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Assessing the possibility of water reclamation for concrete production in Maputo, Mozambique

TU Delft

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Assessing the possibility of water reclamation for concrete production in Maputo, Mozambique

By

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Abstract

The rapid economic and population growth recently drives Maputo to become more metropolitan, with construction sector as one of the pillars to support its transformation. This progressive move is, however, hindered by one of the most crucial problems: water scarcity.

Water is essentially required by construction sector, especially in concrete production. It needs a proper quantity and quality to meet the expected strength. While the quantity is determined by its ratio with cement, the quality varies for plain, structural and high-strength concrete. Drinking or tap water is commonly used in Maputo but previous experiments worldwide show that there is a possibility to use non-drinking water for concrete production. One of the emerging alternatives is treated sewage. This thesis aims to assess whether reclaimed water from the sewage can be used as a source for concrete production in Maputo in order to save tap water for domestic purposes.

To determine water demand from the concrete companies, 156 concrete companies in Maputo and its surrounding, Matola and Machava, were listed and 11 of them were interviewed with the variance of locations, types of products, production methods, existing water source, number of employees, monthly water tariff, current practices and willingness to cooperate for a preliminary water reclamation project. The average amount of water consumption for 11 interviewed companies is 311 ± 36 m^3/day and for the actual population of 156 companies is 4411 ± 257 m^3/day. This value contributes to 12% - 14% from the total tap water use in Maputo. The water price is approximately €0.76/m^3 for the small companies and €0.38/m^3 for both the medium and large companies.

The potential supply sources were investigated from different types, flow rates and locations, such as the outlet endpoints from houses, the wastewater treatment plant and the effluent from other industries. The influent of the wastewater treatment plant was considered the best source for the preliminary plant design with a flow rate of 5682 ± 1196 m^3/day.

Available standards worldwide and previous works were studied to find the safe ranges of water quality for concrete. Field and laboratory measurements were also conducted to provide preliminary information. The results were used as the basis for designing a treatment plant from the demand of 11 interviewed companies, with lower effluent quality than tap water, yet sufficient for concrete production. Recommendations of a large scale plant for all 156 companies were also presented.

The system is designed as a modular scheme to provide different effluent qualities and potential changes, such as the increase of the influent flow rate, the option of combining the new system with the existing plant, etc. The system is divided into four phases. Phase 1, consisting of a coagulation tank (1 x 0.6 x 0.5 m), four flocculation tank (1.5 x 1 x 1 m) and a dissolved air flotation tank (1.6 x 1.4 x 1 m), removes fat, oil and grease, phosphorus and suspended solids. Phase 2 removes remaining suspended solids by a rapid sand filtration (1.50 m bed depth x 0.56 m diameter x 5.45 m height). Phase 3, comprising nine units of nanofiltration in one skid, removes dissolved solids to meet the demand of higher strength concrete. The last phase is disinfection which were excluded since the removal capacities from the previous phases are already sufficient.

The cost of the design is divided into three packages depending on the expected effluent quality from each company. The basic package only consists of phase 1 and costs €0.30/m^3. The intermediate package, comprising phase 1 and 2, costs €0.40/m^3. The advanced package, consisting of phase 1 and 3, costs €0.80/m^3. Only the price of the advanced package is higher than the actual tap water price.

Pumps are installed before the units of rapid sand filtration and nanofiltration. Valves are incorporated to divide the flow for different treatment packages. The delivery of the effluent is performed by renting trucks since it is less expensive than constructing new pipelines.

The design shows that producing concrete with reclaimed water from treated sewage is possible to be performed in Maputo and the sewage does not need to reach drinking water quality. It is the starting point to increase the availability of usable water and the opportunity of supplying tap water as much as possible for domestic purposes.

Keywords: water reclamation, construction, concrete, sewage, Maputo, Mozambique, modular water treatment system

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Delft, November 30, 2016

Nessia Fausta

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List of Abbreviations

General issues and institutions

AdRM	Great Maputo Water Supply Operator (*Águas da Região de* Maputo)
AIAS	Administration of Infrastrucctures of Water and Sanitation
CRA	Regulatory Council of Water Supply
DAS	Department of Water and Sanitation (*Departamento de Água e Saneamento*)
DHV	Dwars, Groothoff and Verhey, civil engineering and consultancy company
DNA	National Directorate of Water (*Direcção Nacional da Água*)
DNI	National Directorate of Industries (*Direcção Nacional da Industria*)
FIPAG	Fund of Investment and Patrimony of Water Supply
GDP	Gross Domestic Product
KPMG	Klynveld Peat Marwick Goerdeler, accounting audit and consultancy company
LG	Local Government
MICOA	Ministry of Earth, Environment and Rural Development
MINED	Ministry of Education and Human Development
MISAU	Ministry of Health
MOPH	Ministry of Public Works and Housing
SWP	Small Water Provider
TU Delft	Delft University of Technology (*Technische Universiteit* Delft)
UEM	Eduardo Mondlane University (*Universidade* Eduardo Mondlane), Maputo
US EPA	United States Environmental Protection Agency

Treatment and design

BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
DAF	Dissolved Air Flotation
DIS	Disinfection
DO	Dissolved Oxygen
EC	Electric Conductivity
FOGs	Fat, Oil and Grease
HC	Hydrocyclone
MF	Microfiltration
NF	Nanofiltration
NTU	Nephelometric Turbidity Unit
C-F	Coagulation - Flocculation
PMF	Porous Media Filtration
PVC	Polyvinyl Chloride
SED	Sedimentation
TDS	Total Dissolved Solids
TOC	Total Organic Carbon
TP	Total Phosphorus
TSS	Total Suspended Solids
UV	Ultraviolet
w/c	Water per cement ratio (of concrete mixture)
WWTP	Wastewater Treatment Plant

Units

Currency

€	EUR (European euros) (€1 = 75 MT)
$	USD (US Dollars) ($1 = 77.87 MT)
MT	MZN (Mozambican meticals) (1 MT = €0.013)

Temperature

^oC	degree Celcius

Time

H	hour
min.	minute
s	second

Length, Distance, Flow, Concentration

CI	Confidence Interval
kg	kilogram
kg/m^3	kilogram per cubic metre
L	litre
m	metre
m^3	cubic metre
m^2	square metre
mm^2	square millimetre
m^3/d	cubic metre per day
$m^3/mth.$	cubic metre per month
m^3/h	cubic metre per hour
m/km	metre per kilometre (of length or distance)
m^3/s	cubic metre per second
mg/L	milligram(s) per litre
mm	millimetre (1 mm = 10^{-3} m)
mm/day	millimetre per day
mm/year	millimetre per year
ppm	parts per million (1 ppm = 1 mg/L)
µm	micrometre (1 µm =10^{-6} m)

Pressure, Energy, Head

atm	atmosphere (1 atm ≈ 0.101325 MPa)
bar	(1 bar ≈ 0.1 Pa)
N	Newton (1 N = 1 kg . m/s^2)
MPa	Megapascal (1 MPa = 1 N/mm^2)
kPa	kilopascal (1 kPa = 10^{-3} N/mm^2)
kW	kilowatt (1 kW = 10^{-3} kg . m^2/s^3)
Wh/m^3	Watt hour per cubic metre
m H_2O	height of water (1 m H_2O ≈ 9.81 kPa)

Water quality

µS/cm	microSiemens per centimetre (degree of electric conductivity measured by the ability of a solution to transfer electric current)
NTU	Nephelometric Turbidity Units (degree of turbidity measured by passing light through a solution)

1. Introduction

This chapter provides preliminary information of Mozambique and Maputo. Section 1.1 consists of geographical, climate, population and water resources conditions of Mozambique. Section 1.2 specifies the conditions of Maputo and includes the background of the problem regarding clean water scarcity issues. Section 1.3 consists of the contribution of construction sector to drinking water use and the idea of saving more tap water by reusing sewage for non-drinking use. The last section of this chapter explains the objective and structure of this report.

1.1 Mozambique: a brief overview

1.1.1 Geographical condition

Located on the southeast coast of Africa, Mozambique lies between 10^{o} 27' and 26^{o} 52' of the south latitude and between 30^{o} 12' and 40^{o} 51' west longitude (Aidenvironment & Water-is-Essential BV, 2015). The country is adjacent to Tanzania on the north, Malawi, Zambia and Zimbabwe on the west, and to Republic of South Africa and Swaziland on the south (Tauacale, 2002). Figure 1.1 shows the geographical location of Mozambique.

Figure 1.1 Location of Mozambique (African Development Bank, 2016)

The total area of Mozambique is approximately 800,000 km^2, including 13,000 km^2 of surface water (Aidenvironment & Water-is-Essential BV, 2015). The border of the country is almost 4,500 km long with its coastline stretches over 2,500 km (Melorose *et al.*, 2015).

1.1.2 Climate condition

The position of Mozambique gives the country a mixture of tropical and subtropical climate (Mcsweeney *et al.*, 2010). It has two seasons in a year. The winter arrives around May and June with a temperature range of 15 – 25^{o}C (Tadross & Johnston, 2012). The summer comes from November to April, bringing the warmest months approximately 25 – 27^{o}C but carrying frequent rainfall of approximately 150 - 300 mm per month over the northern side and around 50 - 150 mm per month over the southern side (Mcsweeney *et al.*, 2010). The maximum yearly rainfall from the northern side is almost 2000 mm but the southern side only receives around 750 mm (Tadross & Johnston, 2012).

The country is vulnerable against hurricanes and cyclones that occur during frequent rainfall periods (Mcsweeney *et al.*, 2010). A catastrophic flood in 2000, affecting more that 2 million people and causing over 700 deaths (Aidenvironment & Water-is-Essential BV, 2015), and the one in 2013, causing at least 113 deaths and temporarily displacing 185,000 people (UNRCO, 2013), also took place based on this phenomenon. In contrast, drought occurs almost in all parts of the country, especially in the south (Figure 1.2).

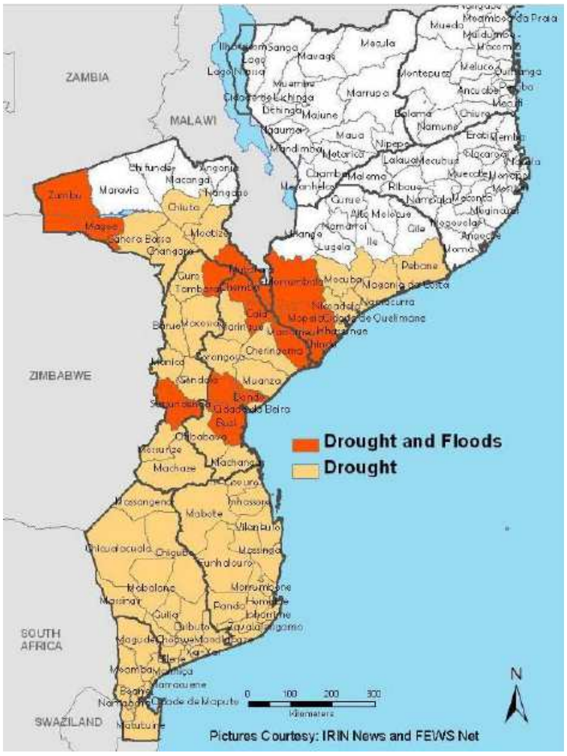

Figure 1.2 Areas in Mozambique that are at risk of droughts and floods (Aidenvironment & Water-is-Essential BV, 2015)

1.1.3 Demographic, historical and social condition

Mozambique had approximately 24 million citizens in 2014, with a rate of population growth of around 2.45% (Aidenvironment & Water-is-Essential BV, 2015). In relation to this rate, the number of people in Mozambique is expected to increase rapidly to 49 million in 2050 (Nepad, 2013).

Shortly after its independence from Portugal in 1975, the country which once was called “The Land of Good Men” was in a long civil war. This war together with the aforementioned floods forced many people to relocate to the suburbs of Maputo, leaving the city with a lack of settlement arrangement and basic service delivery, including potable water supply (Stretz, 2012).

1.1.4 Economic situation

After the civil war ended in 1992, Mozambique experienced a fast-growing economy, with an average annual Gross Domestic Product (GDP) growth of about 9% between 1995 and 2001 (World bank, 2005). It is expected to reach double digits in the coming years for the period of 2010-2030 (Mahumane *et al.*, 2012).

The combination of the massive population growth and rapid GDP growth trigger the increase of construction, transportation, industrial, and communication sectors. In 2010 the growth of infrastructure increased by 17% compared to the previous year, mainly due to the performance of the private sectors, both foreign and local companies, towards the execution of public infrastructure investments, such as roads, bridges, energy, water and sanitation (KPMG, 2011).

1.1.5 Water use and resources condition

Mozambique has 104 river basins and the total volume of the 13 largest basins is approximately 216.5 km^3 (World Bank, 2007). However, almost 50% of these basins are the downstream parts of international rivers, including Angola, Namibia, Botswana, Zambia, Zimbabwe, South Africa, Swaziland and Tanzania, and only 20% of the total basins area is actually located in Mozambique. (Tauacale, 2002). The country is thus highly dependent on other upstream countries. The abstraction of upstream water bodies, flow variation and upstream storage affects the stability of the national water supply. The most crucial areas are certainly in the southern part of the country, where only 4 km^3 can be abstracted from the total 21 km^3 of annual runoff (Marques, 2006). As a consequence, the southern part of Mozambique, especially Maputo, its capital, is in a susceptible condition.

Mozambique experiences frequent water stress due to the increase of population growth and irrigation demand, since the population is highly dependent on agriculture (Aidenvironment & Water-is-Essential BV, 2015). In 2011 the total calculated volume of fresh water withdrawal in Mozambique was 880 million m^3, including agriculture (70%), domestic use (26%) and industries (4%) (Aidenvironment & Water-is-Essential BV, 2015). Based on the comparison with the data in 2000 where the total water consumption was 635 million m^3 (87% for agriculture, 11% for municipal sector and 2% for industries) (Nepad, 2013), a high increase in water withdrawal can be observed, especially for agriculture and industries.

Furthermore, water demand was expected to increase until 918 million m^3 in 2015, due to the population growth, climate change and environmental degradation (Nepad, 2013). Within the national scale, it has been projected that the domestic water demand in urban areas, especially at the south and centre of the country, will increase by about 40% in 2030 and the industrial water use will escalate by almost 65% (Global Water Partnership, 2015).

1.1.6 Governmental water institutions

The government plays an important role in the water sector to provide water supply system for domestic and industrial use, including regulations, investment planning and the participation of external parties, such as private sectors, non-governmental organizations and knowledge institutions. The division of roles within the body of the government for water sector of Mozambique is described in Figure 1.3:

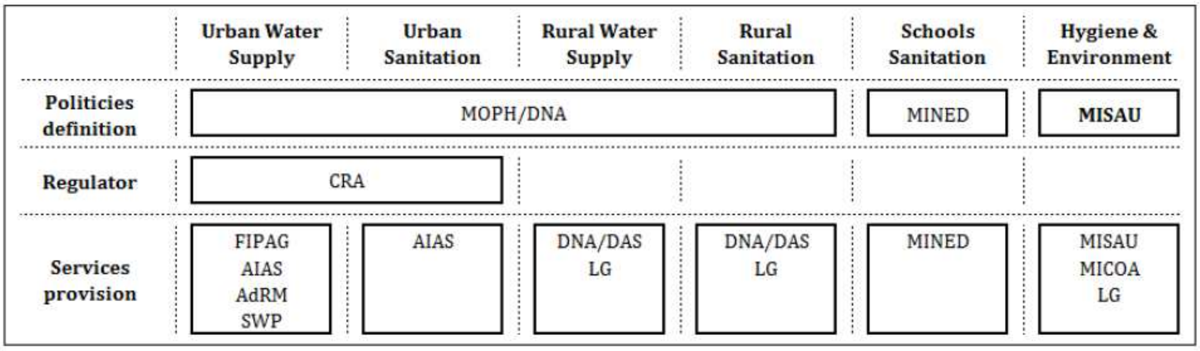

Figure 1.3 Governmental institutions for water sector in Mozambique (Aidenvironment & Water-is-Essential BV, 2015)

Legend:
MOPH = Ministry of Public Works and Housing
MINED = Ministry of Education and Human Development
MISAU = Ministry of Health
CRA = Regulatory Council of Water Supply
MICOA = Ministry of Earth, Environment and Rural Development
DNA = National Directorate of Water
DAS = Department of Water and Sanitation
LG = Local Government
FIPAG = Fund of Investment and Patrimony of Water Supply
AIAS = Administration of Infrastructures of Water and Sanitation
AdRM = Great Maputo Water Supply Operator
SWP = Small Water Provider

The institutional setting of the water sector is governed by the 1991 Water Law and the 1995 National Water Policy. The Water Law determines that the main bodies responsible for water resource management are MOPH and DNA, while the existing water companies, such as the Investment Fund or Assets of Water Supply (FIPAG), are responsible for water supply in the main cities (Nepad, 2013).

1.2 Maputo: a brief perspective

1.2.1 The cosmopolitan pearl of the Indian Ocean

Located in the very south of Mozambique as its capital city, Maputo covers an area of about 350 km^2 with approximately 1.2 million inhabitants (Stretz, 2012). Formerly named Lourenço Marques, after Portuguese trader who explored the area of Delagoa Bay in 1544, it is now eminent as “The City of Acácias”, named after the numerous acacia trees along the streets. This delta city is also famous as “The Pearl of the Indian Ocean” for its importance as an international trading port. Today Maputo is a fast-growing cosmopolitan city (Figure 1.4). It is densely populated, especially in the city centre with a high potential of expansion to the surrounding suburbs.

Figure 1.4 Mozambican capital Maputo at night (Araújo, 2010)

1.2.2 Water resources management

Maputo often experiences high pressures on water resources as it has an average rainfall between 600 - 700 mm/year (Aidenvironment & Water-is-Essential BV, 2015). Its location in the southern part of the country gives this city a subtropical arid climate (Tadross & Johnston, 2012).

In 2015 the total amount of water use in the city of Maputo was expected to be 250 million m^3/year with 10,000 m^3/day for industrial activities (World Bank, 2007). This number is expected to increase again in 2020 as can be seen in Figure 1.5 below.

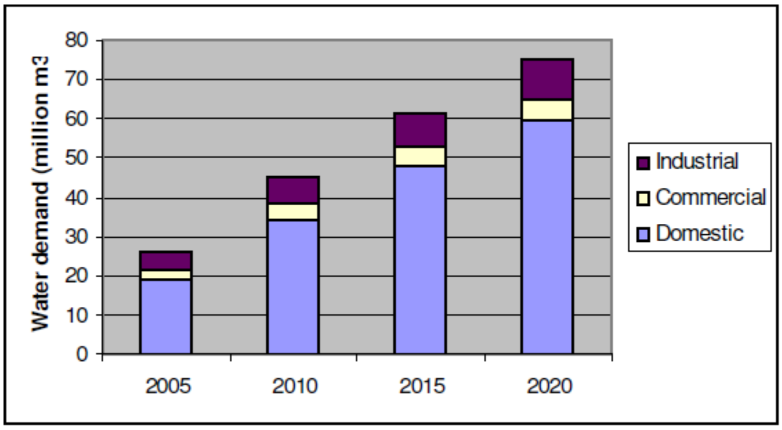

Figure 1.5 Water demand projection of Maputo (World Bank, 2007)

The increase of water demand affects the water scarcity problems in the city of Maputo. In 2007 only 56% of the households have access to tap water (World Bank, 2007) and only 13% of agricultural fields are properly irrigated (Nepad, 2013). Considering the general situation of water resources within the country itself, Maputo is prospective to face a challenge in water shortage (World Bank, 2007).

1.2.3 Sewage management

The sewage in the city of Maputo flows from part of the houses, which use septic tanks as a pre-treatment scheme, through a sewer network which consists of two systems. The first system, constructed by the Portuguese in the 1940s as a stormwater drainage system, now functions as a combined sewer system (van Esch & van Ramshorst, 2014). The second system, partly designed in the 1980s by DHV, a Dutch consultancy company, consists of a complete sewer network, including two pumping stations. The first pumps deliver the sewage from part of the first to the second system although there is no data about the amount of sewage being delivered. The other pumps transport part of the combined sewage into the wastewater treatment plant (WWTP) in Infulene valley, the northwest side of Maputo (van Esch & van Ramshorst, 2014), while the rest runs gravitationally to the plant. Both pumping stations are currently out of order so that most of the sewage from the first system is directly discharged into the bay (van Esch & van Ramshorst, 2014).

The network is thus a combination of gravitational and pressurized system (Salet & Schijfsma, 2016). Figure 1.6 gives a general overview of the collection and transportation network (yellow lines), the two pumping stations in the east side of the city and the final discharge to the WWTP in the northwest. The effluent from the WWTP is discharged gravitationally into the Infulene River.

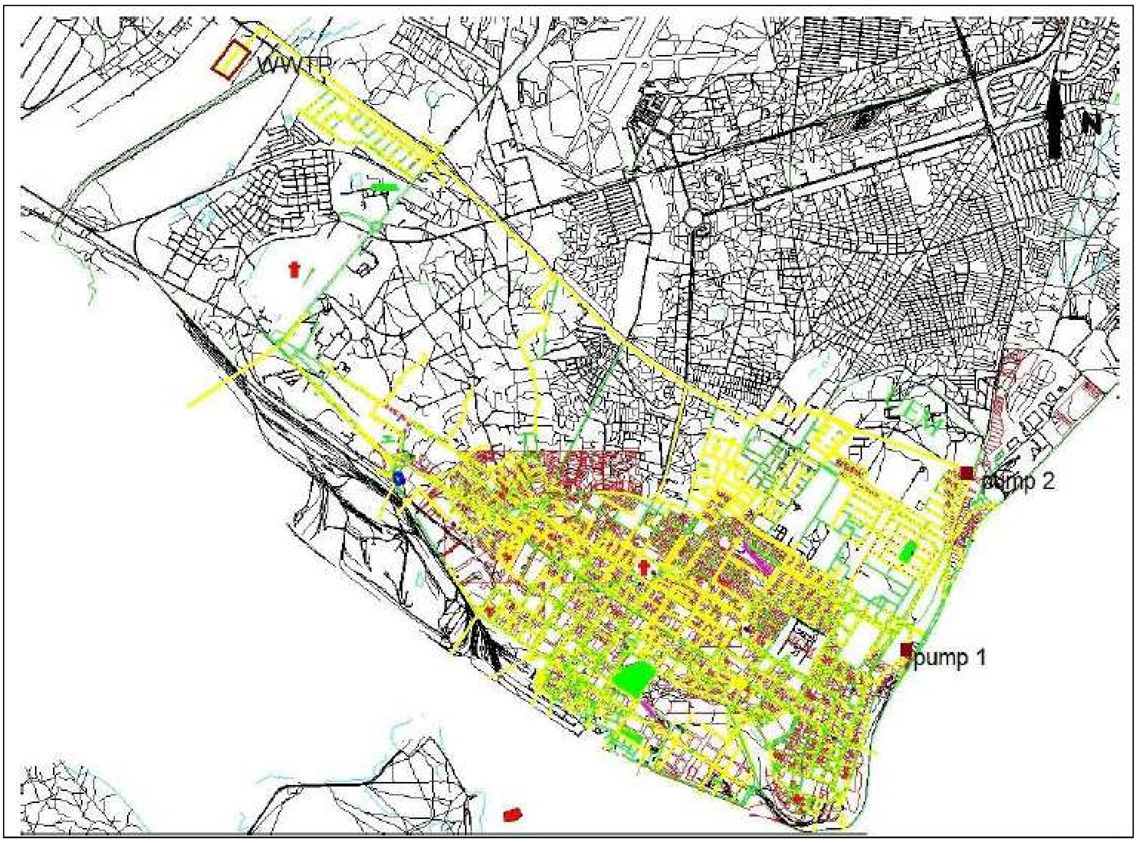

Figure 1.6 Sewer system in Maputo (Salet & Schijfsma, 2016)

As a consequence of non-operating pumping stations today, there is a decrease of the amount of sewage in Maputo that can be discharged into the WWTP. The actual sewage flow to the WWTP is estimated to be only about 4000 m^3/day. If the second pumping station operated properly, the flow would be about 10,000 m^3/day, and if the first pumping station also worked well in such way that there was no direct discharge into the bay, the total flow into the WWTP would be more than 20,000 m^3/day (van Esch & van Ramshorst, 2014).

The only WWTP in Maputo uses stabilization ponds in an open system (DHV, 1984). It consists of an entrance from the main sewer equipped with a trash screen and a venturimeter to measure the flow, a branch in the sewer to divide the flow into two anaerobic ponds with an area of 0.31 ha each, two facultative ponds with an area of 3.4 ha each and three outlet points to discharge the effluent into the Infulene River (DHV, 1984). The plant is currently defective as its removal efficiency is only about 25% (Caltran, 2014).

1.3 Construction: a crucial influence for water supply

As the current situations in Maputo are related to Mozambique as the heart of the country, the increase of construction, sewage production and industrial wastewater urges the city to find alternative water sources. Meanwhile, water reclamation for potable use is still uncommon (Nepad, 2013). Hence, the approach is to utilize it for non-drinking purposes, such as construction industry.

1.3.1 Contribution of construction to drinking water use

Concrete, being the main construction material, is one of the largest water consuming products; approximately 150 L of water is needed for mixing 1 m^3 of concrete, and even more for other applications in the production plant itself (Silva & Naik, 2010). Meyer (2004) stated that the concrete industry uses over 3.8 km^3 of water each year worldwide, not including curing water and wash water for trucks and clinkers (Silva & Naik, 2010). It means that each day approximately 10.5 million m^3 of water is extracted all over the world to produce concrete. Considering that the daily residential water consumption is approximately 400 L per person per day (United Nations, 2014), the amount of water for concrete production is equal to the basic domestic need of more than 26 million people. In other words, the amount of water usage for concrete production is likely to satisfy more than 0.35% of the total population worldwide or nearly 9 times of the total citizens in Maputo. Therefore, Maputo requires considerably high amount of water to perform construction activities.

Ever since concrete was first introduced, drinking water has been and is still used for the mixture (Tay & Yip, 1988). Impurities in water can negatively affect the concrete strength, hardening process and durability (Kulkarni & Patil, 2014), including oil, acids, and organic matters (Su *et al.*, 2002). That is why drinking water quality is always preferable to be used (More & Dubey, 2014). The exact quality of water demand for Maputo, its contribution to the total amount of water use and the opportunity to use another water source will be discussed further in the thesis.

1.3.2 Water reclamation: a new paradigm

Combining the facts that Maputo needs to produce a large amount of concrete and the increasing water crisis in the city, a new development paradigm can be considered; reclaiming sewage water. Thus, instead of discharging the treated sewage directly to surface water bodies, the WWTP effluent can be used for other purposes that require lower water quality than drinking water. This idea is promising as it can increase the efficiency of drinking water supply. Basically, it saves water with drinking quality for domestic uses and reduces the amount of sewage being discharged to surface water bodies, decreasing the environmental impact.

In this study water reclamation will be developed as a substitute for concrete production. However, the limit of impurities to provide the expected strength of concrete with acceptable cost and the amount of water used for concrete production in the city of Maputo are unidentified yet. Therefore, these subjects will be addressed and assessed to finally justify whether it is possible to reclaim sewage for producing concrete in Maputo.

1.4 This thesis

1.4.1 Objective

The goal of this research is to identify the contribution of the construction sector to the total water demand in relation to the drinking water consumption and assess the possibilities of reclaiming sewage for concrete production in Maputo.

1.4.2 Research questions

Following research questions were developed:

1. How crucial is the contribution of construction sector to the tap water supply?
   a) How much water is consumed for concrete production in Maputo?
   b) What are the parameters to be assessed to identify its value of importance?
2. Can water reclamation be a source for construction companies in Maputo?
   a) What are the standards or safe ranges of physical/chemical/biological substances in mixing and curing water for concrete in general?
   b) What are the flows and quality of the available sewage water?
3. If it is possible, how can it be ready as the source?
   a) How can the selected source of sewage water in Maputo be feasibly used for concrete production?
   b) What is the necessary treatment?

1.4.3 Scope

This study contains an inventory of construction firms in Maputo, such as their locations, project scales, type of concrete products, sources of water, prices of water supply, current practices of saving water and their willingness to cooperate for a preliminary water reclamation project for concrete production. It also includes the preliminary design of a treatment plant to reclaim water for being directly used in concrete production. The treatment plant was designed as a preliminary scheme for the companies that were interested in the project, but the considerations for large scale treatment plant for all construction companies in Maputo were also presented, such as the flow rates, dimensions and estimated financial expenses.

The type of cement for this study is considered to be constant, as it is not the coverage of this study to present how different kinds of cement interact with water, but rather as the whole mixture of concrete. It is also not the intention of this study to focus on the strength of concrete in detail although it is still taken into account during the analysis and design stages.

1.5 Structure of the report

This report consists of six chapters, as follows:

Chapter 1. Introduction

This chapter describes the situation of Mozambique and Maputo as preliminary information. It includes the background of the problem regarding clean water scarcity issues, the idea of saving more potable water by reusing sewage for non-drinking use, the contribution of construction sector to drinking water supply and the solution that is linked to the background. This proposed solution is elaborated as the purpose of the research. The last section of this chapter explains the structure of this report.

Chapter 2. Literature Review

This chapter elaborates the theories of concrete production in relevance with water demand. It includes the types of concrete, the methods and stages of concrete-making and the required water quality to produce each type of concrete. It also explains about the efforts of reclaiming water, especially from sewage, including previous experiences from other researchers all-over the world who attempted to alter clean water in producing concrete with treated sewage.

Chapter 3. Materials and Methods

This chapter presents the used materials and applied methods that are applied in this research. It describes the mechanism of data-collection, the procedure for mapping the companies and the fieldwork period spent in Maputo. Furthermore, it also includes the considerations for the design of conceptual sewage treatment plant, both in preliminary and large scale schemes.

Chapter 4. Results and Discussions

This chapter elaborates the findings from the fieldwork. The content includes the number of concrete producers in Maputo, the average amount of water demand for concrete production, the average cost of water, etc. The information is presented in tables and processed statistically to help interpreting the actual general conditions. It includes interesting subjects to be discussed; alternatives, choices, decisions, actual conditions, opportunities and limitations, etc.

Chapter 5. Design

This chapter describes the appropriate design of water treatment plant that is expected to remove only important materials from the sewage to match with the minimum standard of water for concrete production. It includes the dimensions of each facility, both in preliminary and large scale schemes. Furthermore, a simple cost calculation is also presented in three different packages based on the expected water quality of the effluent.

Chapter 6. Conclusions and Recommendations

This chapter concludes the previous chapters to answer the research objective from Chapter 1. This chapter also gives some recommendations that can be developed further as new research ideas in the future.

2. Literature Review

This chapter elaborates the theories of concrete in relevance with water demand. It includes the properties, types and production steps of concrete in Section 2.1 and the water use during production in Section 2.2. The global experiences for substituting clean water with reclaimed sewage in producing concrete is elaborated in Section 2.3.

2.1 Concrete production

2.1.1 Background

Concrete, being one of the most commonly used construction materials after water (Hasanbeigi *et al.*, 2012), is made from a mixture of cement as binder, water and aggregates that is called hydration (Neville, 2011). The proportion of each material influences the properties of concrete during the hardening period that usually lasts at least 28 days (Cement Concrete & Aggregates Australia, 2004).

2.1.2 Properties

The qualities or basic characteristics are defined by a set of parameters; workability, strength, durability and cohesiveness (Cement Concrete & Aggregates Australia, 2004).

Workability is used to identify the easiness of the concrete to be blended, placed, handled, compacted, and finished. It is important to have the cement, water and aggregates correctly for transporting, placing, compacting and finishing to have the concrete properly hardened.

After fully hardened, concrete is ready to be loaded. The capability of concrete in receiving loads is measured by its compressive strength. Strength is also used to classify the types of concrete (see 2.1.5). Concrete with higher density is more watertight, which means that the durability is higher as well. Compaction, a method of applying pressure for removing air voids in concrete, can actually make concrete stronger and more durable.

Cohesiveness indicates how fast the materials in the mixture can create bonds during the plastic state (see Section 2.1.3 below). It is affected by the size range of both the fine and coarse aggregates, called grading. Well-graded aggregates create a more cohesive mixture (Cement Concrete & Aggregates Australia, 2004).

2.1.3 States of concrete

Concrete undergoes three states that can be physically traced from the first time its materials are mixed until it is completely hardened and achieves its designed qualities (Cement Concrete & Aggregates Australia, 2004).

The early plastic state is when the cement, water and aggregates are first mixed. They form soft and clayey dough that can be worked or cast into different shapes. This state is found during placing and its important properties are workability and cohesiveness.

Later on, concrete starts to be more solid, thick and strong. This is the beginning of the setting state. It occurs right after compaction and during finishing. When the concrete is too wet, it may be difficult or take longer time to finish. In contrast, concrete that is too dry may become too brittle to finish. A proper calculation and a field measurement are required to settle this state.

The hardening state is when concrete starts to form compressive strength. The properties of concrete for this state are strength and durability. The strength of concrete after the hardening state, usually around 7 until 28 days from the first time it is placed, is measured using the compression test (Cement Concrete & Aggregates Australia, 2004).

2.1.4 Production steps of concrete

Concrete production is performed in several steps that are alike for all of the types. These steps are affected by the properties of concrete for each state of concrete age (Cement Concrete & Aggregates Australia, 2004).

The first step for concrete production is mixing all materials into one paste, usually performed by a mixer. The type and size of the mixer can influence the properties of concrete, as well as mixing intensity, time and cleaning periods for the mixer and clinker (Hirschi *et al.*, 2005).

Placing or pouring is the second step after the materials are completely mixed. Concrete is placed within a defined time span, from the first time it is poured until it is completely hardened, using a formwork for casting. This process is performed according to the types of concrete being produced (see Section 2.1.5), either in a workshop using a formwork that can be reused or directly at construction site using a truck to transport the mixture and a formwork that is generally used once.

The third step, curing, is the step to keep the concrete wet for a period of time to reach its maximum strength. The aim of curing is to prevent moisture loss from concrete and supply additional moisture for a proper hydration, which means that it is necessary to maintain the moisture, ambient humidity and temperature conditions in a freshly-formed concrete. The volume of water for curing may vary based on the environment conditions, such as temperature, ambient humidity, winds (Cement Concrete & Aggregates Australia, 2004), evaporation, rainfall, etc. (ACI Committee 308, 2001).

Curing time starts from the beginning of placing until the desired concrete properties have been developed (Neville, 2011). The common practices of curing are applying liquid curing agents, leaving concrete in the formwork to ensure water retention, covering fresh concrete with impermeable membranes, cloth or sheets or spraying water continuously to early-hardened concrete (Cement Concrete & Aggregates Australia, 2004).

Based on the European guideline for concrete curing, DIN 1045-3, the minimum curing period is defined by the sufficient strength development on the structure, which is calculated by a ratio of average compressive strength after 2 days and after 28 days. In any special case, for example if the mixture cannot be well-blended or consistent enough until more than 5 hours, an extension of the curing time should be applied (Hirschi *et al.*, 2005).

When the ambient temperature is 15^{o}C and higher, the estimated curing period varies between 3 days for normal limestone cement concrete and 10 days for high ultimate strength concrete with ground granulated blast-furnace slag cement or fly ash. The time increases when the temperature is 5^{o}C or lower from 6 days for the normal concrete until 20 days for the highest ultimate strength concrete (Standards South Africa, 2007).

2.1.5 Types of concrete

Concrete can be classified based on the location of production and the presence of reinforcement. These classifications are not only made according to slight difference in operational steps while producing concrete, but also the expected water quantity and quality for the mixture.

The type of concrete which is mixed on site or transported by trucks as ready-mix is called onsite or cast in-situ concrete. It is usually the default procedure in construction, especially for creating structural items, such as columns, beams and slabs, because these items need to be combined with reinforcing bars which are already placed and interwoven in the field (Hirschi *et al.*, 2005). It is claimed to be financially and operationally beneficial on large construction sites where concrete is massively consumed (Hirschi *et al.*, 2005).

The second type is prefabricated or precast concrete, which is constructed in a workshop elsewhere and delivered to the site after it is hardened (ACI Committee, 2008). This type requires an industrialized production process and a proper mix design that has constant weight stability for each material. It is usually made using special formwork that can be used repeatedly (Hirschi *et al.*, 2005).

Concrete naturally resists compressive loads, but it is prone to failure when loaded by tensile and shear forces. Therefore, it needs another element to reinforce it. This is the reason of placing steel bars inside the concrete. Horizontal and vertical reinforcing bars (usually called rebars) are placed whenever there are tensile or shear loads. Horizontal rebars resists tension loads, while vertical ones handles the shear forces (Cement Concrete & Aggregates Australia, 2004). Based on the Eurocode 2 (EN 1992-1-1. Design of concrete structures), there are 4 main classes of concrete based on the strengths; 16 – 20 MPa for plain concrete, 20 – 25 MPa for reinforced concrete, 25 – 30 MPa for prestressed concrete or concrete which is subjected to chlorides and from 28 MPa until more than 100 MPa for reinforced concrete in foundations (European Committee for Standardization, 2004).

Plain concrete is a type which does not have reinforcement and has minimum requirement for the specifications to resist compressive loads (ACI Committee, 2008). It has high compressive strength but very low tensile and shear strengths (Cement Concrete & Aggregates Australia, 2004).

Reinforced concrete is the structural type of concrete with no less than minimum amounts of reinforcement specifications so that it can resist both compressive and tensile loads (ACI Committee, 2008). It has a high compressive strength and at the same time it also has high tensile and shear strengths (Cement Concrete & Aggregates Australia, 2004). Reinforcement of concrete is made from deformed (or spiral) steel bars, bar mats, wires, welded plain and deformed wire fabric (ACI Committee, 2008). These reinforcing bars are sensitive to corrosion when exposed to chloride ions, salts, (ACI Committee, 2008) or some microorganisms (Neville, 2006).

Prestressed or pressed concrete has superior strength where internal stresses have been introduced to reduce potential tensile and shear forces in concrete. The steel should be high in tensile strength such as wire, bar or strand (ACI Committee, 2008). While prestressing means that the rebars receive internal necessary stresses, they can also accept tensions prior to the period of placing, which is called pretensioning (ACI Committee, 2008). Hence, this type of concrete requires high compressive, tensile and shear strengths (Cement Concrete & Aggregates Australia, 2004).

2.2 Water use in concrete production

2.2.1 Water quantity for concrete

Water quantity for mixing

The amount of water to be used for mixing is calculated using the water to cement (w/c) ratio. This ratio is influenced by the air temperature and the degree of compaction applied to the concrete to remove air voids in the mixture (Neville, 2011). René Féret (1896) and Duff Abrams (1919) discovered the relation between the w/c ratio and compressive strength to be inversely proportional (Neville, 2011). While a lower w/c ratio creates stronger concrete, a higher w/c ratio makes it more workable (Cement Concrete & Aggregates Australia, 2004).

The validity of this ratio is limited within a range of concrete age and types of the mixture. For instance, a low w/c ratio with high cement content (above 530 kg/m^3) exhibits retrogression of strength when the concrete is at later ages. A mixture with a low w/c ratio and extremely high cement amount also declines the strength (Neville, 2011). That is the reason why, despite its common practice as the first factor in determining concrete strength, the w/c ratio has been criticized for not being adequately crucial anymore. The given relation between the strength and the w/c ratio is more or less linear as long as the w/c ratio is between 0.40 and 0.83. For a mixture with a w/c ratio less than 0.38, the maximum possible hydration is less than 100% (Neville, 2011).

Whenever necessary, extra amounts of water are added directly at the field to ensure the workability of concrete mixture based on the result of slump tests; a method of determining workability by moulding the concrete mixture into a cone and pour it to a flat surface. The height difference between the cone and the unsupported moulded concrete determines the workability of concrete whether it is too liquid or too dense (Cement Concrete & Aggregates Australia, 2004).

Throughout time, water requirements have been known to be affected by the conditions of raw constituents, namely cement and aggregates, and by additional chemicals being used for optimizing the use of the materials or stabilizing the ambient conditions, called admixtures (Popovics, 1980). Nonetheless, within a large range, approximately from 240 to 360 kg of cement/m^3 of water, there is hardly any influence from the cement content to the water requirement (Popovics, 1980).

Weather plays an important role in terms of water loss or gain. The amount of water required in concrete production may then be fluctuated (Cement Concrete & Aggregates Australia, 2004). When the weather is warm and windy, concrete mixture may be hardened rapidly and therefore may not be workable enough or cracked (Cement Concrete & Aggregates Australia, 2004). Extra water is needed for curing to save it from drying out. In contrast, water can turn to ice after placing step due to an extreme cold weather, leaving the concrete expanded and cracked (Cement Concrete & Aggregates Australia, 2004).

Water quantity for curing

The proper water quantity is vital for the concrete mixture to meet the desirable strength. That is the reason of curing concrete as an effort to cope with actual conditions in the environment (Cement Concrete & Aggregates Australia, 2004). The volume of water needed for the curing process does not follow the same rule as w/c ratio in mixing because it is done only for direct application in the field as protection (Hirschi *et al.*, 2005).

South African National Standard (2007) stated that the loss of water from the surface within 72 hours shall not exceed 0.40 kg/m^2, otherwise curing agents should be added as protection. The European guidelines for curing concrete (2001), E DIN 1045-3, suggested that when the outside temperature is between 10^oC and 25^oC, the concrete should be kept moist by continuous wetting. When it is over 25^oC, the curing membrane and water spraying should be performed simultaneously. When it is less than 5^oC, cover and heat insulation should be applied or warm water should be used for dampening frost (Hirschi *et al.*, 2005). In fact, when curing is performed outside, a warm and windy weather requires extra water for curing to save it from drying out but cold weather freezes the water and slows down the setting time of concrete which delays the hardening process (Cement Concrete & Aggregates Australia, 2004).

Despite the requirement, water for curing period cannot be calculated in detail, as long as it can keep the concrete in the water to keep the humidity and ensure the on-going hydration process. No specific indications can be given because it depends on the methods of curing itself, either without extra water needed, such as fabric or plastic covering, insulating, electrical curing or placing the concrete in a low-temperature room, or with additional amount of water, such as fogging, spraying, steaming or soaking the concrete inside a water tank (Kosmatka *et al.*, 2003).

2.2.2 Water quality for concrete

Water quality plays a role in concrete industry not only during the production phase, but also during operation, such as shrinkage, salt ingress, chemical attack, corrosion of reinforcement, etc. (Neville, 2011). Therefore, water quality for concrete production is also as important as its quantity.

Water for concrete production should be free from injurious amounts of oil, acids, alkalis, organic matter, and other substances that could impair the strength or durability of the concrete or metal embedded in the concrete (BS EN 1008, 2002). It should not contain undesirable organic or inorganic constituents in excessive proportions (Neville, 2011), and in a range of neutral until slightly higher pH (from 6.0 until 8.0 or sometimes 9.0) (Neville, 2011).

In practice, water for concrete production requires drinking water quality. Neville (2011) argues that "as long as people can drink it, concrete can be made from it." The main reason of meeting drinking water quality is because drinking water usually contains less than 1000 ppm of organic and inorganic solids concentrations (Al-Ghusain & Terro, 2003). The organic solids may hamper the hydration process by lowering the porosity of the hardened cement paste (Al-Ghusain & Terro, 2003). The inorganic solids, which are the salts, may reduce the long-term strength of concrete or cause surface efflorescence (Neville, 2006). However, until today no standard formulates a specific water quality for concrete, partly because the limitations of the harmful components have not been identified yet, but mainly because unnecessary restrictions will increase production costs (Neville, 2011).

Additionally, reinforced concrete should not be exposed to high chloride concentrations (ACI Committee, 2008). Chlorides in water may interfere with the setting of cement, adversely affecting the strength of concrete, causing staining of its surface, leading to corrosion of the reinforcement or attacking the hardened concrete if the water has a high aggressiveness level (Neville, 2011).

The full list of substances that are harmful for concrete can be found in Table 2.1.

