its high subtraction capacity. The distance to the abattoir (1500 m) is fairly high. Despite its far distance to the abattoir this reservoir *will* be worked out in more detail

Reservoir 4
This reservoir shows some potential according to the costs per cubic meter subtraction. . However its maximum subtraction capacity is limited. Also its elevation is a limiting factor. Despite the fact that the costs per cubic meter are not extreme this reservoir *will not* be worked out in more detail.

Reservoir 5
According to the topographic survey this reservoir shows some potential. The board of Novos Horizontes asked to work out this reservoir, which is under construction at the moment. However due to the fact that field research is required for this reservoir (very small capacity) and the lack of time by this research group this reservoir *will not* be worked out in more detail.

Reservoir 6
Because of its high altitude this reservoir shows some potential for Ebenezer college. However due to its very small catchment area and relative high costs this reservoir *will not* be worked out in more detail.

Reservoir 7
For the same reasons as reservoir six this reservoir *will not* be worked out in more detail.

Reservoir 8
This reservoir shows a good potential for Ebenezer College. But, no gravity flow can be used because of its lower elevation compared to Ebenezer College. However, this reservoir shows a high subtraction capacity and this location can also be used for irrigation purposes at Ebenezer College. Therefore this reservoir *will* be worked out in more detail.

Reservoir 9
At first sight reservoir 9 shows quite some potential for the future. However the distance (1700 m) and elevation difference (25 m) to the abattoir can cause some transportation issues. Nevertheless this reservoir *will* be worked out in more detail

Reservoir 10 and 11
These separate reservoirs show not much potential for the future demand for water. However, when these reservoirs are combined it might give some potential due its small distance to the abattoir (400 m) and small elevation difference. Therefore these reservoirs *will* be combined an worked out in more detail.

Reservoir 12
This reservoir shows high potential due to its large catchment area. A high subtraction capacity can be obtained from the catchment area. Also the costs per cubic meter subtraction are the smallest of all reservoirs. On the other hand, the elevation difference of 25 m lower compared to the abattoir and a distance 1800 m have negative effects on the total costs. Despite this, this reservoir *will* be worked out in more detail.

The above conclusions that are drawn, will be worked out into more detail in part C of this report. A more detailed survey for each reservoir and reservoir heights will be done in order to come up with the most optimal solution for a reservoir.

6. Follow-up

After showing Novos Horizontes, as the client, the results of the study on possible solutions it was decided how to proceed. This Follow-up will describe what was decided during this meeting and where these issues can be found in the remaining of the report.

Reuse of water is still a very interesting option. However, it was decided that further elaboration was not feasible within the time frame of this project.

Because of the relative large knowledge and experience with boreholes on the farm it was decided that no further elaboration of boreholes was necessary. Also the extent that further elaboration would require was not feasible within the time and money that was available for the project.

Rainwater harvesting was elaborated in sufficient detail.

For reservoirs it was decided, based on the conclusions made in part B, that the reservoirs 1,3,8,10-11 and 12 should be elaborated in more detail. Especially a costs-benefit analysis of these reservoirs was considered very useful. Part C of this report will be dedicated to further elaboration of the reservoirs.

Finally it was decided that recommendations should be made for the water availability on the farm. These recommendations should include the phasing in expansion that Novos Horizontes has in mind. The phasing consists of estimated expansions within half a year, 2 years and 5 years' time. Part D will cover this.

Part C

Reservoirs

7. Reservoirs

7.1 General setup of this study

The selected reservoirs from part B are being examined more accurate to determine the total costs and costs per cubic meter over its lifetime. Some reservoirs have multiple alternatives. This is because these reservoirs are big and have multiple good dam site locations. With these reservoirs several alternatives have been examined in order to find the optimum for the cost-benefit analysis. The following reservoirs are being examined:

- Reservoir 1 (3 alternatives)
- Reservoir 3
- Reservoir 8
- Reservoir 9
- Reservoir 10
- Reservoir 12 (3 alternatives)
-

In the first part the research methods are explained. After the explanation the data for every possible reservoir is displayed. In the end a review of all data is given in order to compare every possibility. With this data a recommendation is written.

7.1.1 Dam and reservoir characteristics setup

In part B several calculations have been performed to acquire general data about all the reservoirs. In this stage, these calculations will be reviewed to get more detail. More accurate measurements and calculations have been used in order to give better approximations for the dam and reservoir characteristics. Below a list is shown where all characteristics come from.

Water level

The water level is based on a 3D topographic survey provided by Novos Horizontes.

Dam height

Several cross sections of the possible reservoir locations shown in part B where made in order to determine the most suitable location for the dam. In part C the most suitable location is found again using the topographic survey in Autocad. After this the elevation profile is plotted (example in Figure 7.1). A higher order polynomial describes the elevation profile. The dam height is based on the distance from the lowest elevation. For more detailed calculation see Appendix C1

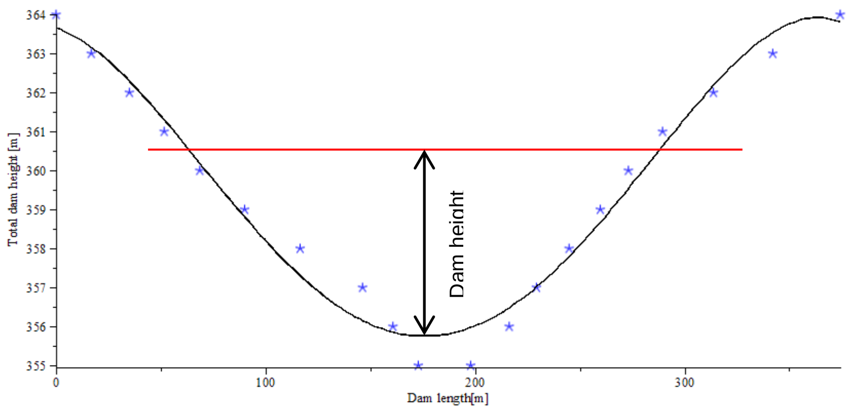


Figure 7.1 Elevation profile, dam height and corresponding curve fitting

Dam length

The dam length is based on the 3D topographic survey provided by Novos Horizontes. The distance between two elevation profiles from the maximum dam height is used for this.

Maximum dam width

The maximum dam width is based on the general dam design. This design can be found in Appendix B9. The maximum dam width at the bottom of the dam can be described as Equation (7.1).

$$width\,[m] = (0.4h + 1) + 2nh \qquad \textbf{(7.1)}$$

In which: n= slope coefficient
h= total height up to the crest height

Reservoir perimeter / area

The reservoir area and perimeter are measured from the 3D topographic survey using AutoCad. The 3D topographic survey can be seen in Appendix C2. The visualization of each reservoir can be seen in Appendix C3 (reservoir visualizations)

Storage capacity

To accurately make a proper estimate for the storage capacity the following numerical solutions have been applied for all reservoirs. This numerical solution can be seen in Figure 7.2.

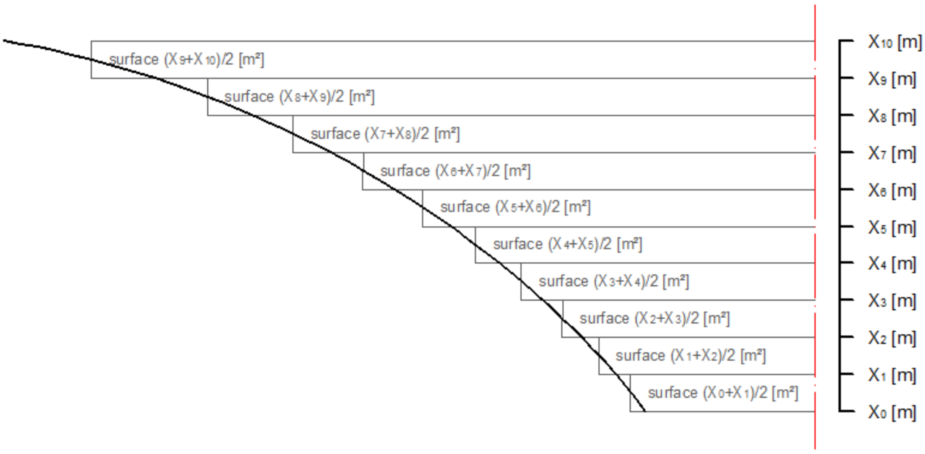


Figure 7.2 Representation for the reservoir capacity

The average reservoir surface is used for each dam height. This has the advantage that only the surface level x_0 has to be estimated. Since the smallest capacity is at the bottom (x_0) of the reservoir, this approximation would be a reasonable estimation of the true storage capacity.

Reservoir elevation level

The reservoir elevation level is taken 1m above the bottom level from the 3D topographic survey.

Reservoir distance to users

The distance to users from a reservoir is taken from the 3D topographic survey. This distance is taken as the crow flies.

Water balance

The water balance used in this part is the same as used in part B. For each dam height calculations are made to investigate how much water can be maximally extracted without emptying the reservoir. In the water balance the following is included: rain, evaporation, constant outflow, water use and seepage. An example of the water balance is shown in Figure 7.3. For some reservoirs it can be seen that the total subtraction capacity will decrease with a higher reservoir volume. This is because it is assumed that a reservoir may never be empty. A larger volume means a bigger surface which means a larger evaporation. Because a higher water volume will always have a larger reservoir surface than a lower reservoir volume, less water can be subtracted because of more evaporation.

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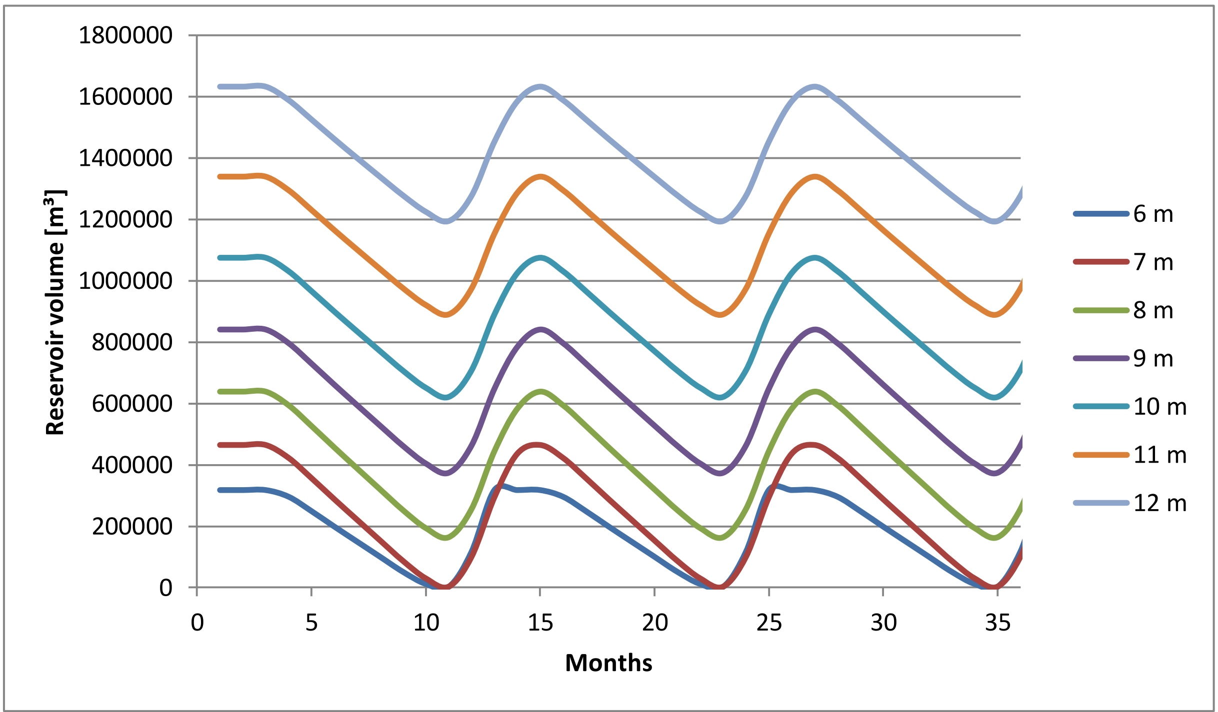


Figure 7.3 Water balance example

Mean Annual runoff

The mean monthly runoff is the average rainfall in a month multiplied with the runoff coefficient and multiplied by the catchment area. The runoff of all the months together is the mean annual runoff, which shows how much water will run through the river each year where the reservoir might be built in.

Storage ratio

The storage ratio is the storage capacity of the reservoir divided by the mean annual runoff. A storage ratio just above 0.5 is recommended. The lower the number, the more water will flow over the spillway. This results in more sedimentation in the reservoir. In the end of the lifetime of the reservoir the storage capacity will be lower if no sediments are removed from the reservoir. By removing sediments the maintenance cost would increase enormously. When the storage ratio is higher than 1, the amount of water which flows into the reservoir is less than the storage capacity of the reservoir.

7.1.2 Spillway setup

In the spillway setup the Probable Maximum Flood (PMF) is an important factor. In this paragraph the PMF and the spillway design will be explained.

Probable Maximum Flood

The Probable Maximum Flood (PMF) is the flood that can be expected from the severest combination of critical meteorological and hydrologic conditions possible for the particular region and it is the flow resulting from the probable maximum precipitation (GONU 2009). Because the spillway discharges should be estimated based on the PMF, it is of high importance to determine the PMF as accurate as possible.

In order to derive the PMF, first the return period of the extreme precipitation event has to be determined. A dam expert from Zimbabwe (P. te Velde) has been consulted for the return period. According to P.te Velde the return period should be 250 years. This implies that every year there is a probability of 1/250 that this event occurs. The probability of the occurrence of the design precipitation event is given by the Poisson distribution in Equation (7.2).

$$P = 1 - \exp(-f \cdot T_l) \quad \textbf{(7.2)}$$

In which: P= probability of occurrence of an event one or more times during the life time of the dam
T_L= life time of dam
f= average frequency of the event per year

Using this formula and a lifetime of 25 years, the probability of occurrence of the extreme precipitation event is 9.5% during the life time of the dam.

Because only rain data for 32 years is known, an extrapolation of the date is made in order to obtain data over a period of 250 years. Because the extrapolation is related to extreme values, an extreme value distribution like a Gumbel distribution is used. As an example the Gumbel distribution for the month January is shown in Table 7.1. In total 32 data points of rain data are available for the month January. This rain data is placed into bins with a width of 50 mm, which can be seen in Table 7.1. The 'amount per bin' column shows the number of rain data which is between these bin sizes. The 'cumulative' column shows the total amount of data which is presented between the first class until the specific class. P is the probability that an amount of rainfall is less or equal to the amount of rainfall in the maximum bin. G is the reduced Gumbel variable, this variable will be discussed into more detail below.

Class	Min [mm]	Max [mm]	Amount per bin	Cumulative	P	G
1	0	50	0	0	0.00	-
2	50	100	0	0	0.00	-
3	100	150	1	1	0.03	-1.24
4	150	200	5	6	0.19	-0.52
5	200	250	10	16	0.50	0.37
6	250	300	7	23	0.72	1.11
7	300	350	4	27	0.84	1.77
8	350	400	5	32	1.00	-

Table 7.1 Gumbel calculation for the precipitation of the month January

The Gumbel distribution is shown as Equation (7.5).

$$P(P \leq P_{ss}) = \exp\left[-exp\left(-\frac{P_{ss} - \gamma}{\beta}\right)\right] \quad \textbf{(7.3)}$$

In which: P= amount of rain
P_{ss}= amount of observed rain
γ= Gumbel coefficient
β= Gumbel coefficient

The coefficients γ and β can be found by regression analysis on the data. This will not be treated in this document, more information about this can be found in the book Breakwaters and closure dams, page 276 – 279, (Henk Jan Verhagen 2009).

After some mathematics Equation (7.3) reduces into Equation (7.4). This equation is called the reduced Gumbel variable G (Henk Jan Verhagen 2009).

$$G = -\ln(\ln(\frac{1}{P}) \quad \textbf{(7.4)}$$

In which: G= Gumbel reduced variable
P= Probability that an amount of rain is equal or less than the amount of rain in the maximum bin

The reduced Gumbel variable (G) is plotted against the maximum bin sizes for the classes 3 to 7 of Table 7.1. The result is shown in Figure 7.4.

In Figure 7.4 the reduced Gumbel variable is shown on the x-axis and not the probability of exceedance. To calculate the probability of exceedance the reduced Gumbel variable needs to be transformed, this is done by using Equation (7.5). Note that the number of data points (N_s) and the life time of the dam (TL) are known, so the Gumbel variable depends solely on the probability of exceedance (Q_s) in the equation below.

$$G(Q_s) = -\ln\left(ln\left(\frac{\frac{N_S}{TL}}{\frac{N_S}{TL} - Q_s}\right)\right) \tag{7.5}$$

In which: N_s= Total amount of data
Q_s= Probability of exceedance
N_s= Number of data points (rainfall events)
TL= Life time of the structure

The red dots represent the reduced Gumbel variables which belong to the exceedance probabilities (Q_s) of 1/10, 1/100, 1/1000 and 1/10000 years. The value of the red dots (Gumbel variables) is received by using Equation (7.5). These results are also shown in Table 7.2. The green dot represents the design value of 1/250 years with a reduced Gumbel variable of 5.76. The values of the Reduced Gumbel Variable can also be negative because they represent a failure probability.

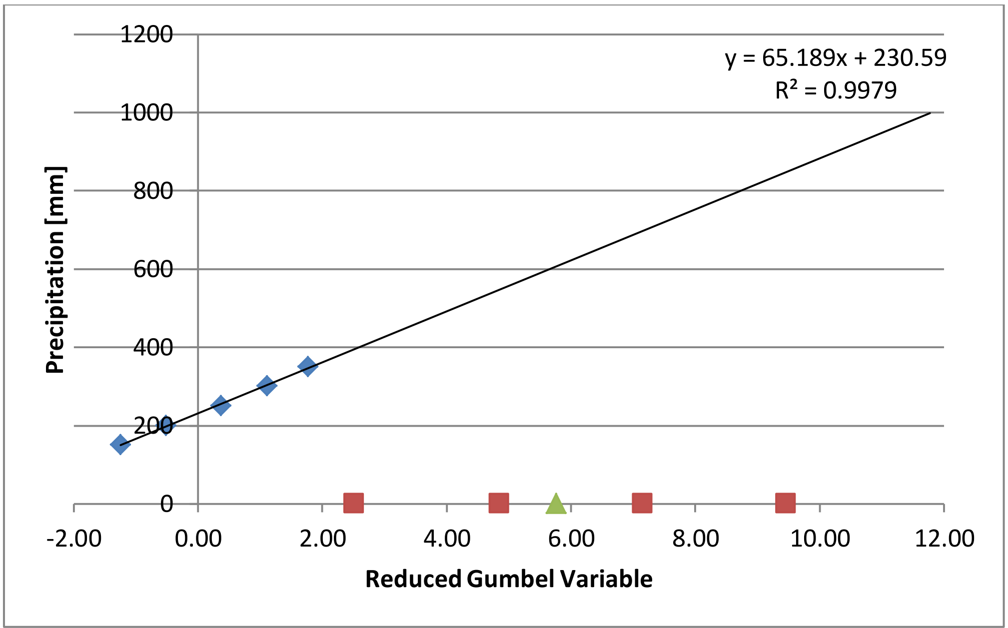


Figure 7.4 The Gumbel exceedance graph

The data for red and green dots in Figure 7.4 are shown in Table 7.2.

Probability of exceedance	Reduced Gumbel variable	Precipitation [mm]
1/10	2.51	394
1/100	4.85	547
1/250	***5.77***	***607***
1/1000	7.15	697
1/10000	9.46	847

Table 7.2 Probability of exceedance and reduced Gumbel variable

The amount of precipitation is received by using the formula (y) given by Excel, which is shown in the right top corner of Figure 7.4. If the value of the reduced Gumbel variable is filled in this formula, than the amount of precipitation is known. The amount of precipitation is shown in the third column of Table 7.2. The R^2 in the graph above shows the correlation of the line which is approximating the blue dots.

The method discussed above is also performed for the other months. These results are shown in Table 7.3. This table shows the extrapolated rain data by the Gumbel distribution and the maximum amount of rain which has been measured over a period of 32 years. From this table it can be concluded that in the month January the most precipitation occurs. Therefore this month is used for further calculations related to the spillway design.

	Amount of precipitation with a probability of occurrence 1/250 per year (extrapolated data) [mm]	Max. modeled amount of precipitation [mm]
January	610	400
February	460	370
March	420	310
April	260	180
May	160	160
June	60	40
July	60	40
August	60	40
September	70	40
October	240	190
November	350	280
December	480	340

Table 7.3 maximum amount of rain (modeled) and extrapolated rain data

From the data of January a general overview is made of the amount of rain with the return period. This can be seen in Figure 7.5.

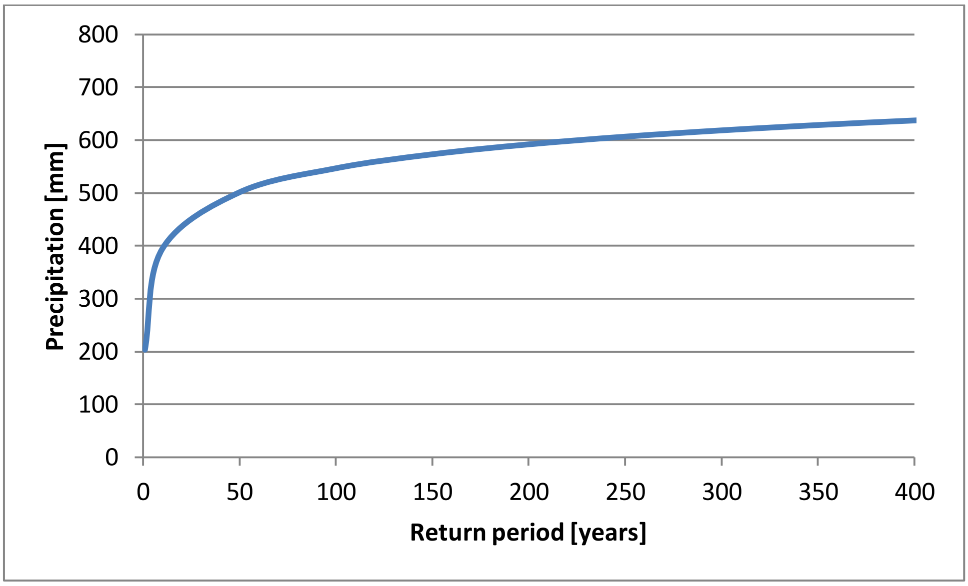


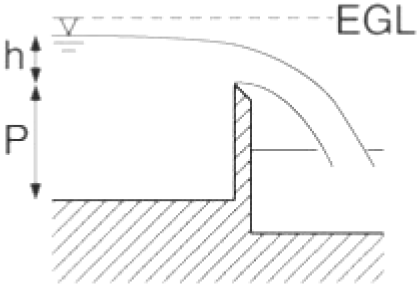
Figure 7.5 Exceedance curve

The data discussed above is per month and not per day. In order to estimate the rain data per day it is assumed that in an extreme event 50% of the amount of rain which falls in a month falls in 24 hours. Assuming a runoff coefficient of 100% this results in 300 mm. This is a large amount of water, but remember that this is only in an extreme situation where the dam is in its Ultimate Limit State (ULS). This data will be used in order to calculate the spillway dimensions.

Spillway design

The spillway has the main function to fix the maximum water level of the reservoir. This implies that the spillway prevents overtopping of the dam, which may cause a dam breach. To prevent overtopping the spillway has to be sufficient capacity to discharge the surcharge of water out of the reservoir.

The PMF is determined in the previous paragraph. Based on the PMF the spillway dimensions are determined. Figure 7.6 shows the schematic view of the spillway on which the calculations are based. It is important that the flow at the crest of the spillway is always critical. This means that the downstream water level has no influence on the water level upstream of the spillway. This can be achieved by creating a slope downstream of the spillway, which enables the water to flow away rapidly.



(Source: Civil Engineering Handbook 2ND edition)

Figure 7.6 Schematic view of ogee type of spillway

The amount of water which has to be discharged by the spillway depends on the catchment area and the PMF. The PMF is calculated in the previous paragraph and is 300 mm for one day. The catchment areas differ per reservoir. The result of this is that every reservoir has its own spillway dimensions.

To determine the dimensions of the spillway the following assumptions have been made for every reservoir:

- h=0.5 m, see Figure 7.6;
- P=0.2 m, Figure 7.6;
- The runoff coefficient is assumed as 100%;
- The reservoir is full when the PMF occurs.

It is expected that a spillway height of 0.2 m is sufficient as long as there is a slope presented downstream of the spillway in order to create critical flow. Equation (7.6) is used to determine the width of the spillway (Nortier 1996). These equations are only valid when there is critical flow above the crest of the spillway.

$$Q = 1.7 \cdot b \cdot h^{\frac{3}{2}} \quad \rightarrow \quad b = \frac{Q}{1.7 \cdot h^{\frac{3}{2}}} \tag{7.6}$$

In which: Q= Discharge based upon the PMF and catchment area
b= Width of the spillway

In this formula the factor 1.7 represents the discharge coefficient. This factor is derived for concrete ogee type crests and is an estimation. Experiments with the crests shape should be performed to determine the exact discharge coefficient. However, in the calculations this factor is used and it turns out that this factor is at the conservative side, because this factor can vary up to 2.25 (Stephens 2010). Note that how larger this factor is, the smaller the width of the spillway becomes.

The spillway design is used to estimate the use of concrete for each reservoir. Therefore the spillway design is integrated into the total costs. However costs reduction can be achieved when building the spillway on rocky soil.

7.1.3 Costs

In this paragraph two subjects are explained which returns in the cost paragraph of each reservoir.

Costs

The investment and maintenance costs are determined with the help of local experts and individual research. All reservoir costs calculations have been added in Appendix C4. The costs setup is clearly explained in part B.

Fulfilling water demand

The fulfilling water demand is a percentage of the total water that a reservoir can deliver compared to the total amount of water that Novos Horizontes will need in the future; 1551 m³/day.

7.2 Reservoir 1 (alternative 1)

To make an impression about the location, size and distances to nearby objects it is important to visualize the reservoir. In Figure 7.7 the location for the reservoir and the extent of the reservoir with the maximum water level is shown. After this some general dam and reservoir characteristics are shown. Secondly the water balance is made in order to determine the maximum allowable subtraction. Afterwards the spillway is calculated in order to give an accurate estimation for the spillway dimensions. This will be integrated in the reservoir costs. As a final result the costs can be determined for each reservoir. Alternative 1 is the medium alternative for the reservoir 1 site.

