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CONTRIBUTION TO THE DEVELOPMENT OF COST FUNCTIONS FOR THE CLARA SIMPLIFIED PLANNINGTOOL (WATER SOURCES, PURIFICATION & DISTRIBUTION)

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List of Abbreviations

ADD	Average daily demand
BoQ	Bill of quantities
cf.	Confer; compare
CLARA	Capacity-Linked water supply and sanitation improvement for Africa's peri-urban and Rural Areas, Contract # 265676, a Collaborative Project within the EU 7th Framework Programme Theme "Environment (incl. Climate Change)", duration: 03/2011 – 02/2014
DCI	Ductile cast iron
DN	Diametre Nominal
e.g.	Exempli gratia; for example
EIA	Environmental Impact Assessment
et al.	Et allii/iae; and others
FP6	EU 6th framework programme
FP7	EU 7th framework programme
HDPE	High-density polyethylene
HTH	High test hypochlorite
MDD	Maximum daily demand
MDG	Millennium Development Goals
No.	Number
NPV	Net present value
O&M	Operation and maintenance
PE	Person equivalent
PVC	Polyvinyl chloride
ROSA	Resource-Oriented Sanitation concepts for peri-urban areas in Africa, FP6 STREP. project no. 037025, duration: 10/2006 – 03/2010.
SPT	Simplified planning tool
SSF	Slow Sand Filtration
SSWM	Sustainable Sanitation and Water Management
SSWP	Strategic sanitation & waste plans
SuSanA	Sustainable Sanitation Alliance
UN	United Nations
WHO	World Health Organisation

Abstract

Trotz großer Fortschritte in vielen Gegenden auf der Erde, werden mehrere afrikanische Länder die Millennium Entwicklungsziele (Millennium Development Goals) der Vereinten Nationen in Bezug auf Trinkwasser-Versorgung und Versorgung mit sanitären Anlagen nach derzeitigen Prognosen nicht erreichen. Das CLARA Projekt versucht in diesem Problemfeld anzusetzen, indem es in Kooperation mit verschiedenen afrikanischen Partnerländern ein vereinfachtes Tool zur Planung von Trinkwasser- und Sanitären Anlagen entwickelt. Dieses Tool stellt ein objektives Instrument zum Vergleich der Kosten verschiedener Projekt-Varianten dar, die als Lösung auf eine Problemstellung im genannten Sektor in Betracht gezogen werden können. Es versucht die Defizite bezüglich der Entwicklungsziele zu minimieren, indem es Planer und Entscheidungsträger unterstützt, unter verschiedenen Alternativen die kosten-effektivste Lösung zu finden.

Ein Schlüsselelement des Planungsprogramms sind Kostenfunktionen für Technologien im Bereich der Trinkwasser- und Sanitärversorgung, welche einen Kostenvergleich zwischen verschiedenen Technologie-Varianten und Kombinationen ermöglichen. Folglich wird in dieser Arbeit die Entwicklung von Kostenfunktionen zu Technologien im Bereich der Trinkwasser-Gewinnung, der Aufbereitung und des Transports beschrieben. Die wichtigsten Schritte zur Ermittlung einer Kostenfunktion waren:
1) Festlegung eines Standarddesigns für eine Technologie auf Basis von Literatur und realisierten Projekten.
2) Definition der Auslegungsgrößen einer Technologie zur Begrenzung des Einsatzbereiches und nötiger Eingabewerte zur Berechnung der erforderlichen Auslegung der Technologie.
3) Ermittlung der Kosten, aufgeteilt in Investition, Betrieb & Wartung, und Reinvestition. Die Kostenermittlung basiert auf einem Leistungsverzeichnis des Siedlungswasserbaus aus Österreich mit Standardpositionen für häufig verwendete Materialien oder angewandte Arbeiten.
4) Rücksprache mit den afrikanischen Partnerländern zu Designfragen der Technologien und Einspeisung von kostenspezifischen Preise für die Positionen im Leistungsverzeichnis
5) Entwicklung der Kostenfunktionen für die definierten Eingabeparametern.

Die Kostenfunktionen wurden in das Planungs-Tool des Projektes implementiert welches derzeit in den CLARA Partnerländern getestet wird.

Abstract English

Despite great progress in many areas of the world, several African countries will not achieve the Millennium Development Goals of the United Nations with regard to drinking water supply and sanitation. The CLARA project is trying to assist in this problem area by developing a simplified planning tool for drinking water and sanitation facilities in cooperation with various African partner countries. It is a tool to objectively compare costs of different project alternatives that can be considered as a solution to a given problem. It tries to overcome the shortcomings towards the development goals by helping planners and decision makers to find most cost-effective solutions between alternatives.

Key elements of the planning tool are cost functions for technologies in the field of drinking water supply and sanitation, which allow a cost comparison between different technologies and combinations. Therefore, in this work the development of cost functions for technologies in the field of drinking water sources, purification and distribution is described. The main steps to determine the cost function were:
1) Establish a standard design for a technology based on literature and realized projects.
2) Define design sizes of a technology to limit application range and determine necessary input parameters to calculate the required design of the technology.
3) Identification of costs, divided into investment, operation & maintenance and reinvestment. The cost estimate is based on a bill of quantities for sanitary engineering in Austria with standard positions for frequently used materials or applied work.
4) Consultation of African partner countries to gain feedback for the standard design of a technology and to get country-specific unit costs for the positions in the bill of quantities
5) Development of cost functions related to the defined input parameters.

The cost functions have been then implemented in the planning tool for testing in the CLARA project countries.

1. Introduction

1.1 About the master thesis

This master thesis contributes to the development of the CLARA (Capacity-Linked water and sanitation for Africa's peri-urban and Rural Areas) simplified planning tool (SPT). The tool aims to support planning of water supply and sanitation in African countries in accordance with the Millennium Development Goals (MDG). While CLARA encompasses the whole water cycle, this thesis focuses on the water supply side. Therefore, the main goal is to develop general cost functions for technologies in the functional groups water sources, water purification and water distribution as defined in the sustainable sanitation and water management (SSWM; *http://www.sswm.info*) toolbox. It is published by the seecon gmbh and available online for free. Main goal of the toolbox is to give a holistic overview about the water cycle, its connections to the nutrient cycle and introduces to questions and solutions towards sustainable water and sanitation management.

1.2 Structure of the thesis

The thesis is divided into several chapters. The introduction chapter intends to give a rough overview about the current sanitation situation in Africa and to explain the gap the CLARA SPT means to bridge. It furthermore introduces the water supply aspect of the water cycle and gives information about technologies included in the CLARA SPT.
The goals and objectives shortly introduce the outcomes this thesis aimed to achieve. Afterwards the methods of the thesis are presented. The main function of this chapter is to explain the general approach of cost function development. The developed cost functions as well as all underlying assumptions are described in detail for each technology in the results chapter.
In the discussion chapter experiences from the work will be presented, decisions and assumptions justified. The outlook gives recommendations for further developing the existing cost functions and adding more technologies to the tool. Finally the summary reviews the achievements and develops conclusions.

1.3 General Introduction to Water Supply & Sanitation in Africa

Currently, an estimated 884 million people lack access to improved water supply in the world and around 2.6 billion people live without improved sanitation (WHO/UNICEF, 2010). Every year, roughly 2 million people die due to diarrheal diseases, most of them children younger than 5 years of age. The most affected are the poor and underprivileged in developing countries, often living in peri-urban or rural areas. “Peri-urban” relates to areas of urban growth that create hybrid landscapes of fragmented urban and rural characteristics.
The United Nations (UN) Millennium Development Goals, more specifically target 10, call for reducing the quantity of people without access to safe drinking water and basic sanitation by half until 2015 (UN, 2000). Although the Millennium Development Goals Report 2012 (UN, 2012) states that the world has met these targets five years ahead of schedule, this progress only is valid on a total, global scale. Compared to urban areas, coverage of improved drinking water in rural areas is still poor. Furthermore, two regions in particular do not meet the expectations, namely sub-Saharan Africa and Oceania. In rural sub-Saharan Africa less than

half of the population has access to any kind of improved water source. The provision of sanitation in rural sub-Saharan Africa is even worse. Figure 1 illustrates the development of the African countries towards the MDG targets in water supply. Regarding drinking water supply only 23 of 49 countries are on track or at least progressing towards meeting the targets. Another rising problem is the predicted impact of climate change in Africa with increasing pressure on the water availability (IPCC, 2007). It is obvious that the sub-Saharan Africa shows extreme difficulties in obtaining the development goals. Project CLARA tries to provide assistance to improve this situation.

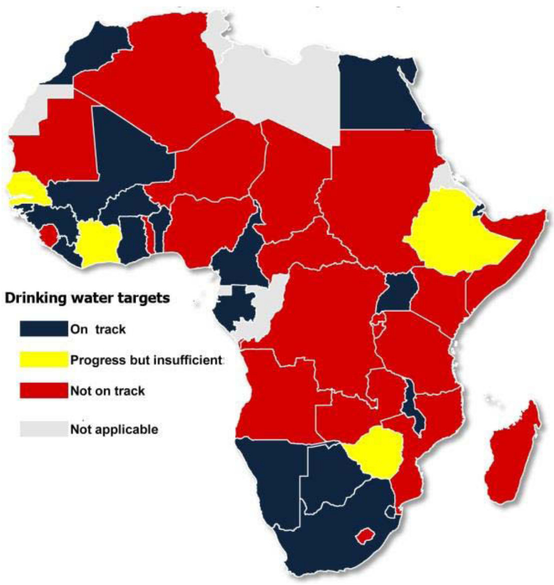

Figure 1 - Progress towards the MDG drinking water targets (AMCOW and WHO/UNICEF, 2012)

1.4 The ROSA project

The ROSA project (Resource-Oriented Sanitation concepts for peri-urban areas in Africa) was part of the Sixth Framework Programme (FP6) of the EU and its main goal was to "promote resource-oriented sanitation concepts as a route to sustainable and ecologically sound sanitation in order to meet the MDGs". In general this project was the predecessor of project CLARA and many decisions are based on the results achieved by project ROSA.
In four model cities, namely Arba Minch (Ethiopia), Nakuru (Kenya), Arusha (Tanzania) and Kitgum (Uganda), strategic sanitation & waste plans (SSWP) were developed for the whole city area. These SSWPs should present optimized solutions for the city by combining several techniques according to the local requirements.
A part of the SSWPs was developed in peri-urban areas, targeting to research the gaps for implementation of these concepts in peri-urban areas. They include for example an implementation study of the updated World Health Organization (WHO) guidelines for use of waste and excreta, the improvement and adaptation of resource-oriented sanitation technologies and the development of community based operation and management strategies (LANGERGRABER et al., 2010). Based on these results project CLARA was developed.

1.5 The CLARA project

As stated before, in Africa a large number of small communities and towns suffer from severe problems with water supply and sanitation. Small communities in rural areas and peri-urban

areas of smaller towns have comparable settlement structures, where the reuse of water and the use of sanitation products can be exploited to improve sanitation conditions drastically. However, at the moment there is only limited local capacity available to adopt and operate integrated water supply and sanitation systems.
From the experiences made in project ROSA it became obvious that for successful implementation of sanitation systems not only the adaptations of technologies to local conditions, but also soft factors are of importance. Examples would be the participation of all stakeholders from the beginning or the consideration of operation and maintenance from the start. Furthermore, a main conclusion was the lack of knowledge about planning in general and especially in practical knowledge and strategic planning in African communities.
Consequently, one key objective of the 7^{th} framework program (FP7) project CLARA is to develop a **simplified planning tool** for integrated water supply and sanitation systems. It is focused on small communities and peri-urban areas and incorporates the key factors for success, i.e. operation and maintenance issues and reuse potential, from the start of the planning process. The tool itself can be tailored to available local capacities. This tool needs to be tested and evaluated in different geographical African regions to include differing economic, cultural and social boundary conditions. Therefore, the African partners include countries all over the continent: Eastern Africa (Ethiopia and Kenya), Southern Africa (South Africa), Western Africa (Burkina Faso) and Northern Africa (Morocco and Tunisia).

1.6 Research objectives

As the overall objective, this thesis aims to develop cost functions for a number of water supply technologies in order to enable cost comparison of different water supply systems within the CLARA simplified planning tool. For the achievement of this goal the following objectives needs to be accomplished for each of the selected technologies:

1. Create a standard design and determine on specific design assumptions
2. Define the investment, operation & maintenance and reinvestment costs for each design size by utilization of Bill of Quantities
3. Technology assessment with participating countries and collection of country-specific unit costs
4. Identify the cost functions for investment, operation & maintenance and reinvestment based on input parameters

1.7 Problem definition

The lack of local capacity in rural areas means more precisely, that decision makers and planners in the water and sanitation sector have often deficits in knowledge to adopt adequate solutions, which could help with their water supply and sanitation issues. Existing knowledge lacks might concern available technical solutions or methods, approaches and criteria for the planning and implementation process of a system (CLARA, 2012a). The CLARA project was initiated to provide a solution to these problems. The simplified planning tool developed within the CLARA project is supposed to become an instrument for comparing water and sanitation systems.
As this thesis is a part in the planning tool development the problem definition focuses on the comparability of different water supply systems in terms of economic costs. The easiest way to compare various systems would be to obtain their actual cost from prior projects. Due to the

lack of real project cost the costs for a comparison have to be derived from a number of different designs. The cost comparison includes all expenditures during the defined period (e.g. 50 years) of consideration that includes investment, operation & maintenance and reinvestment costs.

2. Objective and Definition

2.1 Description of the SPT

2.1.1 Background

The basic design idea of the CLARA SPT is based on a tool used in Austria to compare alternatives of water borne sanitation based on their economic costs. The tool is provided by the government of Lower Austria and mandatory for financial subsidies in the sanitation sector. The tool is flexible to adjust for different framework conditions and suitable for various environments. Its results are transparent due to input parameters and fixed cost bases. It prevents abuse because results cannot be pressured to favor a specific, by some people socially preferred solution. Furthermore, the tool follows technical and legal standards and therefore excludes unsuitable solutions. These advantages transfer to the SPT (LECHNER, 2011).

The tool intention is to provide the missing link for the technical port of the planning process by assisting local planners in identifying the optimal solution for water supply and sanitation in the planning objective. It allows comparing real costs of alternative water supply and sanitation systems, without considering health, social and environmental aspects particularly, because it is assumed that these will be covered by legal requirements. As a result, the comparison can justifiably be reduced to the costs of alternatives, i.e. for investment, operation and maintenance and reinvestment over a specific period (e.g. 50 years). The development of alternative solutions is responsibility of the planner and tool user.
Technologies are grouped into functional groups as defined in the SSWM toolbox. These groups are: Water sources, Water purification, Water distribution, Water use, Waste collection and transport, Waste treatment, and Reuse.
The tool is intended to be used at the early planning stages of a water supply or sanitation project, enabling planners to get a realistic estimation about different scenarios for the realization of a project.

2.1.2 Main actors

This section gives a short overview of the people supposed to be involved in the tool application:

2.1.2.1 Client

The client could be e.g. a municipality or a ministerial department confronted with a problem in water supply and sanitation and in search of a solution. The client should be the one to begin the planning process and who makes the final decisions. For the technical realization the client hires a planner (CLARA, 2012a).

2.1.2.2 Planner

The planner should be an expert with knowledge and experience in water supply and sanitation equipped with legal authorization by the client. The planner is responsible for the development of possible solutions, collection of required data, consideration of local framework and the application of the CLARA planning tool according to the information obtained (CLARA, 2012b).

2.1.2.3 Authority

The authority is ”the responsible body that assures the compliance of legal requirements in the framework conditions of the planning process” (CLARA, 2012a). In addition, it is responsible to specify the unit costs of the CLARA simplified planning tool to enable realistic and transparent system comparisons in their country.

2.1.3 Technology cost functions and input parameters

The basic elements of the SPT are cost functions. For assessment of different alternatives each technology has to show comparable costs at any design size within a realistic range. These costs of a technology are derived from a cost function which depends on certain input parameters which are essential for the specific technology's costs. Costs for any technology comprise investment costs, operation and maintenance costs and reinvestment costs. A crucial element of the cost function is the Bill of Quantity (BoQ) which is a list of positions containing detailed information of material, parts and labor required to construct the specific structure. The unit costs for each position have to be collected for the country. Therefore, one important input parameter is the choice of country in which the project is supposed to be realized, as changing the country requires adaptation of all unit costs.

2.1.4 Comparison of Costs

The CLARA SPT calculates the total costs of a project for a chosen period or project life span. To allow system comparisons it is essential to consider the time value of money of future cash flow in the present. Therefore the SPT determines the net present value (NPV) that is the sum of all the present values of the annual cash flows during the life of the project, minus the initial investments. The period of consideration and the interest rate are general input parameters of the project.

2.2 SSWM toolbox and water cycle

The project aims to cover the complete water cycle regarding human activity, following the SSWM toolbox. The toolbox is an open source collection of tools and literature that covers planning and process approaches as well as implementation tools for the water and sanitation sector. The main goal of the toolbox is to provide a central information point for a more holistic understanding of the topic water and sanitation, its planning and implementation (CONRADIN et al., 2011). Figure 2 shows the water cycle and also the different functional groups as they are defined in the SSWM toolbox and used in the CLARA SPT. Therefore, technologies applied in the tool are split into one of the following seven groups:

1. Water sources
2. Water purification
3. Water distribution
4. Water use
5. Waste water collection
6. Waste water treatment
7. Recharge / Reuse

The technologies presented in this thesis focus on the **water supply side** of the whole water cycle, which means that all technologies in this thesis will belong to one of the first three groups. In the following section, for each functional group the technologies included in the SPT will be introduced.

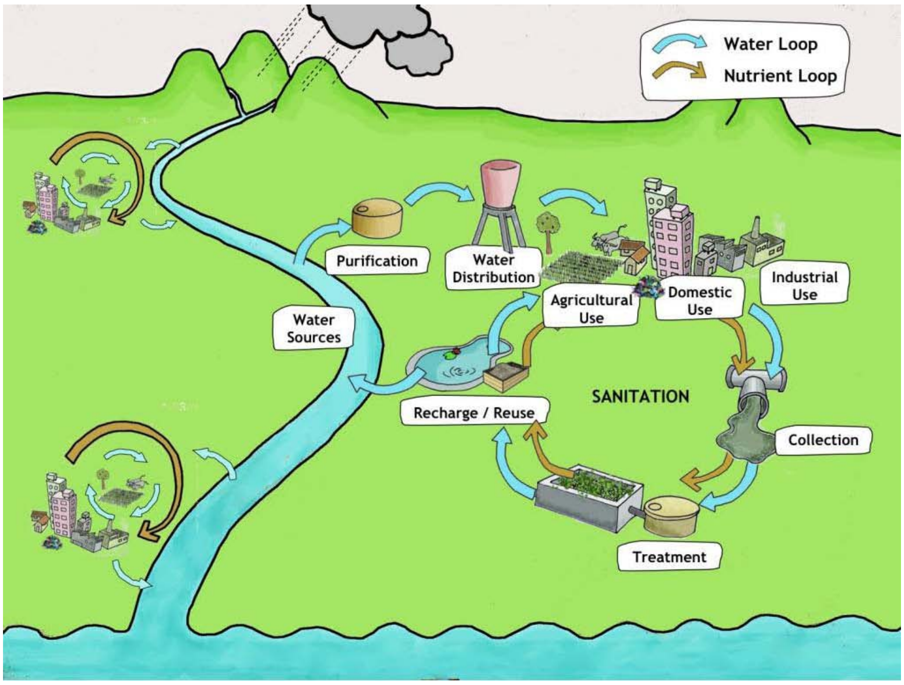

Figure 2 - Idealized Water and Nutrient Loop (SSWM, 2013)

2.3 General description of the selected technologies

As an introduction, the design of a community water supply system consists usually of the following points (HICKEY, 2008):

- **Water Source:** Every distribution network requires a raw water source such as a lake, river or a groundwater source, e.g. a spring or a borehole.
- **Treatment:** The extracted water needs purification in order to gain the desired quality. This is usually executed in a centralized treatment plant by screening, coagulation-flocculation and sedimentation. As a last step the water is disinfected (e.g. chlorination or ozonation).
- **Pumping:** Pumping stations are necessary to move the water against gravity. This is either when water needs to reach areas with higher elevations or to fill gravity tanks in the water supply system.
- **Storage**: An important part in a water distribution system is storage. Storage facilities, usually tanks, enable the system to provide adequate volumes during periods of high demand while also ensuring fire-fighting requirements. The two common storage methods are ground-level storage and elevated storage.
- **Piping:** At the end of the system, water is distributed via pipes to the consumer.

In the following section, the three functional groups of water supply and the respective technologies included in the SPT are introduced in detail.

2.3.1 Water sources

Although water is the most widely occurring substance on earth, only about 2.5% is freshwater. Some two thirds of this freshwater is locked up in glaciers and permanent snow cover. Water resources are renewable (except some ancient *aquifers*), with huge differences in availability in

different parts of the world and wide variations in seasonal and annual precipitation in many places (WWAP, 2006).
Freshwater sources are split into surface water sources and groundwater sources. The sources used in the CLARA tool at the current stage include extraction from springs, from groundwater by boreholes and from rivers. Other possible sources, which could be implemented at a later stage, would be surface waters like lakes, man-made reservoirs or even desalinized sea water, but also rainwater harvesting. The following presented technologies are implemented in the planning tool:

2.3.1.1 Spring Extraction

Where groundwater emerges at the earth's surface, this feature is referred to as a spring. The use of springs as the main source for community water supply is applicable whenever a spring`s yield in terms of quantity and quality is sufficient (BRUNI, 2011). Several types of springs can be distinguished: Gravity springs emerging in a single spot, springs that have no distinct single outlet and require the installation of a catchment drainage system, and finally artesian springs. A spring is one of human's oldest water supply opportunities and they remain a favored source, because the water usually is of high natural quality and the intake is comparatively straightforward. (SMET & WIJK, 2002)

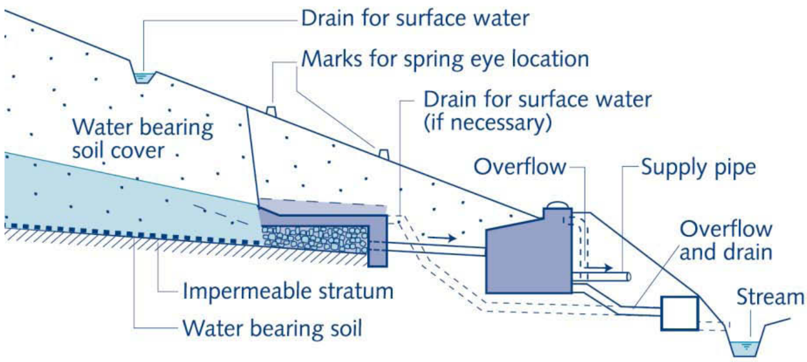

Figure 3 - layout of a typical spring catchment, taken out of (SMET & WIJK, 2002)

Figure 3 illustrates a typical spring catchment construction. The water in the soil is collected in lateral drain pipes. Prior to these pipes the water is filtered through a gravel bed, and drain pipes are protected by clay walls on top and behind. Through a larger pipe the water is guided to the catchment construction from where it then enters the supply network.

2.3.1.2 Borehole for Groundwater Extraction

A borehole is a well or a hole, which is drilled into the aquifer and partially or fully lined for the abstraction of groundwater. If lined, it has a casing consisting of pipes in the non-water bearing formations, and perforated or slotted screen sections in the aquifer. The water that infiltrates into this borehole is then abstracted with the assistance of a pump located at the bottom of the hole. Boreholes can be erected at nearly any part in the world. The construction is quick and simple with various drilling techniques available suiting most geological conditions (BRUNI, 2012a). A small valve box on level with the surface allows for secure access to and protection of the borehole.

Drilling cost components

Borehole construction costs can be divided into four components in general, each of which can be further sub-divided (CARTER, 2006). These components are:

Mobilization and demobilization – costs of transporting equipment to the site and for preparation of the drilling.

Drilling – actual cost of drilling the hole. These costs are highly dependent on the hired company – costs may differ vastly over different countries or even within a country.

Supply and Installation of casing – includes completion of borehole construction with a well screen, the casing, a gravel pack, sanitary seal and concrete works. These costs are naturally related to the depth and diameter of the borehole.

Development and test pumping – includes removal of drill fluids and damage that occurred to the aquifer, as well as testing the borehole.

As mentioned, prices for drilling, casing and development may differ drastically between countries and companies. It is therefore imperative to obtain real costs from various providers in different countries and to include these prices in the final BoQ. Until then, the BoQ assumes a price per meter for the drilling and leaves out casing and development costs, as it is not guaranteed that every borehole will be constructed with casing and proper development.

An important cost factor of bore holes are the success rate and the post-construction failure rate. The success rate refers to boreholes finally delivering water after the drilling, and a usual value is around 70%. The post-construction failure can occur after poor construction, inaccurate assessment of the groundwater layer and its consequences, drought or pump failures, and is assumed to be 30%. Both factors are combined in Figure 4, with the assumption that a “dry” borehole will cost around 60% of the costs for a successful drilling. (CARTER, 2006)

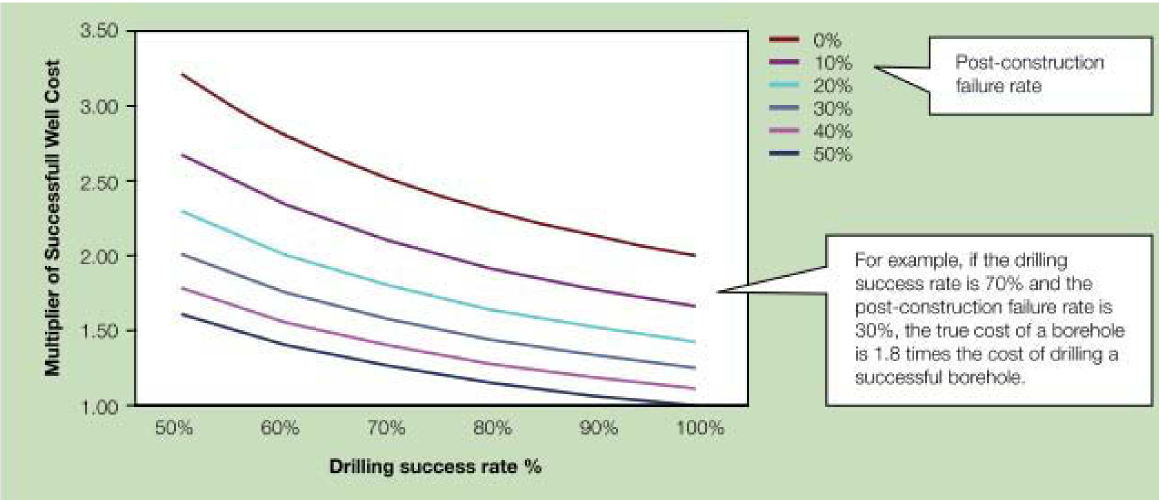

Figure 4 - Effects of drilling success rate and post-construction failure rate on borehole costs, adapted from CARTER, 2006.

2.3.1.3 River Water Extraction

In general, surface water sources for extraction include rivers, channels and lakes. The water usually will be pumped out of the source into the treatment plant. This technology is a combination of river water extraction and a screener.

River water is an important surface water resource for domestic, agricultural (e.g. irrigation) and industrial (e.g. energy production, cooling) areas. River water quantity and quality can differ

greatly and are dependent on the runoff system of the stream, seasonal changes and conditions (e.g. vegetation) the river flows through on its way to the ocean (STAUFFER, 2011). A very coarse screen for pump protection is used as first step of surface water treatment and is part of the extraction structure, which is assumed to be a concrete structure protecting the pump and allowing for maintenance. The water is pumped to a nearby treatment plant. Here, a free-level intake out of a river stream is assumed, "in which the water supply levels are uncontrolled, and the intake operates in all water flow conditions. This system is simple and relatively cheap, but usually requires a reliable water supply that does not fluctuate excessively" (FAO, 2006) In general, the approach is adaptable to any surface water extraction.
A bar screener is often the first, preliminary step of a water treatment plant. It is a screen made out of vertical steel bars located across the water flow to prevent entry of larger solid particles and objects above a certain size, for example plastic cups. These particles get caught at the screen and remain there until removed. Therefore, a bar screen is a mechanical filter to remove large objects. (KODAVBASAL, 2006)

2.3.2 Water purification

Pollutants such as metals, viruses, oils, excess nutrients, and sediment often enter the water cycle and contaminate water to a degree it is no longer useable without risks. While the nature provides some degree of purification itself by filtering water when it moves through forests, wetland areas, riparian zones or groundwater layers (U.S. EPA, 1999), often it is necessary to further ensure that the water used for domestic and commercial purposes is safe. In a drinking water treatment plant the water gets purified to fulfill human drinking water standards. (CWEA, 2004) The following presented technologies are implemented in the planning tool:

2.3.2.1 Grit Channel and Slow Sand Filtration

A grit channel is, as the name indicates, designed to remove so-called grit out of the incoming water. Simply put, it is a channel where all particles above a chosen size will settle at the channel floor. (BRUNI, 2012b) Grit from fresh water sources consists mostly of natural materials like sand, stones, gravel, soil, but also fragments of glass, seeds metals and other materials may be found. More general defined, grit has a specific gravity between 1.5 to 2.7. It has to be removed as it can cause problems further down the treatment plant, e.g. wearing down mechanical equipment, blocking pipes or accumulating in and consequently blocking other tanks Grit settles as discrete particles, unlike organic solids which usually are removed by flocculation. Thus, it settles independently of other particles with a constant velocity. (EPA IRELAND, 1995) Following this concept a grit channel is designed to have a lower horizontal water velocity than the settling velocity of the materials desired to be removed.
Slow sand filtration then filters water by flushing it through multiple layers of sand. Fine particles are filtered out as the sand holds them back. A proper "slow sand filter (SSF) effectively removes turbidity and pathogenic organisms through various biological, physical and chemical processes in a single treatment step." (BRUNI, 2012b) Although the physical removal of sediments is important for the purification process, the relevant aspect in a slow sand filter is the biological aspect. Due to the fine sand and the slow velocity of the filtration process, a microbial community can establish on the top layer of the sand substrate, also referred to as „schmutzdecke'. These microbes usually come from the source water and establish within a few days. The majority of the community is predatory bacteria that feed on water-borne bacteria, viruses and organic matter in the water passing through the filter (WHO, n.y.). The filter reservoirs have drains in the bottom covered with gravel and sand. Raw water slowly enters the

filter through an inlet, and an outlet leads the clean water from the drains to the water mains. (BRIKKE & BREDERO, 2003)

2.3.2.2 Sedimentation and Coagulation

Coagulation-flocculation is a chemical water treatment usually applied with, directly prior to sedimentation to enhance the ability of the treatment process to remove particles. Coagulation neutralizes charges of the particles in the water, forming a gelatinous mass of particles that is large enough to settle. Flocculation is gentle of the particles to promote agglomeration into particle clouds large enough to settle in a final sedimentation tank (MAZILLE, 2011)
Sedimentation is a simple, physical process of removing suspended and colloidal particles by settlement. By the use of gravity small suspended matter, like sand, clay or some biological contaminants, are removed from the water. The process can be aided by adding chemicals, so-called coagulants, to create bigger flock size of colloidal particles and raise the density and surface area to enhance their settlement performance. Common chemicals for this purpose are aluminium sulphate (Alum), polyaluminium chloride (PAC, also aluminium chlorohydrate) and ferric sulphate. (CAWST, 2009)
The steps of this technology are usually split into 3 separate but connected tanks, where the different steps of the process take place. Accordingly, the tanks are called coagulation tank, flocculation tank and sedimentation tank.