Table 2.1 Effects of impurities in the water and the safe range for concrete production

No.	Substances	Effects	Safe Range	Reference
1	Total Suspended Solids (TSS) Total Dissolved Solids (TDS) for Organic & Inorganic Solids	• Hamper hydration by lowering the porosity of hardened cement paste	<2000 ppm	(Al-Ghusain & Terro, 2003
			<1000 ppm if alkali carbonates exist	(Neville, 2006)
2	Chlorides	• Produce a slightly higher early strength but a lower long-term strength	*[Cl^-]* <500 ppm	(Neville, 2006)
		• Slightly accelerate the total setting time of cement; substantially reduce the initial setting time		(Neville, 2006)
		• Cause persistent dampness		(Neville, 2006)
		• Cause surface efflorescence		(Neville, 2006)
		• Cause concrete deterioration		(Chandra & Ohama, 1994)
		• Cause corrosion of reinforcement (steel bars)		(Standards South Africa, 2007)
			<u>*Non-reinforced Concrete*</u> Efflorescence acceptable = 2.0%$^{w}/_{w}$ Efflorescence inacceptable = 0.3%$^{w}/_{w}$ <u>*Reinforced Concrete*</u> Not subject to marine exposure = 0.6%$^{w}/_{w}$ Efflorescence inacceptable = 0.3%$^{w}/_{w}$ Exposed to marine environment = 0.2%$^{w}/_{w}$ <u>*Prestressed Concrete*</u> Wire of diameter over 5mm = 0.08%$^{w}/_{w}$ Stressing strands and wire of diameter ≤5mm = 0.05%$^{w}/_{w}$	(CCAA, 2007)
3	Sulphates	• Produce a slightly higher early strength but a lower long-term strength	*[SO_4^{2-}]* <1000 ppm	(Neville, 2006)
		• Slightly accelerate the total setting time of cement; substantially reduce the initial setting time		(Neville, 2006)
		• Cause persistent dampness		(Neville, 2006)
		• Cause surface efflorescence		(Neville, 2006)

No.	Substances	Effects	Safe Range	Reference
3	Sulphates *(continued)*	• Cause concrete deterioration when it comes in contact with sulphate ions from an outside source, since the hydration products react with sulphates and make expansive salts which lead to expansion and then cracking or softening of the outer layer of concrete. This reaction also occurs due to the existence of alkaline solutions (Na^+, and Mg^{2+}), which in turn formulate Na_2SO_4 and $MgSO_4$		(Chandra & Ohama, 1994) (CCAA, 2007)
		• Knowingly as sulphate attack, the sulphate components, either combined with alkalis or metals, destroy concrete by forming harmful products from the reaction of sulphate with hydrated concrete.	Not higher than 4% of cement in the mixture, usually 2000 – 3000 ppm	(Neville, 2004)
4	Alkalies & Alkali Carbonates	• Generate alkali-silica, alkali-carbonate and/or alkali-silicate reactions, which lead to expansion and cracking	<100 ppm	(Neville, 2006)
		• Cause concrete deterioration in contact with sulphate ions (as described in no.2)		(Chandra & Ohama, 1994)
		• Na^+ and K^+ dissolve in water and migrate to the surface of concrete to react with CO_2 in air.		(Chandra, 1997)
		• Form Na_2CO_3 and K_2CO_3 which are precursors of efflorescence		(CCAA, 2007)
4	Humic Acids	• Impede the hardening of concrete		(Neville, 2006)
5	pH	• Usually harmless, as long as not brackish and not containing humic acids	6.0 - 8.0, sometimes can be 9.0	(Neville, 2006)

No.	Substances	Effects	Safe Range	Reference
5	pH *(continued)*	• Acid condition with HNO_3 may lead to concrete deterioration because the deterioration process with SO_2, similar to carbonation process, is accelerated in the presence of NO_x gases. The process consists of dissolution of $Ca(OH)_2$ with pollutant gases, leaving the concrete more porous and weaker. This dissolution is highest in the environment containing HNO_3.		(Chandra & Ohama, 1994)
6	(Micro)organisms (Bacteria, fungi, insects)	• Release corrosive chemicals through metabolic actions		(Neville, 2006)
		• Create environment which promotes corrosion of reinforcing bars		(Neville, 2006)
		• Create staining in the surface		(Neville, 2006)
		• Cause pathogenic activities, but it is reduced substantially after pH exceeds 12 as the effect of toxicity		(Cebeci & Saatci, 1989)
		• $Ca(OH)_2$ rapid saturation during hydration		(Al-Ghusain & Terro, 2003)
7	Algae	• Create air entrainment with a consequent loss of strength	[Still needs to be tested]	(Neville, 2006), (CCAA, 2007)
8	Temperature	• High temperature reduces setting time, that sometimes reduces workability (difficult to compact and cast or mould)	$18^{o}C – 30^{o}C$ (only laboratory and field tests)	(Neville, 2006)
		• Low temperature increases setting time because it lowers the chemical reaction speed during hydration		(Neville, 2006)
		• After the age of concrete is older than 7 days, the effect of higher temperature may adversely influence the strength because the concrete is more porous, as parts of the pores remain unfilled		(Neville, 2006)
9	Ammonium salts	• Generate concrete deterioration due to the interactions of ammonium sulphate [$(NH_4)_2SO_4$], ammonium chloride (NH_4Cl) and ammonium nitrate (NH_4NO_3)		(Chandra & Ohama, 1994)

No.	Substances	Effects	Safe Range	Reference
10	Heavy metals	• Titanium retards setting time, increases early strength (3 days) but decreases later strength regardless any cooling conditions	<100 ppm	(Chandra, 1997)
		• Zinc precipitates on the surface with Ca-Zn-H_2O-CO_2 compounds and creates retardation of cement hydration. It also slightly leads the pore structure of hardened cement paste		(Chandra, 1997)
		• Manganese retards setting if less than 0.1% as MnO_2. It accelerates setting and increases early strength if coupled with Barium		(Chandra, 1997)
		• Chromium accelerates setting and increases initial strength if less than 0.5% as Cr_2O_3. Above that, it decreases strength regardless of curing age.		(Chandra, 1997)
11	Halogens	• Fluorine increases hydration reactivity and total pore volume. It also decreases durability by increasing air-permeability and water-penetrability of hardened cement paste		(Chandra, 1997)
		• Chlorine increases hydration reactivity. If more than 0.25% in the solution, it may increase the amount of larger capillary pores. It also improves durability of concrete but decreases resistance to freezing and thawing in later age	90 g/m^3 of concrete	(Chandra, 1997)
12	Fat, oil and grease (FOGs)	• Create air-entraining in concrete	<50 ppm	(CCAA, 2007)
13	Sugars	• Cause retardation of setting process	<100 ppm	(CCAA, 2007)

2.3 Global experiences of treated sewage used for concrete production

2.3.1 Previous experiments

Despite the fact that drinking water is typically advised for concrete production, many experiments were conducted using treated sewage. In fact, the interest in reclaiming sewage for mixing and curing is growing around the world. It began with Abrams (1924) who examined the effect of concrete strength using sewage and industrial wastewater (Silva & Naik, 2010).

This research was slightly abandoned until water shortage problems increased in many parts of the world. In the late 1980s, several researchers, especially from the countries with water shortage problems, studied the use of reclaimed water types from cities, mining, and industrial operations which are believed to be safely used for concrete production (Jankovic *et al.*, 2011). The first one came from Singapore as an effort of closing the loop of water from waste to tap (Tay & Yip, 1988). Since then, other countries followed the experiments with many innovations based on their conditions and different types of wastewater as the samples.

Experiments were conducted in Germany (Silva & Naik, 2010), the United States (Silva & Naik, 2010), Kuwait (Al-Ghusain & Terro, 2003), Saudi Arabia, Canada, Iran (Asadollahfardi *et al.*, 2016), Oman (Al-Jabri *et al.*, 2011), Egypt, Qatar (El-Nawawy & Ahmad, 1991), Iraq (Ismail & Al-Hashmi, 2011), India (Sorkor & Miretu, 2015) and Indonesia (Silva & Naik, 2010). In Malaysia the tests covered both the physical and chemical characteristics of the sewage to be used for concrete production (Noruzman *et al.*, 2012) and the appropriate technology to meet the specifications of mixing and curing water for concrete (Lee *et al.*, 2007).

Most of these experiments showed that treated sewage can be reclaimed for concrete production, with a slight loss of compressive strength, that is, in reality, not detrimental to the concrete. For instance, tertiary treated sewage is considered suitable for mixing (Al-Ghusain & Terro, 2003). It is also reported that treated sewage does not have a negative effect on concrete (Silva & Naik, 2010). In some other cases, the compressive strength and setting time can even increase (Lee *et al.*, 2007)

Only two results from India (Kulkarni & Patil, 2014) and Jordan (Mahasneh, 2014) show a considerable decrease in compressive strength which may be the effect of treated sewage for mixing and curing. Both experiments show that the decrease of the strength is possibly due to pore clogging by TSS, precipitates of TDS in the sewage or chemical attacks during hardening state. The result from India was then continued in another lab-scale experiment which indicates that the compressive strength of concrete mixed with secondary treated sewage (after nutrient removal) decreased for about 20% when the concrete was 7 days old but started to regain the strength until at least 90% of the compressive strength from the other samples with tap water and bottled drinking water. Nevertheless, the tensile strength of the concrete made from the sewage was the lowest one compared to the other types of water; bottled drinking water, tap water, well water and borehole water. This latest experiment also suggests that slightly acidic, alkaline, brackish, coloured or polluted smelling water should not be directly rejected (More & Dubey, 2014).

Thus, it is realistically possible to reclaim sewage for concrete production and might be advantageous in the long run if the compressive and tensile strength can be maintained (More & Dubey, 2014).

Selected crucial parameters of water quality have been tested by Liu (2016) and Ratan (2016). They conducted compression test for 14-day-old concrete with a designed strength of 35 MPa produced with different qualities of water and established a set of threshold of concentration for each harmful substance for concrete as listed in Table 2.2 (Liu, 2016). The results show that chloride ions, tested in the form of sodium chloride (NaCl), enhance the early strength of mass concrete but decrease it in the long term. The decrease might also be due to the existence of ammonium nitrate (NH_4NO_3), sulphate (SO_4^{2-}), TP (tested in the form of P_2O_5) and cellulose. The TSS cause clogging in concrete pores which is potentially damaging (Liu, 2016).

2.3.2 Available standards

Although there is a lack of detailed specifications regarding the water quality for producing concrete, there are a few standards from all over the world which have tried to define the minimum requirement. These guidelines were created in the pursuit of identifying suitable water quality for concrete production which is unsurprisingly lower than drinking water quality. Two of them, the British European standard (BS EN 1008:2002) and Australian standard (CCAA 2007) are taken as the source of requirement because both have the most complete parameters to be assessed. These two standards are chosen based on their relations to each other and to other relevant standards, such as from the United States; ASTM C 1602/ C 1602M-06, ASTM C94, ASTM D516, ASTM C114, ASTM D3559, ASTM D1691, from the European Standard; EN 196-21, E DIN 1045-3, ISO 7890-1, APHA 5520, AS 1141.35, AS 1580.505.1 and AS 1379. Both of them also identify the quality of treated sewage and other types of wastewater for concrete production as can be found in Table 2.2 below.

Table 2.2 Standards and laboratory thresholds of concrete mixing water

Data	**Unit**	**Limit**		
		Standards (BS EN 1008: 2002 & CCAA 2007)	**Laboratory Analysis** (Liu, 2016)	**Combined**
Organic substances				
Biological Oxygen Demand (BOD)	mg/L	[no data]	[no data]	[no data]
Chemical Oxygen Demand (COD)	mg/L	[no data]	664	664
Total Organic Content (TOC)	mg/L	[no data]	[no data]	[no data]
Total Kjedahl Nitrogen (TKN)	mg/L	[no data]	[no data]	[no data]
Nitrate (NO_3^-N)	mg/L	100	6.7	6.7
Total Phosphorus (TP, as P, PO_4^{3-} or P_2O_5)	mg/L	100	6.7	6.7
Total Dissolved Solids (TDS)	mg/L	100	[no data]	100
Chloride (Cl^-)	mg/L	100	(no limit for non-reinforced concrete)	100
E. coli	#/L	1000 (class A: open system, worker exposure)	[no data]	100
F.streptococcus	#/L	[no data]	[no data]	[no data]
Total Suspended Solids (TSS)	mg/L	1% of the total aggregate	67	67
Total Solids	mg/L	50,000	-	50,000
Fat, Oil, Grease (FOGs)	mg/L	50	[no data]	50
pH	-	5.0-8.0	6.0-8.0	6.0-8.0
Sulphate (SO_4^{2-})	mg/L	150	86.5	86.5
Alkalis	mg/L	1500	[no data]	1500

Data	Unit	Limit		
		Standards (BS EN 1008: 2002 & CCAA 2007)	Laboratory Analysis (Liu, 2016)	Combined
Harmful chemical substances				
Sugars	mg/L	100	[no data]	100
Lead (Pb)	mg/L	100	[no data]	100
Zinc (Zn)	mg/L	100	[no data]	100
Na_2CO_3 and/or $NaHCO_3$	mg/L	100	[no data]	100
$Ca(HCO_3)_2$ and $Mg(HCO_3)_2$	mg/L	400	[no data]	400
NH_4NO_3	mg/L	-	32.6	32.6
$MgSO_4$ and $MgCl_2$	mg/L	100 (max. 4% of negative ions)	[no data]	100
$CaSO_4$	mg/L	[no data]	[no data]	[no data]
$Ca(NO_3)_2$	mg/L	1.7% of cement	[no data]	[no data]
Na_2SO_4, $MgCl_2$, $MgSO_4$, $CaCl_2$	mg/L	100	[no data]	100
H_2SO_4	mg/L	6250	[no data]	6250
HCl	mg/L	10150	[no data]	10150
NaOH ($Na_2O + H_2O$)	mg/L	1500	[no data]	1500
KOH	mg/L	(1.2% weight of water)	[no data]	[no data]
Mineral oil	mg/L	(0.5% weight of water)	[no data]	[no data]
Chlorides from Ti, Mn, Zn, Cu, Pb	mg/L	2000	[no data]	2000
Na-salts from I, PO_4^{3-}, As, BO_3	mg/L	100	[no data]	100
ZnO_2	mg/L	0.01% weight of cement	[no data]	0.01% c
Na_2SO_3	mg/L	0.01 - 0.1%	[no data]	0.01 - 0.1%
NH_4^+	mg/L	[no specific limit]	5.8	5.8
Tannic acid	mg/L	(0.5% weight of water)	[no data]	0.5%
Silt or clay particles	mg/L	2000	[no data]	2000
Sediment	mg/L	4	[no data]	4
Alkali (Na_2O eq.)	mg/L	600	[no data]	600
Detergents	mg/L	Foam disappears within 2 min.	[no data]	[no data]
Colour	mg/L	Pale yellow or paler	[no data]	[no data]
Odour	mg/L	No smell except potable water	[no data]	[no data]
Humic acids	mg/L	Yellowish brown (adding NaOH)	[no data]	[no data]
Comparative samples strength	mg/L	7-28 days	[no data]	7-28 days
Setting times	mg/L	Initial = 1 h, final = 12 h	[no data]	1 – 12 h

Based on Table 2.2, there are still some organic parameters with no limits, e.g. BOD, TOC and TKN. It indicates that little research has been done to establish the requirements. Similar situation can be drawn from microbial contaminants which are derived based on the health and safety limits for the workers and not from the potential effect to the concrete itself (Cebeci & Saatci, 1989).

The main concerns are given for TSS, FOGs, pH and salts as they attack concrete body and initiate corrosion for rebars. Physical characteristics, e.g. colour and odour, still have no range of acceptance. Phosphate (P_2O_5 or PO_4^{3-}) and sulphate (SO_4^{2-}) have different limit values between the standards and the laboratory analysis, which might be due to the different concrete strengths as the reference.

3. Materials and Methods

This chapter presents the materials and mechanisms of data-collection that are applied in this research. Section 3.1 explains the inventory map of the companies and the fieldwork period spent in Maputo. Section 3.2 describes the interviews taken place in Maputo. Section 3.3 includes the parameters to be used for water quality measurement. Finally, Section 3.4 elaborates the design bases for water quantity and quality.

3.1 Inventory map of construction companies

3.1.1 Criteria of Selection

In line with the possibility of reclaiming sewage for concrete production and the need of producing concrete in Maputo that is prone to water shortage, it is important to identify how impactful this water reclamation effort in construction industries is. The starting point is to look at the number of construction companies which actively operates in Maputo and its surrounding. The locations of these companies are the basis for finding the best source of sewage for reclamation purposes.

There are three basic criteria in selecting the construction companies from multiple sources to be added in the inventory map, as follows:

- The company should be in the field of civil construction services.
- The company should own its batching plant.
- The company should be located in or around the city of Maputo, Matola or Machava.

3.1.2 Preliminary search

The main activity prior to the field work in Maputo was a desk investigation to search for data about construction companies via the Internet. The first source was the Yellow Pages website of Mozambique (http://www.paginasamarelas.co.mz/). The keyword was "civil construction" (*construção civil* in Portuguese) with the location respecting the third criterion (above).

As the second source, a list of registered companies was obtained from the National Directorate of Industry (*Direcção Nacional da Industria*). It consisted of both personal and collective companies in the field of civil construction and material producers. The third source came from the public water supplier for the city of Maputo, ÁdeM (*Águas da Região de Maputo*) as a leasing company for water supply established by FIPAG (*Fundo de Investimento e Património do Abastecimento de Água*), which provided a list of industrial tap water consumers.

A list about 100 best companies in Mozambique, including the detailed information (business, locations, daily productivity, number of employees and available contacts) was found as the fourth source (KPMG, 2011). The companies from this list are thus considered as the large ones. As the last source, information was obtained from personal reference. This source was given after having contacted each company. After the lists have been settled, the companies were contacted.

3.1.3 Contacting the companies

Once the list was developed, the companies were contacted via telephone (first approach), emails, official letters and visits to their offices. Not all companies had valid telephone numbers or emails and postal addresses but they remained in the list as part of the data. Interviews were then scheduled for the interested companies.

3.1.4 Locating the companies

After the interview sessions were finished, the exact addresses of the companies were registered and the map was created. The mapping was performed by inserting the coordinates of the companies as dots into vector layers of ArcGIS programme and plotting the map of Maputo, Matola and Machava.

The insertion of the dots was divided based on the scales of the companies and also among the five sources for company list by differentiating the colours of the dots. The map also includes the sewer system of Maputo city; the connections with the endpoints from domestic sewage, the main sewer network and the WWTP in Infulene (Salet & Schijfsma, 2016) to help determining the water source for designing the plant, both for the preliminary and large scale schemes.

Not all companies had traceable addresses that could be used to locate the coordinates. For instance, the list received from the Ministry of Industries did not automatically include the addresses or telephone number of the companies or some companies searched from the Yellow Pages website had incorrect addresses that could not be found. The missing addresses were then traced by using search engine in the internet or directly visited the alleged locations.

3.2 Interviews with the construction companies

The interviews were conducted to validate the information taken from the list, not only about the amount of water consumption, but also the way they deal with water shortage and environmental issues. It also functions to invite the companies for participating in the preliminary project.

3.2.1 Structure of the interviews

Questionnaire

The interviews were conducted using a questionnaire (Annex 1). It covers a general observation of current practices in the field of concrete production. Knowing the practices directly is important to predict how vast the impact of the project will be and whether the companies are open enough for a new perspective in utilizing water. It includes their existing conditions in terms of their existing projects, their methods of production, the number of employees, their actual productivity, the amount of water consumption, their current source and average cost of water, their effort in saving or recycling the used water, and their future plans (whether they will expand the company, increase productivity, introduce new products, etc.).

These data were also the basis for the classification of the companies. The intention of having one mean value for each class is to assign more reasonable estimation so that for companies with similar situations, the amount of water consumption will also be the same. The amount of consumption for the actual number of concrete companies in Maputo can be obtained from the multiplication of the mean of the samples and the number of the actual companies. The standard deviation is then calculated according to the error propagation rules.

Observations in the Factories

After the interviews, the visits continued with a short tour to the batching plants to directly see the production process. The steps of production, from mixing, placing, curing and transporting were presented and explained.

Each visit was also combined with a quick look to the surrounding, including other water sources or sewage outlets that were considerably close to the area of the company. The coordinates of the locations from the companies were taken from Google Map and Google Earth applications or by cellphone to trace the location during the visits to the factories. The coordinates were then plotted in the map using ArcGIS programme. The locations of the companies are marked by dots and each dot with different groups of sources will have different colour then the others.

3.2.2 Class criteria

The respondents were grouped using a list of criteria, as follows:

- Amount of estimated water consumption
- Scale of the companies (as the number of employees) and future plans
- Volume and type of produced concrete
- Type of production process and stages
- Sources of water and recycling systems
- Water cost

3.3 Water quality measurement

The tested parameters to design the preliminary scheme were separated in two groups based on the location of the samplings; directly in the field or on-site and in the laboratory. These parameters were selected due to their crucial effects on concrete as listed in Table 2.1 or because they have been indicated in the previous works in Table 2.2. These parameters were analysed either directly in the selected influent source or in the laboratory of civil engineering department from the University of Eduardo Mondlane (UEM) in Maputo.

However, the selection of parameters that could be analysed depended on the laboratory facilities and schedule as well so that not all important parameters listed in those two tables could be analysed, such as TSS, humic acids, COD, BOD, total coliforms, sugars, heavy metals; zinc (Zn) and lead (Pb), and halogens; chloride (Cl^-) and fluoride ions (F^-). The parameters which could not be analysed in the laboratory will use the numbers from typical sewage quality after being treated by septic tanks (Washington State Department of Health, 2004).

1. Parameters taken on-site

   These parameters should be taken in the field because the conditions in the field will be totally different from in the laboratory which can cause changes or deterioration of samples after being transported (WHO, 2003). They are selected as the initial overview that might influence hydration in concrete, such as the presence of heat and oxygen in the environment, acidity, particles and ions that might hinder the process (Table 2.1)..

   These parameters include:

   - Temperature
   - pH (as preliminary identification)
   - Electric conductivity (EC)
   - Dissolved oxygen (DO)
   - Turbidity

2. Parameters taken in the laboratory

   These parameters should be taken in the laboratory because they need proper instruments and longer time for the measurements. They are selected due to their potentially damaging effect for concrete, such as hamper the hydration or retard the setting time, reduce porosity, initiate corrosion or create pathogenic activities (Table 2.1).

   These parameters include:

- pH in the laboratory (to see the effect of different environment in the field and in the room)
- Alkalinity
- TSS
- TP (P, PO_4^{3-}, P_2O_5)
- Sulphate
- Chloride ions
- Nitrogen-based compounds, such as nitrate (NO_3^-) and ammonia (NH_4^+)
- Heavy metals; manganese (Mn), zinc (Zn), lead (Pb)
- Total coliforms

Due to the delay of equipment and test kits to Maputo and technical issues during the period of laboratory analysis, the values of TSS, TDS, FOGs, nitrate, BOD, COD and total coliforms could not be tested. Therefore, as the sewage has been treated individually by septic tanks installed in the houses, offices, factories and other buildings, the values can be taken from the typical effluent quality after passing a septic tank (Gross, 2004).

The sampling activities, both the field measurement and laboratory analyses, are still being continued by UEM students and will last for a year.

3.4 Design of sewage treatment scheme for concrete production

The preliminary design considerations were based on Chapter 2, in line with the results of previous experiments worldwide (Section 2.3), to assess whether producing concrete with treated sewage is possible to be performed. The influent flow of the design was based on the demand of the interviewed companies and the water quality requirements were based on the combination of standards for concrete mixture and previous works (Table 2.2) with laboratory analysis (Table 4.7).

4. Results and Discussions

This chapter presents the results of the interviews with 11 concrete companies. Section 4.1 gives the list of construction companies in Maputo from several sources. Section 4.2 elaborates the results of the interviews and a classification of the interviewed companies as a reference of projection for determining the average water consumption from construction sector in Maputo. Section 4.3 explains about water demand from the 11 companies and the projection to all concrete companies in Maputo, which is then followed by Section 4.4 that displays the contribution of construction sector to drinking water use. Section 4.5 describes the products and water quality requirements from the companies. Section 4.6 gives information about current practices in each company and the willingness to participate in the preliminary water reclamation project. Section 4.7 presents the cost of water and Section 4.8 shows the inventory map. Available water quantity and quality are presented in Section 4.9 and 4.10, respectively. Section 4.11 depicts the available space for the treatment plant while Section 4.12 presents the findings during the field work in Maputo.

4.1 Sample selection of construction companies

The final list of companies was compiled from five sources as given in Table 4.1. The table presents the number of companies which were listed, contacted, scheduled for interviews and the ones which could be successfully interviewed.

Table 4.1 Sources and selection steps of construction companies
(DNI = *Direcção Nacional da Industria* or National Directorate of Industries, AdRM = *Águas da Região de Maputo* or Great Maputo Water Supply Operator, KPMG = Klynveld Main Goerdeler, tax and advisory service company, Referrals = personal contacts from previously interviewed companies)

Sources*	Companies			
	Listed	Contacted	Interested & Scheduled	Interviewed
DNI's list	67	34	10	5
AdRM's list	8	5	2	2
Yellow Pages	58	58	20	1
KPMG's list	7	7	1	0
Referrals	16	16	6	3
Total	156	120	39	11
Percentage	100%	77%	25%	7%

When compared to one another, the lists did not include the same companies, which means that the companies which are registered in one list are not registered in another one. Some companies which could physically be found were not registered in one of the lists at that moment. There could be an indication that the lists were not complete or the companies were registered on other names. However the number of "accidentally-seen" companies was insignificant for the total number of the listed ones (less than ten). The list of the companies can be found in Annex 2.

Cimbetão and Britanor, the large construction companies, were in the list made by AdRM and KPMG. Hidroblock, one of the precast concrete producers in Machava, was mentioned DNI's list, on the Yellow Pages and in AdRM's list under the name of Adriano Sumbane, the owner of the company. Thus, it can be assumed that there might be other companies that are not listed yet and they might also use tap water as their primary source.

4.2 Interview Results

4.2.1 Water consumption

The plot of water consumption from 11 companies that were interviewed is depicted in Figure 4.1.

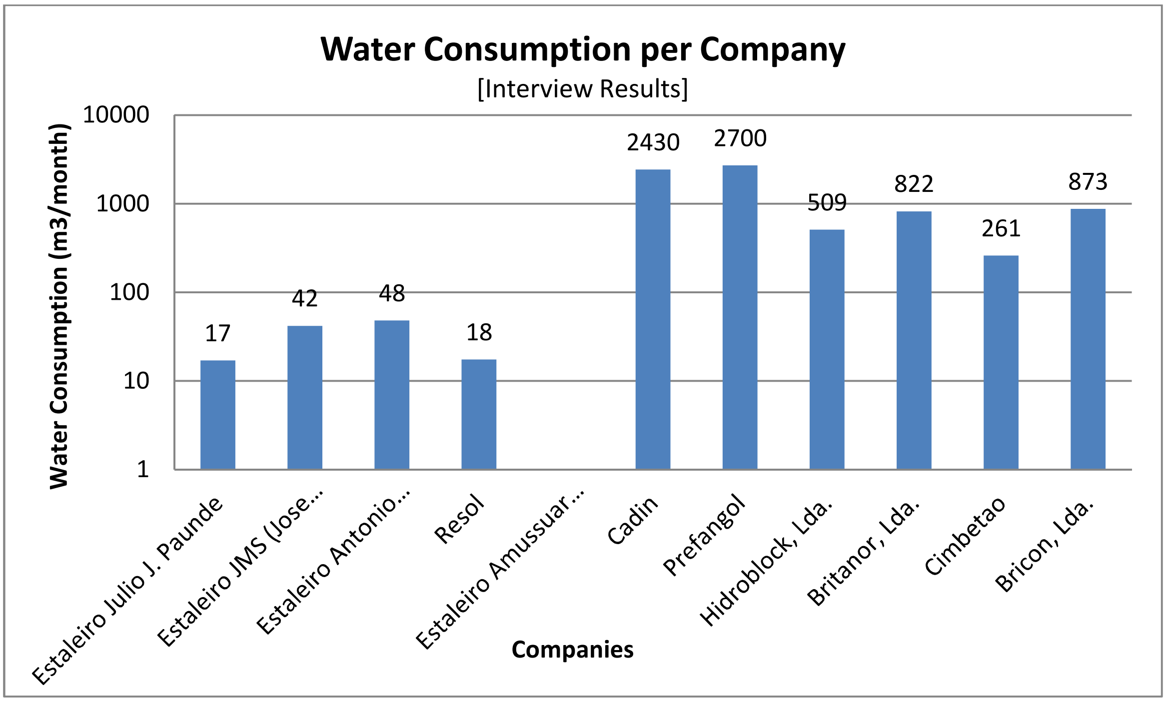

Figure 4.1 Water consumption per company (in logarithmic scale)

According to Figure 4.1, there is a high variation of water consumption from the company to company. Estaleiro Amussuar Rassur reported no water consumption as it individually abstracts groundwater and does not pay for the water. The minimum amount of water consumption is 17 m^3/month, reported by Estaleiro Julio J. Paunde and Resol. In contrast, the maximum water consumption claimed by Cadin and Prefangol can reach above 2400 m^3/month. Cimbetão only reported its consumption for mixing, approximately 261 m^3/month, and did not recorded the usage for curing and cleaning the trucks. This variation indicates that each company should not be treated equally when representing the actual water consumption condition and it can be approached by classifying the companies based on their amount of water consumption, volume of concrete products and water cost from each company which can be found in Table 4.2.

4.2.2 Classification of the companies

Looking at different criteria in the field might be useful for the decision-making process since they describe the general overview and variability of the companies, namely the number of employees and volume of products. Documentations of the site visits can be found in Annex 8. A scaling approach was introduced to recognize how the variability of the samples relates to the actual condition.

The scale is based on the site visits dividing the companies as three different classes; small, medium and large, with a high number of small companies and a few large ones. Small companies have more or less 20 employees and produce less than 5 m^3/day of concrete. Medium companies have 20 – 60 employees and produce around 10 – 150 m^3/day. Large companies have more than 60 employees and produce more than 150 m^3/day. These threshold numbers are taken from the largest intervals from one company to another. This scaling method describes a comparison as in Figure 4.2.

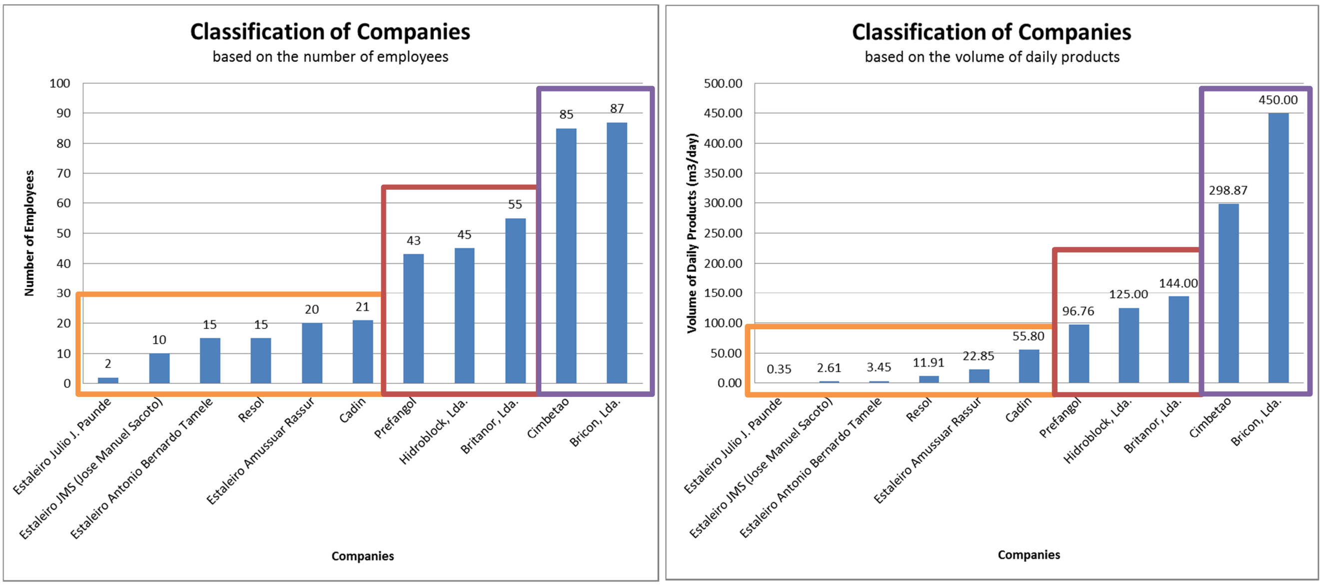

Figure 4.2 Comparison between the number of employees (*left*) and the volume of daily products (*right*)

It can be seen from the Figure 4.2 that the order of the companies from the smallest to the largest one is similar whether it is classified based on the number of employees or the volume of daily products. Both classifications describe that there are gaps with the largest differences between Cadin and Prefangol (21 and 43 for the number of employees, 56 and 97 for the number of daily products) and also between Britanor and Cimbetão (55 and 85 for the number of employees, 144 and 299 for the number of daily products). These gaps divide the companies into three different classes; 6 small companies, 3 medium companies and 2 large companies.

This classification was used to determine the average water consumption from the 11 interviewed companies as can be found in Table 4.2. Since the sample size is small (between 5 – 30), the statistical approach was performed to calculate the mean and standard deviation of each parameter using a wide confidence interval (CI) between 20% and 30% (Sauro, 2013). The estimated CI was 25% (taken as the value in the middle of the range) as this is the first research with no prior information about the total number of companies and the ones that would respond positively. From the equation of the CI:

$$n = \frac{N \cdot X}{X + N - 1} \text{ where } X = \frac{Z^2 \cdot p(1-p)}{MOE^2}$$

Z is the critical value of normal distribution based on the confidence level, MOE is the margin of error, p is the sample proportion and N is the population size (Select Statistical Services Ltd., 2016). This equation gives the number of samples, n = 10, which means that it is statistically sufficient.

Table 4.2 Interview results

Companies	Class of Companies Based on the number of employees			Type of Concrete Production Method			Volume of Products (m^3 concrete/mth.)		Water Consumption (m^3 water/mth.)		Water Consumption/ Volume of Products (m^3 water/m^3 concrete)		Water Tariff* (€/mth.)		Water Tariff* (€/m^3)		Locations of Water Source					Individual Recycling System	
				Precast		In-situ																	
	Large (≥50)	Medium (20-<50)	Small (0-<20)	Non-reinforced (Blocks, Paves, Curbs)	Reinforced (RC Pipes, Tank)	Ready-mix	Reported (m^3/mth.)	Mean (μ), St.Dev (σ)	Reported (m^3/mth.)	Mean (μ), St.Dev (σ)	Reported (m^3/m^3)	Mean (μ), St.Dev (σ)	Reported (€/mth.)	Mean (μ), St.Dev (σ)	Reported (€/m^3)	Mean (μ), St.Dev (σ)	Tap Water (Network)	Surface Water (River)	Ground/ Surface Water (Trucks)	Ground Water (Individual)	Ground Water (External Pipelines)	Yes	No
Estaleiro Julio J. Paunde			2	●	●		78.16	μ =246.95 σ=248.76	17.00	μ=24.90 σ=17.68	0.22	μ=1.14 σ=1.68	7.33	μ=49.31 σ=56.08	1.12	μ=0.76 σ=0.34					●		●
Estaleiro JMS (José Manuel Sacoto)			10	●			10.36		42.00		4.05		19.40		0.45		●						●
Estaleiro Antonio Bernardo Tamele			15	●			357.28		48.00		0.13		24.67		0.40		●					●	
Resol			15		●	●	103.58		17.50		0.17		145.83		1.09				●				●
Estaleiro Amussuar Rassur			20	●			685.36		0.00		-		-		-					●			●
Cadin		21				●	13500.00	μ=6118.2 σ=4291.6	2430.00	μ=1615.25 σ=960.93	0.18	μ=0.32 σ=0.23	108.00	μ=160.34 σ=84.70	0.38	μ=0.38 σ=0.01	●		●				●
Prefangol		43				●	3750.00		2700.00		0.72		83.33		0.38					●		●	
Hidroblock, Lda.		45		●			2902.92		509.00		0.18		148.66		0.38		●			●N			●
Britanor, Lda.		55				●	4320.00		822.00		0.19		301.36		0.37		●	●O				●	
Cimbetão	85					●	1674.00	μ=5320 σ=3646	260.63	μ=1358.54 σ=485.54	0.16	μ=0.13 σ=0.03	800.00	μ=584.35 σ=215.65	3.07	μ=1.72 σ=1.34	●					●	
Bricon, Lda.	87			●	●N		8966.04		873.00		0.10		368.71		0.38		●		●E				●
Total									7719.13	μ=7719.13 σ=1970.43							7	1	3	3	1	4	7

*The costs were reported in MT (Mozambican meticals or MZN), given that €1 (European euro or EUR) is equal to 75 MT (Ostermiller, 2016).

(light) =	small	●O =	occasionally
(medium) =	medium	●E =	Emergency
(dark) =	large	●N =	near future

The complete table can also be found in Annex 1.

4.3 Water quantity requirements

4.3.1 Water demand from the surveyed companies

From the total of 156 construction companies in Maputo, only 11 interviews could be conducted. Since the companies have been classified by their scales, the amount of water consumption, along with the mean and the standard deviation, are calculated within each class. The estimated monthly water consumption is approximately 25 ± 18 m^3 for the small companies, 1615 ± 961 m^3 for the medium and 1358 ± 485 m^3 for the large ones, so that the total amount is 7720 ± 1970 m^3.

The highest water consumers are Prefangol (2700 m^3/month), Cadin (2430 m^3/month), and both of them are ready-mix concrete suppliers (see Section 2.1.5 for types of concrete). It can be argued that the highest water consumers in concrete production are the ready-mix suppliers. The largest volume of water is used to clean the trucks, and the volume is larger than the water for mixing itself.

There are several variables that influence the water consumption in producing concrete, such as the types of production methods, weather, humidity, difference in compressive strengths, applied technologies, additional plasticizers in the mixture or the productivity of the employees. Britanor and Cimbetão stated during the interviews that inaccuracies might occur as they have to cope with warm weather that enhances the evaporation in the mixture or during delivery process but the influence is small compared to the total water consumption.

The majority of the companies use tap water as the main source. Other sources of water include groundwater either from boreholes or individual suppliers delivered by trucks or separated pipelines. Referring to Table 4.2, the water consumption from Estaleiro José M. Sacoto (4 m^3 of water/m^3 of concrete) is higher than the others (less than 1 m^3) although the company is classified small based on the number of employees and the volume of products. It can be indicated that this company is inefficient in their water use. Meanwhile, Estaleiro Amussuar Rassur individually extracts groundwater by pumps so no water cost needs to be paid.

The case of Cimbetão

According to Table 4.2, Cimbetão, largest ready-mix concrete supplier, pays the highest price for water from the network. However, this company only reported 261 m^3/month for the mixing, claiming that there is no measurement or track-keeping system of water for curing and cleaning trucks. This, however, leads to an imbalance in calculating the total amount of water consumption for Cimbetão itself. Hence, trusting that the monthly payment for water consumption is correct after comparing it to the other two ready-mix suppliers, Hidroblock and Britanor, an extrapolation to find the amount of water consumption, including the “loss” of water for curing and cleaning, were performed with the values from Hidroblock and Britanor as the references due to the fact that they only use tap water as the default source and they provided their official copy of monthly water payment receipt from AdRM so that the value of their water consumption and monthly payment are considered to be true. With the assumption that the monthly water price of Cimbetão is correct, the consumption of this company is more likely to be 1844 m^3/month or 61 m^3/day instead of the reported value. The corrected value is now used in the projection of actual population.

Thus, following the mean and standard deviation from each class of the sample population which consists of 5 small, 4 medium and 2 large companies, the total amount of water consumption from these 11 companies is calculated to be 9303 ± 2041 m^3/month or 311 ± 36 m^3/day.

4.3.2 Projected water demand for all companies in Maputo

Assuming that the actual population (156 companies in Maputo) has the same scaling pattern as the samples, the number of the samples will be projected from the number of sample companies in one class divided by the total number of sample companies, multiplied by the actual number of all companies in Maputo, which then divides the actual population into 71 small companies, 57 medium and 28 large ones with each of them belonging to one class that has the same mean and standard deviation in water consumption as from the sample companies.

Table 4.3 is the result of the calculation using daily water consumption in order to see the variability in daily basis. It presents that the amount of water consumption from all concrete producers in Maputo and its surrounding is 4411 ± 257 m^3/day.

Table 4.3 Estimated total daily water consumption for concrete production in Maputo and the surroundings

Class	Number of Companies (Samples)	Mean Consumption (Samples)	Standard Deviation (Samples)	Number of Companies (Actual)	Mean Consumption (Actual)	Standard Deviation (Actual)
	[-]	[m^3/d]	[m^3/d]	[-]	[m^3/d]	[m^3/d]
Small	5	1	0	71	74	4
Medium	4	54	32	57	3069	242
Large	2	45	16	28	1268	86
Total	11	311	36	156	4411	257

4.4 Contribution of concrete production to drinking water use

Since most of the companies use tap water as their source to produce concrete, the amount of water consumption from concrete industries may give significant impact to the total use of drinking water in Maputo. Van Esch and van Ramshorst (2014) presented the distribution of total annual volume of drinking water use in Maputo from AdRM as Table 4.4 below.

Table 4.4 Annual volume of drinking water use in the city of Maputo (van Esch & van Ramshorst, 2014)

Sector	Volume (m^3)	Percentage (%)
Domestic	6,674,053	55.58
Public	1,503,215	12.52
Commercial and services	2,998,977	24.97
Industrial	829,468	6.91
Municipal	2,802	0.02
Total	12,008,514	100

Using the total volume of water consumption for concrete industry, it is estimated that the yearly value is between 1.5 and 1.7 million m^3, which means that it takes approximately 12% - 14% from the total annual volume of drinking water use in Maputo. However, it is stated in Table 4.4 that the industrial usage of drinking water is less than 7%. It might be possible that almost half of the concrete companies in the city of Maputo use other sources of water, such as groundwater with boreholes, surface water from the rivers, private providers by trucks or pipelines, etc. It is also in line with the interview results that some companies which are not mentioned in AdRM's list are indeed mentioned in the others. It is also possible that these companies are included in commercial or domestic sector since some companies are not listed by DNI but exist in the list of AdRM.

If the total amount of water consumption for concrete industry is registered outside the domestic sector, it will be true that an alternative source of water can give crucial impact for the amount of water supply for domestic purposes. However, this data were taken only from AdRM, which means that the companies from the other lists (DNI, KPMG and Yellow Pages) are not registered in AdRM's list yet and it can be assumed that the percentage of concrete industry is larger than the number sector from Table 4.4 above.

On the contrary, the total monthly tap water volume produced and distributed by AdRM for the province of Maputo is about 6.5 million m^3 (AdRM, 2015), which means that more than 77 million m^3 is distributed in a year. From this information, the involvement of concrete industry for drinking water use is only about 2% from the total tap water distribution. While it seems contradictory to the volume of annual drinking water use (Table 4.4), it is more likely that the contribution is higher around the city, namely Maputo city, Matola and Machava, as most of industries are located in these areas (Figure 4.3).

4.5 Products and water quality requirements

The main products of the interviewed companies are ready-mix concrete, precast blocks, paves, curbs, latrines and pipes, with and without reinforcement. There are more companies which produce precast concrete than the ready-mix (see Table 4.2).

Bricon, one of the precast blocks producers, informed that the presence of oil (FOGs) reduces the strength of concrete because it hampers the adhesion among cement, aggregate and water. Considering that precast concrete only requires minimum strength (see Section 2.1.5), FOGs is determined to be the first substance that needs to be removed. Hidroblock also informed that the presence of salts created white spots on the surface of the blocks (called efflorescence) but does not influence the strength so that the salts is considered not mandatory to be removed. Britanor and Prefangol, the ready-mix suppliers which have their own testing laboratories, informed about the reduction of strength caused by sulphate attack but until now there is no actual experience.

Together with Cimbetão, Britanor and Prefangol have their individual water recycling system inside their batching plants. The water used for curing and washing trucks is collected through sloped floor into small open ditches surrounding the plants. The ditches carries the wastewater into decantation tanks, where the water stays between one and three days until the solids are settled at the bottom of the tanks and the water is used again to clean the trucks. In fact, Prefangol has just succeeded to use the recycled water to produce slabs with a compressive strength of less than 16 MPa. However, the company still depends on the groundwater as the primary source. One of the small companies, Estaleiro Antonio B. Tamele, creates an individual decantation system. The effluent is used for curing the concrete blocks. These four companies claimed that they can reduce almost 30% from the total water consumption. It can thus be determined that TSS is compulsory to be removed.

As the ready-mix suppliers, Britanor and Cadin mainly use tap water although during emergency situations Britanor takes water from the river and Cadin purchases water from private suppliers by trucks. Prefangol uses groundwater from their borehole and Cimbetão follows standardized water quality from Portugal, NP EN 1008: 2003 *Água de amassadura para betão*. Britanor, Cadin, Prefangol and Cimbetão require high water quality, including the removal of salts and microorganisms which can be harmful for concrete.

4.6 Future alternatives and participation

Some companies have to search for alternative sources of water. Hidroblock, one of the medium precast blocks producers, considers that the tap water is costly. This company has just finished building a bored well to extract groundwater. Meanwhile, in emergency situations Cadin and Resol have to purchase water from trucks with higher price than tap water.

Almost all interviewed companies are willing to participate in the water reclamation project, except Estaleiro J. M. Sacoto, due to the fear of having unreliable and more expensive source. From Section 4.3.1, this company was also the one that considered tap water price to be expensive since it reported to finish constructing one house for 6 – 12 months, whereas for the same duration, Resol claimed to finish one residential or office building. According to Table 4.2, Estaleiro J. M. Sacoto uses 4 m^3 of water per 1m^3 of concrete, while Resol consumes less than 1 m^3, similar to the values of other companies. It can be inferred that the behaviour in consuming water influences the view of the company regarding the price and the idea of saving and reclaiming water.

4.7 Water price

4.7.1 Regulation

The water tariff for Maputo, Matola and Boane areas follows a written announcement made by Water Regulation Council (*Conselho de Regulação de Águas*) (2011). It is stated that as per April 2012, industrial institutions with a total monthly water consumption of less than 50 m^3 should pay a flat tariff of 1,425 MT/month (Mozambican meticals or MZN) or €19/month, given that €1 (European euro or EUR) is equal to 75 MT (Ostermiller, 2016). Higher consumption will be charged as an additional tariff for 28.50 MT/m^3 or €0.38/m^3 (Imprensa Nacional de Moçambique, 2012). According to Table 4.2, the data reported by the companies have been matched with this regulation.

4.7.2 Average water price for concrete production

Table 4.5 depicts the monthly water price per class. Using the same approach to estimate the water consumption of all concrete companies in Maputo, the mean and standard deviation values are considered exactly the same as the sample population. There is a notable difference between the price of small companies and the medium and large companies. It can be argued that the higher price paid by the small companies occurs as they require more water for 1 m^3 of concrete mixture due to the lack of efficient technologies, methods and manpower skills in producing concrete or because they purchase water from different water sources, e.g. private groundwater suppliers.

Table 4.5 Estimated water price for concrete production in Maputo and the surroundings

Class	Number of Companies (Samples)	Number of Companies (Actual)	Average (μ)	Std. Dev. (σ)
	[-]	[-]	[€/m^3]	[€/m^3]
Small	5	71	0.76	0.34
Medium	4	57	0.38	0.01
Large	2	28	0.38	(interpolation)

4.8 Location of the companies and available wastewater sources

The map showing the locations of the companies and available wastewater sources can be seen in Figure 4.2.

Figure 4.3 Inventory map for Locations of Construction Companies in Maputo

It can be seen from Figure 4.3 that the WWTP is located close to some of the 11 companies that were interviewed. In the northwest of Infulene, Hidroblock (3.62km) and Cadin (4.74 km). From the other side, in the southeast of Infulene, Britanor (3.78 km), Cimbetão (3.83 km) and Prefangol (3.46 km). The larger version can be found in Annex 7 and the list of the coordinates is in Annex 2.

Figure 4.3 also includes the sewer network systems, including the positions of the pumps, the first system (pink area) and the second system (green area) (see Section 1.2.3). The red line symbolizes the main sewer that runs to the WWTP, which is one of the alternatives to be used as the source of the new design system. Other alternatives are the endpoints from the residential areas along the main sewer. However, based on the interview with *Departamento de Água e Saneamento* (DAS), the water and sanitation department for Maputo, these sewer endpoints cannot be exactly located due to the absence of data or drawings and the existence of illegal endpoints that were built by the residents and industries along the main sewer line.

The effluent from other industries can also be an alternative, especially around the area where the majority of concrete companies are located. For instance, in Machava, approximately 1.5 km from Hidroblock and 2 km from Cadin, there was once a factory of Coca-cola soft drink. It was moved to Matola Garde, another part of industrial area, a few weeks prior to the visit. There is also a local beer factory, 2M, and a laundry factory named Laundry Clean, that discharge their treated wastewater around the WWTP area (Caltran, 2014).

Hence, the WWTP is selected to be the source of the new design system because:

- It has sufficient flow to supply the estimated demand from all construction companies in Maputo, Matola and Machava (see Section 4.9)
- It has reliable flow in terms of continuity with considerably constant flow based on domestic use of the residents (see Section 4.4) and rainwater which is partly discharged through the first sewer system (van Esch & van Ramshorst, 2014).
- It receives a considerably constant quality because the type of wastewater running through the main sewer is mostly treated sewage from residential septic tanks (see Section 4.10)
- It is located in the middle of the companies within a distance of less than 6 km (see Figure 4.3 and Section 4.8).

