Analysis of the challenges and solutions in the water and sanitation sector in Greater Maputo, Mozambique

Applying the Dynamic Adaptive Policy Pathways approach

Master of Science - Thesis
Jesper Stuyling de Lange
29-06-2017

Delft University of Technology

Universidade Eduardo Mondlane

Cover page photograph source: casamozambique.co.mz

Analysis of the challenges and solutions in the water and sanitation sector in Greater Maputo, Mozambique

Applying the Dynamic Adaptive Policy Pathways approach

Master Thesis

a thesis submitted to the TU Delft
In partial fulfilment of the degree of Master of Science

By

J. J. Stuyling de Lange

Student Construction Management and Engineering,
at the Delft University of Technology,
The Netherlands, 2017

Colophon

Report

Type:	Graduation Thesis
Title:	Analysis of the challenges and solutions in the water and sanitation sector in Greater Maputo, Mozambique
Subtitle:	Applying the Dynamic Adaptive Policy Pathways approach
Place:	Delft
Date:	29-06-2017

Author

Name:	J.J. (Jesper) Stuyling de Lange
Date of birth:	31-03-1989
Student number:	1379275
Telephone number:	+31647196747
Email:	j.j.stuylingdelange@student.tudelft.nl

Study program

University:	Delft University of Technology
Faculty:	Civil Engineering and Geosciences
Master:	Construction Management & Engineering
Course:	CME 2000 - Graduation Thesis

Graduation Committee

Chairman:	Prof. Dr. ir. L.C. (Luuk) Rietveld Faculty of Civil Engineering, TU-Delft
Committee supervisor:	Dr. ir. A. (André) Marques Arsénio Faculty of Civil Engineering, TU-Delft
Committee supervisor:	Dr. ir. B. (Bert) Enserink Faculty of Technology Policy and Management, TU-Delft
Additional supervisor:	Prof. Dr. ir. N.P. (Nelson) Matsinhe Faculty of Civil Engineering, Universidade Eduardo Mondlane

Universities:

Delft University of Technology
Mekelweg 2
2628 CD Delft, Netherlands

Universidade Eduardo Mondlane
Av. Julius Nyerere,
Maputo, Mozambique

Acknowledgements

First of all I would like to thank each of the supervisors in my graduation committee. My thanks to my direct supervisor Dr. ir. André Marques Arsénio for the idea that finally led to this thesis, but more importantly for the many cycles of feedback, creative new perspectives and your positive attitude encouraging me to continue. My thanks to Prof. Dr. ir. Luuk Rietveld for the sharp observations, even on new methodologies, your wide knowledge about Greater Maputo and for reminding me to switch between perspectives of details and overview. Dr. ir. Bert Enserink thank you for participating in this committee outside your faculty and for your critical methodological perspective that was always accompanied with positive remarks. My thanks to Prof. Dr. ir. Nelson Matsinhe in Mozambique for the warm welcome to Mozambique, the helpful advice, valuable contacts and of course for opening your venue for my online supervisory meetings.

I would like to thank the Lamminga Foundation for providing funds to cover the travel expenses enabling me to visit Greater Maputo for field research. A especial thank you to my travel companions Jay-El Esguerra and Iana Salim, I believe it was the start of a lasting friendship. Johanna Weststrate, thank you for all the information you shared with me, for combining interviews and most importantly for the countless Pastéis De Nata and lunches. All the people living in the EUM residence thank you for the hospitality and your unforgettable company. I feel obliged to thank at least Inancio Guambe personally for all the practical help, translations and friendship. The same is true for Cadafi Inrule, Joachim Campira, Armando Rainde and Idrisse Cossa. Thanks to everybody I met in Mozambique for the best times, it was an awesome experience.

To all my friends and colleagues in the Netherlands, my sincere apologies for delaying the celebration that is bound to follow the defence of this thesis. Finally, thank you Carmen, without your unconditional loving support and patience I wouldn’t have finished at all. The same gratitude goes out to both our families.

Summary

Similarly to other rapidly growing cities in developing countries, Greater Maputo faces multiple challenges related to water and sanitation. Additionally, new trends are visible with the potential to increase the severity of these challenges in future decades; these are for example, climate change, which is causing longer droughts and more severe floods; population growth; and economic growth that are expected to impact drinking water consumption patterns and the demand for sanitation services. These elements and challenges all relate to the underlying challenges towards creating a sustainable freshwater supply and sanitation services for Greater Maputo. This thesis combines an exploration of integral solutions to these challenges, with the Dynamic Adaptive Policy Pathways (DAPPs) approach, resulting in an answer to the following research question.

Research question*:* How can the Dynamic Adaptive Policy Pathways approach be applied to characterize the challenges towards sustainable freshwater supply and sanitation services for Greater Maputo, and be exploited to quantitatively compare the potential paths to address these challenges?

Methodology

In order to answer this research question, increased understanding of the challenges, the system actors and their interrelations in the water and sanitation sector in Greater Maputo is needed. As background research for the DAPPs approach, the methodology of Policy Analysis in Multi-Actor Systems has been conducted providing the necessary understanding of the water and sanitation system and actors. Additionally, quantified insight is needed in the influences of external factors in the system of water and sanitation. Therefore the influence of climate change on the available surface water is assumed, and assumptions are made about the effect of economic and population growth on the amount of DW that will be used in the upcoming years until 2040.

Analysis and results

The results of the DAPPS analysis show that traditional approach only creating additional supply sources with dam that located far away from Greater Maputo, does not meet the requirements towards the extraction of GW nor does it create an acceptable future situation in sanitation. With rapid developments of the external influences, additional action is required to meet this the requirements of a sufficient future. The addition of actions that improve the performance of the supply networks in Greater Maputo has been found to be an effective solution to make the new supply solutions more effective and sustainable. However, the only strategy to create both sustainable sanitation services with sustainable DW services approach to be a combination of additional supply resources, the improvement of the supply networks and solutions to reclaim wastewater for reuse within Greater Maputo.

Conclusions

The model underlying the DAPPs analysis includes assumptions about the relations between GW quality, extraction for use, surface water, and the supply of DW, as well as the influences of external factors like climate change, population and economic growth in Greater Maputo. The DAPPs approach allows to bring freshwater and sanitations services together to their common denominator: piped water (whether it is potable, polluted or reclaimed). Additionally, requirements about the system are included in the DAPPs model, a maximum acceptable extraction of GW to prevent loss of quality and a consequential maximum volume of GW use. With the addition of the quality of supply network and their influence on the amount of DW that actually becomes available for use, the DAPPs analysis creates an overview of the policy options, which makes it possible to include a wide range of alternative actions to improve the current situation.

Solutions for water or sanitation services have been assessed and scored for their cost and benefits in multiple impact criteria relevant in the system (DW supply, surface water, sanitation and GW quality). These scores and the DAPPs model allow to quantitatively compare different strategies in their effectiveness to deal with the challenges for a sustainable freshwater supply and sanitation services in Greater Maputo. Specifically the DAPPs approach allows for testing and comparison of many alternative solution pathways within solution strategies. Different external development scenarios can be applied to tweak strategies to the need of expected developments, which allows policymakers to determine a general development strategy that can be adapted year-by-year to best suit external developments in case they have actually happened in reality.

Table of contents

List of figures

List of tables

List of abbreviations

AdeM	Water for the Maputo Region, or Águas da Região de Maputo, in Portuguese.
AIAS	Administration of Infrastructures for Water and Sanitation, or Administração de Água e Saneamento, in Portuguese.
ARA-Sul	Southern Regional Water Authority, or Autoridades Regionais de Águas Sul, in Portuguese.
CLD	Causal Loop Diagram
CMM	Municipality of Maputo, or Conselho Municipal de Maputo, in Portuguese
CRA	Water Regulating Counsel, or Conselho de Regulação do Abastecimento de Água, in Portuguese.
DAPPs	Dynamic Adaptive Policy Pathways
DNA	National Directorate of Water, or Direção Nacional de Águas, in Portuguese.
DW	Drinking Water
FIPAG	National Urban Water Investment and Asset Holding Fund, or Fundo de Investimento e Património do Abastecimento de Água, in Portuguese.
FS	Faecal Sludge
FSM	Faecal Sludge Management
FSTS	Faecal Sludge Transfer Station
Greater Maputo	Greater Maputo Metropolitan Area
GW	Groundwater
MAR	Managed Aquifer Recharge
Masterplan	Masterplan for drainage and sanitation in Greater Maputo
MDGs	Millennium Development Goals
NRW	Non-revenue water
OSS	On-site sanitation systems
PARPAs	Action Plans for the Reduction of Absolute Poverty
PROMAPUTO	Municipal Development Program Maputo, or Programa de Desenvolvimento Municipal de Maputo, in Portuguese
SDGs	Sustainable Development Goals
SRQ	Sub-research question
SSIPs	Small Scale Independent Providers, or Pequenos Operadores Privados (POPs), in Portuguese.
WTP	Water Treatment Plant
WW	Waste Water
WWTP	Waste Water Treatment Plant
WSUP	Water & Sanitation for the Urban Poor

1. Introduction

1.1. Background information

Maputo is the capital and a rapidly growing and urbanizing city on the coast in the South of Mozambique. Maputo City lies within the Greater Maputo Metropolitan Area[1] (Figure 1 and Figure 2), for practicality this area will be abbreviated to Greater Maputo. Similar to other growing cities in developing countries, Greater Maputo faces several challenges related to water and sanitation, and new trends are visible with the potential to increase the severity of these challenges in future years; these are, for example, climate change, which will lead to longer droughts and more severe floods (UN-HABITAT, 2009); population influx and growth (ENGIDRO, HIDRA, & AQUAPOR, 2015a); and economic growth (UNM & FCD, 2015) that is expected to impact drinking water consumption patterns (ENGIDRO et al., 2015a). These elements and challenges all relate to the underlying challenge of creating a sustainable freshwater supply and sanitation services for Greater Maputo, addressing these challenges is the objective of the research group this thesis is a part of.

Figure 1: Mozambique situation (source: Google Maps)

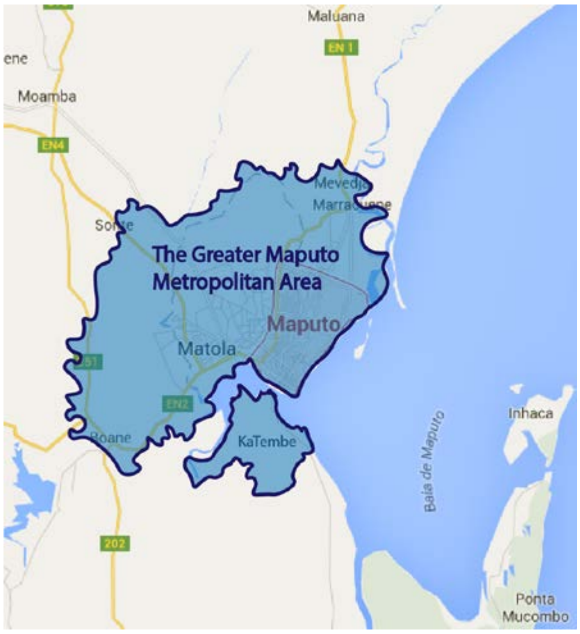


Figure 2: The Greater Maputo Metropolitan Area

1.2. Knowledge gap and relevance

In the past decades multiple research institutes and consultancy firms have conducted research on these topics for the city of Maputo and for the Greater Maputo area. These projects were mostly focused on the technical side of the current and future challenges that Greater Maputo is facing. These issues include availability, quality, treatment and distribution of drinking water (DW) (Hydroconseil & WE Consult, 2011; WaterAid, 2010; WHO & Unicef, 2013), the conveyance and treatment of wastewater (WW) (SEED, 2010; WaterAid, 2010) and faecal sludge management (FSM) (ENGIDRO et al., 2015a; SEED, 2010).

These reports focus on technical issues and challenges in either water or sanitation, but fail to address that water and sanitation form a complex system in which issues are often interrelated and multi-sectorial. For example, the pollution of groundwater with WW from dysfunctional sewer networks, caused by governance issues such as lacking budgets for maintenance or improper use, could influence the availability of groundwater as a safe source for DW. We argue that what appears to be relevant but missing in Greater Maputo is a multi-disciplinary view on these problems, not only technical but also in governance and policy, a holistic analysis that shows the inter-connections between the several issues and the possible solutions. Research in water and sanitation suggest that in places, like Jakarta Indonesia, problems have been caused by institutions with unclear or overlapping responsibilities or dysfunctional organisations, instead of lacking budgets or technical issues (Kooy, 2014).

[1] The Greater Maputo Area or Greater Maputo Metropolitan Area (Grande Maputo in Portuguese) is the combined area of the southern Mozambican Municipalities of Maputo, Matola, KaTembe and Boane surrounding the Maputo Bay.

This thesis is written with the purpose to create a multidisciplinary body of work identifying and connecting the most important challenges in water and sanitation for Greater Maputo. This broader approach will connect issues that have previously been researched separately. Subsequently, a perspective is given on the consequences that possible solutions have on the multiple challenges Greater Maputo is facing. Including actors with their roles and interrelations in this systems analysis could create a base for revealing challenges that are often overseen.

Proposed is a description of the actors and challenges in the water and sanitation sector of Greater Maputo and the exploration of several solution strategies to solve these challenges using the Dynamic Policy Pathways (DAPPs) approach. This analysis can function as a starting point for further research in the application of DAPPs, and both as a planning tool and a knowledge base for local decision makers.

1.3. Research topic

The technical side of this research is focussed on the existing and planned drinking water networks in Greater Maputo, the existing and possible supply sources; the wastewater network in the city; and on the existing and planned FSM services. Additionally the interrelations between wastewater disposal, groundwater and drinking water quality will be described.

The created view of the challenges and issues in the current situation will be the basis for an analysis of the solutions implemented over the past 10 years and the proposed solutions for the upcoming decades. In 2014 the World Bank started funding the creation of a *Masterplan for sanitation and drainage in Greater Maputo* in operational cooperation with the Administração de Água e Saneamento (AIAS) (ENGIDRO et al., 2015a). This masterplan contains the five phases. Of which the first two, Analysis of the Existing Situation and Identification of Solutions, have been made available for this research however they are not yet officially released in 2016. These documents will be used as reference for the proposed solutions that are analysed in this research. The Masterplan contains volumes for Greater Maputo and two more specific institutional development studies for the municipalities of Matola and Boane.

In order to create a concrete scope an area as small as possible is needed that is will still adequately represent the challenges at stake within Greater Maputo. Most of the challenges (such as limited surface water, groundwater pollution and wastewater treatment) and solutions (central drinking water treatment and possible new resources) cover the area of Greater Maputo as a whole. That is why for this research a large area of Greater Maputo is selected, a consequence of this large scope is that the analyses are of a general level of detail.

1.4. Research questions

In this research the following main research question will be answered, supported by a set of six sub research questions (SRQs).

<u>Research question</u>*:* How can the Dynamic Adaptive Policy Pathways approach be applied to characterize the challenges towards sustainable freshwater supply and sanitation services for Greater Maputo, and be exploited to quantitatively compare the potential paths to address these challenges?

- SRQ 1: What is the current situation for drinking water supply, water resources and sanitation services and what solutions have been proposed in the last decade?
- SRQ 2: Why have these proposed solutions (not) been implemented?
- SRQ 3: What solutions have been proposed for the coming decades and which alternative solutions are possible towards creating sustainable sanitation services and freshwater supply?
- SRQ 4*:* What strategies of (combined) solutions are possible towards sustainable freshwater supply and sanitation services for Greater Maputo?
- SRQ 5: How could the application of DAPPs help in reducing the uncertainty in the potential benefits of proposed and alternative solutions or combinations thereof?
- SRQ 6: How could the application of DAPPs help to maximize the probability of implementation of these (alternative) solutions?

<u>Background research</u>

Before the research questions can be answered, background research is necessary to provide insight in the historical context of the water and sanitation sectors in Mozambique and Greater Maputo. Additionally insight is needed in the workings of the system of water and sanitation and the actors that are responsible for and involved in providing and requesting water and sanitation services in Greater Maputo. A description of the system will show what challenges these actors face regarding water resources management, supply of DW, conveyance and treatment of WW and FSM. Finally, before an answer can be provided about the solutions and application of DAPPs in Greater Maputo it should be clear, what the influences are of external trends (e.g. climate change, population growth, economic growth) on the existing and future use of DW and the production of WW and faecal sludge (FS) in Greater Maputo.

Viewpoint

This research is conducted as part of the research group "*Sustainable freshwater supply in urbanizing Maputo, Mozambique*". The viewpoint of this research is therefore an outside overview of scientific, technical and policy challenges regarding the sanitation and drinking water sector for Greater Maputo. This viewpoint allows the exploration of solutions that require the collaboration or involvement of actors that usually operate independently and without consideration of each other's interests.

1.5. Structure of this thesis

This thesis will consist of the following steps with corresponding chapters.

In Chapter 2, a review of existing research on the water and sanitation sector in Greater Maputo is presented and placed in a historic frame to explain the complexity. In Chapter 3 a review of possible approaches for this research is presented to explain why the chosen methodology is suitable the answer the research question as presented in this thesis. The methodologies Policy Analysis in Multi-Actor Systems and Dynamic Adaptive Policy Pathways are explained. This way the research steps and the analyses with their coherence within this thesis are introduced. Chapter 4 contains an exploration and analysis of the existing situation. Therefore an analysis of the system, actors and problems is conducted. In Chapter 5 the certainties and uncertainties about the future that influence the challenges are analysed, therefore currently visible trends are quantified. In Chapter 6 the previously planned and executed projects, as well as the proposed plans and alternative solutions to the challenges in Greater Maputo are described. Chapter 7 contains an analysis of possible pathways of solutions towards a desired future. Different types of solutions are combined into strategies that can lead to an improved future, with regard to the interrelation in the system of water and sanitation. In Chapter 8 the results of this research are discussed, conclusions are drawn as answers to the research questions are formulated. Additionally, the limitations to this research are discussed and recommendations for future research are included.

2. Historical context: Water and Sanitation in Mozambique

This chapter contains a review of grey literature on the history of the sanitation and drinking water sector in Greater Maputo. Findings about the past are introduced and linked to the present situation and some of the existing challenges.

2.1. Historical context of Greater Maputo

To understand the present situation, three important eras of development of Greater Maputo and the reforms in the water and sanitation sector that followed are described.

Colonial period

During the centuries of Portuguese colonial oppression the development of Greater Maputo was focused on the formal settlements (now city parts) used for trading purposes (Jenkins, 2009). The old city centre of Maputo (Figure 3 and Figure 4), currently known as *Cement City* (Cidade de Cimento, in Portuguese) received urban sanitation, drainage and drinking water networks for the colonial privileged (HYDROCONSEIL, 2008, p. 4). Outside this formal settlement the so called *subúrbios* (sub-urban areas) grew quickly without regulation, Figure 4 and Figure 5. The colonial government treated this development as temporary and did not assign land-rights in these areas, contributing to unstructured development of low quality housing. No networks for centralized urban services where created in these areas (Jenkins, 2000a, p. 208). In 1972 the regional government created a masterplan for the urban development of Greater Maputo. However, in implementation attention and funds were mainly focussed on further development of the Cement City (Jenkins, 2000a, pp. 208–209). The urban planning and unequal distribution of urban services formed the base for the present segregated development the different parts of Greater Maputo.

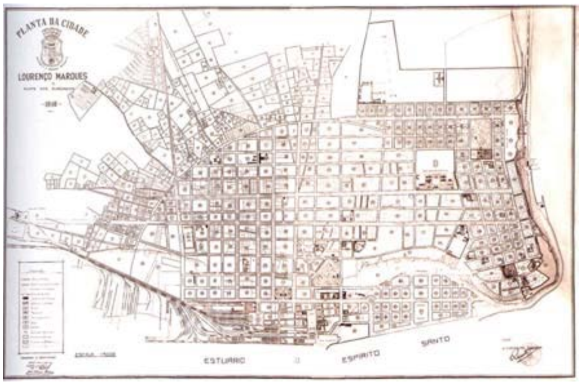


Figure 3: The 1940 city plan (Jenkins, 2009)

Figure 4: Satellite picture Cement City, Maputo 2016

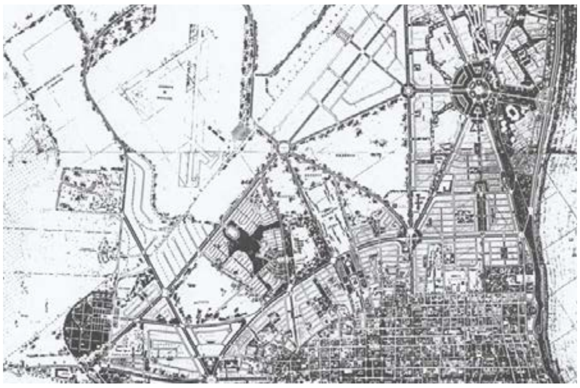


Figure 5: The 1952-55 urban plan (Jenkins, 2009)

Figure 6: Satellite picture wider urban area, Maputo 2016

Post-independence Marxist Regime

After the Independence in 1975, FRELIMO (Frente de Libertação de Moçambique, in Portuguese) introduced a Marxist-Leninist regime, that aimed at transforming Mozambique into a "developed, modern and socialist country" (Pitcher, 2006). Jenkins (2000a) describes that with the Independence administrative controls on moving into the city of Maputo were lifted, triggering a population influx from rural areas. By 1985 the military tensions between FRELIMO and opposing movement RENAMO (Resistência Nacional Moçambicana, in Portuguese) had escalated into a civil war that created unsafe conditions especially in the rural areas of the country. This sparked even more population influx from rural areas towards the safer (peri-)urban areas of Maputo, hence the total population in Maputo kept increasing (Jenkins, 2000a). These population movements continued towards, and even after the end of the civil war, increasing the unstructured densification of some urban and especially the peri-urban areas (Jenkins, 2000a). In turn this dense and unstructured urban development has created a challenge of limited space for the construction of public service networks for DW, drainage or sewerage (SEED, 2010).