2.3.2.3 Disinfection

Killing pathogenic bacteria in the drinking water is called disinfection. Chlorination as disinfection method has proven effective against waterborne pathogenic organisms since the middle 19th century and was massively introduced in the early twentieth century (BRAGHETTA et al, 1997). Moreover, chlorination also reduces iron, manganese and hydrogen sulphide concentrations in water. In most cases, chlorination is even today the least costly and best option to disinfect water supplies. Due to the possibility of a residual amount of chlorine, bacterial growth and recontamination can also be controlled in the water system. Chlorination is usually the final step in the treatment process. (SKINNER, 2001)
In order to eliminate unwanted organisms, the “sufficient chlorine **demand”** has to be met within a certain contact time, usually about 30 minutes. Moreover, a **residual** of chlorine should be kept up throughout the water system as it provides further disinfection and protects against risks of disinfection, e.g. at leaks. Therefore, the total required chlorine dose is the combination of chlorine demand and chlorine residual.
The best time for application is after the other treatment process and before the water enters the distribution system. Chlorination should not be applied prior to biological processes like slow sand as the chlorine attacks the bacteria assisting in the treatment and renders the process ineffective. (PARR et al., 1999)
Chlorine is applied in three different ways: As Chlorine gas (Cl2), which is compressed into a liquid for storage. Chlorine gas is cheaper than either of the other forms. Chlorine in its solid form is given as calcium hypochlorite (Ca(OCl)2) powder, also known as High Test Hypochlorite (HTH). Only about 65 – 70% of the HTH is chlorine, the rest not-disinfecting calcium. Chlorine bleach is a liquid solution of sodium hypochlorite (NaOCl). It usually consists of 3 – 12% chlorine with the rest being water. Bleach is the most expensive form of chlorine and is normally used for disinfecting small wells and water lines. It is sometimes used for water supply disinfection in very small water systems (RAGSDALE AND ASSOCIATES, 2002).

2.3.3 Water distribution

Water distribution systems transport treated water from the plant to the user. The system should supply the required quantities of water, without reducing its quality and at sufficient pressure to meet system requirements.
Storage facilities – usually tanks, reservoirs or towers - provide space for treated water before it is distributed to the end user. The water distribution system demands storage quantities capable for basic domestic purposes, commercial and industrial uses, and needs to account for flows necessary in emergencies such as firefighting. (BHADWAJ & METZGAR, 2001) The following presented technologies are implemented in the planning tool:

2.3.3.1 Water storage

A water tank is a container for storing water. Storage tanks are a very important part of a water system because they ensure that adequate quantities of water are available to meet the demand. They balance the average supply and variable water demands of users. Storage tanks also help in preserving water quality. (WATER FOR THE WORLD, n.y.) They are usually categorized in either ground level storage tanks (3.1) or elevated storage tanks (3.2).
Water tanks are required for many different functions. They increase reliability of supply as they provide a reserve of clean water in case of failures at mains or pumps, as well as a reserve for firefighting or comparable emergencies. The construction of water tanks allows maintaining constant pressure in the whole system, assists pumping at average flow rates and permits to reduce the size of distribution main pipe lines.
The tanks volume depends on the required water for the supplied area. To not only be able to deliver necessary average volumes, but also be flexible enough to respond to unexpected interrupts or emergencies, water tanks are usually classified by function: operating, equalizing, fire and/or emergency, and dead-storage volumes. (BHADWAJ & METZGAR, 2001)

- Operating Storage: Describes the volume difference between the water level when the pump is active and when it is inactive.
- Equalizing Storage: Describes the necessary amount of storage required when the supply pump capacity is lower than the system requirements at peak. It allows water production facilities to operate at a relatively constant rate.
- Fire Storage: Is the water stored in the tank for fire fighting.
- Emergency Storage: This storage provides water during extraordinary, emergency conditions.
- Dead Storage: Describes the volume in tanks that cannot be drawn out because of elevation or low pressure.

For the presented technology designs, operating and equalizing storage have been combined to “active reservoir volume”, while dead storage is no factor.

Elevated water tanks are an alternative to ground water tanks when areas lack of natural elevation. Like ground water tanks, elevated tanks are supplied with drinking water from a purification plant to balance the average supply of the users. They are usually erected at a required height to allow an effective gravity feed and adequate line pressure in the water distribution network. Elevated tanks deliver constant water pressure without the need of a permanent pump operation, as the pump only needs to refill the tank when water is used and taken out of the tank. Elevated tanks are usually of smaller capacity because they require a supporting tower structure. (WATER FOR THE WORLD, n.y.)

2.3.3.2 Pump station

Pumping stations are necessary where large amounts of water is pumped directly into a piped distribution system and have to be transported through this system, or where water pressure in a distribution system has to be increased because there is an insufficient difference in water levels in the distribution system. (WHO, 2006 & STAUFFER, 2012)

All pumps use basic forces of nature to move a liquid. The general concept is comparable to sucking a straw. As the mobile parts of a pump start to move, air is pushed out of the way. This movement creates a partial vacuum of low pressure, which then will be filled up by water. However, centrifugal pumps can lift water no more than 7.9 m at sea level. This drops off approximately 0.6 m for each 305 m of altitude above sea level (THE WORLD BANK, 2012).
Pumps need mechanical maintenance (e.g. lubrication) as described by the manufacturer.
The energy cost is undeniably one of the most important cost components in the water supply system. Large amounts of electricity are required to transport the water to desired heights with the necessary pressure. The profitability of a water supply system is therefore heavily dependent upon energy costs (PULIDO-CALVO & GUTIERREZ-ESTRADA, 2011).

2.3.3.3 Distribution network

The distribution network is a system of pipes and trenches. It aims to supply a community with the appropriate quantity and quality of water. As such networks can be very large, it is sensible to split it into several technologies. From the treatment plant to the end user, the technologies in the SPT are:

- Technology 3.4: Water main transmission line – The main pipe delivering the purified water from the plant to the community. Water transmission mains convey raw water to the treatment plant from various surface and underground sources. After treatment, the transmission mains carry the clean water onward to the water supply network and from there on to the users. Robust pipes are used for this purpose. They are protected by being buried in a trench.
- Technology 3.5: Water distribution network – The actual network within the community with pipes branching from the main line. Water distribution networks consist of pipelines laid into trenches, with the goal to provide a community with the necessary amount of water.
- Technology 3.6: House connections – The last meters of pipe before the water can be drawn out of the system by a user. House connections are the final meters in the pipe network linking a single house to the nearest pipe of the supply network. A water meter is installed to measure the amount of water consumption of a single household.

A water system has two primary requirements: First, it needs to deliver adequate amounts of water to meet consumer consumption requirements plus needed fire flow requirements. Second, the water system needs to be reliable; the required amount of water needs to be available every time of a day, on every day of a year. (HICKEY, 2008)

The hydraulics of such a network is the main component of its design. Pressure in the system is generated through gravity or pumps and lost by friction, depending on the water demand and the pipe dimensions. The system needs to deliver sufficient pressure at the point of supply to provide an adequate flow to the consumer and it needs to ensure hygienically safe water. The more properties a system needs to supply, the higher the minimum pressure becomes. The actual design assumption for the pressure is already listed in technology 3.4 as it is valid for the whole distribution system. (AINSWORTH, 2004)

3. Methods

3.1 Cost function development approach

Creating a cost function is similar for any technology. The basic steps are presented in Figure 5 and further discussed in the subsequent chapter. The development of the cost functions requires following tasks:

1. Create a standard design incl. a short technology description, design assumptions, dimensioning and determine design sizes. A design drawing is very useful for this.
2. Provide a bill of quantity for each design size and calculate with the specific unit price of each position in order to get the individual investment costs.
3. Determine operation and maintenance (O&M) costs for each design size
4. Determine reinvestment costs at defined life span for each design size.
5. Determine revenues if existing.
6. Define input parameters for the cost function.
7. Create investment, O&M and reinvestment cost function based on the input parameters.

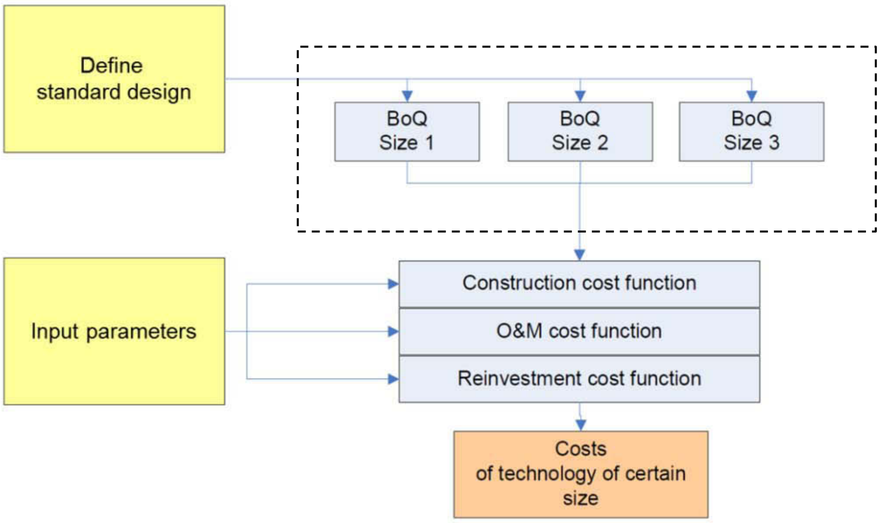

Figure 5 - Overview of cost function development

3.2 Explanation of the cost functions development

3.2.1 Technology descriptions

These short descriptions give a brief overview of the technologies, helping to get a first understanding. If required, more detailed descriptions and further information are available on the Sustainable Sanitation and Water Management Toolbox (SSWM, 2013).

3.2.2 Design assumptions

Without certain assumptions made for a technology, it is hardly possible to develop a cost function. The design assumptions include necessary data to reproduce the selected design. They are based on past knowledge and literature and should represent state of the art design of the technology. An example would be the estimation of trench depth for piping in a distribution network. Without assuming a certain depth, excavations costs cannot be calculated. The planner needs to consider the assumptions carefully and take the right adaptations when he differs from the given information. Following expenditures are not considered in any cost function:

- Land purchase
- Site office
- Any transport costs e.g. for equipment
- Documentation

3.2.3 Input parameters

The input parameters are the variables of the cost functions. They are essential to derive cost functions that display results for any size of the technology.

A frequently used input parameter in water supply is the demanded water volume “Q” which is extracted from a source, treated in a plant, stored or delivered in a network. It is usually measured in m³ per day. For many technologies though, more than a single input parameter is necessary. Where required, the final cost function will consist of 2 variables or even more.

Not really an input parameter, but also important is the opportunity to choose a country. This is important as different countries provide different unit costs for the BoQ, which is explained more detailed in the cost functions chapter.

3.2.4 Dimensioning

The cost functions are based on the standard design of a technology scaled over different sizes, usually dependent on the input parameters. Once the standard design is set, the range of the design sizes can be decided, which should be backed by literature or other knowledge. The next step is to prepare bills of quantities. The calculation for the design sizes is done in the same way as for the standard design. The dimensioning process can differ from technology to technology.

3.2.5 Cost Functions

3.2.5.1 Investment cost function

Investment costs are unique expenses required for the construction of a facility (LAWA, 2005). The investment costs in this thesis are split into categories, which allow determining the cost allocation between the categories if desired. Usually, the different cost categories are earthworks, construction and specific equipment.

The investment cost function serves to determine costs for the planners desired technology size. It is based on the resulting investment costs of the various design sizes and derived by the results of the particular BoQ. A more realistic approach would be the application of real project costs, but without sufficient data the approach of using BoQ and unit costs is a valid alternative. The BoQ is built out of so-called positions of material, parts and labor necessary for the construction of the technology. In short, a BoQ itemizes the costs so that every part adding to the total costs can be selected as an item, e.g. “1 hour of labor” or “1 m³ of earth excavation”. The numbering of the positions is based on the Austrian standard specification for tenders (LB-SW, 2005), but the actual unit prices are delivered by the participating African countries. Some positions do not exist in the standard specification, therefore have no numbering according to LB-SW (2005) and a listed as “non-standard”. The BoQ with inserted unit prices result in the investment costs for a technology of a specific size. The cost functions are derived from the cost for specific design sizes by using trend functions (linear or polynomial).

3.2.5.2 Operation and maintenance cost function

O&M costs include all expenditures during the operation stage required for the process, maintenance and monitoring. The O&M costs include every component that needs reinvestment every 5 years or sooner, unless noted otherwise (LAWA, 2005). Usually O&M cost include:

- Labor costs (e.g. operation staff, service and maintenance staff)
- Energy costs (e.g. fuel, electricity)
- Material costs (e.g. spare parts, chemicals)

The O&M cost function is derived from the O&M costs of selected design sizes, similar to the investment cost function. Most O&M unit costs used in this thesis are based on provided costs from the participating countries, but some costs, e.g. electricity costs, can also be based on literature values or Austrian standards.

3.2.5.3 Reinvestment cost function

Reinvestment costs include replacement expenses for system components whereby their operation life span is longer than 5 years, but shorter than the operational time of the facility (LAWA, 2005). The reinvestment cost function is also derived from the specific reinvestment costs for the respective BoQ. It is important to note that the reinvestment periods are defined separately for different parts of a technology. For example, it can be anticipated that pumps have a longer life expectancy than structures made of concrete or pipes made of polyvinyl chloride (PVC) or unplasticized polyvinyl chloride (UPVC).

3.2.5.4 Development of cost functions

The cost functions were developed in MSExcel®. Based on a technology`s standard design, all necessary calculations were made within the excel sheet to obtain the required amount for each of the positions. All of these positions were identified to be a factor in the costs for the respective technology. Afterwards, the positions were linked to unit costs, specific for each position with input given from the participating countries. The unit costs were stored in an additional excel file. Within each cost function file, the user can choose the country where he wants to build a technology and the unit costs change accordingly.

3.3 Literature Research

Most of this thesis data and assumptions are based on literature research, mainly in the internet. These days plenty of information on water supply and sanitation can be found in the internet from various sources, e.g. governmental or non-governmental organizations that are involved in project realizations or scientific papers covering the rather theoretic aspects. Most of this literature is available for free. Furthermore, the CLARA planning tool works in cooperation with the SSWM toolbox, where lots of information on the topic is given and further readings are listed. Consequently, literature research was the foundation for most information given in this thesis. Following portals and websites provide useful information:

- Sustainable Sanitation and Water Management (SSWM) toolbox
  http://www.sswm.info
  http://www.sswm.info/category/implementation-tools/water-sources
  http://www.sswm.info/category/implementation-tools/water-purification
  http://www.sswm.info/category/implementation-tools/water-distribution

- Sustainable Sanitation Alliance (SuSanA)
  http://www.susana.org

- WHO's Institutional Repository for Information Sharing
  http://apps.who.int/iris/

Additionally, the following two documents proved as extremely resourceful to shape general designs for the technologies presented in this thesis:

- Water Supply Systems and Evaluation Methods. Volume II: Water Supply Evaluation Methods by HICKEY (2008):
  https://apps.usfa.fema.gov/feedback/

- KAUB, J.-M., 2009, Abwasserbehandlung 5. Auflage DWA/Bauhaus-Universität Weimar – Weiterbildendes Studium »Wasser und Umwelt« 4–31, WS 2009/2010, Dipl.-Ing. J.-M. Kaub: Mechanische Reinigung,
  http://www.uni-weimar.de/Bauing/wbbau/studium/online/ww52/objects/print.pdf

3.4 Country-specific Technology Assessment

The technology descriptions including the design assumptions and expected reinvestment intervals were sent to the participating countries. They were asked to give feedback on the documents. This could be simple agreement with the given description and assumptions, but the main goal here was to identify misconceptions in the technologies design. Feedback from the countries included comments on some of the design assumptions, lack of a critical parameters, deviation from the life time assumptions of technologies, requirement of further input parameters or simple basic information about how technologies are used and constructed in the respective country. The feedback was evaluated and, where necessary, adaptations were made. These adaptations can be valid for all countries or specifically tailored to a single country.

4. Results

4.1 General

For 12 different technologies cost functions were developed. For all of these technologies a standard design was defined, technology descriptions and design assumptions made. The technology assessment was completed for each technology respectively. In the following section, each technologies result will be explained in detail.

4.2 Feedback from the participating countries and adaptations

The technology descriptions were sent to the participating countries in order to get feedback on the applicability and acceptance of the general design for each technology. For each technology, the participating countries had to give a brief technological assessment about the design and existing deviations in the countries standards to the given design assumptions. The following chapter presents the feedback of the different countries, more specific Burkina Faso, Ethiopia, Kenya, Morocco and South Africa. It also shows consequences in some cost functions. It also aims to provide insight about why some feedback entails adaptations in the cost functions.

General note:
For some of the technologies, Ethiopia developed cost functions based on existing implementations. Although logic dictates to simply use these existing functions, the recommendation here is to stick with the cost functions derived from the BoQ for the planning tool. This decision is based for some part on the fact that the Ethiopian cost functions are based on their Arba Minch project and might fit specifically for that project, but less so for project in different areas of the country. Furthermore, some cost functions require input parameters that the planning tool does not use as at all or only as an optional input parameter. For a realistic evaluation of the cost functions, the tool needs data of realized projects. These projects should be compared to cost predictions of both cost functions, the one given by the SPT and the other given by Ethiopia, in the future.

4.3 Technologies with realized cost functions

This chapter contains the results for the separate technologies. This includes the technology description that was sent to the countries, the input parameters that were estimated to be necessary and the design assumptions that were taken to allow for concrete calculation of costs. Furthermore, a design description explains the actual realization of a technology and lists possible deviations from the technology descriptions. The results of this process are the cost functions, which will be implemented in the CLARA SPT. Lastly, the country specific assessments for each technology are considered and changes due to these assessments are pointed out. To keep the results concise, the results will only presented for Ethiopia. The cost functions to the other countries are similar, but differ in detail because of the changing unit costs. For all positions listed in one of the tables for a cost function without a standard position given, the assumed costs are stated in the last row of the respective table. Where possible, those assumptions were based on comparable positions with a price input given or literature values were used.

Some technologies offer the possibility to give input for parameters that are not mandatory to get final cost estimations. If provided, these parameters generally increase the accuracy of the estimations, but they are only optional because at early planning stages the correct numbers might be unknown or unavailable. If a technology has optional input parameters, these parameters are listed with the addition “If known” in the input parameters section of the technology.

For all technologies, one and maybe the key input parameter is the daily water demand Qd, given in m^3/d. Alternatively the input parameter might be given as Qhmax, the maximum water demand in one hour, because for some technologies the maximum water flow is required for calculations, instead of the average flow per day. Accordingly, the volume will be multiplied by 24 to calculate the absolute maximum for a day. The rest of the functions stay unchanged, so that the daily water demand Qd will be simply replaced by Qhmax*24.

4.3.1 Technology 1-1 Spring Extraction

4.3.1.1 Technology Description

When groundwater makes its way to the earth's surface and emerges as small water holes or wet spots, this feature is referred to as a spring. The use of springs as the main source for community water supply is applicable whenever a spring occurs and its yield and quality are adequate. Several types of springs can be distinguished: Gravity springs emerging in a single spot, springs that have no distinct single outlet and require the installation of a catchment drainage system, and finally artesian springs.

4.3.1.2 Input parameters

Input parameters for the SPT user are:

- Daily water demand Qd [m^3/d];
  If known:
- Hydraulic conductivity kf [m/s]

4.3.1.3 Design assumptions

To be able to calculate a cost function for a spring, the following assumptions were made:

- Gravity spring with catchment drainage system
- If not given as input factor, the hydraulic conductivity kf is assumed to be 10^{-5} m/s
- The drain pipes are made of PVC
- The depth of trenches is assumed to be 200 cm as a minimum value
- Drain cover: 40x40 cm gravel, rest filled up with excavated soil
- Collection in a concrete chamber/spring box
- The entire gravel cover is not surrounded by a geotextile but can be adapted
- Fenced protection zone: square of 15m around the catchment area

4.3.1.4 Design

The general design of the technology can be seen in Figure 3. The water in the soil is captured by lateral drain pipes and channeled into one central pipe leading to the spring chamber. The drain pipes are buried in trenches on a sand bed. On top and behind these drain pipes the trench will be filled with impermeable clay walls. The incoming groundwater is filtered through a gravel layer before it reaches the drain pipes. The central pipe transports the collected water to the spring box. This box serves as a sedimentation tank and allows for regular control of the water. The planner has to give input for the water demand and can give input for the hydraulic conductivity of the ground if he has data available. Otherwise the kf-factor stated in the design assumptions is applied for the calculations.

4.3.1.5 Dimensioning

The dimensioning is based on the extracted water volume and on the kf-factor provided.
The kf-factor determines how much water can be filtered out of the soil in a given time. Therefore, to achieve the desired volume of water, the area that needs to be covered by the drain pipes increases with lower permeability of the soil.
Instead of letting the spring box grow according to the amount of cubic meters extracted, a more practical approach was taken by differing between two fixed spring box designs. The smaller box is a simple concrete inspection chamber with a manhole cover in the roof for necessary inspections. This chamber can be used for springs with a yield of up to roughly 3 - 30 m^3/d

(MEULI & WEHRLE, 2001). The larger box is based on the "advanced inspection chamber" from MEULI & WEHRLE (2001). It consists of two chambers: One chamber is for the water and the other is an inspection and operation room for the caretaker. The entrance is through a roof, as both chambers are supposed to be dug into ground.
Therefore, dimensioning was done for both, small and large spring boxes. Table 1 shows the daily water demands used for dimensioning.

Table 1 - Dimensioning values for technology 1-1 spring extraction

Daily Water Demand Qd	m³/d	3	6	9	12	15	18	21	24	27	30
Daily Water Demand Qd	m³/d	30	250	500	750	1000	1250	1500	2000	2500	3000
Hydraulic conductivity kf	m/s	0,000001	0.00001			0.0001		0.001			

4.3.1.6 Cost Functions

General

The cost functions are calculated for both chamber types by the prices of the 40 designs each with different water demand and hydraulic conductivity. The investment cost of a spring box comprises of costs for earthworks, construction and specific equipment listed in a bill of quantity. Differences between the spring box versions are pointed out specifically.

Earthworks costs

Earthworks costs include positions shown in Table 2. These positions consider preparation of the site, excavation and backfilling works. For the installation of drain pipes trench excavation is required. The bedding beneath the drain pipes is done with a layer of sand, while a layer of gravel is put in front of the drain pipes as a first filter mechanism. A pit excavation with inward-slope is performed and followed by backfilling after finishing the construction of the spring box. A blinding layer beneath the floor slab of the spring box seals in underlying material and prevents dirt and mud from interfering with the structure. The positions set-up and removal of construction site equipment are listed but set to zero, as they will be added separately at a final step.

Table 2 - Positions of earthworks costs (Extraction from spring)

Item no.	Position	Unit	Description
020201A	Clearing area	m²	
030201A	Remove topsoil	m³	
030206A	Replace Topsoil	m³	
030211B	Re-Cultivate topsoil	m²	
030310A	Trench Excavation	m³	
030331A	Pit excavation with inward-sloping	m³	
030705A	Backfilling and covering of concrete walls	m³	
030701B	Backfilling of trenches	m³	
030703B	Bedding with sand	m³	
030703C	Bedding with gravel	m³	

Construction costs

Construction costs consist of concrete works shown in Table 3. The quality of the concrete is supposed to be C20/25, separated into foundation, walls and ceiling of the construction. Ribbed steel is used to reinforce the concrete. Additionally concrete ancillaries are accounted for with a percentage amount of the total construction costs.

Table 3 - Positions of construction costs (Extraction from spring)

Item no.	Position	Unit	Description
110302A	Slab C20/25 up to 30cm	m³	
110401A	Wall 12-20cm C20/25	m³	
110605A	Concrete slab ceilings C20/25 up to 20cm	m³	
111902A	Ribbed steel < 10mm	kg	
n/a	Concrete ancillaries	%	1% of concrete costs

Equipment costs

Equipment costs include drain and water supply pipes, their valves and connections, a concrete manhole cover for the entrance, the clay walls, the fence and the baffle plate, which slows down the incoming water in the collection chamber. Additionally, for the large spring box stainless steel steps are included to allow the caretaker to climb into the inspection chamber. Table 4 lists all specific equipment positions for the spring catchment

Table 4 - Positions of equipment costs (Extraction from spring)

Item no.	Position	Unit	Description
205101B	Drain pipes plastic, rigid DN100	m	
210401F	UPVC water supply pipes PN10 DN/OD 160	m	
n/a	Valves	%	10% of pipe costs
111601A	Concrete manhole cover DN800 class B 125kN	pcs	
232005A	Stainless steel step plastic coated (large box only)	pcs	
n/a	Clay walls	m³	25€ assumed
n/a	Fencing	m	5€ assumed
n/a	Baffle plate	pcs	50€ assumed

Investment cost function

The final investment cost function is divided into two sets of separate functions, one set for the smaller and one for the larger spring box. The function for the small chamber is valid for values up to 200 m³/d, the large chamber continues then until a maximum of 3000 m³/d. In general, costs increase with the volume of daily water demand and with decreasing hydraulic conductivity. The resulting cost functions are:

Small chamber (≤ 30m³/d)

Investment costs IC (EUR)

$kf \leq 1E\text{-}05$ m/s: $y=10^\wedge(\log(-5E\text{-}05x^2 + 26{,}85x + 11128)+\log(z-5)*(-0.439))$ (1)

$kf > 1E\text{-}05$ m/s: $y=10^\wedge(\log(-5E\text{-}05x^2 + 26{,}85x + 11128)+\log(z-5)*(-0.046))$ (2)

Large chamber (> 30m³/d)

Investment costs IC (EUR)

$kf \leq 1E\text{-}05$ m/s: $y=10^\wedge(\log(-2E\text{-}05x^2 + 34.87x + 86825)+\log(z-5)*(-0.551))$ (3)

$kf > 1E\text{-}05$ m/s: $y=10^\wedge(\log(-2E\text{-}05x^2 + 34.87x + 86825)+\log(z-5)*(-0.072))$ (4)

With x = Daily water demand Qd in m³/d; z = kf-factor in m/s

Both times, the first cost function is for kf values smaller than 0.00001 m/s, the second is for kf values larger than 0.00001 m/s.

Figure 6 shows the resulting investment costs for different water volumes per day for the small spring chamber.

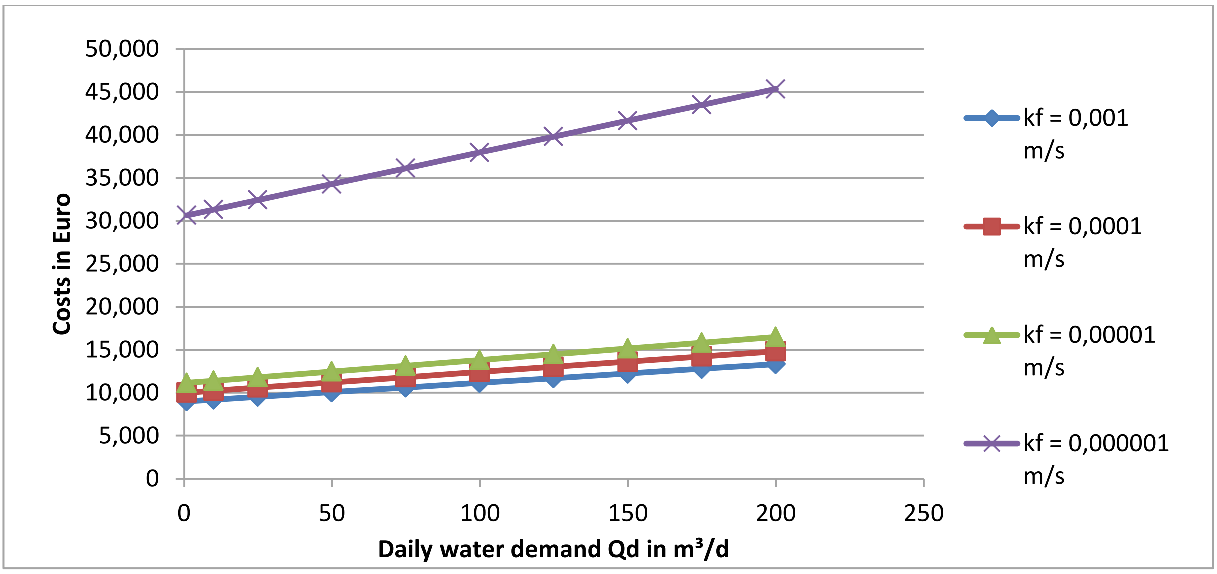

Figure 6 - Investment costs of a small spring chamber for different kf factor, dependent on the daily water demand Qd.

Operation and Maintenance Cost Function

Operation and Maintenance requirements are comparatively simple for spring catchments. It is recommended to have a weekly check-up and, if necessary, conduct minor repairs. It is assumed that the work amount does not increase with the size of the spring chamber. Furthermore, 1% of the total investment costs are added to the annual O&M costs. The resulting cost functions are:

Small chamber (≤ 30m³/d)
O&M costs OC (EUR/y)

kf ≤ 1E-05 m/s: $OC=10\^{}(\log(-5E\text{-}07x^2 + 0.2685x + 618)+\log(y-5)*(-0.138))$ (5)

kf > 1E-05 m/s: $OC=10\^{}(\log(-5E\text{-}07x^2 + 0.2685x + 618)+\log(y-5)*(-0.009))$ (6)

Large chamber (> 30m³/d)
O&M costs OC (EUR/y)

kf ≤ 1E-05 m/s: $OC=10\^{}(\log(-2E\text{-}07x^2 + 0.3487x + 1375)+\log(y-5)*(-0.448))$ (7)

kf > 1E-05 m/s: $OC=10\^{}(\log(-2E\text{-}07x^2 + 0.3487x + 1375)+\log(y-5)*(-0.048))$ (8)

With x = Daily water demand Qd in m³/d; y = kf-factor in m/s

Figure 7 illustrates the Operation and Maintenance costs per year over the total through flow range of the smaller spring chamber, whereas Figure 8 depicts the dependency on the hydraulic conductivity for investment and O&M costs for the small chamber with the fixed water demand Q = 100m³/d.

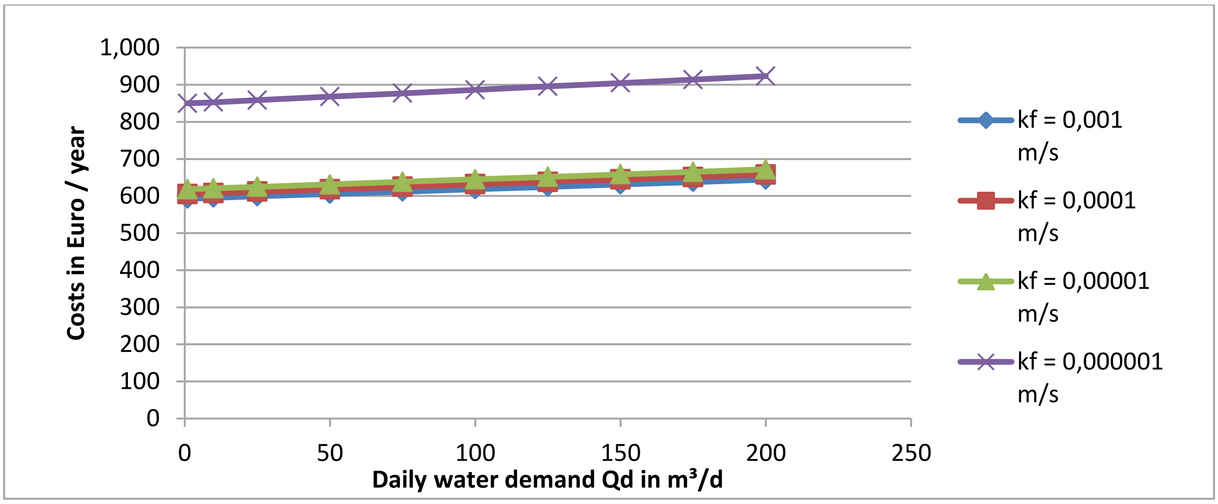

Figure 7 - O&M costs for a small spring chamber per year for different kf factor, dependent on the daily water demand.