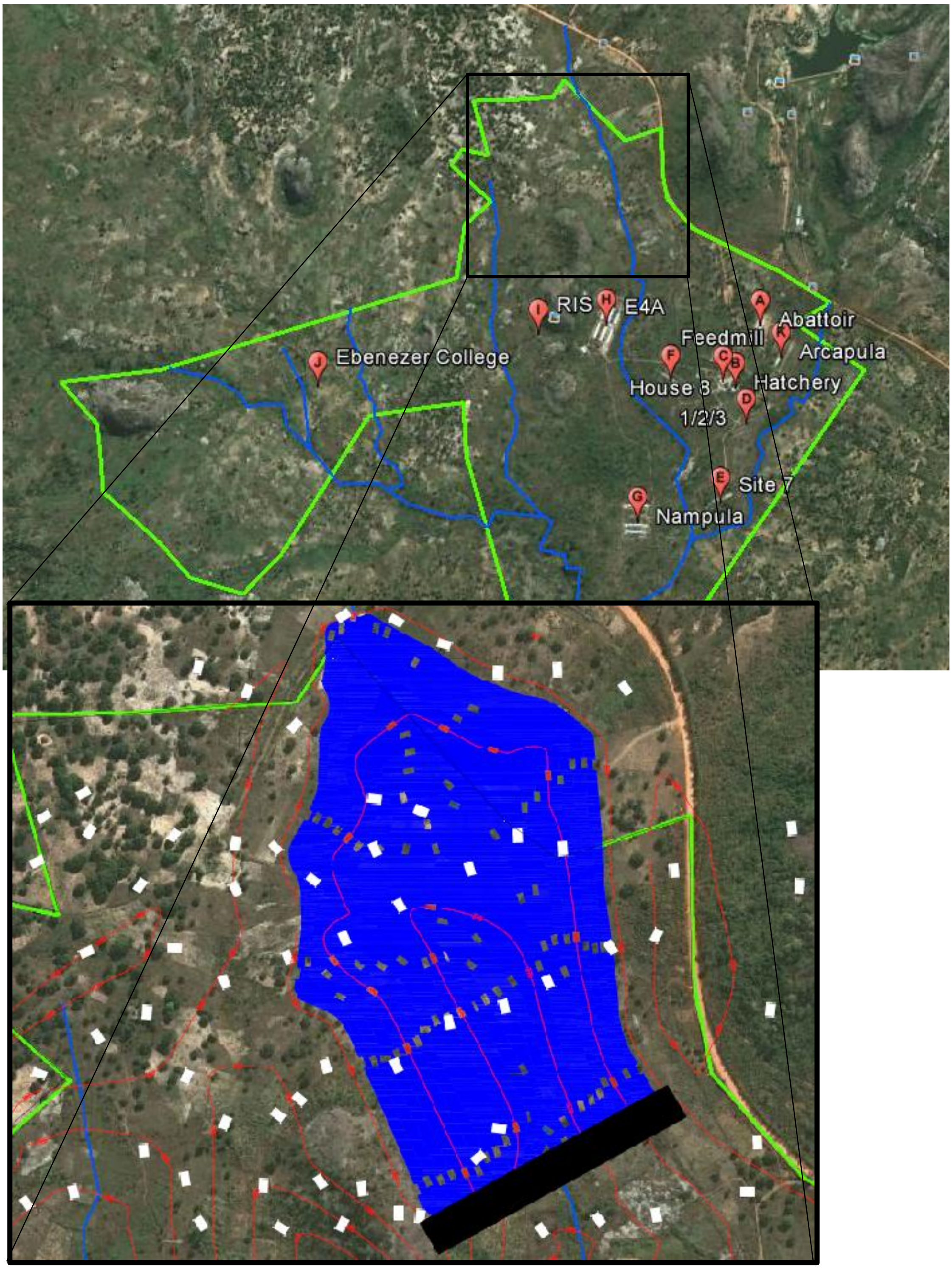


Figure 7.7 Reservoir 1, alternative 1, maximum water level 12 m, dam height 14 m

7.2.1 Dam- and reservoir characteristics

The general dam and reservoir characteristics are shown in Table 7.4. The mean annual runoff for this reservoir is 940,848 m^3/year.

Water depth [m]	Dam height [m]	Dam length [m]	Maximum dam width [m]	Reservoir perimeter [m]	Reservoir area [m^2]	Storage capacity [m^3]	Subtraction capacity [m^3/month]	Storage ratio [-]
1	3	129	20	740	7,298	6,568	3,000	0.01
2	4	154	27	938	22,714	21,574	7,000	0.02
3	5	188	33	1,038	39,592	52,727	12,000	0.06
4	6	207	39	1,448	74,837	109,942	20,000	0.12
5	7	235	46	1,566	103,914	199,317	34,000	0.21
6	8	263	52	1,683	132,990	317,769	49,000	0.34
7	9	290	59	1,821	160,806	464,667	66,000	0.49
8	10	321	65	1,885	186,913	638,526	65,000	0.68
9	11	346	71	2,009	217,743	840,854	61,000	0.89
10	12	368	78	2,151	249,924	1,074,688	56,000	1.14
11	13	389	84	2,245	278,629	1,338,964	52,000	1.42
12	14	410	91	2,316	307,833	1,632,195	47,000	1.73

Table 7.4 Dam and reservoir characteristics reservoir 1 alternative 1

The height, relative heights and crow flies distances to the reservoir are shown in Table 7.5.

	Reservoir	Ebenezer	Abattoir	Hatchery	RIS	E4A	Feed mill
Height [m]	372	361	376	369	373	370	372
Relative height [m]	0	11	-4	3	-1	2	0
Length [m]	0	1,894	873	1,014	829	497	951

Table 7.5 Elevation level and distances to users relative to reservoir 1 alternative 1

With the use of the water balance the maximum subtraction capacity per month is shown in Figure 7.8.

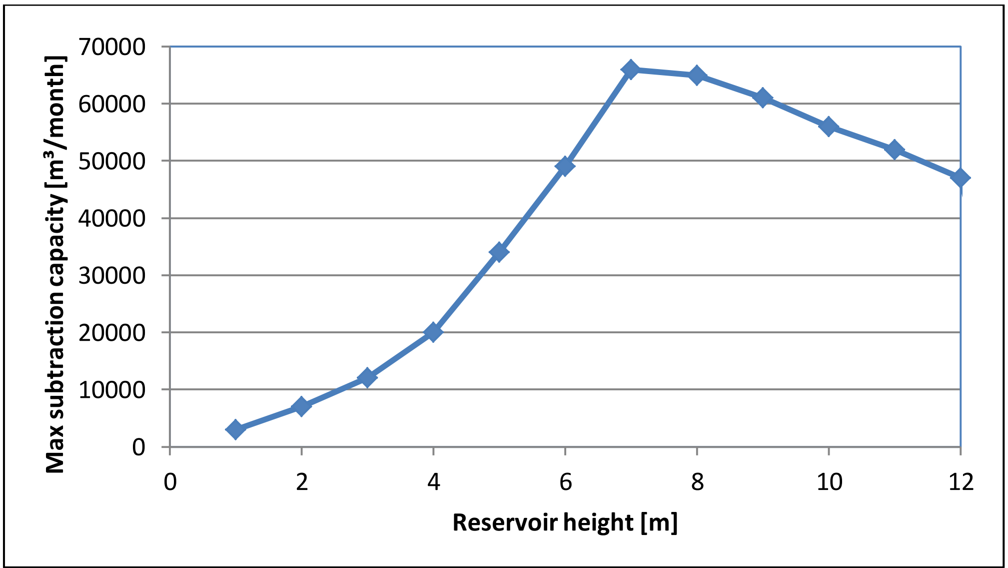


Figure 7.8 Reservoir 1 alternative 1 subtraction capacity

7.2.2 Spillway

The spillway characteristics for reservoir 1 alternative 1 are shown in Table 7.6.

Probable Maximum Flood [mm]	Catchment area [m²]	Discharge [m³/day]	Discharge [m³/s]	Width spillway [m]
300	2,925,608	877,682	10	17

Table 7.6 Spillway characteristics reservoir 1 alternative 1

7.2.3 Costs

Below the costs per cubic meter per economic lifetime is plotted against the reservoir height. Besides this the total costs are plotted in the same figure. The total costs are split up in investment costs (direct costs) and maintenance costs.

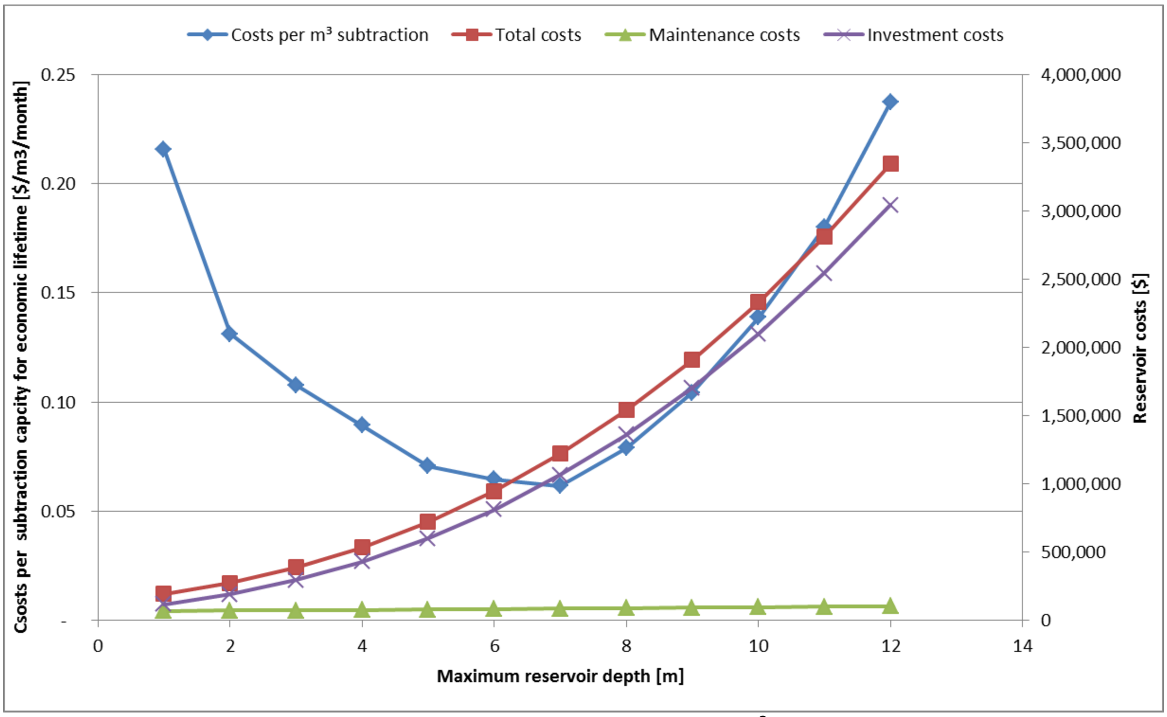


Figure 7.9 Reservoir 1 alternative 1 cost overview and costs per m^3 per economic lifetime

The total costs are plotted with the fulfilling water demand.

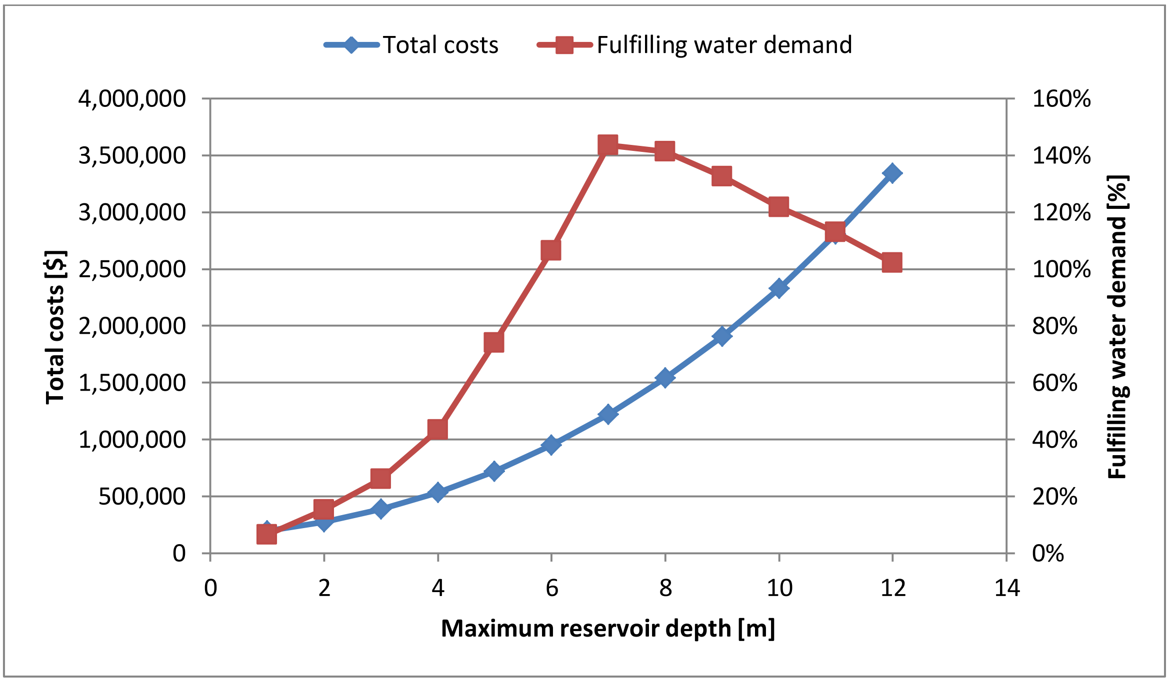


Figure 7.10 Reservoir 1 alternative 1 cost overview and fulfilling water demand per water level

In Table 7.7 a structured overview is given for the total costs, costs per cubic meter and the costs per cubic meter per lifetime subtraction. Maintenance costs increase slightly (factor 1.05) when the water level increases. This is done, because a larger reservoir has higher maintenance costs.

Water depth [m]	Subtraction capacity [m^3/month]	Subtraction / total water demand [%]	Dam volume [m^3]	Total direct cost [$]	Maintenance costs [$]	Total costs [$]	Costs/m^3/lifetime subtraction capacity [$]	Direct cost per m^3 dam volume [$]	Total cost per m^3 dam volume [$]
1	3,000	7%	3,327	117,812	68,694	194,213	0.22	35.4	58.4
2	7,000	15%	6,659	191,037	71,816	275,351	0.13	28.7	41.3
3	12,000	26%	11,464	293,824	74,938	387,984	0.11	25.6	33.8
4	20,000	43%	17,921	429,491	78,061	535,650	0.09	24.0	29.9
5	34,000	74%	26,192	601,128	81,183	721,638	0.07	23.0	27.6
6	49,000	107%	36,435	811,653	84,306	949,057	0.06	22.3	26.0
7	66,000	143%	48,795	1,063,857	87,428	1,220,883	0.06	21.8	25.0
8	65,000	141%	63,415	1,360,436	90,551	1,539,987	0.08	21.5	24.3
9	61,000	133%	80,433	1,704,013	93,673	1,909,163	0.10	21.2	23.7
10	56,000	122%	99,982	2,097,159	96,796	2,331,152	0.14	21.0	23.3
11	52,000	113%	122,197	2,542,414	99,918	2,808,658	0.18	20.8	23.0
12	47,000	102%	147,207	3,042,298	103,040	3,344,367	0.24	20.7	22.7

Table 7.7 Reservoir 1 alternative 1 cost overview

The principle of a higher subtraction capacity for a higher dam does not always holds. The table shows this result. Further details can be seen in the water balance of this reservoir.

7.2.4 Remarks

This reservoir has some remarks that will eventually influence the usability or total costs for this reservoir. These remarks are only comments and are not taken into account in the cost calculation. For the eventual reservoir selection these remarks need to be considered.

- The water level comes close to the main road. Because it is a main road a higher hazard class need have to be considered.
- Downstream, close to the river, Eggs for Africa is settled. They can be negatively affected when failing of the dam occurs.
- The total reservoir surface exceeds the boundary of the farm. Extra land has to be bought. These extra costs have to be taken into account.
- The water level of the abattoir (biggest water consumer) exceeds the elevation of the reservoir. Pumps are needed to pump the water to the abattoir.

7.3 Reservoir 1 (alternative 2)

To make an impression about the location, size and distances to nearby objects it is important to visualize the reservoir. In Figure 7.11 the location for the reservoir and the extent of the reservoir with the maximum water level is shown. After this some general dam and reservoir characteristics are showed. Secondly the water balance is made in order to determine the maximum allowable subtraction. Afterwards the spillway is calculated in order to give an accurate estimation for the spillway dimensions. This will be integrated in the reservoir costs. As a final result the costs can be determined for each reservoir. Alternative 2 is the small alternative for the reservoir 1 site.

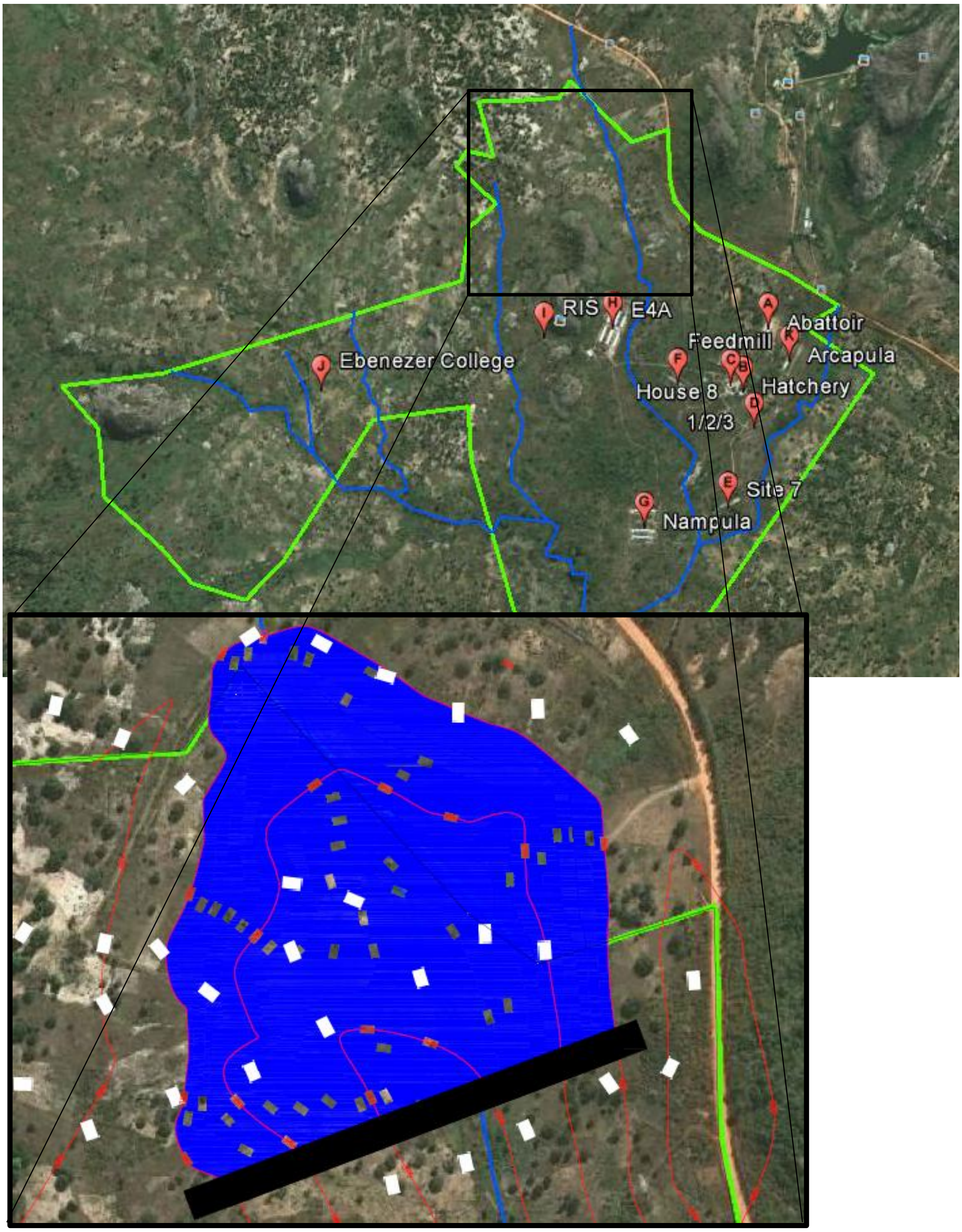


Figure 7.11 Reservoir 1, alternative 2, maximum water level 13 m, dam height 11 m

7.3.1 Dam- and reservoir characteristics

The general dam and reservoir characteristics are shown in Table 7.8. The mean annual runoff for this reservoir is 940,848 m^3/year.

Water depth [m]	Dam height [m]	Dam length [m]	Maximum dam width [m]	Reservoir perimeter [m]	Reservoir area [m^2]	Storage capacity [m^3]	Subtraction capacity [m^3/month]	Storage ratio [-]
1	3	200	20	404	9,282	8,354	4,000	0.01
2	4	230	27	825	33,877	29,933	8,000	0.03
3	5	269	33	956	52,190	72,967	15,000	0.08
4	6	303	39	1,086	70,502	134,313	25,000	0.14
5	7	334	46	1,238	89,220	214,174	37,000	0.23
6	8	364	52	1,311	106,742	312,155	49,000	0.33
7	9	394	59	1,434	127,392	429,222	62,000	0.46
8	10	435	65	1,574	150,955	568,395	67,000	0.60
9	11	451	71	1,675	172,170	729,958	62,000	0.78
10	12	480	78	1,747	190,160	911,123	60,000	0.97
11	13	516	84	1,801	207,014	1,109,710	58,000	1.18

Table 7.8 Dam and reservoir characteristics reservoir 1 alternative 2

The height, relative heights and crow flies distances to the reservoir are shown in Table 7.9.

	Reservoir	Ebenezer	Abattoir	Hatchery	RIS	E4A	Feed mill
Height [m]	374	361	376	369	373	370	372
Relative height [m]	0	13	-2	5	1	4	2
Length [m]	0	1,883	811	916	754	521	851

Table 7.9 Elevation level and distances to users relative to reservoir 1 alternative 2

With the use of the water balance the maximum subtraction capacity per month is shown in Figure 7.12.

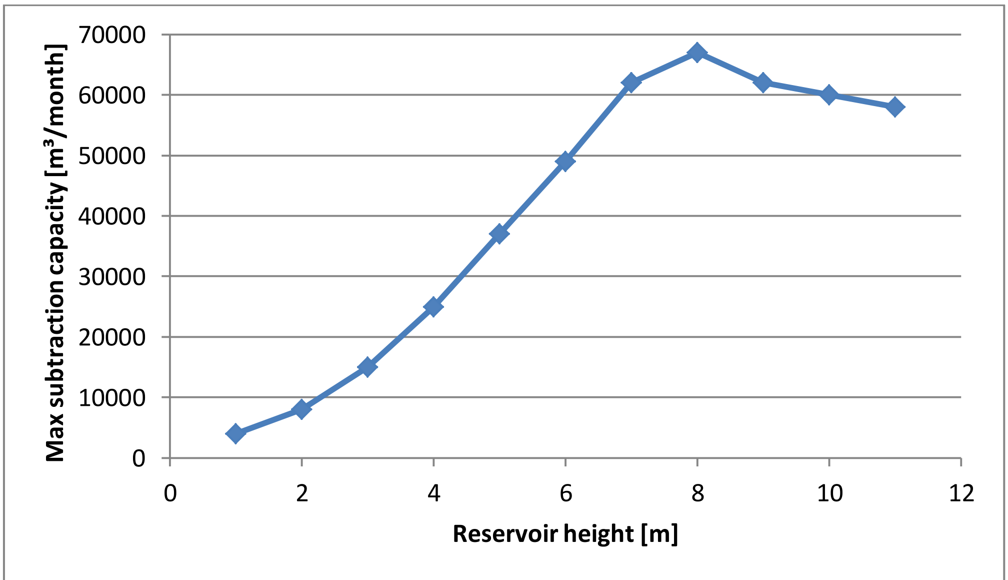


Figure 7.12 Reservoir 1 alternative 2 subtraction capacity

7.3.2 Spillway

The spillway characteristics for reservoir 1 alternative 2 are shown in Table 7.10.

Probable Maximum Flood [mm]	Catchment area [m²]	Discharge [m³/day]	Discharge [m³/s]	Width spillway [m]
300	2,925,608	877,682	10	17

Table 7.10 Spillway characteristics reservoir 1 alternative 2

7.3.3 Costs

Below the costs per cubic meter per economic lifetime is plotted against the reservoir height. Besides this the total costs are plotted in the same figure. The total costs are split up in investment costs (direct costs) and maintenance costs.

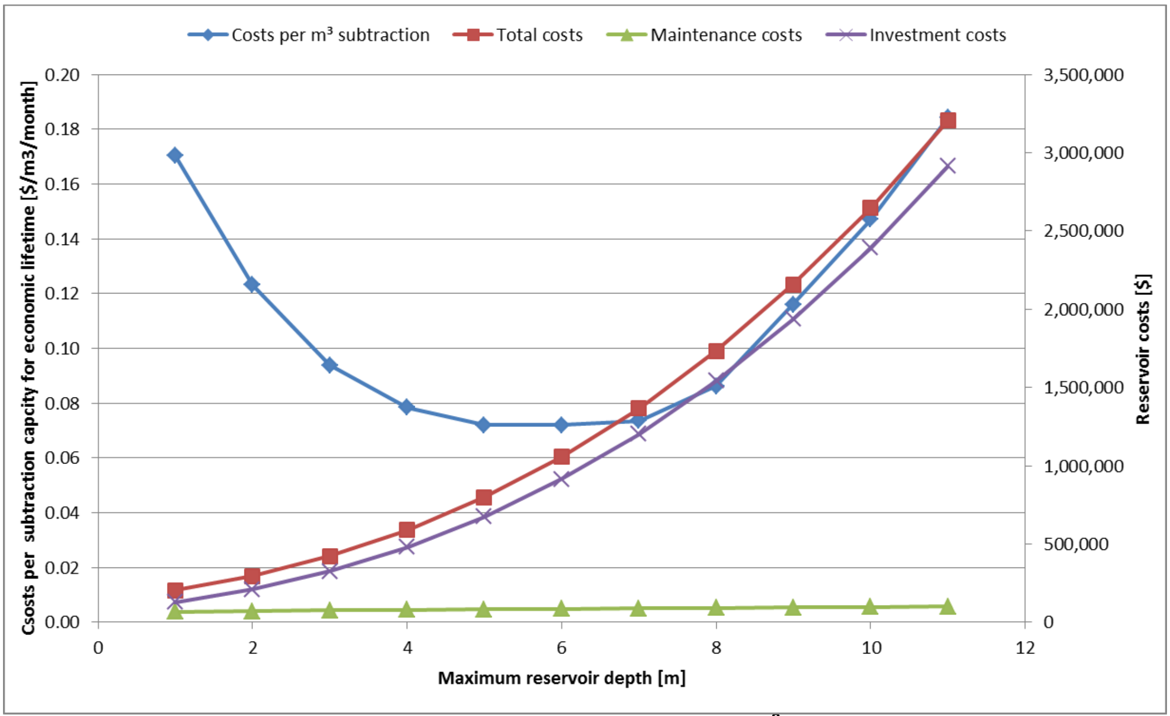


Figure 7.13 Reservoir 1 alternative 2 cost overview and costs per m^3 per economic lifetime

The total costs are plotted with the fulfilling water demand.