Simultaneously, the governmental institutions grew strongly in size and attempted to take total control of the economy. In order to do so the government imposed an ideological *proto-socialist* line. What followed was the nationalisation of banks, industries and enterprises (Jenkins, 2000a). The government also took charge of all urban services and basic services such as water and sanitation where provided subsidized without focus on remuneration. This developed a sense of expectation among Mozambican population of certain social rights and of their government to care for them (Pitcher, 2006).

Alongside these nationalisations the government centralised its decisions power and budgets, while additionally relocating all highly skilled government officials to positions in the central administration. These replacements severely weakened the general capacity of local institutions (Jenkins, 2000a). The disappearance of skilled staff, budgets and decision power left the local government very little possibilities to structure local urban development and subsequently urban services (Jenkins, 2000a).

In short the Marxist regime (1975-1992) weakened decision making and budgeting power, as well as human resources at municipal level, while neglecting the already merely functioning departments for urban water and sanitation services. The ideology is still present in the populations expectations form the governmental services (Pitcher, 2006).

Democracy, decentralisation and market orientation

In 1987 the government started working on economic reforms to enable private initiative and free market. These reforms initially focussed on private participation in sectors like agriculture, fisheries and healthcare (Republic of Mozambique, 2001). Later reforms in the water and sanitation sector followed in 1997 (SEED, 2010, p. 13). After the end of the civil war, in 1992, when FRELIMO was elected as democratic government, the party took an internationally encouraged approach of market orientation. Donor programs related to water and sanitation were launched, these aimed at improving the management of urban investments and maintenance (Jenkins, 2000b). These programs prioritised decentralisation and market orientation of governmental organisations and services (Jenkins, 2000b, p. 4)

This new approach of urban development was imposed as a Local Government Reform Programme (Jenkins, 2000b, p. 16). Unfortunately this reform program insufficiently incorporated ways of dealing with the weakened local governmental institutions, and the program did not confront the severe impacts in organisational capacity and required changes (Jenkins, 2000b, p. 16).

Since the decentralising market orientation has replaced the centralised socialist government ideology, capacity problems in local government persisted. Insufficient policy and institutional analysis was conducted before early donor programs.

Policy reforms in water and sanitation sector

This historical context allows understanding the starting point for various changes in the water and sanitation sector. Specific national reforms and changes in the sector are now explained in their historical context.

To enable independent local development and foreign investments in the drinking water and sanitation sector, new national laws and policy where installed in the mid-90s. In 1997 the national Water Law (Nº 11/97) established that local institutions have the legal power to provide water related services including water supply, wastewater services and solid waste management. "Municipal Framework Law 2/97 defines the responsibilities of various municipals organs and gives the Municipalities the responsibility to set tariffs for public services, including conservation and wastewater treatment."(SEED, 2010, p. 13). Specifically it allows local authorities, instead of solely the central governmental bodies, to create autonomous services or establish public-private enterprises to fulfil local demands (SEED, 2010).

In 1998 Mozambique introduced further policy reform for the development, delivery and regulation of drinking water supply. This reform aimed to create a Delegated Management Framework to allow for private party involvement in management, maintenance and development of the water networks in the five largest cities in Mozambique (World Bank, 2009). FIPAG (Fundo de Investimento e Património do Abastecimento de Água, in Portuguese or National Urban Water Investment and Asset Holding Fund) was created as the owner of drinking water assets in these cities.

These reforms and the creation of FIPAG were quickly followed by the awarding of the first actual contract for the drinking water services for the five biggest cities of Mozambique. The contract with a duration of 15 years was awarded to the foreign consortium of water supply operators *Águas de Moçambique* (AdeM) led by the French operator SAUR (World Bank, 2009), in collaboration with the Portuguese water company Águas de Portugal and Mazi, a group of Mozambican companies. Execution of the contract met large delays and financial difficulties, eventually causing SAUR to drop out of the consortium in 2002 and the contracted to be renegotiated by Águas de Portugal (World Bank, 2009). During the renegotiated contract the Dutch consortium of water operators *Vitens Evides International* (VEI) was contracted to perform management support for services in other cities in Mozambique (World Bank, 2009). More than 15 years of experience has professionalised FIPAG, as a semi-private organisation, in the contracting of DW operations. During these years the DW industry has developed and the coverage of DW networks increased significantly (World Bank, 2009).

Although the laws from 1997 entailed for local government the responsibility and possibility to involve private parties in both drinking water and sanitation services, developments are mainly visible in drinking water services and within the sanitation sector attention was aimed at developing solutions for municipal solid waste management (SEED, 2010). The PROMAPUTO (Programa de Desenvolvimento Municipal de Maputo, in Portuguese or Municipal Development Program Maputo) project initiated and realised an institutionally embedded and city wide service in cooperation between the municipality and private operators. However, development of wastewater services, although mentioned in the Municipal Framework Law 2 / 97, was not given as much attention (SEED, 2010). As shown in the following timeline of documents regarding drainage and urban sewerage in Greater Maputo (Figure 7), only recently documents have been published and even less projects have been conducted to actually improve the coverage or efficiency of the sanitation services.

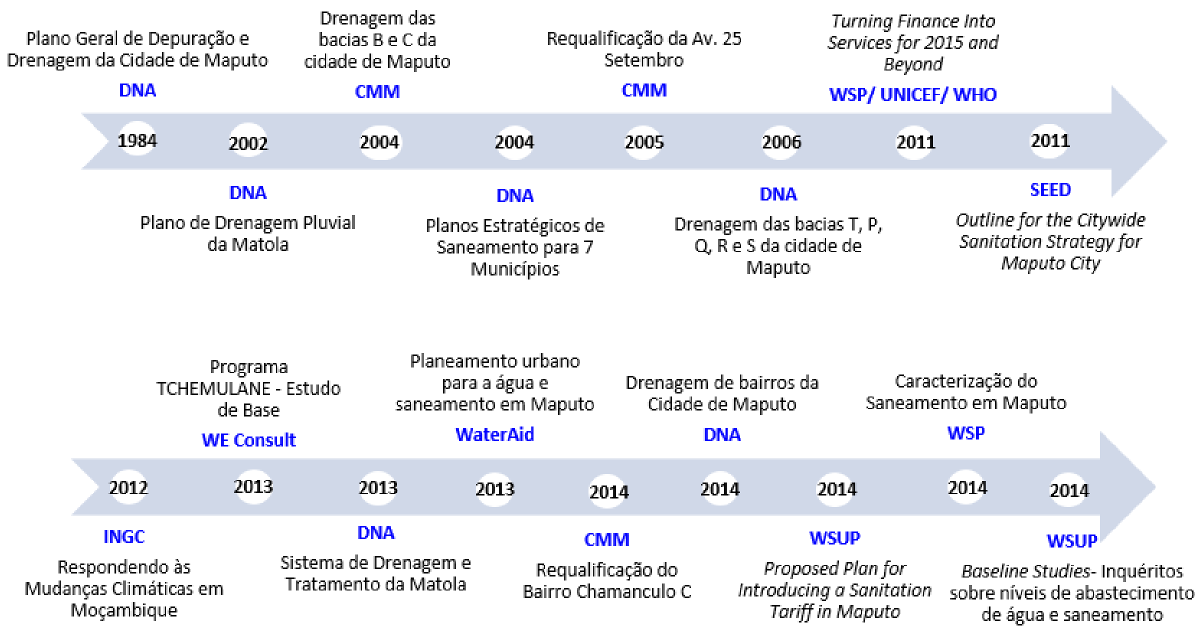


Figure 7 Timeline of documents leading to the Masterplan (ENGIDRO, HIDRA, & AQUAPOR, 2015c).

2.2. Development programs in water and sanitation

Following the market oriented reforms, multiple development programs where conducted. Three are especially relevant for water and sanitation in Greater Maputo. Therefore we elaborate on the *Millennium Development Goals* (MDGs), that have been brought into action in Mozambique with *Action Plans for the Reduction of Absolute Poverty* (PARPAs) and after 15 years been followed by *Sustainable Development Goals* (SDGs)

Millennium Development Goals (MDGs)

In September 2000, world leaders met at the United Nations and adopted the MDGs by signing the United Nations Millennium Declaration. The Mozambican government also committed itself to achieving the MDGs in order to reduce the number of citizens living in absolute poverty by 2015. The two important criteria related to water and sanitation are part of Goal 7: "Ensure environmental sustainability". Under this environmental goal, target 10 defines the goals regarding access to safe drinking water and sanitation, with indicators defining safe as an improved source of drinking water or an improved form of sanitation.

Target 10: Halve, by 2025, the proportion of people without sustainable access to safe drinking water and sanitation.
Indicator 30: Proportion of population with sustainable access to an improved water sources, urban and rural
Indicator 31: Proportion of population with access to improved sanitation, urban and rural.

Figure 8: Improved and unimproved drinking water[2]

Figure 9: Improved and unimproved sanitation[2]

For these objectives two reference situations are used in the MDGs progress reports. The general MDG progress report uses the situation in 1990 as reference (UNICEF & WHO, 2015). Whereas the reports authored by the Mozambican Government use either 1997 or 2001 as the year of reference to measure their progress (Republic of Mozambique, 2005a). In Table 1 figures regarding access to improved sources of drinking water and improved sanitation facilities in Mozambique over the past 25 years are presented. An interesting detail is that the data in 2001 (from Mozambican national reports) appears inconsistent with the development measure in the global MDGs progress reports. Sanitation coverage in urban areas in 2001 is presented as 75%, while 12 years later this percentage is much lower (42.4%). This difference is possibly caused by measuring the wrong type of facilities (counting traditional latrines as improved latrines), degradation of facilities, or disproportional growth of the population in respect to access to sanitation facilities. For whichever reasons, it can be observed clearly that the MDGs on drinking water and sanitation have not been achieved in Mozambique. Table 1 shows that only the access to improved source of drinking water in urban areas has surpassed the MDG.

Even though the goals have not been achieved, progress was clearly made. In the following section we will review the national plans (PARPAs) that the Government of Mozambique launched as a framework of action to implement and achieve the MDGs.

[2] Both figures retrieved from the website of WHO and UNICEF Joint Monitoring Programme (JMP), on 10-11-2016: http://www.wssinfo.org/definitions-methods/watsan-categories/

Table 1 Access to improved sources of DW and sanitation facilities in Mozambique over the past 25 years

	Access to improved drinking water				Access to improved sanitation facility			
	1990 MDG Reference situation	2001 Estimated national progress	2015 MDG Final situation	2015 MDG Target	1990 MDG Reference situation	2001 Estimated national progress	2015 MDG Final situation	2015 MDG Target
Urban	72 % [3]	67 % [4]	81 % [3]	70 % [3]	34 % [5]	75 % [6]	42 % [5]	80 % [5]
Rural	23 % [3]	26 % [4]	37 % [3]	70 % [3]	2 % [5]	29 % [6]	10 % [5]	50 % [5]
Total	35 % [3]	37 % [4]	51 % [3]	70 % [3]	10 % [5]	41 % [6]	20 % [5]	60 % [5]

Action Plans for the Reduction of Absolute Poverty (PARPAs)

Within the framework of the MDGs in 2001 an internationally funded approach was started to fight the continuing poverty in Mozambique. This led to three consecutive (five year) Action Plans for the Reduction of Absolute Poverty (PARPA, Plano de Acção para a Redução da Pobreza Absoluta, in Portuguese) aimed to achieve the MDGs in Mozambique (Republic of Mozambique, 2001, 2006, 2011). In these PARPAs only limited attention was given to the improvement of existing sanitation services. In an effort to explain the failure to achieve the MDGs we will discuss the three PARPAs and their respective reviews.

The original PARPA I included the objective to "Increase supply of low-cost potable water and sanitation to urban areas" (Republic of Mozambique, 2001, p. 176). However it did not define concrete measures to be taken to achieve the objective of coverage of improved latrines to 50% of the urban and 40% rural population. The same is true for the objective to increase coverage of water supply to the same percentages.

In the 2005 review of the PARPA results it was noted that by 2004 rural water supply coverage was raised to 43.2% and to 36.8% in the main urban centres. Regarding sanitation coverage the most important focus was the Beira sanitation network and preparation of a sewage treatment plant. With only around 9,000 of the 27,000 planned improved latrines being realised (Republic of Mozambique, 2005b).

PARPA II in 2006 contained a little more detail on measures planned to increase coverage of both access to sanitation and water supply. Regarding water supply the goals were concrete, in particular a number of new and a number of rehabilitated public water points. However, on sanitation there was a sole focus on rehabilitation of existing infrastructure and the creation of the Beira Wastewater Treatment Plant (Republic of Mozambique, 2006) and no concrete plans were described for the general expansion of sanitation networks or creation of on-site sanitation.

The review, of the results of PARPA II in 2010, found that households increasingly perceive drinking water and sanitation services as areas in which the municipality should increase the quality of service. The review indicated the health risk due to poor sanitation, however at least partly referring to the health risk of rubbish and poor solid waste management. It is acknowledged that improvements were made in the sectors of water and sanitation. However, with a strong indication that there were different degrees of difficulties with cost recovery (Paulo, Rosário, & Tvedten, 2011). In this review of PARPA II, the complexity of the sanitation and water sector was brought forward. Interrelated health risks caused by improper sanitation and rubbish management, with the economic consequences of floods being named in the same section. However, still no (combinations of) solutions are presented or indicated to deal with these challenges (Paulo et al., 2011).

PARPA II was followed by an Poverty Reduction Action Plan (PARP 2011-2014), often referred to as PARPA III. In this plan only general goals of improved coverage in both sanitation and drinking water sectors were described. Additionally, the strategic objectives state to promote the construction of sewerage connections in urban areas and latrines in rural areas (both traditional and improved). No indication of cross sectoral problems or solutions were presented about drinking water, sanitation services or hygiene and health (Republic of Mozambique, 2011). At the moment of writing this thesis no review document of the PARPA III is available and the results will not be discussed.

[3] 2015 Update and MDG Assessment - 25 years Progress on Sanitation and Drinking Water (UNICEF & WHO, 2015, p. 67)
[4] Report on the Millennium Development Goals – Mozambique (Republic of Mozambique, 2005a, pp. 39–40)
[5] 2015 Update and MDG Assessment - 25 years Progress on Sanitation and Drinking Water (UNICEF & WHO, 2015, p. 66)
[6] Report on the Millennium Development Goals – Mozambique (Republic of Mozambique, 2005a, pp. 39–40)

Eventually the lack of concrete plans and the delayed execution appears to have created limited development and improvement of drinking water and sanitation services, in particular the coverage of sanitation. This lack of progress could be perceived as disappointing. However, in other sectors significant progress was made and, as the Mozambican government argues, during the implementation the MDGs many problems have been solved or lessons have been learned because of the difficulties faced (UNM & FCD, 2015).

An interesting observation is that access to water and access to improved sanitation are not discussed as related in terms of improvement measures. Only in the review of PARPA II are cross sectoral benefits of good sanitation and safe water use noted. In the SDGs that will be discussed in the following section this relation and the opportunities that it can bring receive more emphasise.

Sustainable Development Goals (SDGs)

As introduced availability of improved drinking water sources (Table 1) and access to sanitations facilities (Table 1) for both urban and rural areas in Mozambique, are far from achieving the MDGs. A recent study by TAC Economics (independent European research group) predicts that Mozambique will not achieve the MDGs of improved sanitation coverage of 55% or the access to potable water supply of 67% before 2025 (TAC Economics, 2016). This is taken as an indication that the current approach of market participation, contracting and network expansions to reach MDGs were ineffective.

In 2015 the United Nations launched a follow-up program that defined 18 SDGs for the world to achieve by 2030. The SDGs define a separate goal for drinking water and sanitation; Goal 6: "Clean water and sanitation - Ensure access to water and sanitation for all'. The SDGs are defined in a different way than the MDGs, the MDGs contained measurable percentages as targets that had to be reached especially by poor countries, as most wealthier countries already met the goals set. The SDGs contain goals for improvements that all nations can work towards achieving. The first three targets of SDG 6 illustrate this point.

6.1 By 2030, achieve universal and equitable access to safe and affordable drinking water for all

6.2 By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations

6.3 By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally

6.4 By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity

6.5 By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate

6.6 By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes

The targets for Sustainable Development Goal 6 (UN, 2015)

These goals are relative to the current situation and applicable in almost all countries in the world. Another interesting fact is that the goals for clean water and sanitation are presented in a broader frame than before. Instead of aiming for an increased percentage of coverage, the SDGs are placing clean water and sanitation in a broader perspective of improved water resources management where clean water and proper sanitation impact quality of life directly as well as indirectly. Additionally the SDGs pinpoint the importance of clean water and sanitation with its side benefits of increasing health, productivity and equality in access to education.

2.3. Current situation in Greater Maputo

The MDGs depended strongly in national coverages percentages (baselines) that could later be compared to the new (improved) situation. With SDGs, countries have new goals and it is important to create a clear picture of the current situation to enable measuring of future progress and results. The starting point of the new SDGs is the final data from the MDGs reports. However, since this thesis is focussed on the situation in Greater Maputo, we will now elaborate more on the local situation in Greater Maputo with the year 2015 as the reference situation.

The climate

The local climate in Mozambique is semi-arid, like other developing counties freshwater resources are being over-exploited (NEPAD, 2013) and climate change puts these resources at risk of additional hazards (UN-HABITAT, 2009). In Greater Maputo water availability is even more problematic because of the large amounts of water used by the growing population and many industries, while contrastingly the climate is more arid than in northern and inland parts of the county. In general the dry winter season, from May to September is almost without any rainfall (13-40 mm/month[7]) with a duration of 4-6 months, putting pressure on available water resources (Dutch Sustainability Unit, 2015). Throughout the wet summer season, from December to March, large amounts of rainfall (100-130 mm/month[7]) cause frequent floods of the city's drainage systems and especially in the city parts without these systems (Dutch Sustainability Unit, 2015).

Drinking water services in Greater Maputo

In Greater Maputo, 92% of all households have a drinking water connection (WSP, 2014). Water is provided from a semi-public centralised network and from smaller local private supply networks. Águas da Região de Maputo (AdeM) is the central drinking water provider and the local providers are referred to as small independent water providers (SSIPs, or Pequenos Operadores Privados, POPs, in Portuguese) or private water operators (Operadores Privados de Água, OPA in Portuguese). AdeM provides drinking water in a traditional way, first collecting and treating water at the Umbeluzi Dam and treatment plant. Afterwards distributing the water via a central piped network to around 185.000 households connections (SUWASA, 2010). In the peri-urban areas AdeM also operates 46 standpipes, however these are intended to be temporary solutions (SUWASA, 2010). The SSIPs, that are primarily active in the peri-urban areas, distribute water that they abstract from groundwater resources. Over 800 SSIPs presently serve water to over 192.000 households in Greater Maputo (SUWASA, 2010). They primarily offer drinking water as an informal service. The role of the SSIPs was encouraged as unregulated market participation after 1990 because of lacking capacity and coverage of the centralised network. Since 2005 a formalisation and quality regulation process have been implemented, in order to increase control over the private water suppliers (Ahlers, Güida, Rusca, & Schwartz, 2012).

Together AdeM and the SSIPs serve around 92% of the population of Maputo, including people that share the connection of their neighbour or family (WSP, 2014). However, both AdeM and the many SSIPs have their challenges. AdeM deals with spilling from its network, a limited supply of water in the Umblezi Dam and high investments in maintenance of its network (SUWASA, 2010). The SSIPs are dealing with increased regulations of their water quality, water source and distribution network, and increased competition from AdeM (network expansion and construction of standpipes) (SUWASA, 2010). Both AdeM and the SSIPs have large investments made in their networks and therefore opposite stakes in the increasingly direct competition. What increases the complexity is that, the water sector is guided by policy made at the Ministry for Public Works and regulated by a semi-independent authority. Management of water resources is the responsibility of the local water board (ARA Sul) and responsibility of water supply and the ownership of the distribution network is in the hands of another semi-public organisation (CRA). In short there is a complex division of responsibilities and decision making power between the actors in the water sector, on which we will elaborate more in Chapter 4.

Sanitation services in Greater Maputo

The figures for the sanitation sector in Greater Maputo are quite different from those for drinking water. In Maputo around 11% of the population does not have access to an improved form of sanitation (WSP, 2014). For those that have access there is a large variety of sanitation solutions within the different parts of the metropolitan area. *Cement City* is covered by a wastewater network connecting 5-15% of the city's population (SEED, 2010; van Esch & van Ramshorst, 2014). This part of this network are designed to convey wastewater to the Infulene

[7] Precipitation in Maputo retrieved from: http://www.maputo.climatemps.com/precipitation.php (07-11-2016)

wastewater treatment plant (WWTP), located in Infulene River Valley in Matola, near the border with Maputo City (UN-HABITAT, 2008). Out of all WW entering the network (about 25,000 m^3/d), around 10.000 m^3/d is intended to reach the WWTP. However, only about 16% of all collected WW or 40% the intended volume (around 4,000 m^3/d) actually reaches the WWTP (van Esch & van Ramshorst, 2014). However, since the WWTP is not operating well (Caltran, 2014), none of the WW is sufficiently treated before reaching the sea and other surface water. The rest of the water reaching the wastewater network is discharged directly, untreated, to the sea (ENGIDRO, HIDRA, & AQUAPOR, 2015d). In the other parts of the city households have a variety of on-site sanitation systems (OSS), including septic tanks, improved and traditional latrines, which are emptied periodically or abandoned and replaced (SEED, 2010). Of all the faecal sludge (FS) produced in Maputo only a small part is collected and disposed at the WWTP by both municipal and private collection services (Bäuerl, 2015), which is usually defined as Faecal Sludge Management (FSM) services. Since the WWTP is a pond system, that even in operational state was not designed to treat faecal sludge, none of the disposed faecal sludge is sufficiently treated before being discharged into the environment (Caltran, 2014).