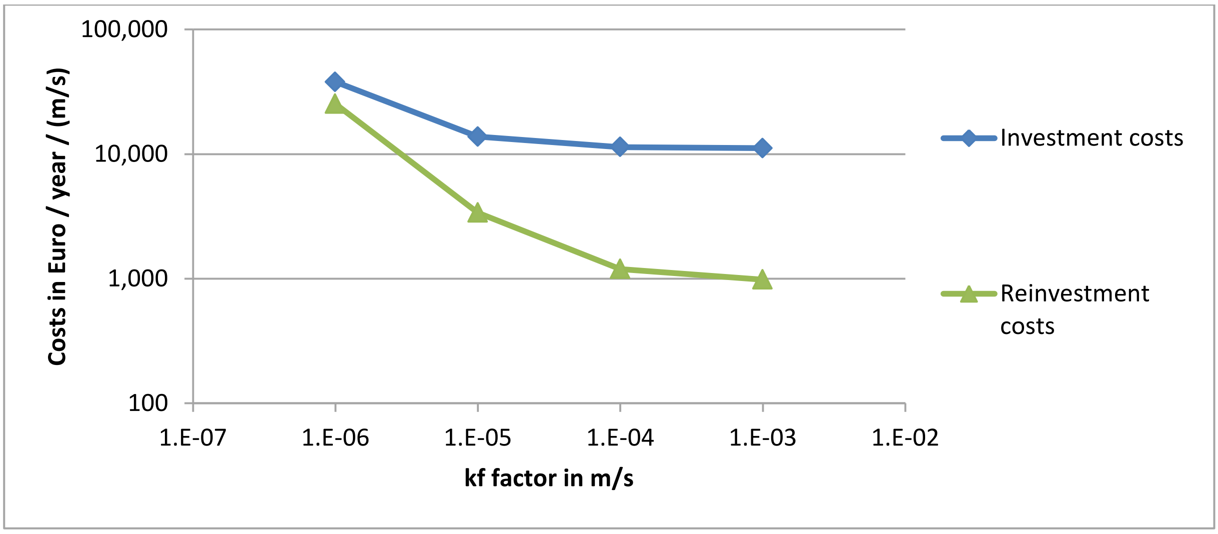

Figure 8 – Dependency on hydraulic conductivity for investment and O&M costs for small chamber with water demand Q = 100m³/d.

Reinvestment Cost Function

PVC pipes have a life expectancy of 40 years. Therefore, drain pipes, their trenches, the clay walls and the PVC pipes connecting the spring box have to be replaced after that time. The spring box, including related earth and concrete works, is expected to last for 25 years until it needs to be replaced.

4.3.1.7 Country specific assessment

This technology was accepted without further comments by **Kenya** and **South Africa**. **Morocco** often has so-called “Khettara” installed, which are an alternative method to catch groundwater. These are subsurface irrigation channels, often several hundred kilometers long. It is assumed that the first Khettara were constructed as early as the 12th century. A report about the Talfiat region states that “The last of the khettara will dry up in the near future, as the water table becomes so deep that "following the water" by extending the depth of mother wells would necessitate the excavation of new horizontal shafts; in essence, excavating new khettara from source to terminus, parallel to the old galleries but at greater depth. This would prove prohibitively labor-intensive and expensive.” (LIGHTFOOT, 1996) As a consequence, a simple adaptation of the design will not suffice to properly describe a khettara technology, but the design of a cost function for khettara does not seem feasible as the technology is on the one hand limited to Morocco and on the other hand rarely used in modern water supply.

Burkina Faso states that a spring catchment can only rarely be applied as the countries geographic are often problematic for this technology. They estimate life span of PVC pipes to be about 50 years instead of the given 40, but the result for reinvestment would not differ over the total project timeframe of 50 years.

Finally, **Ethiopia** prefers the fenced protection zone around the catchment to be of 30m length. This would be a simple adaptation, but as the fence is only a low factor in the total costs it can be neglected for the final cost estimation. Nevertheless, realized projects in Ethiopia will most probably use a protection zone of 30m size. Furthermore, Ethiopia estimates O&M costs to be around 2.2% of the investment costs per year. This value is much higher than the results given in the existing cost function, which were about 0.1 – 1 % depending on the size of the spring catchment. As a consequence, O&M costs for all countries have been adapted to count not only the labor costs for weekly inspections, but also to consider for minor repair costs by adding 1% of the investment costs as O&M costs per year. The resulting O&M costs therefore are between 1.1 – 2% of the investment costs. Table 5 summarizes the technology assessment.

Table 5 - Summary of country-specific assessment for technology 1-1 spring extraction

Burkina Faso	Ethiopia	Kenya	Morocco	South Africa
PVC pipes 50 years lifespan	30m fenced protection zone	-	Old khettara systems	-

4.3.2 Technology 1-2 Borehole for Groundwater Extraction

4.3.2.1 Technology Description

A borehole is a well or hole which is drilled into the aquifer and partially or fully lined for the abstraction of groundwater. If lined it has a casing consisting of pipes in the non-water bearing formations, and perforated or slotted screen sections in the aquifer. At the bottom of the borehole a pump delivers the extracted groundwater to the top.

4.3.2.2 Input parameters

- Daily water demand Qd [m^3/d]
- Diameter (8 inch, 20 inch)

    If known:
- Depth of the groundwater level [m]
- Hydraulic conductivity kf [m/s]

4.3.2.3 Design assumptions

- If not given - Hydraulic conductivity kf assumed to be 10^{-4} m/s
- If not given – Depth to groundwater level 80m
- Borehole lined with PVC pipe
  a) DN 200 (8 inch diameter)
  b) DN 500 (20 inch diameter)
  First 0 m drilled with bigger diameter to allow installation of surface casing
- Standard method: rotary drilled
- Rate of successful drillings: 70%
- Rate of post-construction failure rate: 30%
- Fenced protection zone: square of 15m around the catchment area

4.3.2.4 Design

The design is a basic borehole construction. At the surface a small area is dug out to construct a concrete chamber. In this chamber the borehole pipe connects to the water network, controlled by several valves. This design avoids that the water is pumped to a higher level than in the network and reduces the number of elbows and the respective pressure losses. The actual drilling of the borehole is supposed to be executed by local companies. Therefore, the technology for now assumes costs for drilling per meter. At the bottom of the borehole, where it connects to the groundwater layer, a submersible pump is located that can lift the demanded water volume. Based on literature of CARTER (2006), the calculation includes mean values for the rate of successful drillings (70%) and the rate of post-construction failure (30%). In the event of an unsuccessful drilling, earthwork costs and the drilling costs are still executed. This was considered by multiplying the earthworks costs with the result of 100/70 * 30, which amounts for the 30% of unsuccessful drillings. It is assumed that the rate of successful drillings is included in the drilling costs per meter. A likewise calculation is done with the rate of post-construction failure, but applied to the total investment costs of a borehole. The planner has to demand a daily water volume and choose the diameter of the pipe that extracts water from the borehole. If the information is available, the planner can furthermore provide the depth of the groundwater level and the hydraulic conductivity of the ground. If no input is provided for these parameters, the tool will use the design assumptions.

4.3.2.5 Dimensioning

The dimensioning is based on the extracted water volume and the depth of the groundwater layer. Furthermore, the BoQ is limited to two different commonly used pipe diameters, 8 and 20 inch. The pipe diameter restricts the extraction maximum to a certain threshold. The maximal extraction velocity should not to exceed 1 m/s (DVGW W 118, 2005) leading to maximum extraction values of 1728 m³/d for 8 inch diameters and 14400 m³/d for 20 inch diameters. This is in congruence with values given by BALL (2001), who states that "flows of 10,000–40,000 liters per hour are quite achievable in a productive water". The maximum value for 20 inch is mostly theoretical, as it would require borehole depth of about 340m, with boreholes usually constructed down to depths of 200 m. Particularly in arid or semi-arid regions as represented in the CLARA project, the depth of wells should take seasonal or annual fluctuations in the water table into account to avoid drying up in periods of low water table. (SMET & WIJK, 2002)
Smaller boreholes with shallow depth may be constructed by driving, jetting, boring or sludging. For the rather general approach in the BoQ, drilling is more versatile. It is more appropriate for larger-diameter boreholes and the withdrawal of considerable amounts of water at greater depths and it is also a good approach for tapping aquifers overlaid by rock formations. It does, however, require complicated equipment and specialist drillers with adequate knowledge and experience.
The dimensioning starts at 25 m³/d and goes up to 1728 m³/d for the 8 inch borehole as seen in Table 6, for the 20 inch borehole it starts at 100m³/d and goes up to the maximum of 14400 m³/d, as shown in Table 7.

Table 6 - Dimensioning values for 8 inch diameter borehole

Water demand Q	m3/d	25	100	300	500	750	1000	1200	1400	1600	1728
Depth of gw layer	m	20	50	80							
Kf factor	m/s	0,001	0,0001	0,00001	0,000001						

Table 7 - Dimensioning values for 20 inch diameter borehole

Water demand Q	m3/d	100	500	1000	2000	3000	5000	7500	10000	12000	14400
Depth of gw layer	m	20	50	80							
Kf factor	m/s	0,001	0,0001	0,00001	0,000001						

4.3.2.6 Cost Functions

General

The cost functions are calculated by the varying prices of 60 designs of different diameter, groundwater layer depth and water demand, as identified in the dimensioning. The investment costs of a borehole for groundwater extraction include costs for earthworks, construction and specific equipment in a bill of quantity.

Earthworks costs

Earthworks costs include positions shown in Table 8. These positions consider preparation, excavation and backfilling works for the valve box. The pit excavation is performed as an excavation with inward-slope and followed by backfilling afterwards. The blinding layer is necessary to allow an even valve box construction and it seals in underlying material as well as smoothens over the gaps to give a cleaner, drier and durable platform. The positions set-up and removal of construction site equipment are listed but set to zero, as they will be added separately at a final step.

Table 8 - Positions of earthworks costs (Groundwater Extraction)

Item no.	Position	Unit	Description
020201A	Clearing area	m^2	
030201A	Remove topsoil	m^3	
030206A	Replace Topsoil	m^3	
030211B	Re-Cultivate topsoil	m^2	
030331A	Pit excavation with inward-sloping	m^3	
030705A	Backfilling and covering of concrete walls	m^3	
030708A	Blinding layer <10cm	m^3	

Construction costs

Construction costs consist of concrete works positions required for the valve box, which are shown in Table 9. The quality of the concrete is supposed to be C20/25. Instead of a ceiling made of concrete, the valve box merely needs a simple lid of a cheap and available material. Ribbed steel is used to reinforce the concrete and concrete ancillaries are accounted for in a percentage of the total constructions costs.

Table 9 - Positions of construction costs (Groundwater Extraction)

Item no.	Position	Unit	Description
110302A	Slab C20/25 up to 30cm	m^3	
110401A	Wall 12-20cm C20/25	m^3	
n/a	A simple lid	pcs	100€ assumed
111902A	Ribbed steel <10mm	Kg	
n/a	Concrete ancillaries	%	1% of concrete costs

Equipment costs

Equipment costs in Table 10 cover the pump and its required electronics, piping and the respective valves and fittings, fencing and the drilling cost per meter.

Table 10 - Positions of equipment costs (Groundwater Extraction)

Item no.	Position	Unit	Description
201401D	UPVC water supply pipes PN10 DN/OD 110	pcs	
n/a	Valves and fittings	%	10% of pipe costs
n/a	Fencing	m	5€ assumed
n/a	Pump	-	
n/a	Electronics (Control cabinet, cabeling)	%	10% of pump costs
n/a	Drilling cost	€/m	250€/m for 8 inch 450€/m for 20 inch

Investment cost function

The final investment cost function is divided into two separate functions, one for the 8 inch pipe diameter and one for the larger 20 inch pipe diameter. In general, costs increase with higher extraction volume and higher groundwater level. Furthermore, the lower the hydraulic conductivity the higher the investment costs become. The resulting cost functions are shown in Eq.9 and Eq.10:

Investment costs IC for 8 inch diameter:

$$IC = -0.0053x^2 + 32.201x + 26191 + (y-80)*(-0.0002x^2 + 0.3192x + 250.75) \quad (9)$$

Investment costs IC for 20 inch diameter:

$$IC = -0.0005x^2 + 19.853x + 44241 + (y-80)*(-5E\text{-}06x^2 + 0.0452x + 568.13) \quad (10)$$

With x = Daily water demand Qd in m³/d, y= Depth of Groundwater level in m

Figure 9 shows the resulting investment costs for different water volumes per day for a borehole with an 8 inch pipe.

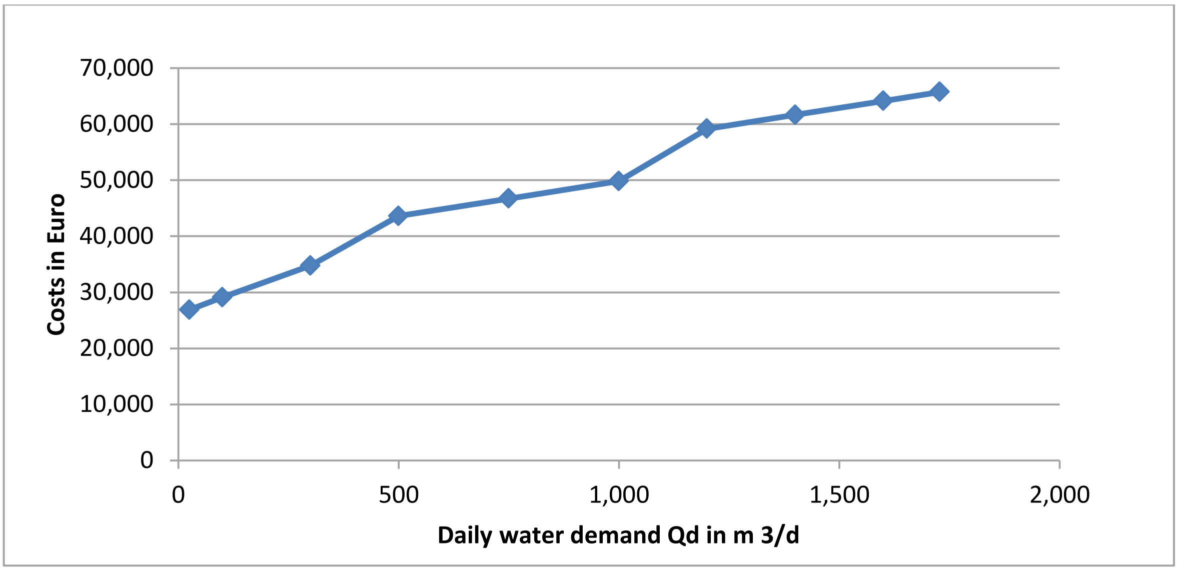

Figure 9 - Investment costs of Groundwater extraction with 8 inch pipe diameter and kf = 0.0001 m/s

Operation and Maintenance Cost Function

Operation and Maintenance costs for Groundwater Extraction consist mainly of the pump operation to lift the water to the surface and on to a treatment plant. Furthermore, inspection and cleaning of the pump after every 5000 operating hours is assumed. The borehole should be jetted every 5 years as the silt at the bottom of the well will accumulate and can be dislodged by a strong jet of water. The water jet will suspend the silt and carry it to the surface, until the water flowing out of the top of the well is clear.
The O&M costs for groundwater extraction for the 8 inch and the 20 inch diameter respectively are scaled over different extraction values up to the according extraction maximum. The resulting cost functions read as follows:

O&M costs OC for 8 inch: $OC = 0.012x^2 + 23.06x + 101.12 + (y-80) * 430.75 \quad (11)$

O&M costs OC for 20 inch: $OC = 0.005x^2 + 23.06x + 101.12 + (y-80) * 793.12 \quad (12)$

With x = Daily Water Demand Q in m³/d, y = Depth of Groundwater level in m

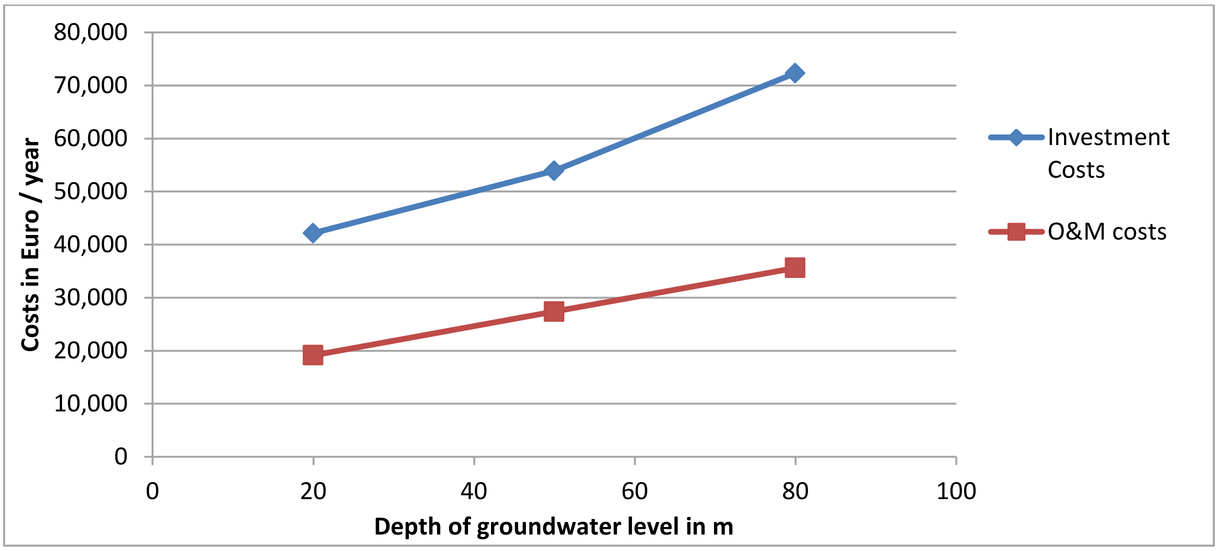

Figure 10 – Investment and O&M costs of groundwater extraction with increasing groundwater level for 8 inch borehole with Q = 1000 m³/d.

Figure 10 shows the dependency of costs with increasing groundwater level depth for both investment costs and O&M costs. Investment costs are nonrecurring, to be accrued at the beginning of the project, while the O&M costs are annual over the projects lifetime. Figure 11 depicts the development of O&M costs over increasing water demand for a borehole with 8 inch diameter and a groundwater level depth of 20m.

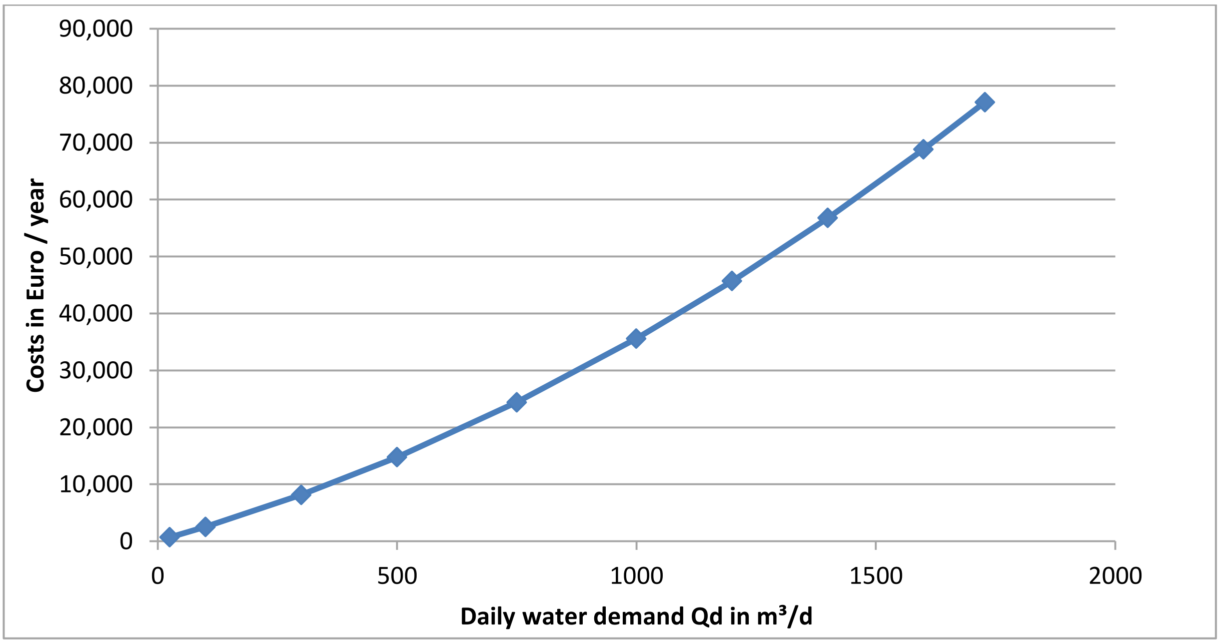

Figure 11 - O&M costs for groundwater extraction (8 inch) per year with groundwater depth level of 20m

Reinvestment Cost Function

The pump in operation has a life expectancy of 10 years and needs replacement after that time. The valve box, including related earth and concrete works, is expected to last for 25 years until it needs replacement.

4.3.2.7 Country Specific Assessment

Burkina Faso often uses hand pumps for groundwater extraction. An adaptation would require a number of changes in the BoQ, as hand pumps are usually employed for smaller water demands. The pump and electricity costs would be left out and the drilling method would presumably not be rotary drilling. Transport costs are accounted for by set-up and remove of construction site equipment.

Ethiopia gives input for the average energy tariff with 0.65 ET Birr / kWh. In Euro, this would be 0.03 Euro / kWh.

Kenya surrounds the pipe with a gravel pack as a pre-filter but the necessity is not definite as the extracted ground water will be transported to a treatment plant according to the basic design in the SPT.

In **South Africa** it is common practice that an Environmental Impact Assessment (EIA) is conducted before the construction of a borehole. As this is a national standard for many constructions it should be considered independently by planners in South Africa and is therefore left out of the tool.

Kenya, **Morocco** and **South Africa** ask for the pump extracting only 70-80% of the maximum yield of the borehole. This is a standard assumption to avoid damaging the groundwater layer, but it is not feasible for the tool as it merely receives the desired water volume to be extracted and then calculates a borehole that can deliver the volume. The true maximum yields of realized boreholes have to be determined on site and cannot be identified at the early planning stage the tool is supposed to be consulted.

Several countries demand pump testing between 24-72 hours of continuous operation. As a consequence, constructions will be complemented by a position called “pump testing” with an assumed test period of 24 hours. Furthermore, some countries give higher life spans for equipment, mechanical equipment 15-20 years and concrete works up to 30 years or longer. Here it seems to be sensible to keep the given, lower assumptions to stay on the safe site. Table 11 summarizes the results.

Table 11 - Summary of country-specific assessment for technology 1-2 Groundwater extraction

Burkina Faso	Ethiopia	Kenya	Morocco	South Africa
hand pumps	pump test	pump test		EIA
training staff manager	energy tariff is 0.65 ETBirr/KWh.	gravel pack around pipe		
		70-80% extraction of maximum yield	70-80% extraction of maximum yield	70-80% extraction of maximum yield

4.3.3 Technology 1-3 River Water Extraction

4.3.3.1 Technology Description

Surface water sources for extraction include rivers, cannels and lakes. The water usually will be pumped out of the source into the treatment plant. Coarse screening for pump protection is used as first step of surface water treatment and is part of the extraction structure.

4.3.3.2 Input parameters

Planner

- Daily water demand Qd [m3/d]
  If known:
- Pumping head [m]

4.3.3.3 Design assumptions

- Electrical pump extracts river water
- Distance pump to treatment plant: 100 m
- If not given - Pumping head: 25 m

Screen: consists of metal bars. Removal of screenings is performed manually. For maintenance and as emergency overflow, 2 screens are placed in parallel.

- Coarse screen flat bar 10mm, spacing e=25mm
- Sum of spacings (Σe) = channel width before screen
- v_{min}= 0.6 m/s; v_{max} 1.2 m/s
- Calculation headloss according to Kirschmer/Mosonyi
- Maximum screen occupation ~ 75%
- Channel width >2 x max. headloss
- 2 parallel waterlines

4.3.3.4 Design

Technology 1.3 is a combination of river water extraction with a bar screener following further away, intended to be the first step of a treatment plant. The water extraction is achieved by two pumps that both can deliver the demanded water volume to ensure functionality in case one pump breaks. They are located at the bottom of the river and protected by a concrete structure reaching from the riverbank into the water. The structure allows a caretaker to climb in and control or maintain the pumps. A very coarse screener protects the intake and a floodgate allows disconnecting the building from the river water. Furthermore, the pumps can be brought to the surface by lifting mechanisms, in case they require more extensive repairs or complete replacement. The extracted water is expected to be pumped to a treatment plant, where the first treatment step is a screener.

The screener is a concrete structure of two parallel waterlines with a bar screener each, made of metal bars. This is advantageous as it allows keeping one screener functional when the other has to be cleaned. The cleaning is done mechanically by a caretaker who can clean the bars from a weeping platform, which is installed across the screener. The planner has to submit the required amount of water and can add the pressure head from the river water extraction to the screener.

4.3.3.5 Dimensioning

The dimensioning is based on the input parameters, the extracted water volume and the pressure head. The technology is derived out of three different pressure heads, which are 10m, 25m and 50m, and of 10 water extraction values ranging from 1000 m³/d up to 5500 m³/d. These values are shown in
Table 12 and are based on information from KAUB (2009).

Table 12 - Dimensioning values for River water extraction

Water demand Qd	m3/d	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500
Pumping head	m	10	25	50							

4.3.3.6 Cost Functions

General

The cost functions are calculated by the total prices of 30 designs of different extraction volume and pressure head. The total cost of surface water extraction includes costs for earthworks, construction and specific equipment in a bill of quantity.

Earthworks costs

Earthworks costs include positions shown in Table 13. These positions consider preparation, excavation and backfilling works. The pit excavation is performed as an excavation with inward-slope and followed by backfilling after finishing the construction. A blinding layer seals in underlying material and prevents dirt and mud from interfering with the structure.

Table 13 - Positions of earthworks costs (River water extraction)

Item no.	Position	Unit	Description
020201A	Clearing area	m²	
030201A	Remove topsoil	m³	
030206A	Replace Topsoil	m³	
030211B	Re-Cultivate topsoil	m²	
030331A	Pit excavation with inward-sloping	m³	
030705A	Backfilling and covering of concrete walls	m³	
030708A	Blinding layer < 10 cm	m³	

Construction costs

The construction costs consist of the concrete works shown in Table 14. The quality of the concrete is supposed to be C20/25. Ribbed steel is used to reinforce the concrete. Additionally concrete ancillaries are accounted for with a percentage of the total construction costs.

Table 14 - Positions of construction costs (River water extraction)

Item no.	Position	Unit	Description
110302A	Slab C20/25 up to 30cm	m³	
110401A	Wall 12-20cm C20/25	m³	
110605A	Concrete slab ceilings C20/25 up to 20cm	m³	
111902A	Ribbed steel < 10mm	Kg	
n/a	Concrete ancillaries	%	1% of concrete costs

Equipment costs

Equipment costs cover the pump, its electronics and a lifting facility for the pumps. Furthermore, manhole covers for the entrance to the extraction building and the exits for the pump lifting facilities are required. A ladder made of stainless steel steps is necessary for the caretaker. The pipes connecting the extraction structure to the treatment plant and screener and their respective valves and fittings are considered. Furthermore, single non-standard cost positions for the water extraction include pothole protection in the streambed, the very coarse screen and the flood gate. Finally, the bar screener and a platform for the caretaker finalize this section. All positions are presented in Table 15.

Table 15 - Positions of equipment costs (River water extraction)

Item no.	Position	Unit	Description
210401D	UPVC water supply pipes PN10 DN/OD 110	m	
n/a	Valves and Fittings	%	10% of pipe costs
n/a	Platform with weepholes (Screener)	m³	106.38€ assumed
n/a	Bar Screener (Screener)	pcs	100€ assumed
230101G	Concrete manhole covers DN800 class B 125kN (Extraction)	pcs	
232007A	Stainless steel step plastic coated (Extraction)	pcs	
n/a	Pothole protection in streambed (Extraction)	m³	106.38€ assumed
n/a	Screen (Extraction)	pcs	500€ assumed
n/a	Flood Gate (Extraction)	pcs	350€ assumed
n/a	Pump (Extraction)	pcs	
n/a	Electronics (control cabinet, cabeling) (Extraction)	%	10% of pump costs
n/a	Pump lifting facility (Extraction)	pcs	500€ assumed

Investment cost function

The final investment cost function is derived out of 30 different combinations of water volume Q and pressure head, with Q ranging from 1000m³/d up to 5500 m³/d and the pressure head ranging from 10m to 50m. In general, costs increase with the extraction volume and the pressure head. The resulting cost function is:

Investment costs IC:

$$IC = (-0.0099x^2 + 10.51x + 13566) + (-1.7E\text{-}05x^2+0.16x+5.80)*(y-25) \quad (13)$$

With x = Daily water demand Qd in m³/d, y = pressure head in m

Figure 12 shows the resulting investment costs for different daily water demands Qd per day with a fixed pressure head of 25m, while Figure 13 depicts the slope the pressure head describes over increasing water volume. In the final cost function this slope is used for a linear function describing the cost increase due to a higher pressure head.