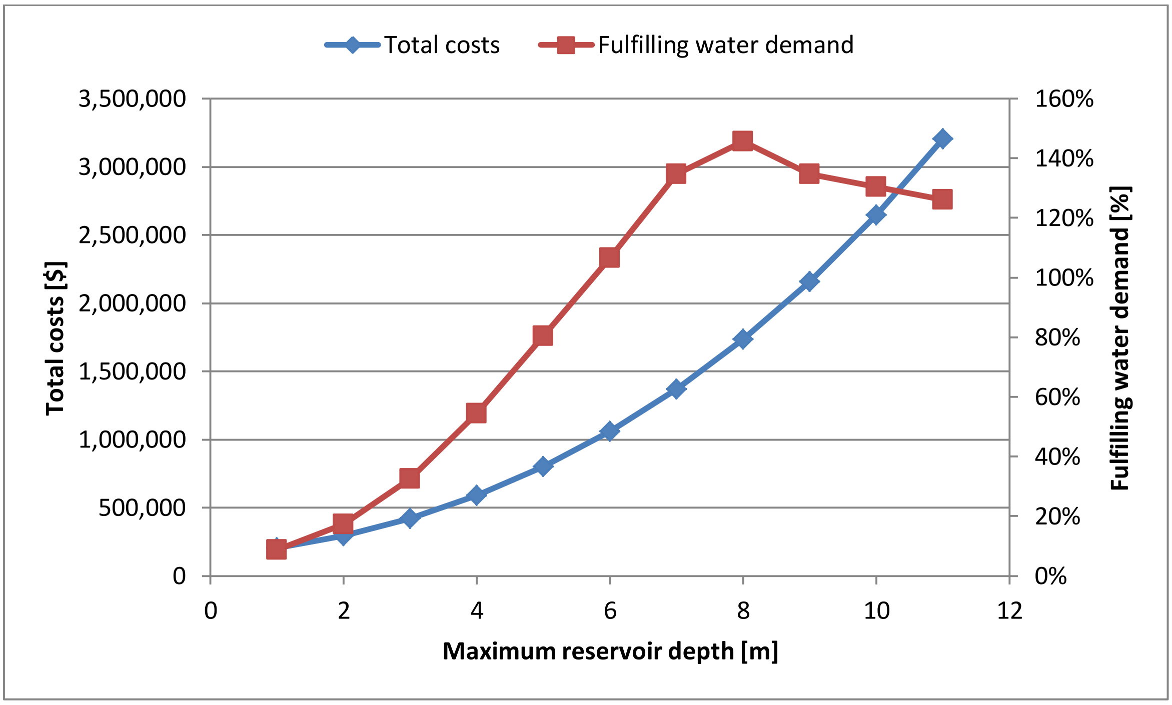


Figure 7.14 Reservoir 1 alternative 2 cost overview and fulfilling water demand per water level

In Table 7.11 a structured overview is given for the total costs, costs per cubic meter and the costs per cubic meter per lifetime subtraction. Maintenance costs increase slightly (factor 1.05) when the water level increases. This is done, because a larger reservoir has higher maintenance costs.

Water depth [m]	Subtraction capacity [m^3/month]	Subtraction / total water demand [%]	Dam volume [m^3]	Total direct cost [$]	Maintenance costs [$]	Total costs [$]	Costs/m^3/lifetime subtraction capacity [$]	Direct cost per m^3 dam volume [$]	Total cost per m^3 dam volume [$]
1	4,000	9%	3,726	127,626	68,694	204,669	0.17	34.3	54.9
2	8,000	17%	7,469	209,947	71,816	295,498	0.12	28.1	39.6
3	15,000	33%	12,880	325,804	74,938	422,057	0.09	25.3	32.8
4	25,000	54%	20,171	479,155	78,061	588,563	0.08	23.8	29.2
5	37,000	80%	29,541	673,763	81,183	799,025	0.07	22.8	27.0
6	49,000	107%	41,181	913,275	84,306	1,057,327	0.07	22.2	25.7
7	62,000	135%	55,279	1,201,290	87,428	1,367,307	0.07	21.7	24.7
8	67,000	146%	72,022	1,541,426	90,551	1,732,818	0.09	21.4	24.1
9	62,000	135%	91,602	1,937,403	93,673	2,157,822	0.12	21.2	23.6
10	60,000	130%	114,220	2,393,165	96,796	2,646,523	0.15	21.0	23.2
11	58,000	126%	140,097	2,913,188	99,918	3,203,689	0.18	20.8	22.9

Table 7.11 Reservoir 1 alternative 2 cost overview

The principle of a higher subtraction capacity for a higher dam does not always holds. The table shows this result. Further details can be seen in the water balance of this reservoir.

7.3.4 Remarks

This reservoir has some remarks that will eventually influence the usability or total costs for this reservoir. These remarks are only comments and are not taken into account in the cost calculation. For the eventual reservoir selection these remarks need to be considered.

- The water level comes close to the main road. Because it is a main road a higher hazard class need have to be considered.
- Downstream, close to the river, Eggs for Africa is settled. They can be negatively affected when failing of the dam occurs.
- The total reservoir surface exceeds the boundary of the farm. Extra land has to be bought. These extra costs have to be taken into account.
- The water level of the abattoir (biggest water consumer) exceeds the elevation of the reservoir. Pumps are needed to pump the water to the abattoir.

7.4 Reservoir 1 (alternative 3)

To make an impression about the location, size and distances to nearby objects it is important to visualize the reservoir. In Figure 7.15 the location for the reservoir and the extent of the reservoir with the maximum water level is shown. After this some general dam and reservoir characteristics are showed. Secondly the water balance is made in order to determine the maximum allowable subtraction. Afterwards the spillway is calculated in order to give an accurate estimation for the spillway dimensions. This will be integrated in the reservoir costs. As a final result the costs can be determined for each reservoir. Alternative 3 is the large alternative for the reservoir 1 site.

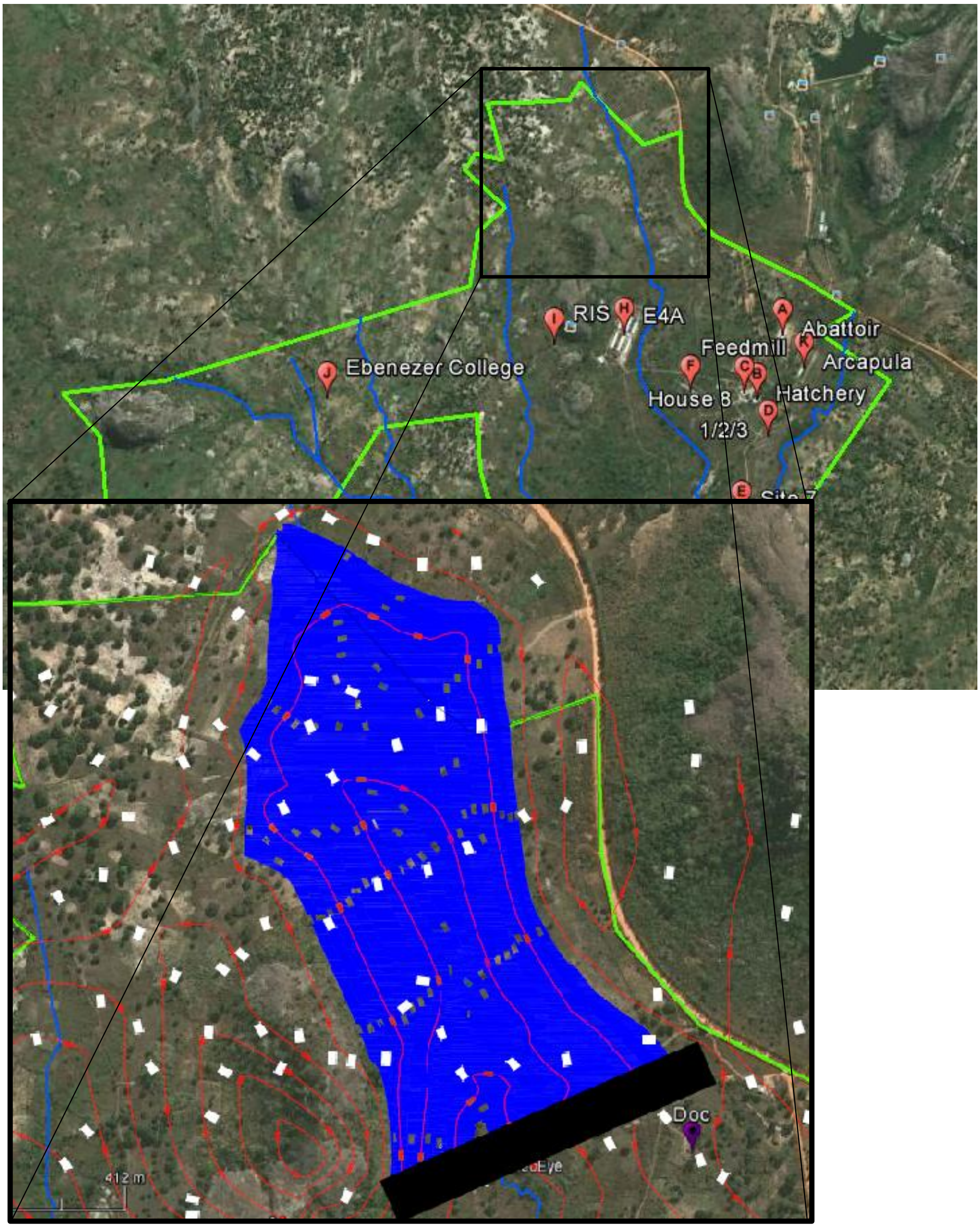


Figure 7.15 Reservoir 1, alternative 3, maximum water level 15 m, dam height 17 m

7.4.1 Dam- and reservoir characteristics

The general dam and reservoir characteristics are shown in Table 7.12. The mean annual runoff for this reservoir is 940,948m^3/year.

Water depth [m]	Dam height [m]	Dam length [m]	Maximum dam width [m]	Reservoir perimeter [m]	Reservoir area [m^2]	Storage capacity [m^3]	Subtraction capacity [m^3/month]	Storage ratio [-]
1	3	136	20	243	3,420	3,078	2,000	0.00
2	4	166	27	408	8,336	8,956	4,000	0.01
3	5	196	33	683	18,903	22,576	7,000	0.02
4	6	225	39	732	26,545	45,300	11,000	0.05
5	7	251	46	1,334	39,488	78,316	16,000	0.08
6	8	288	52	1,528	59,811	127,966	24,000	0.14
7	9	324	59	1,636	82,122	198,932	35,000	0.21
8	10	361	65	2,044	122,171	301,079	47,000	0.32
9	11	384	71	2,178	156,068	440,198	63,000	0.47
10	12	427	78	2,311	189,964	613,214	65,000	0.65
11	13	459	84	2,444	225,308	820,850	61,000	0.87
12	14	493	91	2,508	258,129	1,062,569	56,000	1.13
13	15	526	97	2,690	293,636	1,338,451	51,000	1.42
14	16	559	103	2,785	332,538	1,651,538	46,000	1.76
15	17	606	110	2,884	366,460	2,001,037	40,000	2.13

Table 7.12 Dam and reservoir characteristics reservoir 1 alternative 3

The height, relative heights and crow flies distances to the reservoir are shown in Table 7.13.

	Reservoir	Ebenezer	Abattoir	Hatchery	RIS	E4A	Feed mill
Height [m]	368	361	376	369	373	370	372
Relative height [m]	0	7	-8	-1	-5	-2	-4
Length [m]	0	2,007	1,149	1,334	1,017	796	1,273

Table 7.13 Elevation level and distances to users relative to reservoir 1 alternative 3

With the use of the water balance the maximum subtraction capacity per month is shown in Figure 7.16.

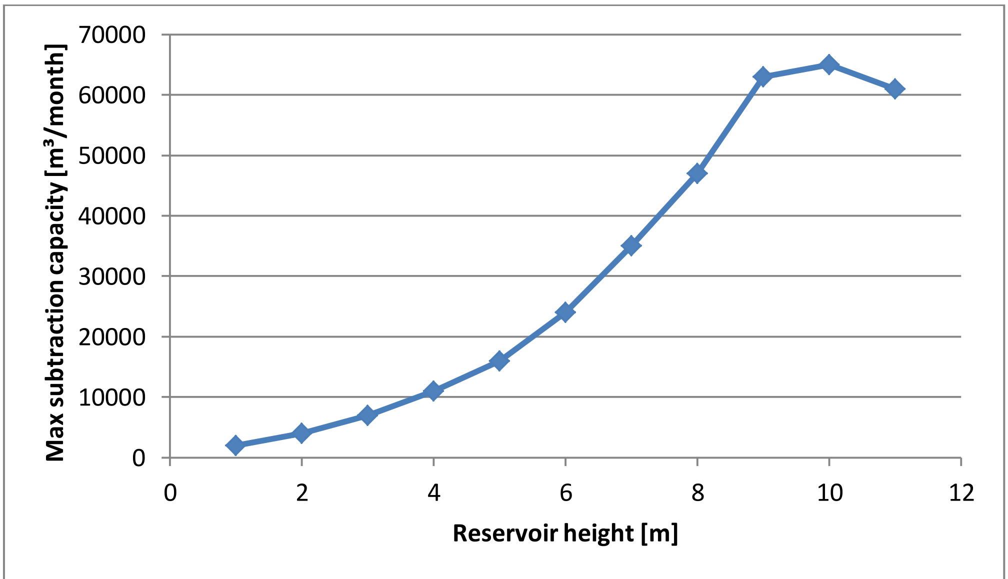


Figure 7.16 Reservoir 1 alternative 3 subtraction capacity

7.4.2 Spillway

The spillway characteristics for reservoir 1 alternative 3 are shown in Table 7.14.

Probable Maximum Flood [mm]	Catchment area [m²]	Discharge [m³/day]	Discharge [m³/s]	Width spillway [m]
300	2,925,608	877,682	10	17

Table 7.14 Spillway characteristics reservoir 1 alternative 3

7.4.3 Costs

Below the costs per cubic meter per economic lifetime is plotted against the reservoir height. Besides this the total costs are plotted in the same figure. The total costs are split up in investment costs (direct costs) and maintenance costs.

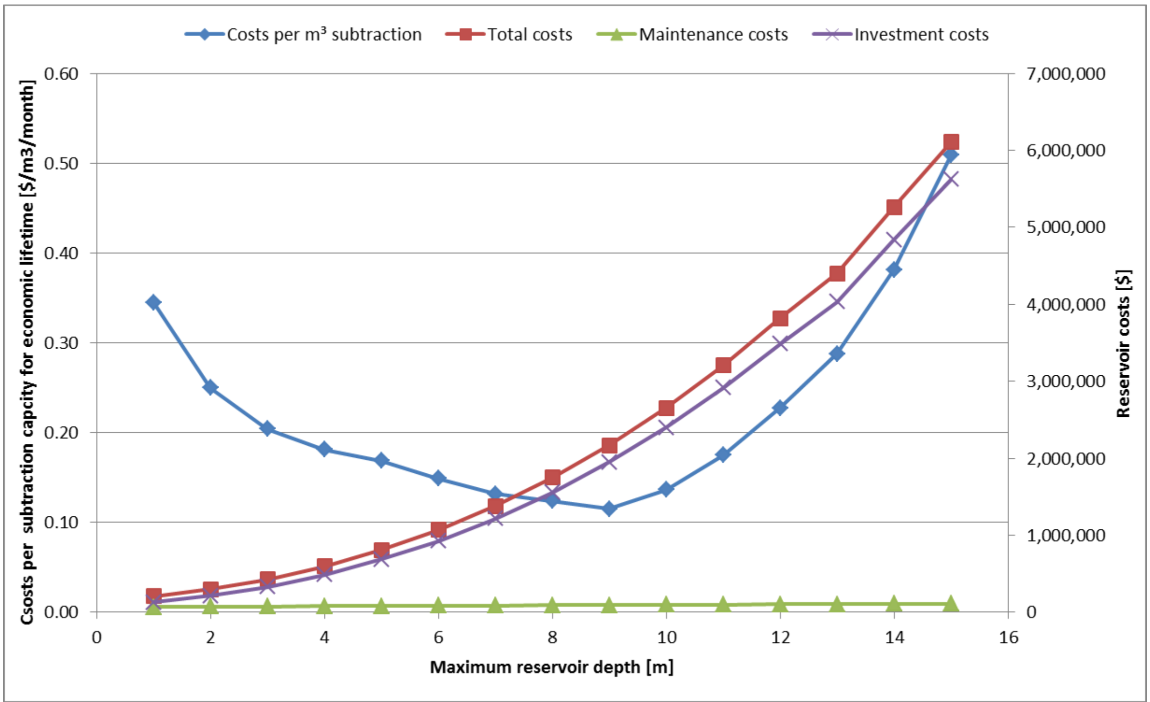


Figure 7.17 Reservoir 1 alternative 3 cost overview and costs per m^3 per economic lifetime

The total costs are plotted with the fulfilling water demand.

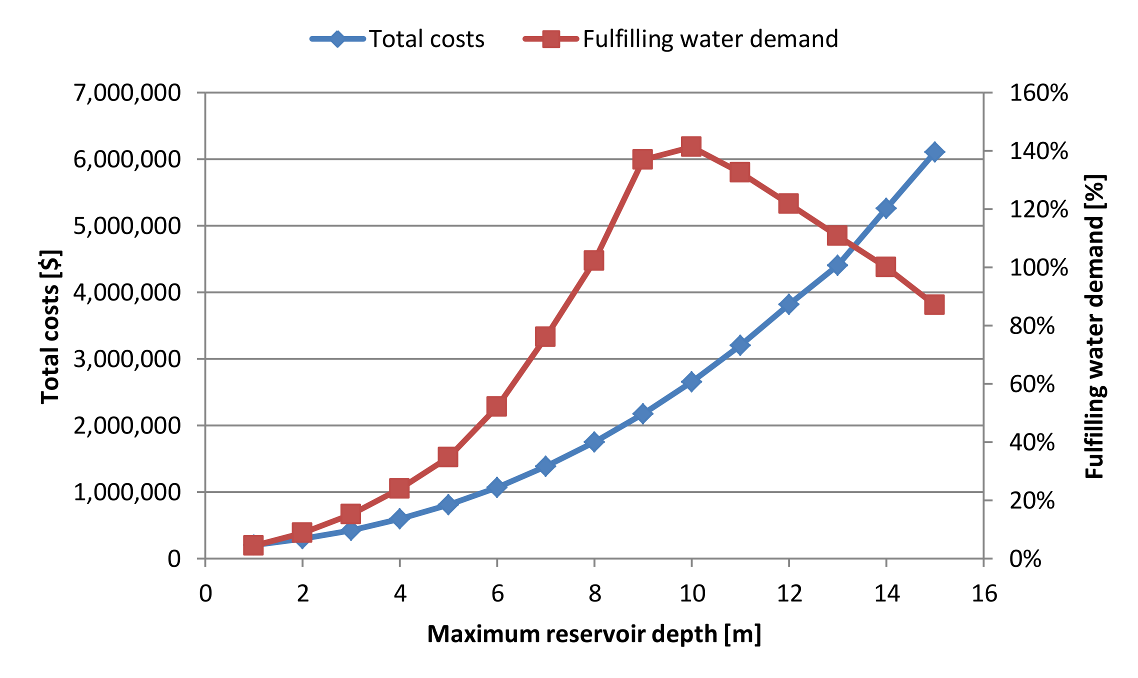


Figure 7.18 Reservoir 1 alternative 3 cost overview and fulfilling water demand per water level

In Table 7.15 a structured overview is given for the total costs, costs per cubic meter and the costs per cubic meter per lifetime subtraction. Maintenance costs increase slightly (factor 1.05) when the water level increases. This is done, because a larger reservoir has higher maintenance costs.

Water depth [m]	Subtraction capacity [m^3/month]	Subtraction / total water demand [%]	Dam volume [m^3]	Total direct cost [$]	Maintenance costs [$]	Total costs [$]	Costs/m^3/lifetime subtraction capacity [$]	Direct cost per m^3 dam volume [$]	Total cost per m^3 dam volume [$]
1	2,000	4%	3,816	129,799	68,694	206,984	0.34	34.0	54.2
2	4,000	9%	7,637	213,765	71,816	299,565	0.25	28.0	39.2
3	7,000	15%	13,146	331,625	74,938	428,259	0.20	25.2	32.6
4	11,000	24%	20,549	487,190	78,061	597,123	0.18	23.7	29.1
5	16,000	35%	30,035	684,007	81,183	809,939	0.17	22.8	27.0
6	24,000	52%	41,780	925,442	84,306	1,070,290	0.15	22.2	25.6
7	35,000	76%	55,957	1,214,719	87,428	1,381,615	0.13	21.7	24.7
8	47,000	102%	72,729	1,554,972	90,551	1,747,250	0.12	21.4	24.0
9	63,000	137%	92,256	1,949,270	93,673	2,170,466	0.11	21.1	23.5
10	65,000	141%	114,698	2,400,655	96,796	2,654,502	0.14	20.9	23.1
11	61,000	133%	140,213	2,912,172	99,918	3,202,606	0.18	20.8	22.8
12	56,000	122%	140,213	3,486,917	103,040	3,818,073	0.23	24.9	27.2
13	51,000	111%	140,213	4,031,788	106,163	4,401,713	0.29	28.8	31.4
14	46,000	100%	140,213	4,839,127	109,285	5,264,991	0.38	34.5	37.5
15	40,000	87%	140,213	5,623,924	112,408	6,104,252	0.51	40.1	43.5

Table 7.15 Reservoir 1 alternative 3 cost overview

The principle of a higher subtraction capacity for a higher dam does not always holds. The table shows this result. Further details can be seen in the water balance of this reservoir.

7.4.4 Remarks

This reservoir has some remarks that will eventually influence the usability or total costs for this reservoir. These remarks are only comments and are not taken into account in the cost calculation. For the eventual reservoir selection these remarks need to be considered.

- The water level comes close to the main road. Because it is a main road a higher hazard class need have to be considered.
- Downstream, close to the river, Eggs for Africa is settled. They can be negatively affected when failing of the dam occurs.
- The total reservoir surface exceeds the boundary of the farm. Extra land has to be bought. These extra costs have to be taken into account.
- The water level of the abattoir (biggest water consumer) exceeds the elevation of the reservoir. Pumps are needed to pump the water to the abattoir.

7.5 Reservoir 3

To make an impression about the location, size and distances to nearby objects it is important to visualize the reservoir. In Figure 7.19 the location for the reservoir and the extent of the reservoir with the maximum water level is shown. After this some general dam and reservoir characteristics are showed. Secondly the water balance is made in order to determine the maximum allowable subtraction. Afterwards the spillway is calculated in order to give an accurate estimation for the spillway dimensions. This will be integrated in the reservoir costs. As a final result the costs can be determined for each reservoir.

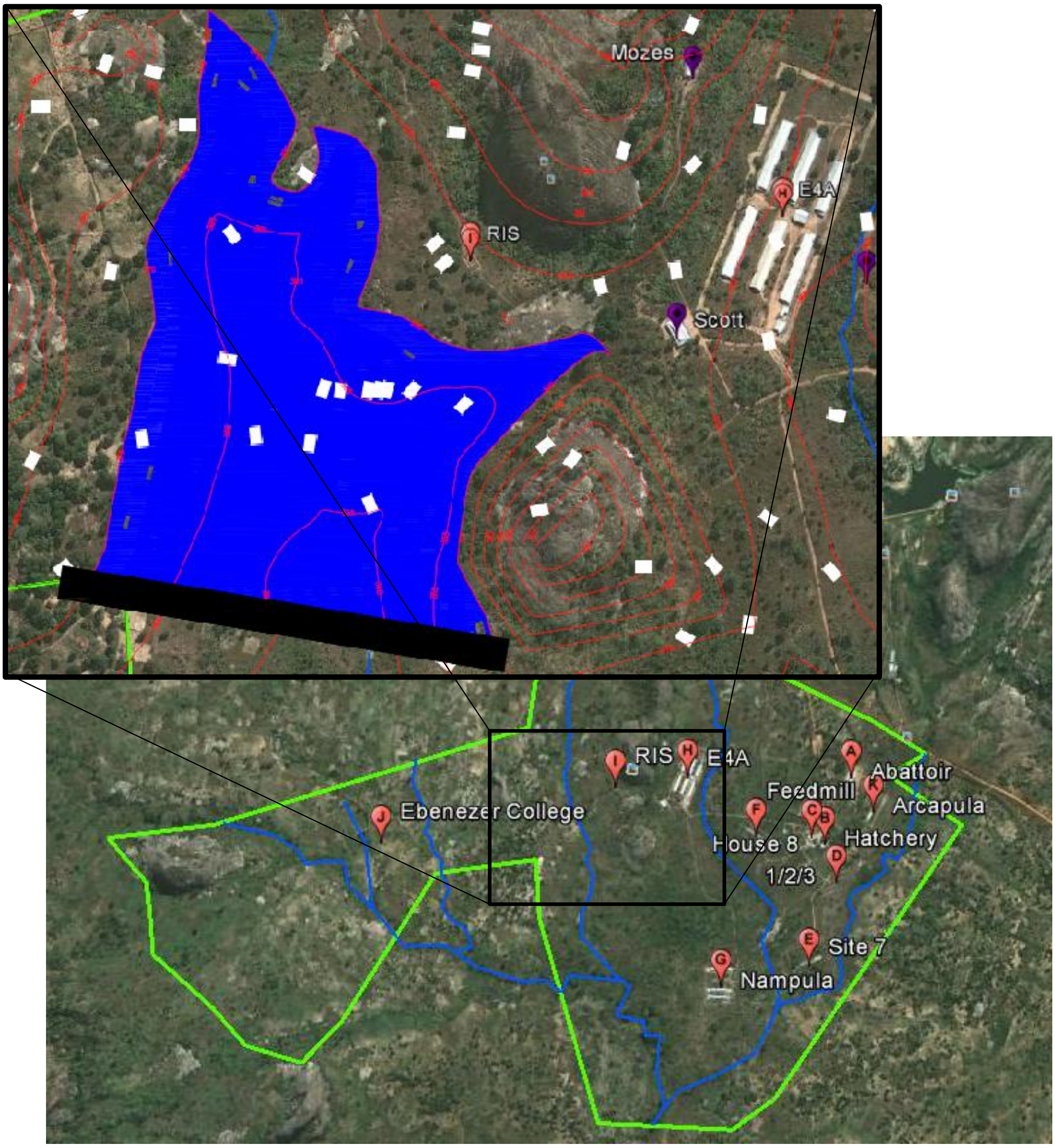


Figure 7.19 Reservoir 3, maximum water level 15 m, dam height 17 m

7.5.1 Dam- and reservoir characteristics

The general dam and reservoir characteristics are shown in Table 7.16. The mean annual runoff for this reservoir is 521,147 m^3/year.

Water depth [m]	Dam height [m]	Dam length [m]	Maximum dam width [m]	Reservoir perimeter [m]	Reservoir area [m^2]	Storage capacity [m^3]	Subtraction capacity [m^3/month]	Storage ratio [-]
1	3	170	20	318	6,741	6,067	1,000	0.01
2	4	201	27	444	11,530	15,202	3,000	0.03
3	5	234	33	581	18,608	30,271	6,000	0.06
4	6	269	39	734	29,285	54,218	9,000	0.10
5	7	305	46	1,200	47,335	92,528	15,000	0.18
6	8	339	52	1,391	71,167	151,779	23,000	0.29
7	9	374	59	1,508	91,508	233,116	32,000	0.45
8	10	406	65	1,838	113,460	335,600	35,000	0.64
9	11	437	71	2,038	135,497	460,079	32,000	0.88
10	12	464	78	2,151	156,906	606,280	29,000	1.16
11	13	490	84	2,337	178,976	774,221	26,000	1.49
12	14	512	91	2,488	200,988	964,203	22,000	1.85

Table 7.16 Dam and reservoir characteristics reservoir 3

The height, relative heights and crow flies distances to the reservoir are shown in Table 7.17.