The consequential pollution of the sea, surface water and groundwater (e.g. with Nitrogen and Phosphorus (Salim, 2016)) are a shared responsibility of the municipalities (local laws and regulation) and of the water board ARA Sul that is responsible for the management of water resources. The wastewater network and WWTP are managed by the Department of Water and Sanitation (Departamento de Água e Saneamento, DAS, in Portuguese) of the Municipality of Maputo (Conselho Municipal de Maputo, CMM, in Portuguese). DAS also provides a service to empty domestic sanitation systems, which content (faecal sludge, FS) is disposed at the WWTP. Within the CMM there are organisational and financial capacity problems to improve the sanitation services (Employee CMM, personal communication, July, 2016). FS emptying services are also provided by private parties that are licenced by the municipality and operate collection trucks. The private sector is faced with challenges of limited accessibility to domestic OSS (e.g. narrow streets), limited investment capacities and uncertainty about laws and regulation, this makes improvement and expansion of their services difficult (WSP, 2015).

This short introduction into the water and sanitation sector shows that the multitude of actors in both parts of the sector increase the complexity of issues and challenges at stake. The fact that actions of the actors in water and sanitation potentially have serious influence on the others sustainability increased the complexity of this coherent system. In the following we will elaborate more on the working of the system of water and sanitation and the roles of the actors that are involved.

3. Research Methodology

This chapter contains a short literature review in policy analysis in complex multi-actor systems and short review of methods for solution analysis in these systems. This is followed by a description of the two theoretical approaches for policy design applied in this thesis. First the approach for policy analysis in multi-actor systems by Enserink et al. (2010) is used to structure the conducted research from problem definition to the analysis of solutions. The Dynamic Adaptive Policy Pathways approach by Haasnoot et al. (2013) is used to combine the proposed solutions with other possible solutions, taking into account the uncertainties about the future developments in Greater Maputo.

3.1. Literature review on Policy Analysis & Dynamic Adaptive Policy Pathways

As previously indicated the water and sanitation sectors appears be a complex system with numerous actors and many uncertainties. This brings up questions, *what is complexity*, *what is a complex system* and *what method is applicable for analysing such a system*?

Complex multi-actor system

Gell-Mann (2002) discussed complexity for engineering design and his findings should be analysed for the purpose of understanding complexity in water and sanitation services. Complexity finds its origin in the Latin word *complexus* meaning as much as *intertwined* or *entangled* (Heylighen, 1999). This indicates that complexity has to do with more than one element that is related but at the same time distinct from another (Heylighen, 1999). Heylighen (1999) also concludes that complexity increases with the variety of interrelations and the number of dimensions in which these interrelations exist.

Gell-Mann (2002) describes that the traditional approach to complexity defines the following elements, Variety and connectivity. While connectivity indicates the types of relations and the number of relations, variety, the types of elements and number of elements. Water and sanitation system consist of a large number and types of elements that are interrelated in different ways.

As introduced in the literature review on Mozambique and Maputo, the water and sanitation sector is influenced by decisions made by a large variety of actors. These actors have different responsibilities and objectives. An important notion is that these actors have various levels of decision making power, and there is not a single actor that can impose one preferred solution. The water and sanitation sector is therefore in line with a complex multi-actor system for which (Enserink et al., 2010) created an approach of policy analysis.

Policy analysis and system analysis

The water and sanitation sector is not only a complex system with multiple active actors, there is also a serious amount of uncertainty about the future. There are economic, environmental and societal uncertainties that influence the decisions of policy makers, these uncertainties combined are referred to as a context of deep uncertainty (Haasnoot et al., 2013). This uncertainty offers the actor in water and sanitation a venerable base for decisions on their future. The approach of policy analysis in multi-actor systems, includes a set of analytical tools to cope with these circumstances. By conducting analysis of the system(s), the involved actors and their objectives, capacities and relations, insight can be provided in the advantages and disadvantages of possible policy actions by different actors (Enserink et al., 2010, p. 13).

Enserink et al. (2010) explains that the approach is suitable when a researcher is looking for a systematic path towards solving the problem of a policy maker. In this thesis we are looking to identify the challenges and opportunities of the actors in the water and sanitation sector. The approach of Policy Analysis in Multi-Actor systems (Enserink et al., 2010) is hereby used to create insights in the problems of the several actors. A thorough analysis of the system and the uncertainties creates a starting point for an analysis of the solutions. As the author explains, the approach offers analyses help create a clarify the working of a complex system, in order to formulate a problem (challenges in our case), and explore a road to future solutions. Among the examples of suitable complex problems that the author names for this approach are; urbanization and public infrastructure planning, climate change and sustainable development, or the expansion of an airport in a populated area (Enserink et al., 2010, p. 26).

Analysis of solutions

This thesis aims at discussing possible solution strategies for the current challenges in Greater Maputo and, for this, an additional approach is necessary. As introduced, this approach needs to be applicable in a complex system with deep uncertainties and it should also enable local decision makers to deal with the frequent occurrence of delayed implementation of plans and even their abandonment. This deep uncertainty is of importance in the selection of a methodology for the analysis of solutions, because most of the proposed solutions in the water sector are imposed as demarcated programs for a pre-defined most probable future (Haasnoot et al., 2013). These programs often have one clear starting date and consist of a sequence of solutions. In Greater Maputo, and in many cities in developing countries, programs are often not executed according to plan and left unfinished or with incomplete results. This makes the future developments and provision of services highly uncertain.

Haasnoot et al. (2013) explains that traditionally decision makers create a desirable or probable future, and match a (set of) solutions to deal with this in the best way. The approach of **Dynamic Adaptive Policy Pathways (DAPP)** (Haasnoot et al., 2013) offers the possibilities to adapt a chosen policy direction to the changing circumstances as a consequence of *deep uncertainty* as defined by Hallegatte et al. (2012). Walker (2013) reviews the differences between several available planning approaches that enable adaptation to deep uncertainty. The author argues that DAPP brings together theory on *Adaptive Policymaking* and theory on *Adaptation Tipping Points and Adaptation Pathways*. It is discussed that of the approaches reviewed, DAPP is the only approach that is both dynamic in nature and suited to deal with a situation of deep uncertainty (Walker et al., 2013).

DAPP allows comparing different (and equally possible) solution strategies for the actors in water and sanitation in Greater Maputo and to handle uncertainties in the influences of external trends and the implementation of planned solutions. This framework also allows decisions makers to identify points in time on which decisions will have to be made. The dynamic nature allows a flexible approach towards the future, without having the knowledge or information for these future decisions in the present. In the Figure 10 a theoretical representation of the adaptation pathways approach is shown to illustrate the core of the approach. This diagram, visually similar to a "metro map", includes the current policy (on the left), and transfer stations to new policy actions (black open circles). An adaptation tipping point indicates when a decision to choose a new (policy) action is necessary. This action can consequently be effective in all scenarios, or it can also meet an adaptation tipping point at which a decision is necessary. The Adaptation pathways approach includes a scorecard for the different paths, where each path is rated on a set of criteria (for example cost, effects and side effects).

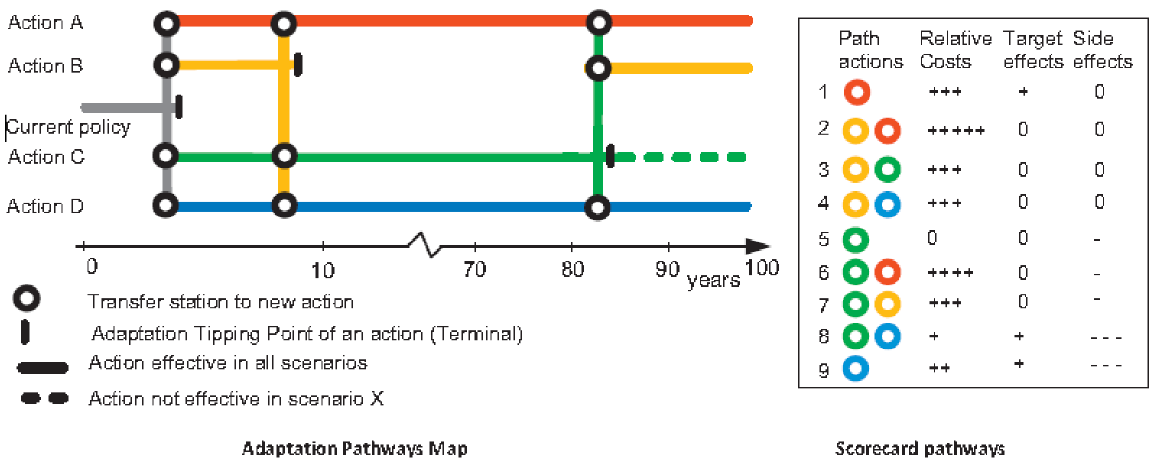


Figure 10 Example of theoretical Adaptation Pathways, including a baseline policy that will last for 3 years, transfer stations to other policy actions and a scorecard (Haasnoot et al., 2013).

DAPPs are being applied on the real case of developing pathways for the Rhine Delta in the Netherlands (Haasnoot, van Deursen, Middelkoop, van Beek, & Wijermans, 2012). This case-study was used to create policy actions to deal with flood protection as well as making sure that sustainable freshwater availability is guaranteed (Haasnoot et al., 2013). As depicted in Figure 11 the map of the adaptation pathways is presented including the transfer stations and tipping points for decision makers. DAPP also includes a representation of less likely pathways, where the lighter paths are unlikely policy actions at a given time. Additionally, the map in Figure 11 includes dotted lines that indicate preferred paths from different perspectives, examples here are hierarchical (large role government), egalitarian (protect the environment) and individualistic (small role government). This case-study included actions that impact the two sides of the system, water demand and water supply. The actions vary in both effect and type of measure, for instance the *optimizing of current policy* is a policy action, while *decreasing level and adapting infrastructure* implies physical actions. A final remark towards embedded management of uncertainty in the DAPP approach concerns the timeline. In Figure 11 the map shows two timelines, the uncertainty present in the situation impacts the duration that an action will function as an adequate solution. For example, the action *optimising current policy* will meet an adaptation tipping point before 2050 in *Scenario Warm*, while it will easily surpass 2050 in *Scenario Crowd*. This dimension allows policy makers to work with evolving circumstances and to include these uncertainties in their decision making process. More explanation on constructing these DAPPs is presented in section 3.3.

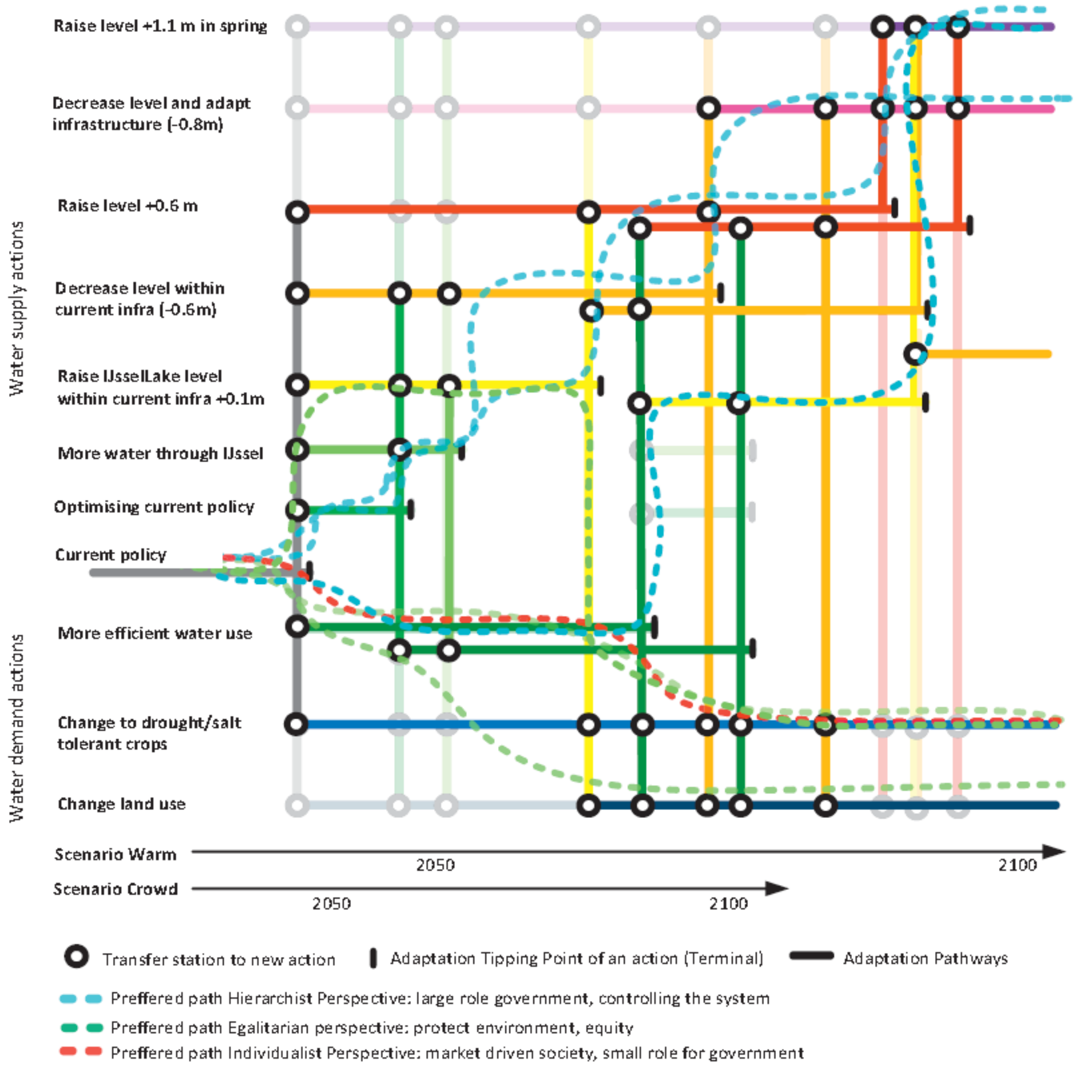


Figure 11 Map of DAPP including preferred paths from different perspectives (Haasnoot et al., 2013).

3.2. Policy Analysis in Multi-Actor Systems

The main research method used to conduct the introduced research is described in the book by Bert Enserink: *Policy Analysis in Multi-Actor Systems* (Enserink et al., 2010). This approach generally stated contains the following research steps, which are interpreted for this specific research. In order to align the methodology with this thesis objective, the steps are linked to the specific SRQ they should help provide an answer to:

Problem formulation
A further introduction of the water challenges in Greater Maputo, description of existing situation (service levels and coverages of networks), problems and challenges with their interrelations. Providing insight for SRQ 1.

Systems Analysis and visualisation
Defining elements inside the Greater Maputo water and sanitation system, and mapping these elements in a causal loop diagram[8] of the system. The diagram contains interrelations between the water resources, drinking water services, wastewater systems and faecal sludge services. This results in an overview of the technical problems in the current situation and will provide overview of the challenges for SRQ 1.

Actor analysis
Describing the role, goals and means of the four types of actors involved within Greater Maputo. Looking at national governing authorities, Municipalities, households and the service providers. After identifying the actors, their role and position in the water and sanitation system are presented. The result will be an overview of the non-technical problems and challenges in the current system in Greater Maputo and will allow answering SRQ 2.

Scenario analysis (exploring future trends)
This step is aimed at describing the uncertainties that influence the system. Examples are the development of trends as climate change, influx or growth of the population, economic growth, changes in water use and the pollution of groundwater. The aim is to explain the consequences these trends can have on the challenges for the actors in the defined system. This way identifying and describing the consequences of external trends to answer SRQ 5.

Synthesis of partial analysis and problem formulation
Revising the systems diagram, checking the consistency between the system, other analyses and new information gathered along the way (e.g. by site visits, interviews and new found sources of information). Defining knowledge gaps, improving the problem formulation and outlining further policy research and the following step conserving the solution analysis. This will improve the answer on SRQ 1, 2 and 3 and outline assumptions for the following steps.

Solution analysis
Summarizing the proposed solutions concerning DW, WW and FSM a in the Masterplan and their effect on the defined system. Additionally the innovative solutions of water reclamation, desalination and Managed Aquifer Recharge (MAR) are described with their challenges and potential effects on the systems. These solutions will become possible actions in the policy pathways analysis (SRQ 3). This way we identify and describe the proposed and possible solutions, answering SRQs 4.

Impact assessment
This is a research step to assess of the impact of several solutions, on the system, with the aim to create an overview of the impact on short and longer term of each solution. This assessment will form the input for the Dynamic Adaptive Policy Pathways method, answering SRQ 4.

[8] "A causal map depicts the causal relations between the factors that are relevant to the problem. It supports a qualitative form of 'what if?' analysis that is helpful in understanding the effects of means and/or external factors, notably the criteria (Montibeller & Belton, 2006)" (Enserink et al., 2010, p. 69)

3.3. Dynamic Adaptive Policy Pathways

After conducting this describing approach to policy and system analysis, we use the method of Dynamic Adaptive Policy Pathways (DAPP) by Haasnoot et al. (2013) to analyse solutions. DAPP has been applied in research on sustainable water management in a changing environment and enables to explore combinations of several solutions. The strength of DAPP is that the approach starts with an analysis of solutions, but also includes an analysis of future decisions making moments instead of predetermined assertions, this incorporates planning flexibility in the core of the methodology, allowing alteration or adjustments during the actual implementation. Working with these pathways will create a more dynamic approach that will enable short term policy decisions instead of all-inclusive long term decisions that face too much uncertainty (Haasnoot et al., 2013)). Figure 12 depicts the steps that are defined to develop DAPPs.

The analyses in the Steps 1 - 3 are covered in the execution of *Policy Analysis in Multi-Actor Systems.* Describing the current situation (Chapter 2), objectives (Chapter 1) and uncertainties (Chapter 5). Steps 2 and 3 consist of analysing the challenges and opportunities (Chapter 4), to identify the possible actions, a base for this is prepared in the exploration of proposed and possible solutions (Chapter 6). Steps 4-8 will be part of this research, to provide an answers to SRQ 4, 5 and 6. Step 4 contains the assessment of the actions (solutions), on their sell-by date (how long will a solution create a desired situation) in Chapter 7. In Step 5 different pathways (or strategies) are developed that would lead to the desired objective (chapter 7). After reassessing the actions inside these strategies a final scheme with three preferred strategies is delivered in Step 6, containing multiple actions in the water and sanitation sector. The pathways of possible solution strategies will be visualised, showing the different options the local actors have to create a sustainable future situation, still regarding a sustainable supply of freshwater as the underlying objective. In Step 7 for the three preferred pathways, contingency actions and triggers are defined. These imply the latest moments that certain decisions can be taken, and the circumstances that influence the occurrence of such a moment. The final Step 8 is to create a dynamic adaptive plan, which contains the short term steps that are recommended to be taken. However, the idea of this plan is that the short term actions should enable choosing to take any of the pathways as long as possible.

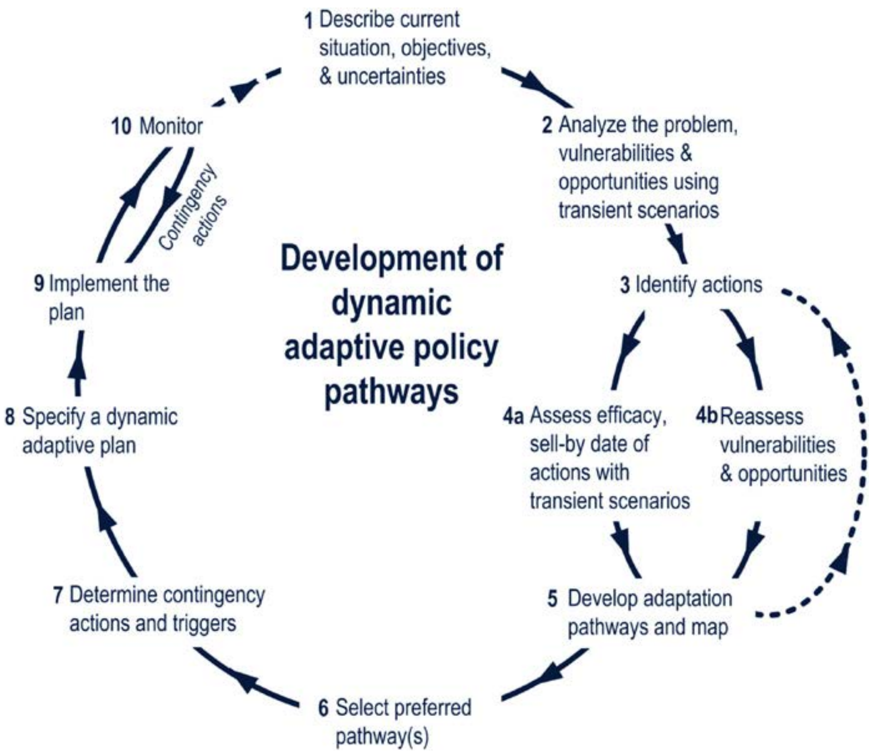


Figure 12. Ten Steps for the development of Dynamic Adaptive Policy Pathways (Haasnoot et al., 2013)

4. System and actor analyses in Greater Maputo

For this analysis two documents were used as main information sources. The first is a report of the project Water & Sanitation for the Urban Poor (WSUP), that contracted the Mozambican consultancy firm SEED in 2010 for the "*Formulation of an outline strategy for Maputo City, citywide sanitation planning"* (SEED, 2010). This outline strategy contained several priority area and suggested the development of a sanitation and drainage masterplan for Greater Maputo. This was followed by a city-wide masterplan funded by the World Bank, which is currently being finalized in a number of phases with several volumes each under one binding name: "*Sanitation and Drainage Master Plan for the Greater Maputo Metropolitan Area*" (ENGIDRO et al., 2015a).