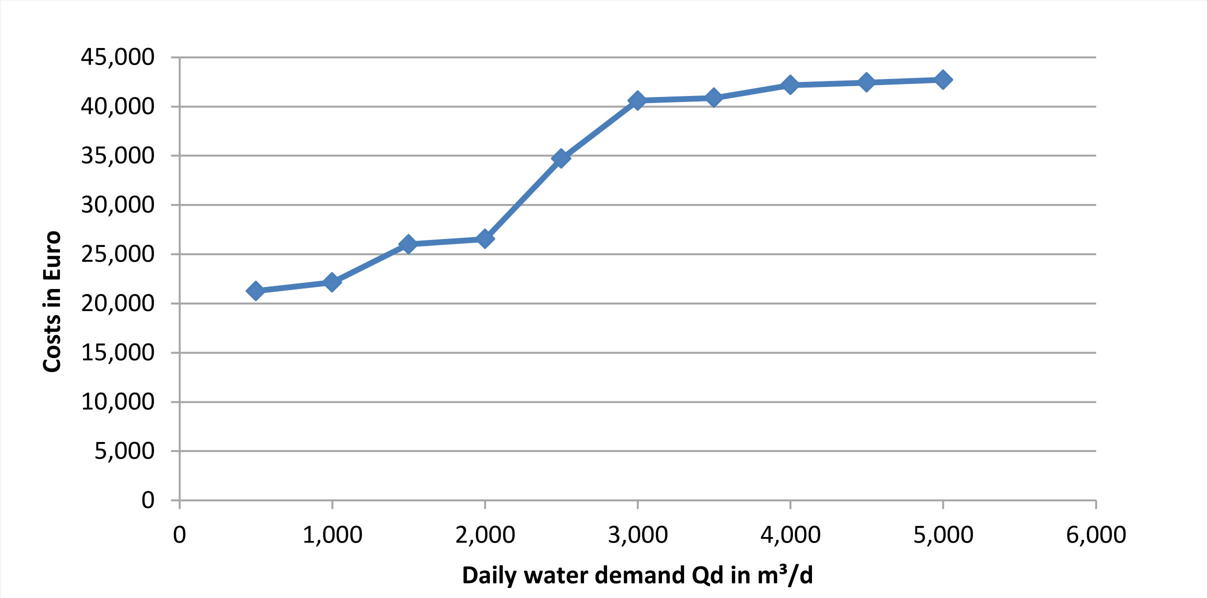

Figure 12 - Investment costs river water extraction with pressure head = 25m

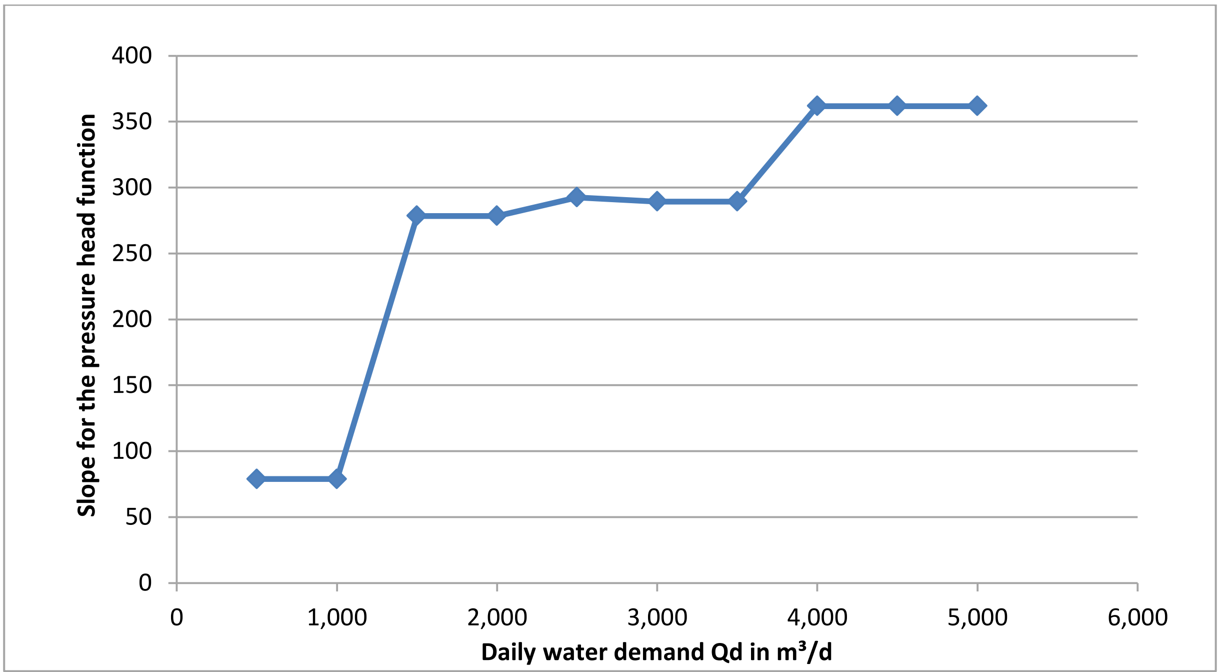

Figure 13 - Development of slope of pressure head with increasing daily water demand.

<u>Operation and Maintenance Cost Function</u>

River water extraction and the bar screener both require regular maintenance.
The river water extraction building and the pumps should be checked every 2 weeks at least. Furthermore, once a year the pumps should be cleaned to maintain efficiency. As water gets pumped out of the extraction building, O&M costs include the necessary power in kWh to pump the water to the bar screener.
The bar screener needs a daily maintenance routine because it requires manual cleaning. Logically, the bar screener maintenance is linked to the amount of water passing through, as more through flow increases debris accumulating at the screen. The assumption of 1 man-hour per 500 m³/d of water per day is realistic. Additionally, 1% of the total constructions costs are added to the annual O&M costs.

The resulting cost function for O&M costs OC is:

$$OC = -1E\text{-}06x^2 + 7.8928x + 46.259 + (-5.7E\text{-}20x^2 + 0{,}27x + 8.9E\text{-}14)*(y - 25) \qquad (14)$$

With x = Daily water demand Qd in m³/d, y = pressure head in m

Figure 14 illustrates the Operation and Maintenance costs per year over the total through flow range of the river water extraction, again with a pressure head of 25m. Figure 15 shows the slope for the pressure head with increasing water volume. This slope is also used for a linear function describing the cost increase with higher pressure head.

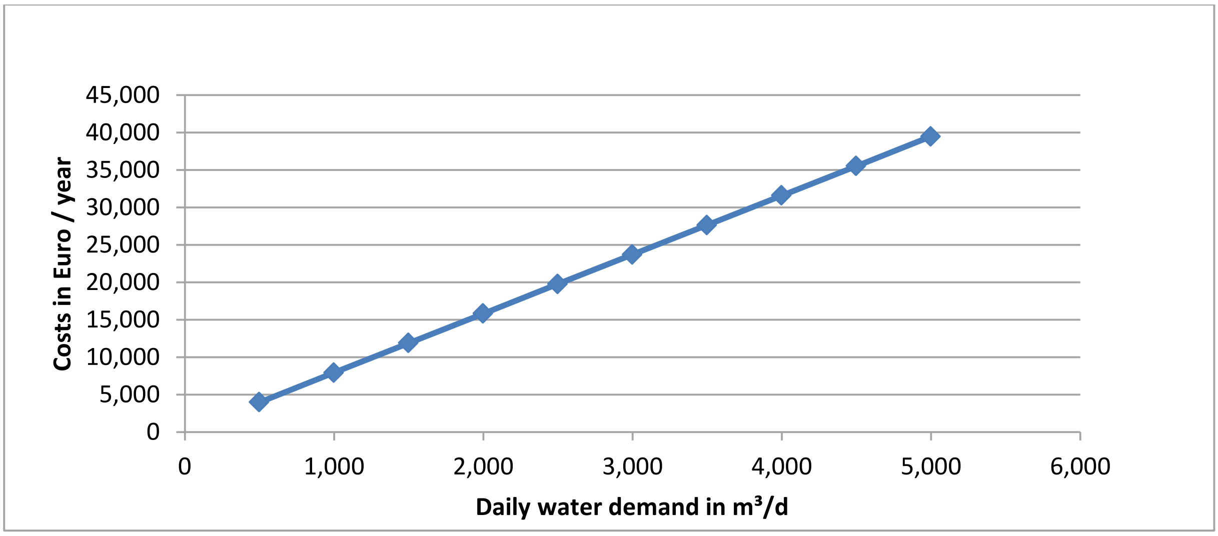

Figure 14 - O&M Costs river water extraction per year with pressure head = 25m

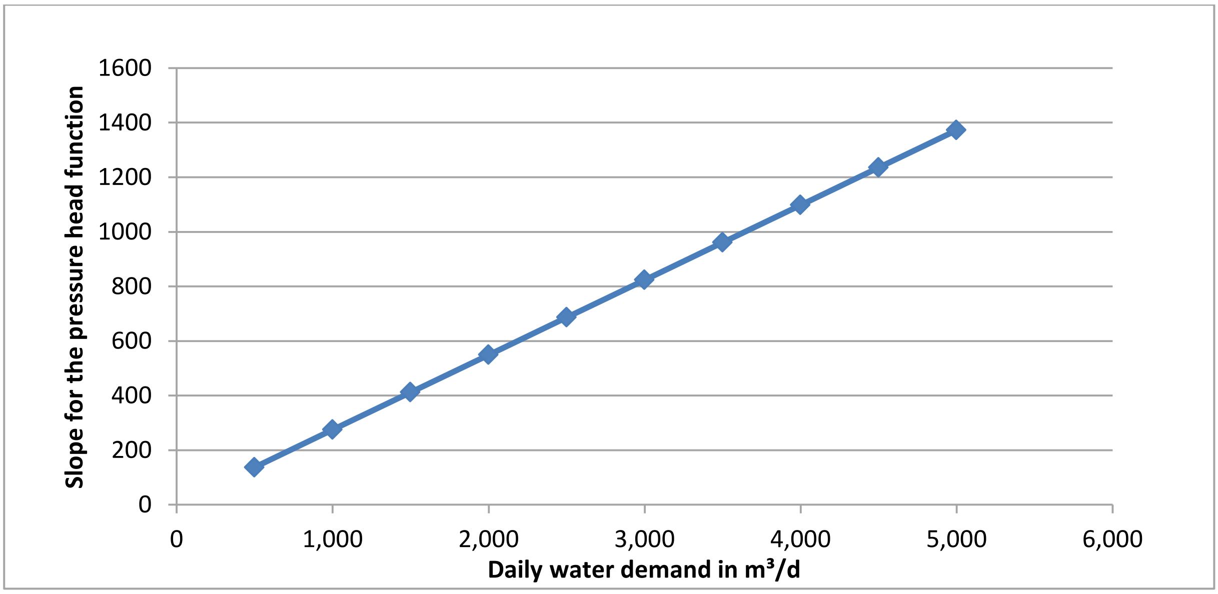

Figure 15 - Development of slope for pressure head with increasing Q

Reinvestment Cost Function

Reinvestment costs for water extraction and screener both are split into mechanical equipment and concrete works. Mechanical equipment, including the operating pump and the metal screen, are expected to need replacement every 10 years, while the concrete works surrounding the pumps and the screen need to be rebuild after 25 years.

4.3.3.7 Country specific assessment

Burkina Faso uses river water extraction mainly for irrigation. They require the training of mechanics as a part of the investment costs to successfully implement the technology. The implementation of this position does not seem feasible as there is no data given about the time and money needed to train mechanics in Burkina Faso. Additionally, trained mechanics might be found from foreign countries either. It seems more sensible to leave the position out and if it proves necessary, the planners in Burkina Faso have to include training costs for the mechanics individually.

Ethiopia and **Kenya** indicate higher life spans for the equipment, but again it seems safer to assume lower life spans. Kenya furthermore specifies the screener at the river intake. The idea for the screener at the river intake is solely to repel damaging debris like tree trunks or rocks. The water treatment by a screener is located further backwards at the entrance of a water treatment plant.

South Africa often applies bank filtration to extract river water. As bank filtration has some key differences to direct river water extraction, it is rather recommended to develop a new cost function for bank filtration than to adapt the existing river water extraction cost function. Table 16 summarizes the feedback given in the technology assessment for this technology.

Table 16 - Summary of country-specific assessment for technology 1-3 River water extraction

Burkina Faso	Ethiopia	Kenya	Morocco	South Africa
used for irrigation	mechanical equipment 15-20 years	-	-	-
training of mechanics	civil works 40-50 years			

4.3.4 Technology 2-1 Surface Water Treatment

4.3.4.1 Technology Description

The Grit Channel is a construction where the velocity of the incoming water is reduced by widening the cross section to allow the settlement of e.g. sand and grit. These particles are removed because they may damage pumps and other equipment or clog channels or pipes further along the purification plant.
The Slow Sand Filter (SSF) process consists of a number of filtration tanks containing a supernatant water layer, a bed of sand filter medium, a gravel bed and a draining system with filter regulation and control accessories (pipes, valves, fittings and others).

4.3.4.2 Input parameters

- Daily water demand Qd [m³/d]

4.3.4.3 Design assumptions

Grit Channel:

- 2 parallel channels > 3,500 m^3/d (in special cases second line is only Bypass-channel)
- Rectangular horizontal flow design
- Manual cleaning
- Ratio: Length/Width 3:1; Length/Depth 15:1
- Settling velocity 7 cm/s (sand particle 0.5 mm)

SSF:

- Min. no. of filters: 2
- Free board: 0.5 m
- Standing Water depth (supernatant depth) over the filter = 1 m
- Period of operation: 24 hr
- Area of each filter preferable between: < 250 m2
- Filtration rate: 0.15 m/h
- Filterbed
- Initial depth of sand filter bed (d10= 0.3mm and Uc=1.5 to 3): layer thickness 1 m
- 4 layers of gravel filter bottom bed:
- Grain size: 0.7-1.4 2-4 6-12 18-36 mm
- Layer thickness: 5 5 5 10 cm
- Using PVC perforated lateral pipe to collect filtered water

4.3.4.4 Design

This technology is a combination of the treatment options “grit channel” and “slow sand filter” and the first part of the treatment plant. The grit channel is a simple rectangular channel with given ratios to ensure that particles larger than the defined specific gravity, as given in the design assumptions, will settle in the concrete channel. A flow control is necessary to keep the velocity in the channel constant. Main purpose of a grit channel is to protect major mechanical equipment in the treatment plant from damage. The slow sand filter is made of multiple layers of sand and gravel with differing grain size. The filter is located in a concrete structure. The water from the grit channel is directed to flow on top of the filter sand and then filtered vertically through the layers of sand and gravel. The design of the SSF is based on a drawing with a circular structure but recalculated to rectangular shape. The planner has to submit the expected water demand passing through the treatment plant.

4.3.4.5 Dimensioning

The dimensioning is based on the only input parameter, the daily water demand that requires treatment in the plant. As all technologies under point 2 are part of a treatment plant, dimensioning has been streamlined for those three technologies. Following a document from Michigan Technological University (MTU, n.y.), the decision has been made to scale all treatment plant technologies up to 35000 m³/d.

The dimensioning starts at 500 m³/d and goes up to the maximum of 35000 m³/d scaling over 10 different values. Both structures of the technology, the grit channel and the sand filter grow in size with increasing water demand. Table 17 lists all dimensioning values.

Table 17 – Dimensioning values for surface water treatment

Daily water demand Qd	m3/d	500	3000	5000	7500	10000	15000	20000	25000	30000	35000

4.3.4.6 Cost Functions

General

The cost functions are calculated by the prices of 10 designs with different water demand. The investment costs of a combination of slow sand filter and grit channel consists of expenses for earthworks, construction works and specific equipment listed in BoQ. For simplicity reasons, both techniques of the technology will be listed in the same tables for the different cost sectors, and only differences will be pointed out specifically.

Earthworks costs

Earthworks costs include positions shown in Table 18. These positions consider preparation, excavation and backfilling works. The pit excavation for both structures is performed as an excavation with inward-slope and followed by backfilling after finishing the construction. A blinding layer to seal in underlying material and to smoothen over the gaps to give a cleaner, drier and more durable finish is poured at the bottom.

Table 18 - Positions of earthworks costs (Surface water treatment)

Item no.	Position	Unit	Description
020201A	Clearing area	m²	
030201A	Remove topsoil	m³	
030206A	Replace Topsoil	m³	
030211B	Re-Cultivate topsoil	m²	
030331A	Pit excavation with inward-sloping	m³	
030705A	Backfilling and covering of concrete walls	m³	
030708A	Blinding layer < 10 cm	m³	

Construction costs

Construction costs consist of concrete works shown in Table 19. The quality of the concrete is supposed to be C20/25. Required concrete amounts have been calculated independently for both structures and then summed up to receive to total amount required. Ribbed steel is used to reinforce the concrete. Additionally concrete ancillaries are accounted for with a percentage of the total concrete costs.

Table 19 - Positions of construction costs (Surface water treatment)

Item no.	Position	Unit	Description
110302A	Slab C20/25 up to 30cm	m³	
110401A	Wall 12-20cm C20/25	m³	
110605A	Concrete slab ceilings C20/25 up to 20cm	m³	
111901A	Ribbed steel < 10mm	kg	
n/a	concrete ancillaries	%	1% of concrete costs

Equipment costs

Equipment costs cover all pipes and their respective valves and fittings, filter sand layers, filter gravel layer and supporting bars for the ceiling of the slow sand filter, as well as a rotatable flow controls for the grit channel. Table 20 lists all equipment costs for the surface water treatment.

Table 20 - Positions of equipment costs (Surface water treatment)

Item no.	Position	Unit	Description
210401D	UPVC water supply pipes PN10 DN/OD 110	m	
n/a	Valves and fittings	%	10% of pipe costs
n/a	Filter sand d10 = 0,3mm; Uc = 1.5-3 (SSF)	m³	80€ assumed
n/a	Filter gravel (SSF)	m³	40€ assumed
n/a	Support bars for ceiling – Truss (SSF)	m	1,9€ assumed
n/a	Rotable flow control (Grit Channel)	pcs	1500€ assumed

Investment cost function

The final investment cost function is derived from the sum of the investment costs for slow sand filtration and the grit channel for the different water demand values. In general, costs increase with the extraction volume in a linear correlation. A polynomial function has been used to describe the cost development as it accounts for higher flexibility if changes should be made to the calculations in the future. The resulting cost function is:

Investment costs IC:

$$IC = -3E\text{-}05x^2 + 50.51x + 13984 \quad (15)$$

With x = Daily water demand Qd in m³/d

Figure 16 shows the resulting investment costs for the different water volumes per day.

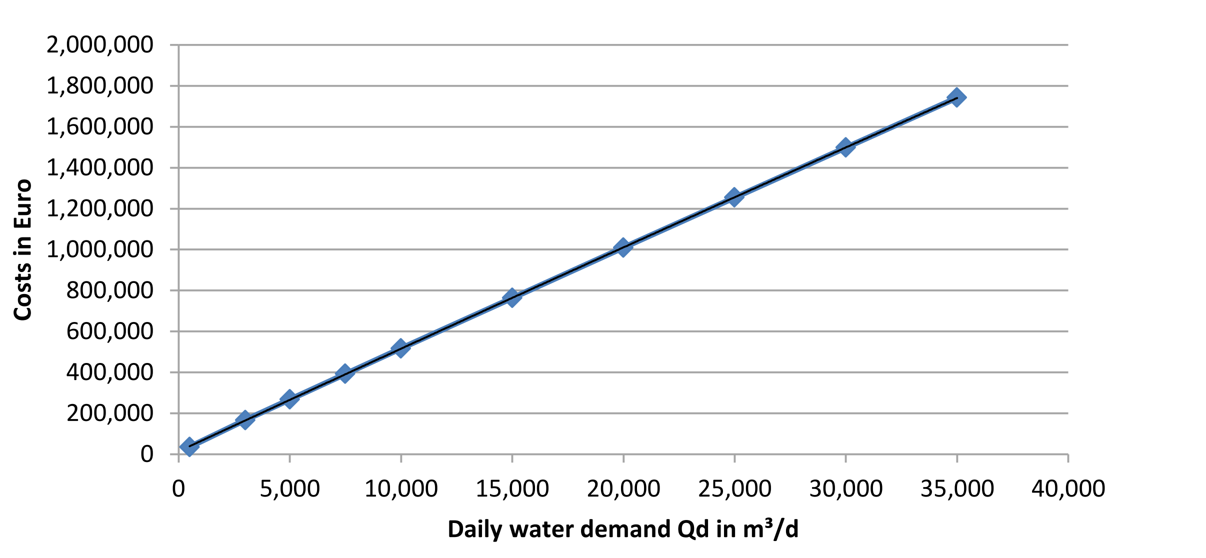

Figure 16 - Investment costs surface water extraction, dependent on the daily water demand.

Operation and Maintenance Cost Function

Both the slow sand filter and the grit channel require regular maintenance.

The slow sand filter requires daily maintenance, with roughly 1 hour of work necessary for every 2000 m³/d. Tasks include monitoring head loss, raw and filtered water turbidity and flow rates. Furthermore, every 2 months the top layer of the sand filter should be scraped to clean the filter and avoid clogging of the sand. Ripening, the reestablishing of the microorganisms, layer usually takes a few days. It is expected that the filter layers need replacement every 5 years. (VIGNESWARAN & VISVANATHAN, 1995)

The grit channel maintenance is comparably straightforward; it needs regular cleaning with experience showing 2 hours per week to be a realistic estimation. Furthermore, 1% of the investment costs for the grit channel are added.

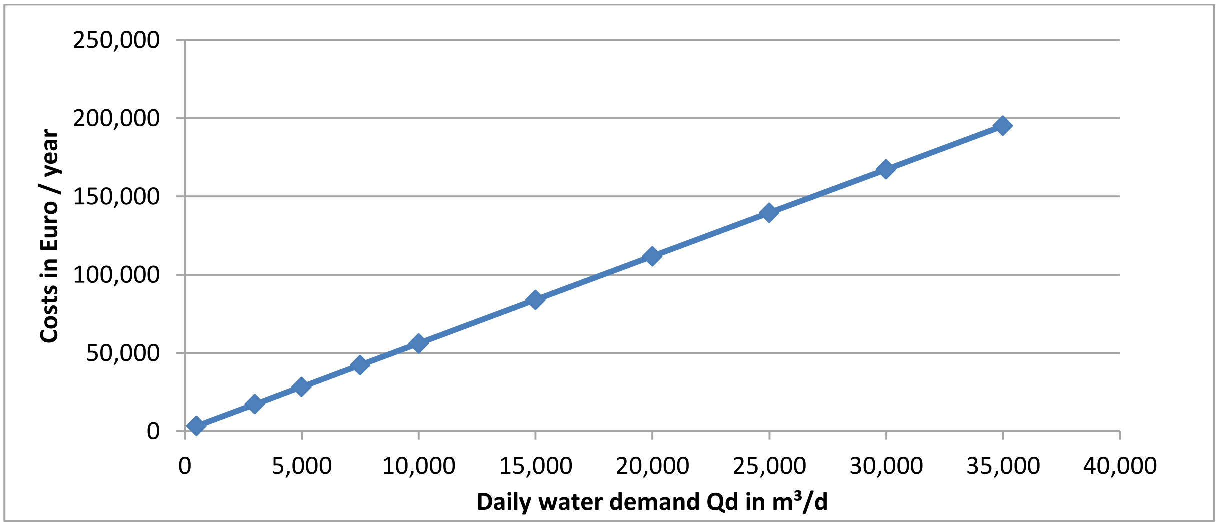

Figure 17 - O&M costs per year for surface water treatment, dependent on the daily water demand.

Figure 17 illustrates the Operation and Maintenance costs per year over the total through flow range of the surface water treatment technology.

The resulting cost function for O&M costs OC is shown in Eq.16:

$$OC = -3E\text{-}07x^2 + 5.57x + 472{,}64 \quad (16)$$

With x = Daily water demand Qd in m³/d

Reinvestment Cost Function

Reinvestment costs for the technology are for both parts (SSF, Grit channel) split into mechanical equipment and concrete works. Mechanical equipment, like the rotatable flow control, is assumed to need replacement every 10 years, while the concrete works should be replaced after 25 years.

4.3.4.7 Country specific assessment

Ethiopia generally agrees with the design assumptions, recommending filter areas of 10-300 m³, which does not differ far from the given assumption of filter areas < 250m³. Furthermore, Ethiopia states that they use SSF mostly in rural areas and opt for rapid sand filtration in urban or peri-urban areas. They agree with resanding every 5 years.

The other countries make rather general statements about water treatment, without challenging the given design assumptions in the technology description. Table 21 summarizes the country specific assessment.

Table 21 - Summary of country-specific assessment for technology 2-1 Surface Water Treatment

Burkina Faso	Ethiopia	Kenya	Morocco	South Africa
10-300m²	surface loading 0.1-0.2 m/h	-	-	-
	If possible 3 units			

4.3.5 Technology 2-2 Sedimentation with Coagulation & Flocculation

4.3.5.1 Technology Description

Sedimentation is the process of removing suspended and colloidal particles by settlement. The process can be aided by adding chemicals to create bigger flock size of colloidal particles and raise the density and surface area to enhance their settlement performance.

4.3.5.2 Input parameters

- Daily water demand Qd [m³/d]
- No. of waterlines [-]
- Kind of flocculant

4.3.5.3 Design assumptions

- Number of waterlines (if not stated otherwise): 2
- Tanks per waterline: coagulation tank with rapid stirrer, flocculation tank, sedimentation tank
- Surface loading: 1 m/h
- Retention time for sedimentation: 3 h
- By using Alum ($KAl(SO_4)2*12H_2O$): Flocculant demand: 30 mg/l
- Flocculation time (20% of Sedimentation time): 0.6 h
- Sludge treatment and disposal included

4.3.5.4 Design

Technology 2.2 is a combination of three concrete tanks, one for each of the processes that are taking place. The first tank is where the coagulant is added and thoroughly mixed into the water by a rapid stirrer. The second tank, called flocculation tank, is where the particles are clumping together in larger flocks, which is stimulated by a slower stirring process. In the third tank the flocks settle at the ground. A walkway allows caretaker to cross over the area of sedimentation and observe the process. Rake arms at the bottom of the sedimentation tank move the sediment to the central discharge, which gets collected in a sludge collection tank. The water in the top of the tank is then directed to the final treatment step, the chlorination.

4.3.5.5 Dimensioning

Similar to technology 2.1, the dimensioning is based on the water volume passing through the treatment plant. Therefore, the volume starts again at 500m³/d and scales up to 35000 m³/d over altogether 10 different numbers, as listed in Table 22. It is possible to split the water volume into one or two waterlines. The presented cost functions are based on the default assumption of 2 waterlines. Finally, the tool offers a choice of chemicals to select, which have different advantages and disadvantages, like price and applicability at certain pH. The chemicals available are Alum, ACH and ferric sulphate.

Table 22 – Dimensioning values for Sedimentation & Coagulation

Daily Water demand Q	m3/d	500	3000	5000	7500	10000	15000	20000	25000	30000	35000
Flocculant	Type	Alum	ACH	F.S.							
Waterlines	No.	1	2								

4.3.5.6 Cost Functions

General

The cost functions are calculated by the prices of 20 designs with different flow volume and number of waterlines, for each of the flocculants available. The final cost of each design`s sedimentation & coagulation technology consists of the costs for earthworks, construction and equipment specified in a bill of quantity. For reasons of simplicity all three tanks are combined in one table per field. Where differences occur, they are noted specifically.

Earthworks costs

Earthworks costs include positions shown in Table 23. These positions consider preparation, excavation and backfilling works. The tanks require only little pit excavation for the foundation, which is performed as an excavation with inward-slope for all tanks. This also reduces the amount of backfilling to zero, but the position is kept to account for possible subsurface constructions. A blinding layer seals in underlying material and prevents dirt and mud from interfering with the structure.

Table 23 - Positions of earthworks costs (Sedimentation with coagulation)

Item no.	Position	Unit	Description
020201A	Clearing area	m^2	
030201A	Remove topsoil	m^3	
030206A	Replace Topsoil	m^3	
030211B	Re-Cultivate topsoil	m^2	
030331A	Pit excavation with inward-sloping	m^3	
030705A	Backfilling and covering of concrete walls	m^3	
030708A	Blinding layer < 10 cm	m^3	

Construction costs

Construction costs consist of concrete works shown in Table 24. The quality of the concrete is supposed to be C20/25. The required amounts of concrete are calculated separately for each of the tanks, the results are then combined to the total concrete amount. Ribbed steel is used to reinforce the concrete and concrete ancillaries are accounted for with a percentage of the total construction costs.

Table 24 - Positions of construction costs (Sedimentation with coagulation)

Item no.	Position	Unit	Description
110302A	Slab C20/25 up to 30cm	m^3	
110401A	Wall 12-20cm C20/25	m^3	
110605A	Concrete slab ceilings C20/25 up to 20cm	m^3	
111901A	Ribbed steel < 10mm	kg	
n/a	concrete ancillaries	%	10% of concrete costs

Equipment costs

Equipment costs cover the positions listed in Table 25. It includes all pipes, their respective valves and fittings, a rapid stirrer and a chemical storage tank for the coagulation tank, a slow stirrer for the flocculation tank, as well as a walkway and rake arms for the sedimentation tank.

Table 25 - Positions of equipment costs (Sedimentation with coagulation)

Item no.	Position	Unit	Description
210401D	UPVC water supply pipes PN10 DN/OD 110	m	
n/a	Valves and fittings	%	10% of pipe costs
n/a	Rapid stirrer (Coagulation tank)	pcs	500€ assumed
n/a	Chemical storage tank (Coagulation tank)	pcs	500€ assumed
n/a	Slow stirrer (Flocculation tank)	pcs	1500€ assumed
n/a	Bridge/Walkway (Sedimentation tank)	pcs	2000€ assumed
n/a	Rake arms (Sedimentation tank)	pcs	1000€ assumed

Investment cost function

The final investment cost function is derived from the sum of the investment costs for the three different tanks and for the different water volumes and number of waterlines. In general, costs increase with the extraction volume in a linear correlation. As the choice of flocculant is not influencing the investment costs of this technology, the investment cost function at the moment only correlates with the number of waterlines and the daily water demand, not with the choice of chemical. Eq.17 and Eq.18 list the cost functions for 1 and 2 waterlines:

Investment costs IC:

1 waterline: $IC = -1.7E\text{-}05\,x^2 + 5.61x + 13376 \quad (17)$

2 waterlines: $IC = -2.4E\text{-}05\,x^2 + 6.18x + 38725 \quad (18)$

With x = Daily water demand Qd in m³/d

Figure 18 shows the resulting investment costs for the different number of waterlines and different water volumes per day.

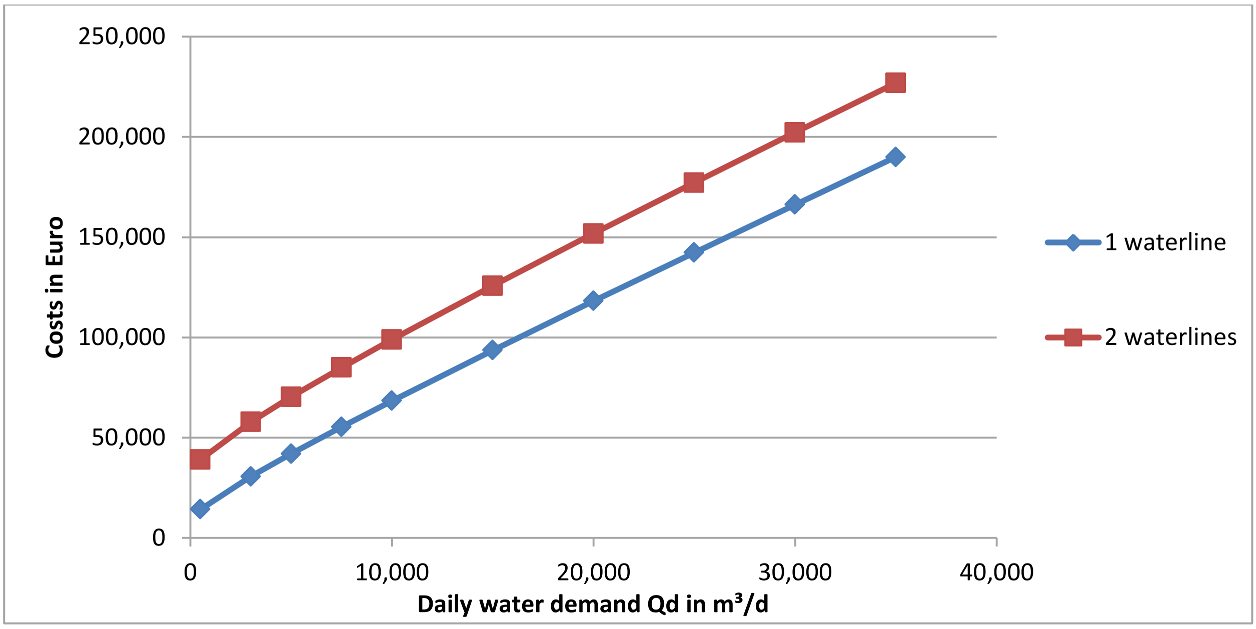

Figure 18 - Investment costs for sedimentation & coagulation

Operation and Maintenance Cost Function

Operation and maintenance costs consist mainly of the amount of chemical required for the coagulation process. The costs for coagulants are based on a paper by GEBBIE (2005) and listed in Table 26. Furthermore, all tanks require regular cleaning and maintenance performances, where 2 hours per week are a realistic estimation. Finally, the stirrers in coagulation and flocculation tank as well as the rake arms in the sedimentation tank need power supply. All costs combine to the following set of cost functions.

Table 26 - Unit costs for the chemicals used for coagulation.