	Reservoir	Ebenezer	Abattoir	Hatchery	RIS	E4A	Feed mill
Height [m]	359	361	376	369	373	370	372
Relative height [m]	0	-2	-17	-10	-14	-11	-13
Length [m]	0	1,070	1,406	1,191	478	704	1,132

Table 7.17 Elevation level and distances to users relative to reservoir 3

With the use of the water balance the maximum subtraction capacity per month is shown in Figure 7.20.

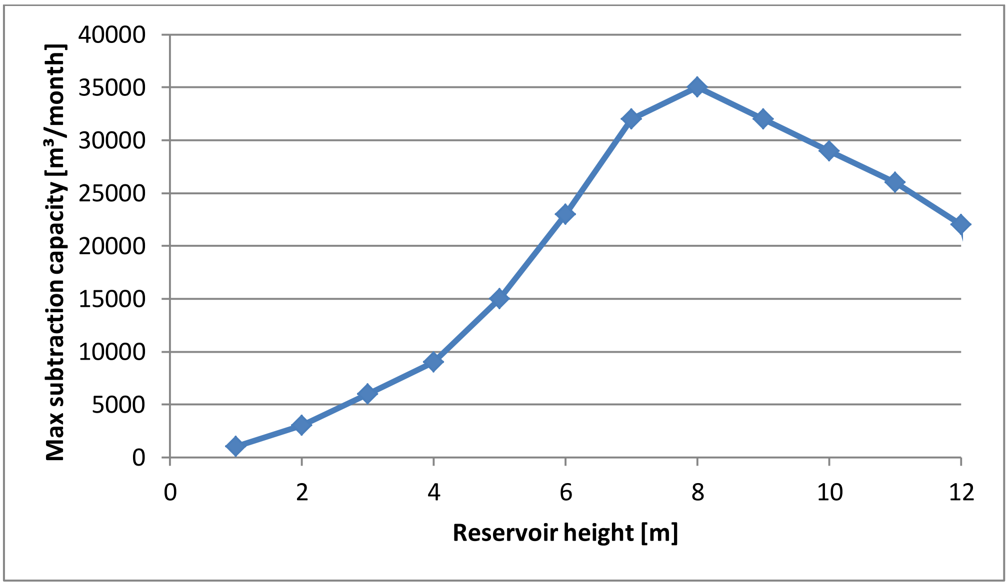


Figure 7.20 Reservoir 3 subtraction capacity

7.5.2 Spillway

The spillway characteristics for reservoir 3 are shown in Table 7.18.

Probable Maximum Flood [mm]	Catchment area [m²]	Discharge [m³/day]	Discharge [m³/s]	Width spillway [m]
300	1,620,359	486,108	6	9

Table 7.18 Spillway characteristics reservoir 3

7.5.3 Costs

Below the costs per cubic meter per economic lifetime is plotted against the reservoir height. Besides this the total costs are plotted in the same figure. The total costs are split up in investment costs (direct costs) and maintenance costs.

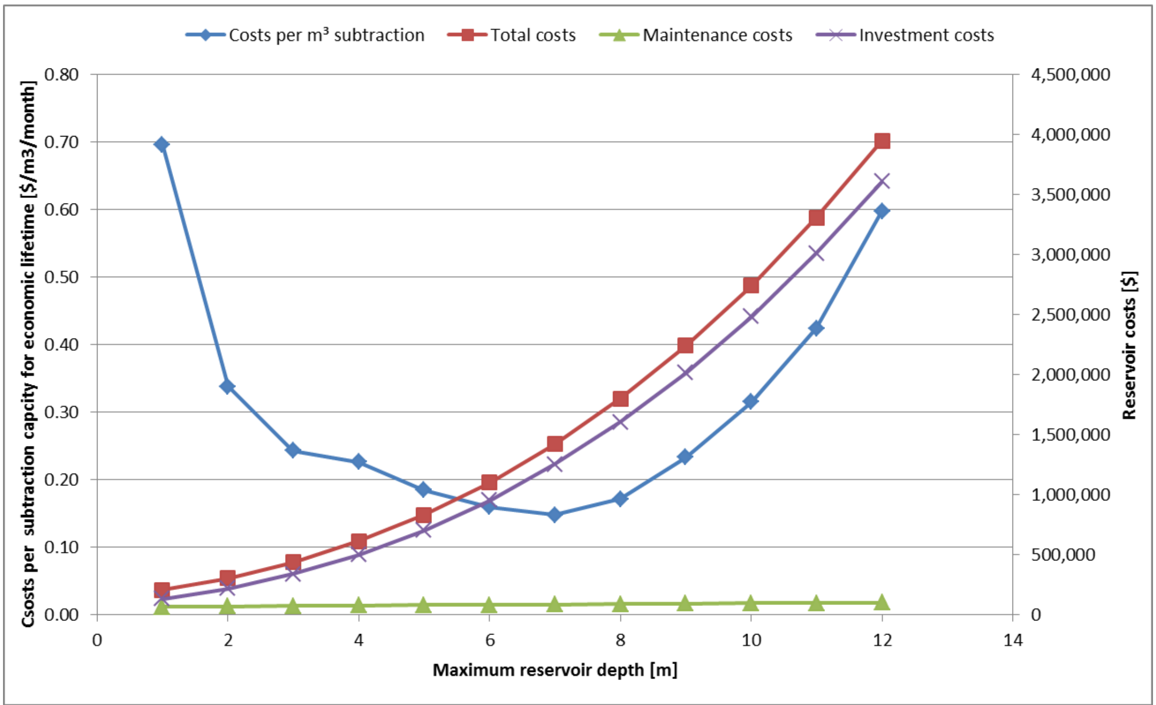


Figure 7.21 Reservoir 3 cost overview and costs per m^3 per economic lifetime

The total costs are plotted with the fulfilling water demand.

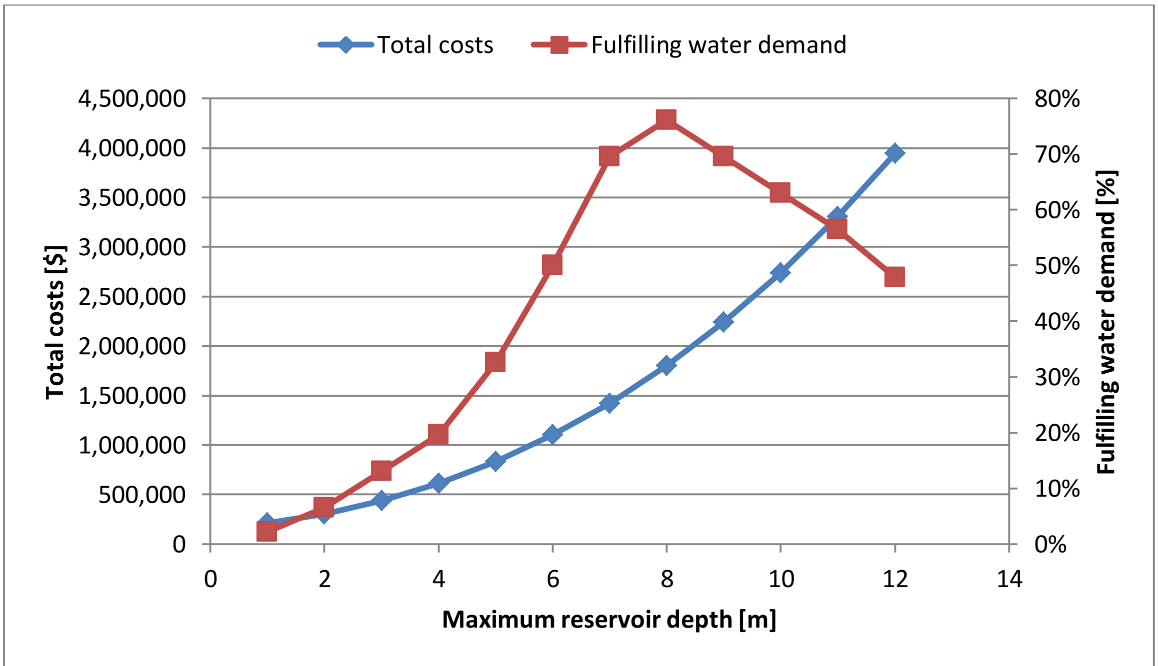


Figure 7.22 Reservoir 3 cost overview and fulfilling water demand per water level

In Table 7.19 a structured overview is given for the total costs, costs per cubic meter and the costs per cubic meter per lifetime subtraction. Maintenance costs increase slightly (factor 1.05) when the water level increases. This is done, because a larger reservoir has higher maintenance costs.

Water depth [m]	Subtraction capacity [m^3/month]	Subtraction / total water demand [%]	Dam volume [m^3]	Total direct cost [$]	Maintenance costs [$]	Total costs [$]	Costs/m^3/lifetime subtraction capacity [$]	Direct cost per m^3 dam volume [$]	Total cost per m^3 dam volume [$]
1	1,000	2%	3,943	131,485	68,694	208,780	0.70	33.3	53.0
2	3,000	7%	7,891	218,260	71,816	304,355	0.34	27.7	38.6
3	6,000	13%	13,586	340,084	74,938	437,271	0.24	25.0	32.2
4	9,000	20%	21,238	500,905	78,061	611,735	0.23	23.6	28.8
5	15,000	33%	31,045	704,406	81,183	831,672	0.18	22.7	26.8
6	23,000	50%	43,191	954,078	84,306	1,100,800	0.16	22.1	25.5
7	32,000	70%	57,853	1,253,274	87,428	1,422,693	0.15	21.7	24.6
8	35,000	76%	75,202	1,605,248	90,551	1,800,815	0.17	21.3	23.9
9	32,000	70%	95,404	2,013,186	93,673	2,238,563	0.23	21.1	23.5
10	29,000	63%	118,624	2,480,243	96,796	2,739,297	0.31	20.9	23.1
11	26,000	57%	145,027	3,009,568	99,918	3,306,373	0.42	20.8	22.8
12	22,000	48%	174,776	3,604,339	103,040	3,943,177	0.60	20.6	22.6

Table 7.19 Reservoir 3 cost overview

The principle of a higher subtraction capacity for a higher dam does not always holds. The table shows this result. Further details can be seen in the water balance of this reservoir.

7.5.4 Remarks

This reservoir has some remarks that will eventually influence the usability or total costs for this reservoir. These remarks are only comments and are not taken into account in the cost calculation. For the eventual reservoir selection these remarks need to be considered.

- The total reservoir surface exceeds the boundary of the farm. Extra land has to be bought. These extra costs have to be taken into account.
- The water level of the abattoir (biggest water consumer) exceeds the elevation of the reservoir. Pumps are needed to pump the water to the abattoir.
- The catchment area is probably estimated to small. This should be taken into account for calculating the spillway.
- Near this reservoir an international school (Rapale international school) is in use. Safety measures should be considered.

7.6 Reservoir 8

To make an impression about the location, size and distances to nearby objects it is important to visualize the reservoir. In Figure 7.23 the location for the reservoir and the extent of the reservoir with the maximum water level is shown. After this some general dam and reservoir characteristics are showed. Secondly the water balance is made in order to determine the maximum allowable subtraction. Afterwards the spillway is calculated in order to give an accurate estimation for the spillway dimensions. This will be integrated in the reservoir costs. As a final result the costs can be determined for each reservoir.

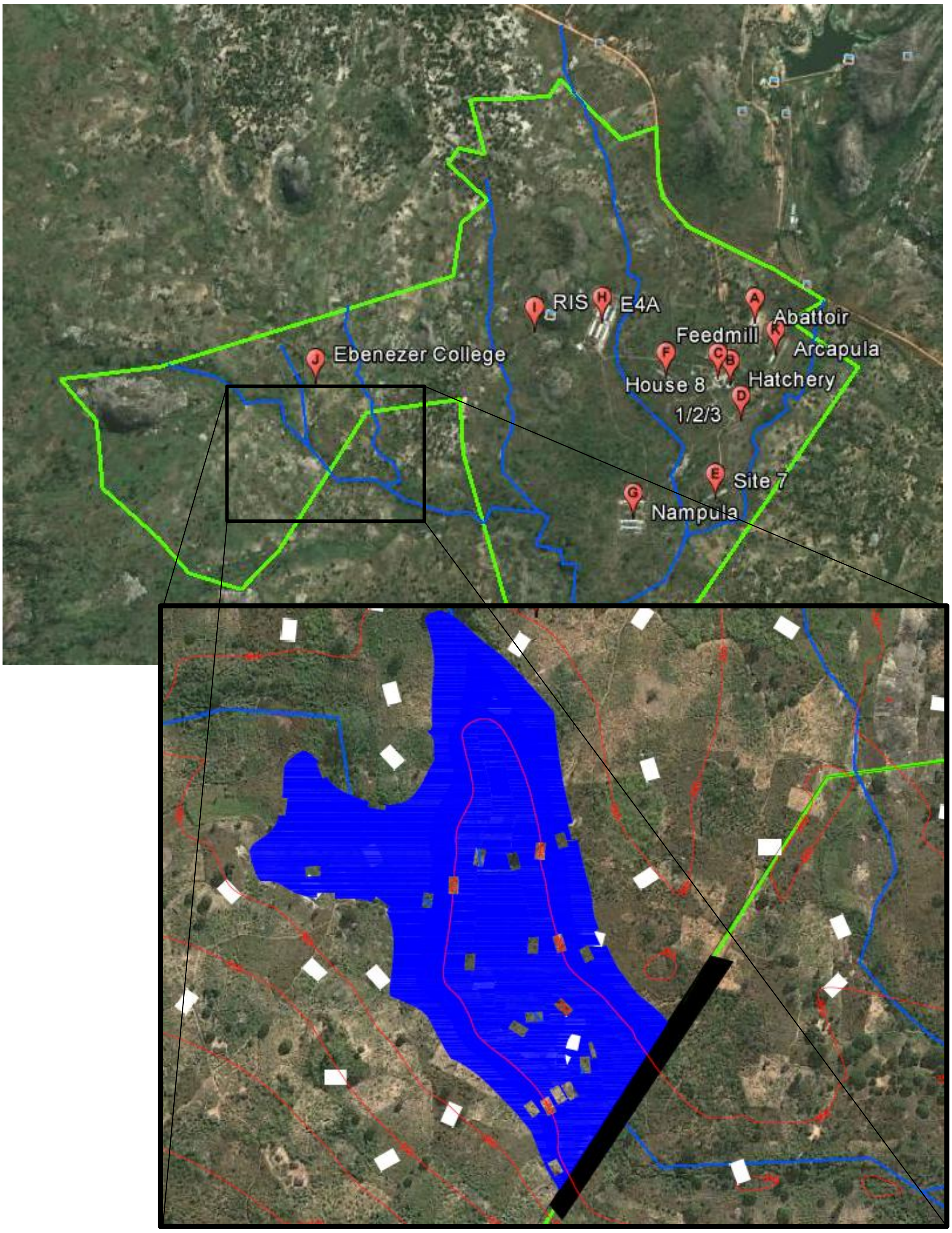


Figure 7.23 Reservoir 8, maximum water level 5 m, dam height 7 m

7.6.1 Dam- and reservoir characteristics

The general dam and reservoir characteristics are shown in Table 7.23.

Water depth [m]	Dam height [m]	Dam length [m]	Maximum dam width [m]	Reservoir perimeter [m]	Reservoir area [m^2]	Storage capacity [m^3]	Subtraction capacity [m^3/month]	Storage ratio [-]
1	3	131	20	440	7,284	6,556	2,000	0.01
2	4	156	27	926	19,664	20,030	5,000	0.03
3	5	182	33	964	33,654	46,689	9,000	0.07
4	6	210	39	1,116	50,167	88,599	16,000	0.14
5	7	272	46	1,524	82,359	154,862	25,000	0.24

Table 7.20 Dam and reservoir characteristics reservoir 8

The height, relative heights and crow flies distances to the reservoir are shown in Table 7.21.

	Reservoir	Ebenezer	Abattoir	Hatchery	RIS	E4A	Feed mill
Height [m]	368	361	376	369	373	370	372
Relative height [m]	0	7	-8	-1	-5	-2	-4
Length [m]	0	2,007	1,149	1,334	1,017	796	1,273

Table 7.21 Elevation level and distances to users relative to reservoir 8

With the use of the water balance the maximum subtraction capacity per month is shown in Figure 7.24.

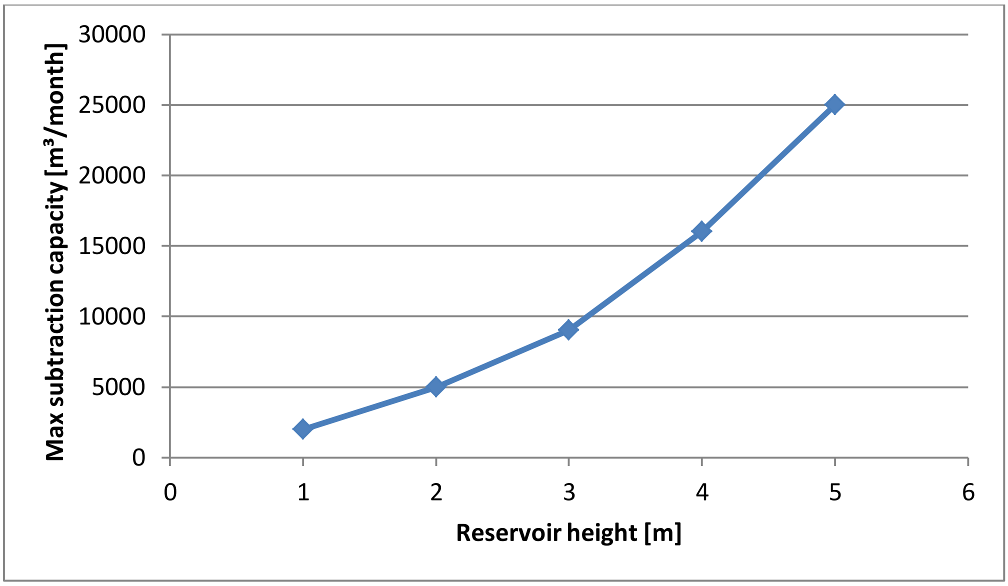


Figure 7.24 Reservoir 8 subtraction capacity

7.6.2 Spillway

The spillway characteristics for reservoir 8 are shown in Table 7.22.

Probable Maximum Flood [mm]	Catchment area [m^2]	Discharge [m^3/day]	Discharge [m^3/s]	Width spillway [m]
300	2,034,425	610,328	7	12

Table 7.22 Spillway characteristics reservoir 8

7.6.3 Total investment costs

Below the costs per cubic meter per economic lifetime is plotted against the reservoir height. Besides this the total costs are plotted in the same figure. The total costs are split up in investment costs (direct costs) and maintenance costs.

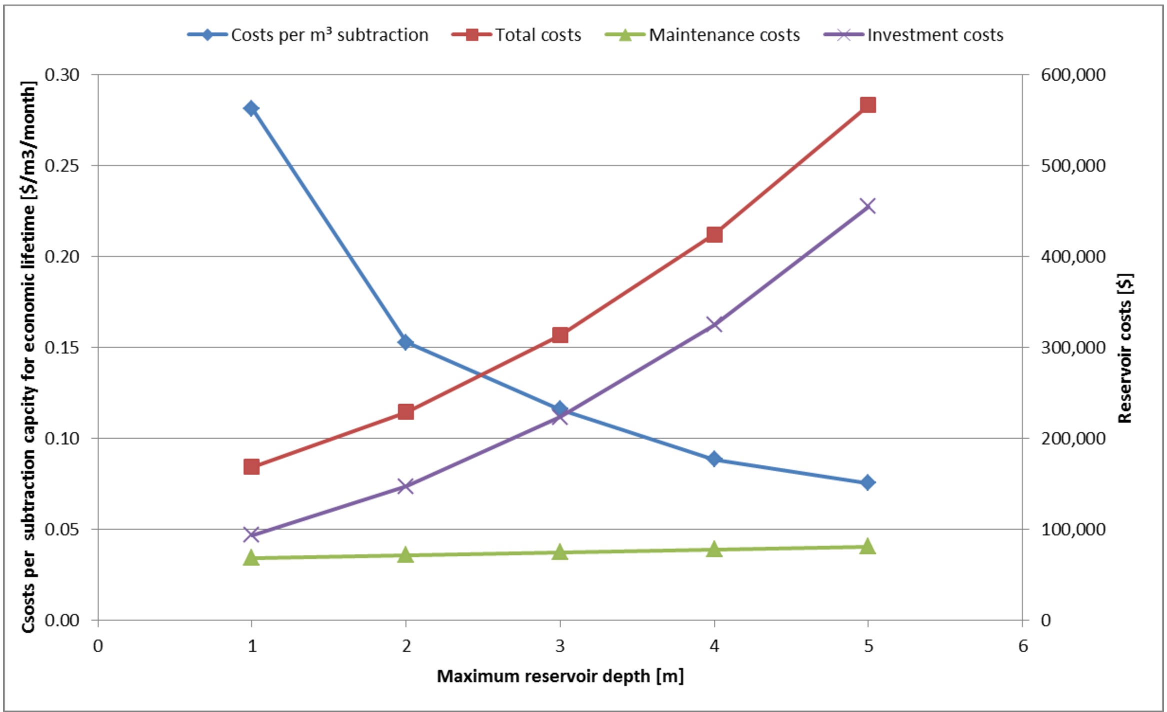


Figure 7.25 Reservoir 8 cost overview and costs per m³ per economic lifetime

The total costs are plotted with the fulfilling water demand.

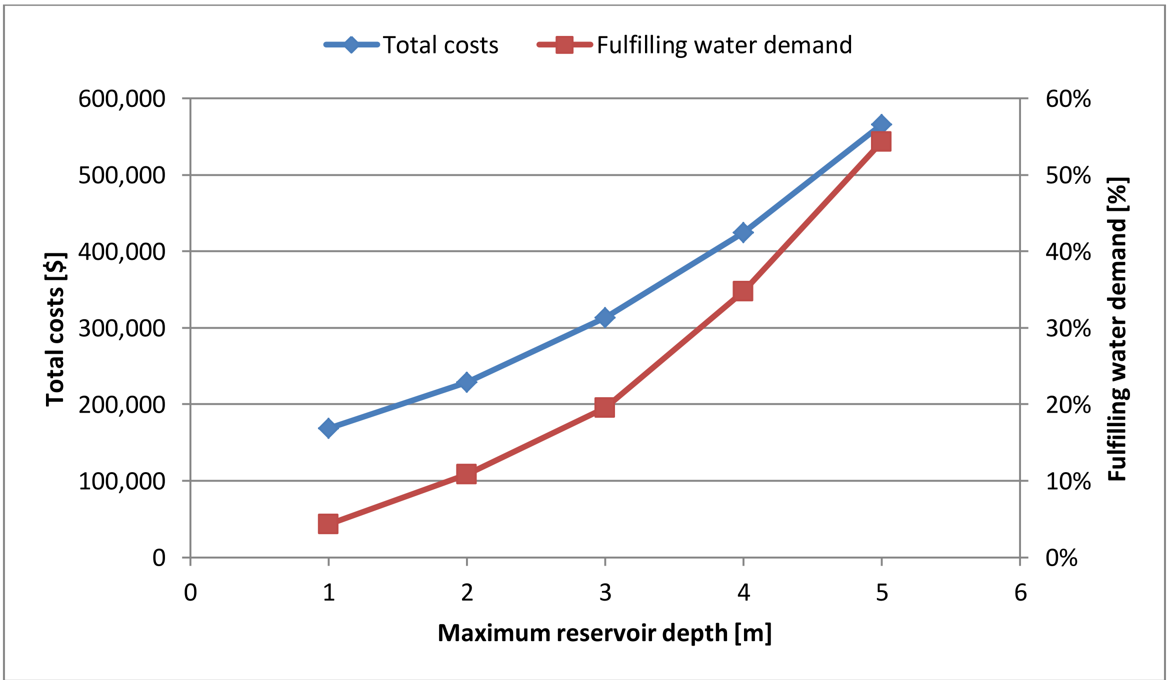


Figure 7.26 Reservoir 8 cost overview and fulfilling water demand per water level

In Table 7.23 a structured overview is given for the total costs, costs per cubic meter and the costs per cubic meter per lifetime subtraction. Maintenance costs increase slightly (factor 1.05) when the water level increases. This is done, because a larger reservoir has higher maintenance costs.

Water depth [m]	Subtraction capacity [m^3/month]	Subtraction / total water demand [%]	Dam volume [m^3]	Total direct cost [$]	Maintenance costs [$]	Total costs [$]	Costs/m^3/lifetime subtraction capacity [$]	Direct cost per m^3 dam volume [$]	Total cost per m^3 dam volume [$]
1	2,000	4%	2,409	93,914	68,694	168,751	0.28	39.0	70.1
2	5,000	11%	4,844	147,547	71,816	229,016	0.15	30.5	47.3
3	9,000	20%	8,384	223,490	74,938	313,049	0.12	26.7	37.3
4	16,000	35%	13,189	324,824	78,061	424,135	0.09	24.6	32.2
5	25,000	54%	19,429	454,984	81,183	565,932	0.08	23.4	29.1

Table 7.23 Reservoir 8 cost overview

7.6.4 Remarks

This reservoir has some remarks that will eventually influence the usability or total costs for this reservoir. These remarks are only comments and are not taken into account in the cost calculation. For the eventual reservoir selection these remarks need to be considered.

- The reservoir could be larger but would exceed the boundary of the farm. The dam is now placed directly on the border of the farm.
- The water level of the abattoir (biggest water consumer) exceeds the elevation of the reservoir. Pumps are needed to pump the water to the abattoir.
- Near this reservoir an international school (Ebenezer college) is in use. Safety measures should be considered.
- The school exceeds the elevation of the dam site. For proper instruction a reservoir needs to make use of gravity flow. Therefore another dam site should be considered or the land for irrigation should be reconsidered. Therefore extra land needs to be bought.

7.7 Reservoir 9

To make an impression about the location, size and distances to nearby objects it is important to visualize the reservoir. In Figure 7.27 the location for the reservoir and the extent of the reservoir with the maximum water level is shown. After this some general dam and reservoir characteristics are showed. Secondly the water balance is made in order to determine the maximum allowable subtraction. Afterwards the spillway is calculated in order to give an accurate estimation for the spillway dimensions. This will be integrated in the reservoir costs. As a final result the costs can be determined for each reservoir.