This chapter contains a system and actor analysis of the water and sanitation system in Greater Maputo.

4.1. System analysis

Enserink et al. (2010) defines a system as the part of reality that will be studied, the system and the problem definition are intertwined because the research problem indicates only the part of reality that needs investigation. Therefore, a system analysis starts with a clear demarcation of the problem, this will allow to define what is included in the system scope and what is defined as external to the system.

Problem demarcation and Means-End analysis

As introduced in Chapter 1, the main objective in this research is to gain insight and explore possible solution/strategies for the challenges in Greater Maputo concerning the sustainable availability of freshwater. The focal points are sanitation services and DW supply within the growing population, institutional problems and the depletion of water resources. These water related challenges create problems in all sectors (e.g. health, economy and agriculture) for actors like households, businesses and farmers. That is why for this research, in the means-end diagram (Appendix A: System Analysis – Means ends diagram) the top 'end' is formulated as *the creation of a sustainable freshwater supply for Maputo*. The perspective for this diagram is an independent research group, instead of a single actor, this allows for the inclusion of cross sectoral means (actions) that would in practise be attributed to different or multiple actors. Three types of actions are distinguished.

The first type, that can be considered the current paradigm in Maputo, entails a more traditional approach to increase water availability, traditional is interpreted in a sense that all these techniques focus solely on the creation of additional supply.

- Building new dams and water treatment plants (WTP) to supply water (from far);
- Desalination of groundwater or seawater (creating a new DW resource from non-potable water);
- Managed aquifer recharge (where aquifers are artificially recharged with pre-treated surface water).

The second type of action is focused on improvements of the efficiency of the existing DW capacity and efficient use of that water.

- Reduction of non-revenue water (NRW), which includes various types of unbilled authorized consumption, apparent losses and real losses (see Appendix A: System Analysis – Means ends diagram);
- Decreasing the amount of domestic water used on non-essential things (e.g. excessive landscaping or swimming pools); this is often referred to as water demand management.

Third are innovative solutions, these are considered innovative because these are not current practise in water supply in Greater Maputo and are not considered in the available development paradigms. These three means for creating a sustainable water supply, are revised as ends and provided with means to obtain them. This results in concrete actions that can be taken in Greater Maputo to obtain the envisioned main objective.

- Rehabilitation of the current wastewater network and WWTP, not only to treat wastewater, but to allow for water reclamation;
- Expansion of the existing sanitation infrastructure or the construction of new networks and WWTPs to allow the reclamation of water for domestic DW use, industries or farmers;
- Oblige the reuse of water at water intensive industries, e.g. car washes, construction and metallurgy..

Objectives tree analysis

To be able to measure the effect of these actions on the main objective we performed an additional analysis of objectives. We use the objectives, as retrieved from the project website[Fout! Bladwijzer niet gedefinieerd.], formulated for the project: Sustainable freshwater supply in urbanizing Maputo, Mozambique. These, combined with the SDGs (Chapter 2), are translated into the tree of objectives (Appendix B: System Analysis – Objectives Tree).

This objective tree consists of one main objective, three sub-objectives and on the bottom level measurable criteria. These criteria will enable researchers to assess the expected effectiveness of their actions. The following sub-objectives and criteria have been defined.

Water availability, is characterized by two factors that together define the number of people that can be served from the water resources available for central DW:

- Amount of DW resources available (criterion: amount of water available for central DW system, in 10^3 m^3/year) and
- Per capita water usage (criterion: amount of DW used per person, in m^3/year).

Sustainable water management, is defined by two factors:

- Surface water pollution (criterion: volume of wastewater (WW) discharged without treatment, in 10^3 m^3/year) and
- Groundwater pollution (criterion: volume of WW or FS lost from collection systems, in 10^3 m^3/year).

The availability and sustainable management of sanitation, is defined by two factors:

- Population with access to improved sanitation (criterion: population with access to improved sanitation, as % of total population) and
- The fraction of WW and FS safely collected (criterion: fraction of treated WW and FS, as % of the total).

These criteria are used to assess the effects of actions (bottom row of the means-end diagram, Appendix A) in the systems diagram (Figure 13).

System Diagram Analysis

The next step in *policy analysis in multi actor systems* is the construction of a causal loop diagram (CLD). This diagram creates an overview of how the systems of water, sanitation and natural water resources interact in Greater Maputo (the CLD is presented in Appendix A: System Analysis – Causal Loop Diagram, as Figure 27). In the Appendix the CLD of the system is presented with an explanation of the factors (blue boxes) and external influences on the system (black squares on the side), the system boundaries are marked with a dark blue striped line. In the CLD the relations between different factors are causal, meaning an increase of one will result in an increase (positive relation) or a decrease (negative relation) of the connected factor.

Causal loop diagram on Sub-system level

In the next step this CLD is generalised into three sub-systems with interconnecting factors, this diagram less complex and creates a better overview (presented in Appendix B: Causal Loop Diagram in sub-systems, Figure 27). The three sub-systems are DW production and supply, sanitation and wastewater service and groundwater resources. In the Appendix B only the coherence of these sub-systems with the connecting factors are elaborated, as the individual factors are explained in the description of the CLD. It is important to note that relations between a factor and a sub-system cannot and therefor are not expressed in as positive or negative, because the relation can imply a relation between more than 2 factors.

System Diagram

In the final step in creating a system diagram is including the means from the means-ends diagram (Figure 23) and the criteria from the objectives tree (Figure 25), to show which factors in the system can be influenced. The system diagram is created and presented in Figure 13. In chapter 4.1 the actions from the means-end diagram were introduced, now these are place on the left side of the system diagram. Each of the actions influences certain factors and/or sub-systems in the system diagram, these relations are explained:

The traditional solutions are focused on increasing the supply of DW. Desalination and building a new dam + WTP are both aimed at creating an additional source of surface water, increasing only this factor in the system diagram. Aquifer management increased the amount of groundwater that is available as a resource for DW (in the system diagram it influences the sub-system of groundwater resources).

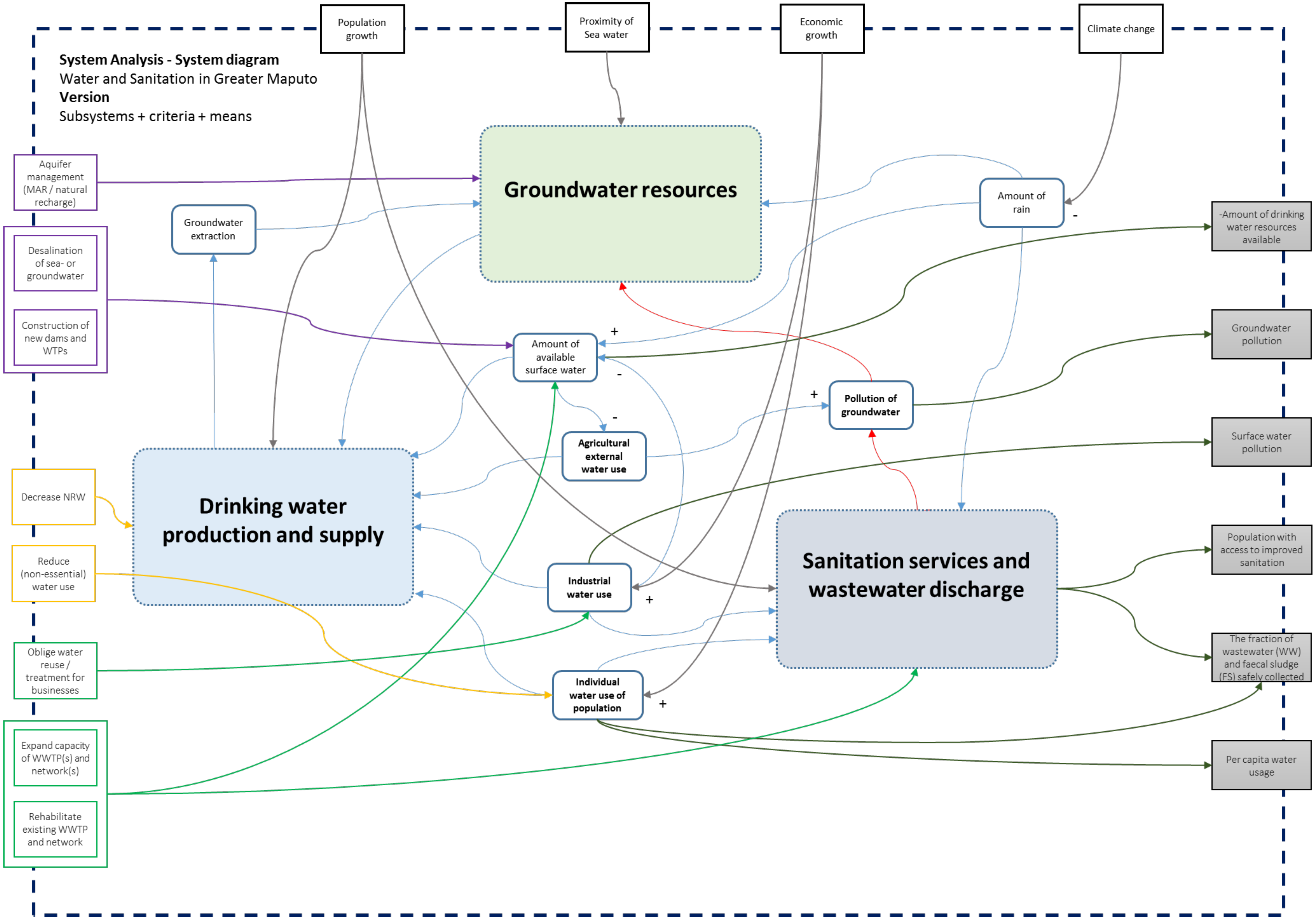
Solutions focussed on improving the current DW supply network, only influence the sub-system of DW supply. Decreasing spilling and NRW increase the amount of water that can be used for as DW from the central system. The consequence of these action is that more people can be served with the same amount of water.

The solutions focussed on water reclamation and the water use per person, influence a more diverse range of factors in system. They influence the supply side, water reclamation by WW treatment creates additional surface water that can be used by industries, agriculture of for DW treatment, and it decreases the amount of pollution released into the environment or surface water. However these actions also effect the use of water, reuse or treatment of water by industries would create lower demand (reuse) or less polluting discharge (could increase the available surface water). Finally the reduction of non-essential water use, decreases the individual use of water, the consequence is that the available DW can be divided over a larger amount of people, more people can suffice in their need for water with the same amount produce.

Finally the six criteria form the objective tree (section 4.1) are placed in the system diagram and connected to factors as indicators for the systems performance. In the objective tree the theoretical criteria have been defined for each objective, now each relation to a factor or subsystem in the system diagram are named.

- Amount of DW resources available, is measured by the amount of surface water available.
- Groundwater pollution, is measured by the pollution of groundwater.
- Surface water pollution, measured by industrial water use (no obliged treatment is currently enforced).
- Population with access to improved sanitation, is measured by population connected to the WW system and the people with OSS that fill up.
- The fraction of WW and FS safely collected, is measured by the treated discharge of WWTPs as a proportion of the Individual water use of the population.
- Per capita water usage, is measured by Individual water use of the population.

Figure 13 Systems Diagram (including external factors, means from the Means-End Diagram and criteria from the Objectives-tree) of the integrated systems of water and sanitation in Greater Maputo



4.2. The current and future challenges

The system of water and sanitation has been described in section 4.1, in this section we explain the current challenges at stake in the each sub-system. Of these challenges the expected developments are shortly introduced in relation to the most important external trends population growth, economic development and climate change.

Water resources

Groundwater extraction / availability

The local water providers extract groundwater for water supply to households and industries, and excessive groundwater extraction, especially in locations close to the sea, can lead to salt water intrusion and raises the risk of rendering the water unusable for human consumption and irrigation. In fact, groundwater salinity has been increasing in recent years also varying in different seasons (HYDROCONSEIL, 2008, p. 4).

Expected developments (without intervention):

- Population growth: increases the demand for DW and the amount of groundwater extraction.
- Economic growth: could increase water use per inhabitant that is using GW as main source, and potentially the industrial use of GW.
- Climate change: causes increased variance in droughts and wet seasons (longer droughts increase saline intrusion)

Groundwater pollution

Groundwater resources are in danger of contamination from unsafe handling of FS; and from untreated WW, leaking from the sewerage network and from the WWTP.

- Population growth will increase amount of FS and WW that is produced and the consequential amount that eventually contaminates the groundwater resources.
- Climate change increase the severity and frequency of serious droughts and floods. Both decrease the amount of natural aquifer recharge, making the risk of groundwater pollution and saline intrusion more urgent..

Surface water availability

The supply of DW and irrigation water in the Southern part of Mozambique, including Maputo, is dependent on river discharge for neighbouring countries Swaziland and South Africa. The three countries have agreements on the amount of water that flows into Mozambique. However, Mozambique lacks sufficient systems to monitor whether or not the agreement is correctly enforced. During periods of draught, such as the one in 2016-2017, compliance to the water share agreement is critical in dealing with water supply shortages in Greater Maputo.

- Population growth increases water use.
- Economic growth could increase water use per inhabitant and the amount of water used by industries.
- Climate change causes increased variance in droughts and wet seasons (limited surface water during droughts)
- Dependency on water use in neighbour countries limits the available water from shared river basins.

DW production and supply

Coverage of FIPAG's network

The centralized DW supply system covers the Cement City and part of the peri-urban areas. Expansion is difficult because of limited investment capacity for both households and FIPAG. Also expanding a network in a informally populated area is more complex than constructing a network in new formal neighbourhoods. FIPAG's targets to increase coverage are generic for the country, allowing them to choose the cheapest or least complex locations as the first areas to expand.

- Population growth will increase the population density in the uncovered areas, making it increasingly difficult to expand to these places in the future.
- Economic growth could allow more people to secure a sufficient income to pay for a household connection of the FIPAG network and the monthly water bill.

Competition with SSIPs

The presence of SSIPs has been and is still crucial, making DW available in large parts of Greater Maputo. However, this market is barely regulated and severely influences the development of the FIPAG network. Expansion of the FIPAG network implies that these SSIPs must to be informed about expansion plans long beforehand and, in some situations, compensated for their investments. The SSIPs all depend on groundwater as their source, exposing them and the connected households to the risk of groundwater pollution and saline intrusion.

- Population growth, means more people, increasing the demand for groundwater. This increases the pressure on groundwater resources and the importance of quality monitoring.
- Climate change, population growth and FIPAG expansion plans create market opportunities, competition and uncertainty uncertainties about future sustainability for SSIPs.

Improper infrastructure management

The lease contract between FIPAG and AdeM that intended to divide the responsibilities for the asset ownership, and maintenance and operations. Organisational and operational problems caused years of limited maintenance and management of the infrastructure. This resulted in a situation where the FIPAG network had non-revenue water percentages of almost 50%. Efforts to decrease this amount, improvement of infrastructure and decreasing the hours of water supply (to limit spilling in nightly hours of little demand) (FIPAG Employee 1, 2016).

Limited regulation and lack of enforcement on quality of DW

SSIPs sprouted in times of a serious need for DW in large parts of the city. Government regulations facilitated and encouraged this free market participation. However, not until recent efforts to formalise the SSIPs services that the municipality and CRA started creating regulation for this part of the DW sector. Currently quality standards are in place for SSIPs. However, the (number of) quality checks and the division of tasks between the CRA and municipality are still in early stages of development (series of interviews conducted with SSIPs, 2016).

- Population and economic growth increase the number of households to be connected to small-scale service providers. The consequences are a growing need for regulations and tasks for enforcement.

WW and FS management

Non-operational sanitation infrastructure

The WW network is smaller in size than the centralised DW system. Several institutional, organisational and other factors that have discouraged the growth of the sewerage network are high investment needs, large maintenance demands and historically limited ways to create financial return on investment. The population in Greater Maputo does not pay a sanitation tariff and the 90% of the population relying on OSS could be especially opposed to paying as they already have to pay to empty their systems. Lack of revenue for sanitation services led to limited budgets, expertise and operational maintenance, consequentially the WW infrastructure (network, pumping stations and WWTP) is severely deteriorated. This causes sever spilling and limited conveyance of WW and FS to the WWTP, with the majority of WW being discharged to the sea. The fact that currently almost no central WW services are provided, increases the difficulty of creating revenues. The result of the current situation is that the little WW collected receives very limited treatment.

- Economic growth enables a larger share of the population to access an improved form of sanitation, enabling more people to connect to a (future) WW network and to afford FS disposal by formal collection.
- Population growth will lead to increase the amount of faecal waste and WW produced, additionally increasing the severity of the consequences of mismanagement for the environment and public health.

Limited FS services

More than 90% of the households in Greater Maputo rely on FS collection services to empty their OSSs. An increasing part of the population is constructing improved sanitation facilities that are suited for emptying, hence the market for FSM is growing. Currently the number of FSM providers is limited and the municipal services are even smaller. The regulation is still in development, with the municipal guidelines for regulation just approved. Enforcement of these guidelines is still non-existent and there is not treatment plant that is actually equipped to fully treat and safely dispose FS in Greater Maputo. The current situation of unclear and non-enforced rules enables the population and service providers to discharge their FS illegally into the direct environment or sea. Unregistered discharge of waste causes a risk of groundwater of environmental pollution.

- Population growth will cause and increase amount of FS, increasing the urgency of more emptying services and sufficient treatment plant(s) to protect the environment and public health.
- Economic growth allows more people access to both improved sanitation facilities and to pay for emptying services.

Legislation allows municipal autonomy on sanitation:
The independent position that municipalities have on sanitation allows them to create the sanitation sector they prefer. In Greater Maputo, Maputo clings strongly to this independency, whereas Matola has more cooperation stance on the involvement of for example AIAS. This independency comes with the risk of multiple municipalities making the same mistakes. The DW model allows FIPAG to roll-out its knowledge in multiple cities, however AIAS is not provided the same authority in the WW sector. Another consequences is that the introduction of a sanitation fee is subject to the local political situation.

- Population and economic growth. Population growth is increasing the problems in the sanitation sector in Greater Maputo. In combination with increasing household budgets and demand for improved sanitation services, the pressure on local municipalities is increasing to enforce rules in the sanitation sector and to provide better sanitation services.

Lack of enforcement of sanitation guidelines
There is no quality control and enforcement on (illegal) discharge of FS. The disposal in the WWTP is not monitored actively nor are there fees charged to create revenues at the WWTP. The lack of enforcement of the newly create guidelines for sanitation, causes very limited incentives for the FS collectors to oblige the rules. Also there is very little insight in the actual amount of FS that is disposed of illegally and in what ways this is happening.

- Population growth is increasing the size and severity of the FS problem.

Most important external trends for this research

In the previous section the challenges in relation to external trends are discussed, to provide an overview for each of the challenges the expected trends are summed up in Table 2. These trends are of importance as they will be discussed and their influence will be quantified in Chapter 5, to provide a bandwidth of the uncertainties that influence the future sustainability of the system of water and sanitation in Greater Maputo.

Table 2 Summary of challenges and trends that are expected influence to influence them

Water resources

Current challenges	Trends expected to influence the challenge.
Groundwater extraction / availability	Population growth, economic growth, climate change
Groundwater pollution	Population growth, climate change
Surface water availability	Population growth, economic growth, climate change, dependency on water use in neighbour countries

DW production and supply

Current challenges	Trends expected to influence the challenge.
Insufficient infrastructure coverage	Population growth, economic growth
Competition with SSIPs	Population growth, climate change
Improper management of infrastructure	
Limited regulation and a lack of enforcement on quality of DW	Population growth, economic growth

WW and FSM

Current challenges	Trends expected to influence the challenge.
Non-operational sanitation infrastructure	Population growth, economic growth
Limited FS services	Population growth, economic growth
Legislation allows municipal autonomy on sanitation:	Population growth, economic growth
Lack of enforcement of sanitation guidelines	Population growth

4.3. Actors analysis

The analysis of the system and the challenges that are currently at stake provides a general insight in local water and sanitation. However, besides the technical working of the system, an understanding of the roles of and relations between the involved actors is necessary to understand the (non-)developments in Greater Maputo. Therefore the actors in both drinking water and sanitation sector have been described thoroughly in Appendix C: Actor Analysis, the following two sections contain tables summarizing the findings about these actors.

4.3.1. Actors in DW and water resources

The following actors are active in the DW sector, Table 2 contains for each actor a concise description of responsibilities and the challenges found.

Table 3 Summary of actors in DW sector and water resources

DNA	National Directorate of Water. Was a part of Ministry of Public Works and Housing (MOPH) responsible to set overall strategic direction for the development of the water and sanitation sectors. DNA, as an institution, has been abolished during the course of this research, any subsequent institutions have been left outside the research scope.
Challenges:	- Municipalities are responsible for collecting taxes for services like sanitation and storm water drainage. However, their autonomy allows them to appropriate these funds to other sectors. DNA is trying to ensure that municipal budgets on water and sanitation are appropriated correctly (DNA Employee, 2016).

ARA-Sul	Southern Regional Water Authority. The Mozambican waterboard of the southern region. Responsible for managing water resources, including surface water reservoirs, dams and groundwater.
Challenges:	- Currently there is no service regulation on tariffs, service quality and monitoring of groundwater (SUWASA,2015). - Conflicting claims on the freshwater in currently existing and future reservoirs, such as for agricultural, industrial (e.g. MOZAL) and domestic use (supplied by FIPAG). - Groundwater pollution from (pit) latrines threatens the aquifer quality, while limited regulation exist to prevent this (Hydroconseil & WE Consult, 2011).

CRA	Water Regulating Counsel. Is responsible for regulatory oversight in water related sectors (including DW and sanitation) in Mozambique. With a mandate to protect consumers, regulate service quality, approve changes in tariffs, and promote and improve the delegated management framework (SUWASA, 2010, p. 9).
Challenges:	- CRA for years did not regulate the private water operators as they thought this was the responsibility of the main operator. CRA gave a license to AdeM to provide water in the Maputo metropolitan and assumed that AdeM should therefore regulate any person providing water in their service area.