4.9 Available water quantity at the WWTP

While the WWTP has been selected as the source instead of sewer endpoints or effluent from other companies, the extraction point still has to be chosen between the influent or the effluent. Flow measurements and quality analysis were conducted to observe the most potential extraction point.

4.9.1 Influent

The estimated flow rate of the influent comes from several references, including the previous work of van Esch and van Ramshorst (2014), Caltran (2014), and the field measurements taken four times in a month which can be found in Annex 3. Those flow rates are listed in Table 4.6. From the table, the available flow from the influent is 5682 ± 1196 m^3/day.

Extra conditions that may decrease the influent are also considered because the amount of effluent from the WWTP should still be sufficient for irrigating agricultural fields nearby. Thus, the available net flow was obtained after being subtracted by irrigation demand and evaporation.

Irrigation demand

In the surrounding of the WWTP, mostly located around the facultative outlets, there are agricultural fields which depend on the effluent of the WWTP as one of the irrigation sources (see Figure 4.5). Thus, the amount of irrigation demand should be subtracted from the total influent flow to guarantee that the farmers still have sufficient irrigation supply.

The total area of agricultural fields is almost 21 ha. The estimated number of farmers from the total area divided by the FAO standard section of 2.70 x 3.77 m^2 is 330 persons (Allen *et al.*, 1998). Each standard section requires 8 water cans during summer with the volume of 10 L/day (Caltran, 2014). Thus, the irrigation demand is about 1100 m^3/day. The calculation can be found in Annex 5.

Evaporation

The WWTP has an open system which means that when the flow runs from the influent to the effluent, part of the flow may be evaporated when the sunshine appears and flow may be reduced. The number of evaporation is taken from ICLEI, the local government institution for sustainability and cities adaptation for climate change, which shows that the monthly evaporation in Maputo varies between 2 mm/day around June and 5 mm/day at the end of the year (Tadross & Johnston, 2012). Thus, the total flow extracted by evaporation during summer in the area of Infulene is nearly 700 m^3/day. The calculation of evaporation can be found in Annex 6.

Hence, the total net estimated flow from the influent is then 4978 m^3/day or 207 m^3/h. The calculation can be seen in Table 4.6.

4.9.2 Effluent

The WWTP has three outlets for its effluent; two general outlets at the end of facultative ponds as the last treatment step and an emergency outlet on the sidewall of one of the ponds. Currently facultative outlet 1 does not discharge water anymore but the emergency outlet discharges continuously. The outlets cannot be combined because they are far from one another (125 m between the general outlets and more than 305 m from the emergency outlet to the nearest general outlet). Thus, the selected outlet is the one that gives the highest flow. The locations of all potential extraction points can be seen in Figure 4.4.

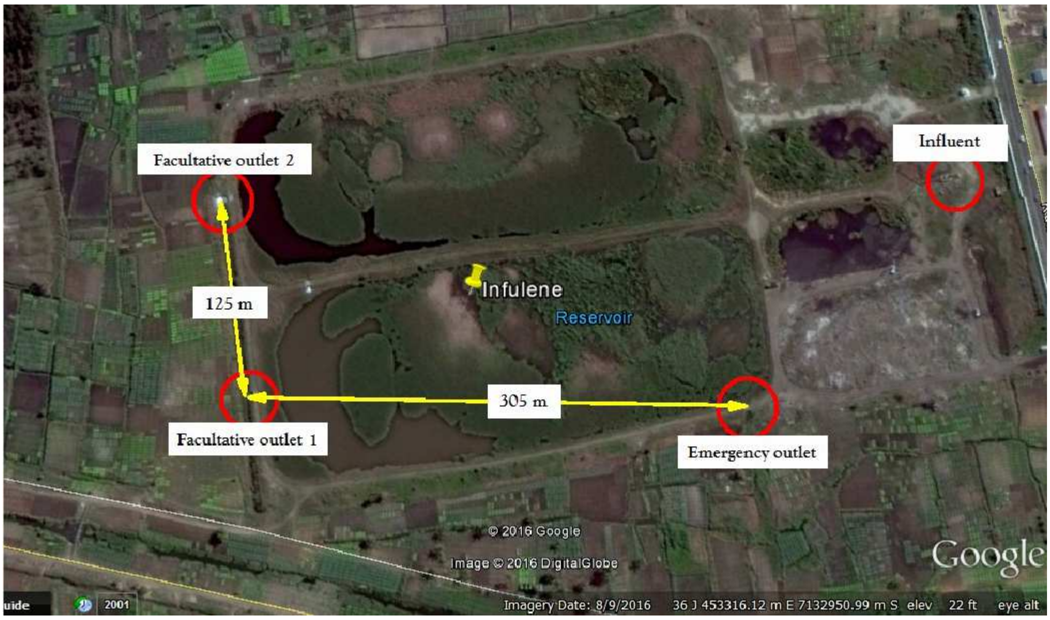

Figure 4.4 Locations of potential extraction points from the effluent of WWTP

The estimated flow rates of the effluent outlets come from the previous work of Caltran (2014) and the weekly field measurements, which is questionable because the value is higher than the influent. The highest flow comes from the emergency outlet (4591 ± 1135 m^3/day). Facultative outlet 2 (4171 ± 2443 m^3/day) can sometimes have higher discharge than the emergency outlet but the flow from the emergency outlet has less fluctuation. If both of them are combined together, it is higher than the main sewer as the influent even without extraction from evaporation and irrigation (5682 ± 1196 m^3/day). The increase of the effluent flow might be due the following conditions:

- The discharge of trucks carrying sewage from the houses or industrial wastewater (textile, steel, detergent, food and beverage industries) directly into the anaerobic pond 1. There are 24 trucks registered by DAS and the WWTP receives about 37 m^3/day (Caltran, 2014).
- Heavy rainfall occurred during the third sampling and loaded the ponds (April 26, 2016).
- Seepage due to the groundwater extraction from the boreholes surrounding the WWTP as the another source of irrigation.
- Located near the shoreline, there might be a seawater intrusion caused by the groundwater extraction. This condition is in line with the higher value of electric conductivity in the effluent (2000 µS/cm), than in the influent (1400 µS/cm) (Table 4.7).

The flow rates are listed in Table 4.6 and the field measurement results can be found in Annex 3.

Since the effluent is the last point of the treatment process, there is no need to subtract it with evaporation anymore. However, it still needs to be deducted by the agricultural consumption nearby in order to let the farmers still obtain the same amount of water for irrigation. Thus, after subtracting those values above with 5 m^3 of daily irrigation demand (Annex 5), the average effluent flow from the emergency outlet is 4586 m^3/day or 191 m^3/h.

Table 4.6 Flow capacity from different sources in WWTP

Source Location	Source Inflow & External Subtraction	Flow: Min. Flow [m^3/d]	Flow: Mean [m^3/d]	Flow: St. Dev. [m^3/d]	Reference
Influent	Main sewer	3957	5682	1196	(van Esch & van Ramshorst, 2014)
		5184			(van Esch & van Ramshorst, 2014)
		6912			(Caltran, 2014)
		6673			Annex 3
	Evaporation	699			(FAO, 2006)
	Irrigation	1100			(Caltran, 2014), (Allen *et al.*, 1998)
	Available net mean flow		3883	1196	= Mean - Evaporation - Irrigation
Effluent	Facultative pond 1	0	432	432	Annex 3
		864			(Caltran, 2014)
	Facultative pond 2	6614	4171	2443	Annex 3
		1728			(Caltran, 2014)
	Emergency outlet pond 1	5725	4591	1135	Annex 3
		3456			(Caltran, 2014)
	Selected mean flow		4591	1135	Max. mean
	Irrigation	1100			(Caltran, 2014), (Allen *et al.*, 1998)
	Available net mean flow		3491	1135	= Max. mean - Irrigation

4.9.3 Selected sources

As can be seen from Section 4.3.1 for the sample population with 11 interviewed companies, the total amount of water demand from the samples is 311 ± 36 m^3/day. Thus, the capacity of the WWTP, either the influent or the effluent, will be more than sufficient.

4.10 Available water quality at the WWTP

The potential sources for alternative water supply for concrete production need to have a quality that can reasonably be treated in terms of effectiveness and efficiency. Thus, four samples of two potential sources; the influent and effluent (emergency outlet) of the WWTP, were taken during the period of fieldwork in Maputo. It can be noticed from Annex 3 (compiled in Table 4.7) that the values of the samples are considerably constant within a month, using different days and times of sampling. Thus, it was assumed that taking four weekly samples in a month was sufficient.

The system of septic tanks present in most houses in Maputo is connected to the sewer network and converts the organic nitrogen compounds into ammonium (NH_4^+) but ideally no conversion of NH_4^+ to nitrate (NO_3^-). This system is also unexpected to affect the phosphorus concentration (TP) in the sewage (Gross, 2004). The common range for FOGs in residential septic tank effluent is between 20 and 50 mg/L (Gross, 2004) with a warning level of 30mg/L to avoid clogging the soil pores after leaving the septic tank (Washington State Department of Health, 2004). As for the TSS, the normal threshold for residential areas is 150 mg/L (Washington State Department of Health, 2004). conventional septic tanks are not effective for the removal of microorganisms and even enhance their growth in a high ambient temperature or tropical climate (Appling *et al.*, 2013).

Table 4.7 shows the results of the field and laboratory measurements taken from the WWTP along with the use of typical septic tank effluent characteristics for the unmeasured parameters. The table also compares the mean values with the limit according to the standards of water for concrete production and the ranges of allowable concentrations for important parameters based on the previous research as listed in Table 2.2.

It can be seen from Table 4.7 that the water quality of the influent is similar to the effluent. The largest difference was measured for SO_4^{2-}, where the influent concentration is almost ten times higher than the effluent (26.50 mg/L and 2.67 mg/L, respectively, which might be due to unfinished conversion to sulphide by sulphate reducing bacteria in the septic tanks (Petersen & Ahring, 1990). Nonetheless, the value is still lower than the limit (Table 2.2).

Table 4.7 also presents that TSS, TDS and total coliforms exceeded the limits. High values of TSS and TDS hamper hydration process by lowering the porosity (Table 2.1). Microorganisms can initiate staining and corrosion but the limit of total coliforms is based on the health of the workers who will be in contact with the water because it is lower than the limit to generate failure in concrete. The mean value of FOGs is considered safe but the upper limit of the range is the same as the limit so that it is advised to be removed. Sulphate and phosphate need to be removed if the required strength of concrete is 35 MPa or higher (Liu, 2016). Table 4.7 shows that currently none of these compounds is higher than the limits.

Table 4.7 Results of field and lab measurements, septic tank typical effluent parameters and their comparison with the limit of effluent quality

Measurement	Parameter	Unit	Influent	Effluent (Emergency Outlet)	Equipment	Combined Limit (Table 2.2)	Removal
Field	Flow	[m^3/s]	0.09	0.13	meter	-	
	Ambient Temperature	[^oC]	28.21	28.13	WTW pH3110 IDS	18 - 30	
	Sample Temperature	[^oC]	28.93	23.90	WTW pH3110 IDS	18 - 30	
	pH - field	[-]	7.43	7.05	WTW pH3110 IDS	6.0 - 8.0	
	Oxygen	[mg/L]	0.24	0.06	WTW Oxi3110 IDS	-	
	Electric Conductivity	[µS/cm]	1367	1945	WTW Cond3110 IDS	-	
	Turbidity	[NTU]	46.04	24.50	WTW Turb 430 IR	-	
Lab	Ambient Temperature	[^oC]	24.60	24.90	WTW pH3110 IDS	18 - 30	
	Sample Temperature	[^oC]	25.08	25.15	WTW pH3110 IDS	18 - 30	
	pH - lab	[-]	7.42	7.46	WTW pH3110 IDS	6.0 - 8.0	
	Alkalis	[mg/L]	-	-		1500	
	Bicarbonate, CO_3^{2-}	[mg/L]	203.17	81.67	Wagtech Photometer 5000	-	
	Carbonate, HCO_3^-	[mg/L]	41.33	102.67	Wagtech Photometer 5000	-	
	Hydroxide, OH^-	[mg/L]	14.83	34.17	Wagtech Photometer 5000	-	
	Sodium, Na^+	[mg/L]	-	-		[No limit]	
	Ammonium nitrate, NH_4NO_3	[mg/L]				33	
	Potassium, K^+	[mg/L]				[No limit]	
	TSS	[mg/L]	150	-	Septic tank effluent (Gross, 2004)	67	Must be removed
	TDS	[mg/L]	497	-	Septic tank effluent (Gross, 2004)	100	Must be removed
	FOGs	[mg/L]	50	-	Septic tank effluent (Gross, 2004)	50	Advised to be removed
	Chlorine, Cl_2	[mg/L]	0.15	0.02	Wagtech Photometer 5000	-	
	Chloride, Cl^-	[mg/L]				100	
	Chloramine, NH_2Cl	[mg/L]				-	

Measurement	Parameter	Unit	Influent	Effluent (Emergency Outlet)	Equipment	Combined Limit (Table 2.2)	Removal
Lab *(continued)*	Flourine, F_2	[mg/L]			[redacted]	-	
	Ammonia, NH_3	[mg/L]	40	40	Wagtech Photometer 5000	-	
	Nitrate, NO_3-N	[mg/L]	0	-	Septic tank effluent (Gross, 2004)	6.7	
	Nitrite, NO_2-N	[mg/L]	-	-	[redacted]	-	
	Total N	[mg/L]	60	-	Septic tank effluent (Gross, 2004)	-	
	Sulphate, SO_4^{2-}	[mg/L]	26.50	2.67	Wagtech Photometer 5000	86.5	May be removed for higher strength
	Phosphate, PO_4^{3-}	[mg/L]	3.69	4.33	Wagtech Photometer 5000	6.7	May be removed for higher strength
	Total Phosporus (P, P_2O_5, PO_4^{3-})	[mg/L]	8.10	-	Septic tank effluent (Gross, 2004)	-	
	Chromium, Cr^{3+}	[mg/L]	-	-	[redacted]	-	
	Sugars	[mg/L]	-	-		100	
	Lead, Pb^{4+}	[mg/L]	-	-		100	
	Zinc, Zn^{2+}	[mg/L]	-	-		100	
	Manganese, Mn^{4+}	[mg/L]	0.004	0.005	Wagtech Photometer 5000	-	
	BOD_5	[mg/L]	120	-	Septic tank effluent (Gross, 2004)	-	
	COD	[mg/L]	60	-	Septic tank effluent (Gross, 2004)	664.23	
	Coliforms	[E. coli/L]	10^7	-	Septic tank effluent (Gross, 2004)	100	Must be removed

Based on the measurement result in Table 4.7, the influent is selected instead of the effluent to be the source of the new design system because:

- Except sulphate, there is no notable difference between water quality of the influent and effluent. This resemblance can indicate inefficiency of the WWTP (Caltran, 2014). Thus, by-passing the main system and treating the influent can be more efficient than treating the effluent again (see Table 4.7).
- The influent does not have multiple outlets. The effluent has 3 outlet that divides the flow and sometimes one outlet does not discharge water (see Section 4.9.2)
- The influent is more accessible from the main street (Joaquim Chissano street) and closer to the empty areas in the WWTP (see Figure 4.5)

A design system for sewage treatment will be presented in Chapter 6 as a pilot scheme using the influent values, the standard values of septic tank effluent and the previous experiments.

4.11 Available space for the treatment plant

The existing WWTP is located in Infulene, the outer ring of Maputo. As there is no official layout map, DAS drew the sketch which includes four types of areas as can be seen in Figure 4.5.

Figure 4.5 Description of each area in Infulene

(Area 1 and 2 are the empty spaces with no coverage of buildings and agricultural fields (first priority for new treatment scheme), Area 3 and 4 are agricultural fields with a little empty space and may be occupied for expansion of treatment plant in the future, Area 5 is the existing WWTP, Area 6 is the total area from DAS but currently used as agricultural fields along the perimeters)

Figure 4.5 shows that the available spaces are located surrounding the WWTP; area 1 with 0.43 ha and area 2 with 0.94 ha, the rectangular areas (3 and 4) with 2.45 ha and 3.08 ha, respectively, area 5 for the WWTP with 11.05 ha for its plant and area 6 with 14.97 ha. The most preferable spaces are area 1 and 2 with 1.36 ha in total, with the priority goes to area 1 because it is closer to the operator's shelter and has less disturbance from the trucks. The layout can be seen in Annex 7.

4.12 Findings during the fieldwork

4.12.1 Production of concrete covers by DAS

DAS is included in one of the interviews because it also produces precast concrete covers for sewers and manholes as it is responsible for all drainage facilities in the city of Maputo. The difference from the other 11 companies and the unrecorded amount of concrete products and water are the reasons why it is reported separately.

According to DAS, the sewers and manholes located in the highways are covered by heavy duty reinforced concrete because they require high strengths to receive loads from vehicles, approximately 150 MPa or higher (OKA Concrete Sdn. Bhd., 2011) with minimum cement content in the water is 360 kg/m^3 and maximum w/c ratio of 0.45 (Bureau of Indian Standards, 2002). Until today no other company can meet this requirement.

On average, DAS produces three covers (or *tampas* in Portuguese) per day with the dimensions of 1500 x 800 x 250 mm (CGH Polska, 1999). Two bags of 50 kg cement are used to produce those covers so that based on the maximum w/c ratio, the volume of water is 0.045 m^3/day. DAS uses tap water for mixing and curing and has the workshop inside the office in Joaquim Chissano street. The exact cost of water consumption is unknown as it is combined with the total use of entire office.

4.12.2 Data collection issues

During the fieldwork period, it became clear that data collecting and processing are complicated. The schedule, procedure and facilities have been provided for the field work, but having usable data is not the only parameter to guarantee a good result. Even at the university, although many efforts have been done, some samples could not be analysed due to the limitation of facilities and schedule of the laboratory occupancy. This may lead to inaccuracy of the recommendations. Data collection from the laboratory is crucial for identifying the actual condition of water quality, which means that the laboratory and the university in general play an important role in succeeding the project.

4.12.3 Language for parameters of concrete

Based on the discussion with Spanjers (personal communication, June 30, 2016), it can be concluded from the language of the standards and readings about concrete that structural or material engineers and water or sanitary engineers occasionally have the same term of a parameter but different definitions. It leads to diverse interpretations in delivering the expected water quality for producing concrete and causes difficulties in understanding the standards.

One of the examples is when describing the total solids. The Australian standard of water for concrete (2007) stated that the maximum limit of solids in the water should be 50,000 ppm, without further information if it includes TSS and TDS (CCAA, 2007). The value is considered too large even if both are combined (150 mg/L and 100 mg/L). Furthermore, TSS and TDS cannot be added up directly with the TSS because the specifications and removal mechanisms are different. Another example is about the visual parameters that gives interpretation without fixed values, such as the colour and odour. The standard presents the limit of colour as “pale yellow or paler” and the odour as “no smell other than potable water” (CCAA, 2007). These limits can be interpreted differently between the material and water practitioners.

4.12.4 Required treatment and integrated phases

Based on the literature study (Table 2.2), currently there is no exact standard of harmful materials in the water for producing concrete, especially for organic materials (BOD, COD, TOC). According to the discussion with van Lier (personal communication, July 28, 2016), it does not mean that the organic removal is not needed. However, since the concentrations are still unknown, it can be assumed for now that it is unnecessary to be removed. The nutrients (N, P) is then better to be removed by chemicals due to the complexity of biological process, especially with the ambient conditions (temperature, pH, presence of oxygen) and the sludge production.

Since the focus of reclaiming water for concrete production is removing the solids, the first approach should be a separation process, which can be done by physical treatment. Later on, the conversion process, namely removing organic contaminants or chemical compounds, can be done by chemical or biological treatment. Then, the soluble salts can be removed by chemical treatment or membrane filtration. The process of separation and conversion proves that it is rather difficult to integrate a complex treatment in one chain all at once, so that these processes should be performed in phases.

5. Design

This chapter describes the design of water treatment plant that is expected to remove important materials from the sewage to match with the minimum standard of water for concrete production. It includes the dimensions of each unity, both in pilot and full-scale schemes. Furthermore, a simple cost calculation is also presented in three different packages based on the expected effluent quality.

5.1 Modular system

5.1.1 Background

The objective of designing a treatment plant is to assess the effluent quality, efficiency and practicality of the treatment system of water reclamation for concrete production in Maputo. The effluent flow of the design is based on the average consumption of 11 companies that were interviewed and the influent flow is thus obtained after the total efficiency of the plant has been identified (see Section 5.1.2).

In order to meet the requirements from the construction companies in terms of water quantity and quality, costs and construction periods, the design was made in a modular system of which treatment processes can be added separately in series depending on the interests of the consumers. The selection of a modular system leads to energy savings and cost reduction since more complex treatment systems are only added when necessary. For example, the basic modular package solely eliminates the most hazardous contaminants. Whenever there is a need for higher water quality, module can be added to the system.

Referring to Table 4.7, there are at least six contaminants to be removed, namely FOGs, TSS, TDS, sulphate, phosphate (from the total phosphorus) and total coliforms. While the priority of removal is based on the expected strength of concrete that will determine the expected water quality, the treatment scheme should still follow the common rules to operate effectively. For instance, any treatment that produces solids and colloids, such as coagulation – flocculation and precipitation, should be performed earlier than suspended solids removal. Energy consumption, operation and maintenance are also taken into account in choosing the alternatives. Conventional-but-robust alternatives are more likely to be selected.

5.1.2 Influent flow rate

From every phase, each alternative is calculated for a pilot-mode based on the hourly influent flow from the total consumption of 11 companies which were interviewed. Since the efficiency of the design system varies per phase with a range of 60% until 99% (Annex 4.8), a total efficiency for the new design system is considered to be around 80%. Thus, since the mean value of ideal influent flow rate from the demand of the companies is 311 m^3/day (see Table 4.3), the actual flow rate will be 388 m^3/day or 16.20 m^3/h.

5.1.3 Phase 0: pre-treatment

Phase zero is a fine screen with 10mm spacing as the pre-treatment to remove dirt and settleable solids (Lenntech, 2016). With the influent flow of 16.20 m^3/h and the maximum velocity from the main sewer is 0.60 m/s (DHV, 1984), the area of the screen should be 0.11 m^2. The width of the sewer is 1.20 m (DHV, 1984) so that the height of the screen should be at least 0.09 m.

5.1.4 Phase 1: Removal of FOGs, Total Phosphorus (TP) and TSS

Phase 1 removes FOGs and TP compounds. FOGs needs to be removed because its limit from the standards is 50 mg/L (Table 2.2) and while the actual concentration in the influent is unknown, there is a tendency of high oil and grease content from household activities, especially from kitchen sinks. TP removal is also important because the concentration from the typical septic tank effluent (8.10 mg/L) (Gross, 2004) is above the threshold (6.7 mg/L) (Table 2.2). High concentration of phosphate (PO_4^{3-}), as part of the TP, lowers the compressive strength of 14-day-age concrete (Liu, 2016).

The removal of these compounds can be performed by physical treatment, such as dissolved air flotation which can remove FOGs until about 80 - 95% and TSS about 70 – 98% (Aries Chemical Inc., 2013), or chemical treatment, such as coagulation - flocculation which can remove FOGs until about 91 - 99% (Daud *et al.*, 2015).

Coagulation and flocculation (C – F)

As the first step, C – F requires additional chemical compounds to separate the FOGs and phosphate from the sewage. In a coagulation process, the ions are destabilized by the coagulants which occur from the suppression of electric double layer by metal salts (Kocamemi, 2012). To enhance the mixing process from these coagulants with the sewage, a mixing mechanism should also be installed. This operation only needs low energy consumption (Yu *et al.*, 2013).

The most common coagulants are calcium hydroxide ($Ca(OH)_2$), barium hydroxide ($Ba(OH)_2$), alum ($Al_2(SO_4)_3.14H_2O$), ferric chloride ($FeCl_3$) or ferric sulphate ($Fe_2(SO_4)_3.9H_2O$) (Ives & Jahn, 2007). A novel precipitant, zerovalent iron (ZVI) is also effective to remove phosphate because it shows no change in different ionic strengths which makes it possible not to remove salts prior to removing phosphate (Wen *et al.*, 2014). A small amount of oxygen in the influent (Table 4.7), is another advantage for ZVI to remove phosphate (Sleiman *et al.*, 2016).

Considering the price and availability, for this pilot plant the selected coagulant w alum ($Al_2(SO_4)_3.14H_2O$). The optimum dose should be tested with a frequent jar test (León-Luque *et al.*, 2016). Based on Table 4.7, total phosphorus (TP) concentration is 8.10 mg/L. Thus, the required alum concentration was calculated by comparing 1 mole of aluminium per mole of compounds to be removed (Minnesota Pollution Control Agency, 2006). The alum dose should thus be 132 mg/L. The strength of alum was estimated to be 49% and specific gravity was 1.29 (Gebbie, 2006) so that the flow of alum injection is 20 mL/min. The calculation can be found in Annex 4.

Thereafter flocculation starts and forms flocs. These flocs can be removed by settling methods, such as DAF, sedimentation, or filtration. The design of flocculator uses hydraulic baffled rather than mechanical mixing because no electric power required and regular maintenance is simpler. However, it also has drawbacks, such as difficulties in adjusting different influent water quality or water production rate of the treatment plant and the presence of head loss (Ives & Jahn, 2007).

Inside this treatment process, the influent runs through a couple of partition walls above or below the flow direction of the water with a minimum detention time of 20 minutes (Ives & Jahn, 2007).

The calculation of one coagulation and four flocculation tanks can be found in Annex 4 and the dimensions for the flocculation and coagulation tanks can be seen in Table 5.1 below.

Table 5.1 Coagulation and flocculation dimensions for pilot plant

Step	Length	Width	Height	n
	[m]	[m]	[m]	[-]
Coagulation	1	0.6	0.5	1
Flocculation	1.5	1	1	4

At the end of flocculation step, the flocs and TSS are removed by physical treatment. Other than DAF, the other alternatives are sedimentation and hydrocyclone, which are selected due to their low energy consumption and regular application nowadays (Spanjers, 2016). Sedimentation has a removal efficiency of about 50 – 100% according to its horizontal velocity (OCW TU Delft, 2007) and hydrocyclone has about 95 – 97% (Wang, 2004). However, when DAF was selected for the first phase, the removal of TSS was not needed anymore because at least 70-98% of TSS had been removed (Annex 4.8).

Dissolved Air Flotation (DAF)

DAF unit removes suspended particles, namely FOGs and TSS, by dissolving air to form microbubbles that can be attached to the particles to increase the buoyancy and bring them to the surface to separate them from the water (Al-Shamrani *et al.*, 2002).

There are three types of DAF system according to the pressure condition in the influent or effluent (Al-Shamrani *et al.*, 2002):

- In the full-flow pressure flotation, the influent is pressurized and released into the tank where the bubbles are formed. It is suitable for influent with no flocculation but needs large air volumes.
- In the split-flow pressure flotation, part of the influent is pressurized and the other is directly introduced to the tank. It is applied when the influent has vulnerable particles, low resistance of shear effects, low concentration and thus needs less air volumes.
- In the recycle-flow pressure flotation, the treated effluent is pressurized and recycled back into the tank. It is used when coagulation and flocculation are required, including in oil removal.

The DAF unit in the preliminary plant was designed as the recycle-flow pressure flotation because the intention is to remove FOGs, total phosphorus (TP) and TSS at the same time. Thus, the only type which can be coupled with coagulation and flocculation is the recycle-flow pressure flotation. The calculation can be found in Annex 4. It can be concluded that the size of DAF tank is sufficient at a width of 1.4 m, a length of 1.6 m and a depth of 1 m for the pilot plant.

Sedimentation

The most commonly used and robust alternative for this step is sedimentation (SED) in a settling tank. The mechanism of this technique is simple, as the water is retained in a tank, suspended particles larger than 50 µm settles down and in the end separate them to be in the bottom of the tank, creating a layer of sludge (OCW TU Delft, 2007). The water which now has lower turbidity enters the next step, while the sludge is pumped out, ideally for dewatering (Caltrans, 2001). Based on the calculation in Annex 4, the design needs a SED tank with a width of 2.5 m, a length of 7.5 m and a depth of 2.3 m, with a detention time of 30 minutes.

Hydrocyclone

The other alternative for removing TSS is hydrocyclone (HC). This method works by separating the solids from the water in a cyclic force from the bottom. The suspended solids will be retained in the bottom and the clear water is in the upper part. The solids are then pumped out of the cyclone to be dewatered or directly discharged (Sabbagh *et al.*, 2016).

Hydrocyclone is advantageous for industrial use because it does not have mobile parts and requires low energy consumption but once it is installed, the mechanism of the operation, especially the division of overflow and underflow rates and number of turns are difficult to be modified so that it is less preferable for a modular system design which has high probability of changes (Cilliers, 2000).

Based on the calculation that can be found in Annex 4, the pilot plant needs a unit of HC a body diameter of 1.5 m, cyclone body length of 4 m with a cone length of 2.4 m, an angle of 7^{o}, overflow diameter of 0.6 m, underflow diameter of 0.15 m and 7 times of effective turns.

5.1.5 Phase 2: Post-treatment of suspended solids

The second phase is intended to polish the effluent from the previous steps so that the remaining suspended particles can be eliminated and the effluent has lower turbidity. The removal efficiency is 95% for porous media filtration (Caltrans, 2001) and 99% for microfiltration (van Halem, 2009).

Porous media filtration

The first alternative for effluent polishing is porous media filtration (PMF). The most common media is sand which was used in this design. While there are other materials, such as gravel or anthracite, silica sand is the most practical and it can also be coupled with those other media to have a multi-layered filtration (Engelhardt, 2012).

Based on the calculation that can be found in Annex 4, the PMF unit for the pilot plant needs to have a filter bed depth of 1.50 m, column diameter of 0.56 m, sand porosity of 38%, and total height of 5.45 m.

Microfiltration

Another alternative for eliminating remaining particles is membrane filtration. As cost is rather high compared to other types of similar treatment, the use of membrane should be wisely considered. Depending on the size of the pores and required effluent quality, microfiltration (MF) is sufficient for this condition and will be operated in cross-flow mechanism with frequent backwash periods (Yu *et al.*, 2013).

For this pilot plant, the MF unit uses Pentair® R-100 as the basis of specifications (Figure 5.1). One typical MF skid consists of maximum 30 units. Based on the calculation in Annex 4, for the pilot 59 MF units placed in two skids is sufficient with cross-flow operation.

INSERT SPECIFICATIONS

Hydraulic Membrane Diameter [mm]	Membrane area [m²]	Insert length L_0 [mm]	Insert outer diameter D_0 [mm]
1.5	9.3	1022	160.6
3.0	5.0	1022	160.6

MODULE SPECIFICATIONS

Module length L_0: 1040 mm
Permeate port protrusion l_1:112 mm
Permeate port lateral recess l_0: 125 mm
Feed connector, DIN 2633 B: 150 NW
Thread, male, DIN11851 A: 65 * 1/6"

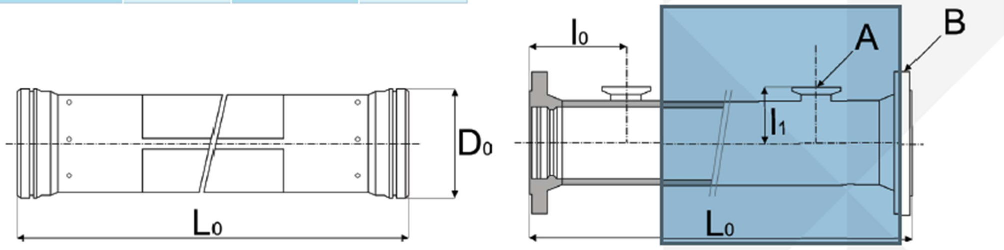

Figure 5.1 Specifications of microfiltration unit (Pentair, 2014)

5.1.6 Phase 3: Removal of dissolved solids

The main intention of the design system is to treat sewage into mixing water for concrete so that the removal of salts does not actually required in general. However, when higher strength of concrete is needed, this step should be performed (Table 2.1).

The salts mostly consist of monovalent ions, such as Na^+, K^+ and Cl^-, and divalent ions, such as Ca^{2+}, Mg^{2+} and SO_4^{2-} (van Halem *et al.*, 2009). These salts are not necessary to be totally removed so that the divalent ions can be removed and the monovalent ones stay in the water.

In order to remove salts as the dissolved solids, a membrane technology is preferred because it is practical to remove the salts without the need of additional chemical compounds. The types of membrane which can remove salts are nanofiltration (bivalent salts, 0.001 – 0.01 µm) or reverse osmosis (monovalent salts and metal ions, 0.0001 – 0.001 µm). However, since there is no need to remove all monovalent ions as in drinking water, nanofiltration is sufficient for the treatment (van Halem *et al.*, 2009). The removal efficiency for nanofiltration is between 80% and 90% (Izadpanah & Javidnia, 2012).

Nanofiltration (NF)

For this pilot plant, the NF device comes from Pentair® HFW 1000, which is installed in a cross-flow mode (Figure 5.2).However, it is also one of the most expensive technologies to be applied due to high investment cost, the sensitivity of the setup and its requirement of excessive pre-treatment to avoid clogging in its membranes (Ranade & Bhandari, 2014). These three conditions need to be considered prior to the final decision to use this treatment process.

Based on the calculation in Annex 4, the pilot plant needs nine NF units in one skid.

ELEMENT SPECIFICATIONS

Membrane Diameter [mm/mil]	Membrane area [m²/ft²]	Feed connection D_0 [mm/Inch]	Element outer diameter D_1 [mm/Inch]	Element length L_0 [mm/Inch]	Permeate connection d_0 [mm/Inch]
0.8 [31]	40 [430]	220.0 [8.66]	200 [7.9]	1537.5 [60.51]	42.6 [1.68]

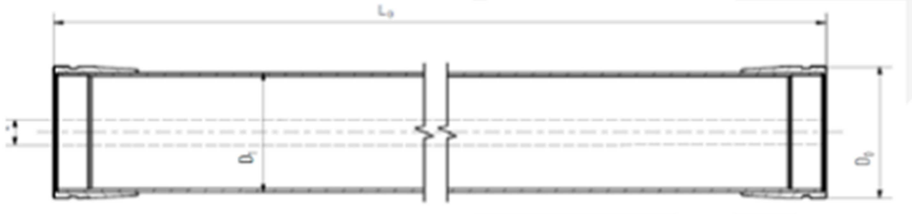

Figure 5.2 Specifications of nanofiltration unit (Pentair, 2015)

5.1.7 Phased construction packages before disinfection

The alternatives were identified and now can be selected one by one for the phased construction modular packages. The selection depends on the different effluent qualities as demanded by the concrete companies. The requirements from the companies can be derived from the types of concrete they produce. Based on the type of concrete products in relation with different water quality, three different treatment packages are introduced.

Basic Package

Based on the interview results in Table 4.2, 6 out of 11 companies; 4 small companies (Estaleiro Julio J. Paunde, Estaleiro José M. Sacoto, Estaleiro Antonio B. Tamele and Estaleiro Amussuar Rassur, 1 medium company (Hidroblock) and 1 large company (Bricon) produce non-reinforced concrete blocks, paves and curbs which do not use reinforcement from the steel bars. It may be possible for this type of concrete to use the treated sewage with the removal of FOGs and TSS. There is no need to remove salts because there is no possibility of corrosion from the rebars. Since this type of concrete is used for non-structural purposes, only minimum strength is required, which is 17 MPa (ACI Committee, 2008). This strength can be achieved with less consideration regarding strength decrease caused by phosphate (Liu, 2016) or deterioration caused by sulphate (Neville, 2004). This type of concrete only needs the basic treatment step which can remove FOGs, TP and TSS at the same time (Phase 1). This treatment scheme is called the basic package due to its objective to remove only the most harmful materials in concrete.

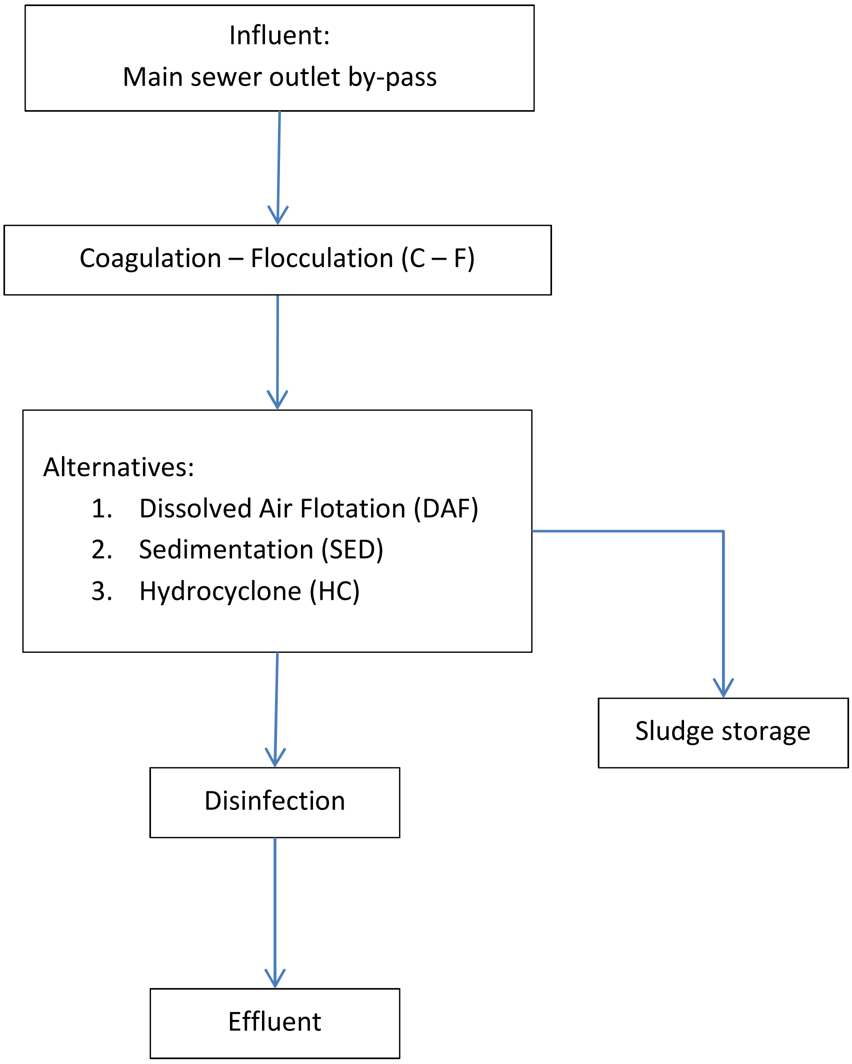

Figure 5.3 Block diagram of basic package

Intermediate Package

A higher level of water quality is required for reinforced precast concrete as the concrete has steel reinforcement inside. According to the interview results, Estaleiro Julio H. Paunde and Resol produce reinforced precast concrete, such as latrines, slabs, manhole covers and tank walls while Bricon plans to produce reinforced concrete pipes in the near future. Reinforced concrete is more sensitive to corrosion, as it has rebars, and to long-term strength decrease or deterioration based on phosphate or sulphate attacks.

For this type of concrete, the second package was introduced, which includes the removal of FOGs TP and TSS (Phase 1). In order to remove the remaining particles, a PMF is selected as a post-treatment (Phase 2).

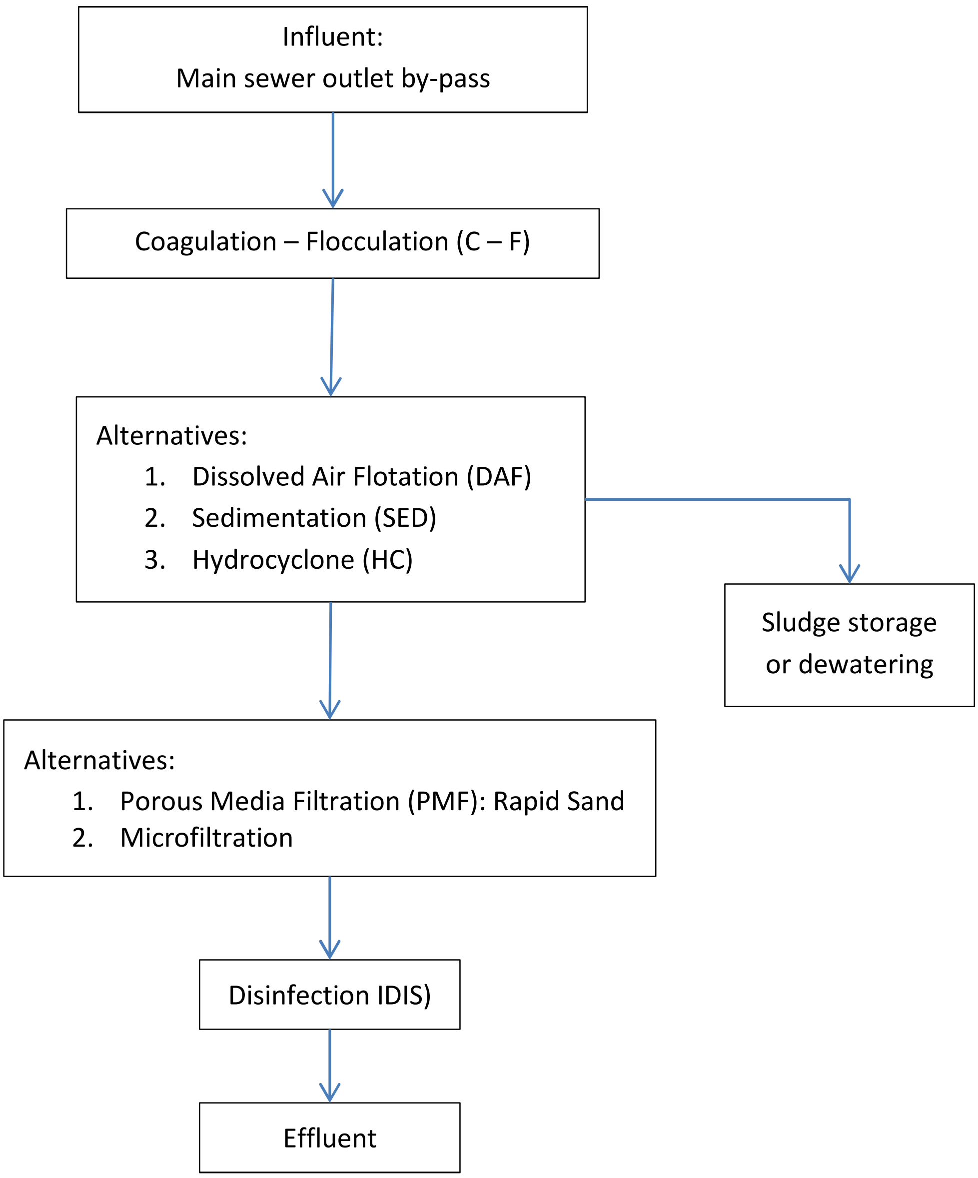

Figure 5.4 Block diagram of intermediate package

Advanced Package

The finest water quality is required by ready-mix concrete. There are 4 companies which produce ready-mix and supply it by trucks; Cadin, Prefangol, Britanor and Cimbetão. Resol also produces a small amount of ready-mix according to the need of each project. Ready-mix concrete is used for structural purposes. The design strength is normally around 27 – 35 MPa which is required to maintain the performance, service life and safety of the structures (ACI Committee, 2008). Thus, harmful materials that may decrease the strength should be removed, such as FOGs, TP, TSS and TDS, especially the divalent ions, such as ammonium salts and alkalis (Table 2.1). Since a nanofiltration unit should be installed, there is no need to apply C - F anymore in the previous step because the salts will be completely removed. Thus, this package consists of DAF for FOGs and TSS removal (Phase 1) and NF (Phase 3). This scheme is called the advanced package as it covers all kinds of removal but comes at high cost as well.

At this moment only 2 out of 11 companies produce more than one type of concrete, for example Estaleiro Julio J. Paunde (reinforced and non-reinforced precast concrete) and Resol (reinforced precast concrete and ready-mix). Bricon is also planning to produce reinforced concrete pipes in the near future. This situation allows these companies to select and combine different types of water they want to order (with different cost). This mechanism may increase the efficiency of cost and energy because less water is treated more than necessary.

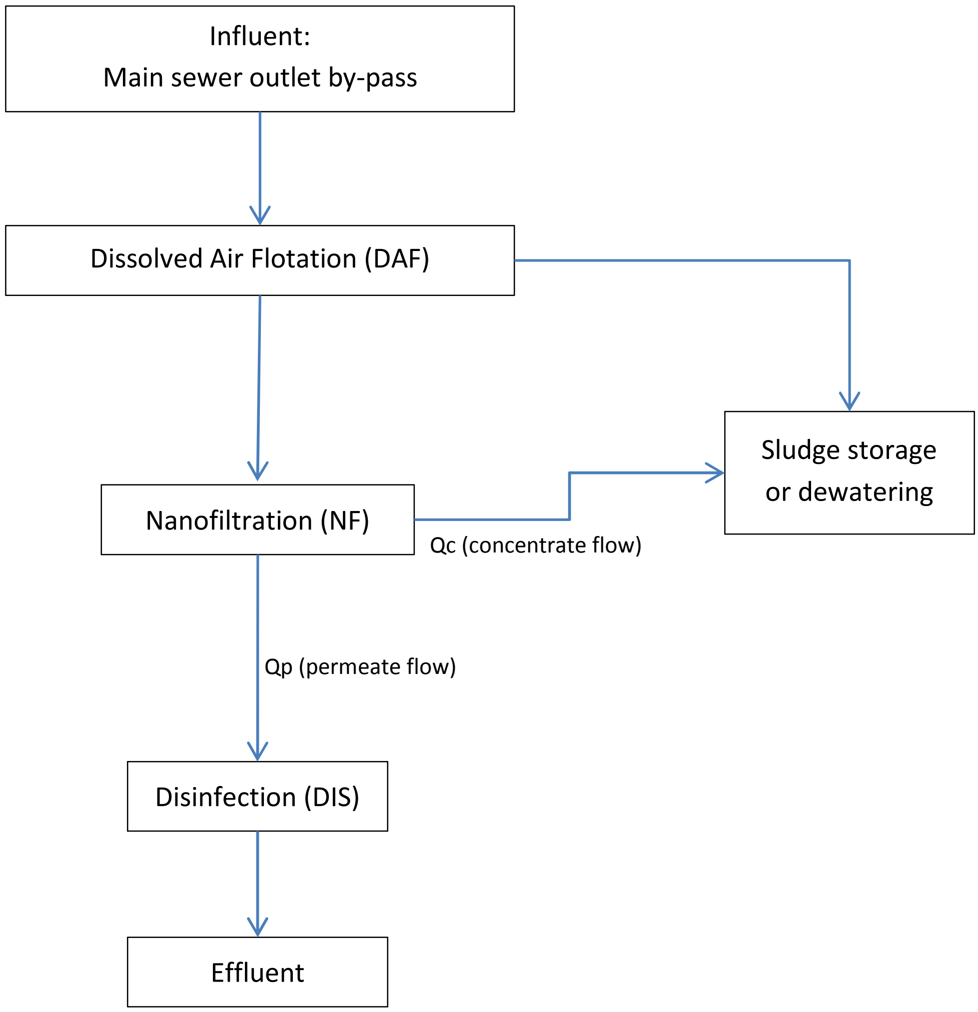

Figure 5.5 Block diagram of advanced package

5.1.8 Phase 5: Removal of pathogens or disinfection (DIS)

The last phase is the disinfection to remove total coliforms. Even though microorganisms can negatively influence the strength and durability of concrete (Cebeci and Saatci, 1989) or promote corrosion on the rebars (Neville, 2006), the main purpose of this phase is the people, especially the concrete production employees in the factories or construction workers who will be in contact with the water.