Chemical	Unit	Costs in €/kg
Alum	kg	0.38
ACH	kg	1.75
Ferric sulphate	kg	0.46

O&M costs OC for Alum

1 waterline: $OC = 4.14x + 199$ (19)

2 waterlines: $OC = 5.95x + 398$ (20)

O&M costs OC for ACH

1 waterline: $OC = 6.42x + 199$ (21)

2 waterlines: $OC = 9.23x + 398$ (22)

O&M costs OC for Ferric Sulfate

1 waterline: $OC = 2.54x + 199$ (23)

2 waterlines: $OC = 3.65x + 398$ (24)

With x = Daily water demand Qd in m³/d

Figure 19 shows the two cost functions for Alum with different numbers of waterlines:

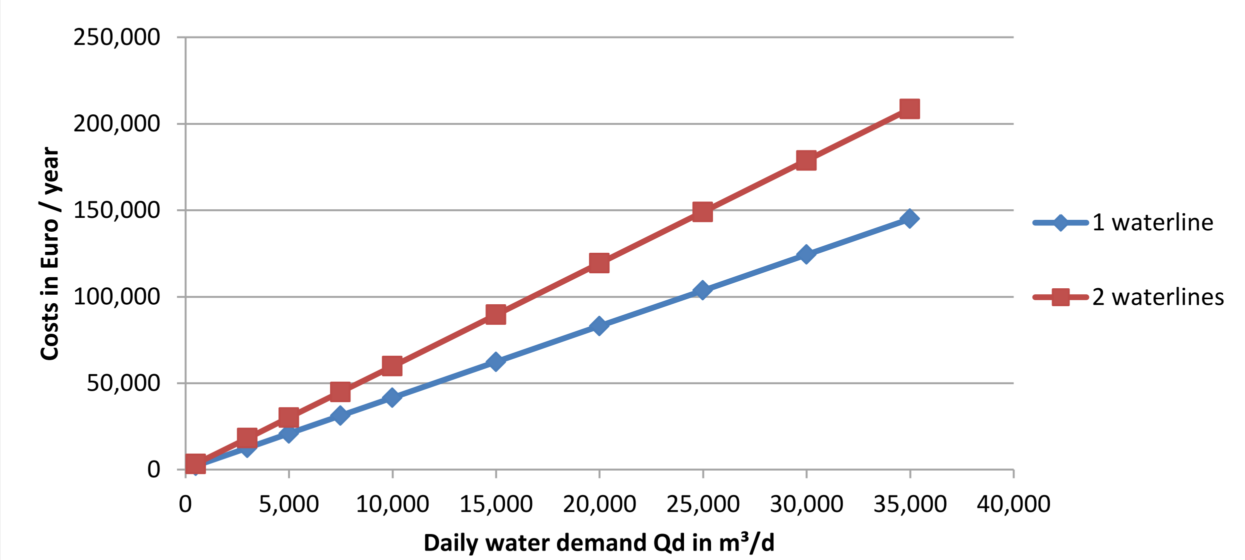

Figure 19 - Operation & Maintenance costs for sedimentation and coagulation with Alum

Reinvestment Cost Function

Reinvestment costs for sedimentation and coagulation both are split into mechanical equipment and concrete works. Mechanical equipment, including the stirrers and the rake arms, are expected to need replacement every 10 years, while the concrete tanks need to be rebuild after 25 years.

4.3.5.7 Country specific assessment

For flocculation and coagulation, **Burkina Faso** claims to use natural flocculants and improve the process by adding clay and sand. Addition of different flocculants should be relatively simple, as long as the necessary amount of flocculant is known for treating given water volumes.

Ethiopia lists the average alum demand to be around 40 mg/l. This number is easily adaptable for a single country in the cost function and the changed alum demand increases the O&M costs significantly. Thus, alum demand could be adapted for Ethiopia specifically. As the feedback is only information about the status quo in Ethiopia, the design assumption of 30mg/l can be kept as long as Ethiopia does not demand a change. They list the requirement for storage of the chemicals used, which is not considered in the current cost function.

Morocco generally agrees with the design assumptions given, stating the flocculation detention time to be higher than 30 minutes and the coagulation time to be higher than 30 seconds. The design assumptions are 36 minutes and 60 seconds respectively.

Finally, **South Africa** claims to mainly use the chemical ACH-polyamine in concentrations of 2-50 mg/l. They furthermore give a price for the chemical of 7000-11000 Rand /ton. As a future goal of the technology should be to increase the possible chemicals used for coagulation and flocculation, focus should be put on implementing ACH-polyamine. Table 27 summarizes the country specific assessment.

Table 27 - Summary of country-specific assessment for technology 2-2 Sedimentation & Coagulation

Burkina Faso	Ethiopia	Kenya	Morocco	South Africa
Use natural coagulants	usually: alum demand 40mg/l	-	-	ACH 2-50mg/l
				7000-11000 Rand/ton

4.3.6 Technology 2-3 Disinfection

4.3.6.1 Technology Description

Sodium hypochlorite solution (NaClO) or Calcium hypochlorite solution ($Ca(ClO)_2$) is chosen to use as disinfectant agent for simplified planning tool. It is injected by a pump directly into the water pipe. A dosage flow controlled unit is used if >500PE (40m³/d).

4.3.6.2 Input parameters

- Daily water demand Qd [m³/d] if pumping in a tank
  OR
- Largest hourly water demand Qhmax [m^3/h] if pumping in a water main
- Kind of disinfectant

4.3.6.3 Design assumptions

- Concentration after dosage 2 mg Cl/l (Residual chlorine at the furthest user point 0.2-0.5 mg/L)
- 75% solution

4.3.6.4 Design Description

The design of technology 2.3 is based on an AutoCAD drawing (see Appendix 8.4). The chlorine is added directly into the pipe, right after it leaves the sedimentation tank and before it gets pumped in the water distribution network. Consequently, the technology does not require a high amount of construction works, but it is assumed that the surrounding area is part of the treatment plant and therefore a concrete foundation is present. The chlorine is injected into the water by a dosage pump. The technology assumes that 2 mg/l of chlorine need to be added to achieve a chlorine residual of 0.5 mg/l. Based on this assumption yearly O&M costs greatly depend on the total amount of total chlorine added. The technology allows choosing between three common chlorination methods: solid calcium hypochlorite, liquid sodium hypochlorite and chlorine gas, unlike stated in the original technology description.

4.3.6.5 Dimensioning

As the technologies in group 2 are connected and assumed to be applied in a treatment plant, dimensioning for disinfection orientates on the other technologies within the group. The amount of required chlorine increases with the water volume that needs to be disinfected and with the degree of pollution in the water. As the required concentration of chlorine is given as a design assumption, the dimensioning is based on the water volume only and allows choosing between three different chlorination methods, as shown in Table 28.

Table 28 - Dimensioning values for Chlorination

Daily Water demand Q	m3/d	500	3000	5000	7500	10000	15000	20000	25000	30000	35000
Kind of disinfectant	-	Sodium hypochlorite			Calcium hypochlorite			Chlorine gas			

4.3.6.6 Cost Functions

General

The cost functions are calculated by the costs for 10 designs of different water demand for each of the disinfectants. The total cost of a particular disinfection construction involves costs for earthworks, construction and equipment specified in a bill of quantity.

Earthworks costs

Earthworks costs include positions shown in Table 29Table 2. These positions consider preparation, excavation and backfilling works. The pit excavation is only necessary for the foundation of the construction, and is performed as an excavation with inward-slope and followed by backfilling after finishing the construction. A blinding layer seals in underlying material and prevents dirt and mud from interfering with the structure.

Table 29 - Positions of earthworks costs (Disinfection)

Item no.	Position	Unit	Description
020201A	Clearing area	m²	
030201A	Remove topsoil	m³	
030206A	Replace Topsoil	m³	
030211B	Re-Cultivate topsoil	m²	
030331A	Pit excavation with inward-sloping	m³	
030705A	Backfilling and covering of concrete walls	m³	
030708A	Blinding layer < 10 cm	m³	

Construction costs

Construction costs consist of concrete works shown in Table 30. The quality of the concrete is supposed to be C20/25. Ribbed steel is used to reinforce the concrete. Additionally concrete ancillaries are accounted for with a percentage amount of the total construction costs.

Table 30 - Positions of construction costs (Disinfection)

Item no.	Position	Unit	Description
110302A	Slab C20/25 up to 30cm	m³	
110401A	Wall 12-20cm C20/25	m³	
110605A	Concrete slab ceilings C20/25 up to 20cm	m³	
111901A	Ribbed steel < 10mm	kg	
n/a	concrete ancillaries	%	10% of concrete costs

Equipment costs

Equipment costs cover all pipes, their respective valves and fittings, the injection pump for the disinfectant and a control unit for the dosage flow, as presented in Table 31.

Table 31 - Positions of equipment costs (Disinfection)

Item no.	Position	Unit	Description
210401D	UPVC water supply pipes PN10 DN/OD 110	m	
n/a	Valves and fittings	%	10% of pipe costs
n/a	Injection pump	pcs	500€
n/a	Dosage flow control unit	pcs	250€

Investment cost function

The final investment cost function is derived from the sum of the investment costs for the various design sizes with different water volumes. Investment costs stay the same independent from the water volume and the disinfectant, as it is assumed that injection pump and dosage flow control are capable of delivering the required chemical amount for all volumes used for scaling. Therefore, the investment cost for all designs is 1724 Euro.

Operation and Maintenance Cost Function

Operation and maintenance costs consist mainly of the amount of chemical required for the chlorination. Furthermore, all tanks require regular cleaning and maintenance performances, where 1 hour of labor per 2000 m³/d is a realistic estimation. Finally, the injection pumps and the flow control unit demand power. All costs combine to the following cost functions:

O&M costs OC for sodium hypochlorite $y = 3.0E\text{-}07x^2 + 3.5x + 314$ (25)

O&M costs OC for calcium hypochlorite $y = 3.0E\text{-}07x^2 + 5.0x + 314$ (26)

O&M costs OC for chlorine gas $y = 3.0E\text{-}07x^2 + 2.1x + 314$ (27)

With x = Water demand Q in m³/d

Figure 20 depicts the O&M costs for disinfection with sodium hypochlorite over increasing water demand.

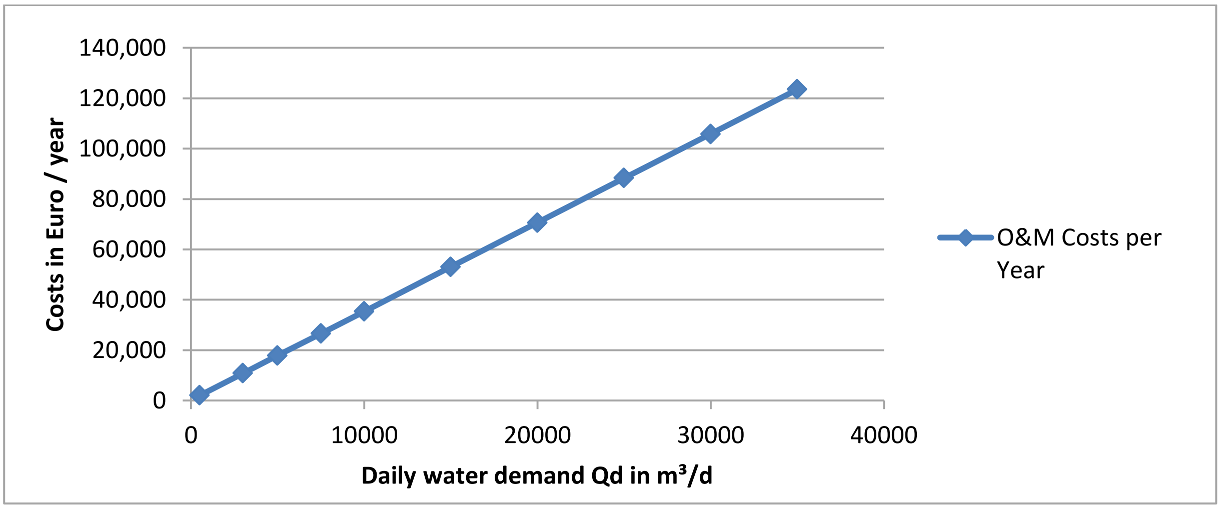

Figure 20 - Operation & Maintenance costs for disinfection

Reinvestment Cost Function

Reinvestment costs for chlorination are split into mechanical equipment and civil works. Mechanical equipment is expected to need replacement after 10 years and includes the injection pump and the dosage flow control. The remaining costs, listed as civil works, consist of concrete works, earthworks and pipes and need to be replaced every 25 years.

4.3.6.7 Country specific assessment

Burkina Faso and **Ethiopia** accept the given design assumptions entirely.

Kenya asks for a minimum contact period of 30 minutes before reaching a consumer. This period is justified but hardly necessary for the cost function. Kenya also asks for a chlorine residual of 0.3-0.5 mg/l, which is in line with the given design assumption.

South Africa demands a design residual lower than 1.5mg/l, which is in accordance with the design assumptions. They usually use liquefied chlorine for disinfection with a concentration of 2.5-3mg/l, which is usually sodium hypochlorite and agrees with the design assumptions.

4.3.7 Technology 3-1 Surface Water Tank

4.3.7.1 Technology Description

The Surface Water Tank stores water from a source or a purification plant to balance the average supply and variable water demands of users.

4.3.7.2 Input parameters

- Daily water demand Qd [m³/d]

4.3.7.3 Design assumptions

Total reservoir volume (m³) = Active reservoir volume (m³) + Storage for fire fighting(m³) + Storage for maintenance (cleaning) (m³)

- Active reservoir volume to balance daily supply and demand = Maximum daily demand/3
- Storage for fire fighting = 65 m^3 = (2 x 32.5 m^3/h) for 2 hour fire fighting
- Storage for maintenance, emergency and cleaning = 10% of average daily demand
- Maximum daily demand =1.8*Average daily demand
- Rectangular shape

4.3.7.4 Design

Technology 3.1 is essentially a rectangular tank made of concrete and dug into the ground at surface level. The tanks size is dependent on the amount of water that requires being stored, calculated as stated in the design assumptions. The tank has a fixed height of 3m and therefore only grows in length and width, with a ratio of 1:0.75. To ensure stability of the structure, for tanks with a base area larger than 25m² supply shores made of concrete are added. A manhole with cover and steps are added to enable access and maintenance.

4.3.7.5 Dimensioning

The dimensioning is based on the daily water demand stored in the tank. Tank volumes can differ vastly, so the cost function should cover a wide range of tanks. Realized tank sizes made of concrete are for example 9000m³ in Jersey (JERSEY WATER, n.y.) or up to 20000m³ in Newfoundland (DAWE, 2010).

The dimensioning starts at 10 m³/d and goes up to the maximum of 10000 m³/d scaling over 10 different values. It is assumed that for higher water demands the construction of 2 or more tanks of smaller size is more feasible than constructing one very huge tank. Table 32 lists all dimensioning values.

Table 32 - Dimensioning values for water surface tank

Daily Water demand Q	m3/d	10	500	1000	2000	3000	4000	5000	6000	8000	10000

4.3.7.6 Cost Functions

General

The cost functions are calculated by the total price of the 10 designs with different water demand. The total investment costs of a particular water surface tank consist of costs for earthworks, construction and equipment specified in a bill of quantity.

Earthworks costs

Earthworks costs include positions shown in Table 33. These positions consider preparation, excavation and backfilling works. The pit excavation is performed as an excavation with inward-slope and followed by backfilling after finishing the construction. A blinding layer seals in underlying material and prevents dirt and mud from interfering with the structure.

Table 33 - Positions of earthworks costs (Water surface tank)

Item no.	Position	Unit	Description
020201A	Clearing area	m^2	
030201A	Remove topsoil	m^3	
030206A	Replace Topsoil	m^3	
030211B	Re-Cultivate topsoil	m^2	
030331A	Pit excavation with inward-sloping	m^3	
030705A	Backfilling and covering of concrete walls	m^3	
030708A	Blinding layer < 10 cm	m^3	

Construction costs

Construction costs consist of concrete works shown in Table 34. The quality of the concrete is supposed to be C20/25. Supply shores support the static of the construction when it is above 25m². Ribbed steel is used to reinforce the concrete. Additionally concrete ancillaries are accounted for with a percentage amount of the total construction costs.

Table 34 - Positions of construction costs (Water surface tank)

Item no.	Position	Unit	Description
110302A	Slab C20/25 up to 30cm	m^3	
110401A	Wall 12-20cm C20/25	m^3	
110605A	Concrete slab ceilings C20/25 up to 20cm	m^3	
110401A	Supply Shores	m^3	
111901A	Ribbed steel < 10mm	kg	
n/a	concrete ancillaries	%	10% of concrete costs

Equipment costs

Equipment costs cover all required pipes to allow water flowing in and out of the tank, their respective valves and fittings, a manhole cover and steel steps as presented in Table 35.

Table 35 - Positions of equipment costs (Water surface tank)

Item no.	Position	Unit	Description
210401D	UPVC water supply pipes PN10 DN/OD 110	m	
n/a	Valves and fittings	%	10% of pipe costs
230101G	Concrete manhole covers DN800 class B 125kN	pcs	
232005A	Stainless steel step plastic coated	pcs	

Investment cost function

The final investment cost function is derived from the different investment costs as a result of the different water demand inputs in the BoQ.

Investment costs IC: $IC = -0.0016x^2 + 64.56x + 65572$ (28)

With x = Water demand Q in m³/d

Figure 21 shows the resulting investment costs in Euro for the different water demands per day.

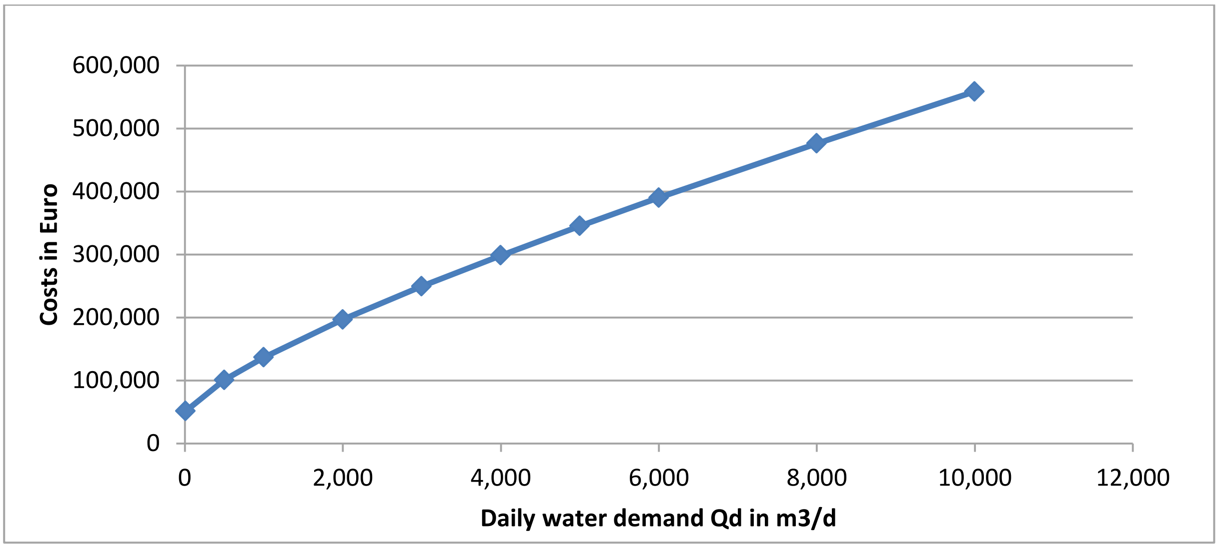

Figure 21 - Investment costs surface water tank

Operation and Maintenance Cost Function

Water tanks are very simple to operate and maintain. It is usually recommended to conduct regular inspections of the tank to ensure proper functionality. Based on existing knowledge the BoQ recommends 24 inspections per year (FRANCEYS et al, 1992). Furthermore, 1% of the investment costs per year are added as a realistic estimate to cover for minor repairs. The resulting cost function is shown in Figure 22 and reads as follows:

O&M costs for water surface tank: $y = 0.4953x + 862.27$ (30)

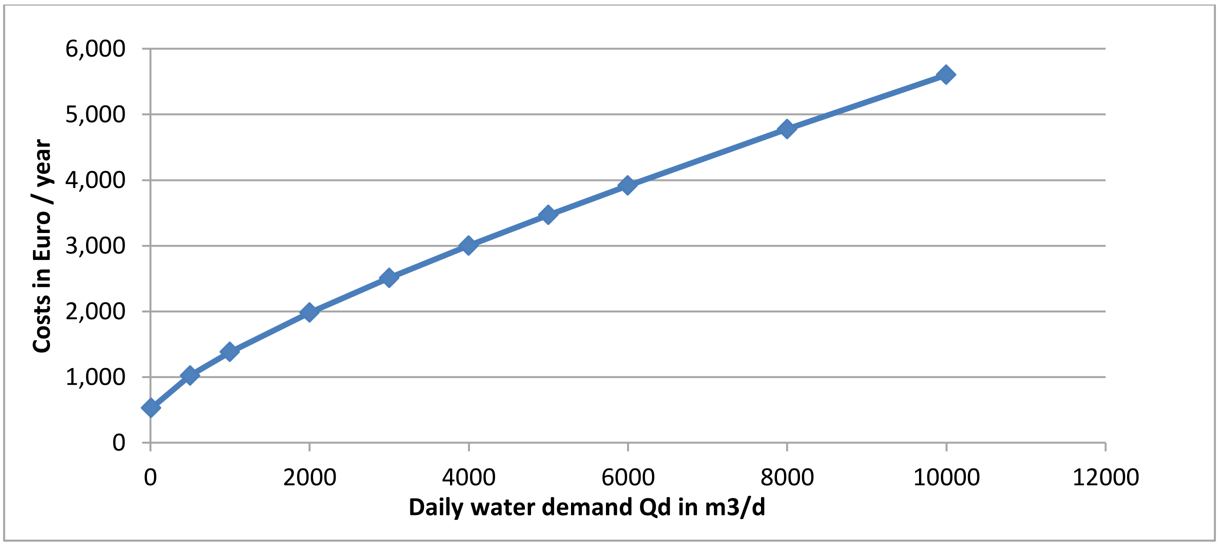

Figure 22 - Operation & Maintenance costs water surface tank

Reinvestment Cost Function

The concrete tank is expected to last for the 50 years design period and need replacement at around the end of this amount of time. Smaller parts like the manhole cover and the pipes are expected to need replacement every 15 years.

4.3.7.7 Country specific assessment

For this technology, **Burkina Faso** gives a design size between 1000 – 2000 m³. This is probably the most realistic range for the country, but does not hinder the cost function to scale for smaller sizes and larger sizes as well.

Burkina Faso and **Ethiopia** both disagree with the Maximum daily demand (MDD) being 1.8*Average daily demand (ADD). They both opt for lower values, with Ethiopia giving an average of 1.3*ADD as a realistic value for the MDD. It might be feasible to adapt the MDD as the current calculation is based on knowledge from western, highly developed countries.

Several countries argue that the O&M costs are set too high with 2% of the investment costs per year. **Ethiopia** and **Kenya** propose 1% of the investment costs, while **Morocco** even proposes 0.5% of the investment costs as a realistic value. As a consequence, it might be a good choice to reduce the O&M costs in general to 1% of the total investment costs per year plus the labor costs for regular inspections, similar to the adaptations of the spring extraction technology.

At last, **Kenya** and **Ethiopia** both prefer circular tanks over rectangular tanks. Leaving advantages and disadvantages aside, the difference in material costs between circular and rectangular tanks of the same volume should only differ insignificantly. The option to choose between these 2 types might be a possibility for the future, but does not seem necessary for the first final version of the SPT. Table 36 summarizes the assessment.

Table 36 - Summary of country-specific assessment for technology 3-1 Surface water tank

Burkina Faso	Ethiopia	Kenya	Morocco	South Africa
MDD = 1.3*ADD	MDD = 1.3*ADD			-
between 1000-2000 m³	O&M costs = 1% of invest	O&M costs = 1% of invest	O&M costs = 0.5% of invest	
	circular tank preferred	circular tank preferred		

4.3.8 Technology 3-2 Elevated Water Tank

4.3.8.1 Technology Description

Elevated water reservoirs are usually erected at a required height to allow an effective gravity feed and adequate line pressure in the water distribution network. It is supplied with drinking water from a purification plant to balance the average supply of users.

4.3.8.2 Input parameters

- Daily water demand Qd [m³/d]

  If known:

- Elevation [m]

4.3.8.3 Design assumptions

Total elevated water reservoir volume (m^3) = Active reservoir volume (m^3) + Storage for fire fighting (m^3) + Storage for maintenance (cleaning) (m^3)

- Active reservoir volume to balance daily supply and demand = Maximum daily demand/3
- Storage for fire fighting = 65 m^3 = (2 x 32.5 m^3/h) for 2 hour fire fighting
- Storage for maintenance, emergency and cleaning = 10% of average daily demand
- Maximum daily demand = 1.8*Average daily demand
- If not given - elevated reservoir is assumed to be erected 15 m above ground
- Circular shape
- Constructed on concrete foundation

4.3.8.4 Design

For technology 3.2 only the foundation of the tank is calculated. It is assumed that the actual steel construction has to be executed by a local company with sufficient knowledge and experience. Therefore, the technology calculates the foundation based on the storage volume and assumes prices for the construction of the steel foundation and the steel tank, until real prices can be obtained. The concrete foundation itself is based on a design drawing for an elevated tank with a volume of 30m². It consists of four concrete base plates for each feet of the steel foundation, which are connected by concrete columns.

4.3.8.5 Dimensioning

The dimensioning is based on the daily water demand of the supplied area and the height of the tank. Tank volumes can differ vastly, but usual tank capacities are lower than for surface level water tanks. The tank design is based on a given 30m³ technical drawing. As the actual tank construction and design differs greatly between countries and companies, the BoQ is reduced to only calculate the concrete foundation of the construction, as it is simple to plan and does not require skilled work to be constructed. Companies constructing the tower would need to supply the tool with prizes for the desired construction, depending on height and volume of the tank.

The dimensioning starts at a water demand of 10 m³/d and goes up to the maximum of 3200 m³/d scaling over 10 different values. The water height is set in a range of 5 to 20m, covering the most common heights. It is assumed that for higher water demands the construction of 2 or more tanks of smaller size is more feasible than constructing one large tank. Table 37 lists all dimensioning values.

Table 37 - Dimensioning values for elevated water tank

Daily Water demand Q	m3/d	10	100	250	500	1000	1500	2000	2500	3000	3200
Elevation of the tank	m	5	10	15	20						

4.3.8.6 Cost Functions

General

The cost functions are calculated by the total costs of 40 designs with different water demand and elevation. The total cost of a particular elevated water tank is split into costs for earthworks, construction and specific equipment listed in a bill of quantity.

Earthworks costs

Earthworks costs include positions shown in Table 38. These positions consider preparation, excavation and backfilling works for the concrete foundation of the tank. The pit excavation is performed as an excavation with inward-slope and followed by backfilling after finishing the construction. A blinding layer seals in underlying material and prevents dirt and mud from interfering with the structure.

Table 38 - Positions of earthworks costs (Elevated water tank)

Item no.	Position	Unit	Description
020201A	Clearing area	m^2	
030201A	Remove topsoil	m^3	
030206A	Replace Topsoil	m^3	
030211B	Re-Cultivate topsoil	m^2	
030331A	Pit excavation with inward-sloping	m^3	
030705A	Backfilling and covering of concrete walls	m^3	
030708A	Blinding layer	m^3	

Construction costs

Construction costs consist of concrete works shown in Table 39. The quality of the concrete is supposed to be C25/30. Ribbed steel is used to reinforce the concrete. Additionally concrete ancillaries are accounted for with a percentage amount of the total construction costs.

Table 39 - Positions of construction costs (Elevated water tank)

Item no.	Position	Unit	Description
110302A	Slab C20/25 up to 30cm	m^3	
110401A	Wall 12-20cm C20/25	m^3	
110902A	Ribbed steel < 10mm	kg	
n/a	Concrete ancillaries	%	1% of concrete costs

Equipment costs

Equipment costs cover the pipes and all valves and fittings. Additionally, the actual water tank and the tower construction are listed here, although real prices are missing yet. Tank and tower construction are assumed to be made of steel. All positions are listed in Table 40.

Table 40 - Positions of equipment costs (Elevated water tank)

Item no.	Position	Unit	Description
210401D	UPVC water supply pipes PN10 DN/OD 110	pcs	
n/a	Valves and fittings	%	10% of pipe costs
n/a	Steel foundation / tower construction	m	500€ assumed
n/a	Steel water tank	m³	25€ assumed

Investment cost function

The final investment cost function is derived from the different investment costs as a result of the different input water demands and heights in the BoQ. The resulting investment cost function is depicted in Eq. 29:

Investment costs IC:

$$IC = -0{,}0018x^2 + 90.064x + 10726 + (500)*(y-10) \qquad (29)$$

With x = Daily water demand Qd in m³/d, y = height of the tank in m

Figure 23 shows the resulting investment costs for the different water volumes per day at a tank height of 10m. The dependency of the investment costs on the height of the tank is strictly linear, with each meter of height adding 500€.

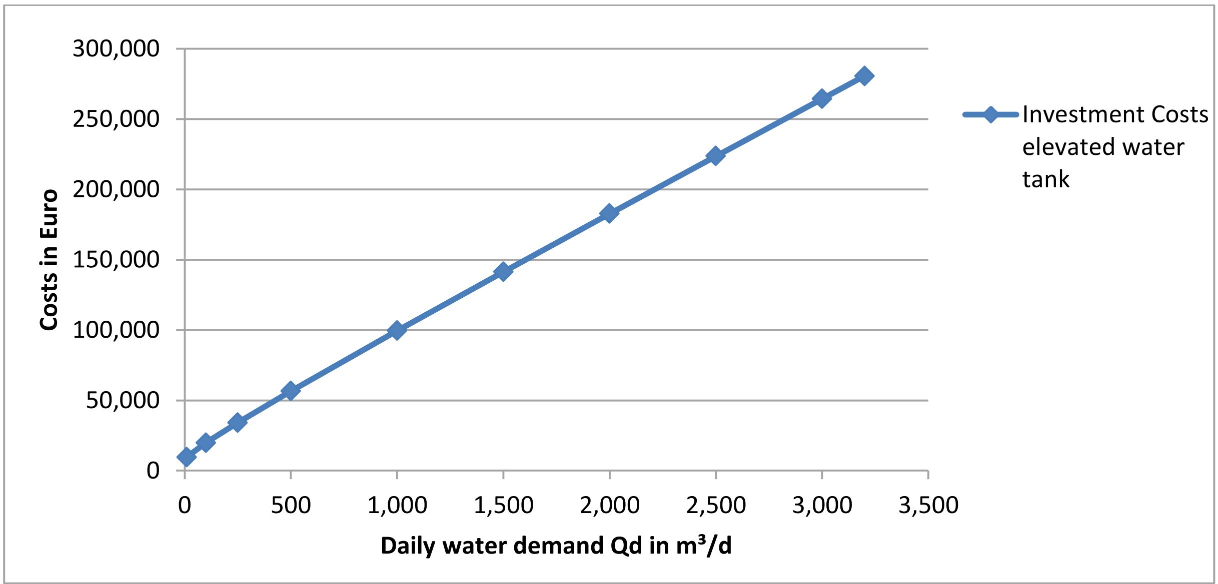

Figure 23 - Investment costs elevated water tank

Operation and Maintenance Cost Function

Comparable with the surface water tanks, operation and maintenance is simple. It is again recommended to conduct regular inspections of the tank to ensure proper functionality. Based on available sources the BoQ recommends 24 inspections per year (FRANCEYS et al, 1992). Furthermore, 3% of the investment costs per year are added as a realistic estimate to cover for especially the painting and minor repairs. The dependency of the O&M costs on the height of the tank is strictly linear, with each meter of height adding 15€ per year. The resulting cost function is shown in Figure 24.