FIPAG	National Urban Water Investment and Asset Holding Fund. Responsible for the investment in and maintenance of DW infrastructure, expanding the national coverage of access to water supply service and production of DW (outside Greater Maputo).
Challenges:	- The Pequenos Limbobos reservoir (river discharge) and the WTP have reached the maximum DW supply capacity, there is not enough water to expand. Therefore FIPAG cannot connect more households or increase service hours (FIPAG Employee 1, 2016). - The high NRW rates in the FIPAG network posed a challenge to attract foreign capital for the construction of supply solutions like Corumana and Moamba dams, as it would limit the profitability of operating new supply capacity (FIPAG Employee 1, 2016). - Expansion to the peri-urban areas of Maputo means competition with local SSIPs. - In the peri-urban areas of Greater Maputo the average income of the population is lower increasing the risk of payment problems that decrease revenues on water services (FIPAG Employee 2, 2016).

	- The unreliable electricity supply to the city severely limits the possibly for FIPAG to keep its reservoirs in the city full. As a consequence the number of hours that households have water service fluctuates (FIPAG Employee 2, 2016).

AdeM	Water for the Maputo Region (English translation of AdeM). AdeM is the main water supplier in Greater Maputo, responsible for management of DW system operations (SUWASA, 2010).
Challenges:	- FIPAG's network has NRW, both physical losses and unauthorized consumption, severely limiting the profitability of the operations by FIPAG and AdeM (FIPAG Employee 1, 2016). - Expansion of services to peri-urban areas, means serving people with lower incomes, increasing the risks of people not being able to pay their water bill (FIPAG Employee 2, 2016).

SSIPs	Small Scale Independent Providers. Responsible for the supply of groundwater to around 192.000 household connections, about half of the city's population.
Challenges:	- Groundwater quality is decreasing - FIPAG is expanding the reach of its supply network, increasing the competition. - Competition among SSIPs on a local level is increasing.

Maputo and Matola Municipalities	The municipalities within Greater Maputo are not responsible for DW supply but are involved creating and checking on rules for water quality (Matola Employee, 2016).
Challenges:	- On one hand the municipality has the responsibility to represent the interest of as many of its inhabitants as possible, urging FIPAG to expand in the peri-urban areas would be a logical consequence. On the other hand the municipality tries to create an economically attractive location for business, for which urging FIPAG and AdeM to expand to the newly developed business and tourist areas of the city is important. - Also, the role of the SSIPs in the poorer peri-urban areas is so important at this moment that the municipality has great responsibility in representing their interest in negotiations with FIPAG.

Households	The households have the ability to choose between alternative available DW services. When they do they base their decision on DW quality, number of service hours and the water price (Zuin, Nicholson, & Davis, 2012).
Challenges:	- It is usual for householders to pay an initial sum of money for the creation of a domestic water connection. Many households are connected to SSIPs and have paid fees for a connection, new costs for a connection to the central network of FIPAG can be constraint for them. - The group of households is diverse in number of people and water use per person. - Many households share a connection with their neighbours or friends living nearby. Others are not connected and use local standpipes connections or resellers.

4.3.2. Actors in sanitation sector

The following actors are active in the sanitation sector, Table 3 contains for each actor a concise description of responsibilities and the challenges found.

Table 4 Summary of actors in sanitation sector

AIAS	Administration of Infrastructures for Water and Sanitation. AIAS was created to provide water supply in non-FIPAG cities and to function as a infrastructure owner in the sanitation sector in all Mozambican cities.
Challenges:	- Sanitation tariff is politically hard to establish and it is still unclear what services the municipality or AIAS will deliver in return for the potential tax contributions (AIAS Employee 1, 2016). - Small budget for sanitation on the national public budget (AIAS Employee 1, 2016) - The masterplan is needed to create a framework to embed individual project investment plans that are needed to secure project finance (AIAS Employee 1, 2016) - The municipality is reluctant to allow their department DAS (in autonomy) or AIAS to collect the dedicated sanitation tax, since they prefer to keep the authority to make sure any tax is used properly. Informally, it is understood that this practically means being able to decide to use a tax for other sectors than sanitation (AIAS Employee 2, 2016). - The Public Sanitation Guideline (Postura de Saneamento in Portuguese) has been approved both in Maputo and Matola. However, in Maputo the intended sanitation tax was not included conform the intended national standard (AIAS Employee 2, 2016).

Municipality of Maputo	After Mozambican independence the responsibility for municipal services as water supply and sanitation where transferred to the central government. Around 10 years ago (DNA Employee, 2016) responsibility for sanitation was decentralised from DNA to the municipality of Maputo, the transfer was finished in 2014 (Bäuerl, 2015, p. 11). Formally, on a national level this responsibility was transferred again recently to AIAS. However the municipality, because of its status, power and seize in the country, still has large autonomy in the sanitation sector and until now has withstood attempts to share or transfer these responsibilities with AIAS (AIAS Employee 2, 2016).
Challenges:	- Currently there is very little municipal budget available for sanitation services, this limits both the organisational capacity as the possibilities to invest in maintenance of the existing system or trucks. - Maintenance and operation of the WWTP has been halted since the plant became out-of-operation during the large flooding in 2000, it was cleaned for the last time in 2007 (Bäuerl, 2015)

Municipality of Matola	Similar to Municipality of Maputo. Matola has a recently combined department for Water and Sanitation (Matola Employee, 2016).
Challenges:	- Currently the department of water and sanitation mainly performs quality checks at water suppliers in Matola, additional budget and organisational capacity are needed to conduct similar services on sanitation (Matola Employee, 2016). - Since there is no current WW network in Matola, implementing a sanitation tax is said not to be possible before investments in emptying services or a sewerage network are made (Matola Employee, 2016). - The department needs state funds to invest in central sanitation infrastructure and afterwards intends to collect a sanitation fee from all users; households, industries and commercial users, dependent on the amount of water used (Matola Employee, 2016). - Maputo municipality has hold on to autonomy on sanitation (AIAS Employee 2, 2016). It is still unclear how both municipalities are going to divide responsibilities for WWTP operation, revenues from private FS collection and revenues from the potential sanitation tax (Matola Employee, 2016).

Private FS collectors	Private companies that provide various FS emptying services in Greater Maputo, currently around 25 enterprises (WE Consult, 2014, p. 15).
Challenges:	- The private collectors dispose the collected FS either legally at the WWTP of Infulene (6% of total produced sludge) or illegally in surface water or the sea (estimated 50% of total produced sludge) and an estimated 34% is safely abandoned and covered (Bäuerl, 2015). - Many of the vacuum trucks are so large that not all locations of septic tanks are accessible (ENGIDRO et al., 2015a). - Faecal sludge transfer stations (FSTS), decentralized reservoirs for FS, have been tested in Greater Maputo but the only station has barely been used, because the owner only operated large collection trucks and the transfer station was not expected to improve revenues (WSUP Employee, 2016). Different stories exist about the successfulness of this station, as the operator in informal communications suggested that exploiting the station is quite profitable for him. - A combined FSTS and digester pilot plant has been vandalised by a local community out of fear for pollution and contamination from toxic fumes that where understood to come from the installation. WSUP indicated that, at least for the short term, they think it is unrealistic to construct a new FSTS to enhance FS collection efficiency for peri-urban areas (WSUP Employee, 2016).

Households	The OSS in households fill up and have to be emptied or closed of periodically. Septic tanks that are connected to the sewerage system still fill up and should be emptied periodically. Before independence this was obligated and enforced by the municipality, since then however this has not been enforced. As a consequence septic tanks connect to the sewer are rarely emptied and overflowing discharge cause increased risk of clogging the sewerage network (WSUP Employee, 2016).
Challenges:	- A lack of proper emptying services of local systems and local circumstances causing large amount of infiltration, create a serious risk of contamination of local environment, surface and groundwater (Bäuerl, 2015). - Limited investment capacity in local households forces them to choose cheapest sanitation options, often these are unimproved pit latrines (Bäuerl, 2015), which are often even cheaper than the emptying of an existing system.

5. Exploring the future

The purpose of this chapter is to show the relation between the challenges in Greater Maputo that have been found in the analyses of the system and the actors in Chapter 4. First the challenges regarding the trends of climate change, population growth and economic growth are described; the (possible) impact of these trends is then quantified in terms of DW use or water availability and amount of WW or FS produced. In the second section the external trends, without a direct quantifiable effect on water and sanitation but that are essential enablers of development in the system, are discussed briefly.

5.1. Quantification of the impact of external trends

First we quantify the possible consequences of the external trends on the demand for water, the available surface water and the sanitation sector (amount of FS produced and services or systems used).

Population growth

In the last decades the population within Greater Maputo has been growing rapidly, up to more than 2,1 million inhabitants in 2015 (Maputo 1,187 million; Matola 937.000) (CIA, 2015). Multiple sources among which the Urban Structure Plan of the City of Maputo (2008) prognoses this growth to continue in the future, and population to double within 30 to 40 years (SEED, 2010). This prognosis appears to be based on the annual population growth over the past years, which has been of 2-3%[9]. As a consequence it is expected that every year an additional 40.000-60.000 inhabitants will need water and sanitation services in Greater Maputo.

Consequences on water use: Consequently the demand for drinking water continues to increase significantly. WE Consult projected in 2011 that the annual water demand (190.000 m^3/d) within the Maputo Metropolitan would double by 2020 (Hydroconseil & WE Consult, 2011). As an example in one decade, the additional 2-3% inhabitants annually, would mean an equivalent average water use of 3.140-4.710 m^3/d.
Calculated over a ten year timespan between 2017 and 2017, with a network efficiency of 50%, this would imply a need for an additional production of 36.000-55.000 m^3/d of DW.

Consequences for sanitation: The additional population will also produce more FS and WW that will have to be handled. As population growth has happened mainly outside the *Cement City* area, which is covered by the sewerage network, the new population with be largely dependent on on-site sanitation systems. According to Bauerl (2015) the 900.000 people in Maputo using on-site sanitation system produces almost 240.000 m^3/y of FS that should be emptied and treated. An population growth of 2-3% per year, would imply an additional 10.000-16.000 m^3/y to be emptied by FS operators.

Economic growth

Economic growth, or growth of the gross domestic product (GDP), in Mozambique has averaged over 7% annually over the past ten years. The Economist Intelligence Unit (EIU) has predicted that the economic growth over the upcoming years (until 2021) will average around 5% annually[10] [11].

Consequences for domestic water use: Economic growth and increased wealth for the population of Maputo will enable more people to supply themselves in their primary needs, amongst which drinking water and sanitation services. Additionally improved wealth is linked with further increase in water consumption, as people tend to use more water in general tasks as well as being able to afford more water consuming products. A recent study on economic growth and water use, links per capita water use to household income increase (Katz, 2015). For this research we assume an annual growth of the water use between 0-2%, as a consequence of the expected influence of economic growth on domestic water use in Greater Maputo.

Consequences for industrial water use: Economic growth is often pushed by or happens alongside industrial growth or the arrival of new industries or businesses. For this research we define industrial water use as; the amount of water used by industries or businesses that are supplied by either SSIPs or FIPAG/AdeM. In the current

---

[9] Source: http://www.tradingeconomics.com/mozambique/population-growth-annual-percent-wb-data.html
[10] Source, as reported on: http://clubofmozambique.com/news/mozambiques-economic-growth-expected-increase-2018/
[11] Source, as reported on: http://www.tradingeconomics.com/mozambique/forecast

situation this industrial water use is estimated to be around 10% of the water used within Greater Maputo. We assume an annual increase of the industrial water use of 3-7% as a consequence of the economic growth. As this is an increase that effects 10% of the total water demand, the consequential annual growth of total water use is 0,3-0,7%.

Consequences for sanitation: An increased household budget is linked to improved sanitation services, people with more income are more likely to use septic tanks or (pour)-flush systems, rather than latrines. Therefore, economic development is related to improvement of the populations sanitation systems. However, as the relation is too complex to quantify simply for this research, it is not taken into account in this analysis.

Climate change

Over the past decades the climate has been changing in Mozambique, affecting especially the southern part of the country. In Greater Maputo, temperatures have been rising slowly but significantly with between 0,3 and 0,6 degrees Celsius over the past 100 years. Alongside this rise the number of hot days has increased by around 7% between 1960 and 2003, including longer periods of draught (Dutch Sustainability Unit, 2015). However, most importantly for this analysis, is the overall decrease of the amount of rain with an average of 3% per decade on a national level between 1960 and 2006 (Dutch Sustainability Unit, 2015). It is projected that this decrease of rain will continue in the South and centre of Mozambique especially. The percentage of rain fallen in problematic heavier rains has increased over the same period (Dutch Sustainability Unit, 2015). Both the increased variety and intensity of rainy and dry are significantly affecting the water resources (both surface and groundwater) in Greater Maputo. For this research the effect on the overall amount rainfall is used, as it can be expected that these developments will affect the amount of surface water that is collected in the Pequenos Libombos reservoir.

Consequences for water availability: The current capacity of the water treatment plant and Pequenos Libombos reservoir is 200.000 m^3/d. A steady decrease of 3% (equal to the reduction in rain in the area), would mean a decrease of 6.000 m^3/d over a period of 10 years. Although the amount of rainfall also impacts natural aquifer recharge, this relation and the potential impact on the groundwater quality is too complex and indirect to be considered in this research.

Consequences for sanitation: Increased occurrence of heavy rainfall have the consequence of more frequent floods in city parts without drainage networks for storm water. This has incentivised the construction of drainage systems for flood relief, in projects as the masterplan for drainage and sanitation. These flood relief systems are currently intertwined with the development of a sustainable solution for WW and FS management. It is noted that this connection is not made in the case of wastewater treatment and reclamation and reuse solutions.

Urgency of trends and policy windows

The quantified influences shows that trends like climate change, economic growth and a population influx create large uncertainties for policy makers, network operators and international investors. Although the recent server droughts call for urgent measure, still no concrete actions are taken.

In other locations external trends (like climate change) have also presented themselves as societal opportunities that create the political support that is needed for policy change. These opportunities are referred to as *policy windows* (Kingdon, 1995). However, for some reason in the current situation in Greater Maputo, the uncertainty about these trends appear to be delaying the process interventions instead of enabling progress.

5.2. Other external trends

The following trends are of important influence on the development of the sectors of DW and sanitation, however their effect is not quantifiable to the volume of DW used or FS produced.

Depletion and pollution of groundwater resources

Along the significantly growing population and demand for water, the changing climate in the coastal parts of Africa is presenting the city of Maputo with yet another water related challenge. During dry seasons, that are increasing in duration, aquifers that are used for potable groundwater and industrial purposes are at risk of becoming unusable because of pollution (Hydroconseil & WE Consult, 2011). Pollution sources include salt water intrusion (near the sea), nitrate (already present in the groundwater, in soil near the aquifer or leaking from OSSs) and bacterial contamination (from OSSs and the dysfunctional sewerage network).

Policy of decentralisation

Decentralisation of government: Since the 1990s the Mozambican government has implemented several changes to enable and encourage decentralisation and liberalisation. The decentralisation is visible in the delegated management framework implemented for the drinking water and sanitation sectors. In sanitation decentralisation have rested the responsibility for sanitation services largely with the municipality. However, in practise the municipalities in Greater Maputo have not taken up a role of leadership within sanitation.

Decentralisation of services: Organisational capacity and financial inability at local governments have limited the expansion of the central sanitation system within Greater Maputo. Alongside this, international donors deployed activities such as implementing legislations and regulations to allow private service provision and projects to create more improved on-site sanitation systems. This private sector involvement has incentivised decentralisation within the market for WW and FSM. The current situation is that households are increasingly investing in improved on-site sanitation facilities. Money invested in on-site sanitation facilities is no longer available for public participation in the investment in a centralised system, indicating a larger scale trend towards decentralisation of sanitation services.

In the DW sector the same trend is visible. However, in practise it does not have the same consequences. Local private operators are expanding their services in parts of the city where no FIPAG DW network is available. Although this implies that investments made by private operators and households are no longer available, some of these networks are suitable of can be made suitable to be connected to the FIPAG DW network. Research on the formalisation and inclusion of private operators in the centralised drinking water network have presented FIPAG and ARM with several options to deal with the SSIPs (USAID and SUWASA), although actual results of this approach have not been presented yet.

These decentralisation trends have an undeniable effect on the development of the DW and sanitation sectors in Greater Maputo. Specifically on the relation between current services and the replaceability of these by new network and services. However as these relations are hard to establish in practise and even harder to predict, the possible consequence are left outside the scope of this research.

6. Previous and planned improvement projects

This chapter contains a short introduction about the water resources for Greater Maputo, followed by an exploration of the current and proposed future improvement projects in the water and sanitation sector. The objective of this chapter is to quantify the available and possible water and wastewater volumes in relation to the cost of the necessary reservoirs, treatment plants and supply networks.

6.1. Surface water resources for Greater Maputo

In 2002 Mozambique signed a tri-country agreement over the minimum and average volume of the water that flows over the border, the agreement also included terms about pollution (The Republic of Mozambique the Republic of South Africa and the Kingdom of Swaziland, 2002). Figure 14 depicts the infrastructure and shared surface water resources of Greater Maputo.

The Incomati river is shared with South Africa and Swaziland, where the river is called Komati (Tauacale, 2002). The water flows into the proposed Moamba Major reservoir some 100 km North South of Greater Maputo. Further North the Sabie river from South Africa enter the Corumana reservoir, and lower joins the Incomati river. The river discharges into the sea some 25 km North of Greater Maputo.

The Umbeluzi is shared with Swaziland, where the river is called Mbuluzi or Mpuluzi (Tauacale, 2002). The water from this river flows into the reservoir at the Pequenos Libombos Dam, south west of Maputo. The Umbeluzi river discharges into the sea just South of Maputo in the Maputo Bay.

Water from the Infulene River, that runs for about 20 km from the north through Maputo into the Bay, and is used by farmers and industries in the city. As Infulene is not shared with neighbouring countries, the volume of water available is dependent on precipitation in above lying areas and industrial effluent, the usability is highly dependent on the pollution of water by industries and agriculture. Downstream, near the Infulene WWTP, farmers expressed informally to the author that they cannot and do not use the water as it is too polluted by industries.

Figure 14 Map of infrastructure to current (blue) and planned water reservoirs (red) (dos Santos Silva, 2014).

6.2. Projects in water resources

The following sections contain: the current situation in water resources (surface and groundwater), the current project being implemented to add water resources, the proposed project that is often discussed as the longer-term future for Greater Maputo and an additional section contains alternative solutions that are rarely discussed as less probable alternatives.

6.2.1. Current situation in water resources

Umbeluzi River and Pequenos Libombos Dam, including a new water treatment plant (WTP)

Dos Santos Silva (2014, p. 17) describes that the Umbeluzi River has been Maputo's main fresh water resource since 1920. In 1969 a first WTP was constructed to supply the colonial inhabited Cement City. To improve the reliability of the river as the main water resource, a reservoir was created by constructing the Pequenos Libombos Dam. The dam became operational in 1987 and a second WTP was built to increase the water supply capacity. The final big change in the Umbeluzi water supply was in 2007, when European donor support was used for the rehabilitation of the WTPs and the network to increase both production and network efficiency (dos Santos Silva, 2014, p. 18).

A FIPAG employee indicated that in 2016 the Pequenos Libombos dam had reached the limits of its supply capacity and that it will not be sufficient for longer than one and a half year, mid-2017 (FIPAG Employee 1, 2016). A study in 2014 predicted that in a likely future the Pequenos Libombos dam could reach very low levels (close to 0%) as soon as 2020 (ARA-Sul, 2014). As predicted seasonal variability has put even more pressure on the available water in Pequenos Libombos, and the latest drought continued through the rainy season in the end of 2016. In January 2017 the reservoir reached historically low level of 14% with 6-8 months of dry season ahead, forcing both the actors in water industry and national politicians to ration water and to look for alternative resources[12].

Table 5 Pequenos Libombos WTP: cost and capacity

	Cost	Volume DW	Year (possible)
Capacity WTP	Sunk cost, unknown.	200.000 m^3/d (current)	Current.

Groundwater resources

Groundwater remains the source for drinking water delivered by SSIPs and in the Northern parts of Greater Maputo by FIPAG standpipes. As mentioned in Section 4.1, there are increasing risks of groundwater pollution and saline intrusion that would make groundwater non-usable as drinking water resource. No solution has been presented, other than that ARA-Sul conducts registration and licensing of groundwater extraction, and periodical quality monitoring (ARA-Sul Employee 1, 2015). The amount of FIPAG groundwater supplied by AdeM in standpipes is estimated at 14.000 m^3/d, however they are reportedly decreasing this in recent years and will continue to do so (FIPAG Employee 2, 2016). No FIPAG strategy is known concerning the use of groundwater as an emergency supply, therefore FIPAGs groundwater is left out of the further analysis.

6.2.2. Current project in water resources

Corumana Dam and WTPs

The Corumana Dam was constructed in the Incomati River Basin 1989 without the spill gates, limiting its storage capacity by half. In 2011, the World Bank approved the National Water Resources Development Plan including the installation of the spill gates to increase the capacity (dos Santos Silva, 2014). The fact that the dam is already constructed makes the Corumana system the primary alternative for drinking water supply, a disadvantage of the Corumana reservoir is the large distance (117 km), 25 km farther than the alternative Moamba Major Dam. However, there are contradicting discourses about the purpose of the increased capacity of Corumana, ranging from irrigation, power generation, drinking water supply and flood prevention (dos Santos Silva, 2014).