The capability of pathogens removal from a treatment step is measured by log-inactivation or log-removal, a measured value of pathogen elimination number. The values of log-inactivation from the previous treatment steps can be found below in Table 5.2 as a set of ranges. The mean value of each range was selected to be used for a balanced approximation.

Table 5.2 Pathogens Removal Capacity for Each Treatment Facility

Process	Removal (log-Inactivation)						
	Cryptosporidium	**Giardia**	**Virus**	**Mean**	**Range**	**Mean**	**Average**
Reference	(Wyoming Association of Rural Water Systems (WARWS), 2013)				(Zhang *et al.*, 2016)		
Primary treatment							
Dissolved air flotation (DAF), *conventional*	2.0	2.5	2.0	2.2	-	-	2.17
Sedimentation, *conventional*	2.0	2.5	2.0	2.2	-	-	2.17
Grit chamber	-	-	-	-	0 – 0.3	0.15	0.15
Fine screen	-	-	-	-	0.1 – 0.2	0.15	0.15
Secondary treatment							
Activated sludge	-	-	-	-	0.7 – 2.9	1.8	1.8
Trickling filter	-	-	-	-	0 – 0.82	0.41	0.41
Membrane Bioreactor (MBR)	-	-	-	-	3.4 – 6.8	5.1	5.1
Tertiary/advanced treatment							
Chemical coagulation with alum, iron salts (P/ C – F)	-	-	-	-	1 – 2.86	1.93	1.93
Microfiltration (MF), 0.1 µm	>2.0	>3.0	3.0	2.7	0.2 – 5.1	2.65	2.66
Ultrafiltration (UF), 0.01 µm	>2.0	>3.0	3.0	2.7	>3.0	3	2.83
Nanofiltration (NF), 0.001 µm	>2.0	>3.0	3.0	2.7	>5.4	5.4	4.03
Reverse osmosis (RO), 0.0001 µm	>2.0	>3.0	3.0	2.7	>6.5	6.5	4.58
Slow sand filtration	>2.0	2.0	2.0	2.0	>6.5	6.5	4.25
Conventional filtration followed by bag or cartridge	2.0	2.5	2.0	2.2	-	-	2.17
Disinfection							
Chlorination (CHL)	-	-	-	-	0.81 – 2.8	1.81	1.81
Ozonation (OZ)	-	-	-	-	0.24 - >6	3.12	3.12
UV radiation (UV)	-	-	-	-	1.43 - 6	3.72	3.72

In order to identify the required additional disinfection process, the values of log-inactivation are calculated using a pathogenic indicator, E. coli. This type of bacteria is selected for its frequent existence in domestic sewage (DHV, 1984) and the typical concentration in raw sewage is 10^7 colonies/L or 7-log (Gross, 2004).

The provision of individual septic tanks does not play a crucial role in eliminating microorganisms. Mbugliwe (2005) stated that a septic tank eliminates almost 40% of total coliforms and Pfluger, *et al*. (2009) found that it is less than 85% (Pfluger *et al.*, 2009). The average value (60%) gives the approximation of 0.2-log removal. The amount of E. coli will still be around 7-log.

According to the Environmental Protection Agency of the United States (2009), the partial-body contact with water allows for an E.coli concentration of 575 colonies/ 100 mL or 3.76-log (Rock & Rivera, 2014). The design system should then provide the total log inactivation at least 3.24-log removal to meet the criteria. Table 5.3 shows the values of log-inactivation from each treatment process and the remaining E.coli concentration in the effluent for each package.

Table 5.3 Log-inactivation for each treatment step, total log-removal and estimated log-effluent

Equipment	Septic Tank	Screen	C - F	DAF	SED	HC	PMF	MF	NF	Total log-removal (before DIS)	Log-effluent (log-influent = 7)
Phase	-	0	1	1	1	1	2	2	3		
Log-removal per treatment process	0.20	0.15	1.93	2.17	2.17	2.17	2.17	2.66	4.03		
Basic Package 1 (Screen + C - F + DAF)											
Step	0.20	0.15	1.93	2.17	-	-	-	-	-	4.45	2.55
Sum	0.20	0.35	2.28	4.45	4.45	4.45	4.45	4.45	4.45		
Basic Package 2 (Screen + C - F + SED)											
Step	0.20	0.15	1.93	-	2.17	-	-	-	-	4.45	2.55
Sum	0.20	0.35	2.28	2.28	4.45	4.45	4.45	4.45	4.45		
Basic Package 3 (Screen + C - F + HC)											
Step	0.20	0.15	1.93	-	-	2.17	-	-	-	4.45	2.55
Sum	0.20	0.35	2.28	2.28	2.28	4.45	4.45	4.45	4.45		
Intermediate Package 1 (Screen + C - F + Phase 1 + PMF)											
Step	0.20	0.15	1.93	2.17	-	-	2.17	-	-	6.62	0.38
Sum	0.20	0.35	2.28	4.45	4.45	4.45	6.62	6.62	6.62		
Intermediate Package 2 (Screen + C - F + Phase 1 + MF)											
Step	0.20	0.15	1.93	2.17	-	-	-	2.66	-	7.11	0.00
Sum	0.20	0.35	2.28	4.45	4.45	4.45	4.45	7.11	7.11		
Advanced Package (Screen + Phase 1 + NF)											
Step	0.20	0.15	-	2.32	-	-	-	-	4.03	6.70	0.30
Sum	0.20	0.35	0.35	2.67	2.67	2.67	2.67	2.67	6.70		

As can be noticed from Table 5.3, E. coli concentration decreases rapidly at the end of the first phase from 7-log to 2.33-log, which means that disinfection is unnecessary to be undertaken because it is already lower than the threshold.

The alternatives from each phase and their dimensions are presented in Annex 4.8 and the selected ones are summarized in Annex 4.9.

5.2 Cost estimation per treatment package

5.2.1 Calculation

The cost estimation is performed by using the cost calculator from RHDHV *Kosten Standaard* 2016 (Royal HaskoningDHV, 2016). The cost of sedimentation was unavailable in the catalogue so that the value was based on a calculation report from Caltrans Resident Engineers (Caltrans, 2001). The estimation was divided among the three packages; the basic, intermediate and advanced packages, which is shown in Table 5.4 until Table 5.9 below.

Table 5.4 Cost estimation of basic package 1

Phase	Facility	Dimensions					Pumps (n)		Energy	1-Cycle Time	Cost			Reference
		L	W	H	Dia.	n	Actual	Spare	W	t	Capital (CAPEX)	Operational (OPEX)	Total	
		[m]	[m]	[m]	[m]	[-]	[-]	[-]	[Wh/m^3]	[min.]	[€]	[€/year]	[ct/m^3]	
0	Screen	-	1.20	0.09		1	-	-	0	-	27,466	2,805	3.22	(Royal HaskoningDHV, 2016)
1	C/F - C	1.00	0.60	0.50	-	1	-	-	20	1.00	25,108	3,010	3.46	(Royal HaskoningDHV, 2016)
	C/F - F	1.50	1.25	1.10	-	4				20.00				
	DAF	1.60	1.40	1.00	-	1	1	1	50	8.30	96,924	9,652	11.43	(Royal HaskoningDHV, 2016)
-	Storage	1.60	1.40	1.00	-	1	-	-	8	[TBD]	92,655	6,638	10.04	(Royal HaskoningDHV, 2016)
Total									78	29.30	242,153	22,105	28.15	

Table 5.5 Cost estimation of basic package 2

Phase	Facility	Dimensions					Pumps (n)		Energy	1-Cycle Time	Cost			Reference
		L	W	H	Dia.	n	Actual	Spare	W	t	Capital (CAPEX)	Operational (OPEX)	Total	
		[m]	[m]	[m]	[m]	[-]	[-]	[-]	[Wh/m^3]	[min.]	[€]	[€/year]	[ct/m^3]	
0	Screen	-	1.20	0.09	-	1	-	-		-	27466	2,805	3.22	(Royal HaskoningDHV, 2016)
1	C/F - C	1.00	0.60	0.50	-	1	-	-	20.0	1.00	25,108	3,010	3.46	(Royal HaskoningDHV, 2016)
	C/F - F	1.50	1.25	1.10	-	4				20.00				
	SED	7.50	2.50	2.30	-	1	1	1	0.7	30.00	109,608	8,604	11.69	(Sharma, 2010)
-	Storage	1.60	1.40	1.00	-	1	-	-	8.0	[TBD]	92,655	6,638	10.04	(Royal HaskoningDHV, 2016)
Total									28.7	51.00	254,838	21,057	28.41	

Table 5.6 Cost estimation of basic package 3

Phase	Facility	Dimensions					Pumps (n)		Energy	1-Cycle Time	Cost			Reference
		L	W	H	Dia.	n	Actual	Spare	W	t	Capital (CAPEX)	Operational (OPEX)	Total	
		[m]	[m]	[m]	[m]	[-]	[-]	[-]	[Wh/m^3]	[min.]	[€]	[€/year]	[ct/m^3]	
0	Screen	-	1.20	0.09	-	1	-	-	-	-	27,466	2,805	3.22	(Royal HaskoningDHV, 2016)
1	C/F - C	1.00	0.60	0.50	-	1	-	-	20	1.00	25,108	3,010	3.46	(Royal HaskoningDHV, 2016)
	C/F - F	1.50	1.25	1.10	-	4				20.00				
	HC	-	-	4.00	1.50	1	1	1	1562	11.83	200,410	7,052	20.54	(Sharma, 2010)
-	Storage	1.60	1.40	1.00	0	1	-	-	8	[TBD]	92,655	6,638	10.04	(Royal HaskoningDHV, 2016)
Total									1590	32.83	345639	19505	37.26	

Table 5.7 Cost estimation of intermediate package 1

Phase	Facility	Dimensions					Pumps (n)		Energy	1-Cycle Time	Cost			Reference
		L	W	H	Dia.	n	Actual	Spare	W	t	Capital (CAPEX)	Operational (OPEX)	Total	
		[m]	[m]	[m]	[m]	[-]	[-]	[-]	[Wh/m^3]	[min.]	[€]	[€/year]	[ct/m^3]	
0	Screen	-	1.20	0.09	-	1	-	-	-	-	27,466	2,805	3.22	(Royal HaskoningDHV, 2016)
1	C/F - C	1.00	0.60	0.50	-	1	-	-	20	1.00	25,108	3,010	3.46	(Royal HaskoningDHV, 2016)
	C/F - F	1.50	1.25	1.10	-	4				20.00				
	DAF	1.60	1.40	1.00	-	1	1	1	50	8.30	96,924	9,652	11	(Royal HaskoningDHV, 2016)
2	PMF	0.60	-	1.11	1.60	1	-	-	-	4.45	85,483	7,995	9.66	(Royal HaskoningDHV, 2016)
-	Storage	1.60	1.40	1.00	-	1	-	-	8	[TBD]	92,655	6,638	10.04	(Royal HaskoningDHV, 2016)
Total									78	33.74	340,958	30,456	39.37	

Table 5.8 Cost estimation of intermediate package 2

Phase	Facility	Dimensions					Pumps (n)		Energy	1-Cycle Time	Cost			Remark
		L	W	H	Dia.	n	Actual	Spare	W	t	Capital (CAPEX)	Operational (OPEX)	Total	
		[m]	[m]	[m]	[m]	[-]	[-]	[-]	[Wh/m^3]	[min.]	[€]	[€/year]	[ct/m^3]	
0	Screen	-	1.20	0.09	-	1	-	-	-	-	27,466	2,805	3.22	(Royal HaskoningDHV, 2016)
1	C/F - C	1.00	0.60	0.50	-	1	-	-	20	1.00	25,108	3,010	3.46	(Royal HaskoningDHV, 2016)
	C/F - F	1.50	1.25	1.10	-	4				20.00				
	DAF	1.60	1.40	1.00	-	1	1	1	50	8.30	96,924	9,652	11.43	(Royal HaskoningDHV, 2016)
2	MF	1.02	0.1606 (Do)	-	0.0015 (d)	59	2	2	500	4.52	249,717	29,759	41.47	(Royal HaskoningDHV, 2016)
-	Storage	1.60	1.40	1.00	-	1	-	-	8	[TBD]	92,655	6,638	10.04	(Royal HaskoningDHV, 2016)
Total									578	33.82	491,870	51,864	69.62	

Table 5.9 Cost estimation of advanced package

Phase	Facility	Dimensions					Pumps (n)		Energy	1-Cycle Time	Cost			Reference
		L	W	H	Dia.	n	Actual	Spare	W	t	Capital (CAPEX)	Operational (OPEX)	Total	
		[m]	[m]	[m]	[m]	[-]	[-]	[-]	[Wh/m^3]	[min.]	[€]	[€/year]	[ct/m^3]	
0	Screen	-	1.20	0.09	-	1	-	-	-	-	27,466	2,805	3.22	(Royal HaskoningDHV, 2016)
1	DAF	1.60	1.40	1.00	-	1	1	1	50	8.30	96,924	9,652	11.43	(Royal HaskoningDHV, 2016)
3	NF	1.54	0.20 (Do)	-	0.0008 (d)	9	1	1	1389	1.61	256,953	33,861	51.68	(Royal HaskoningDHV, 2016)
-	Storage	1.60	1.40	1.00	-	1	-	-	8	[TBD]	92,655	6,638	10.04	(Royal HaskoningDHV, 2016)
Total									1487	9.91	473,998	52,956	76.37	

5.2.2 Selection of alternatives based on the costs

According to Table 5.4 until Table 5.9, the basic package 1 with DAF is selected because it has the lowest total cost (€0.28/m^3), the lowest operation time per cycle (29.30 min.) and although the energy consumption of DAF is higher than SED in the basic package 2, DAF can be operated alone to remove FOGs and TSS whereas SED can only remove TSS. Thus, if DAF is selected for the basic package, the removal of TP in the advanced package can be performed directly by NF and the C-F process can be by-passed. The intermediate package 1 with PMF is selected due to its lower cost (€0.39/m^3) and energy consumption (78 Wh/m^3) compared to MF.

5.2.3 Comparison with tap water price

Table 4.5 gives a range overview of the tap water tariff paid by each class of the companies. The average water tariffs are almost €0.80/m^3 for the small companies and €0.40/m^3 for both the medium and large companies. From those two sides, it can be inferred that the treatment packages are correlated with the classes of the companies in terms of concrete type and source of water. For instance, three small companies that were interviewed (Estaleiro Antonio B. Tamele, Estaleiro Julio J. Paunde, Estaleiro Amussuar Rassur) produce (non-structural) precast concrete blocks and paves which do not need any reinforcement while two others (Estaleiro José M. Sacoto and Resol) deal with residential constructions which requires reinforced concrete. The former can use the basic package and the latter can opt for the intermediate package. It would thus be financially beneficial for these small companies to alter their water source since both the basic and the intermediate packages have lower or similar price per m^3 (€0.30 and €0.40, respectively) than the average actual water tariff paid by these companies (€0.40/m^3).

The medium-sized companies that were interviewed are mostly ready-mix concrete producers (Cadin, Prefangol and Hidroblock) and only one company, Hidroblock, produces precast concrete blocks and paves. Therefore, the ready-mix concrete suppliers are advised to divide their concrete types based on the design strengths to select the appropriate treatment packages. If they only need the normal reinforced concrete (see Section 2.1.5), the water quality can be satisfied by the intermediate package. Meanwhile, if high-strength concrete is required, the companies need to select the advanced package. The ready-mix concrete suppliers might pay more for the treatment since the advanced package (€0.80/m^3) costs twice the average actual water tariff (€0.40/m^3) paid by these 3 companies. Yet, it can still be beneficial if the companies can divide their water demand based on the expected quality so that the water demand from lower strength concrete can be provided by the intermediate package which has the same price as the average actual water tariff.

The large companies from the interview list experience similar situation where one of them is a ready-mix concrete supplier (Cimbetão) and the other one is a precast concrete producer which specializes in blocks and paves (Bricon). Cimbetão may divide their demand based on the required water quality; either purchasing intermediate or advanced package. For the latter Cimbetão might pay a doubled amount from the actual tariff (€0.80/m^3). Bricon, on the other hand, currently needs the basic package since they only produce the non-structural concrete. In the near future, they plan to produce reinforced concrete pipes which require the intermediate package. Any package can be financially beneficial compared to the tap water cost (€0.40/m^3).

5.3 Technical arrangements

5.3.1 Pipe diameter

The pipe diameter was calculated based on Darcy-Weisbach's formula, assuming that the material is polyvinyl chloride (PVC) and the network functions gravitationally, except the ones with the pumps, as follows:

$$\Delta H = \lambda \frac{L}{D}\frac{u^2}{2g} = 0.0826\frac{\lambda L}{D^5}Q^2$$

where ΔH is the friction head loss, about 1 m/km of length (van der Hoek, 2014), λ is the roughness factor, about 0.025 for PVC (van der Hoek, 2010), L is the distance from inlet to outlet of a pipe, between 5 and 10 m for the mainstream line (see Figure 5.11), u is the flow velocity, g is the acceleration of gravity (9.81 m/s^2) and Q is the actual discharge (16.20 m^3/h). Thus, the pipe diameter is approximately 200 mm.

5.3.2 Hydraulic grade schemes

The initial elevations were taken from the WWTP design report by DHV (1984). The other ones follow the grading plan of the WWTP (Annex 7) as a reference in accordance with Google Earth.

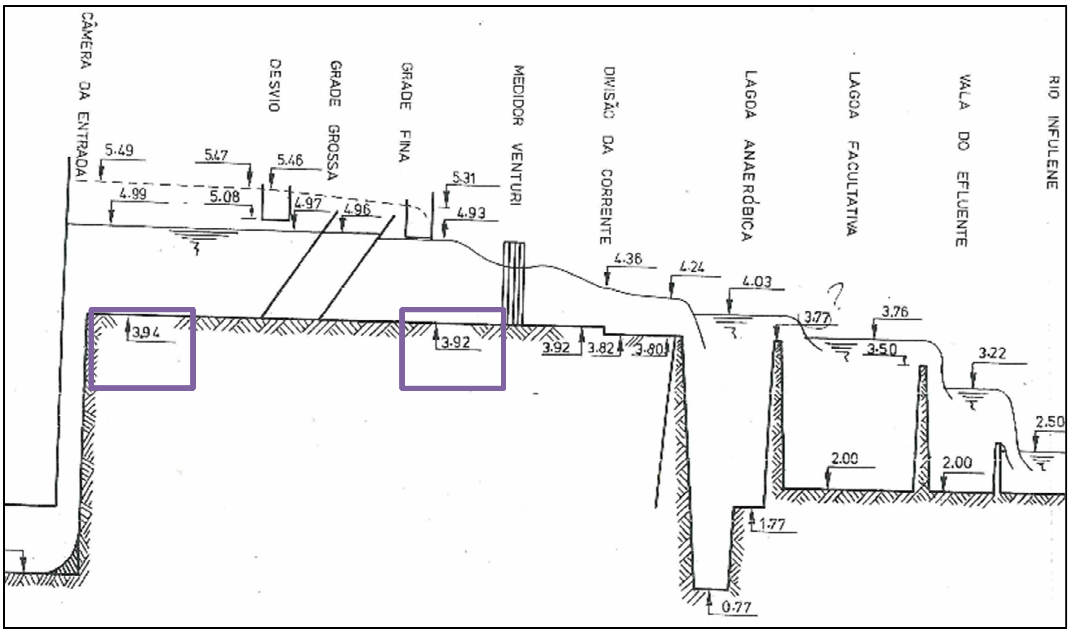

Figure 5.6 Initial elevation at by-passing intake point of the main sewer (DHV, 1984)

The hydraulic grade schemes were plotted by adding the elevations of the ground level (GL) and invert level from the bottom of equipment of each facility (IL) as can be seen in Table 5.10. Pumps were installed prior to the PMF with a total head of 1.10 m and before the NF with a total head of 51 m as per dimensioning calculations (Annex 4).

Table 5.10 Ground and water elevation of each facility per package

(● = step included in the package)

Phase	Facility	Dimensions					Elevation			Number of Pump		Package		
		Length L	Width W	Height H	Dia-meter D	n	Ground Level GL	Invert Level IL	GL+IL	Actual	Spare	Basic	Intermediate	Advanced
		[m]	[m]	[m]	[m]	[-]	[m]	[m]	[m]	[-]	[-]	[-]	[-]	[-]
0	Screen	-	0.40	1.20	-	1	3.94	-1.20	2.74	-	-	●	●	●
1	C - F, Coagulation	1.00	0.60	0.50	-	1	3.92	-1.70	1.04	-	-	●	●	
1	C - F, Flocculation	1.50	1.25	1.10	-	4	3.92	-1.10	-0.06	-	-	●	●	
1	C – F head loss			$2.65 \cdot 10^{6}$			3.92	$-2.65 \cdot 10^{-6}$	-0.06				●	
1	DAF	1.60	1.40	1.00	-	1	3.92	-1.00	-1.06			●	●	●
2	Pump						3.92		-1.06	1	1		●	
2	Pump			1.10			3.92	-3.88	0.04					
2	PMF	0.60		1.10	1.60	1	3.92	-1.10	-1.06				●	
2	PMF head loss		0.38				3.92	-0.38	-1.44				●	
3	Pump						3.92		-1.06	2	2			●
3	Pump			51.00			3.92	46.02	49.94					
3	NF	1.54	-	51.00	0.20	9	3.92	21.77	25.69					●
-	Storage	1.60	1.40	1.00	-	1	3.92	-5.36	-1.44			●	●	●

The hydraulic grade schemes were presented in Figure 5.7, Figure 5.8 and Figure 5.9 below.

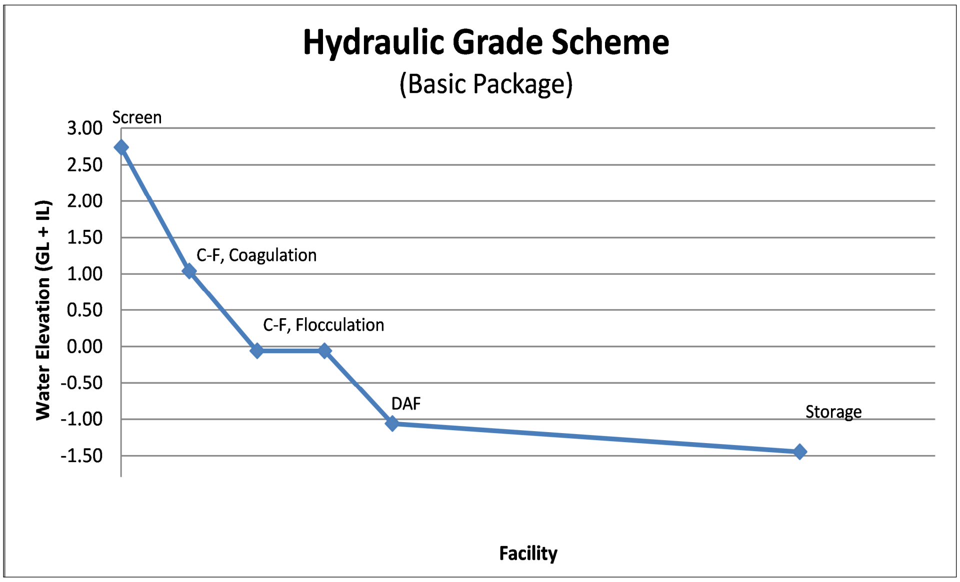

Figure 5.7 Hydraulic Grade Scheme for Basic Package

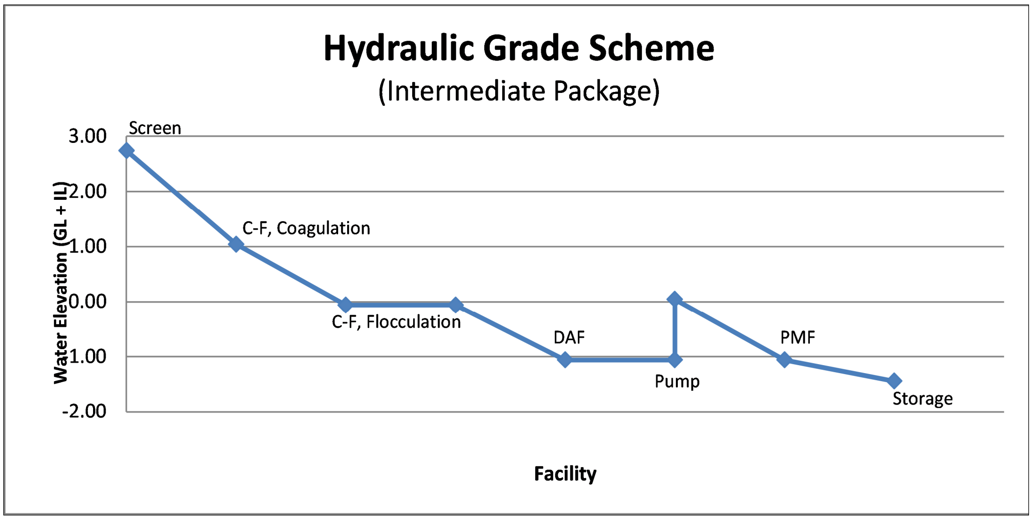

Figure 5.8 Hydraulic Grade Scheme for Intermediate Package

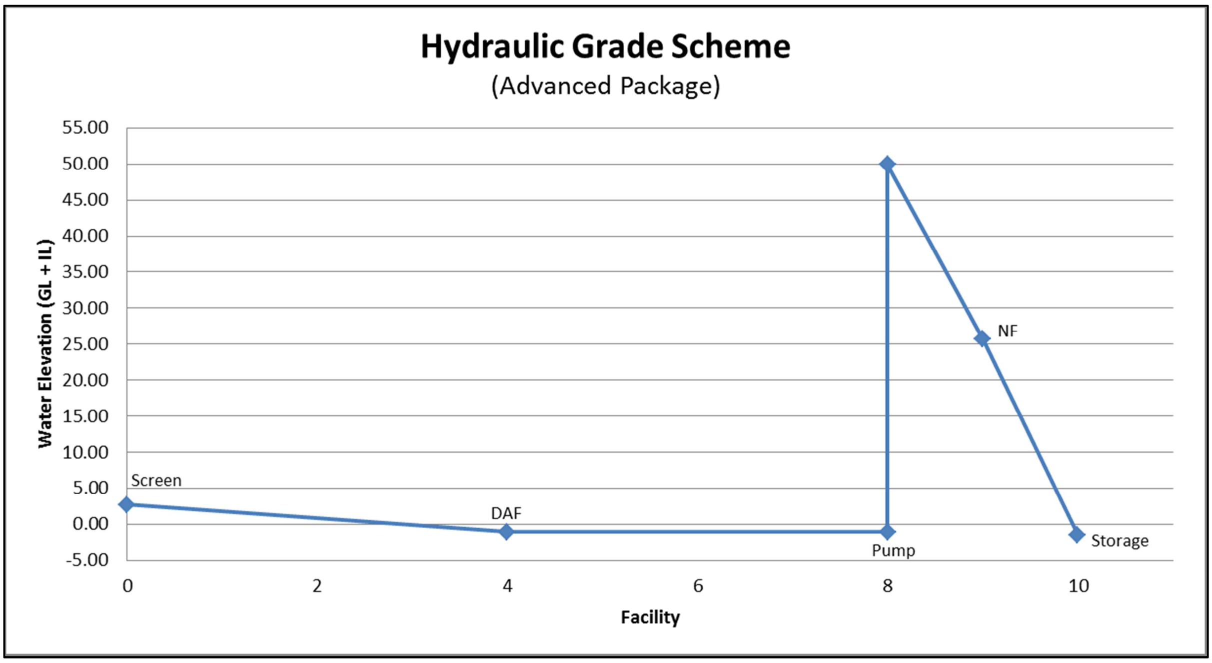

Figure 5.9 Hydraulic Grade Scheme for Advanced Package

5.3.3 Operation

Based on the products of the companies, the basic and intermediate packages were designed to be continuously operated. Thus, the influent will be divided by default for these two packages. The influent of the advanced package will be given once there is a demand for high-quality water. This procedure is conducted because the number of companies that will use the basic and intermediate packages is larger than the advanced package.

The consequences are:

1. A separation tee was placed in the beginning of the network to divide the influent flow.
2. The division of flow were done by separating pipes and installing valves. The valves for the basic and intermediate lines are normally opened and the ones for the advanced package are normally closed. The locations can be found along with the piping and instrument diagram in Annex 4.
3. Three different storage tanks were provided to separate the effluent from each package.

5.3.4 General layout

The location of the new design system with the total area of 0.36 ha can be seen in Figure 5.10 below and followed by the general layout in Figure 5.11. The larger version can be seen in Annex 4.

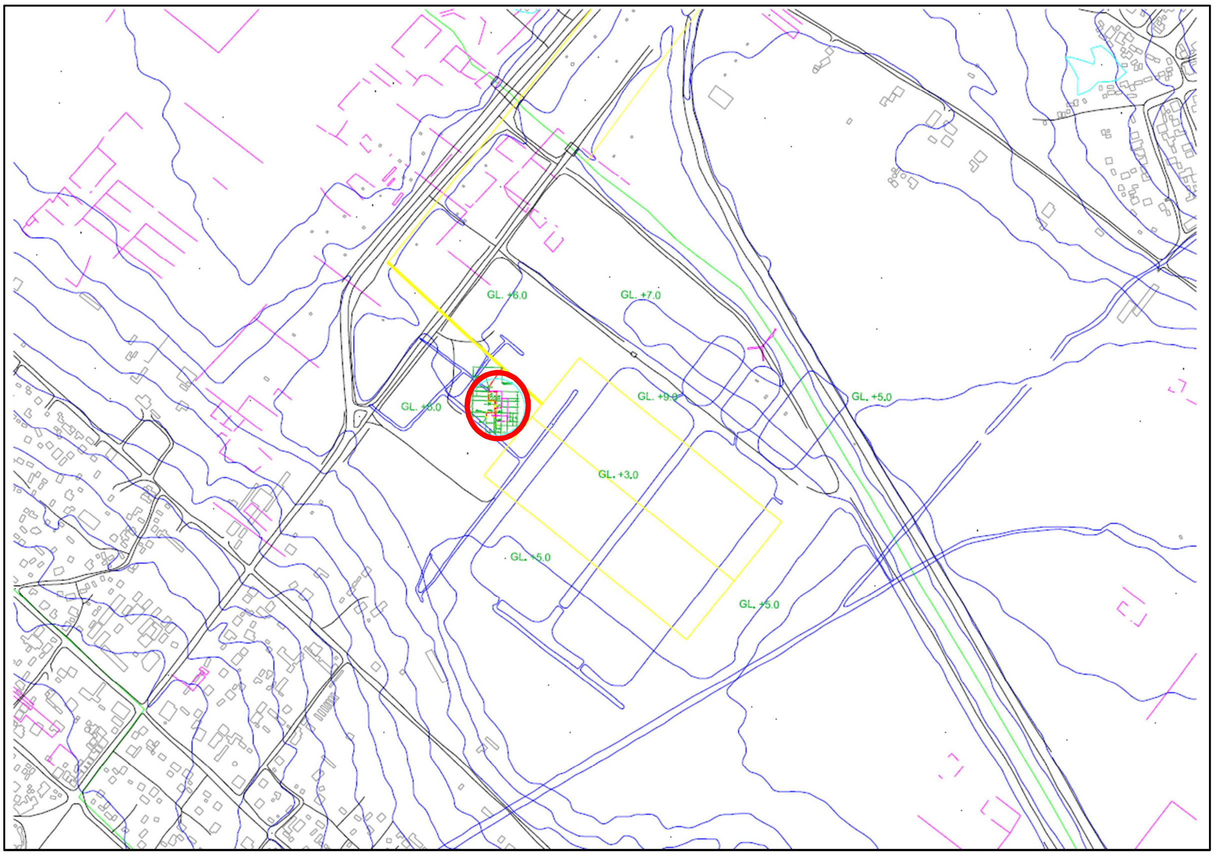

Figure 5.10 Location of the new design system ***(circled)*** **in accordance with the existing WWTP**

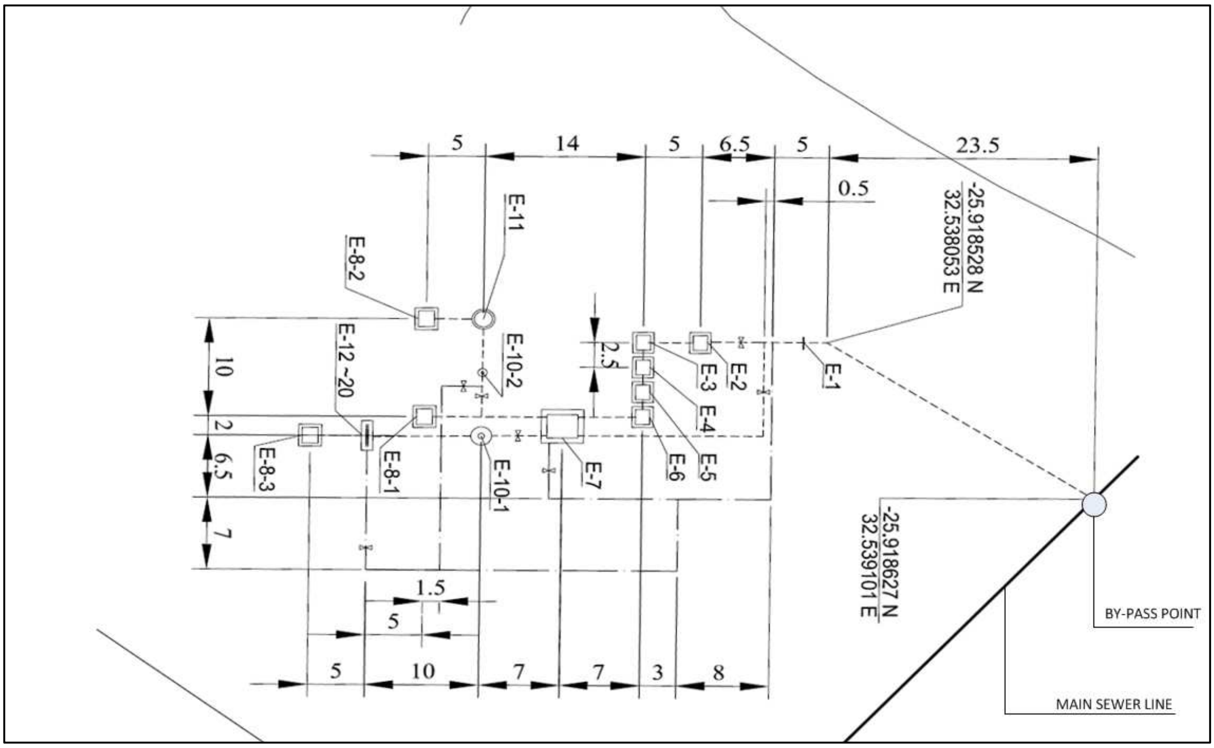

Figure 5.11 General layout of the preliminary plant

(_ _ _ _ _ _ = the main stream, ___ . ___ . ___ . ___ = the recycled or backwashed stream)

5.3.5 Delivery services

The effluent from the design system can be retained in a storage tank and delivered directly to the 11 companies which were interviewed as the consumers, either by trucks or by a new piping network with several outlets near the locations of the companies.

Trucks

During the field work period in Maputo, it was discovered that some concrete companies receive their daily water supply from a private water providers using trucks directly to the consumers and usually operate around Maputo, Matola and Machava.

If the trucks should be purchased, assumed that a truck can carry 20 m^3 of water in one way (Wuhu CIMC Ruijiang Automobile Co., 2016) and each truck can deliver the water to the 11 interviewed companies twice per day. As the total amount of water to be delivered is 388 m^3/day or 16.20 m^3/h (see Section 5.1.2), eight trucks are required with a cost of 2,725,450 MT or €33,710 each (Ostermiller, 2016). The total price is €269,680, without the salary of the drivers.

The total distance from the 11 interviewed companies to the WWTP is 84 km (see Table 5.11) and the price is 45 MT/L or $0.58/L. Considering that 1 km requires 0.05 L of diesel (Numbeo, 2016), the diesel cost is €2.53/day or €76/month. The total cost is then €0.007/m^3.

Based on the field investigation by Gulamussen (personal communication, November 7, 2016), people that have water supplied by trucks pays 1500 MT per 5000 L or €4/m^3. Thus, if the trucks can be rented, the cost for the total flow rate of 16.20 m^3/h is approximately €46,560/month.

Pipelines

The other alternative is constructing a new piping network from the WWTP to the companies. It is a direct solution because the companies can receive the water without having to wait or take the water by themselves.

The capital cost can be estimated by calculating the cost of the pipes while the operational cost may vary according to the utilization. The PVC pipes are used again due to its economical and practical values (van der Hoek, 2014b). The diameter of the pipes is calculated based on the previous Darcy-Weisbach's formula (Section 5.3.1) with the difference in L (84 km) and Q as the discharge based on the minimum and maximum demand from each company. The minimum comes from Estaleiro Julio J. Paunde (17 m^3/month or 6.6×10^{-6} m^3/s) and the maximum is from Prefangol (2700 m^3/month or 0.001 m^3/s) (see Section 4.3.1). Thus, the minimum diameter is 94 mm and the maximum is 716 mm.

Based on the price list (United States Plastic Corporation®, 2016) with Schedule 40 for sewer and drainage use, the pipe with minimum diameter costs 986.18 MT/m or €13/m and the maximum costs 21,493.45 MT/m or €286/m (United States Plastic Corporation®, 2016). The calculation can then be found in Table 5.11.

Table 5.11 Shortest distances from each concrete company to the WWTP and the cost of new piping network

Company	District	Previous Source	Coordinates (Unit Transverse Mercator or UTM)		Shortest Distance from WWTP	Estimated Price for PVC Pipeline			
						Min. Diameter	Max. Diameter	Average	St. Dev
			X	Y	[km]	[€]	[€]	[€]	[€]
Estaleiro Julio J. Paunde	Matola	Groundwater with external piping	442,505	7,141,473	14.06	184,870	4,029,300	2,107,085	1,922,215
Estaleiro JMS (Jose Manuel Sacoto)	Matola	Tap water	443,163	7,136,351	11.07	145,605	3,173,503	1,659,554	1,513,949
Estaleiro Antonio Bernardo Tamele	Matola	Tap water	444,600	7,128,867	10.00	131,473	2,865,504	1,498,489	1,367,015
Resol	Maputo	Groundwater/surface water from clients	457,145	7,127,102	6.81	89,545	1,951,661	1,020,603	931,058
Estaleiro Amussuar Rassur	Matola	Groundwater, individual borehole	446,117	7,130,091	8.13	106,867	2,329,210	1,218,039	1,111,171
Cadin	Machava	Tap water, groundwater by trucks	448,980	7,133,169	4.74	62,271	1,357,220	709,746	647,475
Prefangol	Maputo	Groundwater, individual borehole	455,021	7,129,785	3.46	45,443	990,442	517,942	472,499
Hidroblock, Lda.	Machava	Tap water, ground water borehole	450,148	7,133,602	3.62	47,566	1,036,718	542,142	494,576
Britanor, Lda.	Maputo	Tap water, occasionally surface water	456,821	7,130,833	3.78	49,700	1,083,228	566,464	516,764
Cimbetao	Maputo	Tap water	456,866	7,130,810	3.83	50,361	1,097,642	574,002	523,640
Bricon, Lda.	Matola	Tap water, groundwater by trucks for emergency	441,980	7,124,427	14.52	190,932	4,161,434	2,176,183	1,985,251
WWTP Infulene	Maputo	Main sewer	453,712	7,132,984					
Total					84.01	1,104,634	24,075,863	12,590,248	3,914,946

The total average capital cost of the new piping network is **€12,590,248**, without the operational cost per month. Thus, transporting the water by purchasing trucks with a capital cost of €269,680 and fuel cost of €76/month or by renting them with an approximate cost of €46,560/month is more preferable for transporting the water to the companies than the new piping network because:

- Trucks require less capital or renting cost than the piping network (see Section 5.3.3).
- Trucks do not need excavation during installation along the main street of Joaquim Chissano as piping network does (see Figure 4.3).
- Trucks do not require special maintenance as piping network does, such as frequent cleaning and damage monitoring (van der Hoek, 2014).

6. Conclusions and Recommendations

6.1 Conclusions

In parallel with the construction boom in Maputo, the construction sector, in particular concrete industry, considerably contributes to the total water demand with 4411 ± 257 m^3/day. It is in line with the current situation as it contributes to 12 – 14% tap water consumption around the world.

The result of the study shows that it is possible to use reclaimed water for concrete production in Maputo. The best source for water reclamation for the construction sector is the influent of WWTP in Infulene. The flow is approximately 3883 ± 1135 m^3/day which is to supply all concrete companies in Maputo but the water quality should be improved. The water quality standards for concrete exist today are still not detailed yet but the safe ranges can be found to produce concrete with non-drinking water quality, without compromising the expected strength.

In order to assess the best treatment to be implemented, a preliminary scheme was designed using a modular system. The design flow for the effluent is taken from the 11 surveyed companies, approximately 311 ± 36 m^3/day.

The new design system consists of four phases and is divided into three packages based on the needs of 11 companies which were participated in the interviews. The first one is the basic package which removes FOGs, TP and TSS with C – F and DAF. The intermediate package removes polishes the effluent from the basic package with PMF which allows the production of higher-strength concrete. The advanced package removes FOGs, TP and TSS with C – F and DAF and TDS with nanofiltration. The costs of these packages vary based on the treatment selections. The cost of the basic package (€0.30/m^3) is less than from the tap water (€/0.40m^3), the intermediate package shows similar value (€0.40/m^3) with the tap but the advanced package is more expensive (€0.80/m^3) than the monthly bill of the companies.

6.2 Recommendations

6.2.1 Data collection

Collecting the data by interviewing companies at their own factories was right on target because the information and the situation in the surrounding could be directly obtained and the companies could be easily convinced to participate in the project. However, the disadvantage of this method was the fewer number of results than other methods, such as spreading questionnaire by emails, phone-calls, etc. Adding personnel in the team to reach more respondents or optimizing the schedule of the interviews by grouping companies based on their areas might be useful to increase the confidence interval and develop more reliable data.

6.2.2 Analysis for interview results

Different interpretations and calculations may occur while Integrating the amount of water consumption reported by the companies during the interviews. Having one average value including the standard deviation might become another approach if all companies can be generalized and their characteristics are similar to one another. Different approach may lead to different decisions for the source of sewage, degree of contribution of concrete industry to the tap water use and dimensions of the treatment facilities.

6.2.3 Laboratory analysis

Collecting samples and analysing them in the laboratory might become mandatory for future research since the source of wastewater has been recommended, especially for obtaining daily, monthly or yearly variations, in order to have a proper schedule when extracting the influent and to monitor if the existing design is still sufficient. The 1-year sampling programme has been started by the students of UEM and should be kept on-going.

6.2.4 Concrete testing

Concrete compressive strength test is recommended as it is the only way to know the suitability of the reclaimed water. Similar research has been conducted (see Section 2.3) but the typical sewage in Maputo may have different characteristics so that the products from each package should be tested frequently.

6.2.5 *Departamento de Água e Saneamento* (DAS) as the first consumer

The 11 companies that were interviewed might need an evidence to be sure that producing concrete with reclaimed sewage is possible to be done. A neutral public institution that can show the successfulness would convince them. DAS produces heavy duty sewer and manhole covers (see Section 4.12.1) so that although its amount of water use (1.35 m^3/month) is insignificant compared to the consumption of the surveyed companies, constructing a pilot plant with DAS can be seen as a proof-of-concept that reclaiming water for concrete production is possible and beneficial.

6.2.6 Other contaminants to be removed

One of the most harmful contaminants that can be contained in the sewage is sulphate ions (Neville, 2004). It is the culprit of sulphate attack, a damaging situation of the concrete due to the formation of gypsum (Hime & Mather, 1999). While many guidelines suggest its maximum concentration of approximately 150 mg/L in the water, the mechanism of concrete deterioration remains unexplained yet (Santhanam et al., 2001). Thus, to ensure the effluent water quality, sulphate concentration needs to be taken into account.

In contrast, organic materials have not been raised up as an issue regarding its effect towards concrete. Further research can be advantageous, especially about the effect of treating the sewage to be only physically chemically treated, leaving BOD, COD and nitrogen-based nutrients still in the water, and its impact to the quality of concrete.

6.2.7 Large-scale plant

A large-scale plant is going to be built after obtaining the result from the preliminary plant. It will supply the reclaimed water for all companies in Maputo, 4411 ± 257 m^3/day. The dimensions were calculated using the same method as the preliminary plant (Annex 4.1 – 4.7). The results can be found in Annex 4.8 (Table 4.4).

The modular system can be adaptive when the pumps of the second sewer system are fixed (see Section 1.2.3), which means that the influent can reach more than 10,000 m^3/day. However, it is not the WWTP itself. The new installation can act as a by-passed system while the existing WWTP is also under restoration. In the long run it can be combined as part of the reconstructed WWTP.

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Annexes

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13. Summary of Results

Questionnaire Form
for Construction Firms in Maputo
(March - May 2016)

About the Construction Companies

1. How many projects are now running on for the company?

2. How many employees are there in the company?

3. What are the types of the company's common projects?

4. How long is the usual duration of projects?

5. What are the ranges of cost of the projects? (can be answered only in ranges/estimation)

About the Types of Concrete

6. What are the types of produced concrete that are usually used in the projects? (reinforced, non-reinforced)

7. What is the main type of production mechanism? (cast in-situ, precast)

8. Are there any differences between mixing and curing water for concrete from:

- Quantity (sources/locations, volume)

- Quality

About Water Quantity and Water Price

9. How much water (m^3) is required for concrete producing in 1 project?

10. How much water (m^3) is required for concrete producing in 1 day or in 1 month?

11. How much is the percentage of the cost of water in concrete producing in 1 general project? (in meticals or %)

12. Does the company think that the cost of the water is expensive?

About Water Resource Locations

13. Where are the locations of water resources for mixing and curing concrete? (tap water, groundwater, surface water, etc.).

14. Is there any wastewater outlet near the batching plants/project sites?

15. How is the water intake usually transported from the source to the batching plants?

About Future Plan

16. In the near future, what is your plan for the company in regards to concrete production? (e.g. expansion, gaining more projects, separate some divisions to be the spin-offs, etc.)

Participation Willingness

17. Are you willing to involve in assessing the possibility of using treated wastewater for concrete production and have more benefit instead of using tap water or extracting groundwater?