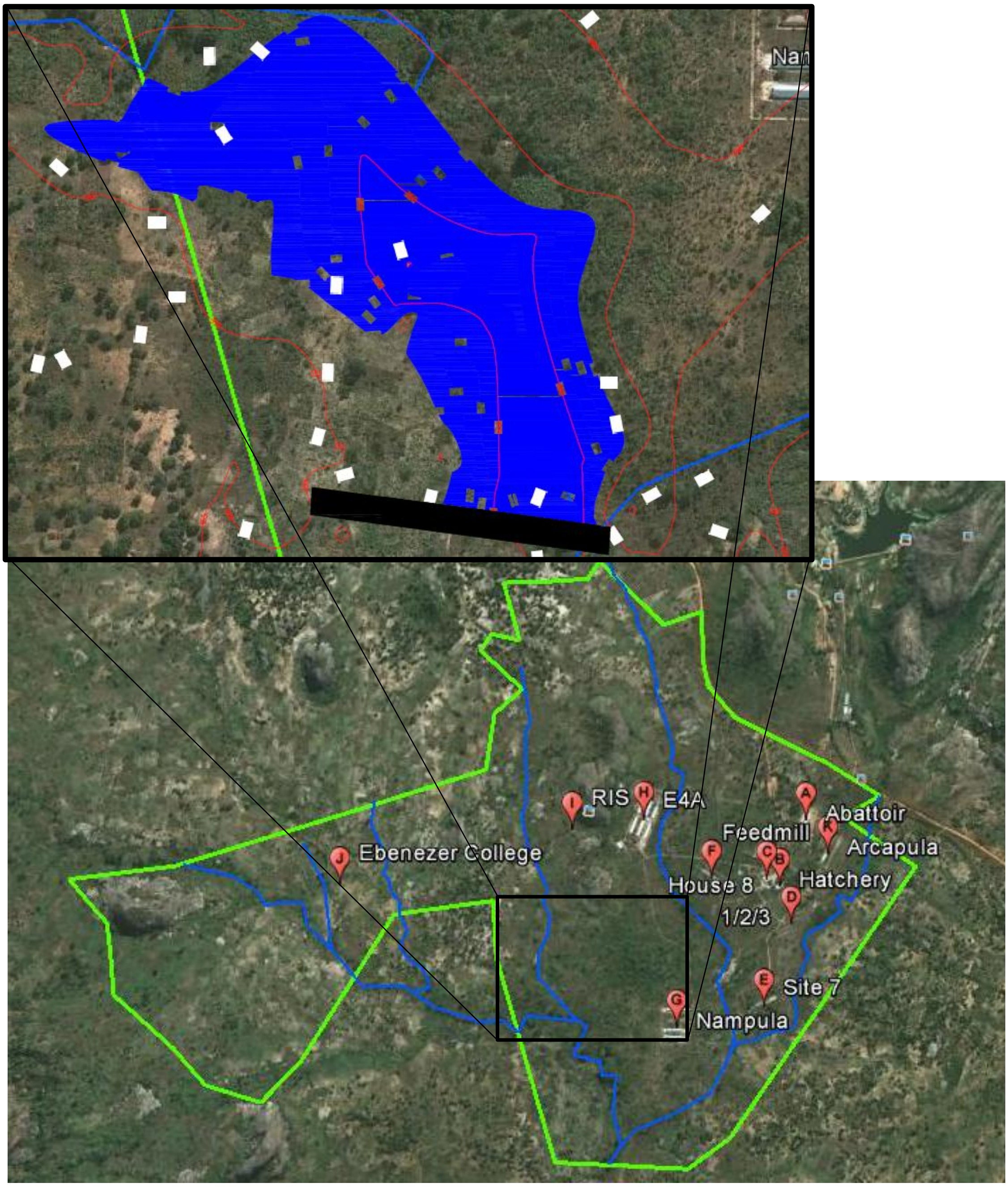


Figure 7.27 Reservoir 9, maximum water level 4 m, dam height 6 m

7.7.1 Dam- and reservoir characteristics

The general dam and reservoir characteristics are shown in Table 7.24. The mean annual runoff for this reservoir is 1,417,674m^3/year.

Water depth [m]	Dam height [m]	Dam length [m]	Maximum dam width [m]	Reservoir perimeter [m]	Reservoir area [m^2]	Storage capacity [m^3]	Subtraction capacity [m^3/month]	Storage ratio [-]
1	3	143	20	1,199	42,270	38,043	13,000	0.03
2	4	176	27	1,398	65,827	92,092	22,000	0.06
3	5	253	33	1,736	104,615	177,313	35,000	0.13
4	6	355	39	2,197	159,199	309,220	54,000	0.22

Table 7.24 Dam and reservoir characteristics reservoir 9

The height, relative heights and crow flies distances to the reservoir are shown in Table 7.25.

	Reservoir	Ebenezer	Abattoir	Hatchery	RIS	E4A	Feed mill
Height [m]	350	361	376	369	373	370	372
Relative height [m]	0	-11	-26	-19	-23	-20	-22
Length [m]	0	1,809	1,849	1,509	1,497	1,512	1,501

Table 7.25 Elevation level and distances to users relative to reservoir 9

With the use of the water balance the maximum subtraction capacity per month is shown in Figure 7.28.

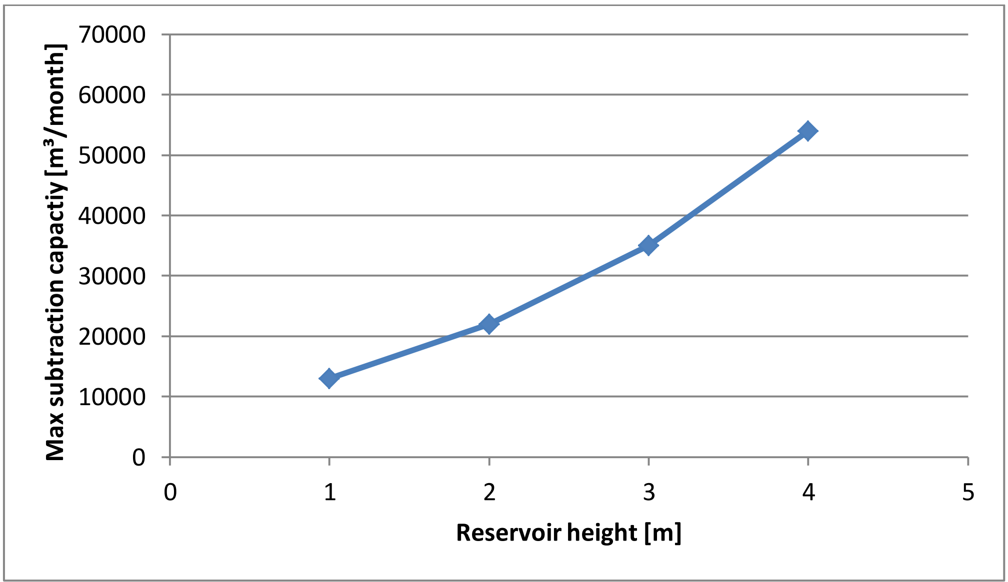


Figure 7.28 Reservoir 9 Subtraction capacity

7.7.2 Spillway

The spillway characteristics for reservoir 9 are shown in Table 7.26.

Probable Maximum Flood [mm]	Catchment area [m^2]	Discharge [m^3/day]	Discharge [m^3/s]	Width spillway [m]
300	4,407,854	132,235,6	15	25

Table 7.26 Spillway characteristics reservoir 9

7.7.3 Total investment costs

Below the costs per cubic meter per economic lifetime is plotted against the reservoir height. Besides this the total costs are plotted in the same figure. The total costs are split up in investment costs (direct costs) and maintenance costs.

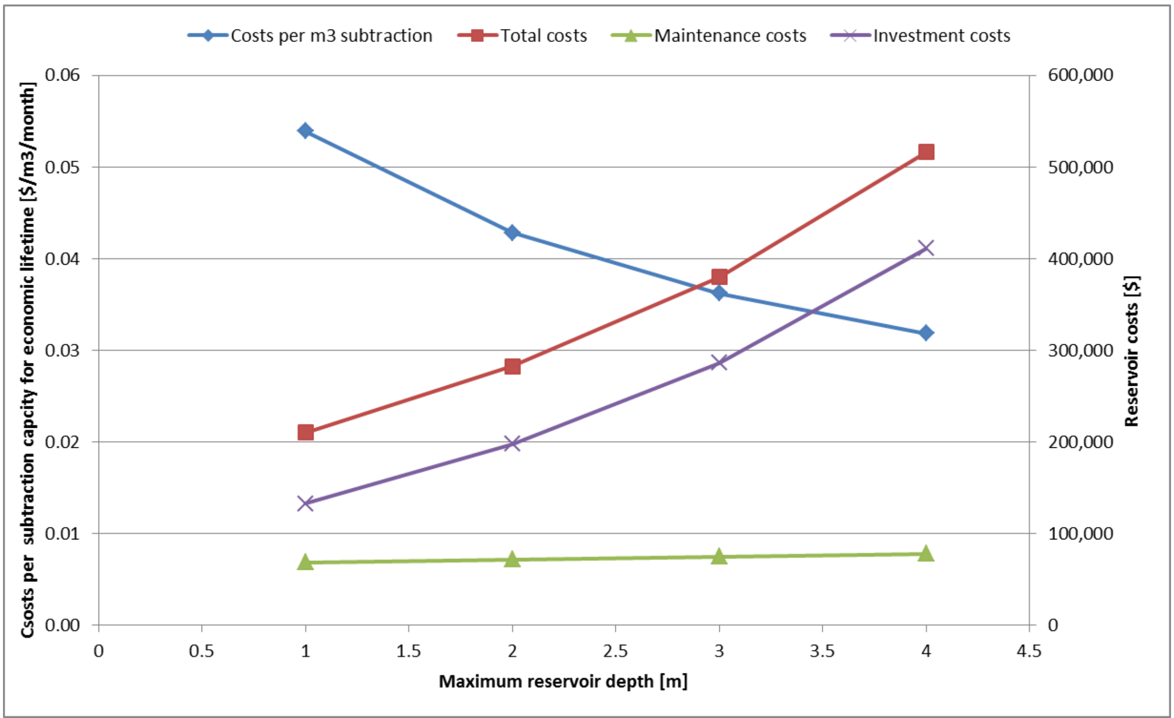


Figure 7.29 Reservoir 9 cost overview and costs per m^3 per economic lifetime

The total costs are plotted with the fulfilling water demand.

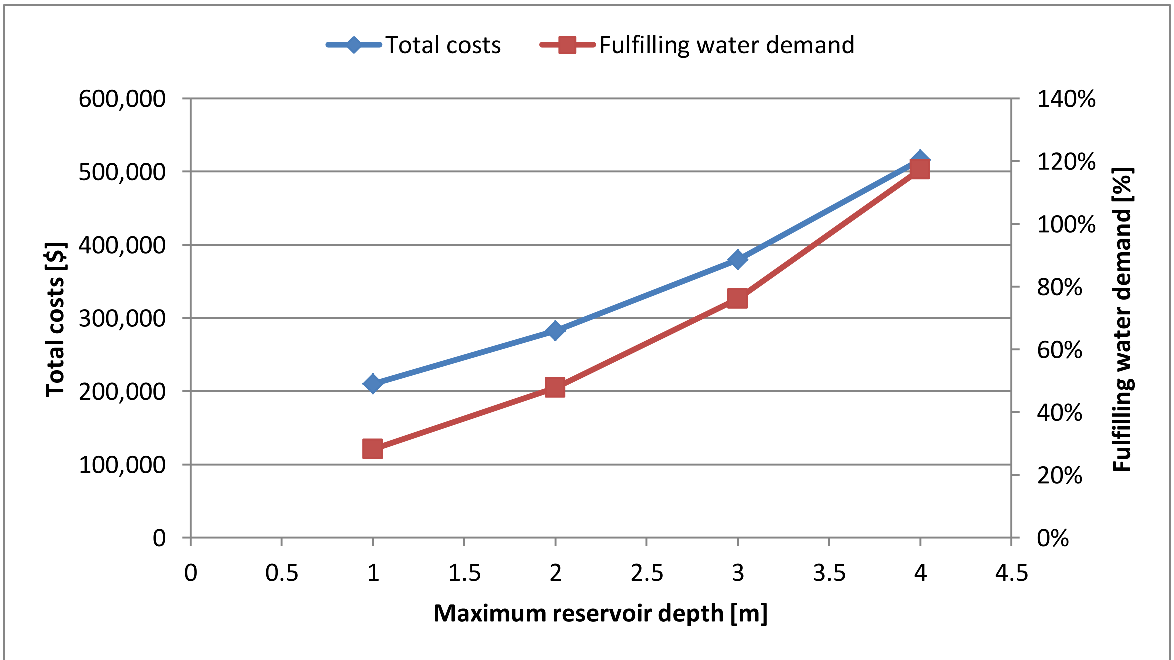


Figure 7.30 Reservoir 9 cost overview and fulfilling water demand per water level

In Table 7.27 a structured overview is given for the total costs, costs per cubic meter and the costs per cubic meter per lifetime subtraction. Maintenance costs increase slightly (factor 1.05) when the water level increases. This is done, because a larger reservoir has higher maintenance costs.

Water depth [m]	Subtraction capacity [m^3/month]	Subtraction / total water demand [%]	Dam volume [m^3]	Total direct cost [$]	Maintenance costs [$]	Total costs [$]	Costs/m^3/lifetime subtraction capacity [$]	Direct cost per m^3 dam volume [$]	Total cost per m^3 dam volume [$]
1	13,000	28%	4,079	132,753	68,694	210,132	0.05	32.54	51.51
2	22,000	48%	7,108	197,955	71,816	282,721	0.04	27.85	39.78
3	35,000	76%	11,277	286,370	74,938	380,043	0.04	25.39	33.70
4	54,000	117%	17,047	411,075	78,061	516,028	0.03	24.11	30.27

Table 7.27 Reservoir 9 cost overview

7.7.4 Remarks

This reservoir has some remarks that will eventually influence the usability or total costs for this reservoir. These remarks are only comments and are not taken into account in the cost calculation. For the eventual reservoir selection these remarks need to be considered.

- The total reservoir surface exceeds the boundary of the farm. Extra land has to be bought. These extra costs have to be taken into account.
- The water level of the abattoir (biggest water consumer) exceeds the elevation of the reservoir. Pumps are needed to pump the water to the abattoir.

7.8 Reservoir 10

To make an impression about the location, size and distances to nearby objects it is important to visualize the reservoir. In Figure 7.31 the location of the reservoir and the extent of the reservoir with the maximum water level is shown. After this some general dam and reservoir characteristics are showed. Secondly the water balance is made in order to determine the maximum allowable subtraction. Afterwards the spillway is calculated in order to give an accurate estimation for the spillway dimensions. This will be integrated in the reservoir costs. As a final result the costs can be determined for each reservoir.

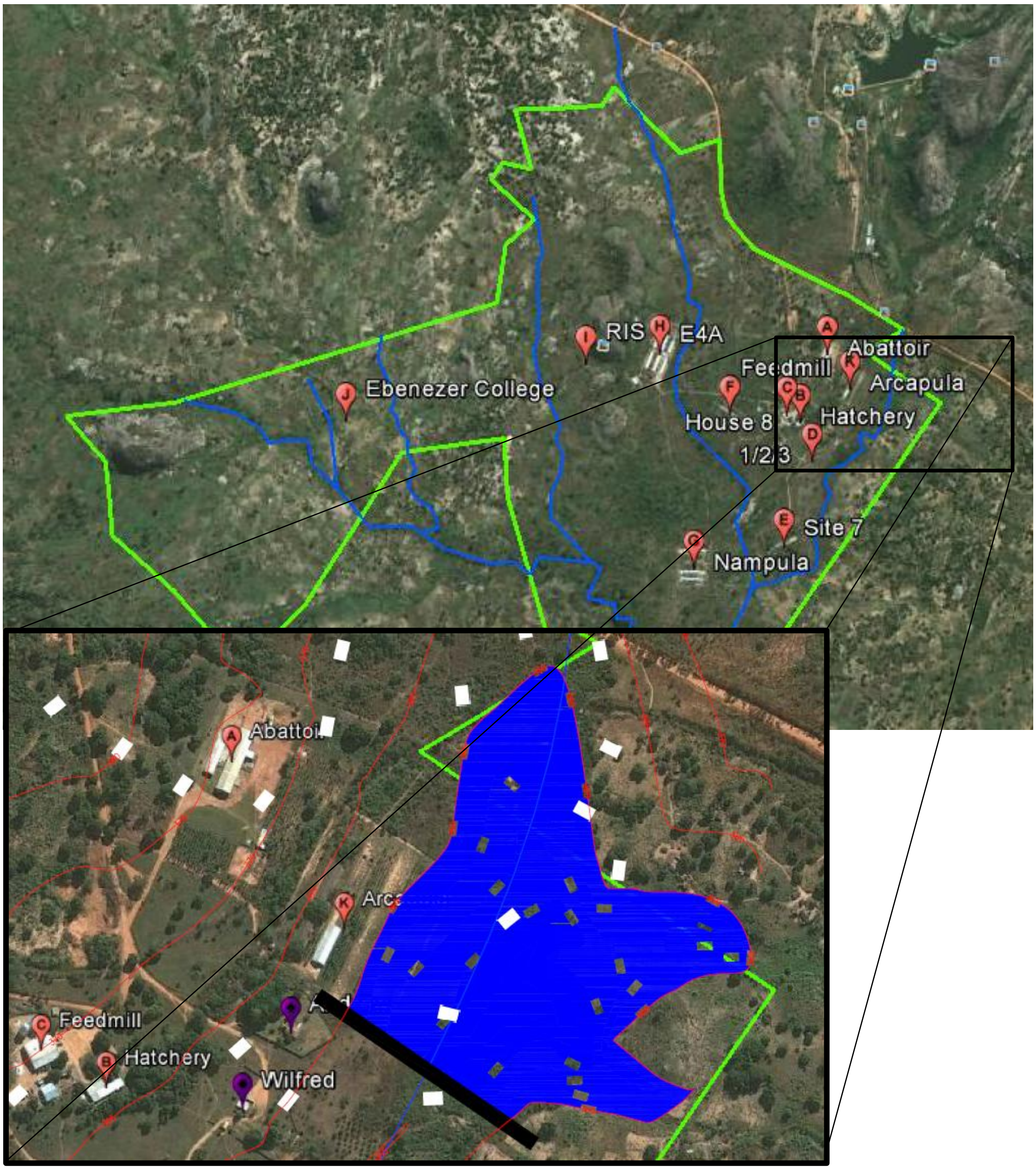


Figure 7.31 Reservoir 10, maximum water level 5 m, dam height 7 m

The position of the dam is quite accurate. However slight position changes should be considered when the terrain requires this.

7.8.1 Dam and reservoir characteristics

The general dam and reservoir characteristics are shown in Table 7.28. The mean annual runoff for this reservoir is 301,082m^3/year.

Water depth [m]	Dam height [m]	Dam length [m]	Maximum dam width [m]	Reservoir perimeter [m]	Reservoir area [m^2]	Storage capacity [m^3]	Subtraction capacity [m^3/month]	Storage ratio [-]
1	3	129	20	560	11,689	10,520	6,000	0.03
2	4	170	27	689	20,253	26,491	8,000	0.09
3	5	205	33	924	40,047	56,641	13,000	0.19
4	6	237	39	1,291	65,642	109,486	19,000	0.36
5	7	280	46	1,545	96,744	190,679	28,000	0.63

Table 7.28 Dam and reservoir characteristics reservoir 10

The height, relative heights and crow flies distances to the reservoir are shown in Table 7.29.

	Reservoir	Ebenezer	Abattoir	Hatchery	RIS	E4A	Feed mill
Height [m]	356	361	376	369	373	370	372
Relative height [m]	0	-5	-20	-13	-17	-14	-16
Length [m]	0	2,545	459	324	1,417	1,098	398

Table 7.29 Elevation level and distances to users relative to reservoir 10

With the use of the water balance the maximum subtraction capacity per month is shown in Figure 7.32.

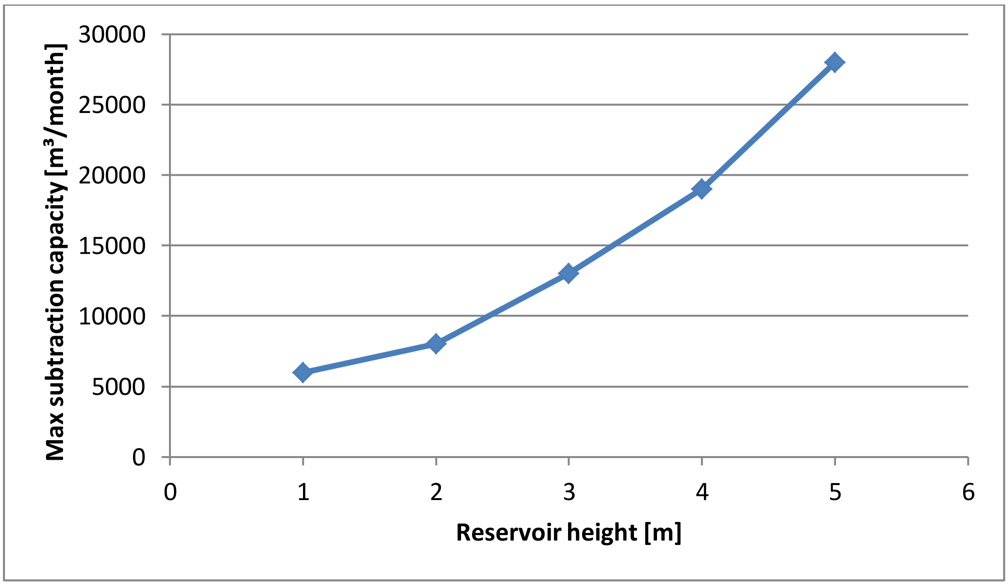


Figure 7.32 Subtraction capacity reservoir 10

7.8.2 Spillway

The spillway characteristics for reservoir 10 are shown in Table 7.30.

Probable Maximum Flood [mm]	Catchment area [m²]	Discharge [m³/day]	Discharge [m³/s]	Width spillway [m]
300	936,130	280,839	3	5

Table 7.30 Spillway characteristics reservoir 10

7.8.3 Total investment costs

Below the costs per cubic meter per economic lifetime is plotted against the reservoir height. Besides this the total costs are plotted in the same figure. The total costs are split up in investment costs (direct costs) and maintenance costs.

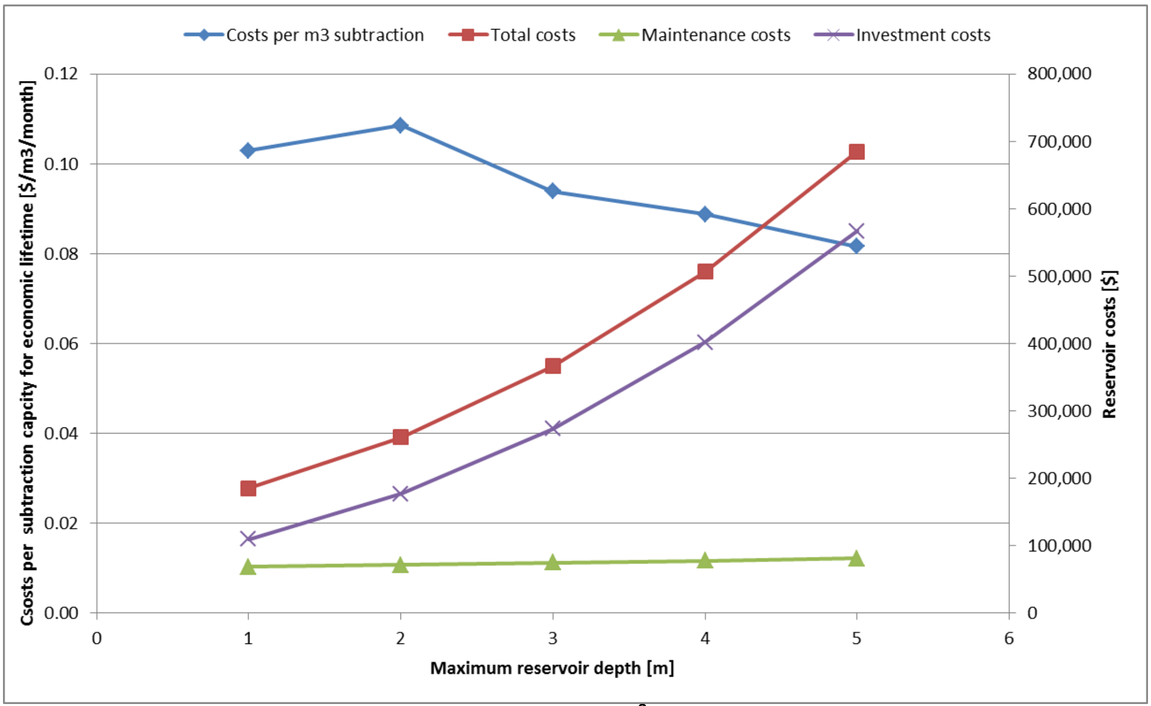


Figure 7.33 Reservoir 10 cost overview and costs per m^3 per economic lifetime

The total costs are plotted with the fulfilling water demand.

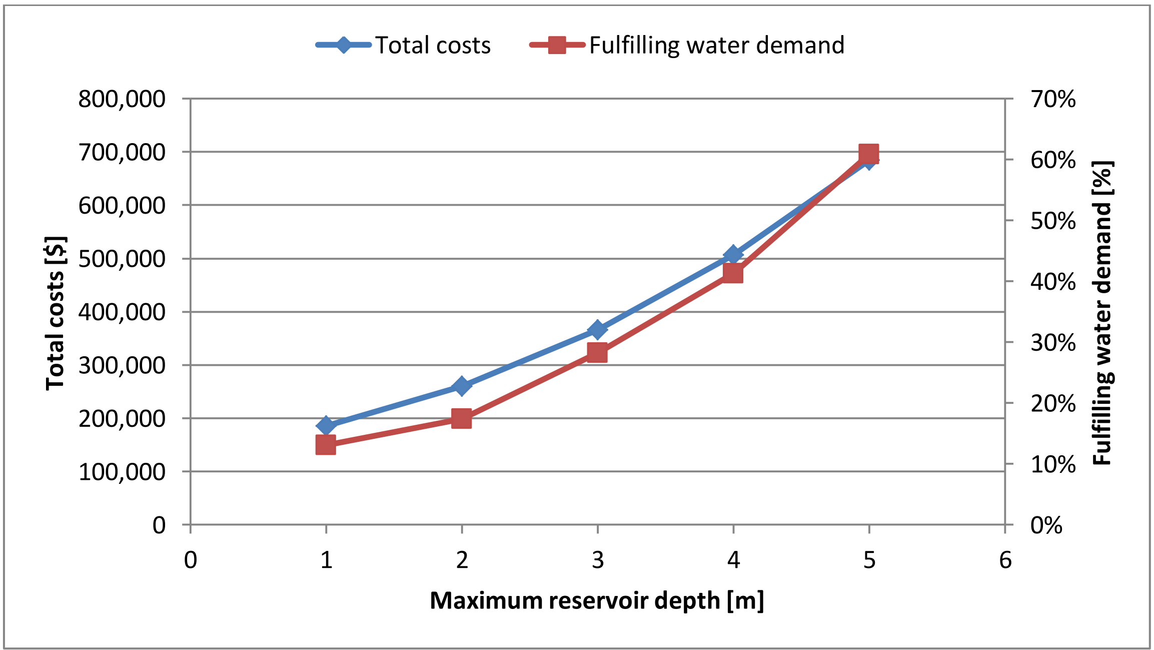


Figure 7.34 Reservoir 10 cost overview and fulfilling water demand per water level

In Table 7.31 a structured overview is given for the total costs, costs per cubic meter and the costs per cubic meter per lifetime subtraction. Maintenance costs increase slightly (factor 1.05) when the water level increases. This is done, because a larger reservoir has higher maintenance costs.