The expansion of the Corumana system and construction of a WTP is part of FIPAGs Greater Maputo Water Supply Expansion Project (GMWSEP), an effort to increase both the supply capacity and coverage of the FIPAG network (dos Santos Silva, 2014). Currently the spill gates are being installed and the first WTP (60.000 m^3/d) is being constructed along with a pipeline and the distribution network to Greater Maputo, the expected delivery is now

[12]Source: https://constructionreviewonline.com/2017/01/water-crisis-in-mozambique-as-major-reservoir-drops-in-water-levels

at the end of 2017 (FIPAG Employee 2, 2016). Additional treatment capacity (60.000 m^3/d) is planned to be available by 2024 (FIPAG, 2013).

Table 6 Corumana Dam and WTPs: Costs and volumes

	Cost (US$)	Volume DW added	Year (possible)
Cost spill gates	70 million (FIPAG, 2013)	None	Current.
Corumana WTP 1	140 million (The World Bank, 2013)	+ 60.000 m^3/d	2018
Corumana WTP 2	42.5 million	+ 60.000 m^3/d	2024
	252.5 million	*120.000 m^3/d*	

6.2.1. Proposed projects in water resources

Moamba Major Dam and WTP

The Moamba Major dam is viewed as the longer term future solution for the Greater Maputo water supply (dos Santos Silva, 2014). The projected Dam and reservoir are located 90 km north west of the city (see Figure 14). Like the Corumana system the Moamba Major is supposed to serve the population of the growing norther peri-urban areas. However, it will also function as increased capacity and a buffer for drinking water in the rest of Greater Maputo (FIPAG Employee 2, 2016). DNA and ARA-Sul have indicated that the Corumana System is a short-term solution that will be replaced by Moamba Major (dos Santos Silva, 2014). However, as this is not a concrete plan, both solutions will be treated as separate solutions in this analysis.

Moamba Major dam is supposed to more add more than twice the existing capacity of DW supply for Greater Maputo. However, there are different discourses about the intended use of Moamba Major water, according to Dos Santos Silva (2014) these vary again from drinking water, irrigation, industrial use, flood control and power generation. Priorities and distribution quotas have never been explicitly issued, creating insecurity about the capacity of drinking water that Moamba Major is going to add for Greater Maputo. This is illustrated by FIPAGs expectations on the water supply from Moamba, in their water balance prospect for 2030 FIPAG considers only 140.000 m^3/d from Moamba and 120.000 m^3/d from Corumana (FIPAG Employee 2, 2016).

Table 7 Moamba Major Dam and WTP: Costs and volumes

	Cost (US$)	Volume DW	Year (possible)
Moamba Major Dam reservoir capacity	466 million, projection in 2012 (dos Santos Silva, 2014)	450.000 m^3/d Surface water volume. (dos Santos Silva, 2014)	After 2025, expected 2030
Moamba Major WTP expectation FIPAG and pipeline to Maputo	100 + 200 = 300 million pipeline + WTP (a cost estimation related to Corumana pipeline and WTP)	+ 140.000 m^3/d DW production capacity. (FIPAG Employee 2, 2016)	After 2025, expected 2030.
	466 + 300 = 766 million	*+ 140.000 m^3/d of DW capacity.*	*Expected 2030*

6.2.2. Alternative projects in water resources

Managed Aquifer Recharge (MAR)

Aquifer recharge is the natural replenishment process of groundwater resources with rainwater or river infiltration. In urbanised areas like Greater Maputo, houses roads, and the lack of vegetation or ponds limits the amount of aquifer recharge that takes place naturally (Foster, 2001). One way to manage an aquifer is to limit groundwater extraction especially in dry seasons, to allow natural recharge to take place. MAR is a technique to inject (pre-treated) surface water into an existing aquifer to replenish this groundwater resource in a controlled way. MAR can be used to prevent saline intrusion from contaminating the groundwater (Maliva & Missimer, 2012). ARA-Sul has expressed a keen interest in the possibilities of MAR, as it could be a way to prolong the sustainability of groundwater as a water resource in Greater Maputo. However, no concrete steps have been taken or plans have been made to realise this solution in the (near) future and it is assumed to not be possible within 15 years (estimation in consultation with supervisor).

Table 8 MAR: cost and capacity

	Cost (US$)	Volume DW	Year (possible)
MAR	Unknown, dependent on scale.	Scalable, depends on capacity and available surface water.	After 15 years (estimation).

Desalination of groundwater or seawater

Desalination in general is a technique where salts are removed from the water resources using membranes and pressure, it requires energy and is therefore often considered an approach with a large environmental footprint (WaterReuse Association, 2011). Additionally, this process creates a concentrated stream of saline water (brine), that should to be taken into account when considering costs because the salinity of the brine can have significant consequences for the environment if not disposed in the right way (Cooley, Ajami, & Heberger, 2013). In Greater Maputo, there is no clear party that would be responsible for a desalination plant, although FIPAG is most likely, ARA-Sul could be responsible or at least involved as they are responsible for making surface water available and environmental protection (in relation to for example the brine). Desalination is assumed to be a longer term solution, possible only after 15 years (estimation in consultation with supervisor).

Table 9 Desalination plant: cost and capacity

	Cost (US$)	Volume DW	Year (possible)
Desalination plant	1,5 - 2 million for every 1.000 m^3/d	Scalable, depending on seawater or groundwater, or plant capacity.	Longer-term, not within 15 years (estimation).
Desalination groundwater	150 million	100.000 m^3/d	After 15 years
Desalination seawater	200 million	100.000 m^3/d	After 15 years

6.3. Projects in drinking water supply

Here the current situation and current improvement projects in surface water supply (as conducted by FIPAG) are discussed, followed by alternative projects in surface water supply, and the proposed or alternative project in groundwater supply (as conducted by SSIPs).

6.3.1. Current projects in FIPAG supply network

The FIPAG network serves about half of Maputo's population. FIPAG has aimed to improve the performance of its network but is still facing challenges of high NRW (45%) and few connections in peri-urban areas. Therefore FIPAG and AdeM are still conducting the following improvement projects:

Network expansion: Efforts to expand this network are specifically aimed at the peri-urban areas. The strategy of increasing the number of households connections is largely dependent on the development of the total amount of available surface water and the water supply capacity (FIPAG Employee 2, 2016). This project is part of the GMWSEP, which was planned to be finished by 2019 (The World Bank, 2013). However, it is currently expected to be finished in 2024, the expansion includes household connections, distribution mains, reservoirs and network. FIPAG has no further plans for short term connection expansion, as expansion is realised in most convenient and profitable locations first (FIPAG Employee 2, 2016). In this thesis it is assumed that the new network will have 25% of NRW, which is significantly better than the performance of the current system as it is expected that a new network will suffer less physical losses. However, it is still far from 0% NRW as even a new network will have malfunctions and similar expansion projects in Jakarta, Indonesia have resulted in increased rates of NRW as expansion provided an opportunity for illegal connections and corruption (Kooy, 2014).

Table 10 Network expansion projects: cost and number of connections (The World Bank, 2013).

	Finished in year	Cost (US$)	Connections	NRW	Total connections	NRW
Current FIPAG network	Current		175.000	45%	175.000	45%
Network expansion phase 1	2018	45 million	+120.000	25%	295.000	37%
Network expansion phase 2	2024	30 million	+100.000	25%	395.000	34%

Standpipes/groundwater services: In the peri-urban areas FIPAG has created networks that supply groundwater to households and standpipes to sell water in gallons. This is an effort to compete with SSIPs and to expand the network before new water resources have been created and connected to supply Greater Maputo (Zuin et al., 2012). FIPAG and AdeM have been decreasing the amount off groundwater standpipes they operate, connecting them to the central network supplying treated surface water instead (FIPAG Employee 2, 2016).

Table 11 Standpipes selling groundwater: cost and capacity

	Cost (US$)	Volume DW	Year (possible)
Standpipes selling GW	Unknown	14.000 m^3/d, estimation[13]	Current.

6.3.2. Alternative projects in FIPAG supply network

Increase network efficiency: FIPAG is running a network improvement program in cooperation with WSUP, to significantly decrease the amount of NRW. This effort will enable FIPAG to sell more water without additional water resources. Besides that, a network with a higher performance will make investment in new reservoirs and WTPs more profitable and more attractive for international investment agencies (FIPAG Employee 1, 2016). In the past years NRW has been decreased form 60% to around 45% of FIPAGs total capacity 200.000 m^3/d (FIPAG Employee 1, 2016).

Table 12 Network improvement actions FIPAG: costs and capacity increases

Action in current FIPAG network	Cost (US$)	Volume DW	Year (possible)
Current NRW at 45%	Unknown.	NRW: - 120.000 m^3/d	2012
		NRW: - 90.000 m^3/d	Current.
Limit NRW to 35%	10 million.	NRW: - 70.000 m^3/d + 20.000 m^3/d added supply	2018
Limit NRW to 25%	25 million.	NRW: - 50.000 m^3/d + 20.000 m^3/d added supply	2020

6.3.3. Projects in supply networks for groundwater

SSIP water services

It is estimated that more than 800 SSIPs are supplying groundwater to around 51% of the population in the Greater Maputo. The SSIPs been a crucial part of the water sector in Greater Maputo, for decades serving the population that was not covered by the FIPAG network, especially during period of droughts the reliability (often 24 hours of service) has been essential in supplying water to the entire city. In recent years programs focussed on formalisation and professionalization of SSIPs have increased the water quality monitoring and the amount of households connections with a water meter (Ahlers et al., 2012).

Increase network efficiency: NRW for SSIPs is estimated to be 51% (Mwanza, 2015). Several projects have been and are still conducted to improve the efficiency and precision of metering and billing at households by using digital or smart readers (ViaWater, 2017), including one led by WSUP, the NGO conducted a project to reduce NRW and let the gained revenues benefit the urban poor by granting them cheap access to DW (WSUP, 2013).

SSIPs score high on customer satisfaction and operational efficiency (low overhead costs and little non-paying customers) (Bhatt, 2014), but their non-regulated water tariff allows them to charge a significantly higher price than AdeM. During an interview with SSIPs in Matola it was found that households with a double connection (FIPAG and SSIP) will use FIPAG water as their primary source. However, outside the FIPAG service hours they use water from their SSIP connection, illustrating that people do prefer the water from FIPAG (Matola Inhabitant, 2016).

Problems with groundwater pollution and saline intrusion are arising in the current situation, therefore the current level of extraction 100.000 m^3/d is used as the threshold to determine of a situation of water use as acceptable.

[13] Amount of groundwater supplied by AdeM = (1-0.93) * 200.000 = 14.000 m^3/d (Salim, 2016).

Table 13 Network improvement actions SSIPs: cost and capacity

SSIPs water supply	Assumptions / Cost (US$)	Volume DW	Year (possible)
Current SSIPs supply	Cost unknown. NRW: 53%	Current GW use: 47.000 m^3/d (own calculation[14]) Extracted GW: 100.000 m^3/d (estimation[15])	Current.
Reduce NRW in SSIPs -10%	10 million.	-10.000 m^3/d of GW needed (for groundwater extraction of 100.000 m^3/d)	2018

6.3.4. Alternative project to influence the use of water

Limit non-essential DW use (-5%): Besides actions that will improve the capacity of DW supply and projects that will improve the efficiency of the supply networks, there is the possibility to influence the demand for water. A policy action is to limit the amount of non-essential DW use, by raising awareness about water scarcity or even prohibiting the use of water for gardening and swimming pools during periods of droughts. Although continuing droughts are increasing the current water crisis in Greater Maputo, the process of implementing and enforcing a policy like this is assumed to take a few years. Therefore 2020 is assumed as the earliest year of implementation of for this action. Gardening is a common practice for many businesses and households in Greater Maputo, and it is conducted primarily during day-light hours, with the consequence of a lot of evaporation. For this reason it is assumed that a quite high percentage of DW use can be spared by this action, 5% of water use.

Table 14 Alternative projects

	Cost (US$)	Volume DW	Year (possible)
Limit non-essential DW use (-5%)	Cost unknown. Policy action.	- 7.850 m^3/d (5% of 157.000 m^3/d)	2020

6.4. Projects in sanitation

First the existing projects in sanitation with their volumes of water are described, thereafter the proposed (in the masterplan) improvement projects and additional solutions that are possible but not currently discussed in Greater Maputo are presented.

6.4.1. Current situation and current projects in sanitation

Infulene WWTP and Maputo wastewater network

The WWTP in Infulene was designed to treat the wastewater produced by 90.000 people, but currently the plant is practically non-operational. However, the plant's untreated effluent is used for irrigation in the proximity of the WWTP (Bäuerl, 2015).

Currently WW from around 38.000 inhabitants is directed to the WWTP, which is equivalent to around 4.000 m^3/d, measured during the dry season. If the existing pumping stations are reactivated the volume of WW arriving at the WWTP would increase to 10.000 m^3/d. With pumping stations the WWTP would be serving around 60.000 people. The total amount of WW collected in the network is 25.000 m^3/d, produced by an estimated 135.000 people (van Esch & van Ramshorst, 2014).

In this thesis it is assumed that with 1 m^3 of WW, 1 m^3 of water could be reclaimed with treatment for fit for purpose reuse (e.g. by industries). That would imply that there currently is a water resource of 4.000 m^3/d available for reuse, which could be increased to 10.000 m^3/d by restoring the pumping stations. With additional pumping stations and network improvements a resource of 25.000 m^3/d could be made available at the plant. The amount of WW that can be collected in the WW network depends on the amount of water that is used in the households and businesses connect to the network, for this analysis it is assumed that 10% of the total DW use in Greater Maputo could potentially be collected and become available for reclamation at Infulene.

[14] Per-capita daily consumption of SSIPs users = 45,9 litre/day = 0,0459 m^3/d (Zuin et al., 2012), part of the population served by SSIPs = 51% (Mwanza, 2015), total population = +/- 2.100.000 (CIA, 2015). Total groundwater provided by SSIPs = 0,0459 * 2.100.000 * 0,51 = 46.818 m^3/d ≈ 47.000 m^3/d.
To work with round amounts in this analysis we use: GW production = 100.000 m^3/d, NRW = 53% and GW use = 47.000 m^3/d.

[15] Based on an average estimated percentage of NRW between 50-60% for SSIPs.

Table 15 Current WW networks and project: cost and volumes.

	Cost (US$)	Volume WW	Year (possible)
WW collected	Unknown.	Arriving at WWTP: 4.000 m^3/d	Current.
WW collectable with rehabilitated pumping stations	Rehabilitation has become a political issue between actors, no longer a financial problem.	Increase at WWTP: 6.000 m^3/d	2018

Faecal sludge management (FSM)

Since the wastewater network has a limited coverage of the city, there is a serious need for emptying services of on-site sanitation systems. There is currently no treatment plant in Greater Maputo equipped to effectively treat FS nor are there collection or transfer stations that actively enable efficient collection of FS.

Municipal FSM: The municipality of Maputo operates a single vacuum truck to empty on-site sanitation systems. The service is delivered free of charge, but the limited capacity makes the services unreliable for people who have a filled up sanitation system (ENGIDRO et al., 2015d).

Private FSM: In addition to providing a municipal FS collection service the municipality has the authority to delegate sanitation services to private companies (SEED, 2010). In practise the municipality has licensed several private companies and some community based organizations providing sanitation services, that are conducting pit and septic tank emptying services. However regulation is limited in practise and little to no information is available about the volumes of FS that are collected and how these are disposed of.

Given the lack of information and limited amount of FS that is currently disposed at the WWTP and given that no FS is treated effectively, this volume is not included in the analysis of the current situation. FSM in our analysis is included in general as it is included in the analysis in the masterplan.

Table 16 Faecal sludge production: volume

	Cost (US$)	Volume WW	Year
FS produced	Unknown.	150.000-250.000 m^3/year = 685 m^3/d	Current.

6.4.2. Proposed projects in sanitation

Storm water and WW drainage network

During the rainy season roads and informal neighbourhoods often become flooded. This damages the infrastructure and creates health risks especially in combination with overflowing on-site sanitation systems (there was a cholera outbreak in the first months of 2017), this proves the necessity of new or rehabilitated drainage systems throughout Greater Maputo. Since 2008 a strategy in Maputo has been to link quick deterioration of roads to the lack of a drainage system. This resulted in some road rehabilitation projects including the construction of a drainage system (SEED, 2010). However, this has not led to significant increases in the coverage of drainage networks in the city.

Masterplan for drainage and sanitation in Greater Maputo: This plan is being created as a city-wide framework for projects like new or improved infrastructure and treatment facilities for both sanitation and drainage. Logically, a WW network covering the whole city would make much larger volumes of water available for reclamation.

Assumptions on Masterplan and collected volumes of WW, FS and storm water

- Two phases: Concerning the volume of water collected in the masterplan networks the following assumptions are made. The average available volume of water that could be collected in Greater Maputo is assumed to be equal to the amount of water received by households and businesses (in other words, the total DW use). We divide the masterplan actions and the potential amount of water that is collected in the networks in two execution phases, phase 1: the short and medium term actions from the masterplan (2018-2030) and phase 2: long term actions for the masterplan (2030-2040).
- WW volumes available for reclamation: The potentially collected volumes of WW, that become available for reclamation, are based on the seize of the investments and related to the total DW used at the time that a part of the Masterplan is completed. Phase 1 contains 62% of the total investments and is related to the total DW use (FIPAG and SSIPs), in 2017 this would correspond to 0,62 x 156.000 m^3/d of WW (97.000 m^3/d). The masterplan phase 2 is assumed to correspond to the remaining 38% (59.000 m^3/d).

- Infulene a part of phase 1: The current WW system collects between 4.000-25.000 m^3/d (or 10%) and transfers it party to Infulene WWTP. Rehabilitating the current network and Infulene are part of phase 1 of the masterplan. Hence, if Infulene is constructed before phase 1, the collected volume in the current system (10%) is subtracted from the WW collected in phase 1 (including Infulene 62%, excluding 52%).
- Separate actions for network and treatment: The masterplan separates the construction cost of the drainage networks and the treatment facilities for the collected WW, FS and storm water. In this research we divide the construction of treatment facilities in the same two phases as the construction of the drainage and collection networks.
- Quality of treated water: The masterplan does not make notice of any reuse of treated water nor does it mention the quality of treated effluent. For this research it is assumed that all collected water is treated to surface water quality. We assume that additional treatment is necessary to produce water-fit-for-use.

Table 17 Sanitation actions proposed: cost and added volume

Proposed solutions	Cost (US$)	Volume WW	Year (possible)
Rehabilitate the current WW network (connect systems 1-3)	10 million 31 million	10.000 m^3/d 25.000 m^3/d	2018 2020
Infulene: treatment to surface water quality	5 million. 10 million. 25 million	4.000 m^3/d 10.000 m^3/d 25.000 m^3/d	2018 2020 2020
Masterplan: Drainage network for WW and storm water	Investments from Masterplan, with percentage of total. Phase 1: 735 million (62%) Phase 2: 437 million (38%)	Volume available for reclamation, in relation to current water use: +97.000 m^3/d (+72.000 m^3/d) +59.000 m^3/d	2016-2040 Phase 1: 2030 Phase 2: 2040
Masterplan: treatment WW and FS to surface water quality	Phase 1: 238 million (62%) Phase 2: 189 million (38%)	+52% / 62% of 157.000 m^3/d +38% (100%) of 157.000 m^3/d	Phase 1: 2030 Phase 2: 2040

6.4.3. Alternative projects in sanitation

Production of water-fit-for-use: In this analysis it is assumed that the water reclaimed in the masterplan, can be treated to produce water-fit-for-use for industries or businesses. In this analysis we assume that this supply could replace DW water. To use the treated wastewater this has to have a "fit-for-use" quality, in some cases it will be necessary to conduct further treatment. The required treatment will be different for each of the selected types of reuse (dependent on the purpose of the water and the quality of the reclaimed water). The cost of the treatment could vary significantly between de different end-uses. However, as treatment to surface water quality is already included in the masterplan, the additional cost of treatment will not be higher than the cost to treat surface water to potable standards. As there are additional cost included like supply infrastructure, it is assumed that cost of water-fit-for-reuse per 1 m^3/d are similar to the per 1 m^3/d treatment cost of surface water to DW at Corumana. For the DAPPs model it is assumed that a network to supply water-fit-for-use will have NRW rate of 25%, similar to new FIPAG supply networks. In Table 17 the cost for water-fit-for-use are presented for Infulene and for the Phase 1 and 2 of the Masterplan.

Table 18 Sanitation actions additional: cost and added volume.

Infulene Reclamation	Cost (US$)	Volume	Year (possible)
Water-fit-for-use: additional treatment of water at Infulene	4 million 8 million 20 million	4.000 m^3/d 10.000 m^3/d 25.000 m^3/d	2018 2020 2020
Additional solutions	**Cost (US$)**	**Volume**	**Year (possible)**
Water-fit-for-use: additional treatment MP effluent	Water-fit-for-use: 70 million Water-fit-for-use: 110-175 mln.	Phase 1: 98.000 m^3/d Phase 2: 157-250.000 m^3/d	After 2030 After 2040

7. Dynamic Adaptive Policy Pathways to a sustainable future

In this chapter the proposed and possible actions as described and quantified in Chapter 6 are used as input for the Dynamic Adaptive Policy Pathways. For creating this chapter steps 4-6 from the DAPPs approach are taken. In this analysis three strategies are tested as preferred pathway to the future in Greater Maputo, this will allow to explain the how the DAPPs work and show the (dis)advantages are of each of the pathways.

First, the desired future is explained and along with the working of the model and what is called and undesired future or a violation of the desired future (Section 7.1). Then the starting situation and two future development scenarios are explained (Section 7.2). After that the actions (as introduced and quantified in Chapter 6) are summarized (Section 7.3), and scored on their individual impacts (Section 7.4). The three improvement strategies are explained (Section 7.5). Finally, in section 7.6, the results of the DAPPs analysis are presented for the three strategies in each of the two developments scenarios.