Interview Result

Company : Estaleiro JJ Paunde
Respondent : Julio José Paunde
Date : 23 March, 2016

About the Construction Companies

1. How many projects are now running on for the company?

Keep producing and people buy

2. How many employees are there in the company?

2 (husband and wife), 2 (not full-time)

3. What are the types of the company's common projects?

Blocks, tanks for washing clothes, latrines

4. How long is the usual duration of projects? (productivity per day)

150-200 blocks/day

5. What are the ranges of cost of the projects? (can be answered only in ranges/estimation)

Varies

About the Types of Concrete

6. What are the types of produced concrete that are usually used in the projects? (reinforced, non-reinforced)

The tanks and latrines use reinforcement, the blocks are non-reinforced.

7. What is the main type of production mechanism? (cast in-situ, precast)

Only precast

8. Are there any differences between mixing and curing water for concrete from:

o Quantity (sources/locations, volume)

Same source (piped groundwater from a provider), the quantity refers to no. 10

o Quality

Same as tap water quality. Curing system: watering with flexible hose once per 2 days for the total duration of 4 days

About Water Quantity and Water Price

9. How much water (m^3) is required for concrete producing in 1 project?

-

10. How much water (m^3) is required for concrete producing in 1 day or in 1 month?

14-15m^3/month, maximum can be 20m^3/month

11. How much is the cost of water in concrete producing in 1 month? (in meticals or %)

500-600MT/month

12. Does the company think that the cost of the water is expensive?

It is expensive

About Water Resource Locations

13. Where are the locations of water resources for mixing and curing concrete? (tap water, groundwater, surface water, etc.).

Groundwater by a small provider who also constructs the piping route

14. Is there any wastewater outlet near the batching plants/project sites?

No. In Machava people only use septic tanks

15. How is the water intake usually transported from the source to the batching plants?

Piping connection from the provider

About Future Plan

16. In the near future, what is your plan for the company in regards to concrete production? (e.g. expansion, gaining more projects, separate some divisions to be the spin-offs, etc.)

-

Participation Willingness

17. Are you willing to involve in assessing the possibility of using treated wastewater for concrete production and have more benefit instead of using tap water or extracting groundwater?

Yes, of course! ☺

Discussions

Interview Result

Company : JMS Estaleiro (Jose Manuel Sacoto, Lda)
Respondent : Jose Manuel Sacoto, Tininha
Date : 22 March, 2016

About the Construction Companies

1. How many projects are now running on for the company?

3

2. How many employees are there in the company?

10

3. What are the types of the company's common projects?

Blocks

4. How long is the usual duration of projects?

6 months for 1 small house

5. What are the ranges of cost of the projects? (can be answered only in ranges/estimation)

Varies

About the Types of Concrete

6. What are the types of produced concrete that are usually used in the projects? (reinforced, non-reinforced)

No production of concrete (purchase from others) Produce blocks (non-reinforced)

7. What is the main type of production mechanism? (cast in-situ, precast)

Only precast

8. Are there any differences between mixing and curing water for concrete from:

o Quantity (sources/locations, volume)

Same source (municipal network), the quantity refers to no. 10

o Quality

Same as tap water/municipal network. Curing takes up until 4 days

About Water Quantity and Water Price

9. How much water (m^3) is required for concrete producing in 1 project?

Varies per project

10. How much water (m^3) is required for concrete producing in 1 day or in 1 month?

$42m^3$/month

11. How much is the cost of water in concrete producing in 1 month? (in meticals or %)

1455MT/month

12. Does the company think that the cost of the water is expensive?

Too expensive

About Water Resource Locations

13. Where are the locations of water resources for mixing and curing concrete? (tap water, groundwater, surface water, etc.).

Tap water (municipal network)

14. Is there any wastewater outlet near the batching plants/project sites?

No. In Machava people only use septic tanks

15. How is the water intake usually transported from the source to the batching plants?

Piping system from the network

About Future Plan

16. In the near future, what is your plan for the company in regards to concrete production? (e.g. expansion, gaining more projects, separate some divisions to be the spin-offs, etc.)

No

Participation Willingness

17. Are you willing to involve in assessing the possibility of using treated wastewater for concrete production and have more benefit instead of using tap water or extracting groundwater?

No, because it receiving water from the network is the easiest way.

Discussions

Interview Result

Company : Estaleiro Antonio Bernardo Tamele
Respondent : Antonio Bernardo Tamele
Date : 22 March, 2016

About the Construction Companies

1. How many projects are now running on for the company?

Keep producing and people buy

2. How many employees are there in the company?

15

3. What are the types of the company's common projects?

Blocks

4. How long is the usual duration of projects? (productivity per day)

Blocks 550-1050/day

5. What are the ranges of cost of the projects? (can be answered only in ranges/estimation)

Varies

About the Types of Concrete

6. What are the types of produced concrete that are usually used in the projects? (reinforced, non-reinforced)

Non-reinforced

7. What is the main type of production mechanism? (cast in-situ, precast)

Only precast

8. Are there any differences between mixing and curing water for concrete from:

- Quantity (sources/locations, volume)

Same source (tap water/municipal network), the quantity refers to no. 10

- Quality

Same as tap water quality. Curing for 1 day.

About Water Quantity and Water Price

9. How much water (m^3) is required for concrete producing in 1 project?

-

10. How much water (m^3) is required for concrete producing in 1 day or in 1 month?

$48m^3$/month

11. How much is the cost of water in concrete producing in 1 month? (in meticals or %)

1700 – 2000MT/month

12. Does the company think that the cost of the water is expensive?

-

About Water Resource Locations

13. Where are the locations of water resources for mixing and curing concrete? (tap water, groundwater, surface water, etc.).

Tap water/municipal network, with individual recycling system (explained in the Discussions)

14. Is there any wastewater outlet near the batching plants/project sites?

No. In Machava people only use septic tanks

15. How is the water intake usually transported from the source to the batching plants?

Piping network

About Future Plan

16. In the near future, what is your plan for the company in regards to concrete production? (e.g. expansion, gaining more projects, separate some divisions to be the spin-offs, etc.)

-

Participation Willingness

17. Are you willing to involve in assessing the possibility of using treated wastewater for concrete production and have more benefit instead of using tap water or extracting groundwater?

Agreed!

Discussions

Antonio has an individual recycling system to save water. First, the water from the tap is used to mix concrete. The concrete blocks that should be cured is placed in the garden and watered by a flexible hose. The water that runs through the ground is collected by small open channels and goes to a storage tank, separated from the tank for his household daily use. After the solids are settled enough and the water is cleaner, the pump sends the water back for curing the blocks again. He can save a large amount of water with this setup.

Interview Result

Company : Resol, Lda.
Respondent : Titus Matsinhe
Date : 29 March, 2016

About the Construction Companies

1. How many projects are now running on for the company?

2 on-going projects

2. How many employees are there in the company?

15 (but varied based on the running project)

3. What are the types of the company's common projects?

Residential areas (houses)

4. How long is the usual duration of projects? (productivity per day)

6 months – 1 year

5. What are the ranges of cost of the projects? (can be answered only in ranges/estimation)

5,000,000MT

About the Types of Concrete

6. What are the types of produced concrete that are usually used in the projects? (reinforced, non-reinforced)

Both

7. What is the main type of production mechanism? (cast in-situ, precast)

Both of them; sometimes in-situ, sometimes precast, or purchase from the suppliers

8. Are there any differences between mixing and curing water for concrete from:

o Quantity (sources/locations, volume)

No

o Quality

No

About Water Quantity and Water Price

9. How much water (m^3) is required for concrete producing in 1 project?

-

10. How much water (m^3) is required for concrete producing in 1 day or in 1 month?

15-20m^3/month

11. How much is the percentage of the cost of water in concrete producing in 1 general project? (in meticals or %)

For 6000L water = 4500MT If the company can go to the depot by themselves, it is a bit cheaper: 4000L = 3000MT

12. Does the company think that the cost of the water is expensive?

Yes, it is expensive

About Water Resource Locations

13. Where are the locations of water resources for mixing and curing concrete? (tap water, groundwater, surface water, etc.).

Resol only receives water from the clients (by trucks), and sometimes river water (when the site is near river). The clients perhaps take it from FIPAG/groundwater.

14. Is there any wastewater outlet near the batching plants/project sites?

No

15. How is the water intake usually transported from the source to the batching plants?

By trucks from the external provider. Sometimes there is a lack of water, so the company has to wait 2-3 days until the truck comes again.

About Future Plan

16. In the near future, what is your plan for the company in regards to concrete production? (e.g. expansion, gaining more projects, separate some divisions to be the spin-offs, etc.)

No

Participation Willingness

17. Are you willing to involve in assessing the possibility of using treated wastewater for concrete production and have more benefit instead of using tap water or extracting groundwater?

Yes, for sure, but as a recommendation, it would be more valuable to team up with the real concrete suppliers (ready-mix or blocks) in a large scale, not just construction companies/contractors like Resol.

Discussions

1. Resol is willing to help for the test of the pilot plant but it would not be a high impact. Titus advised to go for the “real” suppliers of concrete, either precast blocks or ready-mix concrete.
2. Titus is very interested and curious about the result of the pilot plant. Thus, he gave some other names of the companies who produce concrete. (Plus, he offered Nalda a job after graduation ☺)

Interview Result

Company : Estaleiro Amussuar Rassur
Respondent : Amussuar Rassur
Date : 22 March, 2016

About the Construction Companies

1. How many projects are now running on for the company?

Keep producing and people buy

2. How many employees are there in the company?

20

3. What are the types of the company's common projects?

Blocks and paves

4. How long is the usual duration of projects? (productivity per day)

Blocks 1050-2000/day Paves 70-80/day

5. What are the ranges of cost of the projects? (can be answered only in ranges/estimation)

Varies

About the Types of Concrete

6. What are the types of produced concrete that are usually used in the projects? (reinforced, non-reinforced)

Non-reinforced

7. What is the main type of production mechanism? (cast in-situ, precast)

Only precast

8. Are there any differences between mixing and curing water for concrete from:

- Quantity (sources/locations, volume)

Same source (groundwater), the quantity refers to no. 10

- Quality

Same as groundwater quality. Curing takes up until 3 days.

About Water Quantity and Water Price

9. How much water (m^3) is required for concrete producing in 1 project?

Not quantified

10. How much water (m^3) is required for concrete producing in 1 day or in 1 month?

Not quantified because it is extracted directly from the ground using electric pump

11. How much is the cost of water in concrete producing in 1 month? (in meticals or %)

Does not pay for water, only electricity

12. Does the company think that the cost of the water is expensive?

-

About Water Resource Locations

13. Where are the locations of water resources for mixing and curing concrete? (tap water, groundwater, surface water, etc.).

Groundwater

14. Is there any wastewater outlet near the batching plants/project sites?

No. In Machava people only use septic tanks

15. How is the water intake usually transported from the source to the batching plants?

Pumped from the ground to the storage tank

About Future Plan

16. In the near future, what is your plan for the company in regards to concrete production? (e.g. expansion, gaining more projects, separate some divisions to be the spin-offs, etc.)

No

Participation Willingness

17. Are you willing to involve in assessing the possibility of using treated wastewater for concrete production and have more benefit instead of using tap water or extracting groundwater?

No, because extracting groundwater is the cheapest way

Discussions

Interview Result

Company : Cadin, Lda.
Respondent : Carlos Delgado
Date : 29 March, 2016

About the Construction Companies

1. How many projects are now running on for the company?

Only delivering: in 2015 = 28,000 units and in 2014 = 32,000 units

2. How many employees are there in the company?

21

3. What are the types of the company's common projects?

Ready-mix concrete

4. How long is the usual duration of projects? (productivity per day)

$450m^3$/day

5. What are the ranges of cost of the projects? (can be answered only in ranges/estimation)

30,000,000MT

About the Types of Concrete

6. What are the types of produced concrete that are usually used in the projects? (reinforced, non-reinforced)

- (only ready-mix)

7. What is the main type of production mechanism? (cast in-situ, precast)

Cast in-situ

8. Are there any differences between mixing and curing water for concrete from:

o Quantity (sources/locations, volume)

- (the curing process is performed by the constructors in the field)

o Quality

- (the curing process is performed by the constructors in the field)

About Water Quantity and Water Price

9. How much water (m^3) is required for concrete producing in 1 project?

180L of water/m^3 of concrete mix The company does not calculate the volume of water for cleaning the clinkers/trucks

10. How much water (m^3) is required for concrete producing in 1 day or in 1 month?

-

11. How much is the percentage of the cost of water in concrete producing in 1 general project? (in meticals or %)

0.02% (5000L = 500MT)

12. Does the company think that the cost of the water is expensive?

Yes

About Water Resource Locations

13. Where are the locations of water resources for mixing and curing concrete? (tap water, groundwater, surface water, etc.).

Groundwater and tap water (FIPAG)

14. Is there any wastewater outlet near the batching plants/project sites?

No (only septic tanks)

15. How is the water intake usually transported from the source to the batching plants?

Pipes from the network and a small truck

About Future Plan

16. In the near future, what is your plan for the company in regards to concrete production? (e.g. expansion, gaining more projects, separate some divisions to be the spin-offs, etc.)

No

Participation Willingness

17. Are you willing to involve in assessing the possibility of using treated wastewater for concrete production and have more benefit instead of using tap water or extracting groundwater?

Why not if it is possible? ☺

Discussions

Interview Result

Company : Prefangol
Respondent : Sergio Major
Date : 6 April, 2016

About the Construction Companies

1. How many projects are now running on for the company?

8 on-going projects

2. How many employees are there in the company?

43

3. What are the types of the company's common projects?

Normally common buildings and coastal protection

4. How long is the usual duration of projects? (productivity per day)

8 months – 1 year, (45,000m^3/year with 13 trucks)

5. What are the ranges of cost of the projects? (can be answered only in ranges/estimation)

-

About the Types of Concrete

6. What are the types of produced concrete that are usually used in the projects? (reinforced, non-reinforced)

- (only ready mix concrete)

7. What is the main type of production mechanism? (cast in-situ, precast)

Only cast in-situ (ready mix concrete)

8. Are there any differences between mixing and curing water for concrete from:

o Quantity (sources/locations, volume)

No (groundwater individual borehole and pumps)

o Quality

No

About Water Quantity and Water Price

9. How much water (m^3) is required for concrete producing in 1 project?

Varies

10. How much water (m^3) is required for concrete producing in 1 day or in 1 month?

90,000L/day (37,000L for production, the rest is for washing trucks and clinkers, moistening aggregates, curing, etc.)

11. How much is the percentage of the cost of water in concrete producing in 1 general project? (in meticals or %)

Not paying for water, only paying the license to extract groundwater, it is about U$D1500 /year

12. Does the company think that the cost of the water is expensive?

Fair

About Water Resource Locations

13. Where are the locations of water resources for mixing and curing concrete? (tap water, groundwater, surface water, etc.).

Groundwater (*furo*), extracted by pumps

14. Is there any wastewater outlet near the batching plants/project sites?

No

15. How is the water intake usually transported from the source to the batching plants?

By pumps

About Future Plan

16. In the near future, what is your plan for the company in regards to concrete production? (e.g. expansion, gaining more projects, separate some divisions to be the spin-offs, etc.)

Prefangol already has its own water recycling system, and it has successfully made concrete wall from recycled water (it is the first and the only one in Mozambique). The concrete wall can have the strength until 16MPa. The recycling system will be explained in **Discussions**.

Participation Willingness

17. Are you willing to involve in assessing the possibility of using treated wastewater for concrete production and have more benefit instead of using tap water or extracting groundwater?

Yes, of course, for Prefangol (and personally for Sergio, too), using reused water is really not a problem. Even if now Sergio is given recycled water to drink, he will drink it. The only thing to be considered is the quality of the water. Government can give an instruction that all construction companies should use recycled water from wastewater, as long as they can guarantee that the quality of the water is good and it will not decrease the quality of the concrete. And, it is already possible in many parts of the world. In Cape Verde, concrete suppliers already use recycled water from wastewater. In Namibia, people drink the recycled water. It is indeed possible.

Discussions

1. There are 2 big sprinklers that moistening the aggregates continuously.
2. Prefangol has 2 decantation tanks; the first one is shallow and it functions as collecting tanks to retain water that flows on the ground after being used for cleaning or moistening aggregates. The water then flows to the second tank for settling down the solids. After that, the pump will take the water into the clinker again to be mixed with cement and aggregates.
3. Prefangol claimed that they can save almost 95% of the water to be reused again by their recycling system.
4. Prefangol has its own laboratory for analyzing the optimum mix for concrete (they use superplasticizer and water reducer, too), testing the compressive strength, and a curing room with controlled temperature (curing varies from 3 – 20 days).
5. Pictures can be seen in the **Pictures** folder.

Interview Result

Company : Hidroblock, Lda.
Respondent : Chandu
Date : 23 March, 2016

About the Construction Companies

1. How many projects are now running on for the company?

3 big ones and some small ones

2. How many employees are there in the company?

45

3. What are the types of the company's common projects?

Production of concrete paves, cubes, blocks, curbs (*lancis*)

4. How long is the usual duration of projects? (productivity per day)

Varies per project, usually 6 months until 1 year. The on-going biggest project now is for 5 years

5. What are the ranges of cost of the projects? (can be answered only in ranges/estimation)

Around 20,000,000MT

About the Types of Concrete

6. What are the types of produced concrete that are usually used in the projects? (reinforced, non-reinforced)

Only non-reinforced concrete

7. What is the main type of production mechanism? (cast in-situ, precast)

Only precast

8. Are there any differences between mixing and curing water for concrete from:

o Quantity (sources/locations, volume)

Same source (municipal network), the quantity refers to no. 10

o Quality

Same as tap water/municipal network. Curing takes 3 days

About Water Quantity and Water Price

9. How much water (m^3) is required for concrete producing in 1 project?

Varies per project

10. How much water (m^3) is required for concrete producing in 1 day or in 1 month?

Total = 509m^3/month (refer to the water cost data)

11. How much is the percentage of the cost of water in concrete producing in 1 general project? (in meticals or %)

Average = 11,149.492MT/month (refer to the water cost data)

12. Does the company think that the cost of the water is expensive?

Tap water is getting more and more expensive. Now we start to build well and extract groundwater, but we don't know the water quality yet.

About Water Resource Locations

13. Where are the locations of water resources for mixing and curing concrete? (tap water, groundwater, surface water, etc.).

Tap water (municipal network), and in the near future also from groundwater.

14. Is there any wastewater outlet near the batching plants/project sites?

No. In Machava every house has septic tank and it is not integrated with the others.

15. How is the water intake usually transported from the source to the batching plants?

Piping system from the network

About Future Plan

16. In the near future, what is your plan for the company in regards to concrete production? (e.g. expansion, gaining more projects, separate some divisions to be the spin-offs, etc.)

In the near future, they will try to change water source from the municipal network to the groundwater.

Participation Willingness

17. Are you willing to involve in assessing the possibility of using treated wastewater for concrete production and have more benefit instead of using tap water or extracting groundwater?

Yes, of course, we are looking for another source of water! ☺

Discussions

1. The blocks are sometimes covered with white spots that can be the indication of salt existence. Sometimes it affects the strength of the blocks.
2. There are several other companies who runs the same business, for example: (Blitz, Bricon, Deconstron, Fortaleza, Cadin).

Interview Result

Company : Britanor, Lda.
Respondent : José Marcos Massango
Date : 23 March, 2016

About the Construction Companies

1. How many projects are now running on for the company?

5, consists of: 2 port constructions, 1 road construction, 1 with Resol, 1 with Rushtail

2. How many employees are there in the company?

55

3. What are the types of the company's common projects?

Ready-mix concrete, precast concrete blocks based on client's request, laboratory for strength compressive test.

4. How long is the usual duration of projects? (productivity per day)

Varies per project, from 6 months until very long (more than 5 years)

5. What are the ranges of cost of the projects? (can be answered only in ranges/estimation)

Around 26,000,000MT for the duration of 8 months until 1 year

About the Types of Concrete

6. What are the types of produced concrete that are usually used in the projects? (reinforced, non-reinforced)

Reinforced and non-reinforced concrete

7. What is the main type of production mechanism? (cast in-situ, precast)

Cast in-situ and precast

8. Are there any differences between mixing and curing water for concrete from:

o Quantity (sources/locations, volume)

Same source (municipal network), the quantity refers to no. 10. The largest consumption of water is not from mixing or curing, but from cleaning the mixing trucks (wash water). Mixing and curing water is only 20% of wash waster, because the trucks should be cleaned everytime we want to load the mixture and the trucks deliver it to the sites. Now we have 6 trucks and 1 truck can go back and forth 4 times a day.

o Quality

Same as tap water/municipal network. Curing takes 2-3 days in curing tanks, once a week the tanks are emptied, cleaned and refilled. The water goes to the recycling system. Creates a water recycling system for washing the mixing trucks. This system has been proven to recover 30% of total water consumption (explained in Discussions)

About Water Quantity and Water Price

9. How much water (m^3) is required for concrete producing in 1 project?

Varies per project

10. How much water (m^3) is required for concrete producing in 1 day or in 1 month?

Total = 822m^3/month (refer to the water cost data)

11. How much is the percentage of the cost of water in concrete producing in 1 general project? (in meticals or %)

Average = 22,602.16MT/month (refer to the water cost data)

12. Does the company think that the cost of the water is expensive?

Fair enough

About Water Resource Locations

13. Where are the locations of water resources for mixing and curing concrete? (tap water, groundwater, surface water, etc.).

Tap water (municipal network).

14. Is there any wastewater outlet near the batching plants/project sites?

No. In Machava every house has septic tank and it is not integrated with the others.

15. How is the water intake usually transported from the source to the batching plants?

Piping system from the network

About Future Plan

16. In the near future, what is your plan for the company in regards to concrete production? (e.g. expansion, gaining more projects, separate some divisions to be the spin-offs, etc.)

-

Participation Willingness

17. Are you willing to involve in assessing the possibility of using treated wastewater for concrete production and have more benefit instead of using tap water or extracting groundwater?

Yes, sure! ☺

Discussions

1. The recycling system aims to recollect water that was used to clean the trucks. The water should come continuously and shower the whole mixing tank because the temperature of the mixture is high. Showering water makes the tank wall has more stable temperature.
2. Then, the used water goes to a recycling tank from inclined ground level. It enters the tank to settle down the solids. After the settlement finishes, the same water is used for another batch of cleaning: the outlet of the mixing tank should be cleaned from hardened concrete or sludge that sticks to it. The water also goes back to the recycling tank and ends up in the settlement process again.
3. The sludge from the settling tank is removed frequently and stored in the disposal area.

Interview Result

Company : Cimbetao, Lda. (Cimpor Betão)
Respondent : Paulo LanÇa (Head of Central Laboratory)
Date : 10 May, 2016

About the Construction Companies

1. How many projects are now running on for the company?

Only producing ready-mix concrete

2. How many employees are there in the company?

-

3. What are the types of the company's common projects?

Ready-mix concrete, laboratory for strength compressive test.

4. How long is the usual duration of projects? (productivity per day)

1674m^3 in April 2016

5. What are the ranges of cost of the projects? (can be answered only in ranges/estimation)

-

About the Types of Concrete

6. What are the types of produced concrete that are usually used in the projects? (reinforced, non-reinforced)

Ready mix concrete

7. What is the main type of production mechanism? (cast in-situ, precast)

Cast in-situ (ready mix)

8. Are there any differences between mixing and curing water for concrete from:

o Quantity (sources/locations, volume)

Same source (municipal network), the quantity refers to no. 10.

o Quality

Same as tap water/municipal network. With the standards: Norma Portuguesa NP EN 1008 2003 Agua de amassadura para betão espeçificacoes (água recuperada) (used for sampling, testing, assessing suitability of water for concrete)

About Water Quantity and Water Price

9. How much water (m^3) is required for concrete producing in 1 project?

Varies per project

10. How much water (m^3) is required for concrete producing in 1 day or in 1 month?

Total = 260,62957m^3 in April 2016 (only for producing, excluding cleaning clinkers and trucks)

11. How much is the percentage of the cost of water in concrete producing in 1 general project? (in meticals or %)

Average = 60,000MT in April 2016

12. Does the company think that the cost of the water is expensive?

Fair enough

About Water Resource Locations

13. Where are the locations of water resources for mixing and curing concrete? (tap water, groundwater, surface water, etc.).

70% tap water, 30% recycling system

14. Is there any wastewater outlet near the batching plants/project sites?

There is the main sewer in front of the factory but the waste from industries is not discharged there.

15. How is the water intake usually transported from the source to the batching plants?

Piping system from the network

About Future Plan

16. In the near future, what is your plan for the company in regards to concrete production? (e.g. expansion, gaining more projects, separate some divisions to be the spin-offs, etc.)

-

Participation Willingness

17. Are you willing to involve in assessing the possibility of using treated wastewater for concrete production and have more benefit instead of using tap water or extracting groundwater?

Yes, sure! ☺

Discussions

1. The recycling system consists of 2 decantation tanks in series and a pump. The wastewater goes into the tanks and after the water is considered clean enough from solids, it is pumped back to the clinkers/silos to be mixed with other materials.
2. The pump is not working properly at this moment.
3. In Portugal, Cimbetao has 42 steps of water recycling system. It is already well-known that saving/recycling water is important.
4. The standard of water for concrete is used by all companies both in Portugal and in Mozambique. Nowadays Cimbetao has 7 factories in Mozambique; Maputo, Matola, Xai-xai, Dondo (Beira), Nacala, Nampula, Pemba.

Interview Result

Company : Bricon, Lda.
Respondent : Sven Dervoldy, Hassan
Date : 21 March, 2016

About the Construction Companies

1. How many projects are now running on for the company?

12

2. How many employees are there in the company?

87 (Bricon has just let 20 employees go in December)

3. What are the types of the company's common projects?

Production of concrete paves, cubes, blocks

4. How long is the usual duration of projects? (productivity per day)

It depends on the demand from the clients (starting from 20,000 blocks per project). Bricon keeps producing and store it in the storage, so the company just has to deliver it whenever some clients asked. Operation hour is 7am to 5pm, Monday to Friday, but on busy periods we also work on Saturday and Sunday. Paves = 1000m^2/day Blocks = 10,000pcs/day In the future, we will produce concrete pipes as well, and this type needs reinforcement Pipes = 15pcs/day

5. What are the ranges of cost of the projects? (can be answered only in ranges/estimation)

1,000,000 – 50,000,000

About the Types of Concrete

6. What are the types of produced concrete that are usually used in the projects? (reinforced, non-reinforced)

Only non-reinforced concrete (blocks)

7. What is the main type of production mechanism? (cast in-situ, precast)

Only precast

8. Are there any differences between mixing and curing water for concrete from:

- Quantity (sources/locations, volume)

Same source (municipal network), the quantity refers to no. 10 Some blocks and paves are packed with plastic cover, not only as a packaging, but also as an alternative for curing process.

- Quality

Same as tap water/municipal network. Curing takes 2 days for small trapezoid blocks and 3 days for normal blocks

About Water Quantity and Water Price

9. How much water (m^3) is required for concrete producing in 1 project?

Varies per project

10. How much water (m^3) is required for concrete producing in 1 day or in 1 month?

10,000L/day (total for mixing and curing) 500L/month (for cleaning the clinker, once a month) Total = 873m^3/month (refer to the water cost data)

11. How much is the percentage of the cost of water in concrete producing in 1 general project? (in meticals or %)

Average = 27,653.23MT/month (refer to the water cost data)

12. Does the company think that the cost of the water is expensive?

No, it is fair enough compared to the individual tariff and in other countries

About Water Resource Locations

13. Where are the locations of water resources for mixing and curing concrete? (tap water, groundwater, surface water, etc.).

Tap water (municipal network) In one emergency case in Feb-March 2015, the municipal supply ran out and Bricon had to take river water. The company transported the water with trucks, 1 truck to deliver 10,000L of water costs 4,000MT.

14. Is there any wastewater outlet near the batching plants/project sites?

No, only with septic tanks. The municipality of Matola is now arranging the strategic plan of the main sewer, but still be a bit longer to be constructed.

15. How is the water intake usually transported from the source to the batching plants?

Piping system from the network

About Future Plan

16. In the near future, what is your plan for the company in regards to concrete production? (e.g. expansion, gaining more projects, separate some divisions to be the spin-offs, etc.)

In the near future, Bricon will start producing reinforced concrete pipe, and the company already has 15 formworks, so the estimated daily production is 15 pipes/day.

Willingness to Participate

17. Are you willing to involve in assessing the possibility of using treated wastewater for concrete production and have more benefit instead of using tap water or extracting groundwater?

Sure! Bricon will be really happy to help ☺

Discussions

1. For producing concrete, water should not have salts and oil in it. Those are two major points based on the experience
2. Rainwater harvesting is one of the biggest concerns. The father-in-law of Sven has his house installed with rainwater harvesting and water recycling system. The rainwater is collected by gutter from the roof, goes to storage tank and filtered to be used for daily activities. The wastewater (greywater) from showering and washing dishes is reused for flushing toilets. The only water to be wasted is only the one from the toilet to the septic tank.
3. Education for the people to use water wisely and save water as much as they can.
4. Government should insist a proposal of water plan for companies, factories and industries, rather than only Environmental Impact Assesment (EIA). For example: car washing station.
5. The benefit from changing the source of water from the municipal network to the treated wastewater effluent depends on the investment and payback period. If within a range of time (maybe on 2-3 years) the companies can have a payback period from their first investment, they will be willing to change the source.
6. There is another alternative to obtain freshwater, which is from seawater desalination. This is more expensive, but thinking that Mozambique has easy access to the coast, it is recommended.

Companies	Class of Companies Based on the number of employees			Type of Concrete Production Method			Volume of Products (m^3 concrete/mth.)		Water Consumption (m^3 water/mth.)		Water Consumption/ Volume of Products (m^3 water/m^3 concrete)		Water Tariff* (€/mth.)		Water Tariff* (€/m^3)		Locations of Water Source					Individual Recycling System	
				Precast		In-situ																	
	Large (≥50)	Medium (20-<50)	Small (0-<20)	Non-reinforced (Blocks, Paves, Curbs)	Reinforced (RC Pipes, Tank)	Ready-mix	Reported (m^3/mth.)	Mean (μ), St.Dev (σ)	Reported (m^3/mth.)	Mean (μ), St.Dev (σ)	Reported (m^3/m^3)	Mean (μ), St.Dev (σ)	Reported (€/mth.)	Mean (μ), St.Dev (σ)	Reported (€/m^3)	Mean (μ), St.Dev (σ)	Tap Water (Network)	Surface Water (River)	Ground/ Surface Water (Trucks)	Ground Water (Individual)	Ground Water (External Pipelines)	Yes	No
Estaleiro Julio J. Paunde			2	•	•		78.16	μ =246.95 σ=248.76	17.00	μ=24.90 σ=17.68	0.22	μ=1.14 σ=1.68	7.33	μ=49.31 σ=56.08	1.12	μ=0.76 σ=0.34					•		•
Estaleiro JMS (José Manuel Sacoto)			10	•			10.36		42.00		4.05		19.40		0.45		•						•
Estaleiro Antonio Bernardo Tamele			15	•			357.28		48.00		0.13		24.67		0.40		•					•	
Resol			15		•	•	103.58		17.50		0.17		145.83		1.09				•				•
Estaleiro Amussuar Rassur			20	•			685.36		0.00		-		-		-					•			•
Cadin		21				•	13500.00	μ=6118.2 σ=4291.6	2430.00	μ=1615.25 σ=960.93	0.18	μ=0.32 σ=0.23	108.00	μ=160.34 σ=84.70	0.38	μ=0.38 σ=0.01	•		•				•
Prefangol		43				•	3750.00		2700.00		0.72		83.33		0.38					•		•	
Hidroblock, Lda.		45		•			2902.92		509.00		0.18		148.66		0.38		•			•N			•
Britanor, Lda.		55				•	4320.00		822.00		0.19		301.36		0.37		•	•O				•	
Cimbetão	85					•	1674.00	μ=5320 σ=3646	260.63	μ=1358.54 σ=485.54	0.16	μ=0.13 σ=0.03	800.00	μ=584.35 σ=215.65	3.07	μ=1.72 σ=1.34	•					•	
Bricon, Lda.	87			•	•N		8966.04		873.00		0.10		368.71		0.38		•		•E				•
Total									7719.13	μ=7719.13 σ=1970.43							7	1	3	3	1	4	7

*The costs were reported in MT (Mozambican meticals or MZN), given that €1 (European euro or EUR) is equal to 75 MT (Ostermiller, 2016).

(light)	=	small
(medium)	=	medium
(dark)	=	large

•O	=	occasionally
•E	=	Emergency
•N	=	near future

2. List of Construction Companies in Maputo

Sources:

1. Ministry of Industries *(Direcção Nacional da Industria)*
2. Water Consumption List of Industries from AdRM (*Águas da Região de Maputo)*
3. Yellow Pages Mozambique (Online)
4. Top 100 Companies in Mozambique 2010 (a list from KPMG Mozambique)
5. Other Companies' Contacts

Annex 2. List of Construction Material Companies in Maputo, Matola and Machava

List 1. Construction Material Industries in Maputo based on *Direcção Nacional da Industria* or National Directorate of Industries

No.	Name of the Company	Main Activity	Main Production	Province	District	Address	Telephone	Cell	Email	X	Y
1	2F Company lda	Fabrication of cement blocks for construction	Blocks	Maputo - Província	Matola	Bairro 1° de Maio, Q. 29, n°117		82 458 1760/ 84 296 4181			
2	Alberto Madocuane Matine	Fabrication of cement blocks for construction	Blocks	Maputo - Província	Matola	Bairro Tsalala, Q. 163, parcela 857		86 733 8683			
3	Albino Maguiana Magagule	Fabrication of cement blocks for construction	Cement blocks	Maputo - Província	Matola	Bairro Ndlavela, Q.9, C.11					
4	Alice Ancha Boana Mahomad Rachid	Dockyard	Blocks	Maputo - Província	Matola	Bairro de Tsalala, Q.88		82 877 0960			
5	Amussuar Rassur	Fabrication of cement blocks for construction (dockyard)	Blocks	Maputo - Província	Matola	Bairro da Matola F Rua Unidade Nacional Escola Industrial da Matola 146		84 404 7286		446116.8	7130091
6	Antonio Bernardo Tamele	Dockyard, concrete blocks	Blocks	Maputo - Província	Matola	Bairro Matola A nr 80		82 375 0399/ 84 778 5583		444600	7128867
7	Assistência Prom. H. Kuyaka	Fabrication of cement blocks for construction	Blocks	Maputo Cidade	Ka Mubukwana	AVª DE MOÇAMBIQUE, Nº 9610					
8	Benjamim Bombe	Blocks		Maputo - Província	Matola						
9	Blocos King	Fabrication of cement blocks for construction	Blocks	Maputo Cidade	Nhlamankulu	Bairro de Maxaquene Q.24/860 R.3.338					
10	C.E. Servicos, El	Fabrication and selling of construction material	Cement blocks	Maputo - Província	Matola	Bairro de Malhampsene		82 639 2574			
11	Chinmagul	Fabrication of cement blocks for construction	Blocks	Maputo Cidade	Ka Mfumo	Av. Da OUA nº96					
12	Claudino Fernando Sumbana	Fabrication of cement blocks for construction (dockyard)	Blocks	Maputo - Província	Matola	Bairro Nkombe, Q. 13					
13	Construtora M. B. Soc. Unip, Lda	Fabricação de blocos e pavês		Maputo Cidade	Mpfumo	Rua Gago Countinho nº 594					
14	Dinis trico Langa	Fabrication of cement blocks for construction (dockyard)	Blocks	Maputo - Província	Matola	Bairro da Liberdade, Av. Angonia, Q.4, n° 208		82 871 5080			
15	Estaleiro Cuinica & Filhos, Lda	Fabrication of cement blocks for construction	Cement blocks	Maputo - Província	Matola	Bairro da Matola					
16	Estaleiro Fernando Domingos Sigauque, El	Dockyard, concrete blocks	Blocks	Maputo - Província	Matola	Bairro da Liberdade, Q. 23, casa nr 520, Rua 13.541		82 737 7370/ 84 461 3009		446818.26	7134546.57
17	Estaleiro JJ Paunde El	Dockyard, concrete blocks	Blocks	Maputo - Província	Matola	Bairro Matola Gare, Q. 01, nr 103 B		82 664 0824		442504.98	7141473.47
18	Estaleiro Joaquim Tovele	Dockyard, concrete blocks	Blocks	Maputo - Província	Matola	Bairro da Matola C, q 7 nr 257, factory: Matola Joao Mateus Banco Procredito Parageu Boane		82 805 0400/ 82 455 4812		445208.98	7129005.89
19	Estaleiro Kula Matsolo, El	Fabrication of cement blocks for construction	Blocks	Maputo - Província	Matola	Bairro Nkobe		84 486 8750		443027.43	7136359.01
20	Estaleiro Lacerda, El	Fabrication of cement blocks for construction		Maputo - Província	Matola	Bairro Nkobe, Q. nº 03, nº 1245		82 599 3306/ 84 035 2321		442992.06	7136294.06
21	Estaleiro Macaringue El	Dockyard		Maputo - Província	Matola	Bairro da Matola G, Q. 6 R. 1281					
22	Estaleiro Mapasse, El	Dockyard		Maputo - Província	Matola	Bairro Ndlavela, Q. 20, casa nr 235		82 486 1440			
23	Estaleiro Mauricio e Filhos, lda	Fabrication of cement blocks for construction	Cement blocks	Maputo - Província	Matola	Bairro da Matola C, Q. 1,					
24	Estaleiro para Fabrico de Blocos e Venda de Material de Construcao	Fabrication of cement blocks for construction	Cement blocks	Maputo - Província	Matola	Bairro de Nkobe, Posto Administrativo da Machava					
25	Estaleiro Rasta 2, E.I	Gabrication of Construction Materials		Maputo - Província	Matola			84 535 2560			
26	Estaleiro Sabadar	Fabrication of cement blocks for construction	Cement blocks	Maputo - Província	Matola	Bairro da Liberdade - Machava					
27	Estaleiro Sarça Ardente	Fabrication of cement blocks for construction	Cement blocks	Maputo - Província	Matola	Bairro da Liberdade					
28	Estaleiro Tchumene, E.I	Fabrication of cement blocks for construction (dockyard)		Maputo - Província	Matola			84 798 8597			
29	Estaleiro Transporte El	Fabrication of cement blocks for construction		Maputo - Província	Matola	Bairro Matola Gare, Q. 18		82 891 6224			
30	Estaleiro Zunguze	Fabrication of cement blocks for construction	Cement blocks	Maputo - Província	Matola	Matola					
31	Estaleiro, Fabrico de Blocos e Venda de Material de Construcao	Fabrication of cement blocks for construction	Cement blocks	Maputo - Província	Matola	Bairro da Machava Socimol				447812.59	7138525.12
32	Eugenio Elias	Fabrication of cement blocks for construction (dockyard)	Blocks	Maputo - Província	Matola						
33	Faruke Mussa	Fabrication of cement blocks for construction	Cement blocks	Maputo - Província	Matola	Av. De Namaacha					
34	Fema Estaleiros Construções, Sociedade Unipessoal, Lda	Dockyard	Blocks	Maputo - Província	Matola	Bairro Matola C, Q. 12, casa nr 08		82 392 7500	fema.construcoes@gmail.com	444139.54	7132711.55
35	Ferragem estaleiro Ngomache	Fabrication of cement blocks for construction (dockyard)	Blocks	Maputo - Província	Matola	Bairro da Matola Gare		84 438 9853		443096.66	7141748.92
36	Figo e Irmaos Comercial, El	Fabrication of materials for construction		Maputo - Província	Matola	Matola Gare, Q. 25		82 708 2820		447509.29	7138537.17
37	Francisco da Silva Banze	Fabrication of cement blocks for construction	Blocks	Maputo - Província	Matola	Bairro de Infulene A		82 314 7390			
38	Gabriel Silva Noce Muianga	Dockyard	Blocks	Maputo - Província	Matola	Bairro Patrice Lumumba		82 529 8654			
39	Hidroblock, Lda	Fabrication of cement blocks and paves	Blocks, paves	Maputo - Província	Machava	Av. Josina Machel, Q. 96, bairro Machava Sede	21 750 268	84 938 3020	jose.nhavolo@hidroblock.com, geral@hidroblock.com	450148	7133602
40	Indústria Mipre	Fabrication of cement blocks for construction	Blocks	Maputo Cidade	Ka Mavota	Bairro de Hulene, Prolong. Da J. Nyerere					
41	J.M.S Estaleiro, El (Jose Manuel Sacoto, Lda)	Dockyard	Blocks	Maputo - Província	Matola	Bairro Nkobe, Q. 2, casa 237		84 437 6094	celestemartyn94@gmail.com	443163	7136351
42	Joao Americo Jose Guiamba	Fabrication of cement blocks for construction	Blocks	Maputo - Província	Matola			82 866 8730			
43	Joao Domingos Mucavele	Dockyard	Blocks	Maputo - Província	Matola	Bairro Machava km 15, Q 18 nr 1784					
44	Joaquim Joao da Cruz Fumo	Fabrication of cement blocks for construction (dockyard)	Blocks	Maputo - Província	Matola			82 588 1667			
45	John Black Yard	Fabrication of construction materials		Maputo - Província	Matola						
46	Jonas Lourenço Miambo Nhambe	Micro-manufacturing industry for yard blocks and sale of building materials		Maputo - Província	Matola			82 783 7890			
47	Julio Langa	Fabrication of cement blocks for construction (dockyard)	Blocks	Maputo - Província	Matola	Bairro Nkobe		82 590 2191		443057.74	7136298.58
48	Kevin Enterprise	Fabrication of cement blocks for construction (dockyard)	Blocks, stones/rocks	Maputo - Província	Matola	Matola F		84 700 0086			
49	Lau Ming Kwan	Fabrication of cement blocks for construction	Cement blocks	Maputo - Província	Matola	Bairro Tchumene					
50	Lemos Mangulene Muungone	Dockyard	Blocks	Maputo - Província	Matola	Bairro Acordos de Lusaka					
51	Louis Manuel Paul	Fabrication of cement blocks for construction	Blocks	Maputo Cidade	Ka Maxakeni	Av. Acordos de Lusaka P.M. Mazambane					
52	Malique Ambasse	Fabrication of cement blocks for construction		Maputo - Província	Matola			84 438 8043			
53	Marcelino de Sousa Armando	Fabrication of cement blocks for construction	Blocks	Maputo - Província	Matola			82 701 5550/ 84 677 2331			
54	Matoa Hardware, El	Fabrication of construction materials		Maputo - Província	Matola	Bairro Matola F, Q. 14, nº 1078, Av. Joaquim Chissano		84 383 8443			
55	Moisés Bila	Fabrication of cement blocks for construction	Blocks and tiles	Maputo Cidade	Ka Mfumo	Av. Amílcar Cabral 896					
56	Moviblocos- Sociedade Unipessoal, Lda	Fabrication of cement blocks for construction (dockyard)		Maputo - Província	Boane	Matola Rio, Distrito de Boane					
57	Moz Gates, El	Manufacturing structures and metal constructions		Maputo - Província	Matola	Bairro Zona Verde, Q. 22		84 447 0927			
58	Mozambique Blocos	Fabrication of cement blocks for construction	Blocks	Maputo - Província	Matola	Matola "A"					
59	Mozarga, Lda	Production of mortar and building materials		Maputo - Província	Matola	Matola C, nr 356, Q.04, Municipio da Matola		82 476 8462			
60	Nazevo Comercial	Fabrication of cement blocks for construction	Blocks	Maputo Cidade	Ka Mfumo	Br. Polana C Q. 37 C nº. 57					
61	Remirelis R. Construções	Fabrication of cement blocks for construction	Blocks	Maputo Cidade	Ka Mubukwana	Av. de Moçambique Q.5 Casa 54					
62	Sheng Hui Construções, Lda	Fabrication of cement blocks for construction (dockyard)	Blocks and paves	Maputo Cidade	Ka Mubukwana	Av. de Moçambique, Parcela nº 16/365					
63	Tutuvala Manala	Fabrication of cement blocks for construction	Dockyard blocks	Maputo - Província	Matola	Bairro Skvama					
64	Virginia Antonio Matuto Lissenga	Fabrication of cement blocks for construction	Cement blocks	Maputo - Província	Matola	Machava Socimol					
65	Vladmiro Zitha	Fabrication of cement blocks for construction	Blocks	Maputo Cidade	Ka Mfumo	Av. Milagre Mabote nº.1072					
66	W.R.T. Construções, Lda.	Fabrication of bricks and tiles, production of clay for constructions	Construction materials	Maputo - Província	Matola	Av. das Industrias					
67	Wilblocks & Paving - soc.Unip, lda	Fabrication of cement blocks for construction (dockyard)	Blocks and paves	Maputo Cidade	Ka Nhlamankulo	Rua Tindzen nº 5564					

List 2. Industries in Maputo with Largest Water Consumption based on Águas da Região de Maputo

No.	Client Code	Client Name	Main Production	Telephone	Cell	Email	Website	Location/Address	Province	District	X	Y
1	2054175	Amigo Construções, Lda	Construction Materials		84 5000 007	luxorapido@gmail.com	http://amigoconstrucoes.yolasite.com/	Av.Samora Machel nr:506	Maputo	Matola	444132	7132624
2	90182	Bricon, Lda	Paves, Blocks, Cements	21 777 002	82 302 6443, 82 284 3399	balcao1@bricon.co.mz, sderfoldy@gmail.com		Estr Nacional nº 2 Km 15/Parcela 875	Maputo	Belo Horizonte	441980	7124427
3	2053942	Cimpor Betão Portugal Moçambique SARL	Construction Materials	21 407 868		https://mz.linkedin.com/in/daniel-mazive-a1629354		Av.Alberto Massavanhane 5	Maputo	Maputo	456085	7127929
4	75523	Construções CCM, Lda	Construction Materials	21 310 801		construcoesccm1998@gmail.com		Av. Vladimir Lenine 130, F: Av.União Africana Matola A	Maputo	Maputo	449414	7131026
								Av.Samora Machel nr:269			443477	7131848
5	73027	Guca Engenhil Construções						Rua Sofala	Maputo		446363	7129647
6	1406167	MC Maxaka Consultores	Construction Materials	21 770 400				(Rua Boane) ETA Umbeluzi	Maputo		437307	7117101
7	951302	Soares da Costa	Construction Materials	21 431 059	82 315 5290	scosta.sec@teledata.mz	http://www.soaresdacosta.com/pt/	Av. Ho Chi Minh, 1178 - 2º	Maputo	Andar	448422	7133586
8	71927	Tâmega	Construction Materials					Rua Tamega			450246	7133266

List 3. Industries in Maputo with Largest Water Consumption based on Yellow Pages website