Water depth [m]	Subtraction capacity [m^3/month]	Subtraction / total water demand [%]	Dam volume [m^3]	Total direct cost [$]	Maintenance costs [$]	Total costs [$]	Costs/m^3/lifetime subtraction capacity [$]	Direct cost per m^3 dam volume [$]	Total cost per m^3 dam volume [$]
1	6,000	13%	3,037	109,376	68,694	185,225	0.10	36.01	60.98
2	8,000	17%	6,114	177,182	71,816	260,590	0.11	28.98	42.62
3	13,000	28%	10,595	273,331	74,938	366,151	0.09	25.80	34.56
4	19,000	41%	16,683	401,763	78,061	506,108	0.09	24.08	30.34
5	28,000	61%	24,591	566,668	81,183	684,923	0.08	23.04	27.85

Table 7.31 Reservoir 10 cost overview

7.8.4 Remarks

This reservoir has some remarks that will eventually influence the usability or total costs for this reservoir. These remarks are only comments and are not taken into account in the cost calculation. For the eventual reservoir selection these remarks need to be considered.

- The total reservoir surface exceeds the boundary of the farm. Extra land has to be bought. These extra costs have to be taken into account.
- The water level of the abattoir (biggest water consumer) exceeds the elevation of the reservoir. Pumps are needed to pump the water to the abattoir.
- At the same position of the newly positioned dam an existing dam has been build. In the costs it has not been taken into account that this dam is already here. Also a part of this reservoir needs some sediment removal, because the existing reservoir has been silted.
- The water level comes close to the main road. Because it is a main road a higher hazard class need have to be considered.
- The Arcapula chicken houses come very close to the reservoir. To avoid spreading chicken deceases, the Arcapula chicken houses should be moved. These costs need to be taken into account.
- Two houses are close to the reservoir. When failing of the dam occurs it can have major consequences for the people there.
- Downstream, close to the river, Chicken houses are in use. They can be negatively affected when failing of the dam occurs.

7.9 Reservoir 12 (alternative 1)

To make an impression about the location, size and distances to nearby objects it is important to visualize the reservoir. In Figure 7.35 the location for the reservoir and the extent of the reservoir with the maximum water level is shown. After this some general dam and reservoir characteristics are showed. Secondly the water balance is made in order to determine the maximum allowable subtraction. Afterwards the spillway is calculated in order to give an accurate estimation for the spillway dimensions. This will be integrated in the reservoir costs. As a final result the costs can be determined for each reservoir. Alternative 1 is the medium alternative for the reservoir 12 site.

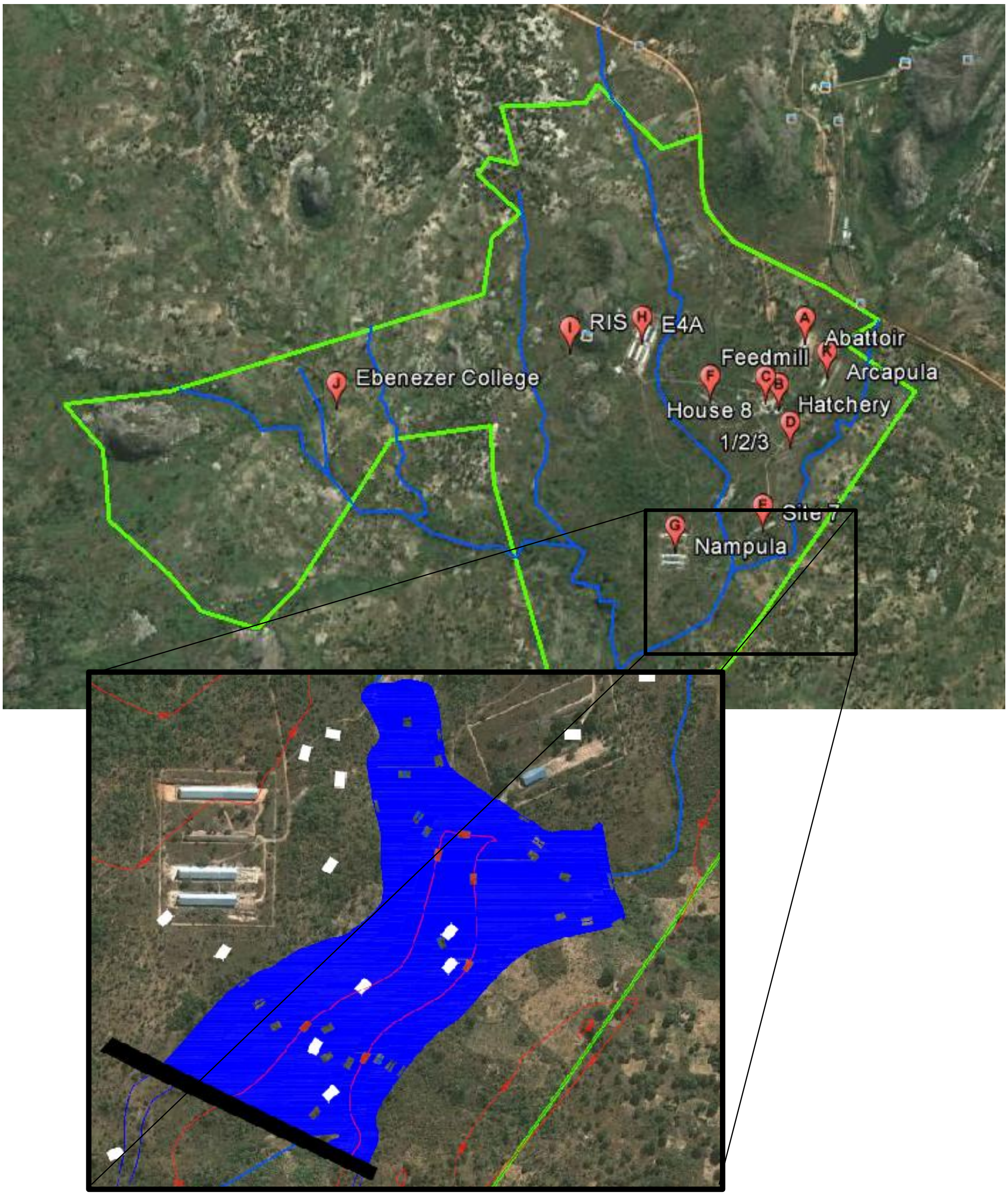


Figure 7.35 Reservoir 12 alternative 1, maximum water level 5 m, dam height 7 m

7.9.1 Dam- and reservoir characteristics

The general dam and reservoir characteristics are shown in Table 7.32. The mean annual runoff for this reservoir is 1,898,270m^3/year.

Water depth [m]	Dam height [m]	Dam length [m]	Maximum dam width [m]	Reservoir perimeter [m]	Reservoir area [m^2]	Storage capacity [m^3]	Subtraction capacity [m^3/month]	Storage ratio [-]
1	3	186	20	400	6,737	6,063	8,000	0.00
2	4	222	27	894	16,164	17,514	11,000	0.01
3	5	267	33	1,268	40,506	45,849	18,000	0.02
4	6	311	39	1,502	74,427	103,315	28,000	0.05
5	7	356	46	1,656	102,505	191,781	42,000	0.10
6	8	400	52	2,078	148,133	317,100	61,000	0.17

Table 7.32 Dam and reservoir characteristics reservoir 12 alternative 1

The height, relative heights and crow flies distances to the reservoir are shown in Table 7.33.

	Reservoir	Ebenezer	Abattoir	Hatchery	RIS	E4A	Feed mill
Height [m]	348	361	376	369	373	370	372
Relative height [m]	0	-13	-28	-21	-25	-22	-24
Length [m]	0	2,089	1,496	1,151	1,470	1,362	1,161

Table 7.33 Elevation level and distances to users relative to reservoir 12 alternative 1

With the use of the water balance the maximum subtraction capacity per month is shown in Figure 7.36.

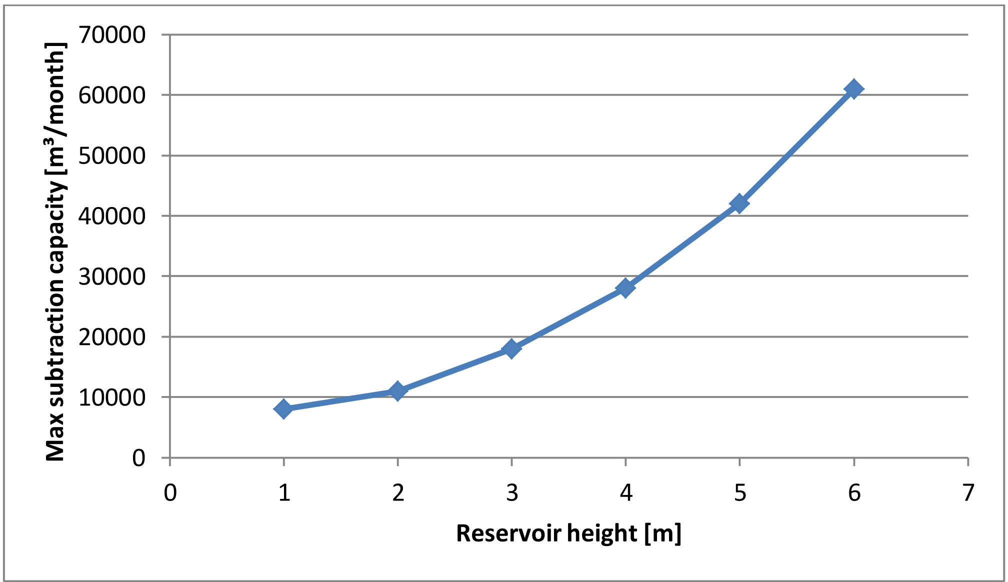


Figure 7.36 Reservoir 12 alternative 1 subtraction capacity

7.9.2 Spillway

The spillway characteristics for reservoir 12 alternative 1 are shown in Table 7.34.

Probable Maximum Flood [mm]	Catchment area [m^2]	Discharge [m^3/day]	Discharge [m^3/s]	Width spillway [m]
300	5,902,130	177,063,9	20	34

Table 7.34 Spillway characteristics reservoir 12 alternative 1

7.9.3 Total investment costs

Below the costs per cubic meter per economic lifetime is plotted against the reservoir height. Besides this the total costs are plotted in the same figure. The total costs are split up in investment costs (direct costs) and maintenance costs.

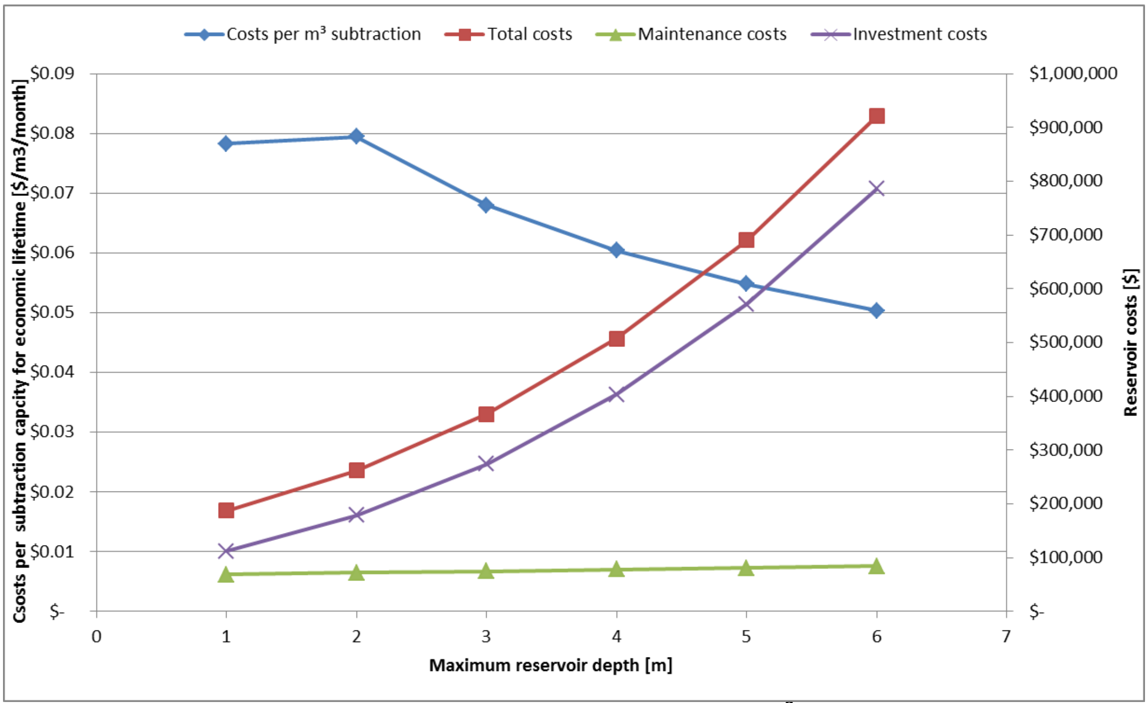


Figure 7.37 Reservoir 12 alternative 1 cost overview and costs per m^3 per economic lifetime

The total costs are plotted with the fulfilling water demand.

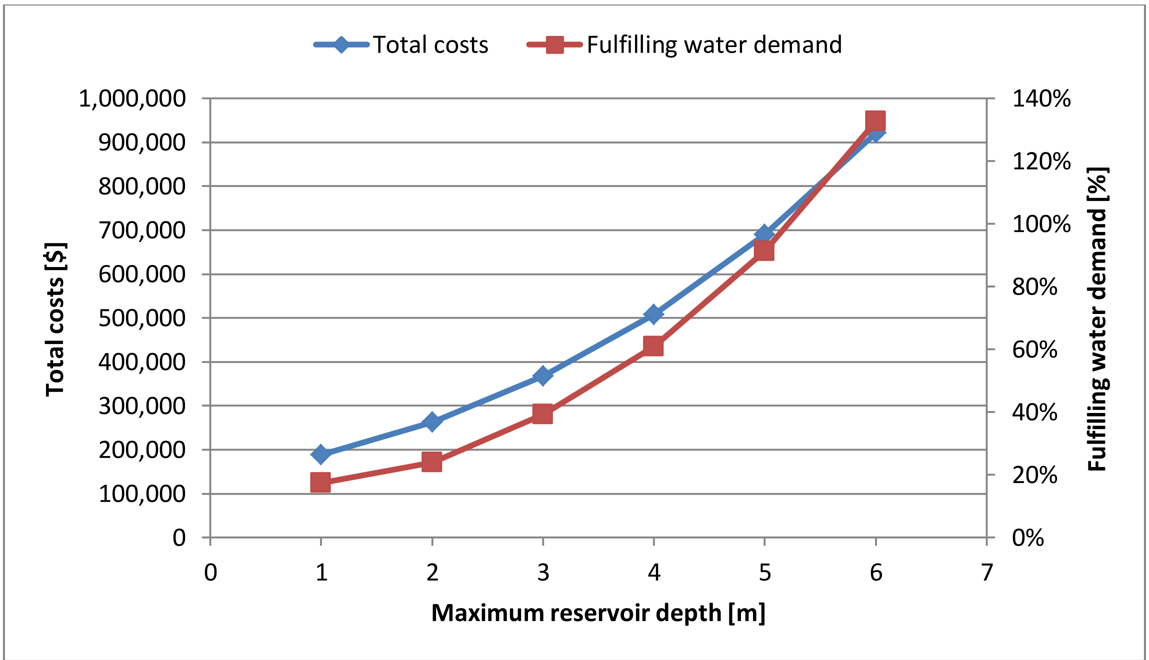


Figure 7.38 Reservoir 12 alternative 1 cost overview and fulfilling water demand per water level

In Table 7.35 a structured overview is given for the total costs, costs per cubic meter and the costs per cubic meter per lifetime subtraction. Maintenance costs increase slightly (factor 1.05) when the water level increases. This is done, because a larger reservoir has higher maintenance costs.

Water depth [m]	Subtraction capacity [m^3/month]	Subtraction / total water demand [%]	Dam volume [m^3]	Total direct cost [$]	Maintenance costs [$]	Total costs [$]	Costs/m^3/lifetime subtraction capacity [$]	Direct cost per m^3 dam volume [$]	Total cost per m^3 dam volume [$]
1	8,000	17%	2,957	111,768	68,694	187,773	0.08	37.80	63.50
2	11,000	24%	5,981	178,551	71,816	262,048	0.08	29.85	43.82
3	18,000	39%	10,420	274,100	74,938	366,971	0.07	26.30	35.22
4	28,000	61%	16,517	403,196	78,061	507,634	0.06	24.41	30.73
5	42,000	91%	24,545	571,439	81,183	690,006	0.05	23.28	28.11
6	61,000	133%	34,832	785,365	84,306	921,050	0.05	22.55	26.44

Table 7.35 Reservoir 12 alternative 1 cost overview

7.9.4 Remarks

This reservoir has some remarks that will eventually influence the usability or total costs for this reservoir. These remarks are only comments and are not taken into account in the cost calculation. For the eventual reservoir selection these remarks need to be considered.

- The water level of the abattoir (biggest water consumer) exceeds the elevation of the reservoir. Pumps are needed to pump the water to the abattoir.
- The chicken houses come very close to the reservoir. To avoid spreading chicken deceases, the chicken houses should be moved. These costs need to be taken into account.

7.10 Reservoir 12 (alternative 2)

To make an impression about the location, size and distances to nearby objects it is important to visualize the reservoir. In Figure 7.39 the location for the reservoir and the extent of the reservoir with the maximum water level is shown. After this some general dam and reservoir characteristics are showed. Secondly the water balance is made in order to determine the maximum allowable subtraction. Afterwards the spillway is calculated in order to give an accurate estimation for the spillway dimensions. This will be integrated in the reservoir costs. As a final result the costs can be determined for each reservoir. Alternative 2 is the large alternative for the reservoir 12 site.

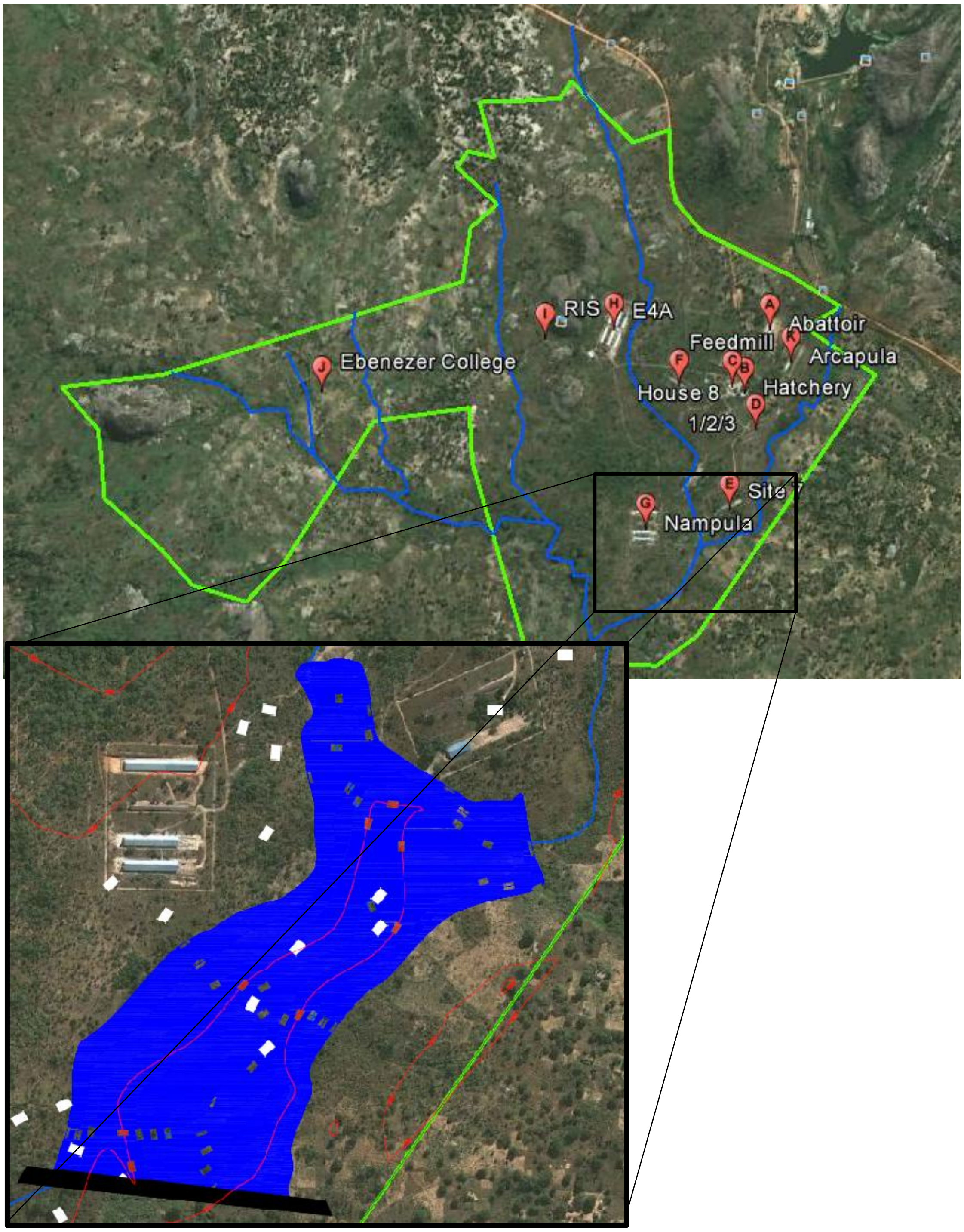


Figure 7.39 Reservoir 12 alternative 2, maximum water level 5 m, dam height 7 m, elevation 349 m

The position of the dam is quite accurate. However slight position changes should be considered when the terrain requires this.

7.10.1 Dam- and reservoir characteristics

The general dam and reservoir characteristics are shown in Table 7.36. The mean annual runoff for this reservoir is 1,989,270m^3/year.

Water depth [m]	Dam height [m]	Dam length [m]	Maximum dam width [m]	Reservoir perimeter [m]	Reservoir area [m^2]	Storage capacity [m^3]	Subtraction capacity [m^3/month]	Storage ratio [-]
1	3	252	20	1,165	41,795	37,616	16,000	0.02
2	4	293	27	1,561	71,050	94,038	26,000	0.05
3	5	336	33	1,867	115,774	187,450	41,000	0.10
4	6	381	39	2,013	149,110	319,892	62,000	0.17
5	7	427	46	2,433	201,354	495,124	85,000	0.26

Table 7.36 Dam and reservoir characteristics reservoir 12 alternative 2

The height, relative heights and crow flies distances to the reservoir are shown in Table 7.37.

	Reservoir	Ebenezer	Abattoir	Hatchery	RIS	E4A	Feed mill
Height [m]	350	361	376	369	373	370	372
Relative height [m]	0	-11	-26	-19	-23	-20	-22
Length [m]	0	2,120	1,730	1,381	1,629	1,600	1,391

Table 7.37 Elevation level and distances to users relative to reservoir 12 alternative 2

With the use of the water balance the maximum subtraction capacity per month is shown in Figure 7.40.

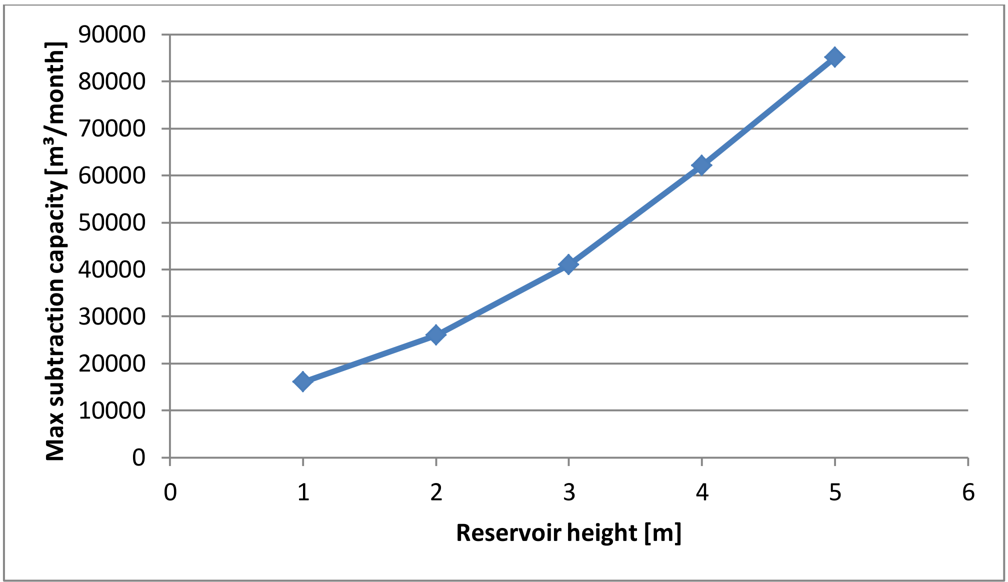


Figure 7.40 Reservoir 12 alternative 2 subtraction capacity

7.10.2 Spillway

The spillway characteristics for reservoir 12 alternative 2 are shown in Table 7.38.

Probable Maximum Flood [mm]	Catchment area [m²]	Discharge [m³/day]	Discharge [m³/s]	Width spillway [m]
300	5,902,130	177,063,9	20	34

Table 7.38 Spillway characteristics reservoir 12 alternative 2

7.10.3 Total investment costs

Below the costs per cubic meter per economic lifetime is plotted against the reservoir height. Besides this the total costs are plotted in the same figure. The total costs are split up in investment costs (direct costs) and maintenance costs.