Investment costs IC:

$$IC = -6E\text{-}05x^2 + 2.70x + 337.09 + 15 * (y-10) \qquad (30)$$

With x = Daily water demand Qd in m³/d, y = height of the tank in m

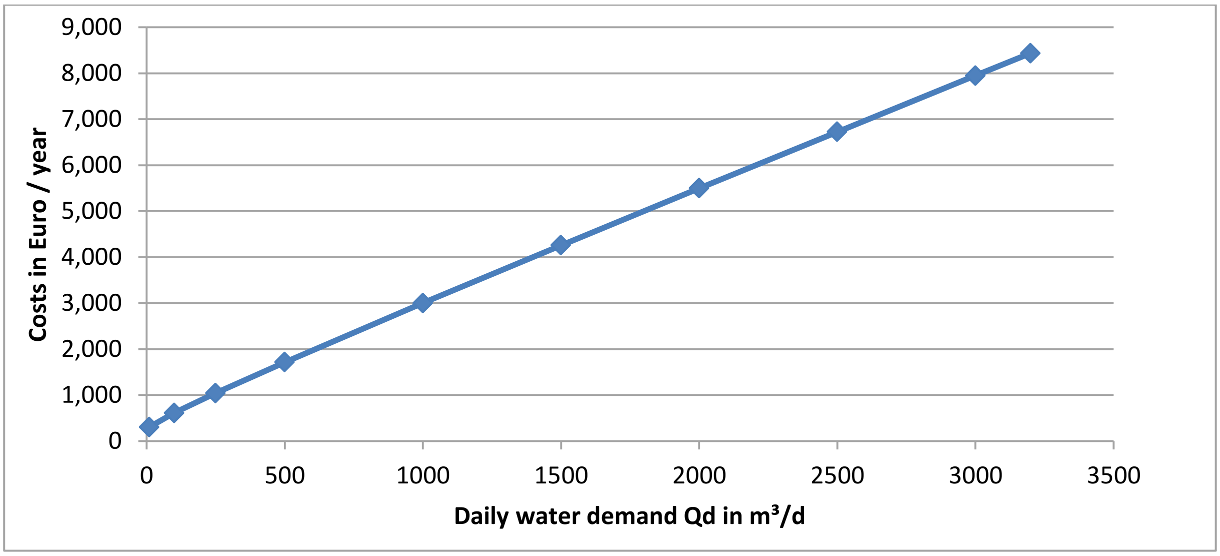

Figure 24 - Operation & Maintenance costs for elevated water tank dependent on daily water demand

Reinvestment Cost Function

The steel tank construction is expected to last at least for the 50 years design period and needs replacement at around the end of this amount of time. The concrete foundation and its related earthworks are also expected to last for at least 50 years. The pipes are anticipated to require replacement every 15 years.

4.3.8.7 Country specific assessment

Both **Burkina Faso** and **South Africa** have not given any objections to the design assumptions. **Morocco** gives a common tank volume range of 10-1000 m³, but once again this does not hinder the cost function to scale for smaller sizes and larger sizes as well.
Ethiopia rejects the fixed height of the elevation tower and proposes a range between 14-32m, but the height has already been adapted to a variable input in the cost function, with 15m height as the standard assumption if no different input is given.
Similar to the water surface tank, the MDD calculation should be adapted to specific countries if desired, but no country made an explicit statement for this technology. Table 41 lists the results of the assessment.

Table 41 - Summary of country-specific assessment for technology 3-2 Elevated water tank

Burkina Faso	Ethiopia	Kenya	Morocco	South Africa
-	-	-	10-1000 m³ most common	-

4.3.9 Technology 3-3 Centrifugal Pump Station

4.3.9.1 Technology Description

A Pumping station is an integral part of most water supply systems and is used mainly for following purposes:

- To continuously pump water in a storage tank (open system)
- To increase the water pressure or head (potential energy) in the conveyance system (closed system)
- To increase the flow rate of supply (kinetic energy) to the systems (closed system)

4.3.9.2 Input parameters

- Daily water demand Qd [m^3/d] if pumping in an open system (tank)
  OR
- Largest hourly water demand Qhmax [m^3/h] if pumping in closed system (main pipe)
- Pressure head [m]
- Surface or Subsurface

4.3.9.3 Design assumptions

- Electrical connection available on site
- Energy = $Q^*\rho^*g^*h/\eta$
  Q = water demand [m^3/s]
  ρ = density of fluid
  g = acceleration of gravity [m/s^2]
  h = height [m]
  Pump efficiency = 0.5
- no. of pumps = 2 (100% reserve)
- incl. air vessel if pumping into closed system (booster pumps)
- small pumping house on the surface

4.3.9.4 Design

The pump station is a structure made of concrete in which two pumps are located with the necessary power to transport the water with necessary pressure through the system to the users. The concrete structure is of rectangular design with fixed sizes for height, length and width, covered by a small pump house to restrict access. It is intended that the pump station is constructed below the surface, but depending on the user`s wishes, the pump station can be constructed on the surface too. The surface pump station does not require earth works and the concrete structure, instead only the small pump house is erected to restrict access to the pumps. The pump house is assumed to be of a cheap but robust material, e.g. corrugated iron. A list of pumps for different water demands and pressure heads is filed into the tool. Depending on the input values for these two parameters, the tool selects the smallest pump able to deliver the required water volume under the given circumstances.

4.3.9.5 Dimensioning

The dimensioning is based on the daily water demand of the supplied area and the pressure head the pump has to overcome. The pump can be either on the surface or dug into the ground. The dimensioning starts at a water demand of 10 m^3/d and goes up to the maximum of 3600 m^3/d scaling over 10 different values. It is assumed that for higher water demands the usage of

2 or more parallel pumps of smaller size are more feasible than implementing large types. The pressure head is scaled from 10m up to 150m. Table 42 lists all dimensioning values.

Table 42 – Dimensioning values for centrifugal pump station

Daily water demand Q	m3/d	10	100	250	500	1000	1500	2000	2500	3000	3200
Pressure head	m	10	50	150							

4.3.9.6 Cost Functions

General

The cost functions are calculated by the total price of 30 designs with different water demand and pressure head. The investment cost of a particular pumping station comprises of costs for earthworks, construction and equipment specified in a bill of quantity.

Earthworks costs

Earthworks costs include positions shown in Table 43. These positions consider preparation, excavation and backfilling works. The pit excavation is performed as an excavation with inward-slope and followed by backfilling after finishing the construction. A blinding layer seals in underlying material and prevents dirt and mud from interfering with the structure.

Table 43 - Positions of earthworks costs (Centrifugal pump station)

Item no.	Position	Unit	Description
020201A	Clearing area	m^2	
030201A	Remove topsoil	m^3	
030206A	Replace Topsoil	m^3	
030211B	Re-Cultivate topsoil	m^2	
030331A	Pit excavation with inward-sloping	m^3	
030705A	Backfilling and covering of concrete walls	m^3	
030708A	Blinding layer < 10 cm	m^3	

Construction costs

Construction costs consist of concrete works shown in Table 44. The quality of the concrete is supposed to be C20/25 for the foundation, walls and for the ceiling. Ribbed steel is used to reinforce the concrete. Additionally concrete ancillaries are accounted for with a percentage of the total construction costs.

Table 44 - Positions of construction costs (Centrifugal pumping station)

Item no.	Position	Unit	Description
110302A	Slab C20/25 up to 30cm	m^3	
110401A	Wall 12-20cm C20/25	m^3	
110605A	Concrete slab ceilings C20/25 up to 20cm	m^3	
111902A	Ribbed steel < 10mm	kg	
n/a	concrete ancillaries	%	1% of concrete costs

Equipment costs

Equipment costs cover the pump, its electronics, piping and the respective valves and fittings. Depending on if the pump is located at the surface or underground, the BoQ adds a small house to protect the pump and a manhole cover and steps to allow access to the concrete structure if the pump in underground. Table 45 lists all positions.

Table 45 - Positions of equipment costs (Water tank surface)

Item no.	Position	Unit	Description
210401D	UPVC water supply pipes PN10 DN/OD 110	m	
n/a	Valves and fittings	%	10% of pipe costs
111601A	Concrete manhole cover DN800 class B 125kN (subsurface)	pcs	
232005A	Aluminium step plastic coated (subsurface)	pcs	
n/a	Small pumping house	pcs	2500€
n/a	pump	pcs	various
n/a	pump electronics (control cabinet, cabeling)	%	10% of pump costs

Investment cost function

The final investment cost function is derived from the different investment costs as a result of the varying water demand and pressure head inputs in the BoQ.

Investment costs IC:

$$IC = -0.0006x^2 + 8.96x + 4125 + (1.3E\text{-}05x^2 + 5.9E\text{-}03x + 31)*(y-50) \quad (31)$$

Investment costs IC:

$$IC = -0.0006x^2 + 8.96x + 7277 + (1.3E\text{-}05x^2 + 5.9E\text{-}03x + 31)*(y-50) \quad (32)$$

With x = Daily water demand Qd in m³/d; y = pressure head in m

Figure 25 shows resulting investment costs for the subsurface pump station over different water volumes. Figure 26 shows the development of the pressure head slope that changes with increasing water demand. In the final cost function this slope is used for a linear function describing the cost increase with higher pressure head. Generally, investment costs increase with increasing water volume and pressure head.

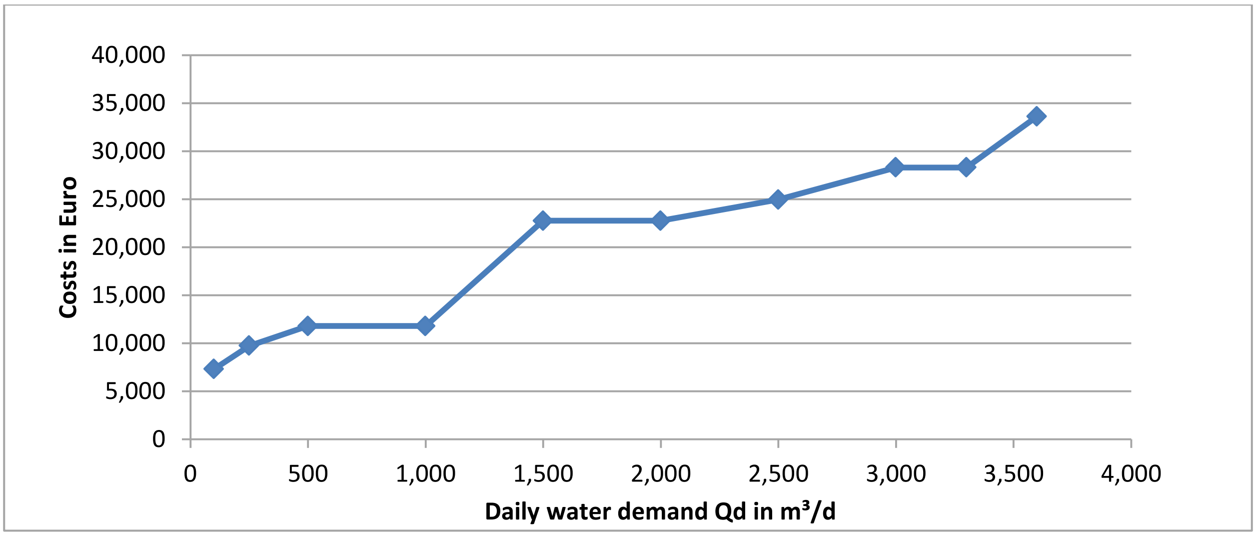

Figure 25 - Investment costs for centrifugal pump station (subsurface)

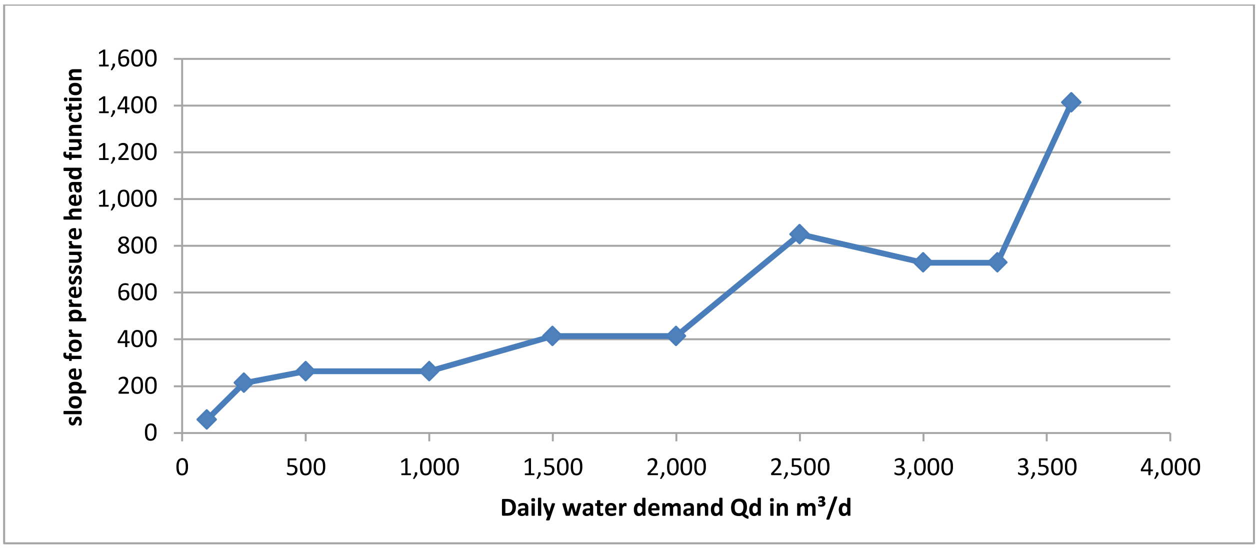

Figure 26 - Development of Slope for Pressure head with increasing Water demand Qd (Subsurface)

Operation and Maintenance Cost Function

Operation and maintenance costs are the main cost factor for a pump station. A general inspection is recommended once a week for every pump station. Additionally, each pump should be checked thoroughly after 5000 operating hours. The biggest part of the O&M costs is made up of the pumps power requirements. There is no difference in O&M costs between surface and subsurface. Figure 27 shows the O&M costs scaling over the different water volumes used to derive the cost functions. Figure 29 represents the pressure head slope that changes with increasing water demand. In the final cost function this slope is used for a linear function describing the cost increase with higher pressure head. O&M costs increase with increasing water volume and pressure head.

O&M costs OC for surface and subsurface pump station:

$$OC = 14.27x + 33.19 + (1.3E\text{-}20x^2 + 2.7E\text{-}01x - 1.5E\text{-}13)*(y-50) \quad (33)$$

With x = Daily water demand Qd in m³/d; y = pressure head in m

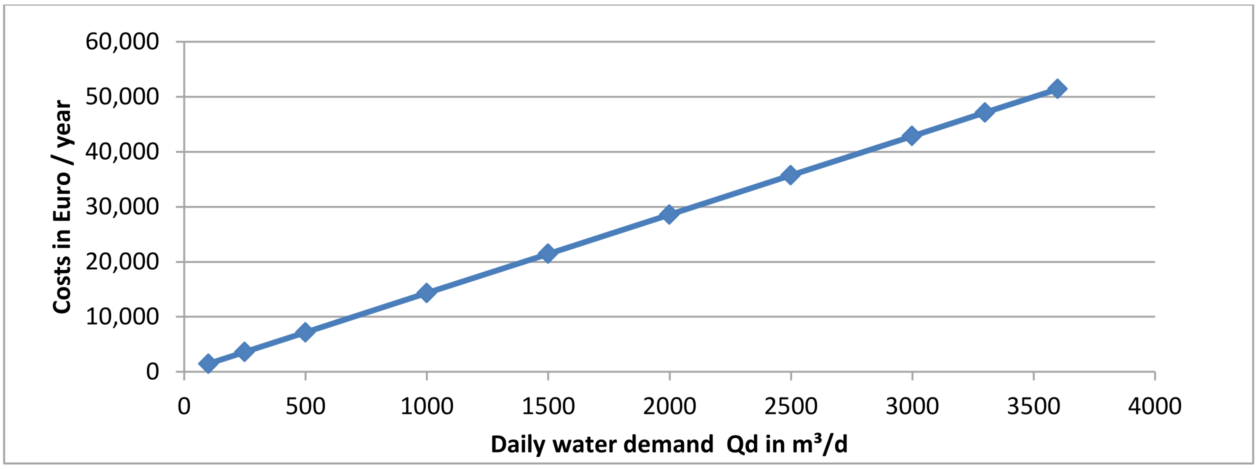

Figure 27 - Operation & Maintenance costs for subsurface and surface pump station, dependent on the daily water demand.

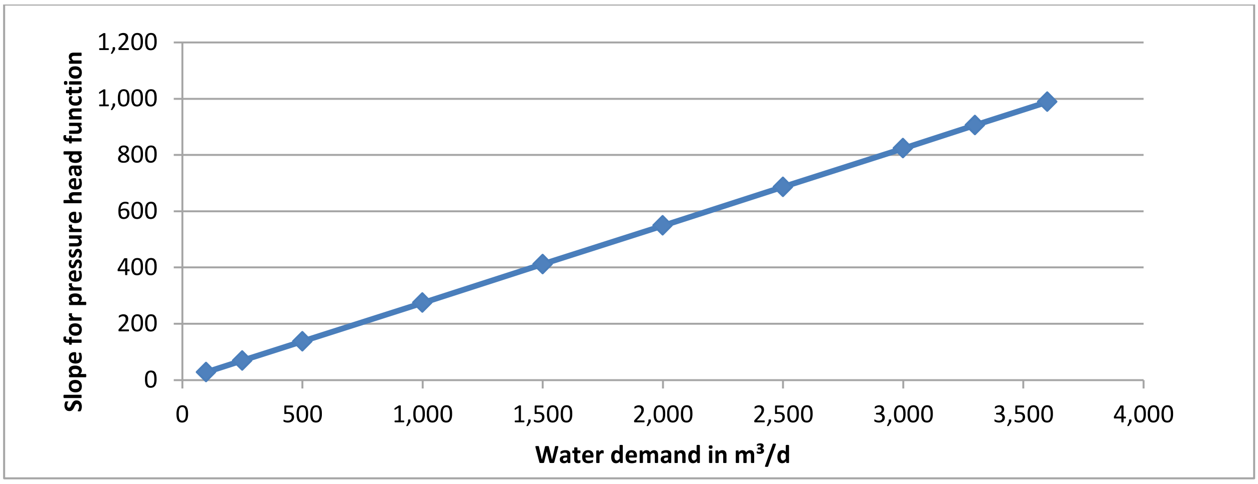

Figure 28 - Development of slope for pressure head over increasing daily water demand for the pump station

Reinvestment Cost Function

The pump in operation needs replacement every 15 years. It is expected that the concrete structure for a subsurface pump station needs to be replaced after 25 years.

4.3.9.7 Country specific assessment

Burkina Faso also powers pump stations with solar energy, resulting in improved O&M costs. Solar power is an environmental friendly option and should be encouraged when its application is feasible. Therefore it is recommended to introduce a solar powered option for this technology in a future update.

The **other countries** agree with the given design assumptions in general. Some countries propose to calculate the O&M costs on a percentage basis of the investment costs, but the results would differ vastly from the current version, as increasing water demand leads to higher energy requirements of the pump, but the investment costs only increase little.

Table 46 - Summary of country-specific assessment for technology 3-3 Pump station

Burkina Faso	Ethiopia	Kenya	Morocco	South Africa
solar power as option	-	-	-	-

4.3.10 Technology 3-4 Water Main Transmission Line

4.3.10.1 Technology Description

Water needs to be transported from the source to the purification plant, and onward to the water supply network. Robust pipes are used for this purpose. They are protected by being buried in a trench.

4.3.10.2 Input parameters

- Daily water demand Qd [m^3/d]
  OR
- Largest hourly water demand Qhmax [m^3/h]
- Pipe Length [m]
- Average depth [m]

4.3.10.3 Design assumptions

- DN calculated for flow rate > 0.6 m/s and < 1.2 m/s; nearest norm diameter
- Pressure 10 bar
- Excavation volume and type of trench according to pipe depth
- Pipe material: PVC or HDPE (only < 3 inch)
- Fitting and Valves cost assumed to be 10% flat

4.3.10.4 Design

This technology describes the main pipeline that transports the clean water from the treatment plant to its area of usage. The pipeline increases in diameter depending on the water demand so that the flow velocity will be within the limits defined in the design assumptions. The pipeline is laid into a trench with a minimum depth of 2m and a width depending on the pipe`s diameter. The length of the trench is consequently the distance from the treatment plant to the destined area. Costs of this technology are calculated on per meter. The pipe material is usually PVC, but for diameters smaller than 3 inch high-density polyethylene (HDPE) is assumed to be used.

4.3.10.5 Dimensioning

The technology is dimensioned over the largest water demand per day OR the average water demand per day and the depth of the trench in which the pipe will be laid.
In accordance with other technologies belonging to a distribution network, the water main is dimensioned for values of up to 10000 m³/d, over altogether 10 different values. Table 47 lists all values used for dimensioning.

Table 47 - Dimensioning values for water main transmission

Daily water demand Q	m3/d	10	500	1000	2000	3000	4000	5000	6000	8000	10000
Trench depth	m	2	3	4							

The technology is also dependent on the length of the pipeline but as the cost calculation will be based on a "per meter"-base, the length of the pipeline will be simply multiplied with the cost per meter in the end.

4.3.10.6 Cost Functions

Investment Cost Function

The investment cost function is calculated by the total price of the 30 designs with varying water volume and trench depth, multiplied with the total length of the pipe. The investment costs of a particular main transmission line include costs for earthworks, construction and equipment specified in a bill of quantity.

Earthworks costs

Earthworks costs include positions shown in Table 48. These positions consider preparation, excavation and backfilling works. The pit excavation is performed as an excavation with inward-slope and followed by backfilling after finishing the construction. The bedding beneath at the ground of the trench is done with sand. The trenches upper edges are on level with the surface.

Table 48 - Positions of earthworks costs (Water Main)

Item no.	Position	Unit	Description
020201A	Clearing area	m^2	
030201A	Remove topsoil	m^3	
030206A	Replace Topsoil	m^3	
030211B	Re-Cultivate topsoil	m^2	
030331A	Trench excavation	m^3	
030705A	Backfilling and covering of concrete walls	m^3	
030703B	Bedding with sand	m^3	

Construction costs

For the construction of a water main no concrete works are necessary. Therefore, no positions are given under “construction costs” for this BoQ.

Equipment costs

Equipment costs cover the all pipes, their valves and fittings, leakage testing and commissioning and a final disinfection of the pipeline before it can be used. All positions are listed in Table 49.

Table 49 - Positions of equipment costs (Water main transmission)

Item no.	Position	Unit	Description
210505 D-G	PE water supply pipes PN10 with DN/OD of varying sizes	m	Pipes < 3 inch
210401 C-K	UPVC water supply pipes PN10 with DN/OD of varying sizes	m	Pipes > 3 inch
n/a	Valves and Fittings	%	10% of pipe costs
n/a	Leakage testing and commissioning	%	15% of total invest
n/a	Disinfection of pipeline	%	5% of total invest

Investment cost function

The final investment cost function is derived out of the 10 different values for water demand ranging from 100m³/d up to 10000 m³/d and the trench depth, which is assumed to be at a minimum of 2m and scales up to 4m. As the BoQ calculates the costs per meter of the pipeline, the resulting price will be multiplied with the total length of the pipe to achieve the final costs. In general, costs increase with the extraction volume and the trench depth. The resulting cost function is shown in Eq. 34:

Investment costs IC:

$$IC = ((-9E\text{-}08x^2 + 0.0022x + 14.807) + (-1.7E\text{-}08x^2 + 4.0E\text{-}04x + 4)*(y - 2)\hat{}2)) * z \qquad (34)$$

With x = Daily water demand Qd in m³/d, y = trench depth in m, z = length of pipe in m

Figure 29 shows the resulting investment costs per meter for different water demands per day, with a trench depth of 2m. Figure 30 represents the slope for the trench depth, changing with increasing water demand. In the final cost function this slope is used for a linear function describing the cost increase with larger trench depth. Investment costs increase with increasing water volume and trench depth in general.

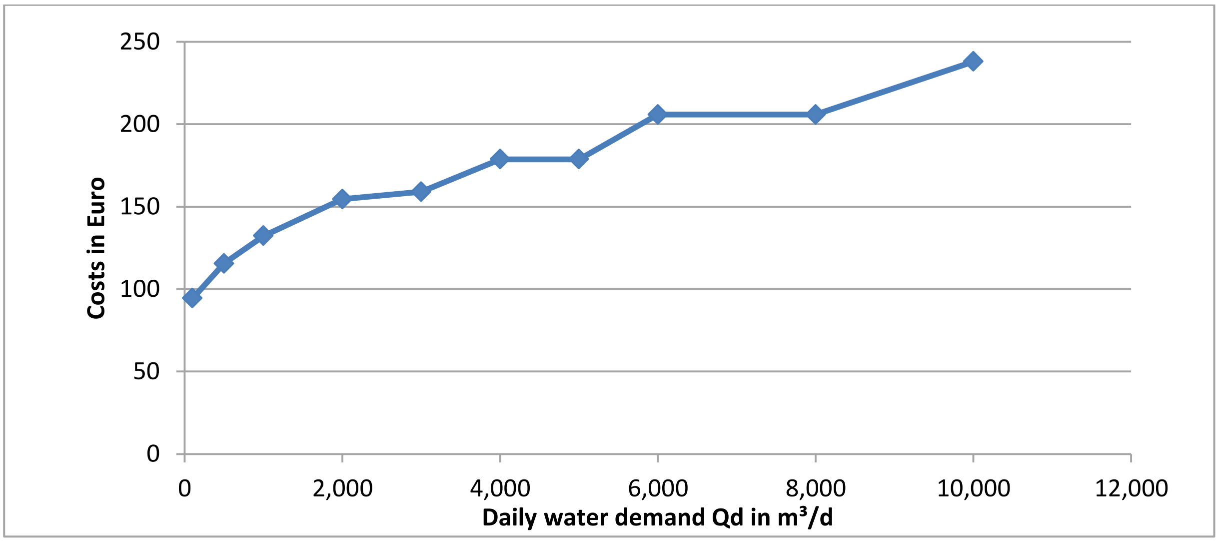

Figure 29 - Investment costs main transmission line per meter, dependent on daily water demand.

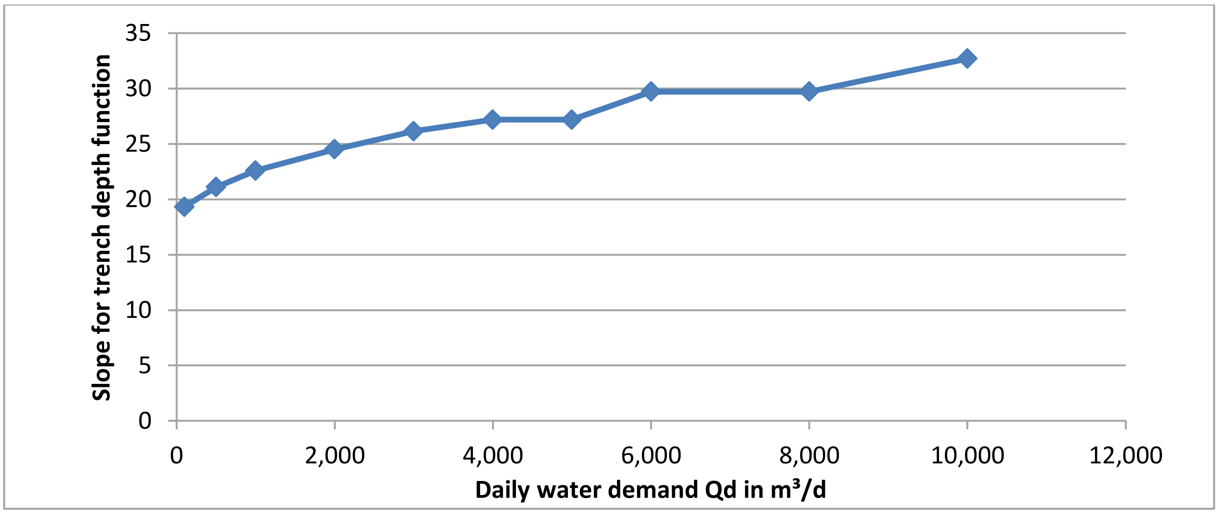

Figure 30 - Development of Slope for Trench depth with increasing daily water demand.

Operation and Maintenance Cost Function

Comparable to the water storage tanks, operation and maintenance is rather simple for a pipeline. Besides usual inspection and maintenance at critical points (e.g. valves), a pipeline only requires more specific attention when leakage or disinfection is detected. As a consequence, it is standard to assume a fixed rate of O&M costs per meter. Here the assumption of 1 Euro per meter pipeline is taken.

Reinvestment Cost Function

Due to the long life time of PVC pipes, replacement of the whole transmission line will become necessary after 50 years or more since life time of material higher than 50 years project time. Therefore, no reinvestment cost function is derived.

4.3.10.7 Country specific assessment

Burkina Faso uses cast iron pipes for their main transmission lines, with sizes of up to 1000mm diameter, not dug into ground but lying on the ground surface. There is no argumentation why PVC could not be used for new constructions, as they are cheaper and less heavy and oxidation is avoided. As long as Burkina Faso does not explicitly demand cast iron pipes for new projects, the design assumption should be kept.

Ethiopia also refers to ductile cast iron (DCI) as pipe material, but the argumentation is the same as with Burkina Faso, while **Kenya** prefers the PVC pipes. Furthermore, **Ethiopia** refers to the 6 bar pressure in the pipe to be not feasible and lists a value between 10 to 16 bar as realistic. As the pressure is actually not of significance for calculating the cost function, this value is adapted for all countries to 10 bar.

All countries but **South Africa** calculate the O&M costs as a percentage of the investment costs, which differs from the design assumption of 1 Euro per meter. It is up for discussion which calculation method is more realistic and therefore the design assumption remains unchanged for now. Table 50 summarizes the technology assessment.

Table 50 - Summary of country-specific assessment for technology 3-4 Water main transmission

Burkina Faso	Ethiopia	Kenya	Morocco	South Africa	General
used DCI for old pipes	used DCI for old pipes	-	common: human transport in 20l jugs	O&M costs percentage of invest	Valves & Fittings surcharge 10% of pipe costs

4.3.11 Technology 3-5 Water Distribution Network

4.3.11.1 Technology Description

Supply networks are a system of pipes, fittings (manholes) and trenches. The aim of a distribution network is to supply a community with the appropriate quantity and quality of water.

4.3.11.2 Input parameters

- Daily water demand Qd [m^3/d]
  OR
- Largest hourly water demand Qhmax [m^3/h]
- Pipe Length [m]
- Average depth [m]

4.3.11.3 Design assumptions

- Average DN according to planner's best estimate (> 0.5 m/s and < 1.5 m/s)
- Excavation volume and type of trench according to pipe depth
- Pipe material: PVC or HDPE (< 3 inch)
- Surcharge for fittings (valves, T's, etc.) 15% flat

4.3.11.4 Design

This technology covers the network of pipes in the area where the treated water is used. As the pipe diameters decrease the closer the water gets to the end user, the technology calculates with two different diameters for pipes. Likewise to technology 3.4, the pipes are buried in a trench with a minimum depth of 2m, width depending on the diameter of the pipes and a total network length given by the planner. For pipes with a diameter smaller than 3 inch, HDPE is recommended as material of choice. For bigger diameters PVC is used in the calculations.

4.3.11.5 Dimensioning

The technology is from a dimensioning point of view very similar to the main transmission line. Again the technology will be dimensioned over the largest water demand per hour or the average demand per day and the depth of the trench in which the pipe will be laid.
In accordance with other technologies under point 3 - water distribution - the network is dimensioned for values of up to 10000 m³/d, with altogether 10 different values. Table 51 lists all values used for dimensioning.