No.	Name of the Company	Main Activity	Main Production	Province	District	Address	Telephone	Cell	Email	Website	X	Y
1	ABD Construções Lda	Construction and fabrication	Construction materials	Maputo	Maputo	Av. Vladimir Lenine 1895	21 414 890	82 080 4035	abdconstrucoes@gmail.com, aabdconstrucoes@yahoo.com.br		458963.51	7129690.87
2	Abrantina/ Lena Construções	Construction and fabrication	Construction materials	Maputo	Maputo	Av. Emilia Dauusse 474	21 32 94 68			www.abrantina.pt	457040.25	7128901.40
3	Azka Construções, Lda	Construction and fabrication	Construction materials	Maputo	Costa Sol	R Paz 420 r/c Bº	21 414 991	82 307 0650	azkaconstrucoes@hotmail.com		458292.08	7136271.35
4	Adilson Construções, Lda	Construction and fabrication	Construction materials	Maputo	Maputo	Av. Ho Chi Min 1527 2^0 05	21 493 875	82 322 2950, 84 322 2950	geral@adilsonconst.co.mz, jorgebranco@live.com		457868.89	7127464.19
5	Agecon	Construction and fabrication	Construction materials	Maputo	Maputo	Av. Eduardo Mondlane 1040 1A	21 305 564		agecomlda@gmail.com		457942.79	7127981.72
6	Aveng Moçambique, Lda	Construction and fabrication	Construction materials	Maputo	Sommerschield	Rua Rosas 91, Bº, Rua Jose Craveirinha 141A	21 488 703		moises.maposse@avenggroup.com, aveng.mozambique@avenggroup.com, louis.odendaal@avenggroup.com, https://mz.linkedin.com/in/manuel-pearson-28423455?trk=pub-pbmap	www.avenggroup.com, www.avenggroup.co.za	460399.70	7128709.77
7	Brakxem Construções	Construction and fabrication	Construction materials	Maputo	Maputo	Av. 25 Setembro 1509 2^0	21 307 512		dcomercial.brakxem@tvcabo.co.mz		448463.00	7132516.00
8	Camargo Corrêa Moçambique	Construction and fabrication	Construction materials	Maputo	Maputo	Av 24 Julho 7, 9º	21 245 100	82 301 2269		http://www.camargocorrea.com.br/	455320.00	7129297.22
9	CETA - Engenharia e Construção	Construction and fabrication	Construction materials	Maputo	Andar	Av 25 Setembro 420 3º	21 301 855	82 316 0510	ceta@ceta.co.mz			
10	Chibuco Construções	Construction and fabrication	Construction materials	Maputo	Maputo	Av. 25 Setembro 2206 1^0	21 303 887				448176.75	7132145.98
11	China Geo Engineering Corporation	Construction and fabrication	Construction materials	Maputo	Boane	E.T.A. Umbeluzi 294	21 901 175	84 818 2552	stonekeh@gmail.com		432672.68	7119214.60
12	China Henen International Coop Group Co., Lda	Construction and fabrication	Construction materials	Maputo	Sommerschield	R Beijo Mulata Bº Sommerschield 248	21 496 054		chicomoz@c-chico.com, hanchaoji@c-chico.com	www.c-chico.com	460435.22	7129881.55
13	Construtora do Mendeso	Construction and fabrication	Construction materials	Maputo	Maputo	Av. 25 Julho 1623 R/C	21 303 632				457402.99	7127949.55
14	EcoàJuan, Lda	Construction and fabrication	Construction materials	Maputo	Maputo	Rua da gase de Mercadarian 480	21 460 887	82 399 0160	ecoajuan.mz@gmail.com			
15	Edimade Moçambique SA	Construction and fabrication	Construction materials	Maputo	Maputo	R Resistência 2623	21 415 514		edimademocambique@gmail.com	http://www.edimade.com/	458979.86	7129967.56
16	Electricidade Construccies Civile J.S.	Construction and fabrication	Construction materials	Maputo	Maputo	Av. Trabalho 42RC	21 401 725				456147.58	7129090.47
17	Empresa de Reparações de Imóveis e Construção Civil	Construction and fabrication	Construction materials	Maputo	Maputo	Av. Eduardo Mondlane 1659 R/C	21 305 882					
18	Enge Concret	Construction and fabrication	Construction materials	Maputo	Maputo	Av. Trabalho 127 2^0	21 404 998				455305.99	7129795.85
19	Estaleiro de Venda de Material de Construção	Construction and fabrication	Construction materials	Maputo	Bagamoyo	R Principal 4176 Cl F/Q 8 Bº	21 472 872	82 416 9300	emo@tdm.co.mz			
20	Gilectrica	Construction and fabrication	Construction materials	Maputo	Maputo	R Cabo Delgado 61	21 414 630	82 430 0260	construcoesgilectrica@gmail.com		457933.68	7129026.23
21	HC Construções	Construction and fabrication	Construction materials	Maputo	Maputo	R. Chonguene Bº Munhuana 123/Q 7	21 405 832		hcconstrucoes3@gmail.com			
22	Infra Engineering Mozambique	Construction and fabrication	Construction materials	Maputo	Maputo	R. Tchamba 46	21 498 154		flora_nhamizinga@yahoo.com		461588.62	7135292.99
23	Isowat Moçambique	Construction and fabrication	Construction materials	Maputo	Maputo	R. Infriensa 256 4^0 401	21 312 764		isowat.mocambique.lda@gmail.com	www.isolux_es		
24	Julen Construções, Lda	Construction and fabrication	Construction materials	Maputo	Maputo	R. Orlando Mendes	21 497 576	84 497 5760	julenmoz@yahoo.com, julenconstrucoes.lda.secretary@gmail.com	www.julenmoz.com	460053.45	7128930.86
25	Lac Construções, Lda	Construction and fabrication	Construction materials	Maputo	Maputo	Av. Vladimir Lenine/537 E 545 R/C	21 304 854					
26	Lopes Eng. E Construccies	Construction and fabrication	Construction materials	Maputo	Maputo	Av. Angola 4	21 903 081					
27	Manutenção e Construção Civil - MCC	Construction and fabrication	Construction materials	Maputo	Matola	R Eusébio S Ferreira 474	21 902 067	84 924 4587	juma.cangy@mcc.co.mz			
28	Massaro Comercial Ferragens, Lda	Construction and fabrication	Construction materials	Maputo	Machava	Av 4 Outubro 131/D Bº Infulene	21 708 474	82 233 4040/ 84 304 6780				
29	Mendip Madiezenta Projects, Lda	Construction and fabrication	Construction materials	Maputo	Maputo	R. Mesquita 1145 1^0	21 328 026					
30	Minc Construcoes	Construction and fabrication	Construction materials	Maputo	Maputo	B. Maxaquene B Cel B Casa 29 Q21	21 414 926		minc_constructora@tdm.co.mz		458620.83	7130662.58
31	Moçambique Lda NC	Construction and fabrication	Construction materials	Maputo	Maputo	Av. Paulo Samuiel Kaukhomba 395 1^0	21 720 397					
32	Moçambique Constructora	Construction and fabrication	Construction materials	Maputo	Piso 3 Porta2	Av. Zedequias Manganhela 520	21 304 544		mocambique.construtora@gmail.com	http://mocambiqueconstrutor.wix.com/		
33	Monte Adriano Mocambique	Construction and fabrication	Construction materials	Maputo	Maputo	Av. Zedequias Mangarlela 267 4^0	21 303 980					
34	MOTA - Engil Engenharia e Construção SA	Construction and fabrication	Construction materials	Maputo	Maputo	Av Vladimir Lenine 142 15º	21 305 485		geral@mota-engil.co.mz	www.mota-engil.pt	449785.00	7133811.00
35	Moza Construction, Lda	Construction and fabrication	Construction materials	Maputo	Machava	Av 24 Julho 3549 3º	21 402 271		mozaconstruction@moza.co.mz		459212.78	7126862.38
36	Obra Prima, Lda	Construction and fabrication	Construction materials	Maputo	Maputo	200 R. Fernaie Lopez	21 720 546		celina@obraprima.com		459677.53	7128665.36
37	Oga Construções SARL	Construction and fabrication	Construction materials	North	North	Av. 24 Julho 919	21 314 164	82 031 4164	oga.moz@oga.co.mz		456681.00	7128421.32
38	Optima Engenharia e Contrução Civil	Construction and fabrication	Construction materials	Maputo	Maputo	Av. Ahmed S Touré 3395 2º	21 404 726		optimacivil@gmail.com		456279.04	7128818.59
39	Portico Construções Lda	Construction and fabrication	Construction materials	Maputo	Porta2	R. Estâncias Dias 344	21 300 590	82 436 4620	portconstrucoes@tdm.co.mz			
40	Procom	Construction and fabrication	Construction materials	Maputo	Maputo	R. Udenamo 218 RC	21 400 563					
41	Proconstrói, Lda	Construction and fabrication	Construction materials	Maputo	Maputo	Av. Base N'tchinga 395	21 418 304		proconstroi@tdm.co.mz	www.proconstroi.co.mz	458681.75	7128900.25
42	Projecto Bad	Construction and fabrication	Construction materials	Maputo	Maputo	Av. Ahmed S. Torc 980 3^0	21 302 800					
43	Renna Construções Civile Obr	Construction and fabrication	Construction materials	Maputo	Matola	107 B^0 Formento	21 782 090					
44	Resol Construção Civil, Lda	Construction and fabrication	Construction materials	Maputo	Maputo	R Joe Slovo 102 1º	21 304 388	82 374 5463/ 84 407 0890	rccivil.rcc@gmail.com		457145.05	7127101.78
45	SETHMOZ - Construção, Engenharia & Obras Públicas SA	Construction and fabrication	Construction materials	Maputo	Maputo	Rua B 153 Bº Coop	21 415 401		geral@sethmoz.co.mz	www.sethmoz.co.mz		
46	Stedone Group Mozambique, Lda	Construction and fabrication	Construction materials	Maputo	Maputo	R. Argelia 299 R/C	21 493 177	82 921 4404		http://www.stedone.co.za/		
47	Stine Construções, Lda	Construction and fabrication	Construction materials	Maputo	Maputo	Av. Trabalho 127 1	21 402 454	82 497 1170	stineconstrucoes@tvcabo.co.mz, m.davidjulio@yahoo.com		455305.99	7129795.85
48	SS Construções Moçambique, Lda	Construction and fabrication	Construction materials	Maputo	Maputo	Av. Moçambique Km 13 7160	21 471 607	82 329 6540	ssconstrucoes@stestocks.com	www.stefanuttistocks.com	456908.34	7143184.77
49	Teixeira Duarte Moçambique, Lda	Construction and fabrication	Construction materials	Maputo	Maputo	Av. Julius Nyerere 130 R/C	21 491 401		teixeiraduarte@tvcabo.co.mz			
50	Tetris, Lda	Construction and fabrication	Construction materials	Maputo	Maputo	Fr R João Santos 97 1º	21 414 417	82 301 7710	tetrislda@gmail.com			
51	Trevi Spa	Construction and fabrication	Construction foundations	Maputo	Maputo	Av. Namaacha	21 783 908	84 307 6079	profuro@profurointlda.com			
52	Terratech Construções, Lda	Construction and fabrication	Construction materials	Maputo	Maputo	Av. 24 Julho 730	21 902 031				456216.50	7128770.66
53	Uamba Construções	Construction and fabrication	Construction materials	Maputo	Matola	R. Unango 57/Tal 352 Qtº 30	21 720 097					
54	VCL - Vuma Construções Lda	Construction and fabrication	Construction materials	Maputo	Maputo	Av. Josina Machel 140 1º	21 314 474					
55	Vista Um Internacional, Lda	Construction and fabrication	Construction materials	Maputo	Maputo	Av. FPLM 1991	21 462 615		vistafeedback@tdm.co.mz, georger@tdm.co.mz			
56	WBHO Projects, Lda	Construction and fabrication	Construction materials	Maputo	Matola	Av. Samora Machel 259	21 747 936		saralopes@tdm.co.mz	www.wbho.co.za		
57	WK Construções, Lda	Construction and fabrication	Construction materials	Maputo	Matola	Av. Samora Machel 468	21 782 173		manueljaime@wk.co.mz		444826.00	7131449.00
58	Zagope - Construções Engenharia SA	Construction and fabrication	Construction materials	Maputo	Maputo	Av. Zimbabwe 560	21 492 754					

List 4. Construction Material Industries in Maputo in KPMG List (2011) and Personal Referrals

From Top 100 Companies in Mozambique 2011 (KPMG)

No.	Name of the Company	Main Activity	Main Production	Province	District	Address	Telephone	Cell	Email	Website	X	Y
1	CAPA Engenharia Moçambique, Lda (ex Capáfrica)	Construction		Maputo	Maputo	Av. Moçambique, nº2300	21 477 142	82 302 3050			461823.53	7149673.85
2	C.M.C. Africa Austral, Lda	Construction		Maputo	Matola	Av Vladimir Lenine 142 10º, Av. da Namaacha Km. 6 – Parcela 728	21 78 03 57		info@cmcaa.co.mz	www.cmcafricaaustral.com	448580.41	7130910.9
3	CETA - Construções e Serviços, SARL	Construction	blocks, paves, roads & ports construction, etc.	Maputo	Maputo	Av. 24 de Julho, nº 2548, 1º andar, Av. Joaquim Chissano	21 35 56 60	82 314 8660/ 82 314 366			456889.39	7130784.47
4	Conduril, SA - Construtora Durience Delegação de Moçambique	Construction		Maputo	Maputo	Rua nº 1393 (Transversal da Av. José Craveirinha), nº 120	21 48 31 20				446324.69	7127920.43
5	Construtores Chemane	Construction		Maputo	Maputo	Av. 25 de Setembro, nº 1676, 1º andar p/6	21 32 42 36				550086.68	7886812.91
6	Ecori, Lda	Construction		Maputo	Maputo	Av. Lg Algarve 16/100 r/c	21 48 49 48 /9					
7	ENOP, Lda - Engenheria de Obras Públicas	Construction		Maputo	Maputo	Rua nº 1393 (Transversal da Av. José Craveirinha), nº 120	21 48 31 20				446381.69	7128095.74

From Personal Referrals

No.	Name of the Company	Main Activity	Main Production	Province	District	Address	Telephone	Cell	Email	Website	X	Y
1	Blitz L.M. Lda	Construction	Paves, curbs, blocks, etc.	Maputo	Boane	Estrada Nacional n° 2 Umbeluzi-Boane	21 77 02 70	82 31 00 460	blitz@blitz.co.mz	http://www.blitz.co.mz/	432746.15	7119690.71
2	Cadin Lda. (Concretos e Agregados do Indico)	Construction	Ready mix concrete	Maputo	Machava	Av. Das Industrias n° 3263		82 37 67 38 0 (Ineida)	cadinlda@gmail.com		448980	7133169
								82 08 18 50 0 (Carlos Delgado)	cdelgado@grupomv.es			
3	Britanor, Lda	Construction	Ready mix concrete, roads & ports, blocks (precast), strength lab	Maputo	Maputo	Av. Joaquim Chissano - Estaleiro da CETA	21 406 516	82 300 5795/ 84 661 7977	jmassango@britanor.co.mz		456820.74	7130832.97
4	Decostone	Construction Materials	Ready mix concrete	Maputo			21 30 56 25				457005.77	7127112.95
5	Sobrita	Construction Materials	Concrete blocks	Maputo								
6	Hard Stone Block	Construction Materials	Concrete blocks	Maputo				82 72 13 46 0				
7	Prefangol	Construction Materials	Ready mix concrete	Maputo	Sommerschield	R. Kibiriti Diwane, N.º 92	21 49 82 67 /8	84 80 82 53 5 (Sergio)	sergio.major@prefangol.com, info.mozambique@prefangol.com, comercial.mozambique@prefangol.com	http://www.prefangol.com/	455020.56	7129784.63
8	Cimbetão	Construction Materials	Ready mix concrete	Maputo	Maputo	Av. Joaquim Chissano	84 31 23 83 7	84 32 92 01 5 (Leonardo)			456866	7130810
9	Trans Aly	Construction Materials	Ready mix concrete	Maputo							447287.5	7129413.44
10	Lalgy	Construction Materials	Ready mix concrete	Maputo	Matola			84 63 32 39 2 (Sheid)			447508.8	7129632.72
11	Sulbuta	Construction Materials	Ready mix concrete	Maputo							445861.34	7129467.99
12	Servifuturo	Construction Materials	Ready mix concrete	Maputo				84 45 43 20 7 (Zamil)				
13	Nifiquile	Construction Materials	Ready mix concrete	Maputo				84 30 27 32 0 (Zuber)			463767.14	7134876.14
14	MRB	Construction Materials	Ready mix concrete	Maputo								
15	Xun Tong	Construction Materials	Ready mix concrete	Maputo								
16	China Road and Bridge Company	Construction Materials	Ready mix concrete	Maputo								

List 5. Potential Sources for Water Reclamation Treatment Scheme

Potential Sources

No.	Name of the Company	Main Activity	Main Production	Province	District	Address	Telephone	Cell	Email	Website	X	Y
1	Infulene (Wastewater Treatment Plant)	Construction Materials	Ready mix concrete	Maputo	Infulene	Infulene (Av. Eduardo Mondlane - Av. Joaquim Chissano)					453712.3	7132983.53
2	Coca Cola Factory			Maputo	Machava	(moved to Matola Gare)					450786.26	7133064.64
3	Fábrica de 2M			Maputo	Maputo	Av. Eduardo Mondlane - Av. Joaquim Chissano - Rua Do Cha					454405	7132764

3. Field and Laboratory Measurement Results

1. Preliminary sampling periods (April – May 2016)
2. Results from UEM students (June – September 2016)

Annex 3.1

	Date	Point of Location	Flow	Oxygen			Conductivity			Turbidity	PH			Organic		Total Nitrogen				Total Phosphorus		Solids	Other Chemicals	
			Q	T0	T1	OX	T0	T1	Cond		T0	T1	PH	COD	BOD	Nitrogen (N)	Ammonia (NH_4^+)	Nitrite (NO_2^-)	Nitrate (NO_3^-)	PO_4^{3-}	P_2O_5	TSS	Calcium (Ca^{2+})	Chlorine (Cl_2)
			(m^3/s)	(°C)	(°C)	(mg/L)	(°C)	(°C)	(µS/cm)	(NTU)	(°C)	(°C)	(-)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
Week 1	08.06.16	Influent	0.09	27.1	25.8	0.23	28	25.9	1346	89.30	27.1	26.2	7.29	230.00		71.50	56.00	0.18	0.64	-	20.00	-	88.00	-
	08.06.16	Emergency outlet	-	23.8	22	0.21	24.2	21.8	1805	29.71	24.2	22.3	7.06	145.00		87.00	54.00	0.09	0.94	-	17.50	-	100.00	-
	08.06.16	Facultative pond outlet 2	-	23.2	21	0.93	22.4	21.1	1501	15.97	22.7	21.1	7.15	60.00		55.10	63.70	0.07	0.40	-	20.00	-	96.00	-
Week 2	15.06.16	Influent	0.08	26.5	25.3	1.19	32.2	25.6	1382	60.50	24.7	24.4	7.35	185.00	57.43	60.70	53.60	0.14	1.59	51.60	12.60	82.5	-	-
	15.06.16	Emergency outlet	-	23.7	20.4	0.36	23.8	20.3	1876	25.35	20.9	20.5	7.06	140.00	56.92	110.00	72.00	0.11	2.64	70.80	24.90	67.5	-	-
	15.06.16	Facultative pond outlet 2	-	21.7	20.8	0.48	20.8	20.3	1563	7.72	19.6	20.6	7.17	60.00	58.97	78.70	64.00	0.08	2.17	52.21	11.60	-	-	-
Week 3	22.06.16	Influent	61.05	23.6	24.6	0.21	24.3	24.7	1420	87.67	21.1	24.8	7.37	215.00	58.38	82.00	57.70	0.16	0.51	17.70	-	-	-	-
	22.06.16	Emergency outlet	-	22.5	21	0.21	23.6	20.8	1954	58.07	20.8	21	7.06	230.00	51.81	99.30	65.10	0.02	0.43	35.90	-	-	-	-
	22.06.16	Facultative pond outlet 2	-	20.6	20	0.89	20.4	20.8	1577	7.80	19.1	20.5	7.18	85.00	54.15	81.00	53.80	0.08	0.07	16.80	-	50	-	-
Week 4	29.06.16	Influent	3.72	28.5	25.2	0.13	25.9	25.2	1550	78.35	26.4	25.8	7.37	215.00	51.96	-	65.40	0.17	0.62	22.20	-	288.75	-	435.00
	29.06.16	Emergency outlet	-	22.5	20.7	0.17	21.1	20.6	2040	36.30	21.4	20.7	7.05	200.00	50.50	-	72.70	0.06	0.03	35.30	-	-	-	1005.50
	29.06.16	Facultative pond outlet 2	-	28.1	21.3	0.69	29.8	20.9	1614	7.99	25.7	21	7.12	70.00	49.92	-	65.40	0.07	0.42	18.30	-	-	-	333.70
Week 5	06.07.16	Influent	3.81	29.9	25.4	0.01	31.6	25.6	1410	89.23	26.4	25.6	7.42	215.00	540	43.50	53.50	0.15	0.38	19.20	-	-	-	246.00
	06.07.16	Emergency outlet	-	24.7	20.3	0.47	21.8	20	2050	26.50	21.1	20.5	7.15	185.00	70	67.40	3.50	0.08	0.48	56.70	-	-	-	330.00
	06.07.16	Facultative pond outlet 2	-	22.2	20.4	0.94	23.4	20.2	1655	8.32	18.7	19.9	7.19	100.00	55	18.40	77.70	0.04	0.55	18.90	-	-	-	386.00
Week 6	20.07.16	Influent	-	28	24.8	0.22	27.2	24.6	1506	83.17	23.8	24.6	7.34	170.00	15	34.30	44.80	0.12	0.52	18.40	-	-	-	218.00
	20.07.16	Emergency outlet	-	23.4	20	0.11	22.8	20.2	2020	150.00	20.5	20.1	7.11	200.00	220	69.80	3.50	0.24	1.34	52.80	-	-	-	656.00
	20.07.16	Facultative pond outlet 2	-	22.8	19.9	1.21	26	19.5	1715	8.16	20.5	19.5	7.14	100.00	90	44.40	66.10	0.06	0.31	19.00	-	-	-	512.00
Week 7	27.07.16	Influent	-	23.7	22.1	0.31	23.4	22.1	712	83.87	22.9	22.1	7.04	215.00	-	19.10	17.70	0.84	-	16.50	-	-	-	64.00
	27.07.16	Emergency outlet	-	25.1	20.9	0.55	24.8	20.8	2410	1260.40	23.7	21.1	7.04	260.00	-	73.40	95.40	0.40	1.61	47.50	-	-	-	644.00
	27.07.16	Facultative pond outlet 2	-	25.2	20.5	1.27	25	25	-	8.96	24.2	20.6	7.16	100.00	-	57.90	62.50	0.04	0.27	18.90	-	-	-	254.00
Week 8	03.08.16	Influent	-	30.3	24.5	0.07	31.7	24.2	1330	136.00	24.7	24.1	7.41	215.00	-	50.50	57.50	0.11	0.78	20.90	-	-	-	76.00
	03.08.16	Emergency outlet	-	26.3	21.1	0.31	29.5	20.8	1736	44.37	23.2	20.8	7.04	230.00	-	67.10	78.10	0.17	1.22	32.00	-	-	-	38.00
	03.08.16	Facultative pond outlet 2	-	26.3	19.9	0.99	24.3	19.5	1551	7.89	25.4	19.9	7.1	85.00	-	54.30	56.00	0.17	3.89	18.70	-	-	-	10.00
Week 9	10.08.16	Influent	-	30.4	24.5	0.01	36.5	24.5	939	122.00	32.2	24.8	7.32	-	-	-	-	-	-	-	-	-	-	-
	10.08.16	Emergency outlet	-	39	23.3	0.32	41.5	20.8	1458	48.25	40.2	21.3	6.98	-	-	-	-	-	-	-	-	-	-	-
	10.08.16	Facultative pond outlet 2	-	32.7	20.7	0.28	31.8	20.7	1320	10.65	-	21.1	7.02	-	-	-	-	-	-	-	-	-	-	-

Annex 3.2

Measurement	Parameter	Unit	Influent								Effluent (Emergency Outlet)						Effluent (Facultative Pond 2)								Equipment	Combined Limit (Table 2.3)
			1	2	3	4	Mean	St. Dev	Accuracy	Total Error	1	2	Mean	St. Dev	Accuracy	Total Error	1	2	3	4	Mean	St. Dev	Accuracy	Total Error		
Field	Date	[-]	14-Apr-16	19-Apr-16	26-Apr-16	3-May-16					26-Apr-16	3-May-16					14-Apr-16	19-Apr-16	26-Apr-16	3-May-16						
	Flow	[m3/s]	0.10	0.10	0.08	0.08	0.09	0.01	0.001	0.01	0.20	0.07	0.13	0.08	0.001	0.08	0.08	0.11	0.11	0.11	0.11	0.01	0.001	0.01	meter	-
	Ambient Temperature	[°C]	28.60	30.10	28.63	25.50	28.21	1.68	0.10	1.68	28.13	28.13	28.13	13.63	0.10	13.63	32.03	32.93	-	27.43	27.43	2.41	0.10	2.41	WTW pH3110 IDS	18 - 30
	Sample Temperature	[°C]	29.70	29.23	29.30	27.50	28.93	0.85	0.10	0.85	23.90	23.90	23.90	11.71	0.10	11.72	27.40	26.30	-	27.50	27.50	0.54	0.10	0.55	WTW pH3110 IDS	18 - 30
	pH - field	[-]	7.54	7.48	7.32	7.37	7.43	0.09	0.50%	0.09	7.05	7.05	7.05	3.50	0.50%	3.50	7.11	7.16	-	7.14	7.14	0.02	0.50%	0.02	WTW pH3110 IDS	6.0 - 8.0
	Dissolved Oxygen	[mg/L]	0.65	0.21	0.07	0.05	0.24	0.24	0.50%	0.24	0.06	0.06	0.06	0.09	0.50%	0.09	0.64	0.46	-	0.20	0.20	0.18	0.50%	0.18	WTW Oxi3110 IDS	-
	Conductivity	[µS/cm]	1445.00	1293.00	1415.00	1315.00	1367.00	64.36	0.50%	64.36	1945.00	1945.00	1945.00	956.68	0.50%	956.68	1412.00	1486.00	-	1573.00	1573.00	65.80	0.50%	65.80	WTW Cond3110 IDS	-
	Turbidity	[NTU]	24.10	34.00	50.70	75.37	46.04	19.42	2%	19.42	17.77	31.23	24.50	11.15	2%	11.15	29.40	7.81	42.97	10.10	26.53	14.46	2%	14.46	WTW Turb 430 IR	-
Lab	Ambient Temperature	[°C]	23.00	25.70	26.10	23.60	24.60	1.32	0.10	1.33	26.20	23.60	24.90	12.14	0.10	12.14	23.00	25.70	26.10	24.40	25.25	1.21	0.10	1.22	WTW pH3110 IDS	18 - 30
	Sample Temperature	[°C]	23.60	25.90	26.20	24.60	25.08	1.04	0.10	1.05	26.00	24.30	25.15	12.31	0.10	12.31	24.00	25.80	26.00	24.50	25.25	0.85	0.10	0.85	WTW pH3110 IDS	18 - 30
	pH - lab	[-]	7.36	7.38	7.41	7.51	7.42	0.06	0.50%	0.06	7.39	7.53	7.46	3.71	0.50%	3.71	7.08	7.25	7.41	7.44	7.43	0.14	0.50%	0.14	WTW pH3110 IDS	6.5
	Alkalinity-M	[mg/L]	323.00	290.67	313.00	110.67	259.33	86.63	2%	86.63	305.33	131.67	218.50	111.26	2%	111.26	334.00	300.33	295.33	138.33	216.83	75.76	2%	75.76	Wagtech Photometer 5000	-
	Alkalinity-P	[mg/L]	15.00	20.67	21.33	85.00	35.50	28.68	2%	28.68	71.00	100.00	85.50	38.38	2%	38.38	32.50	67.00	69.00	28.33	48.67	18.86	2%	18.86	Wagtech Photometer 5000	-
	Alkalies	[mg/L]																								1500
	Bicarbonate	[mg/L]	293.00	249.33	270.33	0.00	203.17	118.31	2%	118.31	163.33	0.00	81.67	72.18	2%	72.18	269.00	166.33	157.33	81.67	119.50	66.65	2%	66.65	Wagtech Photometer 5000	-
	Carbonate	[mg/L]	30.00	41.33	42.67	51.33	41.33	7.59	2%	7.59	142.00	63.33	102.67	56.78	2%	56.78	65.00	134.00	138.00	56.67	97.33	37.73	2%	37.73	Wagtech Photometer 5000	-
	Hydroxide	[mg/L]	0.00	0.00	0.00	59.33	14.83	25.69	2%	25.69	0.00	68.33	34.17	27.92	2%	27.92	0.00	0.00	0.00	0.00	0.00	0.00	2%	0.02	Wagtech Photometer 5000	-
	Sodium	[mg/L]																								[No limit]
	NH_4NO_3	[mg/L]																								32.65
	Potassium	[mg/L]																								[No limit]
	TSS	[mg/L]	-	-	-	-	150.00	-	-	-	-	-	150.00	-	-	-	-	-	-	-	150.00	-	-	-	Septic tank effluent	67.03
	TDS	[mg/L]	-	-	-	-	497.00	-	-	-	-	-	497.00	-	-	-	-	-	-	-	497.00	-	-	-	Septic tank effluent	1000
	FOGs	[mg/L]	-	-	-	-	50.00	-	-	-	-	-	50.00	-	-	-	-	-	-	-	50.00	-	-	-	Septic tank effluent	50
	Chlorine	[mg/L]	0.16	0.07	0.15	0.23	0.15	0.06	2%	0.06	0.01	0.04	0.02	0.02	2%	0.03	0.25	0.03	0.12	0.10	0.12	-	-	-	Wagtech Photometer 5000	
	Chloride	[mg/L]																								100
	Chloramine	[mg/L]																								-
	Flourine	[mg/L]																								-
	Ammonia	[mg/L]	-	-	-	-	40.000	-	-	-	-	-	40.000	-	-	-	-	-	-	-	40.00	-	-	-	Wagtech Photometer 5000	-
	Nitrate, NO_3-N	[mg/L]	-	-	-	-	0.00	-	-	-	-	-	0.00	-	-	-	-	-	-	-	0.00	-	-	-	Septic tank effluent	6.748
	Nitrite, NO_2-N	[mg/L]																								-
	Total N	[mg/L]	-	-	-	-	60.00	-	-	-	-	-	60.00	-	-	-	-	-	-	-	60.00	-	-	-	Septic tank effluent	-
	Sulphate, SO_4^{2-}	[mg/L]	45.33	37.67	17.33	5.67	26.50	15.79	2%	15.79	2.67	2.67	2.67	6.16	2%	6.16	4.75	4.33	9.00	0.00	4.50	3.19	2%	3.19	Wagtech Photometer 5000	86.5
	Phosphate	[mg/L]	4.92	2.79	3.78	3.25	3.69	0.79	2%	0.79	4.49	4.16	4.33	1.98	2%	1.98	5.06	3.43	5.06	4.78	4.92	0.68	2%	0.68	Wagtech Photometer 5000	-
	tal Phosporus (P, P_2O_5, PO_4	[mg/L]	-	-	-	-	8.10	-	-	-	-	-	8.10	-	-	-	-	-	-	-	8.10	-	-	-	Septic tank effluent	6.7
	Chromium	[mg/L]																								-
	Sugars	[mg/L]																								100
	Lead	[mg/L]																								100
	Zinc	[mg/L]																								100
	Manganese	[mg/L]	0.002	0.005	0.000	0.006	0.004	0.003	2%	0.02	0.004	0.005	0.005	0.008	2%	0.02	0.002	0.005	0.003	0.000	0.002	-	-	-	Wagtech Photometer 5000	-
	BOD	[mg/L]	-	-	-	-	120.000	-	-	-	-	-	120.000	-	-	-	-	-	-	-	120.00	-	-	-	Septic tank effluent	-
	COD	[mg/L]	-	-	-	-	60.000	-	-	-	-	-	60.000	-	-	-	-	-	-	-	60.00	-	-	-	Septic tank effluent	664.23
	Coliforms	[E.coli/L]	-	-	-	-	1.00E+07	-	-	-	-	-	1.00E+07	-	-	-	-	-	-	-	1.00E+07	-	-	-	Septic tank effluent	100

4. Design Calculations

1. Dissolved Air Flotation
2. Coagulation – Flocculation
3. Sedimentation
4. Hydrocyclone
5. Porous Media Filtration
6. Microfiltration
7. Nanofiltration
8. Summary of Alternatives

Annex 4.1

Coagulation/Flocculation

<u>Design for 11 interviewed companies</u>

<u>1. Coagulation</u>

Inflow, Q	=	16.20 m^3/h	=	388.75 m^3/d	
	=	4.50 L/s			

<u>Dosing</u>

Alum, $Al_2(SO_4)_3.18H_2O$, will be used as coagulant.

Assumed alum as $Al_2(SO_4)_3.18H_2O$ with:

Percentage of Al	=	49%			(Gebbie, 2006)
Specific gravity, SG	=	1.29			(Gebbie, 2006)
Optimum pH	=	5.6 - 6.5			(Gebbie, 2006)

The source of water is from the influent of the WWTP, thus:

Phosphate concentration, [P]	=	3.69 mg/L			(Table 4.7)
Sulphate concentration, $[SO_4^{2-}]$	=	26.50 mg/L			(Table 4.7)
Molar mass of P, Mr.P	=	31 g/mol			
Molar mass of SO_4^{2-}, $Mr.SO_4^{2-}$	=	96 g/mol			
Phosphate concentration, [P]	=	([P]/1000)/Mr.P	=	1.19E-04 mol	
Sulphate concentration, $[SO_4^{2-}]$	=	$([SO_4^{2-}]/1000)/Mr.\ SO_4^{2-}$	=	2.76E-04 mol	
Total contaminant concentration, [Cont.]	=	$[P] + [SO_4^{2-}]$	=	3.95E-04 mol	
	=	Required [Al]			

From the reaction balance:

$$Al_2(SO_4)_3.18H_2O \rightarrow 2Al^{3+} + 3SO_4^{2-} + 18H_2O \rightarrow 2Al(OH)_3 + 6H+ + 3SO_4^{2-} + 12H_2O$$

Thus;

Required alum concentration, [alum]	=	Required [Al]/2			
	=	1.98E-04 mol			
Molar mass of Al, Mr. Al	=	27 g/mol			
Molar mass of alum, $KAl_2(SO_4)_3.18H_2O$, Mr.alum	=	666 g/mol			
Alum dose	=	[alum] x Mr.alum	=	0.13 g/L	
	=	132 mg/L			
Flow rate	=	Alum dose x Q x 1000 x 60 / (10,000 x Percentage x SG)			
		56.19 L/min.			

Thus:

Required alum dose	=	132 mg/L	=	0.13 kg/m^3	
	=	51.14 kg/d			
Settling time, ts	=	60 s	=	1 min.	(Wang, et al., 2014)

<u>Sizing</u>

Assumed that the length, width and depth are equal for the first iteration.

Volume, V	=	Q . ts	=	0.27 m^3	=	L . W . H

where L = length, W = width, H = height

If L = W = H, L . W . H = x^3

x^3	=	0.27 m^3
x	=	0.65 m

Based on the location, the dimension can be adjusted by having different dimensions:

L	=	1 m
W	=	0.6 m
H	=	0.5 m
Volume, V	=	0.30 m^3
Volume check	=	OK

<u>Energy</u>

Static mixing will be used for using gravity to give the mixing effect (Shammas, 2005).

Density of water, ρ	=	1000 kg/m^3			
Acceleration of gravity, g	=	9.81 m/s^2			
Minimum head loss of overflow tank, ΔH	=	0.1 m			(Kocamemi, 2012)
Dynamic viscosity, μ	=	0.798 kg/m/s	(for T = 30^oC)		
Power, P	=	ρ x g x Q x ΔH	=	4.41 kW	
Gradient, G	=	$(P/\mu V)^{0.5}$			
	=	4.29 /s			

2. Flocculation

Design flow, Q = 16.20 m^3/h = 388.75 m^3/d

Baffled Flocculator

Retention time, tr = 20 min. (Ives & Jahn, 2007)

Required volume, V = tr . Q = 5.40 m^3

4 flocculation units will be used, thus:

Number of units, n = 4

Required volume of 1 unit, Vreq = 1.35 m^3

Based on the location, the dimension can be adjusted by having different dimensions:

Length, Lf = 1.5 m (length of flow line)

Width, Wf = 1.25 m

Height, Hf = 1.1 m

Area, Af = 1.875 m^2

Volume, Vf = 2.06 m^3

Volume check (same or higher than Vreq) = OK

Head loss is calculated by considering the following causes:

1. Straight channel conduction

Headloss, Hf = $L . v^2 / (C^2 . R)$

Velocity of water, v = Q/A = 0.002 m/s

Manning coefficient = 0.012 (for concrete)

Hydraulic radius, R = A/P = 0.34 m

Chezy coefficient, C = $(1/n) . (R^{1/6})$ = 69.75 $m^{0.5}/s$

Thus, Hf = 5.17E-09 m

2. Flow direction changes

Headloss, Hb = $n . Cd . v^2 / 2g$

Number of direction changes, n = 3 (direction change to 3 other units)

Velocity of water, v = 0.002 m/s

Gravity constant, g = 9.81 m/s^2

Thus, Hb = 2.64E-06 m

Total headloss, h = Hf + Hb = 2.65E-06 m

Energy

Density of water, ρ = 1000 kg/m^3

Dynamic viscosity, μ = 7.98E-04 kg/m/s (for T = 30°C)

Assumed that overall velocity gradient (G) for 4 compartment varies as follows (Shammas, 2005):

G1 = 100 /s

G2 = 50 /s

G3 = 25 /s

G4 = 5 /s

Average velocity gradient, G = 45 /s

Total detention time, tr = 20 min. = 1200 s (Ives & Jahn, 2007)

Velocity, v = 0.2 m/s (Ives & Jahn, 2007)

G . tr = 54,000

G . tr check (between 50,000 and 100,000) = OK

Power, P = $\mu V G^2$ per stage

With G varies in 4 stages:

Stage	$P = \mu . Vf . G_i^2$ [kW]
1	0.016
2	0.004
3	0.001
4	0.000
Total P	0.022

Final specifications

Step	L [m]	W [m]	H [m]	n [-]	P [kW]	Dose [kg/day]
Coagulation	1	0.6	0.5	1	4.41	51.14
Flocculation	1.5	1.25	1.1	4	0.02	-

For this design, coagulation tank will follow the dimensions of flocculation tank to facilitate the difference from the dimensions of the main sewer.

Coagulation/Flocculation						
Design for 156 concrete companies						
1. Coagulation						
Inflow, Q	=	229.74 m^3/h	=	5513.75 m^3/d		
	=	63.82 L/s				
Dosing						
Alum, $Al_2(SO_4)_3.18H_2O$, will be used as coagulant.						
Assumed alum as $Al_2(SO_4)_3.18H_2O$ with:						
Percentage of Al	=	49%			(Gebbie, 2006)	
Specific gravity, SG	=	1.29			(Gebbie, 2006)	
Optimum pH	=	5.6 - 6.5			(Gebbie, 2006)	
The source of water is from the influent of the WWTP, thus:						
Phosphate concentration, [P]	=	3.69 mg/L			(Table 4.7)	
Sulphate concentration, [SO_4^{2-}]	=	26.50 mg/L			(Table 4.7)	
Molar mass of P, Mr.P	=	31 g/mol				
Molar mass of SO_4^{2-}, Mr.SO_4^{2-}	=	96 g/mol				
Phosphate concentration, [P]	=	([P]/1000)/Mr.P	=	1.19E-04 mol		
Sulphate concentration, [SO_4^{2-}]	=	([SO_4^{2-}]/1000)/Mr. SO_4^{2-}	=	2.76E-04 mol		
Total contaminant concentration, [Cont.]	=	[P] + [SO_4^{2-}]	=	3.95E-04 mol		
	=	Required [Al]				
From the reaction balance:						
$Al_2(SO_4)_3.18H_2O \rightarrow 2Al^{3+} + 3SO_4^{2-} + 18H_2O \rightarrow 2Al(OH)_3 + 6H+ + 3SO_4^{2-} + 12H_2O$						
Thus;						
Required alum concentration, [alum]	=	Required [Al]/2				
	=	1.98E-04 mol				
Molar mass of Al, Mr. Al	=	27 g/mol				
Molar mass of alum, $KAl_2(SO_4)_3.18H_2O$, Mr.alum	=	666 g/mol				
Alum dose	=	[alum] x Mr.alum	=	0.13 g/L		
	=	132 mg/L				
Flow rate	=	Alum dose x Q x 1000 x 60 / (10,000 x Percentage x SG)				
		796.93 L/min.				
Thus:						
Required alum dose	=	132 mg/L	=	0.13 kg/m^3		
	=	725.39 kg/d				
Settling time, ts	=	60 s	=	1 min.	(Wang, et al., 2014)	
Sizing						
Assumed that the length, width and depth are equal for the first iteration.						
Volume, V	=	Q . ts	=	3.83 m^3	=	L . W . H
where L = length, W = width, H = height						
If L = W = H, L . W . H = x^3						
x^3	=	3.83 m^3				
x	=	1.56 m				
Based on the location, the dimension can be adjusted by having different dimensions:						
L	=	3 m				
W	=	1.25 m				
H	=	1.5 m				
Volume, V	=	5.63 m^3				
Volume check	=	OK				
Energy						
Static mixing will be used for using gravity to give the mixing effect (Shammas, 2005).						
Density of water, ρ	=	1000 kg/m^3				
Acceleration of gravity, g	=	9.81 m/s^2				
Minimum head loss of overflow tank, ΔH	=	0.1 m			(Kocamemi, 2012)	
Dynamic viscosity, μ	=	0.798 kg/m/s	(for T = 30°C)			
Power, P	=	ρ x g x Q x ΔH	=	62.60 kW		
Gradient, G	=	$(P/\mu V)^{0.5}$				
	=	3.73 /s				

2. Flocculation

Design flow, Q = 229.74 m^3/h = 5513.75 m^3/d

Baffled Flocculator

Retention time, tr = 20 min. (Ives & Jahn, 2007)

Required volume, V = tr . Q = 76.58 m^3

4 flocculation units will be used, thus:

Number of units, n = 4

Required volume of 1 unit, Vreq = 19.14 m^3

Based on the location, the dimension can be adjusted by having different dimensions:

Length, Lf = 5 m (length of flow line)

Width, Wf = 3 m

Height, Hf = 1.5 m

Area, Af = 15 m^2

Volume, Vf = 22.50 m^3

Volume check (same or higher than Vreq) = OK

Head loss is calculated by considering the following causes:

1. Straight channel conduction

Headloss, Hf = $L . v^2 / (C^2 . R)$

Velocity of water, v = Q/A = 0.004 m/s

Manning coefficient = 0.012 (for concrete)

Hydraulic radius, R = A/P = 0.41 m

Chezy coefficient, C = $(1/n) . (R^{1/6})$ = 71.80 $m^{0.5}/s$

Thus, Hf = 4.29E-08 m

2. Flow direction changes

Headloss, Hb = $n . Cd . v^2 / 2g$

Number of direction changes, n = 3 (direction change to 3 other units)

Velocity of water, v = 0.004 m/s

Gravity constant, g = 9.81 m/s^2

Thus, Hb = 8.30E-06 m

Total headloss, h = Hf + Hb = 8.35E-06 m

Energy

Density of water, ρ = 1000 kg/m^3

Dynamic viscosity, μ = 7.98E-04 kg/m/s (for T = 30°C)

Assumed that overall velocity gradient (G) for 4 compartment varies as follows (Shammas, 2005):

G1 = 100 /s

G2 = 50 /s

G3 = 25 /s

G4 = 5 /s

Average velocity gradient, G = 45 /s

Total detention time, tr = 20 min. = 1200 s (Ives & Jahn, 2007)

Velocity, v = 0.2 m/s (Ives & Jahn, 2007)

G . tr = 54,000

G . tr check (between 50,000 and 100,000) = OK

Power, P = $\mu V G^2$ per stage

With G varies in 4 stages:

Stage	$P = \mu . Vf . G_i^2$
	[kW]
1	0.18
2	0.04
3	0.01
4	0.00
Total P	0.24

Final specifications

Step	L	W	H	n	P	Dose
	[m]	[m]	[m]	[-]	[kW]	[kg/day]
Coagulation	3	1.25	1.5	1	62.60	725.39
Flocculation	5	3	1.5	4	0.24	-

For this design, coagulation tank will follow the dimensions of flocculation tank to facilitate the difference from the dimensions of the main sewer.