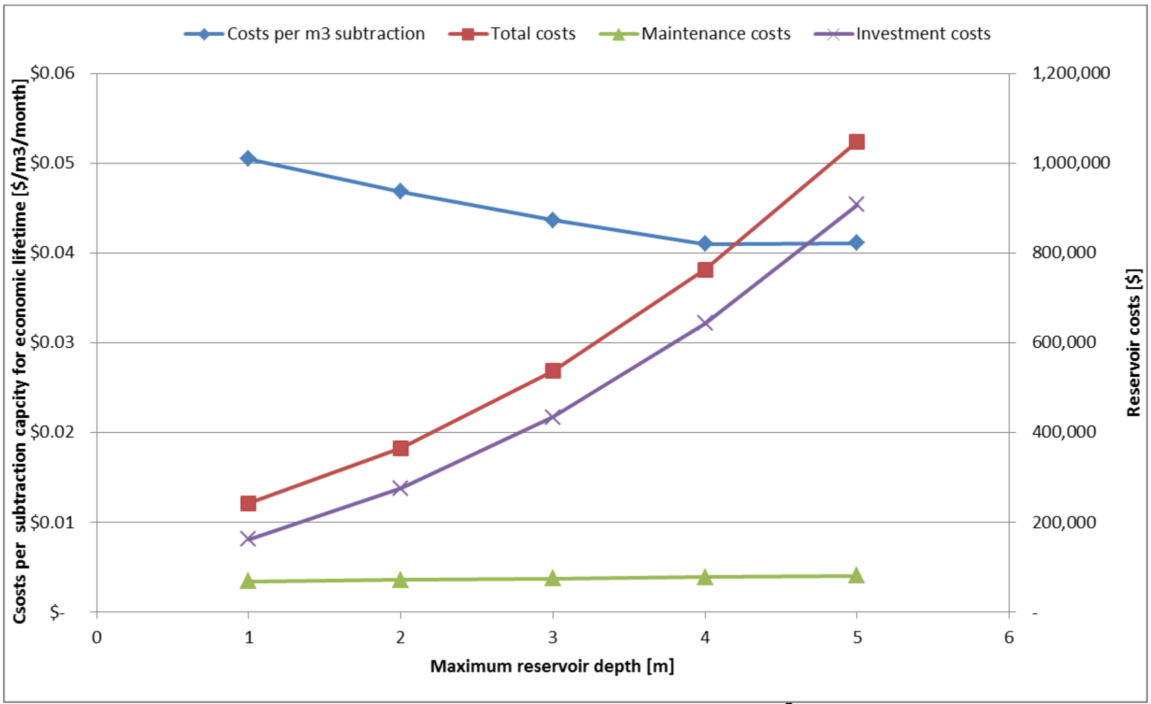


Figure 7.41 Reservoir 12 alternative 2 cost overview and costs per m^3 per economic lifetime

The total costs are plotted with the fulfilling water demand.

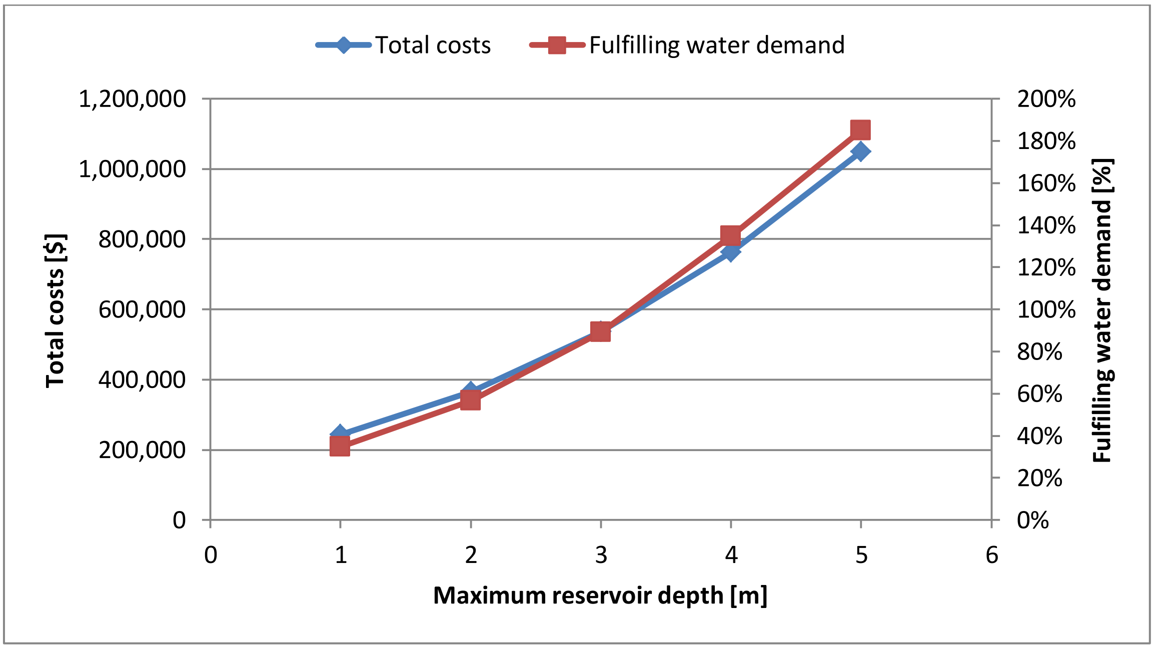


Figure 7.42 Reservoir 12 alternative 2 cost overview and fulfilling water demand per water level

In Table 7.39 a structured overview is given for the total costs, costs per cubic meter and the costs per cubic meter per lifetime subtraction. Maintenance costs increase slightly (factor 1.05) when the water level increases. This is done, because a larger reservoir has higher maintenance costs.

Water depth [m]	Subtraction capacity [m^3/month]	Subtraction / total water demand [%]	Dam volume [m^3]	Total direct cost [$]	Maintenance costs [$]	Total costs [$]	Costs/m^3/lifetime subtraction capacity [$]	Direct cost per m^3 dam volume [$]	Total cost per m^3 dam volume [$]
1	16,000	35%	5,105	162,897	68,694	242,248	0.05	31.91	47.45
2	26,000	57%	10,225	275,453	71,816	365,289	0.05	26.94	35.72
3	41,000	89%	17,618	433,652	74,938	536,960	0.04	24.61	30.48
4	62,000	135%	27,564	642,764	78,061	762,875	0.04	23.32	27.68
5	85,000	185%	40,329	907,771	81,183	1,048,341	0.04	22.51	25.99

Table 7.39 Reservoir 12 alternative 2 cost overview

7.10.4 Remarks

This reservoir has some remarks that will eventually influence the usability or total costs for this reservoir. These remarks are only comments and are not taken into account in the cost calculation. For the eventual reservoir selection these remarks need to be considered.

- The water level of the abattoir (biggest water consumer) exceeds the elevation of the reservoir. Pumps are needed to pump the water to the abattoir.
- The chicken houses come very close to the reservoir. To avoid spreading chicken deceases, the chicken houses should be moved. These costs need to be taken into account.

7.11 Reservoir 12 (alternative 3)

To make an impression about the location, size and distances to nearby objects it is important to visualize the reservoir. In Figure 7.43 the location for the reservoir and the extent of the reservoir with the maximum water level is shown. After this some general dam and reservoir characteristics are showed. Secondly the water balance is made in order to determine the maximum allowable subtraction. Afterwards the spillway is calculated in order to give an accurate estimation for the spillway dimensions. This will be integrated in the reservoir costs. As a final result the costs can be determined for each reservoir. Alternative 3 is the small alternative for the reservoir 12 site.

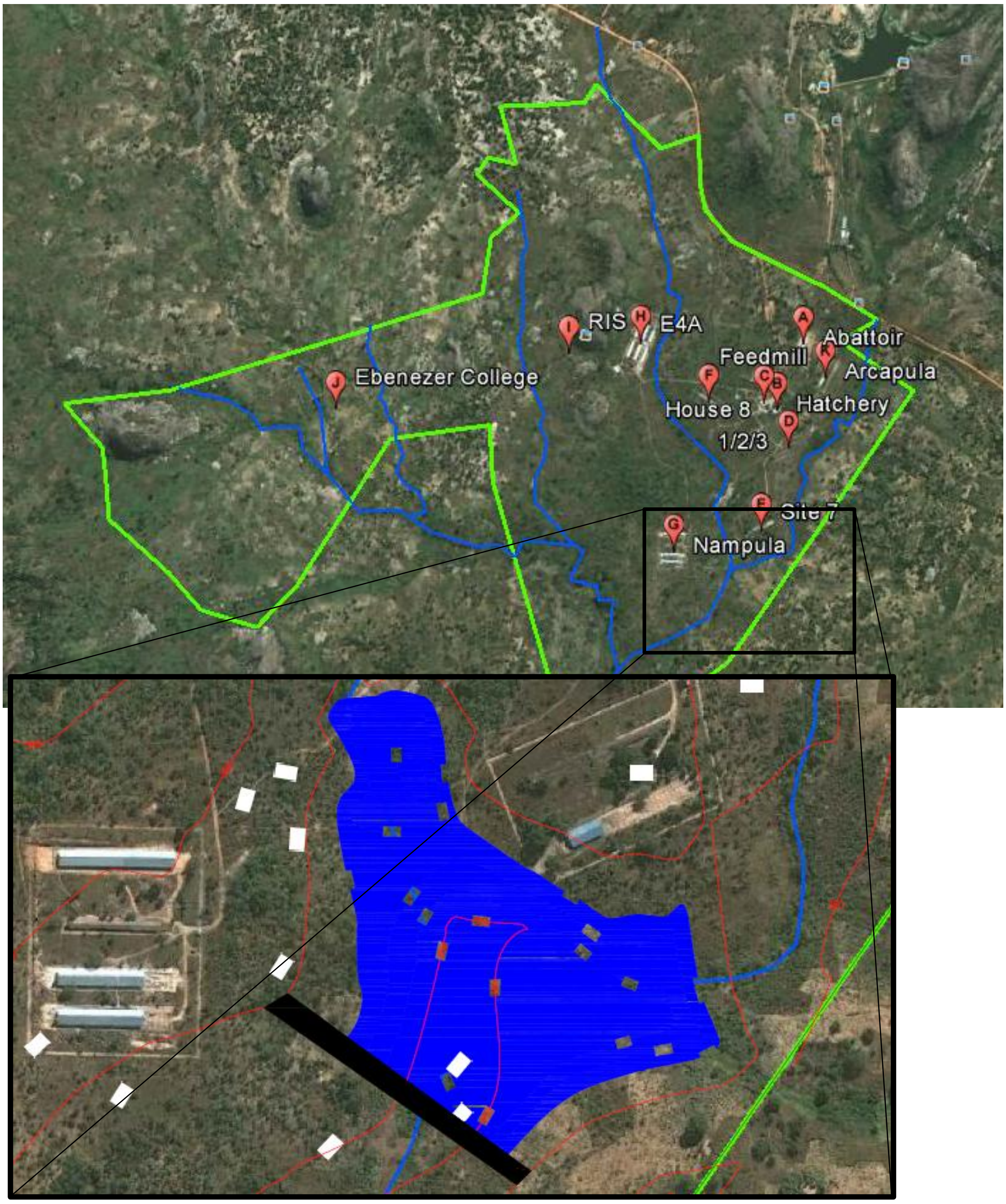


Figure 7.43 Reservoir 12 alternative 3, maximum water level 4 m, dam height 6 m

7.11.1 Dam- and reservoir characteristics

The general dam and reservoir characteristics are shown in Table 7.40. The mean annual runoff for this reservoir is 1,989,270m^3/year.

Water depth [m]	Dam height [m]	Dam length [m]	Maximum dam width [m]	Reservoir perimeter [m]	Reservoir area [m^2]	Storage capacity [m^3]	Subtraction capacity [m^3/month]	Storage ratio [-]
1	3	146	20	516	11,977	10,779	10,000	0.01
2	4	180	27	751	32,365	32,950	15,000	0.02
3	5	223	33	890	45,425	71,845	23,000	0.04
4	6	268	39	1,291	75,300	132,208	33,000	0.07

Table 7.40 Dam and reservoir characteristics reservoir 12 alternative 3

The height, relative heights and crow flies distances to the reservoir are shown in Table 7.41.

	Reservoir	Ebenezer	Abattoir	Hatchery	RIS	E4A	Feed mill
Height [m]	350	361	376	369	373	370	372
Relative height [m]	0	-11	-26	-19	-23	-20	-22
Length [m]	0	2,144	1,308	968	1,407	1,295	984

Table 7.41 Elevation level and distances to users relative to reservoir 12 alternative 3

With the use of the water balance the maximum subtraction capacity per month is shown in Figure 7.44.

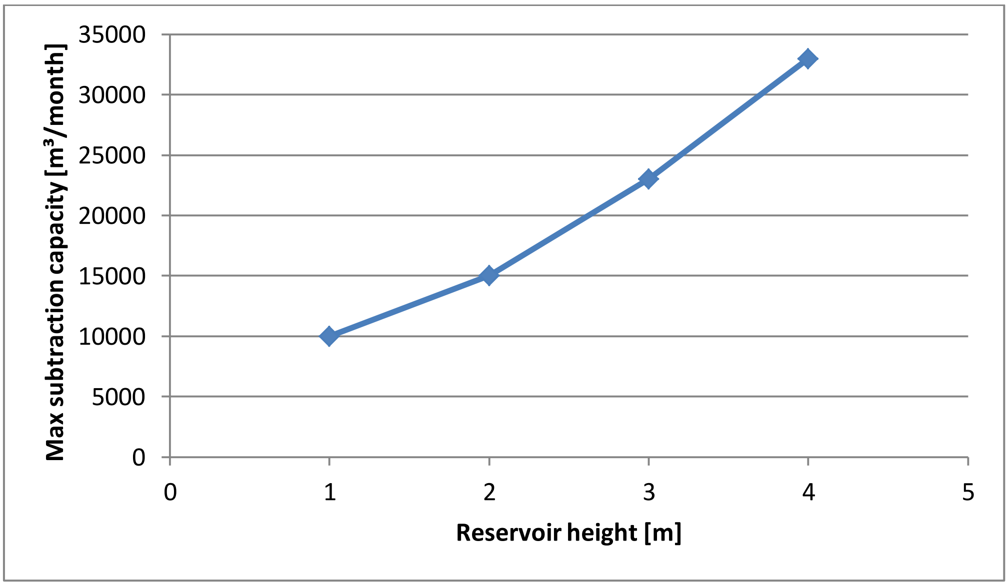


Figure 7.44 Subtraction capacity reservoir 12 alternative 3

7.11.2 Spillway

The spillway characteristics for reservoir 12 alternative 3 are shown in Table 7.42.

Probable Maximum Flood [mm]	Catchment area [m²]	Discharge [m³/day]	Discharge [m³/s]	Width spillway [m]
300	5,902,130	177,063,9	20	34

Table 7.42 Spillway characteristics reservoir 12 alternative 3

7.11.3 Total investment costs

Below the costs per cubic meter per economic lifetime is plotted against the reservoir height. Besides this the total costs are plotted in the same figure. The total costs are split up in investment costs (direct costs) and maintenance costs.

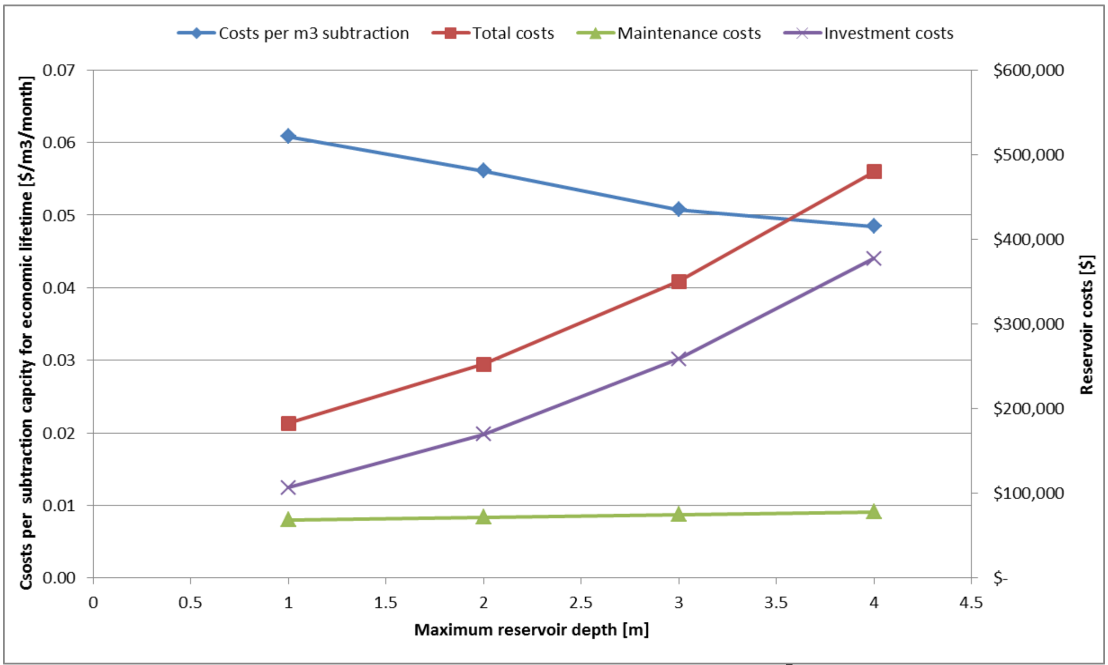


Figure 7.45 Reservoir 12 alternative 3 cost overview and costs per m^3 per economic lifetime

The total costs are plotted with the fulfilling water demand.

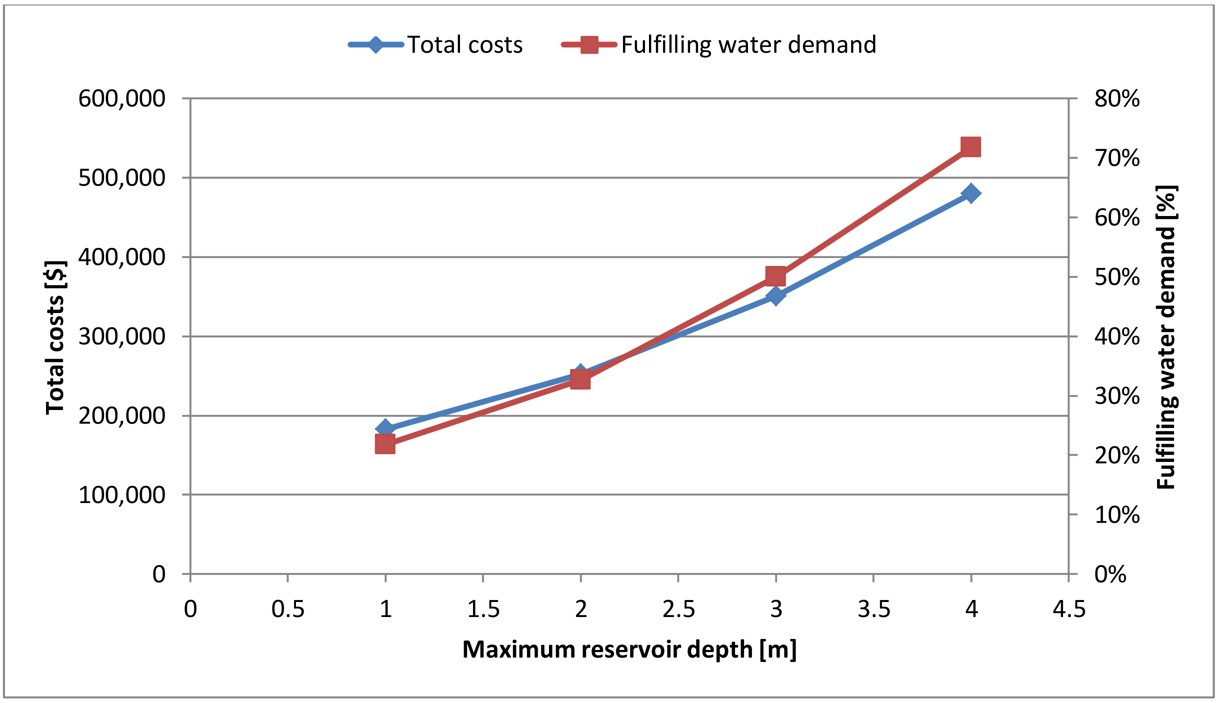


Figure 7.46 Reservoir 12 alternative 3 cost overview and fulfilling water demand per water level

In Table 7.43 a structured overview is given for the total costs, costs per cubic meter and the costs per cubic meter per lifetime subtraction. Maintenance costs increase slightly (factor 1.05) when the water level increases. This is done, because a larger reservoir has higher maintenance costs.

Water depth [m]	Subtraction capacity [m^3/month]	Subtraction / total water demand [%]	Dam volume [m^3]	Total direct cost [$]	Maintenance costs [$]	Total costs [$]	Costs/m^3/lifetime subtraction capacity [$]	Direct cost per m^3 dam volume [$]	Total cost per m^3 dam volume [$]
1	10,000	22%	2,817	106,807	68,694	182,488	0.06	37.91	64.77
2	15,000	33%	5,666	169,554	71,816	252,462	0.06	29.92	44.56
3	23,000	50%	9,808	258,422	74,938	350,266	0.05	26.35	35.71
4	33,000	72%	15,433	377,046	78,061	479,774	0.05	24.43	31.09

Table 7.43 Reservoir 12 alternative 3 cost overview

7.11.4 Remarks

This reservoir has some remarks that will eventually influence the usability or total costs for this reservoir. These remarks are only comments and are not taken into account in the cost calculation. For the eventual reservoir selection these remarks need to be considered.

- The water level of the abattoir (biggest water consumer) exceeds the elevation of the reservoir. Pumps are needed to pump the water to the abattoir.
- The chicken houses come very close to the reservoir. To avoid spreading chicken deceases, the chicken houses should be moved. These costs need to be taken into account.

7.12 Alternative selection

In this chapter the most appropriate alternative will be chosen for reservoir 1 and 12.

7.12.1 Reservoir 1

For the total costs per alternative see Figure 7.47 and for the water demand see Figure 7.48. The cost for reservoir 1.2 is below the cost of reservoir 1.3. The values for these reservoirs are almost the same.

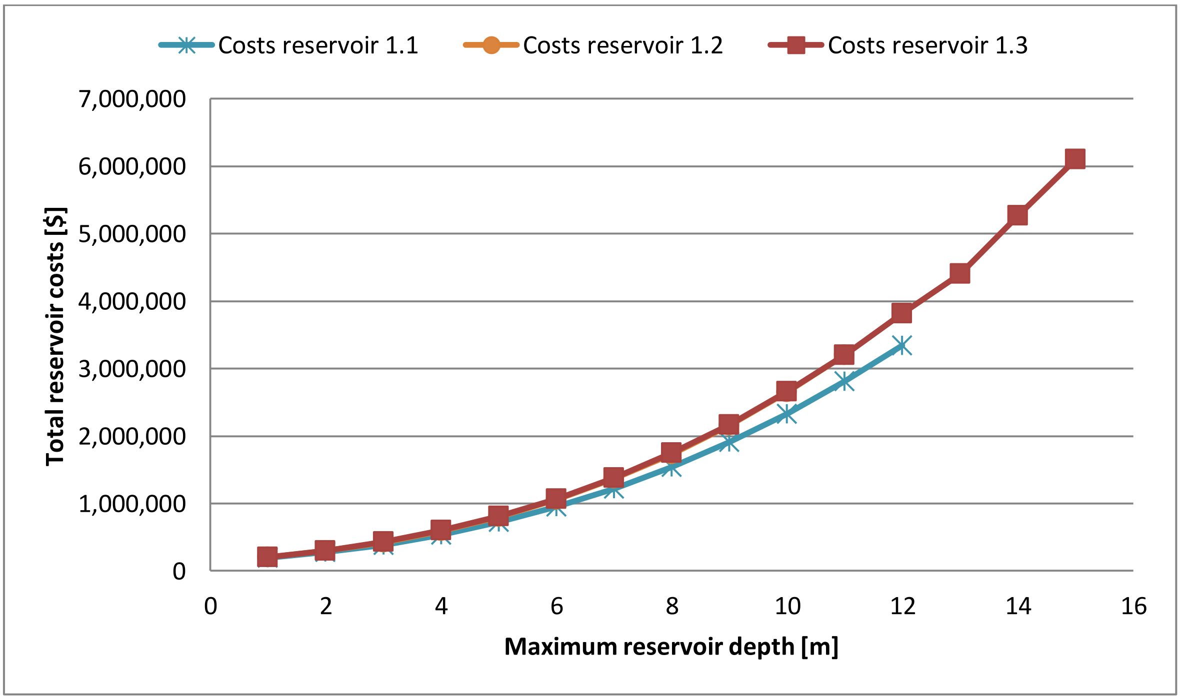


Figure 7.47 Costs per reservoir alternative

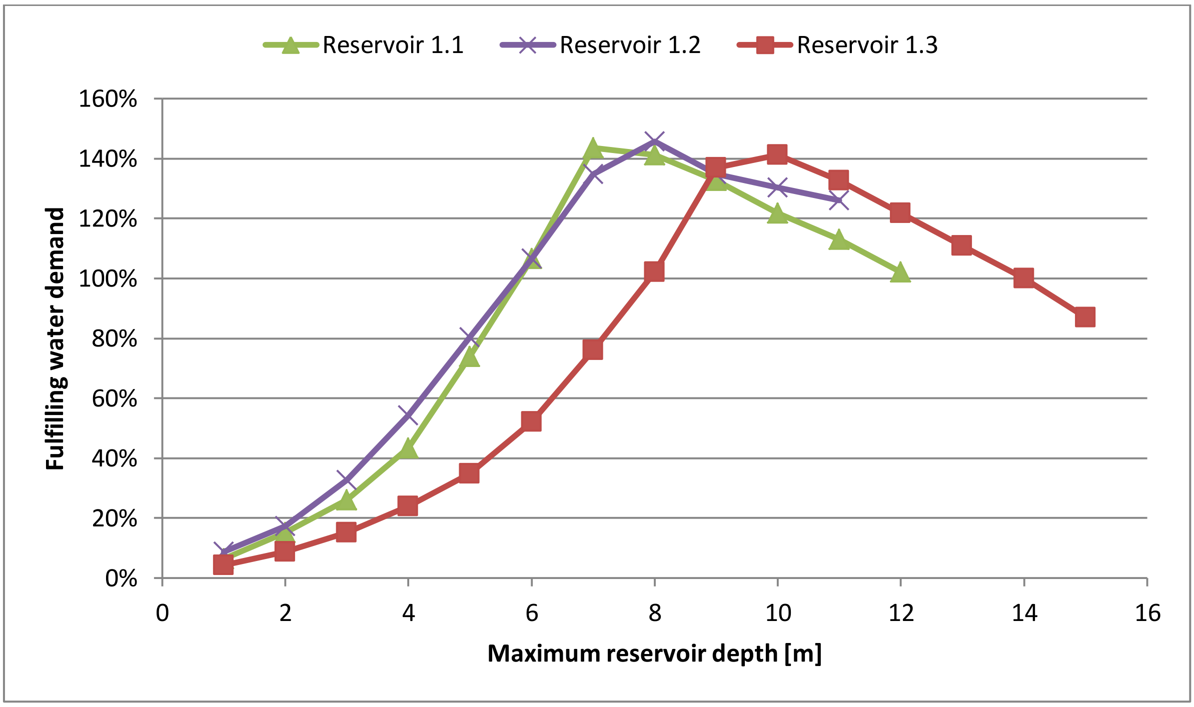


Figure 7.48 Fulfilling water demand as percentage of total demand

From above figures the following can be concluded. Reservoir 1.3 has the highest costs for 100% water fulfillment. Reservoirs 1.1 and 1.2 have almost the same amount of water fulfillment for the same dam height. However the costs for reservoir 1.1 are approximately $100,000 less than reservoir 1.2. With these facts it can be concluded that reservoir 1.1 is the most promising solution.

7.12.2 Reservoir 12

For the total costs per reservoir alternative see Figure 7.49 and for the water demand see Figure 7.50.