Table 51 – Dimensioning values for water distribution network

Daily water demand Q	m3/d	10	500	1000	2000	3000	4000	5000	6000	8000	10000
Trench depth	m	2	3	4							

The technology is once more dependent on the length of the pipe network but as the cost calculation will be based on a "per meter"-base, the total length can be multiplied with the cost per meter in the end.

4.3.11.6 Cost Functions

General

The cost functions are calculated by the total price of 30 designs with varying water volume and trench depth, multiplied with the total length of the pipe. The investment costs of a particular main transmission line include costs for earthworks, construction and equipment specified in a bill of quantity.

Earthworks costs

Earthworks costs include positions shown in Table 52. These positions consider preparation, excavation and backfilling works. The pit excavation is performed as an excavation with inward-slope and followed by backfilling after finishing the construction. The bedding beneath at the ground of the trench is done with sand. The trenches upper edge is on level with the surface.

Table 52 - Positions of earthworks costs (Water distribution network)

Item no.	Position	Unit	Description
020201A	Clearing area	m^2	
030201A	Remove topsoil	m^3	
030206A	Replace Topsoil	m^3	
030211B	Re-Cultivate topsoil	m^2	
030331A	Pit excavation with inward-sloping	m^3	
030705A	Backfilling and covering of concrete walls	m^3	
030708A	Blinding layer < 10 cm	m^3	

Construction costs

For the construction of a water distribution network no concrete works are necessary. Therefore, no positions are given under “construction costs” for this BoQ.

Equipment costs

Equipment costs cover the all pipes, their valves and fittings, leakage testing and commissioning and a final disinfection of the pipeline before it can be used. All positions are listed in Table 53.

Table 53 - Positions of equipment costs (Water distribution networks)

Item no.	Position	Unit	Description
210505 D-G	PE water supply pipes PN10 with DN/OD of varying sizes	m	Pipes < 3 inch
210401 C-K	UPVC water supply pipes PN10 with DN/OD of varying sizes	m	Pipes > 3 inch
n/a	Valves and Fittings	%	15% of pipe costs
n/a	Leakage testing and commissioning	%	15% of total investment
n/a	Disinfection of pipeline	%	5% of total investment

Investment cost function

The final investment cost function is derived out of the 10 different values for the water volume ranging from 100m³/d up to 10000 m³/d and the trench depth, which is assumed to be at a minimum of 2m and scales up to 4m. As the BoQ calculates the costs per meter of the network, the resulting price will be multiplied with the total network length to achieve the final costs. In general, costs increase with the extraction volume and the trench depth, and of course the size of the network. The resulting cost function is shown in Eq.35:

Investment costs IC:

$$IC = ((-9E\text{-}08x^2 + 0.0017x + 10.833) + (-1.6E\text{-}08x^2 + 3.0E\text{-}04x + 3)*(y - 2)^{\wedge}2)) * z \qquad (35)$$

With x = Daily water demand Qd in m³/d, y = trench depth in m, z = length of pipe in m

Figure 31 shows the resulting investment costs per meter for different water volumes per day, with a trench depth of 2m. Figure 32 represents the slope for the trench depth over increasing water demand. In the final cost function this slope describes a linear function representing the cost increase with larger trench depth. In general, investment costs rise with increasing water volume and trench depth.

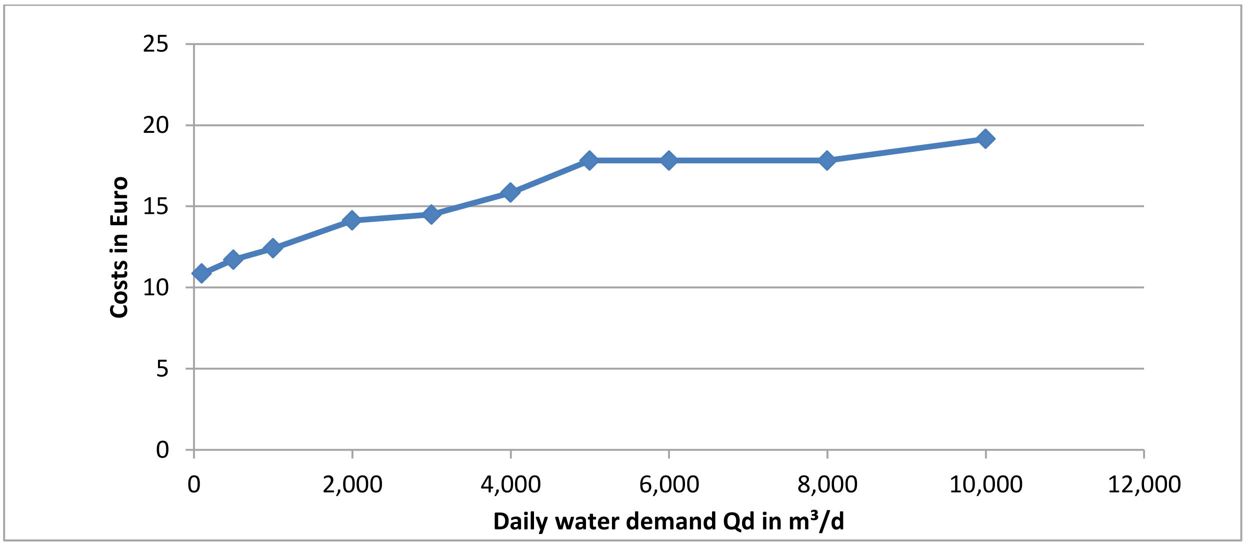

Figure 31 - Investment costs of water distribution network per meter

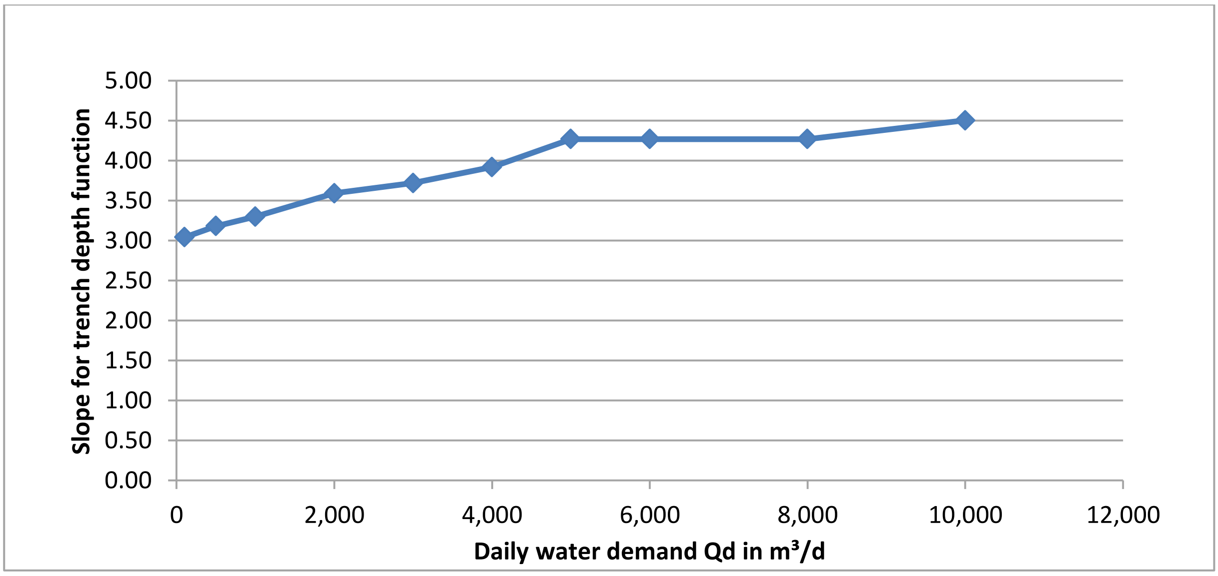

Figure 32 – Slope development for the trench depth with increasing Q

Operation and Maintenance Cost Function

Comparable to the water storage tanks, operation and maintenance is rather simple for a pipeline. Besides usual inspection and maintenance at critical points (e.g. valves), the network only requires more specific attention when leakage or disinfection is detected. As a consequence, it is standard to assume a fixed rate of O&M costs per meter. The costs are assumed to be 1 Euro per meter.

Reinvestment Cost Function

Due to the long life time of PVC pipes, replacement of the whole transmission line will become necessary after 50 years or more since the life time of the material is higher than 50 years project time. Therefore, no reinvestment cost function is derived.

4.3.11.7 Country specific assessment

Ethiopia states that surcharge for fittings between HDPE and UPVC differ greatly and should be adapted accordingly. This statement needs to be confirmed, but in general the surcharge for fittings make up only a small amount, around 2%, of the total investment costs. Still, adaptation of fitting costs should be conducted for all countries if the difference between HDPE and UPVC fittings is large. Ethiopia furthermore claims that the maximum hourly water demand is sufficient to calculate costs for a distribution network. This matches the concept of the current version of the cost function and therefore will be changed in the technology description.

Burkina Faso estimates life spans of more than 60 years, while **Kenya** lists 30 years as life span estimate. If constructed properly, HDPE/UPVC pipes should last longer than the projects duration of 50 years.

Morocco and **South Africa** list no specific objections to the given design assumptions. Table 54 gives an overview over the results of the technology assessment.

Table 54 - Summary of country-specific assessment for technology 3-5 Water distribution network

Burkina Faso	Ethiopia	Kenya	Morocco	South Africa	General
life span 60 years	-	life span 30 years	-	-	Valves & Fittings add 15% of pipe costs

4.3.12 Technology 3-6 House Connections

4.3.12.1 Technology Description

House connections are the final pipes linking a single house to the nearest pipe of the supply network. A water meter is installed to measure the amount of water consumption.

4.3.12.2 Input parameters

- No. of house connections [-]
- Average connection length (m]
- Average depth [m]

4.3.12.3 Design assumptions

- If not given – trench depth: 3m
- Average DN 1.5”
- Excavation volume and type of trench according to pipe depth
- If not given - length of pipe from network to water meter: 10m
- Pipe material: HDPE
- Surcharge for fittings (valves, T’s, water meter, etc.) 20% flat
- Life time of water meter: 20 years

4.3.12.4 Design

House connections cover the last meter of a distribution network before the water can be extracted by a user. Because of the small diameters that are required at the end of the system, the pipes used here are supposed to be made of HDPE with an average diameter of 1.5 inch. The length can be chosen by the tool user, but is assumed to be 10m if no other input is given. A water meter is installed at the point of discharge.

4.3.12.5 Dimensioning

The technology is scaled over the number of connections, the average length of the house connection and the average depth in which the pipes are buried. As the costs are calculated per single connection and per single meter of a connection, the only dimensioning value in the xls sheets is the average trench depth, as listed in Table 55.

Table 55 – Dimensioning values for house connections

Trench depth	m	1.25	1.75	4.00

4.3.12.6 Cost Functions

General

The cost functions are calculated by the total prices of 9 different designs with changing trench depth and length of the connection. The total investment costs for a house connection consist of costs for earthworks, construction and equipment specified in a bill of quantity.

Earthworks costs

Earthworks costs include positions shown in Table 56. These positions consider preparation, excavation and backfilling works. The pit excavation is performed as an excavation with inward-slope and followed by backfilling after finishing the construction. The bedding beneath at the ground of the trench is done with sand. The trench upper edge is on level with the surface.

Table 56 - Positions of earthworks costs (House connections)

Item no.	Position	Unit	Description
020201A	Clearing area	m^2	
030201A	Remove topsoil	m^3	
030206A	Replace Topsoil	m^3	
030211B	Re-Cultivate topsoil	m^2	
030331A	Pit excavation with inward-sloping	m^3	
030705A	Backfilling and covering of concrete walls	m^3	
030708A	Blinding layer < 10 cm	m^3	

Construction costs

For the construction of a house connection no concrete works are necessary. Therefore, no positions are given under “construction costs” for this BoQ.

Equipment costs

Equipment costs cover the all pipes, their valves and fittings, leakage testing and commissioning and a final disinfection of the pipeline before it can be used. Furthermore, the water meter to measure the consumption is included. All positions are listed in
Table 57.

Table 57 - Positions of equipment costs (House connections)

Item no.	Position	Unit	Description
201001A	PE water supply pipes PN10 DN/OD 40	m	
n/a	Valves and Fittings	%	20% of pipe costs
n/a	Leakage testing and commissioning	%	15% of total investment
n/a	Disinfection of pipeline	%	5% of total investment
216001A	Water meter PN16, 3m3/h	pcs	

Investment cost function

The final investment cost function is derived out of the different values for the connection length ranging from 5m to 20m and the different values for the trench depth, ranging from 2m to 4m. As the BoQ calculates the costs for price per single house connection, the resulting price will be multiplied with the total number of connections to achieve the final costs. In general, costs increase with the connecting length and the trench depth. In the end, the resulting cost pro connection will be multiplied with the numbers of house connections to get the total investment costs for the planned project. The resulting cost function is:

Investment costs IC:

$$IC = z*(200 + (x-10) * 18.2 + (y-3) * 37) \quad (36)$$

With x = average length of connection in m, y = average trench depth in m, z = number of house connections

Figure 33 shows the resulting investment costs per house connection for different average trench depths and different average length per house connection:

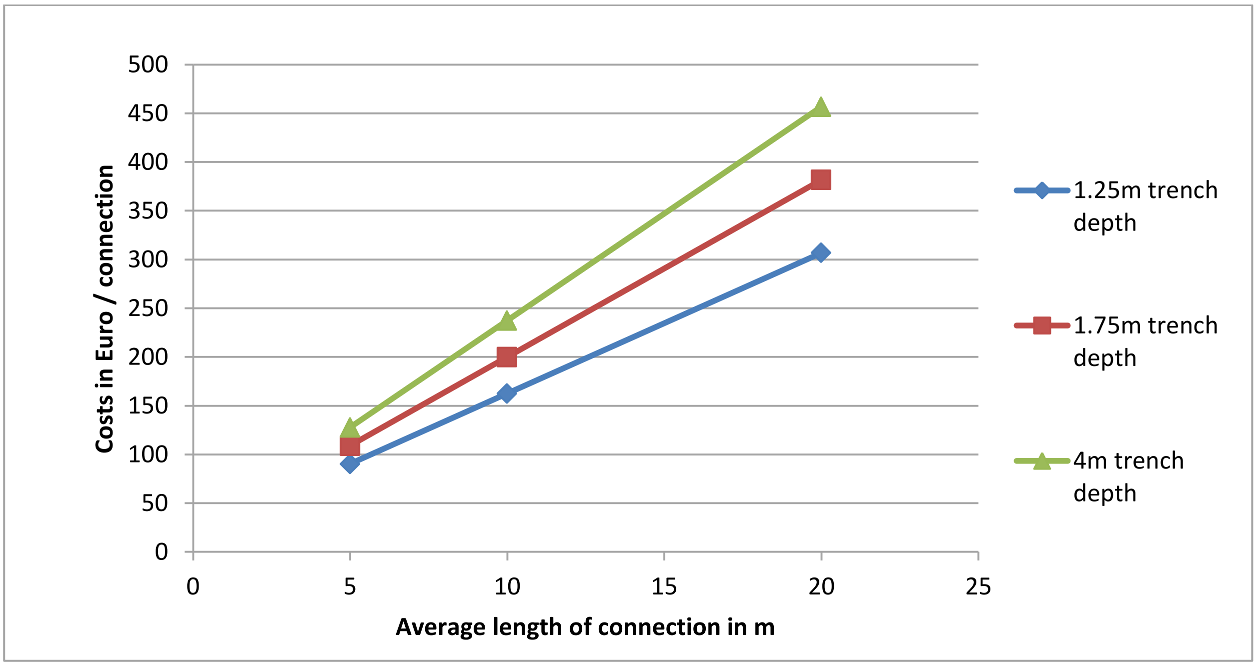

Figure 33 - Investment costs for house connections over differing trench depth and average connection length

Operation and Maintenance Cost Function

Like with the other technologies in water distribution, operation and maintenance is relative straightforward for house connections. Besides inspection and maintenance at critical points (e.g. valves), for house connections the water meter requires replacement and new calibration at constant intervals. As a result of the technology assessment, this interval has been set to 20 years. This leads to the result, that the O&M costs per house connections are not affected by the length of the connection and the depth of the trench. Therefore, no figure is shown for this cost function, but the resulting cost function is:

O&M cost OC function for house connections: $OC = z*3.77$ *(37)*

With z = number of house connections

Reinvestment Cost Function

Due to the long life time of PVC pipes, replacement of the whole house connection will become necessary after 50 years or more since the life time of the material is higher than 50 years project time. Therefore, no reinvestment cost function is derived.

4.3.12.7 Country specific assessment

Morocco and **South Africa** list no specific objections to the given design assumptions.
Kenya, **Burkina Faso** and **Ethiopia** argue that the life time of water meters should be increased, giving estimations of 10-20 years. Ethiopia refers to ALLENDER (1996). According to the arguments made there, the expected life time of water meters will be adapted to 20 years.
Lastly, **Ethiopia** argues that the surcharge for valves and fittings should be higher, again especially for HDPE. Leaving out the difference between HDPE and UPVC surcharges, it is reasonable that a water main requires fewer fittings than a distribution network and that the distribution network also requires fewer fittings than the house connections, simply because the number of junctions and connections increases. As a consequence, surcharge for valves and fittings have been adapted as follows:

10% for technology 3.4 – Water main transmission line
15% for technology 3.5 – Water supply network
20% for technology 3.6 – House connections

Table 58 lists the results of the technology assessment for the house connections.

Table 58 - Summary of country-specific assessment for technology 3-6 House connections

Burkina Faso	Ethiopia	Kenya	Morocco	South Africa	General
watermeter life time: 10-20 years	watermeter life time: 10-20 years	watermeter life time: 10-20 years	-	-	Valves & Fittings add 20% of pipe costs

5. Discussion

5.1 What was achieved

Within this thesis general cost functions for a number of selected water supply technologies have been developed. These cost functions are based on a standard design: For all technologies short technology descriptions have been provided including the most important design assumptions. For every cost function, a set of BoQ has been created for investment, O&M and reinvestment costs. The positions in the BoQ have been standardized following the guidelines from LB-SW (2005). First feedback from the participating countries has been received and adaptations were made to account for the technology assessment of those countries.
All cost functions have been developed in MSExcel® and many assumptions, formulas and calculations are explained within these files. To list all of these formulas and calculations here would go beyond the scope of this master thesis. To get a complete picture of the calculation steps of a single technology it is necessary to access not only the thesis, but also the respective Excel file.

5.2 Problems, inaccuracies, limitations

It is important to keep in mind that the CLARA SPT is supposed to be applied at early planning stages. As a consequence, for some technologies there is a lack of critical information. A good example for this is technology 1-2 groundwater extraction:
Without knowing the depth of the groundwater layer and the kf factor of the soil, it is hardly possible to calculate the total drilling depth necessary to extract the desired volume of water. It would be necessary to find a potential spot for a borehole and then apply geological tests that can lead to accurate results for the two mentioned parameters. But at early stages of a planned construction the precise location of the constructions is frequently unknown. That is why the tool allows giving input to those two values, if they can be given by the planners – which would result in way more reliable cost estimation. If not, the tool is calculating with the most common, mean values to hopefully deliver a cost estimation that is realistic. Still, the possibility exists that the tool might estimate significantly higher or lower costs for a project than what the expenditures are at final realization.

Another point to mention is that the cost functions are trend lines or curves adapted from the single cost points for the different design sizes. They are only estimators of the actual costs and will never be a hundred percent accurate. Some still are very accurate, some are less accurate, especially when the costs do not follow a regular trend but rather jump at certain threshold. This can be seen at technology 3-3, the centrifugal pump station, where investment costs are dependent on the market price of the pump.

Finally, although the cost functions are already scaled within a certain minimum and maximum thresholds, sometimes it might be more feasible to build two smaller sized buildings of a technology than a single big construction. Where possible, the cost functions should be set to the most logical number of constructions. For example, 2 waterlines are assumed for the treatment plant technologies and as a consequence the total water demand is divided by that number to calculate the tank sizes, and the costs per construction are then multiplied by that number to get the total costs. Smaller sizes but more numbers can often be of advantage especially when dealing with failures, avoiding a total system shutdown.

5.3 Outlook

Now that the first version of cost functions exists, future effort should be focused on the following points:

- First of all, the cost functions might still be improved to a certain degree, in situations where the calculation might be too rough. Another point would be more specific adaptations to single countries. The technology assessment was a start but some necessary adaptations might only become visible after the tool is tested. Planners might find limitations in the design assumptions they prefer to be adapted or they want to use specific material (e.g. solar power for borehole operation) that is not included in the current version. Also, the existing cost functions could be extended by adding new chemicals, new materials or similar further options.

- Another area of interest could be the possibility to add more technologies to the tool. In the field of water supply, examples would be rapid sand filtration as another treatment option or rainwater harvesting as a smaller scale, decentralized water source option. Again this should be in close cooperation with the target countries – They might come up with a request for specific technologies as each country has specific preferences and standards. Although it is out of date, the khettara is an example for a technology used in Morocco only.

- A long term target of the CLARA simplified planning tool should be to replace the rather theoretical BoQs as a cost base by real costs of realized projects. If enough projects of different sizes are constructed, scaling of cost functions can be achieved by putting in the costs of the projects. In the end, this approach should deliver results that are more realistic than the approach with the BoQs. Arguably, it might take years or decades to obtain enough data for the investment and O&M costs, not even considering the reinvestment data for 50 year long projects. Until then the approach presented here will hopefully prove feasible to be used for future water supply and sanitation projects in Africa.

6. Summary and Conclusion

The technologies cost functions are the backbone of the CLARA simplified planning tool and allow cost comparisons of different solutions for problems in the water supply and sanitation sector. From the results of this work it can be summarized that following steps were implemented to derive a first set of cost functions:

1) Define a standard design with design assumptions and input parameters
2) Determine sensible design sizes
3) Obtain BoQ according to standardized LB-SW guidelines, including price input from the participating countries for the standard positions
4) Obtain and include feedback from participating countries to design assumptions
5) Derive cost functions for investment, O&M and reinvestment costs

As a result, cost functions for the following list of technologies have been realized in the areas of water sources (1), water purification (2) and water treatment (3):

1.1 - Spring Extraction
1.2 - Groundwater Extraction (Borehole)
1.3 - River Water Extraction
2.1 - Grit Channel + Slow Sand Filtration
2.2 - Sedimentation + Coagulation
2.3 - Chlorination
3.1 - Surface Water Tank
3.2 - Elevated Water Tank
3.3 - Pump Station
3.4 - Water Main Transmission
3.5 - Water Distribution Network
3.6 - House Connections

Furthermore, another conclusion from working on the development of cost functions is the necessity of several future tasks for the further development of the CLARA simplified planning tool:

- Further adaptation of the technologies to meet country-specific standards and demands.
- Where feasible, combination of technologies for each functional group in order to simplify the use of the tool
- Create the possibility to adapt the cost base as a planner in order to adjust the cost function based on gained experience with project realization
- Replace the cost function with real project cost in remote future for a more accurate result
- Implement additional technologies to allow for more planning solutions for various situations

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8. Appendix

8.1 List of figures

8.2 List of tables

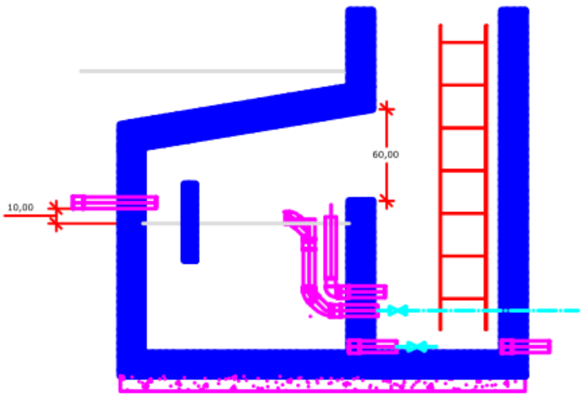
Following appendices can be found on the attached compact disk:

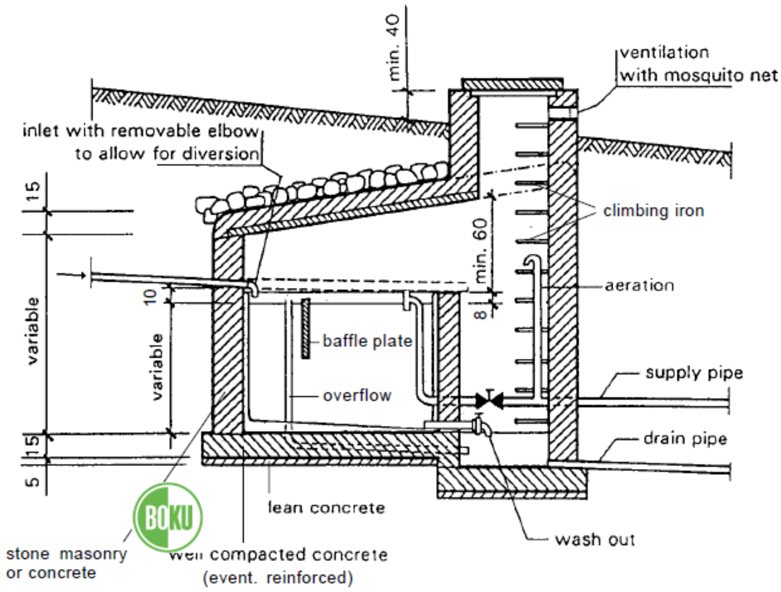
8.3 Cost function spread sheets in MSExcel®

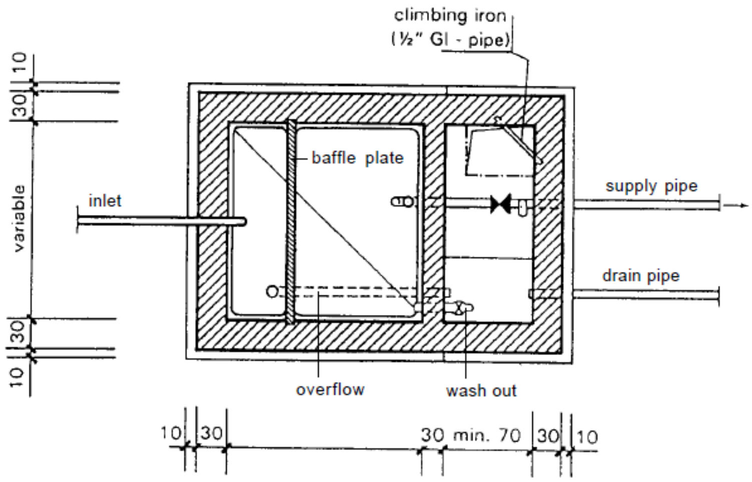
1-1 BoQ Extraction from Spring
1-2 BoQ Extraction of Groundwater (Boreholes)
1-3 BoQ River Water Extraction
2-1 BoQ Surface Water Treatment
2-2 BoQ Flocculation and Sedimentation
2-3 BoQ Chlorination
3-1 BoQ Water Tank (Surface)
3-2 BoQ Water Tank (Elevated)
3-3 BoQ Water Pumping Station
3-4 BoQ Water Main
3-5 BoQ Water Supply Network
3-6 BoQ House Connections Supply