Dissolved Air Flotation (DAF)

Design for 11 interviewed companies

Preliminary dimensions for the first iteration:

Width, w	=	1.4	m			
Length, L	=	1.6	m			
Depth, d	=	1	m			
Depth/width ratio	=	d/w		=	0.71	
Design flow for the pilot plant, Q	=	16.20	m^3/h	=	0.005	m^3/s
Surface area, As	=	w x L		=	2.24	m^2

Sludge Type and Loading Capacity (Bisogni, 2004)

Sludge Type	Loading		
	kg/m^2-day		
Activated Sludge	24	-	73
Settled Sludge	49	-	98
Primary + AS	98	-	195
Primary		<	269
Guideline/rule of thumb	150		

Loading flux capacity, Φ	=	150	kg/m^2-day				
Hydraulic loading rate, v	=	Q / As		=	0.0024	$m^3/s/m^2$	
Hydraulic loading rate, v	=			=	8.68	m/h	
Air circulation rate	=	20	%				(Alemayehu, 2011)

Checking and Iteration for Sizing

1. Air to Solids Ratio (A/S)

Saturation value for dissolved air, Cs	=	20.9	mg/L	(1 atm pressure, 30^{o}C)		(Bisogni, 2004)
Operating pressure of chamber, P	=	2.72	atm	(2.72 - 5.44 atm)		(Shamrani, et al, 2001)
Volume required, Vreq	=	4.05	m^3	(volume required)		
Fraction of saturation in pressure chamber, fx	=	0.8		(0.5 to 0.8 depends on the mixing level and detention time)		
Concentration of air dissolved in water leaving the pressure chamber, Cp	=	f . Cs (P/1atm)		(concentration of air dissolved in water leaving the chamber)		
	=	16.72	mg/L			
FOGs influent	=	50	mg/L			
Available air for flotation (release pressure = 1	=	24.58	mg/L			
Total solids (TSS, TDS, FOGs), Xo	=	1390	mg/L	(suspended solids plus FOGs)		
Air to solids ratio, A/S	=	[Cs (f.P/1atm - 1)]/Xo	=	0.018		
	=	0.002	-	0.027	kg	
Rule of thumb comparison for A/S	=	OK				(Bisogni, 2004)
Air required, A	=	14.32	mg/L			

Volume of tank from As+, V+	=	As+ / As x V	=	3.14	m^3	
Width, w	=	1.4	m			
Length, L	=	1.6	m			
Depth, d	=	1	m			
Surface area, As	=	2.24	m^2			
Hydraulic loading rate, v	=	0.0024	$m^3/s/m^2$			
Φ	=	150	kg/$m^{2/}$day	(loading flux capacity)		(Bisogni, 2004)

2. Hydraulic Loading Rate

Width, w	=	1.4	m				
Length, L	=	1.6	m				
Depth, d	=	1	m				
Surface area, As	=	2.24	m^2				
Design flow, Q	=	0.005	m^3/s				
Hydraulic loading rate, Hr	=	As / Q		=	0.002	$m^3/s/m^2$	
Rule of thumb comparison for Hr	=	0.000		-	0.002	$m^3/s/m^2$	(Ward, 2011)
	=	OK					

3. Required DAF Surface Area

Width, w	=	1.4 m				
Length, L	=	1.6 m				
Depth, d	=	1 m				
Surface area, As	=	2.24 m^2				
Sample lab test rise rate, vs	=	0.003 m/s			(constant comparison)	(Ward, 2011)
Design flow, Q	=	0.005 m^3/s				
Required surface area, As-req	=	Q / vs	=	2.13 m^2		
Rule of thumb DAF for As	=	> 125% of the required minimum				
	=	As / As-req	=	105.36 %		(Ward, 2011)
Required DAF versus actual DAF	=	OK				

4. Test Sample Rise Rate

Width, w	=	1.4 m				
Length, L	=	1.6 m				
Depth, d	=	1 m				
Volume, V	=	2.24 m^3				
Sample lab test rise rate, vs	=	0.003 m/s			(constant comparison)	(Ward, 2011)
DAF retention time, tr	=	V / Q / 60	=	8.30 min.		
DAF rise rate, v-DAF	=	d/ (tr x 60)	=	0.002 m/s		
Rule of thumb for vs versus v-DAF	=	v-DAF < vs				(Ward, 2011)
	=	OK				

5. Solids Loading Rate

Width, w	=	1.4 m			
Length, L	=	1.6 m			
Depth, d	=	1 m			
Surface area, As	=	2.24 m^2			
Total solids, TS (TSS, FOGs, TDS)	=	1390 mg/L			
DAF TS loading, v-TS	=	(TS/1000) x (Q/As)	=	0.0028 $kg/m^2/s$	
Surface loading rate, v-sur	=	v-TS / (3600)	=	10.05268 $kg/m^2/h$	(Ward, 2011)
Rule of thumb comparison for v-sur	=	4.88	-	29.29 $kg/m^2/h$	
	=	OK			

6. Energy Consumption

Pressure per design flow, Pq	=	P/ Q	=	167.90 L.atm/h
	=	6.00 kW		

Final specifications

Width, w	=	1.4 m
Length, L	=	1.6 m
Depth, d	=	1 m
Pressure, P	=	2.72 atm
Air content, A	=	14.32 mg/L
Detention time, tr	=	8.30 min.
Energy	=	6.00 kW

Dissolved Air Flotation (DAF)

Design for 156 concrete companies

Preliminary dimensions for the first iteration:

Width, w	=	4 m			
Length, L	=	6 m			
Depth, d	=	2 m			
Depth/width ratio	= d/w		=	0.50	
Design flow for the pilot plant, Q	=	229.74 m^3/h	=	0.064 m^3/s	
Surface area, As	= w x L		=	24 m^2	

Sludge Type and Loading Capacity (Bisogni, 2004)

Sludge Type	Loading kg/m^2-day		
Activated Sludge	24	-	73
Settled Sludge	49	-	98
Primary + AS	98	-	195
Primary		<	269
Guideline/rule of thumb	150		

Loading flux capacity, Φ	=	150 kg/m^2-day			
Hydraulic loading rate, v	= Q / As		=	0.0032 $m^3/s/m^2$	
Hydraulic loading rate, v	=		=	11.49 m/h	
Air circulation rate	=	20 %			(Alemayehu, 2011)

Checking and Iteration for Sizing

1. Air to Solids Ratio (A/S)

Saturation value for dissolved air, Cs	=	20.9 mg/L	(1 atm pressure, 30^oC)	(Bisogni, 2004)
Operating pressure of chamber, P	=	3.51 atm	(2.72 - 5.44 atm)	(Shamrani, et al, 2001)
Volume required, Vreq	=	57.44 m^3	(volume required)	
Fraction of saturation in pressure chamber, fx	=	0.8	(0.5 to 0.8 depends on the mixing level and detention time)	
Concentration of air dissolved in water leaving the pressure chamber, Cp	=	f . Cs (P/1atm)	(concentration of air dissolved in water leaving the chamber)	
	=	16.72 mg/L		
FOGs influent	=	50 mg/L		
Available air for flotation (release pressure =	=	37.79 mg/L		
Total solids (TSS, TDS, FOGs), Xo	=	1390 mg/L	(suspended solids plus FOGs)	

	= [Cs (f.P/1atm - 1)]/Xo		=	0.027	
Air to solids ratio, A/S	=	0.002	-	0.027 kg	
Rule of thumb comparison for A/S	=	OK			(Bisogni, 2004)
Air required, A	=	312.27 mg/L			

Volume of tank from As+, V+	= As+ / As x V		=	67.20 m^3	
Width, w	=	4 m			
Length, L	=	6 m			
Depth, d	=	2 m			
Surface area, As	=	24 m^2			
Hydraulic loading rate, v	=	0.003 $m^3/s/m^2$			
Φ	=	150 kg/$m^{2/}$day	(loading flux capacity)		(Bisogni, 2004)

2. Hydraulic Loading Rate

Width, w	=	5 m	(changed from the first iteration)		
Length, L	=	7 m	(changed from the first iteration)		
Depth, d	=	2 m	(changed from the first iteration)		
Surface area, As	=	35 m^2			
Design flow, Q	=	0.064 m^3/s			
Hydraulic loading rate, Hr	= As / Q		=	0.002 $m^3/s/m^2$	
Rule of thumb comparison for Hr	=	0.000	-	0.002 $m^3/s/m^2$	(Ward, 2011)
	=	OK			

3. Required DAF Surface Area							
Width, w	=	5	m				
Length, L	=	7	m				
Depth, d	=	2	m				
Surface area, As	=	35	m^2				
Sample lab test rise rate, vs	=	0.003	m/s	(constant comparison)			(Ward, 2011)
Design flow, Q	=	0.064	m^3/s				
Required surface area, As-req	= Q / vs			=	30.15	m^2	
Rule of thumb DAF for As	= > 125% of the required minimum						
	= As / As-req			=	116.09	%	(Ward, 2011)
Required DAF versus actual DAF	=	OK					
4. Test Sample Rise Rate							
Width, w	=	5	m				
Length, L	=	7	m				
Depth, d	=	2	m				
Volume, V	=	70	m^3				
Sample lab test rise rate, vs	=	0.003	m/s	(constant comparison)			(Ward, 2011)
DAF retention time, tr	= V / Q / 60			=	18.28	min.	
DAF rise rate, v-DAF	= d/ (tr x 60)			=	0.002	m/s	
Rule of thumb for vs versus v-DAF	= v-DAF < vs						(Ward, 2011)
	=	OK					
5. Solids Loading Rate							
Width, w	=	5	m				
Length, L	=	7	m				
Depth, d	=	2	m				
Surface area, As	=	35	m^2				
Total solids, TS (TSS, FOGs, TDS)	=	1390	mg/L				
DAF TS loading, v-TS	= (TS/1000) x (Q/As)			=	0.0025	$kg/m^2/s$	
Surface loading rate, v-sur	= v-TS / (3600)			=	9.12396	$kg/m^2/h$	(Ward, 2011)
Rule of thumb comparison for v-sur	=	4.88		-	29.29	$kg/m^2/h$	
	=	OK					
6. Energy Consumption							
Pressure per design flow, Pq	=	P/ Q		=	15.28	L.atm/h	
	=	0.55	kW				
Final specifications							
Width, w	=	5	m				
Length, L	=	7	m				
Depth, d	=	2	m				
Pressure, P	=	3.51	atm				
Air content, A	=	312.27	mg/L				
Detention time, tr	=	18.28	min.				
Energy	=	0.55	kW				

Sedimentation

Annex 4.3

Pilot Design

Design flow, Q = 16.20 m^3/h = 388.75 m^3/d

= 0.004 m^3/s

Sedimentation tank is calculated as secondary clarifier (Phase 3).

Settling Velocity

Discrete particles settling velocity from Stokes Law:

$$v_s = \frac{g(\rho_p - \rho_w)d_p^2}{18\mu}$$

where v_s = settling velocity, g = acceleration of gravity, ρ_p = particle density, ρ_w = water density, d_p = particle diameter and μ = dynamic viscosity.

Particle density, ρ_p	=	2650	kg/m^3		(concrete mixture)	
Water density, ρ_w	=	1000	kg/m^3		(water)	
Particle diameter, d_p	=	0.5	mm		(standard settleable solids)	(Kocamemi, 2012)
Gravity constant, g	=	9.81	m/s^2			
Dynamic viscosity, μ	=	0.80	kg/m/s	(for T = 30^{o}C)		
Thus, settling velocity, v_s	=	2.82E-04	m/s	= 0.28 mm/s		
	=	1.01	m/h	= Q/A		

Check of v_s = between 0.50-2.50mm/s for removal of turbidity

= OK

Dimensioning

Required area, A	=	Q/v_s		=	15.97 m^2	

For the first iteration, assumed the width from the typical values (Kocamemi, 2012):

Width of tank, W	=	3 m				
Length of tank, L	=	A/W		=	5.32 m	
Detention time, tr	=	30 min.		=	0.5 h (between 30 min. and 2 h)	(Huisman, 2004)
	=	V/Q		=		
Volume, V	=	Q . tr		=	8.10 m^3	
	=	L . W . D				
Depth of tank, D	=	V/(L . W)		=	0.51 m	

If the depth of the tank is too shallow (check settling capability = NOT OK), increase the depth (D') and recalculate the W' and L'. The iteration process will then become as follows:

Depth of tank, D'	=	2.30 m			
Width of tank, W'	=	2.50 m			
Length of tank, L'	=	7.50 m			
Area, A'	=	18.75 m^2			
Volume, V'	=	43.13 m^3			
Check actual volume	=	same or higher than V	=	8.10 m^3	
	=	OK			

Overflow Rate

Overflow rate, OFR	=	Q/A'	=	20.73 $m^3/d/m^2$	(Kocamemi, 2012)

Check OFR = between 20 - 70 $m^3/d/m^2$ based on Gregory & Zabel (1990), ASCE & AWWA (1990).

= OK

Surface Loading

Kinematic viscosity, ϑ	=	8.05E-07 m^2/s		(for T = 30^{o}C)	
Reynolds number, Re	=	vs . d/ϑ	=	1.75E-04	
Re		< 1	=	laminar	
Horizontal velocity, vo	=	Q/(W . D)			
	=	7.83E-04 m/s	=	2.82 m/h	
Surface loading, vso	=	Q/(W . L)			
	=	2.40E-04 m/s	=	0.86 m/h	
Settling time, Ts	=	D/v_s	=	2.27 h	
Residence time, Tr	=	L/vo	=	2.66 h	
Check settling capability	=	Ts <		Tr	
	=	OK			
Suggested slope		1%			(Huisman, 2004)

Final Specifications

Type	=	secondary clarifier, rectangular
Length	=	7.50 m
Width	=	2.50 m
Depth	=	2.30 m
Detention time	=	30 min.
Slope	=	1%

Sedimentation

Full-scale Design

Design flow, Q = 229.74 m^3/h = 5513.8 m^3/d

= 0.064 m^3/s

Sedimentation tank is calculated as secondary clarifier (Phase 3).

Settling Velocity

Discrete particles settling velocity from Stokes Law:

$$v_s = \frac{g(\rho_p - \rho_w)d_p^2}{18\mu}$$

where v_s = settling velocity, g = acceleration of gravity, ρ_p = particle density, ρ_w = water density, d_p = particle diameter and μ = dynamic viscosity.

Particle density, ρ_p = 2650 kg/m^3 (concrete mixture)

Water density, ρ_w = 1000 kg/m^3 (water)

Particle diameter, d_p = 0.5 mm (standard settleable solids) (Kocamemi, 2012)

Gravity constant, g = 9.81 m/s^2

Dynamic viscosity, μ = 0.80 kg/m/s (for T = 30^oC)

Thus, settling velocity, v_s = 2.82E-04 m/s = 0.28 mm/s

= 1.01 m/h = Q/A

Check of v_s = between 0.50-2.50mm/s for removal of turbidity

= OK

Dimensioning

Required area, A = Q/v_s = 226.52 m^2

For the first iteration, assumed the width from the typical values (Kocamemi, 2012):

Width of tank, W = 3 m

Length of tank, L = A/W = 75.51 m

Detention time, tr = 120 min. = 2 h (between 30 min. and 2 h) (Huisman, 2004)

= V/Q =

Volume, V = Q . tr = 459.48 m^3

= L . W . D

Depth of tank, D = V/(L . W) = 2.03 m

If the depth of the tank is too shallow (check settling capability = NOT OK), increase the depth (D') and recalculate the W' and L'. The iteration process will then become as follows:

Depth of tank, D' = 5.00 m

Width of tank, W' = 10.00 m

Length of tank, L' = 23.00 m

Area, A' = 230.00 m^2

Volume, V' = 1150.00 m^3

Check actual volume = same or higher than V = 459.48 m^3

= OK

Overflow Rate

Overflow rate, OFR = Q/A' = 23.97 $m^3/d/m^2$ (Kocamemi, 2012)

Check OFR = between 20 - 70 $m^3/d/m^2$ based on Gregory & Zabel (1990), ASCE & AWWA (1990).

= OK

Surface Loading

Kinematic viscosity, ϑ = 8.05E-07 m^2/s (for T = 30^oC)

Reynolds number, Re = vs . d/ϑ = 1.75E-04

Re < 1 = laminar

Horizontal velocity, vo = Q/(W . D)

= 1.28E-03 m/s = 4.59 m/h

Surface loading, vso = Q/(W . L)

= 2.77E-04 m/s = 1.00 m/h

Settling time, Ts = D/v_s = 4.93 h

Residence time, Tr = L/vo = 5.01 h

Check settling capability = Ts < Tr

= OK

Suggested slope 1% (Huisman, 2004)

Final Specifications

Type = secondary clarifier, rectangular

Length = 23.00 m

Width = 10.00 m

Depth = 5.00 m

Detention time = 120 min.

Slope = 1%

Annex 4.4

Hydrocyclone

Design for 11 interviewed companies

Design flow rate, Q	=	16.20 m^3/h	=	0.004 m^3/s	
Sizing					
For the first iteration, define the diameter, height, width and length of cyclone body:					
Cyclone diameter (inside), D	=	1.50 m			(3")
Assumed cut size, Rf	=	60%			
Overflow rate, Qo	=	Rf . Q	=	0.003 m^3/s	
Underflow rate, Qu	=	(1 - Rf) . Q	=	0.002 m^3/s	
Overflow diameter, Do	=	0.60 m			(to be changed for iteration)
Underflow diameter, Du	=	0.15 m			(to be changed for iteration)
Check overflow diameter, Do/D > 0	=	OK			
Overflow area, Ao	=	0.25 . π . Do^2	=	0.283 m^2	
Underflow area, Au	=	0.25 . π . Du^2	=	0.018 m^2	
Cyclone Area, A	=	0.25 . π . D^2	=	1.767 m^2	
Velocities					
Cyclone vertical velocity, vz	=	$\frac{4Q}{\pi\left(D^2-D_0^{\,2}\right)}$	=	0.0030 m/s	
Cyclone length, L	=	4 m			(changed for iteration)
Particle density, ρ_p	=	2650 kg/m^3			(concrete mixture)
Water density, ρ_w	=	1000 kg/m^3			(water)
Gravity constant, g	=	9.81 m/s^2			
Dynamic viscosity, μ	=	0.80 kg/m/s			(for T = 30°C)
Particle diameter, dp	=	0.50 mm			(same as in sedimentation)
Particle terminal velocity, vt	=	$\frac{g(\rho_p-\rho_w)d_p^2}{18\mu}$	=	2.82E-04 m/s	
Radial velocity, vr	=	(D/2L) . vz	=	5.68E-04 m/s	(Sabbagh, *et al* , 2016)
	=	$\frac{(\rho_p-\rho_w)d_p^2}{18\mu}\cdot\frac{v_\theta^{\,2}}{r}$			
From the equation above, tangential velocity, v_θ	=	3.85 m/s			(to be iterated)
By assuming that the radius of rotation, r, is the same as the radius of the hydrocyclone, the tangential velocity, v_θ, can be obtained.					
Radius of rotation, r	=	D/2	=	0.75 m	
The recommended value of tan θ	=	1/8	=	0.13	(Wang, 2004)
Angle of cyclone body, θ	=	arctan(1/8)	=	7.13 deg	(Albrecht, 2010)
Check of angle, θ < 45 deg	=	OK			
Cyclone vertical flow, Qc	=	$2v_g\frac{\pi(D^2-D_0^{\,2})L}{4gD}\cdot\frac{v_\theta^{\,2}}{r}$	=	0.004 m/s	(Sabbagh, *et al* , 2016)
Inlet diameter (inside), Di	=	0.10 m			(Di = 0.2D for the first iteration)
Check inlet diameter, Di/D < 1	=	OK			
Inlet Area, Ai	=	0.25 . π . D^2	=	7.85E-03 m^2	
Inlet velocity, vi	=	Q/A	=	0.57 m/s	
Inlet height, Hi	=	0.4 m			(to be changed for iteration)
Inlet width, Wi	=	0.2 m			(to be changed for iteration)
Water inlet velocity, vi	=	Q/(W . H)	=	0.056 m/s	
Length of cyclone straight body, Lb	=	0.4 L	=	1.60 m	(to be changed for iteration)
Length of cyclone cone, Lc	=	0.6 L	=	2.40 m	(to be changed for iteration)
Number of effective turns, Ne	=	$\frac{1}{H}\left(L_b+\frac{L_c}{2}\right)$	=	7	
Time spent by water during spiraling descent, Δt	=	Wi/ vt			(Scrubbers, 2012)
	=	709.92 s	=	11.83 min.	
Check all diameters, (2Di/D + Do/D) ≤ 1	=	OK			

Pressure

Presssure drop head, Hv	=	$K \cdot Hi \cdot Wi/ Do^2$			
where K is a constant for normal tangential inlet	=	16			(Scrubbers, 2012)
Thus, Hv	=	3.56 m			
Pressure drop, ΔP	=	$0.5 \cdot \rho_w \cdot vi^2 \cdot Hv$	=	5.62 Pa	(Scrubbers, 2012)
Required power, W	=	$Q \cdot \Delta P$	=	25.30 kW	(Scrubbers, 2012)

Final Specifications

Cyclone diameter	=	1.50 m
Cyclone length	=	4.00 m
Overflow diameter	=	0.60 m
Underflow diameter	=	0.15 m
Angle of cyclone	=	7.13 deg
Number of effective turns	=	7
Length of cyclone straight body	=	1.60 m
Length of cyclone cone	=	2.40 m
Required power	=	25.30 kW

Hydrocyclone

Design for 156 concrete companies

Design flow rate, Q	=	229.74 m^3/h	=	0.064 m^3/s	

Sizing

For the first iteration, define the diameter, height, width and length of cyclone body:

Cyclone diameter (inside), D	=	10.00 m			(3")
Assumed cut size, Rf	=	60%			
Overflow rate, Qo	=	Rf . Q	=	0.038 m^3/s	
Underflow rate, Qu	=	(1 - Rf) . Q	=	0.026 m^3/s	
Overflow diameter, Do	=	7.00 m			(to be changed for iteration)
Underflow diameter, Du	=	4.00 m			(to be changed for iteration)
Check overflow diameter, Do/D > 0	=	OK			
Overflow area, Ao	=	$0.25 . \pi . Do^2$	=	38.485 m^2	
Underflow area, Au	=	$0.25 . \pi . Du^2$	=	12.566 m^2	
Cyclone Area, A	=	$0.25 . \pi . D^2$	=	78.540 m^2	

Velocities

Cyclone vertical velocity, vz	=	$\frac{4Q}{\pi\left(D^2 - D_0^{\,2}\right)}$	=	0.0016 m/s	
Cyclone length, L	=	19 m			(changed for iteration)
Particle density, ρ_p	=	2650 kg/m^3			(concrete mixture)
Water density, ρ_w	=	1000 kg/m^3			(water)
Gravity constant, g	=	9.81 m/s^2			
Dynamic viscosity, μ	=	0.80 kg/m/s			(for T = 30°C)
Particle diameter, dp	=	0.50 mm			(same as in sedimentation)
Particle terminal velocity, vt	=	$\frac{g(\rho_p - \rho_w)d_p^2}{18\mu}$	=	2.82E-04 m/s	
Radial velocity, vr	=	(D/2L) . vz	=	4.19E-04 m/s	(Sabbagh, *et al*, 2016)
	=	$\frac{(\rho_p - \rho_w)d_p^2}{18\mu}\cdot\frac{v_\theta^{\,2}}{r}$			
From the equation above, tangential velocity, v_θ	=	8.54 m/s			(to be iterated)

By assuming that the radius of rotation, r, is the same as the radius of the hydrocyclone, the tangential velocity, v_θ, can be obtained.

Radius of rotation, r	=	D/2	=	5.00 m	
The recommended value of tan θ	=	1/8	=	0.13	(Wang, 2004)
Angle of cyclone body, θ	=	arctan(1/8)	=	7.13 deg	(Albrecht, 2010)
Check of angle, θ < 45 deg	=	OK			
Cyclone vertical flow, Qc	=	$2v_g\frac{\pi(D^2 - D_0^{\,2})L}{4gD}\cdot\frac{v_\theta^{\,2}}{r}$	=	0.064 m/s	(Sabbagh, *et al*, 2016)
Inlet diameter (inside), Di	=	0.10 m			(Di = 0.2D for the first iteration)
Check inlet diameter, Di/D < 1	=	OK			
Inlet Area, Ai	=	$0.25 . \pi . D^2$	=	7.85E-03 m^2	
Inlet velocity, vi	=	Q/A	=	8.13 m/s	
Inlet height, Hi	=	1.9 m			(to be changed for iteration)
Inlet width, Wi	=	0.9 m			(to be changed for iteration)
Water inlet velocity, vi	=	Q/(W . H)	=	0.037 m/s	
Length of cyclone straight body, Lb	=	0.4 L	=	7.60 m	(to be changed for iteration)
Length of cyclone cone, Lc	=	0.6 L	=	11.40 m	(to be changed for iteration)
Number of effective turns, Ne	=	$\frac{1}{H}\left(L_b + \frac{L_c}{2}\right)$	=	7	
Time spent by water during spiraling descent, Δt	=	Wi/ vt			(Scrubbers, 2012)
	=	3194.66 s	=	53.24 min.	
Check all diameters, (2Di/D + Do/D) ≤ 1	=	OK			

Pressure

Presssure drop head, Hv	=	$K \cdot Hi \cdot Wi / Do^2$				
where K is a constant for normal tangential inlet	=	16				(Scrubbers, 2012)
Thus, Hv	=	0.56 m				
Pressure drop, ΔP	=	$0.5 \cdot \rho_w \cdot vi^2 \cdot Hv$	=	0.39	Pa	(Scrubbers, 2012)
Required power, W	=	$Q \cdot \Delta P$	=	24.81	kW	(Scrubbers, 2012)

Final Specifications

Cyclone diameter	=	10.00	m
Cyclone length	=	19.00	m
Overflow diameter	=	7.00	m
Underflow diameter	=	4.00	m
Angle of cyclone	=	7.13	deg
Number of effective turns	=	7	
Length of cyclone straight body	=	7.60	m
Length of cyclone cone	=	11.40	m
Required power	=	24.81	kW

Porous Media Filtration (Sand)

Design for 11 interviewed companies

The sand filtration is designed as rapid conventional stratified system baed on the design features of monomedium filter beds for wastewater treatment by Metcalf & Eddy (1991) (Kocacemi, 2012).

Sizing

Filter bed depth, L	=	0.6 m			
		in the range of 0.50 - 0.76 m.			(to be changed for iteration)
Kinematic viscosity, ϑ	=	7.98E-07 m^2/s			
Gravity, g	=	9.81 m/s^2			
Porosity, po	=	0.38			
		assumed rounded material based on Oroste (1997).			
Flow rate, Q	=	16.20 m^3/h	=	0.004 m^3/s	
Surface area, A	=	2 m^2			(to be changed for iteration)
Diameter of the column, D	=	1.60 m			
Superficial velocity, v	=	Q/A			
	=	0.002 m/s	=	8.10 m/h	
Check of velocity (5 - 15 m/h)	=	$\boxed{\text{OK}}$			
Particle size, do	=	0.6 mm			(to be changed for iteration)
		in the range of 0.4 - 0.8mm.			

Head Loss

The head (driving force) per length of the column can be obtained by Kozeny-Carman's equation:

$$\frac{H_o}{L} = 180 \cdot \frac{\upsilon}{g} \cdot \frac{(1-p_o)^2}{p_o^{\ 3}} \cdot \frac{v}{d_{o^2}}$$

Ho/L	=	0.64 m			
Head loss, Ho	=	0.38 m			
Filtration time, t	=	L/v			
Backwashing	=	266.70 s	=	4.45 min.	
Bed expansion, E	=	20%			
		assumed for particle diameter 0.8 mm or less (OCW TU Delft, 2007).			
Expanded bed length, Le	=	(1 + E) . L	=	0.72 m	
Expanded porosity, pe	=	(po + E)/(1 + E)	=	0.48	
Resistance, He	=	$130 \cdot \frac{\upsilon^{0.8}}{g} \cdot \frac{(1-p_e)^{1.8}}{p_e^{\ 3}} \cdot \frac{v^{1.2}}{d_{o^{1.8}}} \cdot L_e$			
	=	0.275 m			
Max. length of unit, Lf	=	Le + He	=	1.10 m	
Backwash rate, ve	=	30 m/h	=	0.01 m/s	
		assumed for having at least 20% bed expansion (OCW TU Delft, 2007).			
Backwashing time, te	=	Le/ve			
	=	86.4 s	=	1.44 min.	

Final Specifications

Type	=	rapid conventional sand stratified system
Filter bed depth	=	0.6 m
Filter unit depth	=	1.10 m
Diameter	=	1.60 m
Particle size	=	0.6 mm
Filtration time	=	4.45 min.
Backwashing time	=	1.44 min.

Porous Media Filtration (Sand)

Design for 156 concrete companies

The sand filtration is designed as rapid conventional stratified system baed on the design features of monomedium filter beds for wastewater treatment by Metcalf & Eddy (1991) (Kocacemi, 2012).

Sizing

Filter bed depth, L = 0.7 m
in the range of 0.50 - 0.76 m. (to be changed for iteration)

Kinematic viscosity, ϑ = 7.98E-07 m^2/s

Gravity, g = 9.81 m/s^2

Porosity, po = 0.38
assumed rounded material based on Oroste (1997).

Flow rate, Q = 229.74 m^3/h = 0.064 m^3/s

Surface area, A = 20 m^2 (to be changed for iteration)

Diameter of the column, D = 5.05 m

Superficial velocity, v = Q/A
= 0.003 m/s = 11.49 m/h

Check of velocity (5 - 15 m/h) = OK

Particle size, do = 0.6 mm (to be changed for iteration)
in the range of 0.4 - 0.8mm.

Head Loss

The head (driving force) per length of the column can be obtained by Kozeny-Carman's equation:

$$\frac{H_o}{L} = 180 \cdot \frac{\upsilon}{g} \cdot \frac{(1-p_o)^2}{p_o{}^3} \cdot \frac{v}{d_{o^2}}$$

Ho/L = 0.909 m

Head loss, Ho = 0.636 m

Filtration time, t = L/v

Backwashing = 219.38 s = 3.66 min.

Bed expansion, E = 20%
assumed for particle diameter 0.8 mm or less (OCW TU Delft, 2007).

Expanded bed length, Le = (1 + E) . L = 0.84 m

Expanded porosity, pe = (po + E)/(1 + E) = 0.48

Resistance, He $= 130 \cdot \frac{\upsilon^{0.8}}{g} \cdot \frac{(1-p_e)^{1.8}}{p_e{}^3} \cdot \frac{v^{1.2}}{d_{o^{1.8}}} \cdot L_e$
= 0.359 m

Max. length of unit, Lf = Le + He = 1.20 m

Backwash rate, ve = 30 m/h = 0.01 m/s
assumed for having at least 20% bed expansion (OCW TU Delft, 2007).

Backwashing time, te = Le/ve
= 100.8 s = 1.68 min.

Final Specifications

Type = rapid conventional sand stratified system

Filter bed depth = 0.7 m

Filter unit depth = 1.20 m

Diameter = 5.05 m

Particle size = 0.6 mm

Filtration time = 3.66 min.

Backwashing time = 1.68 min.

Microfiltration						
Design for 11 interviewed companies						
Type of mechanism	=	cross-flow				(van Halem, 2009)
Type of membrane	=	capillary				(Pentair, 2014)
Level of recovery	-	10%				(van Halem, 2009)
Design flow, Qf	=	16.20 m^3/h				
Superficial velocity, v	=	1 m/s				(Pentair, 2014)
Cross-flow, Qcf	=	13.7 . v	=	13.70	m^3/h	
Permeate flow, Qp	=	10% Qf	=	1.62	m^3/h	
Concentrate flow, Qc	=	90% Qf	=	14.58	m^3/h	
Required membrane modules						
Membrane area, Amem	=	9.3 m^2				(Pentair, 2014)
Hydraulic membrane diameter, d	=	1.5 mm				(Pentair, 2014)
Rear flow at the end of module, ve	=	0.19 m/s				(van Halem, 2009)
Membrane capillary area, Acap	=	$0.25 . \pi . d^2$	=	1.77E-06	m^2	
Insert outer diameter, Do	=	160.60 mm				
Insert outer module area, Amod	=	$0.25 . \pi . Do^2$	=	0.02	m^2	
Number of membrane in a module, n		Amod/Acap	=	11464	pcs.	
Membrane length, L		1.02 m				
Module volume, Vmod	=	Amod . L	=	0.02	m^3	
Membrane specific area, Aspec	=	Amem/Vmod	=	449.21	m^2/m^3	
Flux						
Microfiltration flux, J	=	30 $L/m^2/h$	=	Q/Areq		(van Halem, 2009)
		in the range of 20 - 40 $L/m^2/h$.				
Required Area, Areq	=	Q/J	=	539.93	m^2	
Required modules, n	=	Areq/Amem	=	59	units	
Actual area, Ar	=	n . Amem	=	548.70	m^2	
Check actual area, Ar > Areq	=	OK				
One skid consists of 30 units of membrane modules. Thus:						
1 skid	=	30 units				
Total required skid, S	=	2 skid(s)				
Backflush						
Required backflush time	=	5 s				(van Halem, 2009)
Backflush flux, Jbw	=	150 $L/m^2/h$	(for 30 - 40^{o}C)			(van Halem, 2009)
Backflush flow, Qbw	=	Jbw . A	=	1.40	m^3/h	
Pressure						
Trans Membrane Pressure, TMP	=	(Pf + Pc)/2 - Pp = Pf - (ΔPhydr/2) - Pp				
where Pf is the feed pressure, Pc is concentrate pressure and Pp is the permeate pressure. Thus:						
Pf	=	0.5 bar				(van Halem, 2009)
Pp	=	0.1 bar				(van Halem, 2009)
ΔPhydr	=	0 bar				(van Halem, 2009)
TMP	=	0.4 bar	=	40.53	kPa	
Max. TMP	=	200 kPa	(for 50 - 65^{o}C)			(Pentair, 2014)
Check actual TMP (<max.TMP)	=	OK				
Assuming that 1 bar	=	10.2 m of head (ConvertUnits.com, 2016), then:				
Total head for feed, Hf	=	5.1 m				
Energy						
The energy consumption of a cross-flow system is about 5 kWh/m^3 permeate (Qp) (van Halem, 2009). Thus:						
Energy, E	=	Qp . 5 kWh/m^3	=	8.10	kW	
Final specifications						
Type	=	Pentair capillary R-100				
Length	=	1.02 m				
Diameter	=	1.50 mm				
Energy	=	8.10 kW				
Unit(s)	=	59				
Skid(s)	=	2				

Microfiltration

Design for 156 concrete companies

Type of mechanism	=	cross-flow			(van Halem, 2009)
Type of membrane	=	capillary			(Pentair, 2014)
Level of recovery	-	10%			(van Halem, 2009)
Design flow, Qf	=	229.74 m^3/h			
Superficial velocity, v	=	1 m/s			(Pentair, 2014)
Cross-flow, Qcf	=	13.7 . v	=	13.70 m^3/h	
Permeate flow, Qp	=	10% Qf	=	22.97 m^3/h	
Concentrate flow, Qc	=	90% Qf	=	206.77 m^3/h	

Required membrane modules

Membrane area, Amem	=	9.3 m^2			(Pentair, 2014)
Hydraulic membrane diameter, d	=	1.5 mm			(Pentair, 2014)
Rear flow at the end of module, ve	=	0.19 m/s			(van Halem, 2009)
Membrane capillary area, Acap	=	$0.25 . \pi . d^2$	=	1.77E-06 m^2	
Insert outer diameter, Do	=	160.60 mm			
Insert outer module area, Amod	=	$0.25 . \pi . Do^2$	=	0.02 m^2	
Number of membrane in a module, n		Amod/Acap	=	11464 pcs.	
Membrane length, L		1.02 m			
Module volume, Vmod	=	Amod . L	=	0.02 m^3	
Membrane specific area, Aspec	=	Amem/Vmod	=	449.21 m^2/m^3	

Flux

Microfiltration flux, J	=	30 $L/m^2/h$	=	Q/Areq	(van Halem, 2009)
		in the range of 20 - 40 $L/m^2/h$.			
Required Area, Areq	=	Q/J	=	7657.99 m^2	
Required modules, n	=	Areq/Amem	=	824 units	
Actual area, Ar	=	n . Amem	=	7663.20 m^2	
Check actual area, Ar > Areq	=	OK			

One skid consists of 30 units of membrane modules. Thus:

1 skid	=	30 units			
Total required skid, S	=	28 skid(s)			

Backflush

Required backflush time	=	5 s			(van Halem, 2009)
Backflush flux, Jbw	=	150 $L/m^2/h$		(for 30 - 40°C)	(van Halem, 2009)
Backflush flow, Qbw	=	Jbw . A	=	1.40 m^3/h	

Pressure

Trans Membrane Pressure, TMP = (Pf + Pc)/2 - Pp = Pf - (ΔPhydr/2) - Pp

where Pf is the feed pressure, Pc is concentrate pressure and Pp is the permeate pressure. Thus:

Pf	=	0.5 bar			(van Halem, 2009)
Pp	=	0.1 bar			(van Halem, 2009)
ΔPhydr	=	0 bar			(van Halem, 2009)
TMP	=	0.4 bar	=	40.53 kPa	
Max. TMP	=	200 kPa		(for 50 - 65°C)	(Pentair, 2014)
Check actual TMP (<max.TMP)	=	OK			
Assuming that 1 bar	=	10.2 m of head (ConvertUnits.com, 2016), then:			
Total head for feed, Hf	=	5.1 m			

Energy

The energy consumption of a cross-flow system is about 5 kWh/m^3 permeate (Qp) (van Halem, 2009). Thus:

Energy, E	=	Qp . 5 kWh/m^3	=	114.87 kW	

Final specifications

Type	=	Pentair capillary R-100
Length	=	1.02 m
Diameter	=	1.50 mm
Energy	=	114.87 kW
Unit(s)	=	824
Skid(s)	=	28

Nanofiltration

Design for 11 interviewed companies

Type of mechanism	=	cross-flow			(van Halem, *et al* , 2009)
Type of membrane	=	capillary			(Pentair, 2015)
Level of recovery	-	10%			(van Halem, 2009)
Required membrane modules					
Design flow, Qf	=	16.20 m^3/h	=	0.004 m^3/s	
Membrane area, Amem	=	40 m^2			(Pentair, 2015)
Hydraulic membrane diameter, d	=	0.8 mm			(Pentair, 2015)
Membrane hydraulic area, Ahyd	=	$0.25 . \pi . d^2$	=	5.03E-07 m^2	
Design velocity, v	=	Qf/Ahyd	=	0.14 m/s	
Superficial velocity, v'	=	1 m/s			
Cross-flow, Qcf	=	19.8 . v'	=	19.80 m^3/h	
Permeate flow, Qp	=	10% Qf	=	1.62 m^3/h	
Concentrate flow, Qc	=	90% Qf	=	14.58 m^3/h	
Insert outer diameter, Do	=	200.00 mm			(Pentair, 2015)
Insert outer module area, Amod	=	$0.25 . \pi . Do^2$	=	0.03 m^2	
Number of membrane in a module, n		Amod/Ahyd	=	62500 pcs.	
Membrane length, L		1.5375 m			(Pentair, 2015)
Module volume, Vmod	=	Amod . L	=	0.05 m^3	
Membrane specific area, Aspec	=	Amem/Vmod	=	828.12 m^2/m^3	
Flux					
Nanofiltration flux, J	=	50 $L/m^2/h$	=	Q/Areq	(van Halem, *et al* , 2009)
		in the range of 20 - 80 $L/m^2/h$.			
Required Area, Areq	=	Q/J	=	323.96 m^2	
Required modules, n	=	Areq/Amem	=	9 units	
Actual area, Ar	=	n . Amem	=	360.00 m^2	
Check actual area, Ar > Areq	=	OK			
One skid consists of 30 units of membrane modules. Thus:					
1 skid	=	30 units			
Total required skid, S	=	1 skid(s)			
Pressure					
Trans Membrane Pressure, TMP	=	(Pf + Pc)/2 - Pp = Pf - (ΔPhydr/2) - Pp			
where Pf is the feed pressure, Pc is concentrate pressure and Pp is the permeate pressure. Thus:					
Pf	=	5 bar			(van Halem, *et al* , 2009)
		in the range of 5 - 10 bar.			
Pp	=	0 bar			(van Halem, *et al* , 2009)
ΔPhydr	=	$0.5 \lambda . (L/d) . \rho . v^2$			(van Halem, *et al* , 2009)
where:					
Friction factor of membrane, λ	=	64/Re (for Re ≤ 2000)			
	=	0.316Re^(-0.25) (for Re > 2000)			
		for capillary type (van Halem, *et al* , 2009).			
Kinematic viscosity, ϑ	=	7.98E-07 m^2/s			
Water density, ρ	=	1000 kg/m^3		(water)	
Reynolds number, Re	=	v . d/ ϑ			
	=	143.58			
From the calculation, Re	<	2000			
Thus, λ	=	64/Re	=	0.45	
Then, ΔPhydr can be obtained:					
ΔPhydr	=	8786.07 Pa	=	0.09 bar	
Because ΔPhydr = Pf - Pc, then Pc	=	Pf - ΔPhydr	=	4.91 bar	
Thus, TMP	=	4.96 bar	=	502.17 kPa	
Max. TMP	=	600 kPa		(for 0 - 40^oC)	(Pentair, 2015)
Check actual TMP (<max.TMP)	=	OK			
Assuming that 1 bar	=	10.2 m of head (ConvertUnits.com, 2016), then:			
Total head for feed, Hf	=	51 m			
Energy					
The energy depends on the feed pressure (Pf) of a cross-flow system (van Halem, *et al* , 2009).					
Energy, E	=	Qf . Pf	=	22.50 kW	
Final specifications					
Type	=	Pentair X-Flow HFW 1000			
Length	=	1.54 m			
Membrane diameter	=	0.80 mm			
Module diameter	=	0.20 m			
Energy	=	22.50 kW			
Unit(s)	=	9			
Skid(s)	=	1			

Nanofiltration

Design for 156 concrete companies					
Type of mechanism	=	cross-flow			(van Halem, *et al* , 2009)
Type of membrane	=	capillary			(Pentair, 2015)
Level of recovery	-	10%			(van Halem, 2009)
Required membrane modules					
Design flow, Qf	=	229.74 m^3/h	=	0.064 m^3/s	
Membrane area, Amem	=	40 m^2			(Pentair, 2015)
Hydraulic membrane diameter, d	=	0.8 mm			(Pentair, 2015)
Membrane hydraulic area, Ahyd	=	$0.25 . \pi . d^2$	=	5.03E-07 m^2	
Design velocity, v	=	Qf/Ahyd	=	2.03 m/s	
Superficial velocity, v'	=	1 m/s			
Cross-flow, Qcf	=	19.8 . v'	=	19.80 m^3/h	
Permeate flow, Qp	=	10% Qf	=	22.97 m^3/h	
Concentrate flow, Qc	=	90% Qf	=	206.77 m^3/h	
Insert outer diameter, Do	=	200.00 mm			(Pentair, 2015)
Insert outer module area, Amod	=	$0.25 . \pi . Do^2$	=	0.03 m^2	
Number of membrane in a module, n		Amod/Ahyd	=	62500 pcs.	
Membrane length, L		1.5375 m			(Pentair, 2015)
Module volume, Vmod	=	Amod . L	=	0.05 m^3	
Membrane specific area, Aspec	=	Amem/Vmod	=	828.12 m^2/m^3	
Flux					
Nanofiltration flux, J	=	50 $L/m^2/h$	=	Q/Areq	(van Halem, *et al* , 2009)
		in the range of 20 - 80 $L/m^2/h$.			
Required Area, Areq	=	Q/J	=	4594.79 m^2	
Required modules, n	=	Areq/Amem	=	115 units	
Actual area, Ar	=	n . Amem	=	4600.00 m^2	
Check actual area, Ar > Areq	=	OK			
One skid consists of 30 units of membrane modules. Thus:					
1 skid	=	30 units			
Total required skid, S	=	4 skid(s)			
Pressure					
Trans Membrane Pressure, TMP	=	(Pf + Pc)/2 - Pp = Pf - (ΔPhydr/2) - Pp			
where Pf is the feed pressure, Pc is concentrate pressure and Pp is the permeate pressure. Thus:					
Pf	=	5 bar			(van Halem, *et al* , 2009)
		in the range of 5 - 10 bar.			
Pp	=	0 bar			(van Halem, *et al* , 2009)
ΔPhydr	=	$0.5\ \lambda . (L/d) . \rho . v^2$			(van Halem, *et al* , 2009)
	=	0 bar			
where:					
Friction factor of membrane, λ	=	64/Re (for Re ≤ 2000)			
	=	0.316Re^(-0.25) (for Re > 2000)			
		for capillary type (van Halem, *et al* , 2009).			
Kinematic viscosity, ϑ	=	7.98E-07 m^2/s			
Water density, ρ	=	1000 kg/m^3		(water)	
Reynolds number, Re	=	v . d/ ϑ			
	=	2036.43			
From the calculation, Re	>	2000			
Thus, λ	=	0.316Re^(-0.25)	=	0.05	
Then, ΔPhydr can be obtained:					
ΔPhydr	=	186.52 Pa	=	0.002 bar	
Because ΔPhydr = Pf - Pc, then Pc	=	Pf - ΔPhydr	=	4.998 bar	
Thus, TMP	=	4.999 bar	=	506.53 kPa	
Max. TMP	=	600 kPa		(for 0 - 40°C)	(Pentair, 2015)
Check actual TMP (<max.TMP)	=	OK			
Assuming that 1 bar	=	10.2 m of head (ConvertUnits.com, 2016), then:			
Total head for feed, Hf	=	51 m			
Energy					
The energy depends on the feed pressure (Pf) of a cross-flow system (van Halem, *et al* , 2009).					
Energy, E	=	Qf . Pf	=	382.90 kW	
Final specifications					
Type	=	Pentair X-Flow HFW 1000			
Length	=	1.54 m			
Membrane diameter	=	0.80 mm			
Module diameter	=	0.20 m			
Energy	=	382.90 kW			
Unit(s)	=	115			
Skid(s)	=	4			

4.8. Summary of Alternatives

Table 4.1 Details of available treatment technologies

Treatment	Removal Efficiency	Removed Material	Influent Concentration (Table 4.7)	Expected Effluent Concentration	Concentration Limit (Table 2.2)	Reference(s)
	[%]	[-]	[mg/L]	[mg/L]	[mg/L]	
Phase 1						
A. FOGs, TSS						
Dissolved Air Flotation (DAF)	80 - 95 (FOGs)	FOGs	50.00	5 - 14	50.00	(Al-Shamrani *et al.*, 2002)
	70 - 98 (TSS)	TSS	150.00	3 - 45	67.03	(Aries Chemical Inc., 2013)
Coagulation - Flocculation (C - F)						
Alum, $Al_2(SO_4).24H_2O$	99	FOGs	50.00	0.50	50.00	(Daud *et al.*, 2015)
Ferric chloride, $FeCl_3.6H_2O$	97	FOGs	50.00	1.50	50.00	(Daud *et al.*, 2015)
Ferric sulphate, $Fe_2(SO_4)_3$	94	FOGs	50.00	3.00	50.00	(Daud *et al.*, 2015)
Zeolite	91 - 98	FOGs	50.00	1 - 4.5	50.00	(El-gawad, 2014)
B. TP → only if necessary						
Coagulation - Flocculation (C - F)						
Alum, $Al_2(SO_4).24H_2O$	99	TP	50.00	0.50	50.00	(Daud *et al.*, 2015)
Calcium hydroxide, $Ca(OH)_2$	99	TP	3.69	0.04	6.70	(Benatti *et al.*, 2009)
Barium hydroxide, $Ba(OH)_2$	64.1	TP	3.69	1.32	6.70	(Benatti *et al.*, 2009)
Ferric chloride, $FeCl_3.6H_2O$	63	TP	3.69	1.36	6.70	(Fytianos *et al.*, 1998)
C. Flocs → if DAF is not used						
Sedimentation (SED)	100	TSS	150.00	0.00	67.03	(FSC, 2003), (Caltrans, 2001)
Hydrocyclone (HC)	99	TSS	150.00	1.50	67.03	(Sabbagh *et al.*, 2016)

Treatment	Removal Efficiency	Removed Material	Influent Concentration (Table 4.7)	Expected Effluent Concentration	Concentration Limit (Table 2.2)	Reference(s)
Phase 2						
Post-treatment for TSS						
Porous media filtration (PMF)	80	TSS	150.00	30.00	67.03	(Spanjers, 2010)
Microfiltration (MF)	97	TSS	50.00	1.50	50.00	(Song *et al.*, 2006)
Phase 3						
TDS → only if necessary						
Nanofiltration (NF)	80 - 90	TDS	497.00	49.7 - 99.4	100.00	(Izadpanah & Javidnia, 2012)
Phase 4						
Disinfection						
Chlorination (CHL)	99.9 - 99.99	Coliforms	7-log	0 - 2.55-log	3.76-log	(Hijnen & Medema, 2010), (CCAA, 2007), (BS EN 1008, 2002) (Rock & Rivera, 2014)
UV Radiation (UVR)	99.99	Coliforms	7-log	0 - 2.55-log	3.76-log	(Rock & Rivera, 2014)

Table 4.2 List of alternatives per phase for the preliminary plant

Treatment	Removal Efficiency	Removed Material	Dose	Dimension				Influent Concentration (Table 4.7)	Actual Effluent Concentration	Concentration Limit (Table 2.2)
				Length	Width	Depth	n			
	[%]	[-]	[mg/L]	[m]	[m]	[m]	[-]	[mg/L]	[mg/L]	[mg/L]
Phase 1										
Alternative 1.1										
Coagulation				1	0.6	0.5	1			
Flocculation				1.5	1.25	1.1	4			
Alum, $Al_2(SO_4).24H_2O$	99	P, FOGs	132	1.5	1.25	1.1	1	0.00	0.00	50.00
Dissolved Air Flotation (DAF)	80 - 95 (FOGs)	FOGs		1.6	1.4	1	1	50.00	5 - 14	50.00
	70 - 98 (TSS)	TSS						150.00	3 - 45	67.03
Alternative 1.2										
Coagulation				1	0.6	0.5	1			
Flocculation				1.5	1.25	1.1	4			

Treatment	Removal Efficiency	Removed Material	Dose	Dimension				Influent Concentration (Table 4.7)	Actual Effluent Concentration	Concentration Limit (Table 2.2)
				Length	Width	Depth	n			
	[%]	[-]	[mg/L]	[m]	[m]	[m]	[-]	[mg/L]	[mg/L]	[mg/L]
Alum, $Al_2(SO_4).24H_2O$	99	P, FOGs	132					50.00	0.50	50.00
Sedimentation	100		-	7.5	2.5	2.3	1	150.00	0.00	67.03
Alternative 1.3										
Coagulation				1	0.6	0.5	1			
Flocculation				1.5	1.25	1.1	4			
Alum, $Al_2(SO_4).24H_2O$	99	P, FOGs	132					150.00	1.50	67.03
Hydrocyclone	99	TSS	-	-	1.5 (D)	4.0	7 turns	150.00	1.50	67.03
Phase 2										
Alternative 2.1										
Porous media filtration (PMF)	80	TSS	-	0.6	1.6 (D)	0.88 (Ho)	1	150.00	30.00	67.03
Alternative 2.2										
Microfiltration (MF)	97	TSS		1.022	0.16 (Do)	0.0015 (d)	59 units 2 skids	0.00	0.00	50.00
Phase 3										
Nanofiltration (NF)	80 - 90	TDS	-	1.5375	0.2 (Do)	0.0008 (d)	9 units 1 skid	497.00	49.7 - 99.4	100.00
Phase 4										
Alternative 4.1										
Chlorination	99.9 - 99.99	Coliforms	0.5	30 minutes			1	7-log	0 - 2.55-log	3.76-log
Alternative 4.2										
UV Radiation	99.99	Coliforms		15 minutes			1	7-log	0 - 2.55-log	3.76-log

Table 4.3 Final selections for the preliminary plant

Treatment	Removal Efficiency	Removed	Dose	Dimension				Influent Concentration (Table 4.7)	Actual Effluent Concentration	Concentration Limit (Table 2.2)
				Length	Width	Depth	n			
	[%]	[-]	[mg/L]	[m]	[m]	[m]	[-]	[mg/L]	[mg/L]	[mg/L]
Phase 1										
Alternative 1.1										
C - F										
Coagulation				1	0.6	0.5	1			
Flocculation				1.5	1.25	1.1	4			
Alum, $Al_2(SO_4).24H_2O$	99	P, FOGs	132					0.00	0.00	50.00
DAF	80 - 95 (FOGs)	FOGs		1.5	1.25	1.1	1	50.00	5 - 14	50.00
	70 - 98 (TSS)	TSS						150.00	3 - 45	67.03
Phase 2										
Alternative 2.1										
Porous media filtration (PMF)	80	TSS	-	1.5	1.25 (D)	1.1	1	0.00	0.00	67.03
Phase 3										
Nanofiltration (NF)	80 - 90	TDS	-	1.5375	0.80 (Do)	0.0008 (d)	9 units 1 skid	497.00	49.7 - 99.4	100.00
Phase 4										
No disinfection needed										

Table 4.4 Final selections for the large-scale plant

Treatment	Removal Efficiency	Removed	Dose	Dimension				Influent Concentration (Table 4.7)	Actual Effluent Concentration	Concentration Limit (Table 2.2)
				Length	Width	Depth	n			
	[%]	[-]	[mg/L]	[m]	[m]	[m]	[-]	[mg/L]	[mg/L]	[mg/L]
Phase 1										
Alternative 1.1										
C - F										
Coagulation				3	1.25	1.5	1			
Flocculation				5	3	1.5	4			
Alum, $Al_2(SO_4).24H_2O$	99	P, FOGs	132					0.00	0.00	50.00
DAF	80 - 95 (FOGs)	FOGs		7	4.5	3	1	50.00	5 - 14	50.00
	70 - 98 (TSS)	TSS						150.00	3 - 45	67.03
Phase 2										
Alternative 2.1										
Porous media filtration (PMF)	80	TSS	-	1.1	5.05 (D)	0.7	1	0.00	0.00	67.03
Phase 3										
Nanofiltration (NF)	80 - 90	TDS	-	1.5375	0.80 (Do)	0.0008 (d)	115 units 4 skids	497.00	49.7 - 99.4	100.00
Phase 4										
No disinfection needed										

5. Irrigation Demand

The calculation of irrigation demand from agricultural fields is adapted from the field investigation and interviews (Caltran, 2014). Some values are adjusted based on the FAO standard of irrigation and drainage (Allen, Pereira, Raes, & Smith, 1998).