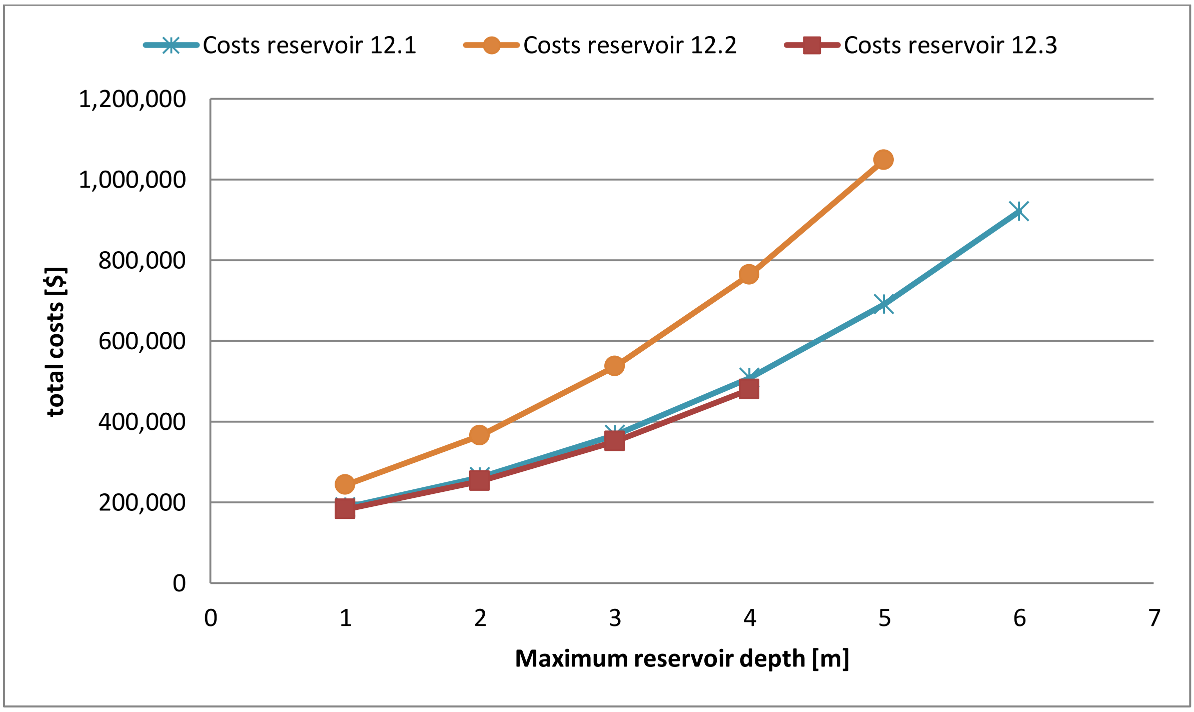


Figure 7.49 Costs per reservoir alternative

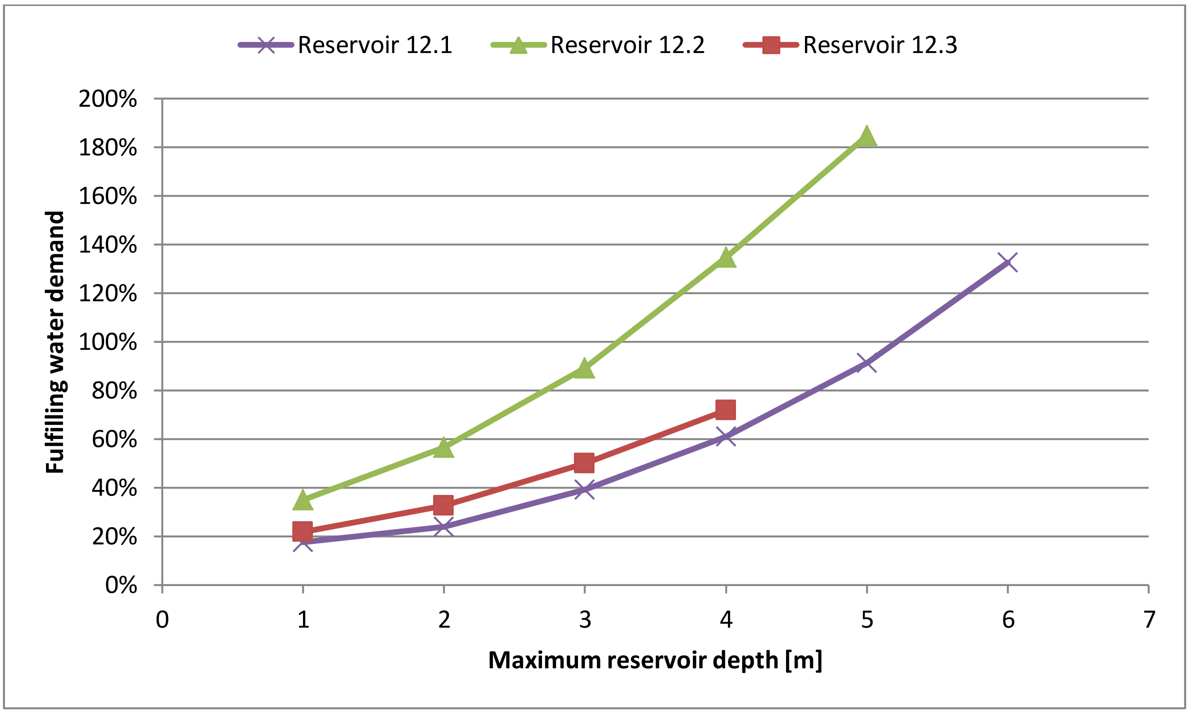


Figure 7.50 Fulfilling water demand as percentage of total demand

From above figures the following can be concluded. Reservoir 12.3 cannot reach the 80% water demand. For 100% water demand reservoir 12.2 is much cheaper than reservoir 12.1. With these facts it can be concluded that reservoir 12.2 is the most promising solution.

7.13 Conclusions and recommendations

7.13.1 Conclusions

From all the reservoirs that have been worked out in part C, in which reservoir 1 with alternative 2 and 3 and reservoir with 12 alternative 1 and 3 are excluded, the total costs are shown per percentage water fulfillment in Table 7.44. This table is also visualized as a graph shown in Figure 7.51. For these calculations a Maple script is used which is shown in Appendix C5.

nr.	10 %	20 %	30 %	40 %	50 %	60 %	70 %	80 %	90 %	100 %
1.1	226,986	329,931	421,481	503,450	577,651	645,895	709,997	771,767	833,019	895,566
3	359,967	601,656	818,862	966,877	1,061,605	1,179,554	1,457,845	2,094,205	-	-
8	223,843	309,645	387,919	462,123	535,713	-	-	-	-	-
9	142,158	180,253	217,523	254,028	289,828	324,983	359,555	393,603	427,189	460,371
10	149,986	284,384	396,115	493,227	583,768	675,789	-	-	-	-
12.2	77,497	145,889	210,305	271,214	329,079	384,368	437,547	489,081	539,436	589,079

Table 7.44 Total costs in dollars per water fulfillment per reservoir

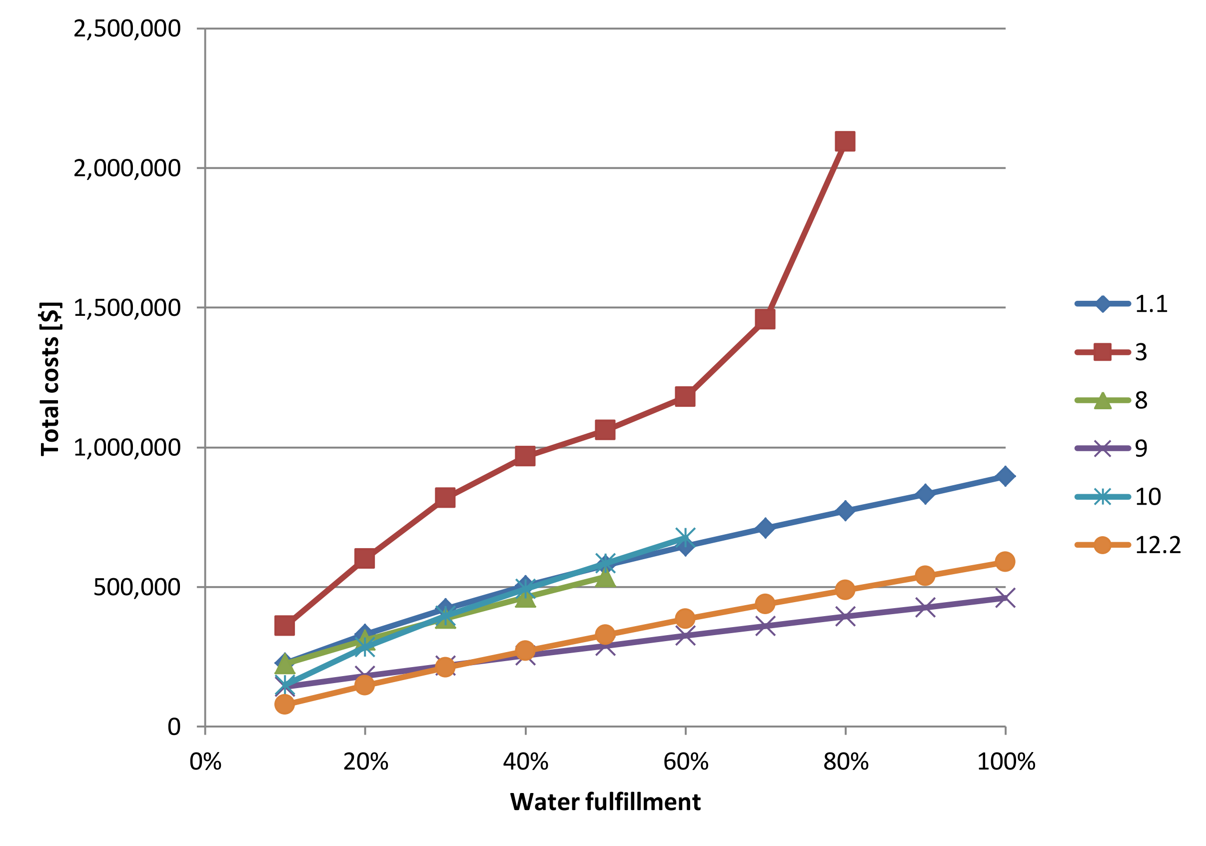


Figure 7.51 Total costs per water fulfillment per reservoir

From Figure 7.51 it can be seen that only three reservoirs reach the 100% water fulfillment demand. Out of these three reservoirs reservoir 9 is the cheapest. For 50% water demand fulfillment reservoir 9 and 12.2 have approximate the same price. For lower than 40% water demand reservoir 12.2 will be cheaper than the other reservoirs.

The total costs per m³ per lifetime per reservoir are shown in Table 7.45 and are visualized in Figure 7.52.

Reservoir	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
1.1	$ 0.18	$ 0.14	$ 0.10	$ 0.08	$ 0.07	$ 0.06	$ 0.06	$ 0.06	$ 0.07	$ 0.07
3	$ 0.31	$ 0.18	$ 0.18	$ 0.20	$ 0.18	$ 0.13	$ 0.12	$ 0.30	-	-
8	$ 0.18	$ 0.10	$ 0.09	$ 0.10	$ 0.09	-	-	-	-	-
9	$ 0.07	$ 0.06	$ 0.05	$ 0.05	$ 0.04	$ 0.04	$ 0.04	$ 0.04	$ 0.03	$ 0.03
10	$ 0.11	$ 0.10	$ 0.10	$ 0.09	$ 0.08	$ 0.08	-	-	-	-
12.2	$ 0.06	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.04	$ 0.04	$ 0.04

Table 7.45 Costs per m³ per lifetime per water fulfillment per reservoir

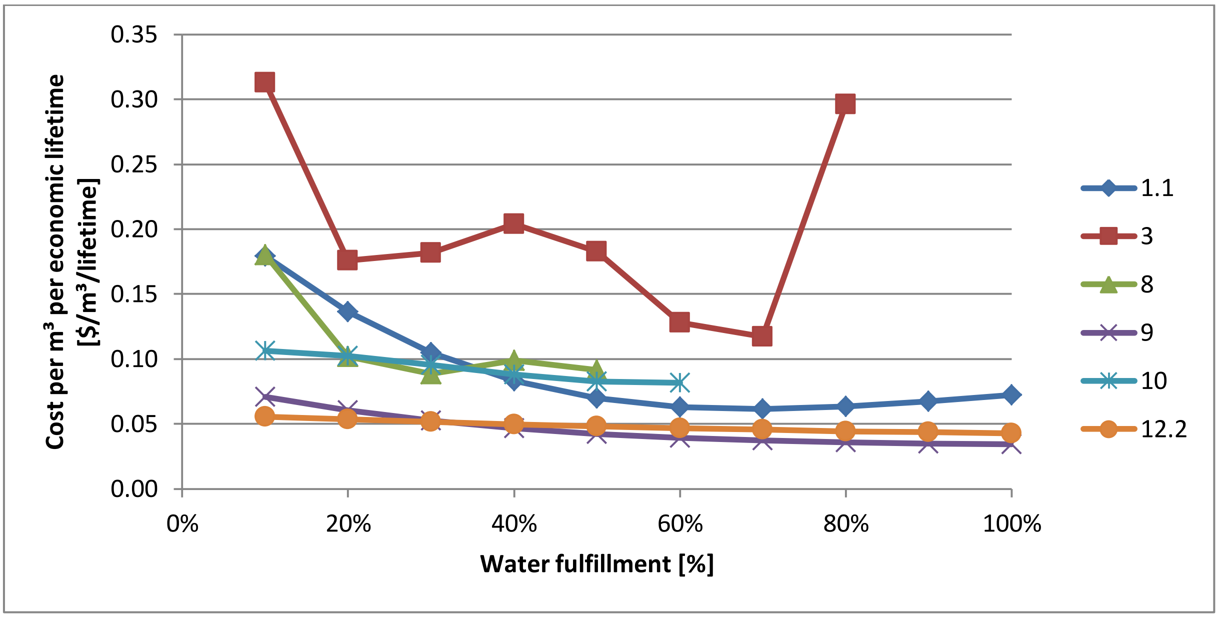


Figure 7.52 Costs per m³ per lifetime per water fulfillment per reservoir

From Figure 7.52 it can be seen that the cost per m³ per economic lifetime is for reservoir 9 the lowest for more than 40% water demand. For lower values of the water demand reservoir 12.2 will be cheaper.

7.13.2 Recommendations

In part C several improvements and more research is possible. Below a list of improvements and other aspects that could be worked out in more detail are given.

- When a reservoir is actually being built, the location of the spillway should be located on the side of the reservoir and preferably on a rocky bottom.
- To make the reservoirs cheaper the reservoirs should not be built with bulldozers and dump trucks but with dam scoops. These dam scoops are cheap in use and can also be used to compact the dam. For a small production cycle these dam scoops costs \$5-6/m³ and a large cycle \$7-8/m³.
- Instead of a sand filter inside the reservoir another option is to choose for a borehole just behind the reservoir. In this way a natural sand filter is used.
- The reservoir should never be cleared of sediment. When the reservoir is cleared of 1m³ of sediment only 1m³ of water will return. In this way a lot of sediment will have to be removed to get more volume of water inside the reservoir. The sediment traps can be emptied once in a while. So silt traps will have to be built.
- To protect the reservoir against too much sediment the total catchment area should be protected with bank protection. Bank protection will make sure no extra sediment will be added to the river in the wet period.
- To reduce costs, only the dam site can be cleared for the future reservoir.
- The catchment areas of the reservoir should be looked in into more detail. Because catchment areas are very important to determine how much water really comes into the river, it is important to determine these more accurate.
- The execution should always start just after the wet period. In these months the ground is still a little wet which improves the compact ability of the ground. Besides this enough water is still available in these months which means no extra costs of pumping water to the execution site is necessary.
- When a dam site is chosen, the subsoil should be looked into more detail. With this information it might be possible to reduce the slope of the dam upstream to 1:2 and downstream 1:2.5. This will enormously reduce the total costs.
- The evapotranspiration instead of the evaporation is used in the calculations for the water balance because the evaporation was not known. To get a more accurate water balance the evaporation should be taken.

8. Follow-up

In part B and C, insight is given into the various options for solving the water problem. Now sufficient information about the various possibilities is available, a total water solution can be made. However, this falls outside the scope of this project. In addition, it is recommended to first investigate the reuse of water before starting with the preparation of making a total water solution. Therefore, Part D considers a phased development of the water demand. Part D ends with recommendations for making a total water solution with the use of this report.

Part D

Phasing and recommendations

9. Phasing and recommendations

This chapter concerns a phasing of the water demand and recommendation with regard to the development of a complete water plan of the project area, excluding Eggs for Africa and Arcapula. The latter mentioned partner organizations are not included in the water plan because the expansion of these organizations is unknown and significant expansions are not possible within the current space that is available for these organizations.

The recommendations include an advice on the strategy that should be followed in order to make enough water available for the short-term expansion (within 5 years) and long-term expansion of the activities of Novos Horizontes. Therefore first a phased water demand is given. Subsequently an overview of the water sources elaborated in part B and C is given. Also a top view of the location of all the water sources and water users is given.

9.1 Phasing

The phasing in the expansion is defined by Novos Horizontes and will cover the following 5 years of planned expansion. The phasing will include the current situation, the situation in half a years' time, the situation after 2 years and 5 years. Strictly the first five years will be regarded. However the long-term expansion, as described in chapter 3, will be taken into account as well. The phasing is schematized in Figure 9.1.

Figure 9.1 Phasing

The phasing is defined differently for different operations. The expansion of the abattoir is based on the total number of chickens slaughtered per day, Table 9.1.

	Current	After 0.5 year	After 2 year	After 5 year
Abattoir	4,000	6,667	10,000	20,000
Hatchery	8,000	13,333	20,000	40,000

Table 9.1 Planned expansion of process buildings

It is assumed that the hatchery will expand as the abattoir expands. At the moment the hatchery hatches twice as many eggs as chickens are slaughtered in the abattoir. This line is assumed to be followed in the future. Expansions expected in chicken operations are shown in Table 9.2.

	Current	After 0.5 year	After 2 year	After 5 year
Site 1/2/3	7,000	7,000	-	-
House 8	7,000	7,000	7,000	-
Site 7	14,000	14,000	21,000	42,000
Nampula	28,000	28,000	35,000	42,000
New	-	14,000	28,000	42,000

Table 9.2 Chicken capacity at different locations

The development of Rapale International School and Ebenezer College is shown in Table 9.3.

	Current	After 0.5 year	After 2 year	After 5 year
RIS	60	60	75	150
Ebenezer College	-	-	30	60

Table 9.3 Students attending school

It is assumed that the total of residential buildings will increase from 8 (present) to 10 houses within half a year and to 12 houses in 2 years. Irrigation activities will also start within 2 years.

9.2 Water use

Based on the planned expansion described in the previous paragraph, the development in water use can be defined, Table 9.4.

	Current [m^3/day]	**0.5 year [m^3/day]**	**2 years [m^3/day]**	**5 years [m^3/day]**
Process buildings				
Abattoir	48	80	120	240
Hatchery	10	12	18	30
Feed mill	-	-	-	-
Chicken operations				
Site 1/2/3	4.2	4.2	-	-
House 8	4.2	4.2	4.2	-
Site 7	8.4	8.4	12.6	25.2
Nampula	16.8	16.8	21.0	25.2
New	-	8.4	16.8	25.2
Residential buildings[7]				
8 houses	2.0	-	-	-
10 houses	-	2.5	-	-
12 houses	-	-	3.0	3.0
Other demand sites				
Novos Horizontes office	0.009	0.009	0.014	0.018
Rapale International School	0.42	0.42	0.53	1.05
Ebenezer College	-	-	0.21	0.42
Workshop	-	-	-	-
Irrigation Ebenezer College	-	-	50	100
Irrigation Farm	-	-	25	50
Other users	5	5	10	20
Total	**99**	**142**	**281**	**520**

Table 9.4 Development in water use

[7] All houses have an estimated water demand of 250 l per day

The water use of the abattoir, the chicken operations and the schools are based on the unit water use. The unit water use is the water demand of one unit. The units here are slaughtered chickens, hatched eggs and students. The development in water use of the other demand sites is based on experience of Novos Horizontes.

9.3 Water sources

Water sources in this context are defined as the locations where water can be made available. This can be done by either extraction from the ground, capturing from a roof or subtracting from a reservoir. Also reuse of waste water from the abattoir is an option. The numbers indicated in this paragraph are a review of part B and C of this report.

A study on the quantity of water that can be treated at the abattoir is not preformed and thus numbers are hard to attach to the water availability. Capacity of the treatment facility and/or costs will be decisive in the amount of water that comes available by treatment of the waste water.

Seven boreholes are available at the moment. The average discharge from these boreholes is estimated around 19 m^3/day. It is considered possible to increase the amount of boreholes on the farm. This increase is however limited but the extent to which it is limited is unknown. This depends on the total size of the subsurface water source and the recharge of these sources. With a field survey performed, it is estimated that the performance of future boreholes can increase to almost 25 m^3/day per borehole. The water quality of boreholes is considered to meet the quality requirements.

Domestic rainwater harvesting is, as an individual source, only an option for relative small water demand sites including residential buildings, offices and both schools. For bigger demand sites it is not feasible to apply domestic rainwater harvesting as an individual solution. As supplementary source rainwater harvesting can be applied. Depending on the roof area and the rainfall, the total volume of captured water from roofs varies between 52 and 19,512 m^3 per year. Rainwater harvesting from rocks can capture between 7,537 and 59,127 m^3 per year, however performance in combination with other solutions are questionable and large storage tanks are not considered feasible. Water quality of captured rainwater is also considered to be sufficient.

Reservoirs can supply large volumes of water and are therefore very suitable also for the large demand sites e.g. abattoir and chicken operations. From the 12 possible reservoir locations, 6 locations show very promising characteristics and 3 of them can meet the water demand for the long-term expansion. The costs will be lower than the costs for boreholes and the quality can meet the water quality demands.

9.4 Overview map

The water demand sites (paragraph 9.2) and water sources (paragraph 9.3) are combined and shown in Figure 9.2.

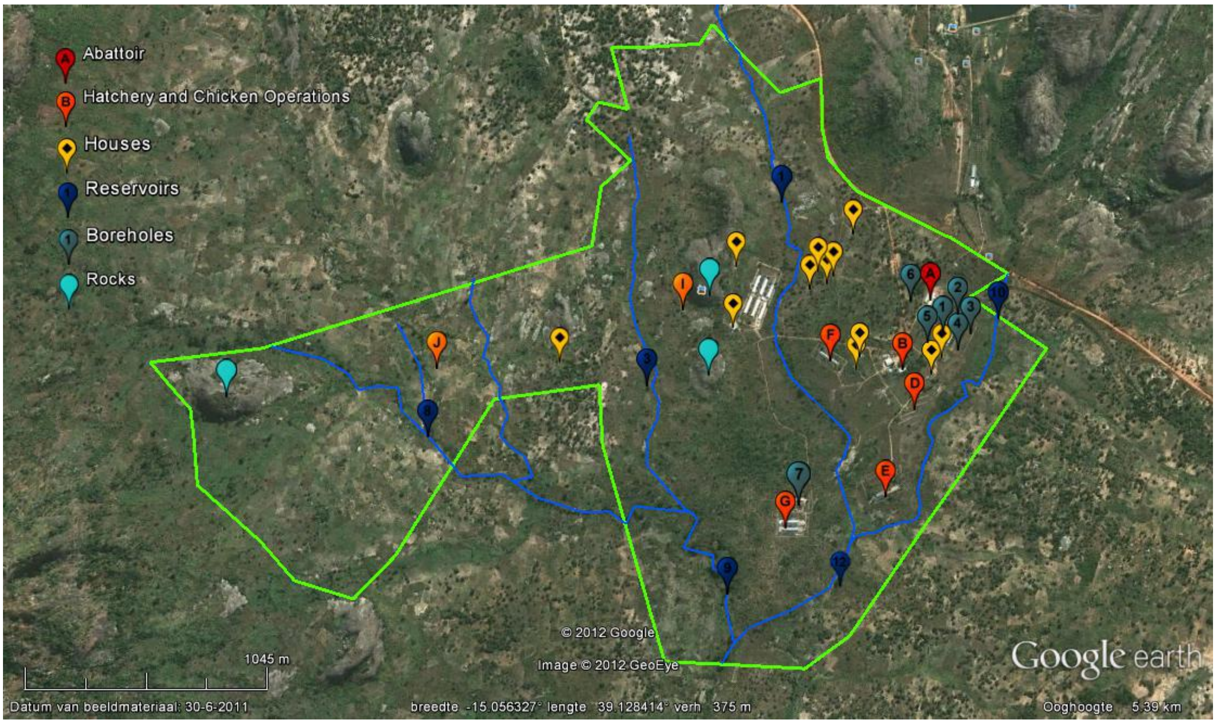


Figure 9.2 Overview map water demand sites and water sources

The blue balloons represent water sources. The color scale indicates the quantity of water that can be made available. Dark blue are the large sources, the lighter the color becomes the smaller the capacity of the source. The turquoise balloons represent the rock from which rainwater harvesting is possible. The dark red colors are the biggest demand sites, the lighter red and orange colors represent smaller demand sites. Residential houses are indicated with yellow balloons.

Figure 9.2 only shows the current boreholes as water sources. However, increasing of the number of boreholes is possible. These future boreholes are not shown in the figure because the locations are not known and have to be determined by extensive geophysical survey.

9.5 Recommendations

Future expansion of the activities of Novos Horizontes will have a big impact on the water management of the operations on the farm and the entire area in general. Increasing the total demand of water almost 14 times is extreme and it should be stressed out that increasing the activities as planned will have an enormous impact on the area. The costs involved will be severe and long term management is recommended to come to an efficient and economically responsible plan to increase the availability of water.

This report gives reason to believe that it is possible in technical and spatial terms. A reservoir and increasing the number of boreholes proved to be suitable as a single source of water that will meet the long term water demand.

Reuse of water is certainly a good option and depending on the treatment plant capacity and available storage capacity it could provide a significant amount of water. Reuse of water is not considered to be suitable as a single source of water for the entire project area. Even if 100 % of the water flowing into the abattoir can be reused the amount of water that will be available is not sufficient to provide the whole project area with water. Also rainwater harvesting proved to be insufficient as a single source. Reuse of water and rainwater harvesting are suitable as supplementary sources.

It is recommended to investigate a combination of the possible solutions described in this report to come to an efficient and economically responsible water plan to increase the availability of water, for the short-term expansion (within 5 years) and long-term expansion. Despite the fact that it is difficult to give the best solution without the insight into reuse of water and without knowing the exact wishes of the Communities of Fusion, it is clear that reservoir 9 has great opportunities to meet the long term water demand.

If chosen for the construction of a dam, further research into the following aspects is recommended:

- Catchment area
  Because the catchment area has a large influence on the safety of the dam and the recharge of the reservoir, a more detailed calculation based on a detailed topographic map is needed.

- Spillway
  The spillway has a direct impact on the safety of the dam. A more detailed design is recommended

- Soil investigation
  Soil investigation can lead to an optimization of the design. The slope of the dams in this report is conservatively assumed at 1:3. Soil test could lead to the application of a steeper slope, which will result in a reduction of the costs

Furthermore it is recommended to elaborate on the reuse of water in a follow-up of this report to get insight in all the aspects of this possible solution. Together with the aspects of the possible solutions elaborated on in this report, this should lead to a total water solution that meets the demands and wishes of the Communities of Fusion.

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