8.4 Technology drawings or pictures

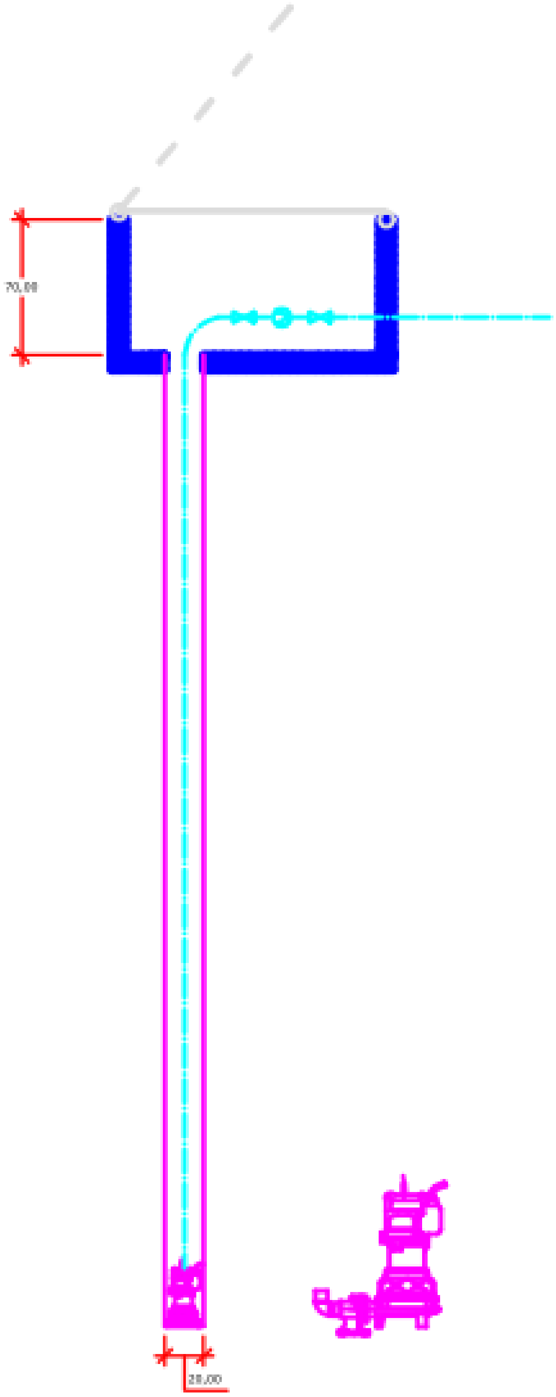
Technology 1-1 Spring Catchment



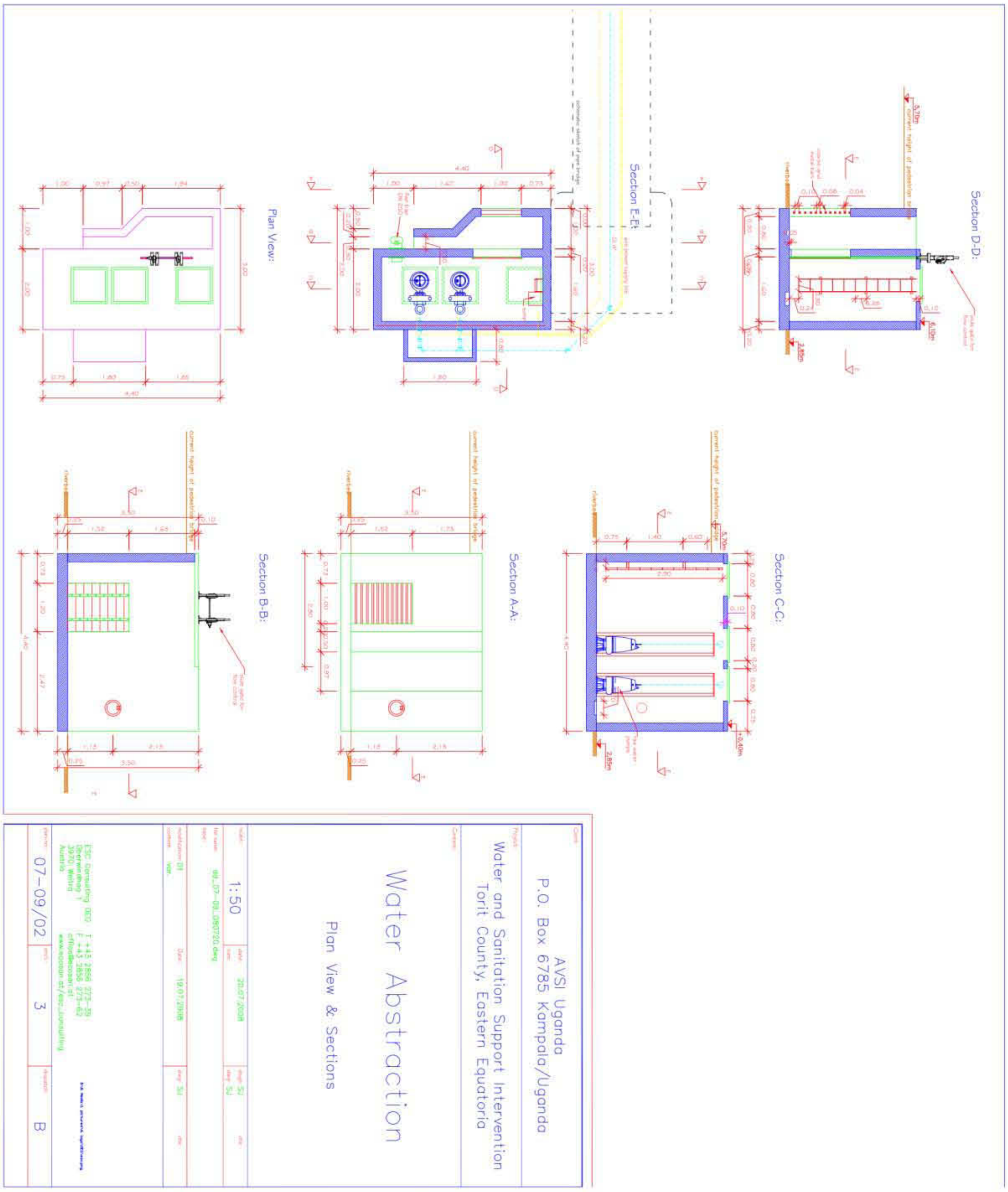




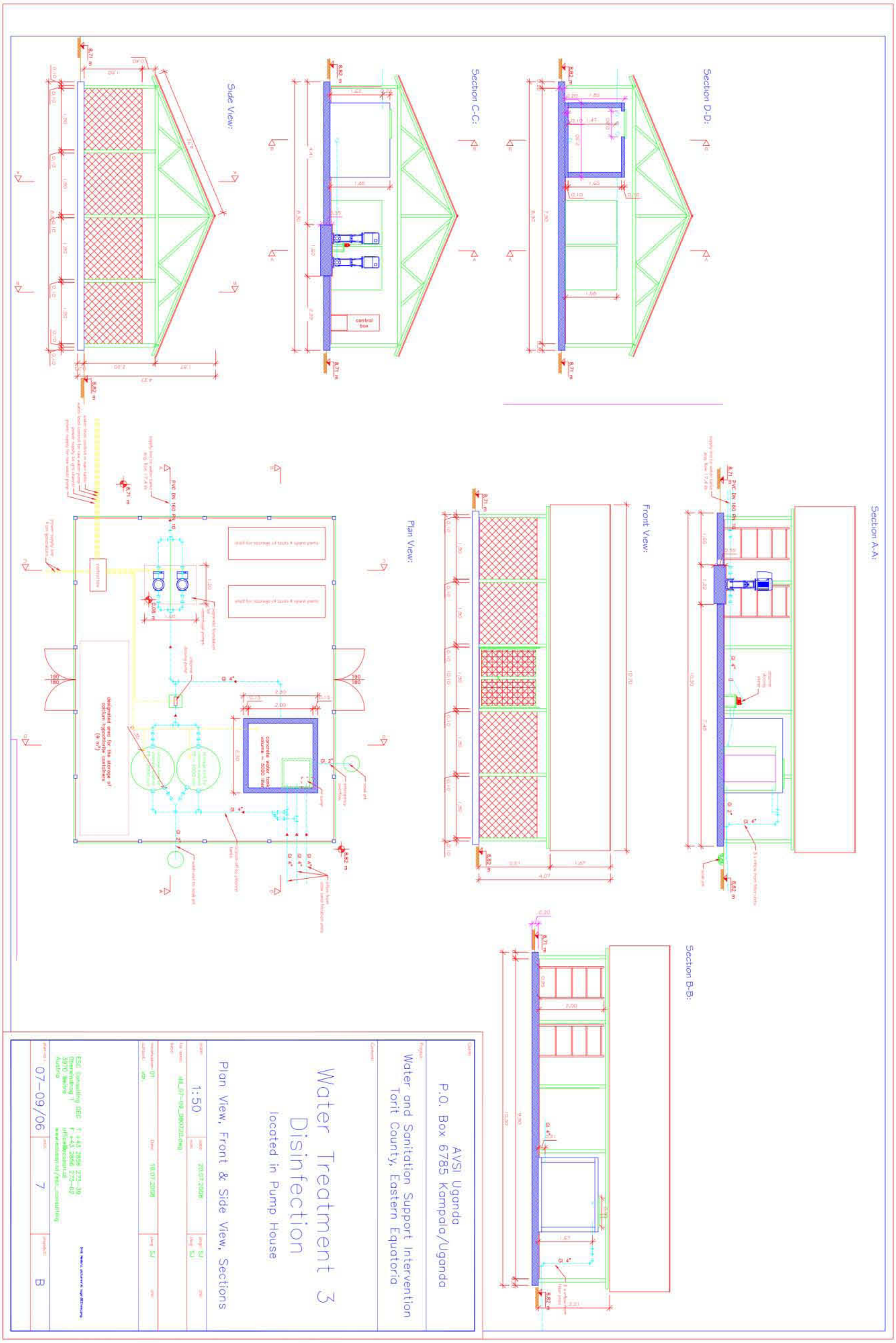
Technology 1-2 Groundwater Extraction (Borehole)



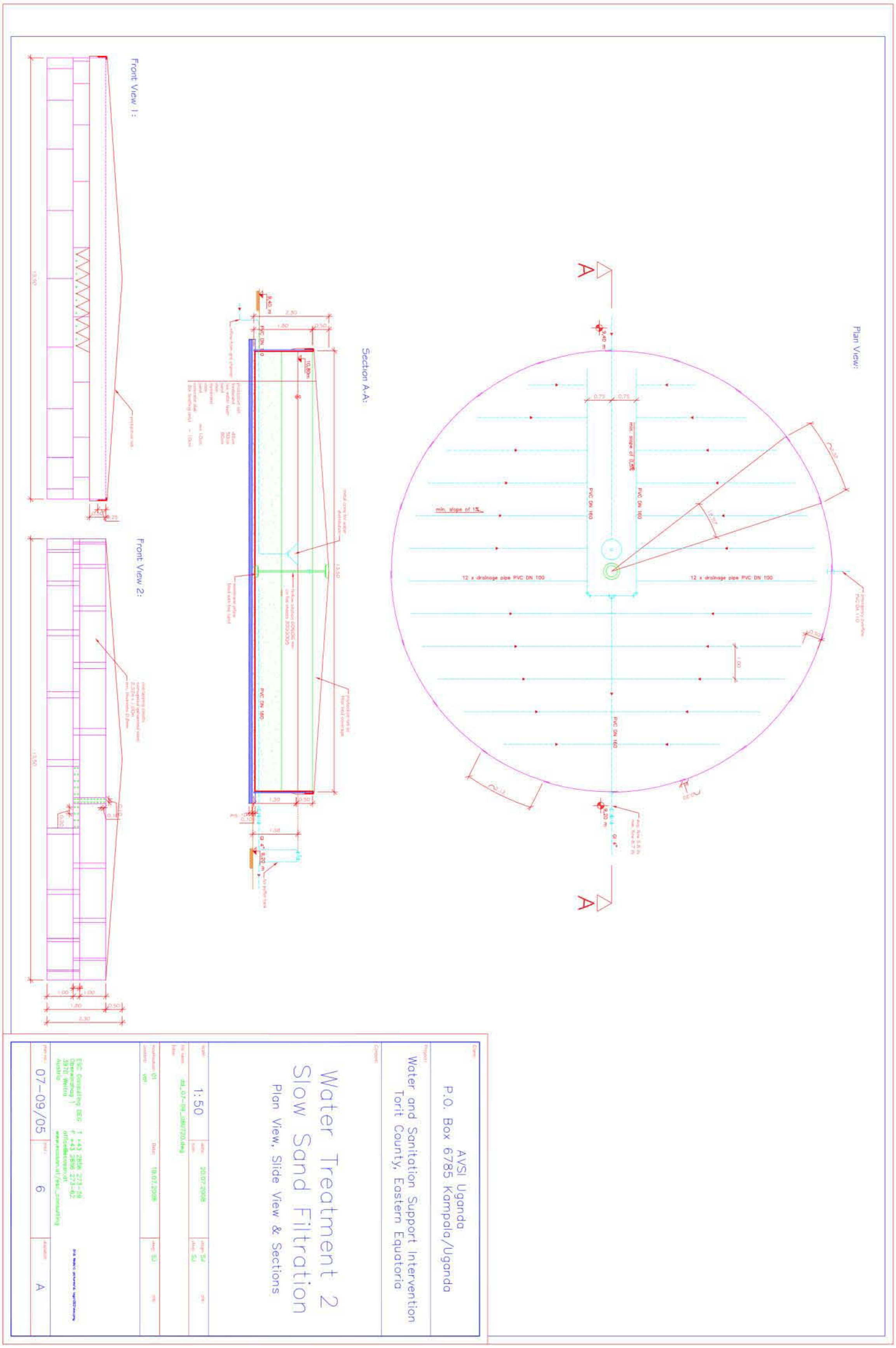
Technology 1-3 River Water Extraction



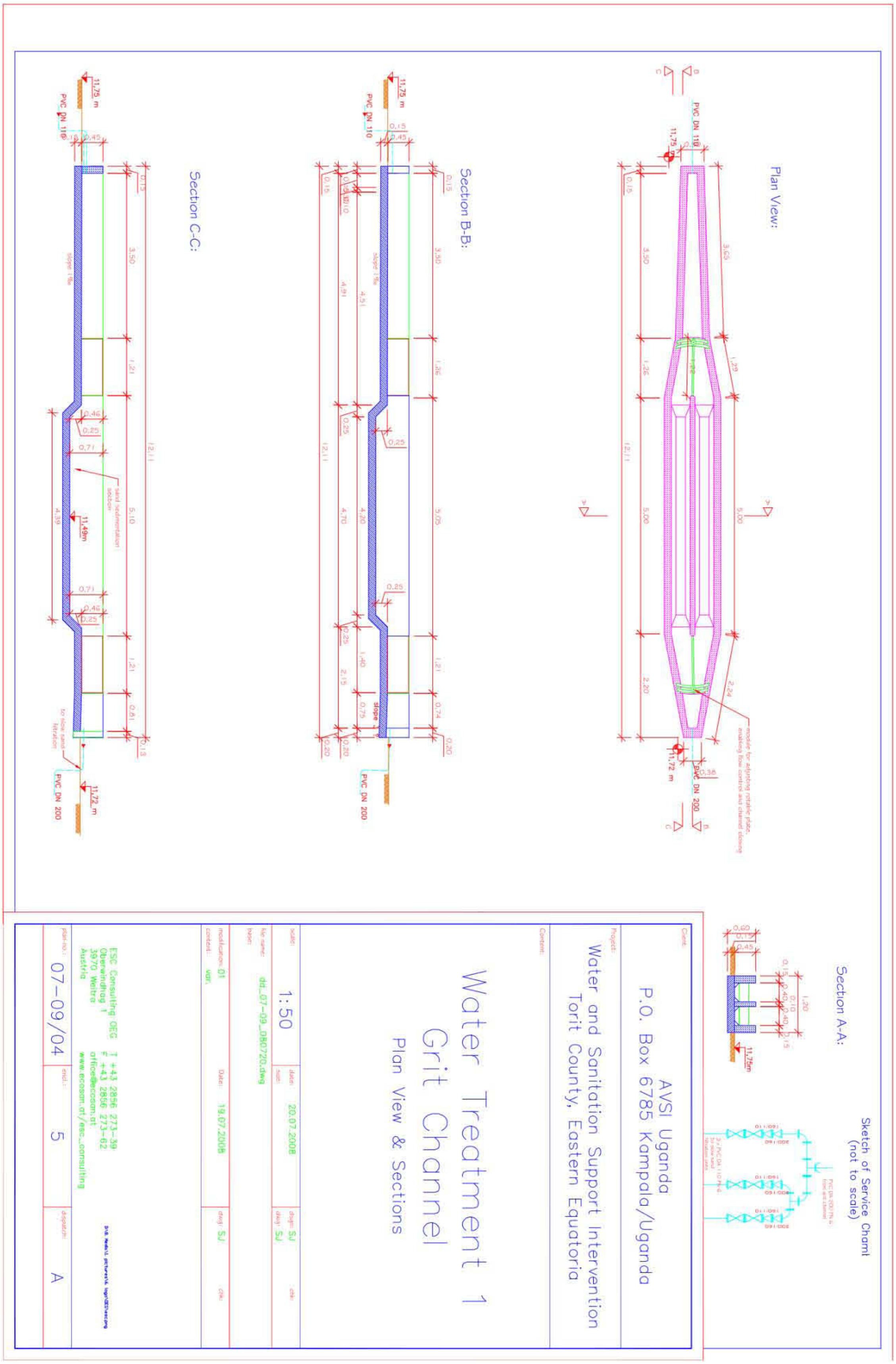
Technology 2 Treatment Plant



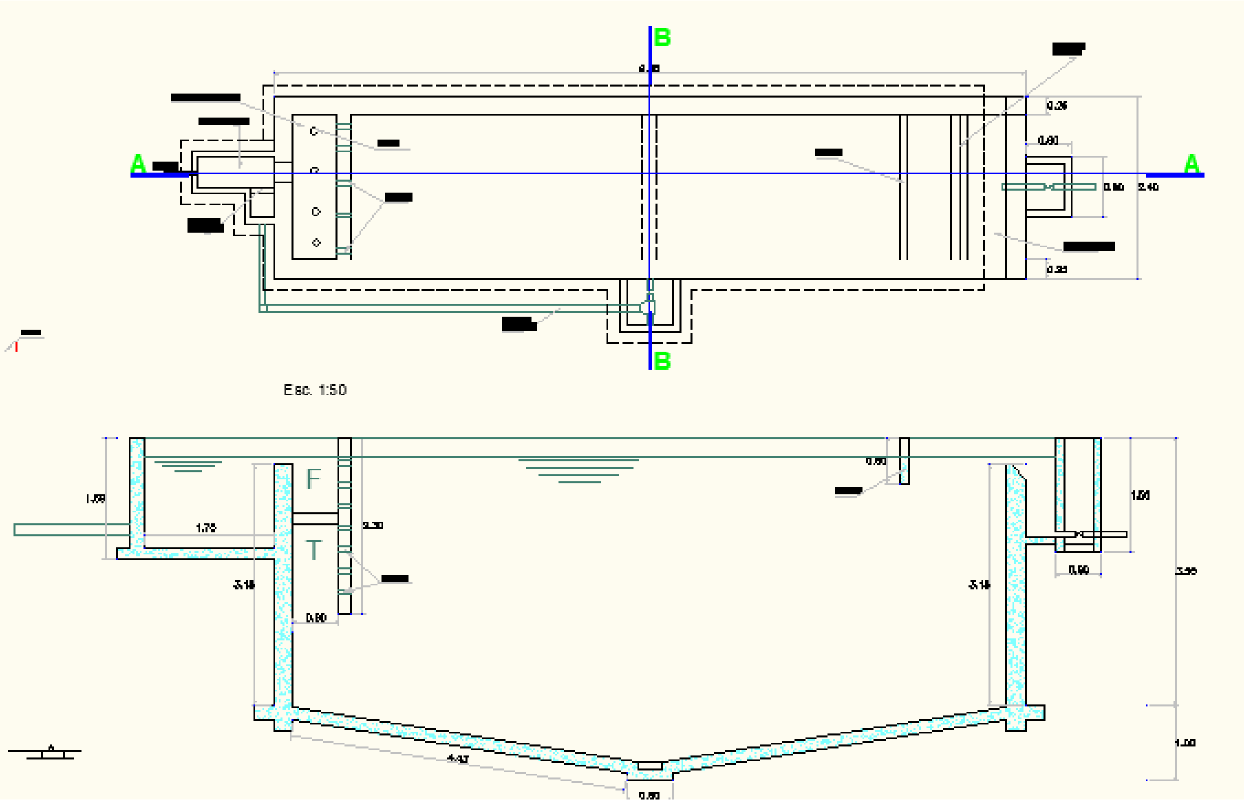
Technology 2-1 Surface Water Treatment (SSF)



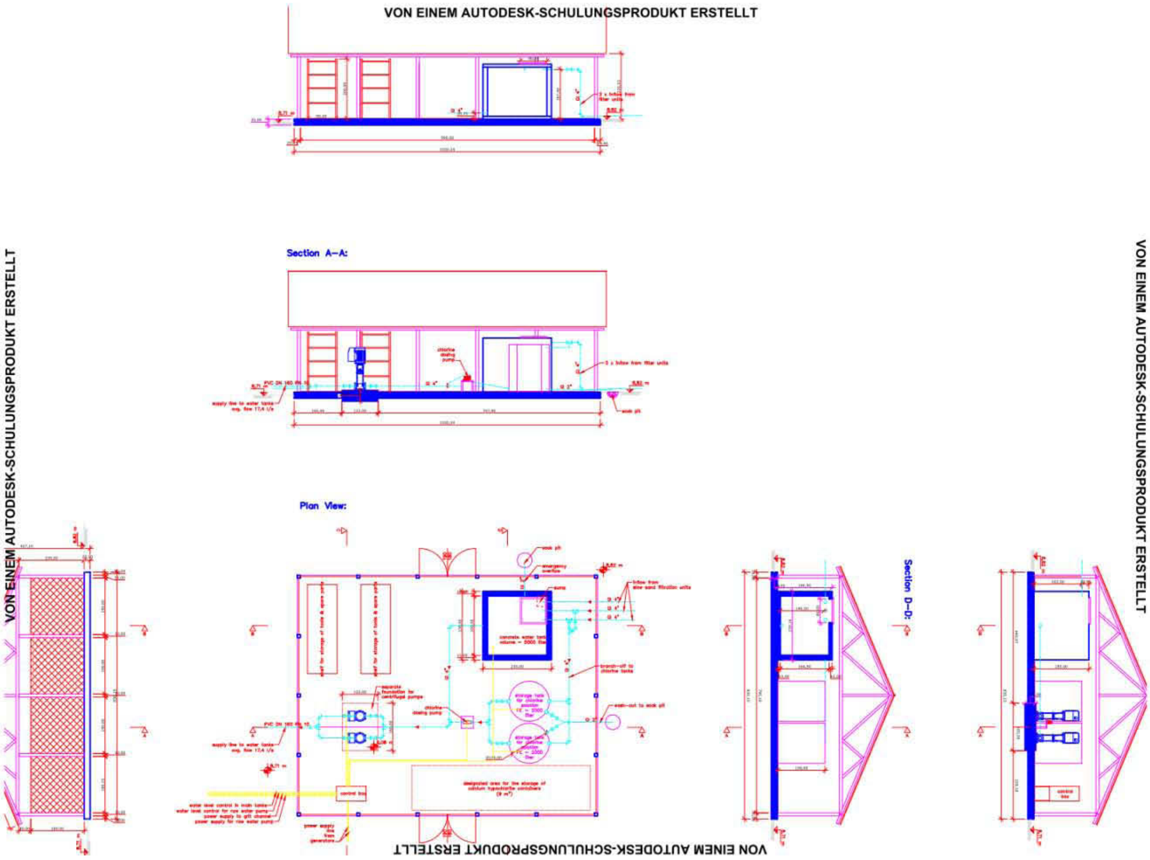
Technology 2-1 Surface Water Treatment (Grit Channel)



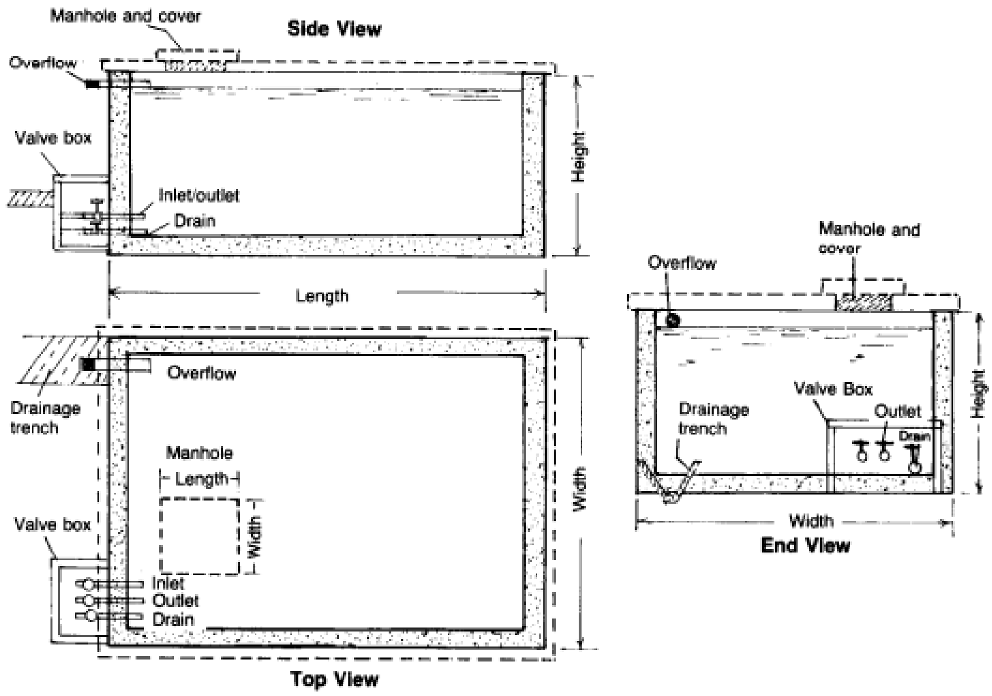
Technology 2-2 Sedimentation



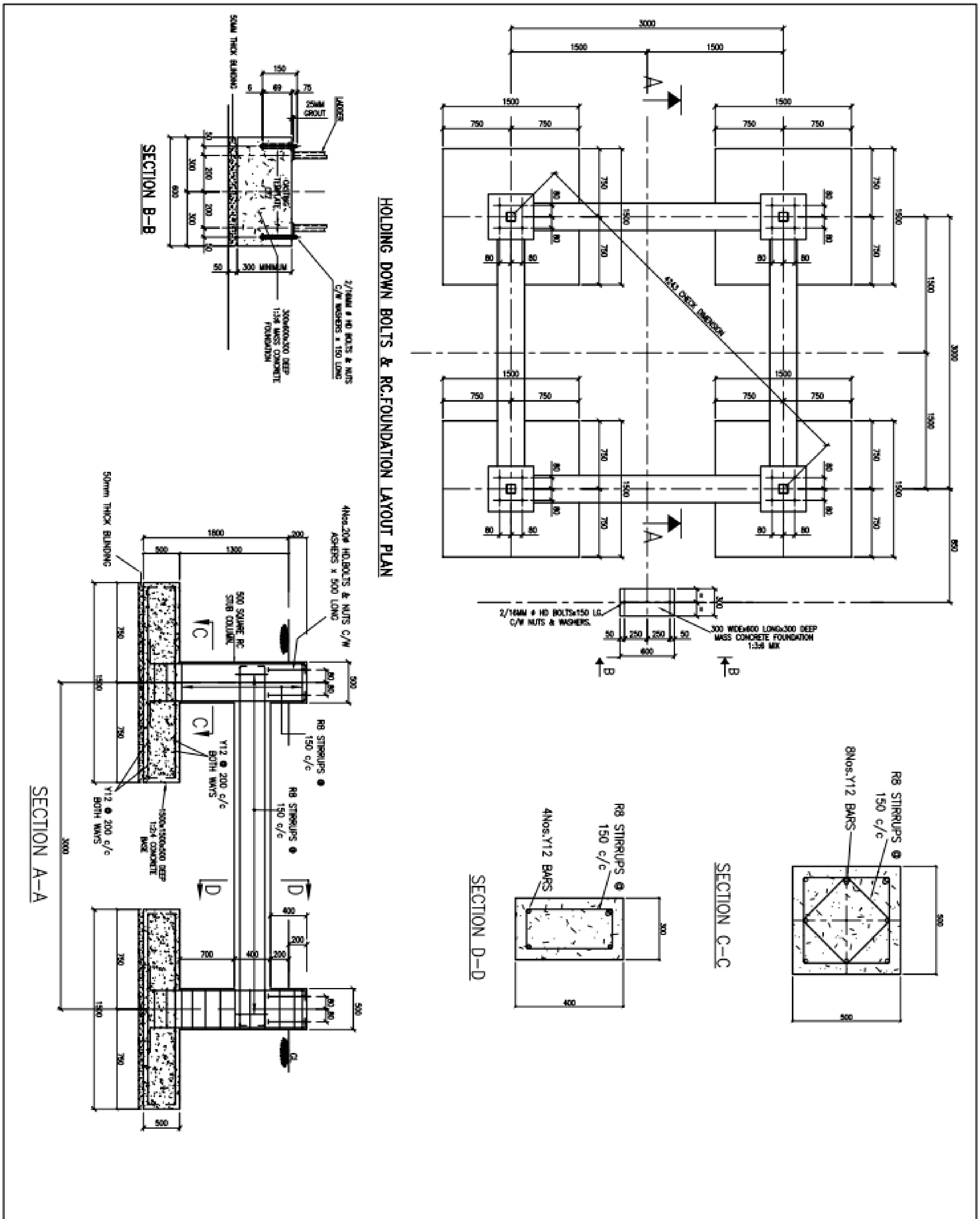
Technology 2-3 Chlorination



Technology 3-1 Surface Water Tank



Technology 3-2 Elevated Water Tank



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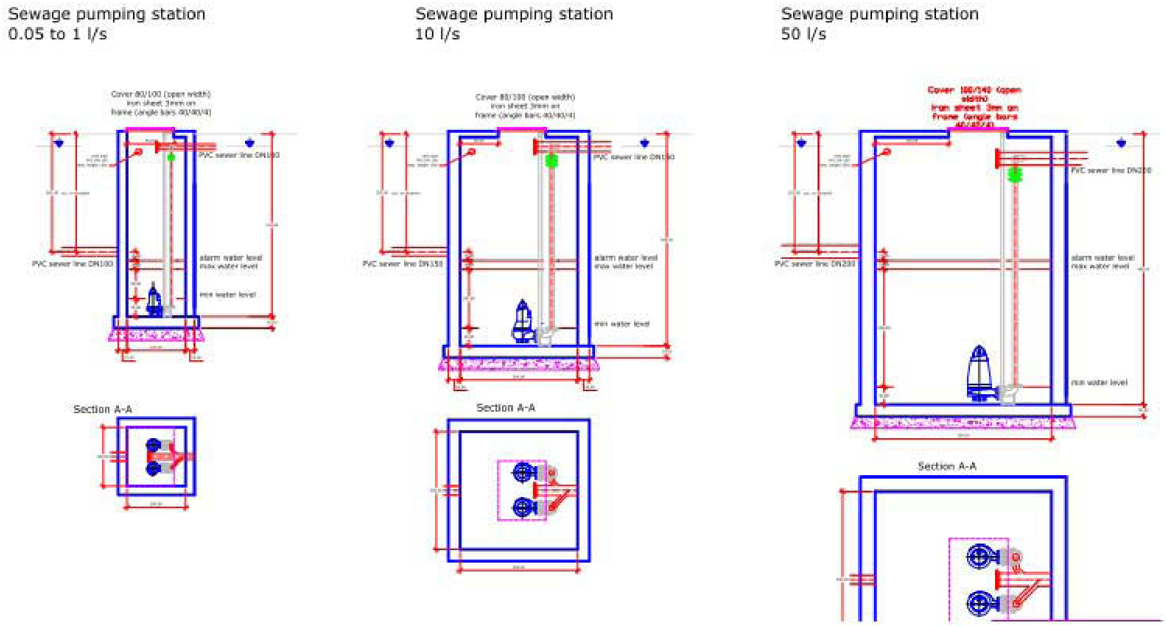
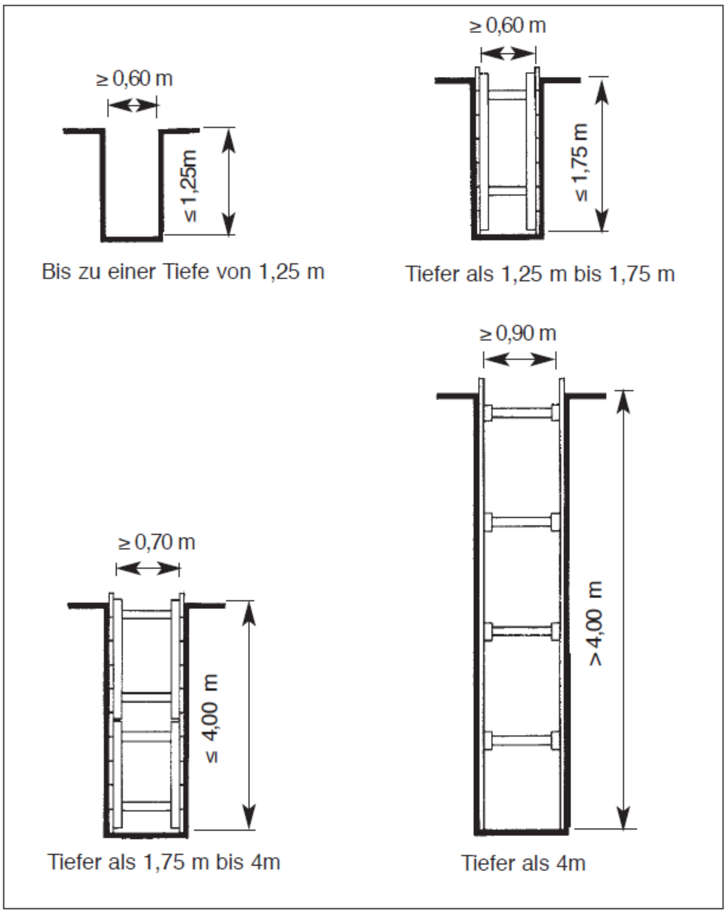
		Job :- 5Mx3Mx2M TANK ON 8M HIGH TOWER-S.SUDAN			
		Drg. Title :- FOUNDATIN AND H.D. BOLTS LAYOUT PLAN			
		Drawn: Julius	Date: 10/01/2012	Job No.: P271/2011	
		Checked: D. MWIRURI	Scale: N.T.S	Drg. No. P271/1	

Technology 3-3 Pump Station



Technology 3-4, 3-5, 3-6 Trench forms



9. CURRICULUM VITAE

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PERSONAL DATA

Date of birth	28th of July 1987
Place of birth	Köln, Germany
Nationality	German
Family status	unmarried

EDUCATION

10/2007 – 09/2010	*University of Cologne*, Germany Bachelor of Science – Biology Graduation: Bachelor of Science with grade 2.2
08/1997 – 06/2006	*High School* ″Stadtgymnasium″ in Köln, Germany Graduation: A-Levels (″Abitur″) certificate with grade 2.3
08/1993 – 07/1997	*Primary School* ″Gesamtgrundschule“ (GGS) Köln Porz Eil, Germany

CIVILIAN SERVICE

09/06 – 06/07	Alexianer Krankenhaus Köln, Station Kamillus

INTERNSHIP

02/10 – 03/10	“Can Population Dynamics of Leopards (Panthera pardus) in the Western Soutpansberg of South Africa be studied through the Use of Scouting Cameras?”

TRAVELLING ABROAD

08/2007 – 10/2007	Australia & New Zealand
02/2010 – 03/2010	South Africa

COMPUTER SKILLS

Knowledge in MS Office (Word, Excel, PowerPoint)

LANGUAGE SKILLS

German	*(native speaker)*
English	*(very good)*
Spanish	*(basics)*

INTERESTS

sports

reading

traveling

C. vom Berg

Christopher vom Berg