7.1. Desired future and model specification

Desired future

The DAPPs approach prescribes the definition of a desired future and thresholds to determine whether or not a certain strategy creates an acceptable future situation in any given year. For this analysis the desired future is formulated like the objective of this thesis, *a sustainable freshwater supply in the landscape of water providers in Greater Maputo*. This desired future is interpreted as follows, *sustainable freshwater supply;* sufficient production capacity of DW for now and on a longer term (until 2040), *in the landscape of water providers in Greater Maputo*; with possible solutions ranging from surface water, to GW or alternatives.

Model specification

From the system analysis conducted in Chapter 4, a relationship between total amount of water used (domestic and industrial) and the amount of DW production by FIPAG and the groundwater used as DW (and groundwater extraction as a consequence) has been derived. In the current situation GW extraction functions as a buffer between the demand for DW and the production capacity of FIPAG, as GW extraction increases when demand for water is higher than the DW production of FIPAG.

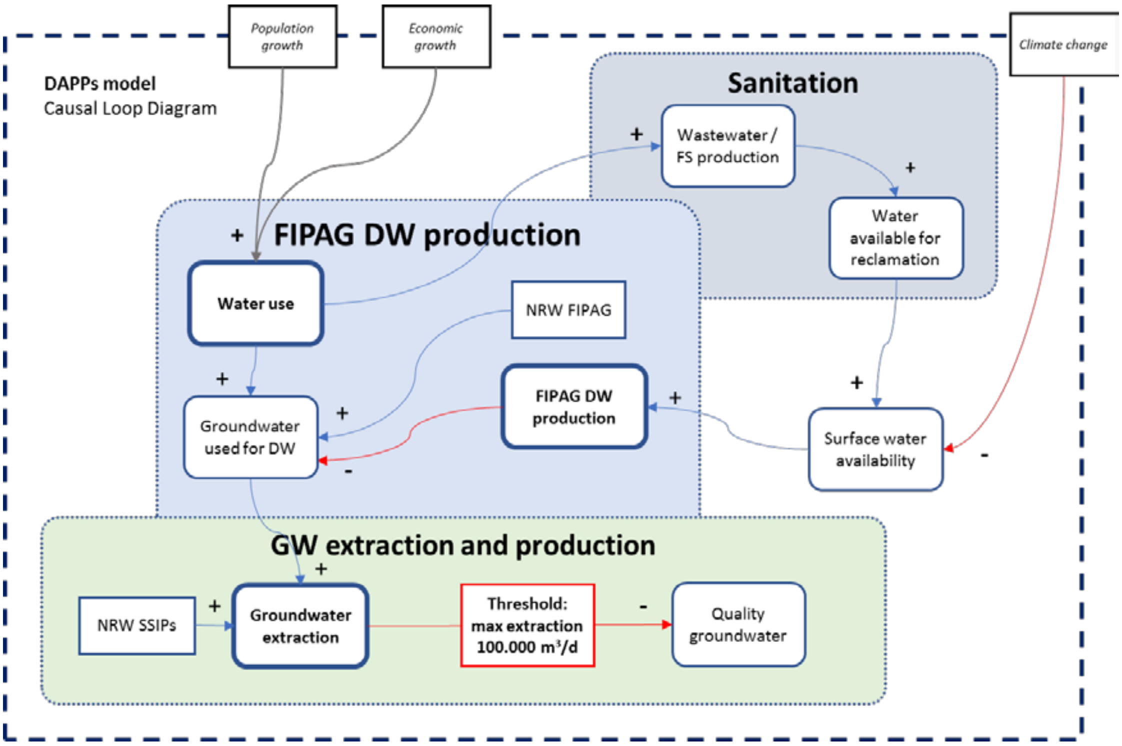


Figure 15 CLD depicting the relations in the model used for DAPPs analysis (model specification, Appendix G).

The underlying assumption is that people will use GW as a replacement for FIPAG DW when the use of DW exceeds the FIPAG production capacity (they prefer FIPAG water because of low cost and high quality, as long as it is available). Network expansion project will enable the interchangeability of FIPAG DW and SSIPs GW, because more households will obtain a double connection. In the model this is reflected as a direct relation between the *GW use*, the *FIPAG supply* and the *total water use.* Figure 15 visualises all relation in the DAPP model, it is specified in Appendix G. The main formulas used in the model for the relation between GW use and FIPAG water are:

$$GW\ used\ for\ DW = Water\ use - \frac{(FIPAG\ DW\ production)}{(1-NRW\ FIPAG)}, \quad GW\ extraction = \frac{GW\ used\ for\ DW}{(1-NRW\ SSIPs)}$$

Unacceptable future

GW pollution is an increasing problem in Greater Maputo, further increase of the volume of GW extracted is assumed to threaten the sustainability of GW as a water resource. Because GW plays a vital role in the DW supply sector, the current situation of GW extraction is taken as the largest amount of extraction that is acceptable, the volume currently extracted is 100.000 m^3/d. This volume is used as a threshold to determine whether a future situation is deemed acceptable. If, starting from the current situation, the use of DW rises without a rise of FIPAG DW production, the GW extraction will surpass or *violate* the threshold, and a new policy action is necessary.

7.2. Current situation and two development scenarios

Current situation

In Table 16 the starting situation is depicted and taken as the input for the pathways analysis. The population has been introduced in Chapter 2 and the developments of external trends that influence the water use (population and economic growth) and the available surface water (climate change) have been described in Chapter 5. As shown the industrial water use (10%) and domestic water use (90%) are split in the starting situation to clearly illustrate the influence of economic growth and population growth. In the rest of the analysis the growth of the general water use is with the combine growth is used. The NRW in both FIPAG and SSIPs follow from Chapter 6.

Table 19. Starting situation for DAPPs quantified.

	Starting value	Annual growth	
Starting Year	2017	Annual change	Percentage
Population	2.100.000	42.000 - 63.000	2-3%
Domestic water use (pop. growth)	141.300 m^3/d	2.826 - 4.239 m^3/d	2-3%
Domestic water use (econ. growth)	141.300 m^3/d	0 - 2.826 m^3/d	0-2%
Industrial water use (econ. growth)	15.700 m^3/d	471 - 1.099 m^3/d	3-7%
Water use	157.000 m^3/d	3.297 - 8.164 m^3/d	2,1 - 5,2%
Surface water / FIPAG production	200.000 m^3/d	- 600 m^3/d	- 0,3%
Groundwater extraction	100.000 m^3/d	*Threshold value for GW extraction*	
NRW FIPAG network	45%		
NRW SSIPs networks	53%		

Two development scenarios

The DAPPs analysis is used to compare the effectiveness of different strategies under uncertain circumstances, to quantify this uncertainty we created two scenarios. These two scenario provide a bandwidth to the uncertainty of the external developments, for this one scenario assumes progressive development and one assumes conservative developments. In Table 17 the scenarios are presented: rapid climate change, population and economic growth versus slow climate change, population and economic growth.

Table 20. Two development scenarios of the current situation in water and sanitation.

	Scenario 1 Rapid climate change, population growth and economic growth		Scenario 2 Slow climate change, population growth and economic growth	
	Annual change	Percentage	Annual change	Percentage
Population	63.000	3%	42.000	2%
Domestic water use (pop. growth)	4.239 m^3/d	3%	2.826 m^3/d	2%
Domestic water use (econ. growth)	2.826 m^3/d	2%	0	0%
Industrial water use (econ. growth)	1.099 m^3/d	7%	471 m^3/d	3%
Water use	8.164 m^3/d	5,2%	3.297 m^3/d	2,1%
Surface water / FIPAG production	- 700 m^3/d	0,35%	- 500 m^3/d	0,25%
Groundwater extraction	Dependent on water use and FIPAG production.			

Time for which a solution is 'sufficient'

To supply the growing need of Greater Maputo an additional 3.500 - 9.000 m^3/d of DW is needed each year starting in 2017. As the annual growth is assumed to be a percentage, this growth itself will steadily increase over the years, to an annual growth of 5.000-25.000 m^3/d. That would mean that an action that creates an additional supply of 60.000 m^3/d, would be sufficient for 3-15 years, dependent on the assumptions, and in this case dependent on the scenario and the year of action. This illustrates that a solution to construct the Corumana dam with two WTPs of 60.000 m^3/d capacity, seems like a very significant increase of the water supply in Greater Maputo. However, taking into account that the current FIPAG supply network has NRW rates of 45%, the duration of planning and construction, and the growing demand for DW, the effective result of this action could well be only a few years of sufficient DW supply. A more conservative scenario could show that the same action would be sufficient for over 15 years, in other words, this approach provide insight in the effect of actions under different circumstances.

7.3. Identified actions

In Table 18 the actions, as discussed in Chapter 6, are summarised explaining the consequences of each action on i) the amount of surface water available, ii) the amount of DW supply capacity, iii) the amount of DW that can actually be used by consumers, iv) the period for which this action is an adequate solution and v) the cost associated with this action.

Table 21 Summary of action in relation to surface water availability and DW supply capacity.

	Available surface water	Water supply (DW / fit-for-use)	Water use	Sufficient until	Additional cost (US$)
Current situation: Pequenos Libombos and groundwater supply	200.000 m^3/d	SW: 200.000 m^3/d GW: 100.000 m^3/d = **300.000 m^3/d**	110.000 m^3/d 47.000 m^3/d = **157.000 m^3/d**	2017-2020	-
Corumana Dam and WTP	+120.000 m^3/d	2018: +60.000 m^3/d 2024: +60.000 m^3/d	-	5-15 years 5-15 years	250 million
Moamba Major Dam and WTP	+450.000 m^3/d	2030: +140.000 m^3/d	-	10-30 years	766 million
Desalination groundwater	-	+100.000 m^3/d	-	8-20 years	150 million
Desalination seawater	-	+100.000 m^3/d	-	8-20 years	200 million
MAR	- 60.000 m^3/d	-	-	-	Unknown.
Decrease NRW in current network (-10%) to 35%	-	-	+20.000 m^3/d	2-5 years	10 million
Decrease NRW in current network (-20%) to 25%	-	-	+20.000 m^3/d	2-5 years	30 million
Decrease NRW in SSIPs networks (-10%)			+10.000 m^3/d	1-3 years	10 million
Limit non-essential DW use (-5%)	-	-	- 7.850 m^3/d	1-2 years	Policy action
Rehabilitate current network and WWTP Infulene	+15.000 m^3/d (+10%)	-	-	-	50 million
Water-fit-for-use: additional treatment of water at Infulene	- - -	+4.000 m^3/d +10.000 m^3/d +25.000 m^3/d	- - -	1 year 1-3 years 2-6 years	4 million 8 million 20 million
Masterplan: drainage networks for WW and storm water	2030: +52% / +62% 2040: +100% *% of total water use*	- -	- -	- -	735 million 437 million
Masterplan: treatment of WW and FS to surface water quality	2030: +52% / +62% 2040: +38% (100%) *% of total water use*	- -	- -	- -	238 million 189 million
Water-fit-for-use: additional treatment MP effluent	- -	2030: +52% / +62% 2040: +38 (100%)	- -	11-30 years 5-15 years	70 million 50 million

Network expansion as external influence in DAPPs model

The abovementioned actions are available to decision makers in Greater Maputo and will impact the amount of water available. Besides these actions, as mentioned in Section 6.3.1, a network expansion project is taking place, that will deliver new connections at the end of 2018 and 2014. As explained these new networks are assumed to have significantly lower rates of NRW than the current system (25% NRW). In this analysis these expansion projects have been placed outside the scope of policy actions, and are put into the model as external influences. Their influence on the NRW of the FIPAG network will therefore be the same in each scenario and for every strategy.

7.4. Table of actions with benefits and cost

In Table 22 each action is scored on its costs and benefits. These are presented as impacts on DW, surface water, sanitation and GW quality, and the actual costs are listed. In the section 7.6 each strategy is quantified in the DAPPs model, and each strategy is scored using the impact assessment per action from Table 22. This will allow to compare the effectiveness of each strategy as well as to compare the impacts of each strategy. Below the table the scoring system and scoring systems are explained.

Table 22 Overview of the impacts of the actions (from chapter 6), the 'sell by year' and cost of each action.

Action	Impact				Sell by year		Cost
	Drinking water	*Surface water*	*Sanitation*	*GW quality*	*Scen 1*	*Scen 2*	*(million US$)*
Current situation: Pequenos Libombos and GW supply	-	-	o	-	2018	2018	
Corumana Dam and WTP	++	+	o	++	2027	2039	250
Moamba Major Dam and WTP	+++	+++	o	+++	2033	2053	766
Managed Aquifer Recharge (MAR)	o	- -	o	++	-	-	150
Desalination of seawater	++	- -	o	++	2032	2053	200
Desalination of groundwater	++	-	o	- -	2032	2053	Unknown.
Decrease NRW in current network FIPAG (-10%)	+	o	o	+	2021	2026	10
Decrease NRW in current network FIPAG (-20%)	+	o	o	+	2022	2028	30
Decrease NRW in SSIPs networks (-10%)	+	o	o	+	2020	2023	10
Limit non-essential DW use (-5%)	+	o	o	o	2020	2024	0[16]
Rehabilitate current network and WWTP Infulene	o	+[17]	+	+	-	-	50
Water-fit-for-use: additional treatment of water at Infulene	+	-[17]	o	o	2021	2027	20
Masterplan: drainage networks for WW and storm water	o	o	+++ ++	+	-	-	P1: 735 P2: 437
Masterplan: treatment of WW and FS to surface water quality	o	+++[17] ++	++ +	o	-	-	P1: 238 P2: 189
Water-fit-for-use: additional treatment MP effluent	+++ ++	- - - - -	o o	+++ ++	-	-	P1: 70 P2: 50

- - = Strong negative effect, - = negative effect, **o** = no significant effect, **+** = positive effect, **+ +** = strong positive effect.

[16] This is a policy action, that will not require investments but political dedication.

[17] This surface water is available as effluent of the WWTPs and not yet available as a resources for the production facilities of FIPAG. Hence in the model it is not included as surface water before further treatment and supply facilities are also available.

Drinking water, this impacts illustrates the amount of drinking water that become available as a consequence of this action. A + or – equals 0-50.000 m^3/d of additional DW supply available or lost, as is the case in the current situation, where DW supply is decreasing because of limited surface water or GW sources that become to saline.
Surface water, this impact indicator shows the amount of additional surface water that becomes available or that is lost because of this action. Like the DW the indicator is scored with a + or – equals 0-50.000 m^3/d.
Sanitation, this impact indicator is more complex than the former, the improvement of sanitation includes the construction of WW infrastructure and FSM systems, but also WWTPs and FS treatment plants. The + or – equal an estimated treatment of 0-50.000 m^3/d of WW or FS.
GW quality is measured by the amount of GW that is extracted from GW resources, the scores + or – represent 0-50.000 m^3/d of less (+, positive) or more (-, negative) necessary extraction.
Sell-by-date indicates until what year the action would by a sufficient solution if taken in 2018 (although this is not possible in practise for each action). Cost, represent simply the cost of each action.

7.5. Three strategies towards a sustainable freshwater supply

Out of these actions three strategies have been created based upon; the current attitudes to DW supply in Greater Maputo, completed with two alternative means of creating a sustainable freshwater supply that have been identified in the means-end analysis in Chapter 4.1 (network improvement and innovative supply). First strategy is a traditional approach, similar to the current approach in Greater Maputo, that combines the construction of large dams with the additional of a potential desalination plant. Second, an approach of system improvement that aims to minimize waste from the network and postpone necessary investment in traditional supply capacity. The third strategy is an innovative approach that combines system improvements with water reclamation.

Strategy 1: Traditional approach in freshwater supply

The traditional strategy is a sequence of three actions all focussed solely on the creation of more DW supply; Corumana Dam, Moamba Major Dam and a desalination plant in the further future.

Short/medium-term - Corumana Dam and Moamba Major: Future expansion is aimed at the construction of two new dams (Corumana and Moamba Major), creating a large water supply capacity. Both are located at large distance from Greater Maputo, hence costly transportation by pipeline is necessary to enable water supply.

Long term - Desalination of groundwater/seawater: Desalination is considered technologically advanced and both a financially and environmentally costly approach. Therefore, in the traditional approach it is considered a longer term solutions that is chosen after the both Corumana and Moamba have been constructed.

Sequence of actions:

- Corumana Dam and WTPs
- Moamba Major Dam and WTP
- Desalination of groundwater or seawater

Strategy 2: Traditional approach with improvement to the current system

The traditional approach can also be combined with extensive focus on improving the existing supply networks and minimizing unnecessary uses of water. This could push the necessity of the construction of Moamba Major or a desalination plant further to the future.

Short/medium-term - Corumana Dam and limiting DW waste: First the Corumana dam is constructed and the amount of non-essential DW used is minimized. Additionally, network improvement to the FIPAG network are conducted as SSIPs are traditionally perceived as replaceable on the longer term.

Long term - Moamba Major: In the further future Moamba Major is still the solution. However, it could be necessary later and sufficient for a longer period of time.

Sequence of actions:

- Limit non-essential DW use (-5%)
- Decrease NRW in current network (-10%)
- Corumana Dam + WTP
- Decrease NRW in current network (-20%)
- Moamba Major Dam + WTP

Strategy 3: Innovative approach: combine demand management with water reclamation and reuse

The strategy combines the network improvements and water savings to postpone the construction of the Corumana Dam and includes after 2030 the possibility of reusing wastewater and storm water collected in a city wide drainage network.

Short term - Increasing network and water use efficiency: This approach starts pro-actively with limiting losses in the system and non-essential water use, as the current situation demands direct improvement actions.

Medium term - Corumana Dam and reduce NRW: As the first steps are taken Corumana is still being advanced and it will function as a medium term solution that increases the supply capacity. However, Corumana is postponed as far to the future as possible. After and during the construction of Corumana focus is shifted to further limiting NRW and creating innovative water resources in the form of conducting the first phase of the masterplan creating a citywide drainage network.

Long term - Drainage and WWTPs: In this approach from the Masterplan for drainage and sanitation, the drainage network is constructed (harvesting storm water and wastewater). After this treatment facilities are created to enable reclamation of the collected water and finally treat the water to fit-for-use quality.

Sequence of actions:

- Limit non-essential DW use (-5%)
- Decrease NRW in current network (-10%)
- Decrease SSIPs NRW (-10%)
- Corumana Dam + WTP (only if necessary)
- Decrease NRW in current network (-20%)
- Masterplan: Drainage network for WW and storm water
- Masterplan: Treatment WW and FS to surface water quality
- Water-fit-for-use: additional treatment MP effluent
    - Infulene: reclaim 10% of DW used
    - MP Phase 1: reclaim 62% (additional +52%) of DW used
    - MP Phase 1: reclaim 100% (additional +38%) of DW used

7.6. Dynamic Adaptive Policy Pathways

In this section the strategies as introduced are presented in a diagram of dynamic adaptive policy pathways. In this diagram only the viable paths are presented, to illustrate the different choices between the three strategies. In the Appendix H a DAPPs diagram is presented with all action, including viable and less likely paths.

7.6.1. DAPPs scenario 1: Rapid climate change, population growth and economic growth

In Figure 16 the DAPPS diagram for scenario 1 is presented. For each strategy a diagram is presented, that follows from the model indicating the performance of the specific strategy FIPAG DW use and groundwater extraction. In this scenario DW use is increasing quickly so solutions and actions taken have sell-by dates on relative short term. The three scenarios are presented as dotted lines in Figure 16.

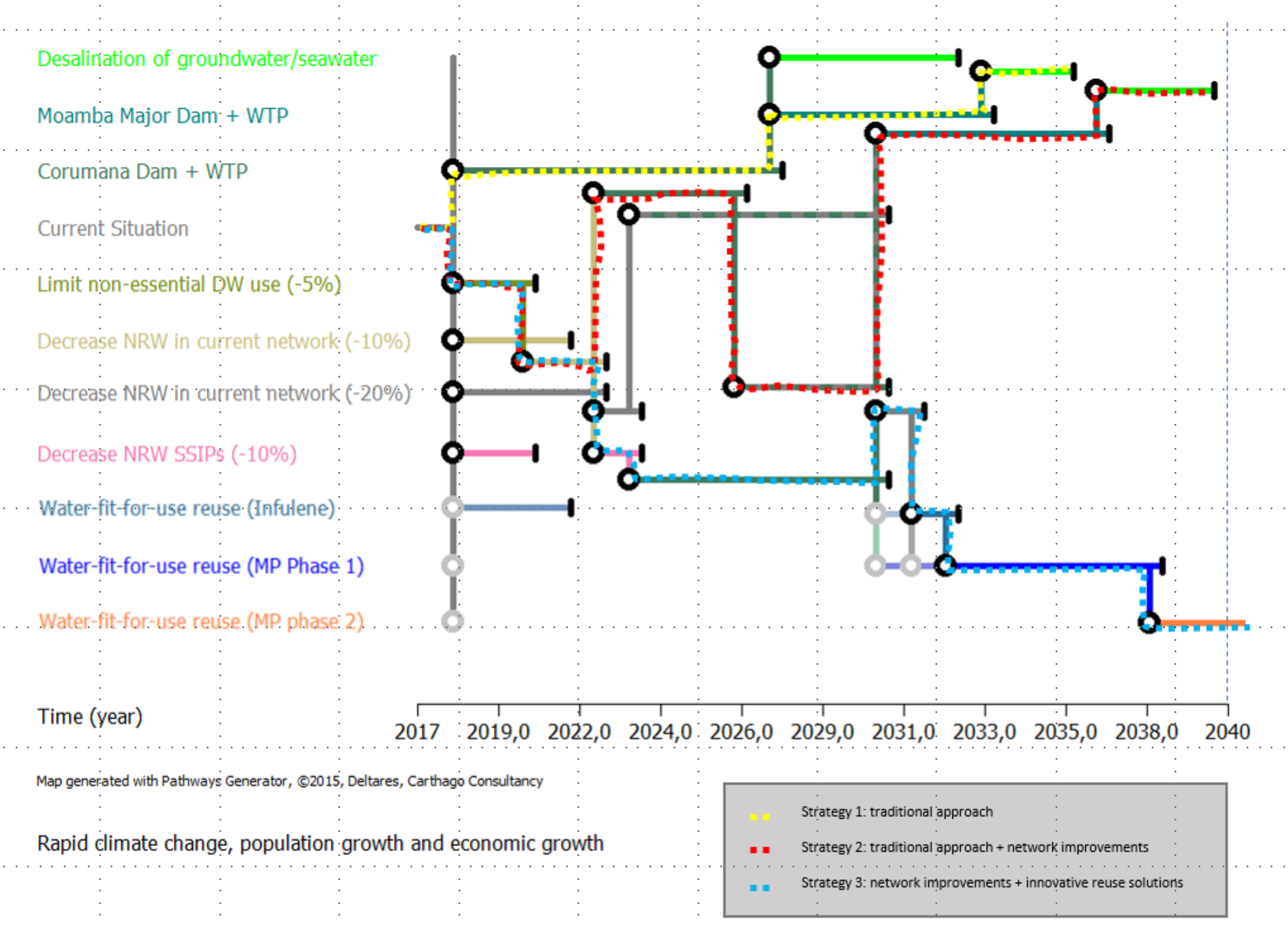


Figure 16 DAPPs, scenario 1: Rapid climate change, population growth and economic growth.