The estimated area of irrigation comes from the areas surrounding the WWTP that are used for agricultural fields (Section 4.12, Figure 4.5), approximately 21 ha. During one of the sampling periods, it was estimated that it took 5 minutes of light walk from the agricultural fields nearby to reach the outlet of facultative pond 2 as the source of water, which is equal to 400 m (Bumgardner, 2016). This distance is used as the comparison with the longest distance from the outlet of facultative pond 2 to the perimeter of the WWTP area, which is 622 m. Thus, considering that the walking path of a farmer is not farther than 400 m, the walking area of the farmer can be calculated as (622 m / 400 m) x 21 ha = 13.18 ha.

The estimated number of farmers is calculated from the walking area for farmers divided by the small standard section of an agricultural field, which is 20 m x 20 m per one farmer (Caltran, 2014). The number of farmers is then 13.18 ha / (20 x 20 / 10^4) ha = 330 persons.

Considering that the highest amount of irrigation demand is in summer, it is reported that the daily estimated number of cans per farmer in the summer is 8 pcs./day for a large standard section of 2.70 x 3.77 m^2. A can of water has a volume of approximately 10 L (Caltran, 2014). Thus, the estimated volume per day per section in the summer is 80 L/day/section.

Thus, knowing that:

1 standard section	= 2.70 x 3.77 m^2	= 0.00102 ha
Estimated volume/day/section	= 80 L/day/section	

gives:

Volume/day/ha in the summer	= (volume/day/section) / (standard section)
	= (80 L/day/section) / (0.00102 ha) / (1000 m^3)
	= 78.59 m^3/day/ha
The walking area of the farmers	= 13.18 ha
Volume/day in the summer	= (volume/day/ha) x (walking area)
	= (78.59 m^3/day/ha) x (13.18 ha)
	= 1098 m^3/day

Thus, the irrigation demand flow from the agricultural fields surrounding the WWTP is approximately 1100 m^3/day.

6. Evaporation

The evaporation data is taken from Maputo and Changalane stations from the period of 1960 until 2006 (Tadross & Johnston, 2012). The combined data are presented in the following graphs:

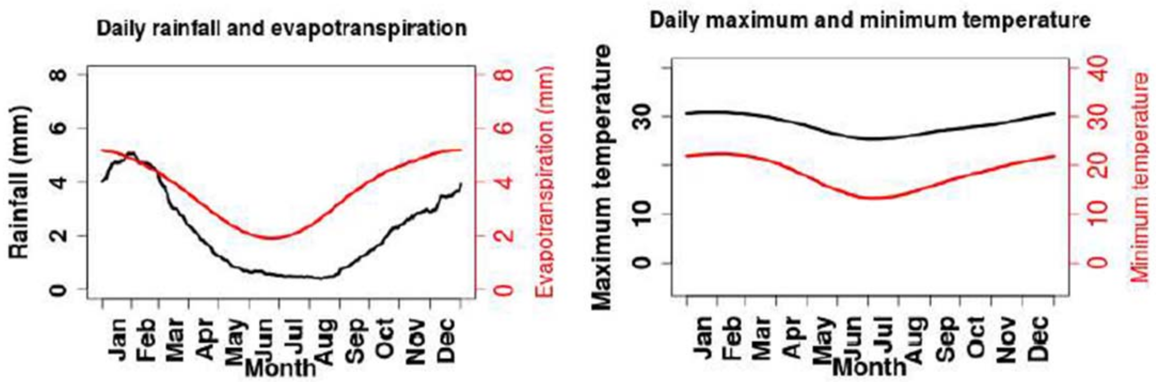


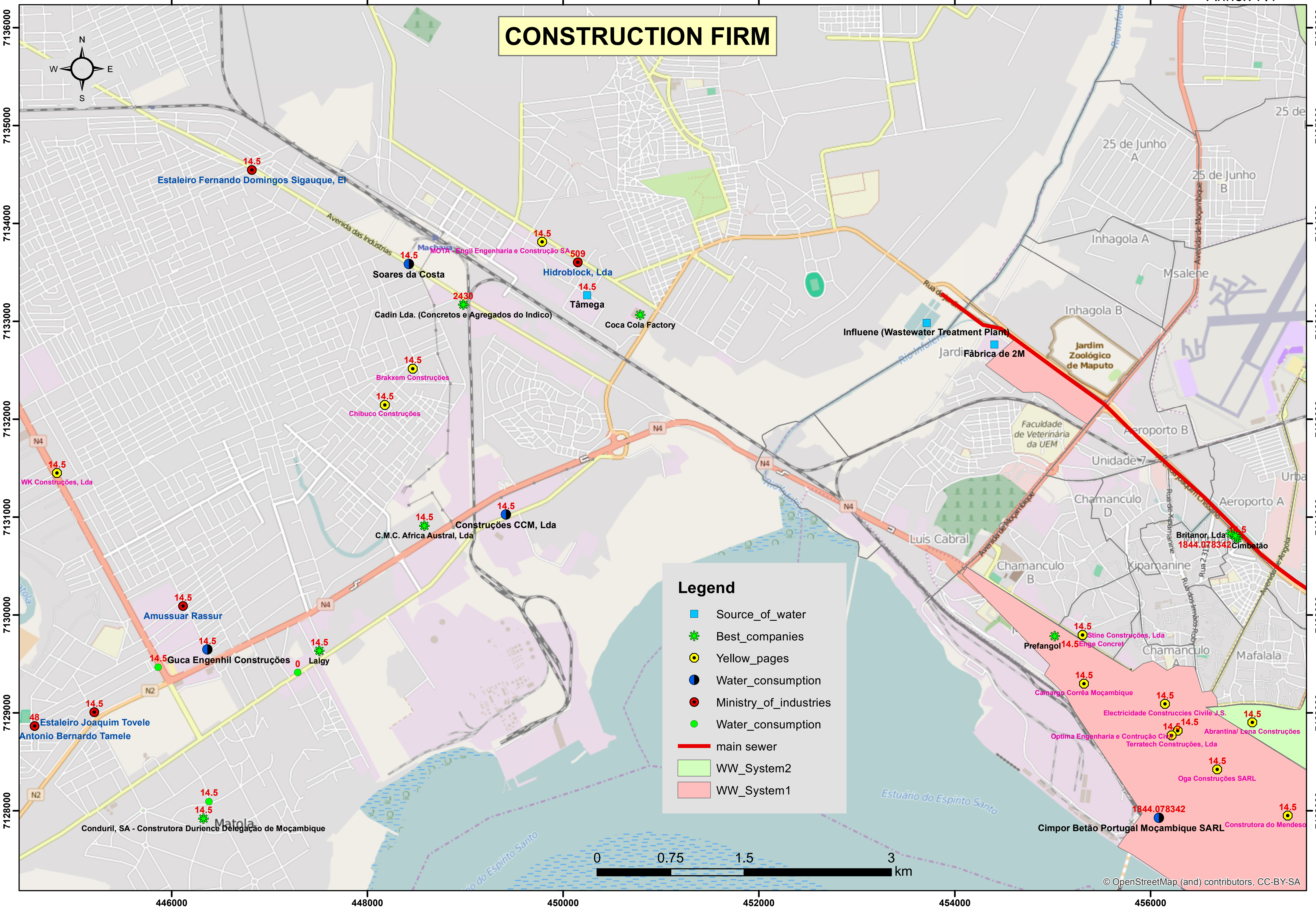
Figure 6.1 Daily climatology of rainfall, temperatures and reference evaporation at Maputo (Tadross & Johnston, 2012)

It can be identified from Figure 6.1 that the maximum evapotranspiration, as the highest extraction amount, comes around December and January with approximately 5 mm/day. Considering that the estimated walking area for farmers is 13.97 ha (from Annex Section 4), the estimated daily evaporation flow in summer is calculated from the daily evaporation times walking area of farmers, which is equal to approximately 700 m^3/day.

7. General Layout and Drawings

1. Inventory map
2. Process flow diagram (all packages)
3. Piping and instrument diagram (per package)
4. Piping and instrument diagram (all packages)
5. Hydraulic grade scheme (per package)
6. General layout (all packages of water reclamation preliminary plant)
7. Grading plan of WWTP area in Infulene, Maputo - Mozambique

Annex 7.1



CONSTRUCTION FIRM
Legend
Source_of_water
Best_companies
Yellow_pages
Water_consumption
Ministry_of_industries
Water_consumption
main sewer
WW_System2
WW_System1
0
0.75
1.5
3
km
Estaleiro Fernando Domingos Sigauque, EI
Soares da Costa
MOTA - Engil Engenharia e Construção SA
Hidroblock, Lda
Tâmega
Cadin Lda. (Concretos e Agregados do Indico)
Coca Cola Factory
Influene (Wastewater Treatment Plant)
Fábrica de 2M
Brakxem Construções
Chibuco Construções
WK Construções, Lda
C.M.C. Africa Austral, Lda
Construções CCM, Lda
Amussuar Rassur
Guca Engenhil Construções
Lalgy
Estaleiro Joaquim Tovele
Antonio Bernardo Tamele
Conduril, SA - Constructora Durience Delegação de Moçambique
Britanor, Lda
Cimbetão
Prefangol
Stine Construções, Lda
Enge Concret
Camargo Corrêa Moçambique
Electricidade Construcções Civile J.S.
Abrantina/ Lena Construções
Optima Engenharia e Contrução Civil
Terratech Construções, Lda
Oga Construções SARL
Cimpor Betão Portugal Moçambique SARL
Construtora do Mendeso
Jardim Zoológico de Maputo
Faculdade de Veterinária da UEM
Estuário do Espírito Santo
Matola
Machava
Avenida das Industrias
446000
448000
450000
452000
454000
456000
7128000
7129000
7130000
7131000
7132000
7133000
7134000
7135000
7136000
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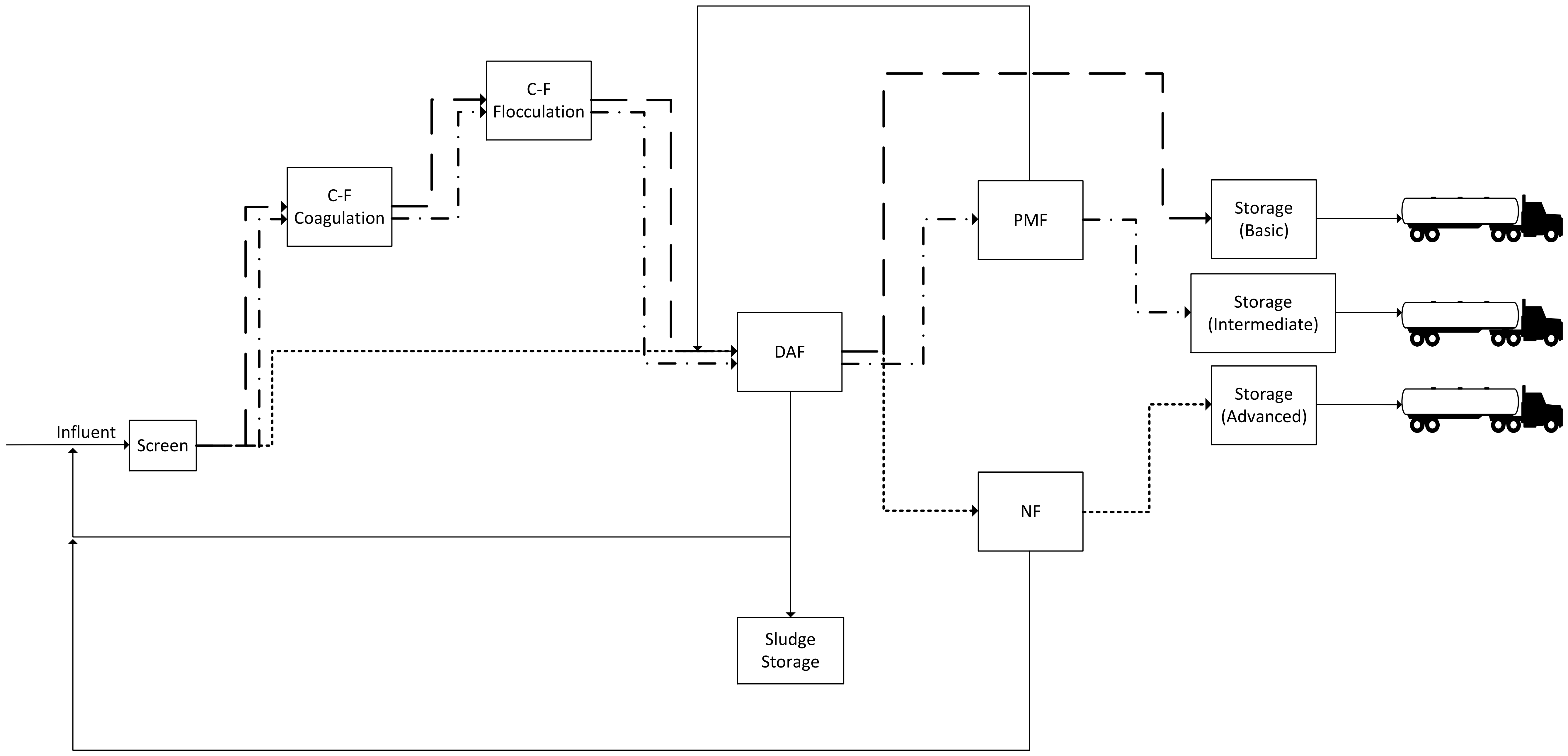


DRAWING NUMBER : RCFM-TUDC-0001

DRAWING TITLE :

PROCESS FLOW DIAGRAM

(ALL PACKAGES)

PREPARED FOR :
WATER RECLAMATION PROJECT
FOR CONCRETE PRODUCTION IN MAPUTO

PREPARED BY : NESSIA FAUSTA
REVIEWED BY : -
APPROVED BY : -
ISSUED BY : -

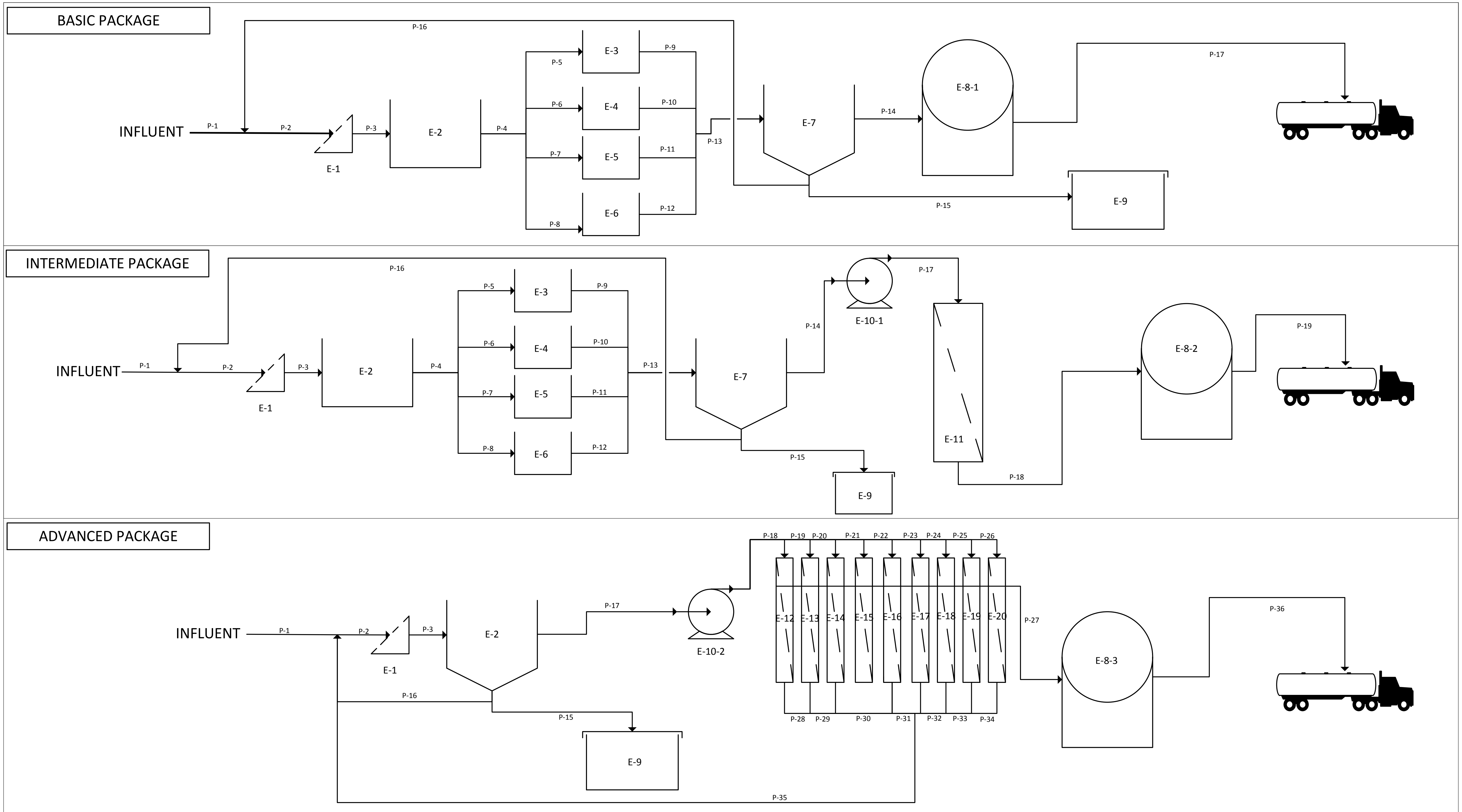
SUPERVISED BY:

SCALE: NTS

REV.: 0

ABBREVIATIONS :

C – F	COAGULATION – FLOCCULATION
DAF	DISSOLVED AIR FLOTATION
PMF	POROUS MEDIA FILTRATION
NF	NANOFILTRATION
	TRUCK FOR DELIVERY
	LINE FOR BASIC PACKAGE
	LINE FOR INTERMEDIATE PACKAGE
	LINE FOR ADVANCED PACKAGE
	LINE FOR RECYCLE/BACKWASH/WASTE



DRAWING NUMBER : RCFM-TUDC-0002

DRAWING TITLE :

PIPING AND INSTRUMENT DIAGRAM

(PER PACKAGE)

PREPARED FOR :
WATER RECLAMATION PROJECT
FOR CONCRETE PRODUCTION IN MAPUTO

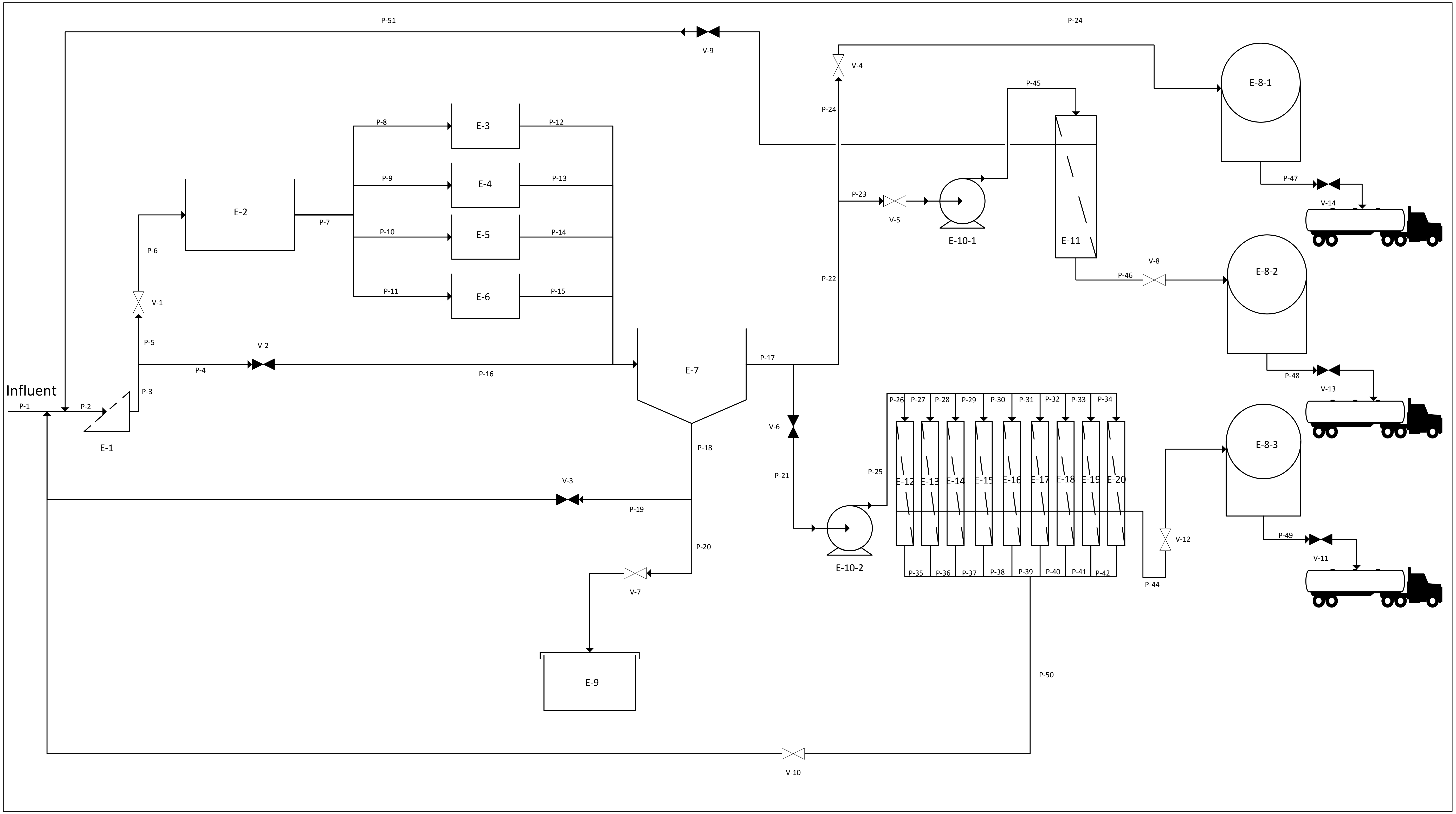
PREPARED BY : NESSIA FAUSTA
REVIEWED BY : -
APPROVED BY : -
ISSUED BY : -

SUPERVISED BY:	SCALE	REV.
TUDelft, Universidade Eduardo Mondlane	NTS	0

EQUIPMENT LEGEND:

E-1	SCREEN
E-2	COAGULATION TANK
E-3, 4, 5, 6	FLOCCULATION TANKS
E-7	DISSOLVED AIR FLOTATION TANK
E-8-1, 2, 3	STORAGE TANK
E-9	SLUDGE TANK
E-10	FILTRATION PUMP
E-11	POROUS MEDIA FILTRATION UNIT
E-12, 13, 14, 15, 16, 17, 18, 19, 20	NANOFILTRATION UNITS

Annex 7.4



DRAWING NUMBER : RCFM-TUDC-0003

DRAWING TITLE :

PIPING AND INSTRUMENT DIAGRAM

(ALL PACKAGES)

PREPARED FOR :
WATER RECLAMATION PROJECT
FOR CONCRETE PRODUCTION IN MAPUTO

PREPARED BY : NESSIA FAUSTA
REVIEWED BY : -
APPROVED BY : -
ISSUED BY : -

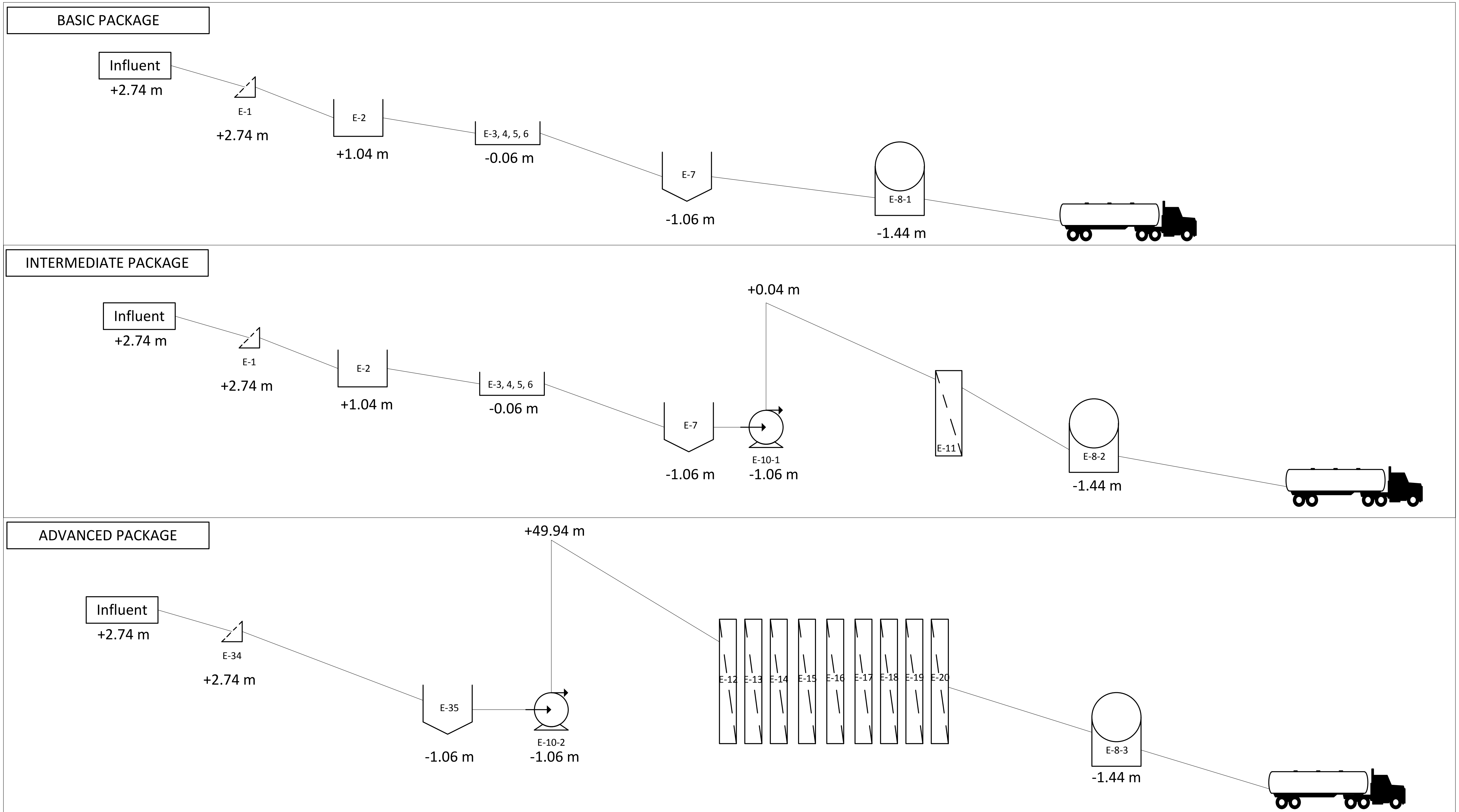
SUPERVISED BY:

SCALE: NTS

REV.: 0

EQUIPMENT LEGEND:

E-1	SCREEN
E-2	COAGULATION TANK
E-3, 4, 5, 6	FLOCCULATION TANKS
E-7	DISSOLVED AIR FLOTATION TANK
E-8-1, 2, 3	STORAGE TANKS
E-9	SLUDGE TANK
E-10-1, 2	FILTRATION PUMPS
E-11	POROUS MEDIA FILTRATION UNIT
E-12, 13, 14, 15, 16, 17, 18, 19, 20	NANOFILTRATION UNITS
V-1 ~ 14	VALVES (NORMALLY OPENED) (NORMALLY CLOSED)



DRAWING NUMBER : RCFM-TUDC-0004

DRAWING TITLE :

HYDRAULIC GRADE SCHEME
(PER PACKAGE)

PREPARED FOR :
WATER RECLAMATION PROJECT
FOR CONCRETE PRODUCTION IN MAPUTO

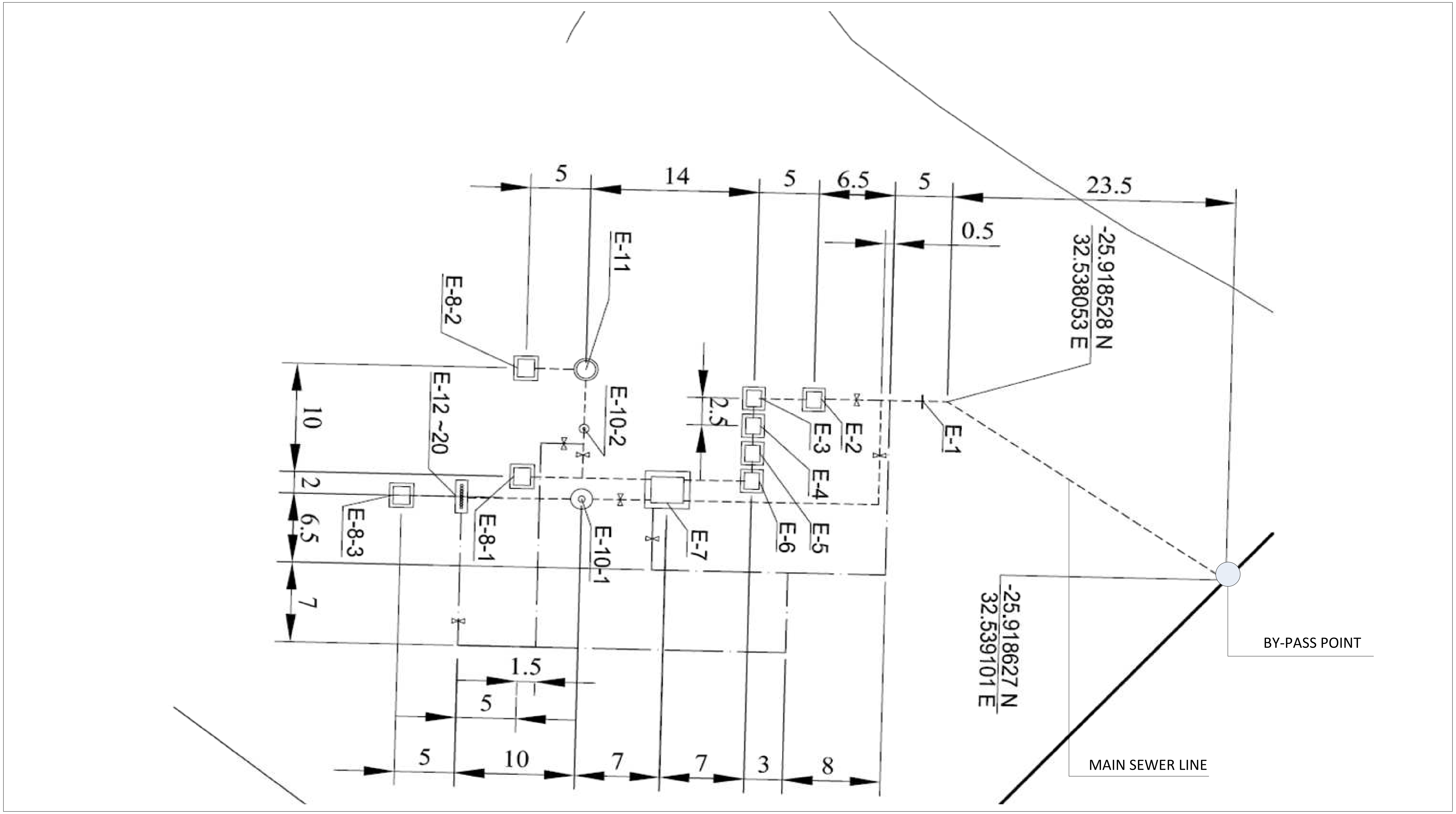
PREPARED BY	: NESSIA FAUSTA
REVIEWED BY	: -
APPROVED BY	: -
ISSUED BY	: -

SUPERVISED BY:	SCALE	REV.
TU Delft; UNIVERSIDADE EDUARDO MONDLANE	NTS	0

EQUIPMENT LEGEND:

E-1	SCREEN
E-2	COAGULATION TANK
E-3, 4, 5, 6	FLOCCULATION TANK
E-7	DISSOLVED AIR FLOTATION TANK
E-8	STORAGE TANK
E-9	SLUDGE TANK
E-10-1, 2	FILTRATION PUMPS
E-11	POROUS MEDIA FILTRATION UNIT
E-12, 13, 14, 15, 16, 17, 18, 19, 20	NANOFILTRATION UNITS

ALL ELEVATIONS ARE IN METER AND REFER TO BOTTOM OF EQUIPMENT/PIPE



DRAWING NUMBER : RCFM-TUDC-0005

DRAWING TITLE :

GENERAL LAYOUT

(ALL PACKAGES OF WATER RECLAMATION PRELIMINARY PLANT)

PREPARED FOR :
WATER RECLAMATION PROJECT
FOR CONCRETE PRODUCTION IN MAPUTO

PREPARED BY : NESSIA FAUSTA
REVIEWED BY : -
APPROVED BY : -
ISSUED BY : -

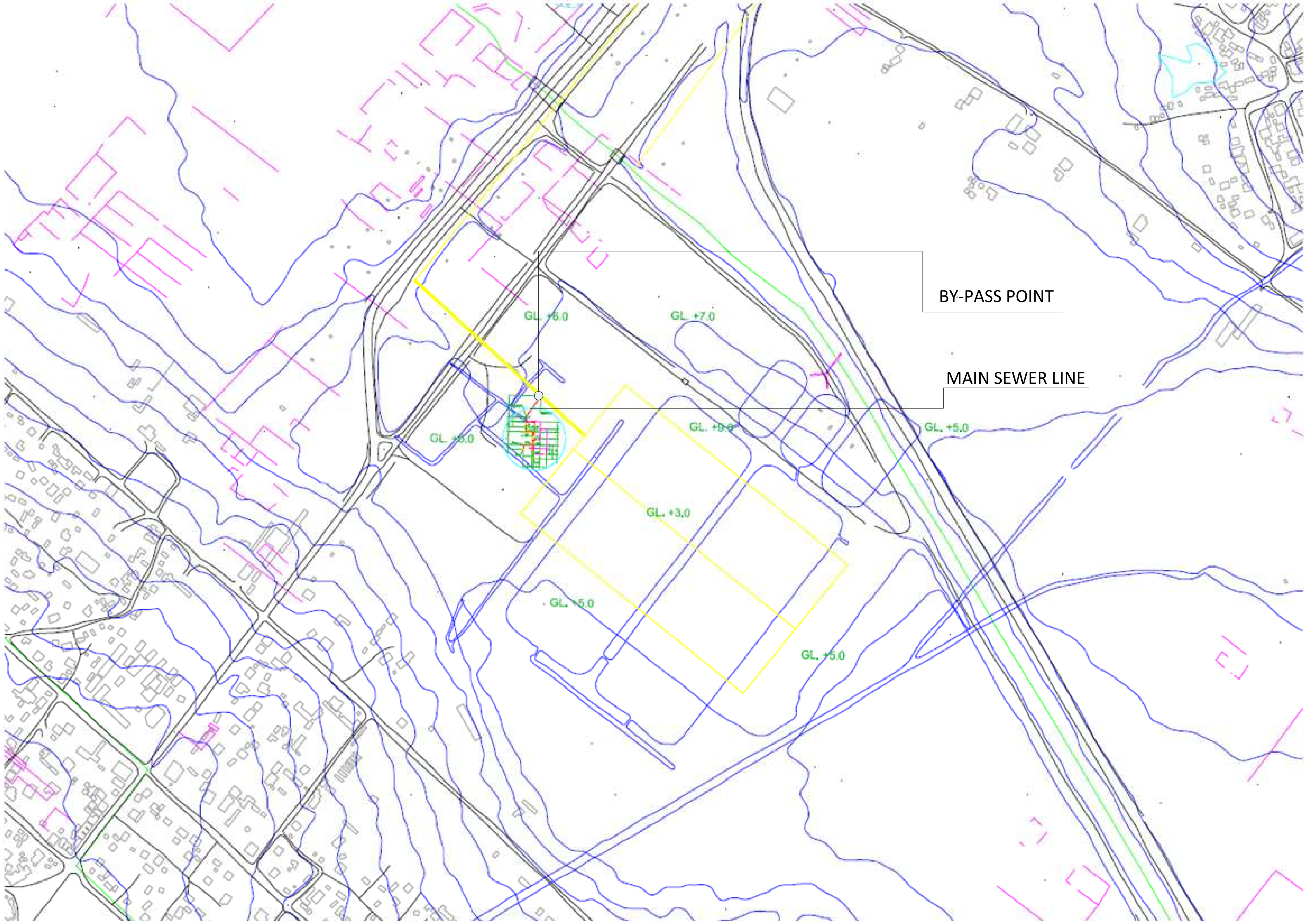
SUPERVISED BY: TUDelft, Universidade Eduardo Mondlane

SCALE: NTS

REV.: 0

EQUIPMENT LEGEND:

E-1	SCREEN
E-2	COAGULATION TANK
E-3, 4, 5, 6	FLOCCULATION TANKS
E-7	DISSOLVED AIR FLOTATION TANK
E-8-1, 2, 3	STORAGE TANKS
E-9	SLUDGE TANK
E-10-1, 2	FILTRATION PUMPS
E-11	POROUS MEDIA FILTRATION UNIT
E-12, 13, 14, 15, 16, 17, 18, 19, 20	NANOFILTRATION UNITS
V-1 ~ 14	VALVES (NORMALLY OPENED) (NORMALLY CLOSED)



DRAWING NUMBER : RCFM-TUDC-0006

DRAWING TITLE :

GRADING PLAN

OF WWTP AREA IN INFULENE
MAPUTO - MOZAMBIQUE

PREPARED FOR :
WATER RECLAMATION PROJECT
FOR CONCRETE PRODUCTION IN MAPUTO

PREPARED BY : NESSIA FAUSTA
REVIEWED BY : -
APPROVED BY : -
ISSUED BY : -

SUPERVISED BY:	SCALE	REV.
	NTS	0

LEGEND:

GL.	GROUND LEVEL (IN METER)
	EXISTING WASTEWATER TREATMENT PLANT
	CONTOUR LINE
	AREA OF NEW DESIGN SYSTEM
	STREET
	CONSTRUCTION LINE
	BUILDING

8. Documentations

8.1. Factory visits

Estaleiro Julio J. Paunde

Figure 8.1 Freshly-hardened latrines

Figure 8.2 Concrete paves before being transported

Estaleiro José M. Sacoto

Figure 8.3 Preparation of a house construction

Figure 8.5 Storage for bulk materials

Figure 8.4 Concrete blocks for the walls

Figure 8.6 Free delivery for concrete blocks

Estaleiro Antonio B. Tamele

Figure 8.7 Curing the concrete blocks (The floor has a slope to collect water into a small side ditch)

Figure 8.9 Drain connected with the decantation tank

Figure 8.8 Small ditch traps the excess of curing water and transports it to the drain

Figure 8.10 Pumping water out of the decantation tank to be used for curing again

Resol

Resol does not have a specific workshop or factory. It installs small batching plant in each construction site or cooperates with other suppliers, such as Britanor for highway and port projects.

Estaleiro Amussuar Rasur

Figure 8.11 Curing by sprinkling with flexible hose

Figure 8.12 Storage of bulk materials

Cadin

Figure 8.13 The company logo

Figure 8.15 The open storage of aggregates

Figure 8.14 The clinkers and truck ready to be filled-up

Figure 8.16 The water truck used during unavailability of tap water

Prefangol

Figure 8.17 The company truck and wet aggregates in a sheltered storage

Figure 8.18 The aggregates are being sprinkled with water (The sprinklers are circled)

Figure 8.19 Open ditch that transports the collected wastewater (after being used for washing the trucks) **into a decantation system**

Figure 8.20 The clinkers and the horizontal hose (The hose brings the effluent of decantation system is used again in the concrete mixture)

Figure 8.21 Testing apparatus in the lab; curing room (left) **and compressive strength test machine** (right)

Hidroblock

Figure 8.22 The company logo and products

Figure 8.23 Evidence of efflorescence

in the concrete surface

Figure 8.24 Groundwater borehole well as future alternative (not operated yet)

Figure 8.25 Curing with fabric cover to reduce water consumption

Britanor

Figure 8.26 Curing tanks

Figure 8.27 The clinkers with a truck beneath it being filled-up with ready-mix concrete

Figure 8.28 Washing the trucks (The floor is sloped to let the water flow into the recycling system)

Figure 8.29 Filling-up the truck with ready-mix concrete (The excess water drops down from a side outlet)

Figure 8.30 The entrance of water recycling system

Figure 8.31 The disposal and sludge storage

Cimbetão

Figure 8.32 The clinkers and a hose that supplies water

Figure 8.34 Decantation pond
(for water recycling system)

Figure 8.33 A truck having been washed and the used water collected in a pond

Figure 8.35 Curing pond

Bricon

Figure 8.36 The company logo and products

Figure 8.37 The clinker for mixing concrete

Figure 8.38 Freshly-hardened concrete blocks

Figure 8.40 Curing with plastic wrap (saving water)

Figure 8.39 Handling of products before delivery

Figure 8.41 Formwork of reinforced concrete pipe

DAS

Figure 8.42 Heavy duty sewer and manhole covers produced by DAS

8.2. Selected Sources (WWTP in Infulene)

Figure 8.43 Influent from the main sewer

Figure 8.45 Facultative outlet 2
(surrounded by agricultural fields)

Figure 8.44 Facultative outlet 1 (empty)

Figure 8.46 Emergency outlet