Strategy 1: Traditional approach

In the traditional approach the Corumana dam is the first action, it will deliver additional water supply from 2019 and 2025. As visible in Figure 17 the amount of groundwater extracted will exceed the maximum of 100.000 m^3/d in 2018 and between 2023-2024. However, as Corumana Dam and the WTPs have a scheduled planning accepting these violations are a part of this strategy.

The next action is the construction of Moamba Major dam and WTPs (Moamba Major), these are not expected to be finished before 2030. However, as visible in both the pathways diagram (Figure 16) and in the model results (Figure 17) the Corumana dam is only an acceptable solution until 2027. By only taking Moamba Major as an action this strategy needs to accept another violation of the maximum amount of groundwater extracted, in the period of 2027-2029.

As Moamba Major is delivered late compared to the volume of DW needed and demand is projected to keep rising the next action is demanded quickly after the construction of Moamba Major. By 2032 the planned desalination plants are needed to keep groundwater extraction below the desired threshold, and it will only be sufficient until 2035. This strategy does not include enough actions to deliver sufficient results until the defined timeline 2040. However, the complete pathways diagram in Appendix H illustrates that by using the DAPPS approach will present decision makers with several ways to improve this strategy.

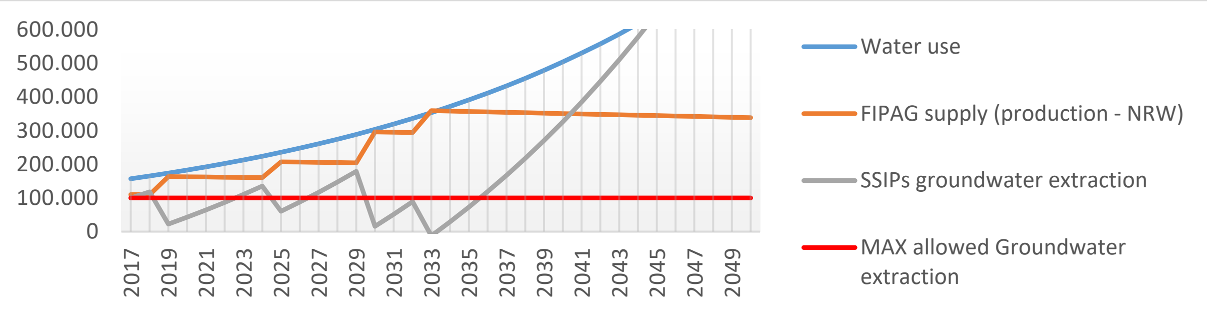


Figure 17 Model results for strategy 1 with Scenario 1.

In the following Table 23 the impacts and cost of this strategy are presented, along with reference to the amount of years that this strategy violates the maximum amount of GW extraction.

Table 23 Table of impacts and costs for strategy 1 in scenario 1

Strategy 1	Impact				Years in violation of max GW	Cost *(million US$)*
	Drinking water	*Surface water*	*Sanitation*	*GW quality*		
Corumana Dam and WTP	++	+	o	++	2018 2023-2024	250
Moamba Major Dam and WTP	+++	++++	o	+++	2027-2029	766
Desalination of seawater	++	- -	o	++	2035-2040	200
Strategy 1 total	+++++ ++	+++	o	+++++ ++	6 years + last 5 years	1.216

Strategy 2: Traditional approach with improvement to the current system

In the second strategy additional smaller actions are included to improve the current system (focussing only on FIPAG's network). These actions make this approach more flexible and should allow to minimize the number of years with a violation of the threshold for GW extraction.

The first action is limiting the amount of DW used for non-essential purposes. As the result of this is a 5% decrease in DW use (close to the annual growth), this solutions is sufficient for 1 year. Instead of assuming that the Corumana will be ready by 2019, this strategy focusses on decreasing the NRW in the FIPAG system by 10% first, postponing the need for Corumana until 2022, and the second WTP at Corumana in 2027 after improving the network efficiency by another 10% in 2026. Because of the improvements in the network efficiency Corumana will be sufficient until 2030, the subsequent construction of Moamba Major (in 2031, one year of violation)) will be sufficient until 2036. Constructing a desalination plant like in strategy 1, will create a sufficient situation until 2039.

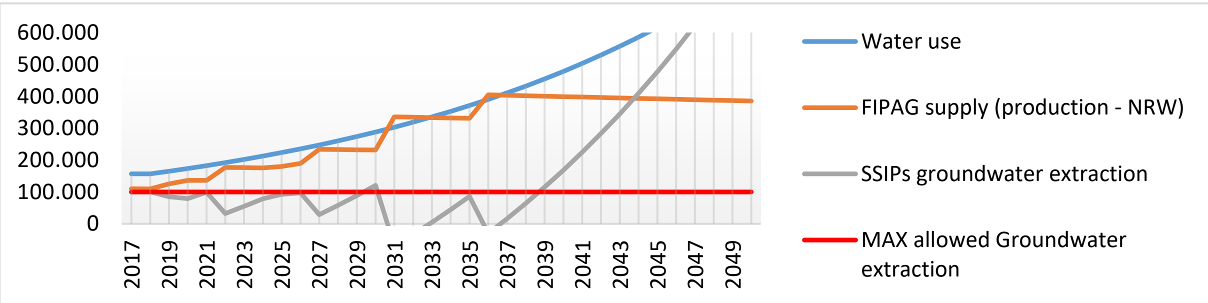


Figure 18 Model results for strategy 2 with Scenario 1.

In the following Table 22 the impacts and cost of this strategy are presented, along with reference to the amount of years that this strategy violates the maximum amount of GW extraction.

Table 24 Table of impacts and costs for strategy 2 in scenario 1

Strategy 2	Impact				Years in violation of max GW	Cost *(million US$)*
	Drinking water	*Surface water*	*Sanitation*	*GW quality*		
Limit non-essential DW use (-5%)	+	o	o	o	o	Policy.
Decrease NRW in current network FIPAG (-10%)	+	o	o	+	o	10
Corumana Dam and WTP	++	+	o	++	o	250
Decrease NRW in current network FIPAG (-20%)	+	o	o	+	o	30
Moamba Major Dam and WTP	+++	+++	o	+++	2031	766
Desalination of seawater	++	- -	o	++	2039-2040	200
Strategy 2 total	+++++ +++++	++	o	+++++ ++++++	1 years + last 2 years	1.256

Strategy 3: Innovative approach: combine demand management with water reclamation

This strategy starts similar to strategy 2, with the limiting of non-essential DW use and the improvement of the current FIPAG network, this is sufficient until 2022. To postpone the construction of Corumana further the action of decreasing the NRW of SSIPs is taken, creating a sufficient situation until 2023. Corumana is constructed in 2023 and the second WTP in 2027, after which the FIPAG network is improved further (NRW to 25%) in 2030 so that new action is necessary in 2031.

With these actions the DW production capacity has been made sufficient until after 2030, when the Phase 1 of the masterplan can be finished, enabling the execution of WW reclamation actions. First a water-fit-for-use is created at Infulene, creating a source of water supply equal to around 10% of the current water use (+/-30.000 m^3/d in 2031). This is a sufficient solution for an additional year, after which fit-for-use reclamation will have to be constructed at multiple other locations in Greater Maputo. Following the masterplan Phase 1 this will create a DW source of an additional 52% of the current DW use in 2032 (+/- 165.000 m^3/d), it will be a sufficient solution until 2038, when the Masterplan phase 2 has almost been finished. At that moment the remaining 38% of wastewater can be reclaimed as water-fit-for-use, an additional capacity of around 150.000 m^3/d could be created in and around Greater Maputo. This action will be sufficient until 2042, however by that time the DW use has increased strongly, this will also increase the amount of water available for reclamation at for example Infulene (this increase in not included in this analysis).

This strategy shows that in scenario 1, a combination of network improvement, Corumana and WW treatment can be a sufficient solution until at least 2040.

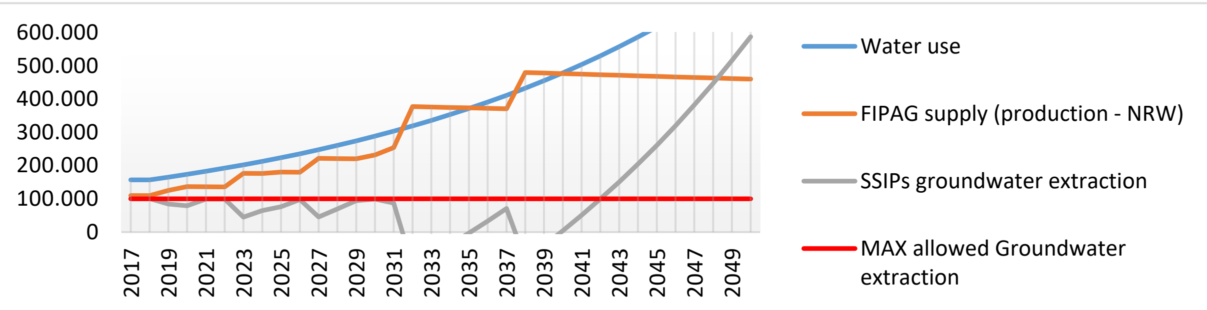


Figure 19 Model results for strategy 3 with Scenario 1.

In this strategy there is a logical follow-up action after the 2038, conducting the MP phase 2. However this is an expensive action and it would be taken around the year that strategy 1 and 2 would accept a violation of the GW extraction threshold. Therefore in order to enable a fair comparison of all strategies cost and benefits, the MP phase 2 and the water-fit-for-use action are presented within brackets, to show the impacts that are sufficient until 2038 and the cost and impacts for a solution that will suffice longer.

Table 25 Table of impacts and costs for strategy 3 in scenario 1

Strategy 3	Impact				Years in violation of max GW	Cost *(million US$)*
	Drinking water	*Surface water*	*Sanitation*	*GW quality*		
Limit non-essential DW use (-5%)	+	o	o	o	o	Policy.
Decrease NRW in current network FIPAG (-10%)	+	o	o	+	o	10
Decrease NRW in SSIPs networks (-10%)	+	o	o	+	o	10
Corumana Dam and WTP	++	+	o	++	o	250
Decrease NRW in current network FIPAG (-20%)	+	o	o	+	o	30
Rehabilitate current network and WWTP Infulene	o	+	+	+	o	50
Water-fit-for-use: additional treatment of water at Infulene	+	-	o	o	o	20
Masterplan: drainage network for WW and storm water	o	o	+++ (++)	+	o	P1: 735 (P2: 437)
Masterplan: treatment WW and FS to surface water quality	o	+++ (++)	++ (+)	o	o	P1: 238 (P2: 189)
Water-fit-for-use: additional treatment MP effluent	+++ (++)	- - - (- -)	o	+++ (++)	o (2038-2040)	P1: 70 (P2: 50)
Strategy 3 total	++++++ ++++(++)	+	+++++ +(+++)	++++++ ++++(++)	last 3 years (0 years)	1.413 (2.089)

7.6.2. DAPPs scenario 2: Slow climate change, population growth and economic growth

In Figure 19 the DAPPs diagram for scenario 2 is presented. Scenario 2 contains slow development of the external trends, the effect is that sell-by dates for the actions lay further in the future, more time is available to take actions. In the same Figure 19 only the viable paths within the three strategies are presented.

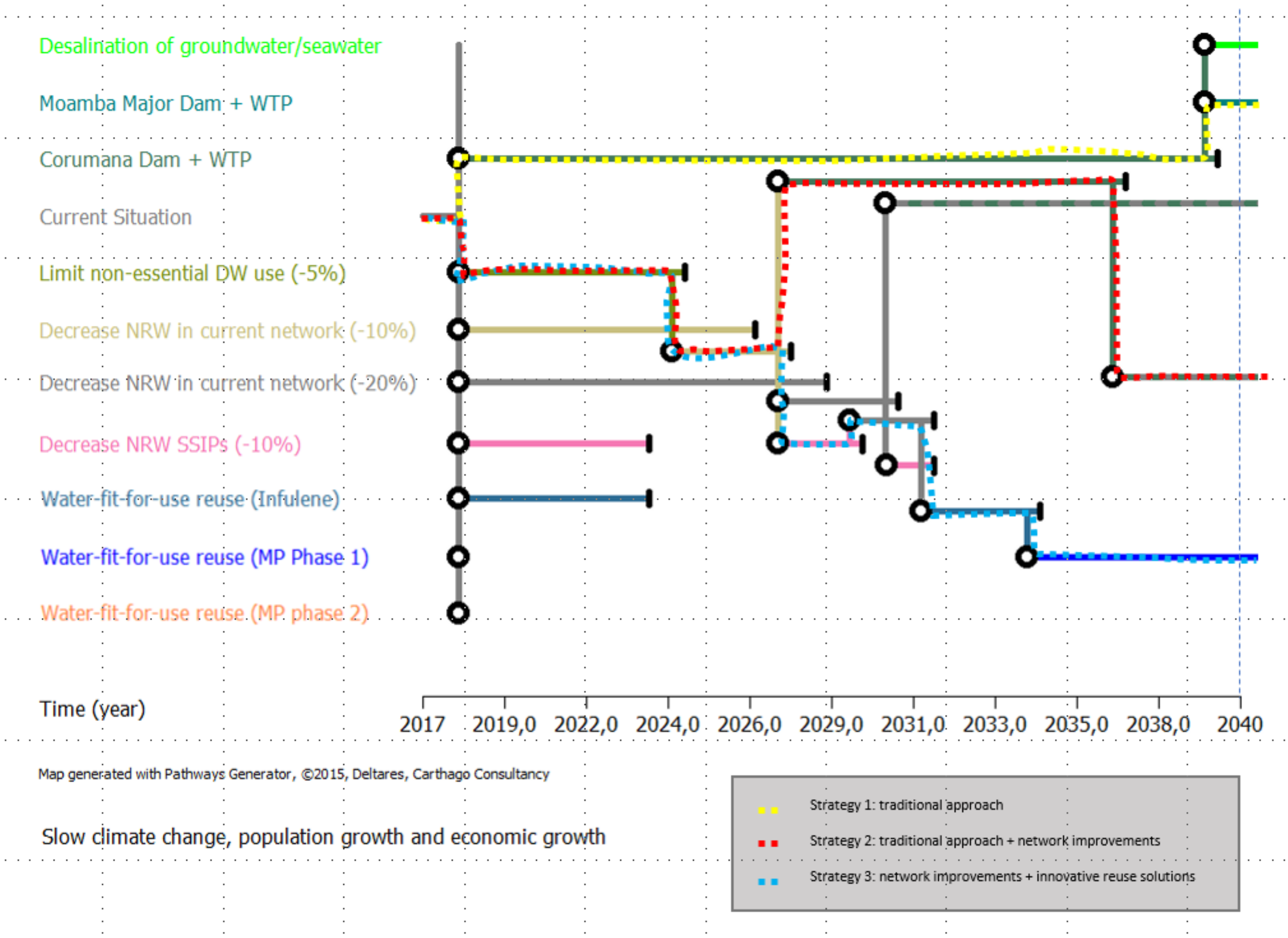


Figure 20 DAPPs, scenario 2: Slow climate change, population growth and economic growth.

Strategy 1: Traditional approach

The traditional approach in scenario 2 is similar to the actions taken in scenario 1. In 2019 and 2025 the Corumana plants are delivered creating sufficient supply until 2031 when Moamba Major scheduled to be available. In this scenario the construction of Moamba Major could even been postponed until 2039 (as is visible in the Figure 20). In the following Figure 21 the actions as scheduled in reality are included, Table 26 shows impacts and costs.

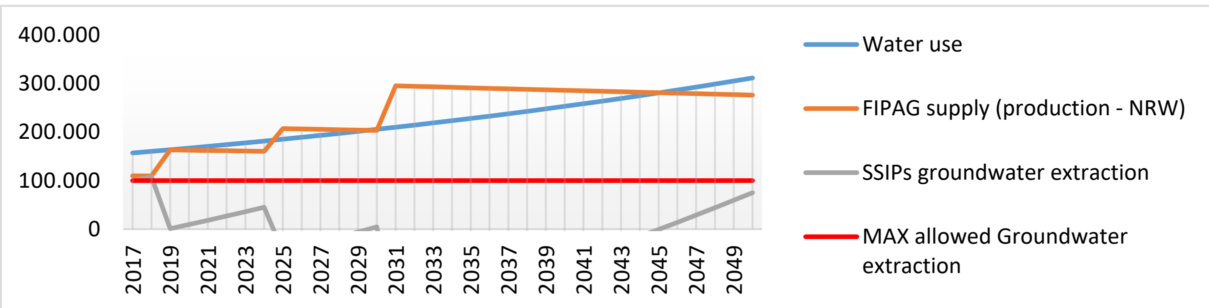


Figure 21 Model results for strategy 1 with Scenario 2.

Table 26 Table of impacts and costs for strategy 1 in scenario 2

Strategy 1 in scenario 2	Impact				Years in violation of max GW	Cost *(million US$)*
	Drinking water	*Surface water*	*Sanitation*	*GW quality*		
Corumana Dam and WTP	++	+	o	++	o	250
Moamba Major Dam and WTP	+++	++++	o	+++	o	766
Strategy 1 total	+++++	+++++	o	+++++	0 years	1.016

Strategy 2: Traditional approach with improvement to the current system

In scenario 2 strategy 2, limiting non-essential DW use and decreasing NRW (-10%) will postpone the need for Corumana until 2028 (first WTP) and 2036/2038 (second WTP) in combination with and additional decrease in NRW in FIPAG network (-20%). Corumana and the efficiency gains will allow to postpone the construction of a Moamba Major until 2046.

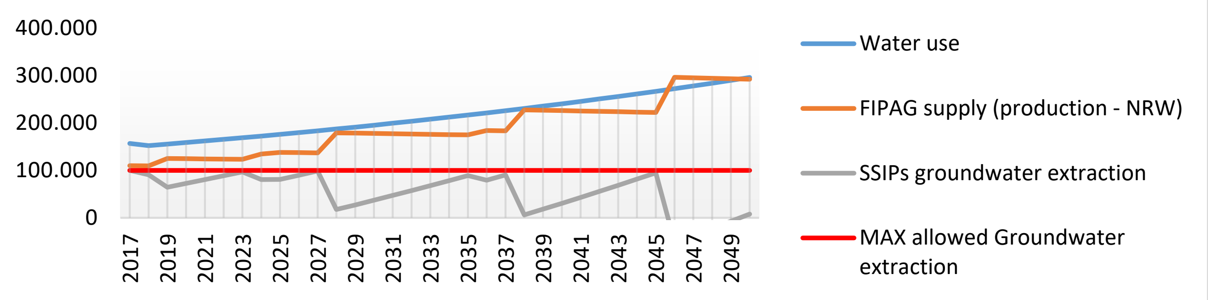


Figure 22 Model results for strategy 2 with Scenario 2.

In Table 27 the cost and impacts of Moamba Major are not taken into account as they have been postponed until after 2040, which is outside of the timeframe (2040).

Table 27 Table of impacts and costs for strategy 2 in scenario 2

Strategy 2 in scenario 2	Impact				Years in violation of max GW	Cost *(million US$)*
	Drinking water	*Surface water*	*Sanitation*	*GW quality*		
Limit non-essential DW use (-5%)	+	o	o	o	o	Policy.
Decrease NRW in current network FIPAG (-10%)	+	o	o	+	o	10
Corumana Dam and WTP	++	+	o	++	o	250
Decrease NRW in current network FIPAG (-20%)	+	o	o	+	o	30
Moamba Major Dam and WTP	(+++)	(+++)	(o)	(+++)	(o)	(766)
Strategy 2 total	+++++	++	0	+++	0 years	290

Strategy 3: Innovative approach: combine demand management with water reclamation

The aim of strategy 3 in scenario 2 is to try to postpone the necessity of constructing Corumana until after 2030, which would allow fulfilling the demand for additional water by means of water reclamation. Limiting the amount of non-essential DW used and decreasing the amount of NRW in both the FIPAG system (-20%) and in the SSIPs networks (-10%) enables postponing Corumana until after 2030. In 2031 water reclamation as water-fit-for-use at Infulene could create an additional supply of 10% of the DW use, around 20.000 m^3/d. After that in 2034 additional production capacity would be required, as the Masterplan Phase 1 would be completed by then, additional fit-for-use supply capacity of +56% (+/-120.000 m^3/d) should be possible by then. That would be a sufficient solution until 2048, afterwards the Phase 2 of the Masterplan could long be completed to further allow water reclamation.

This strategy shows that in scenario 2, a combination of network improvement and WW treatment could avoid the necessity for constructing Corumana and still be a sufficient solution until far beyond 2040.

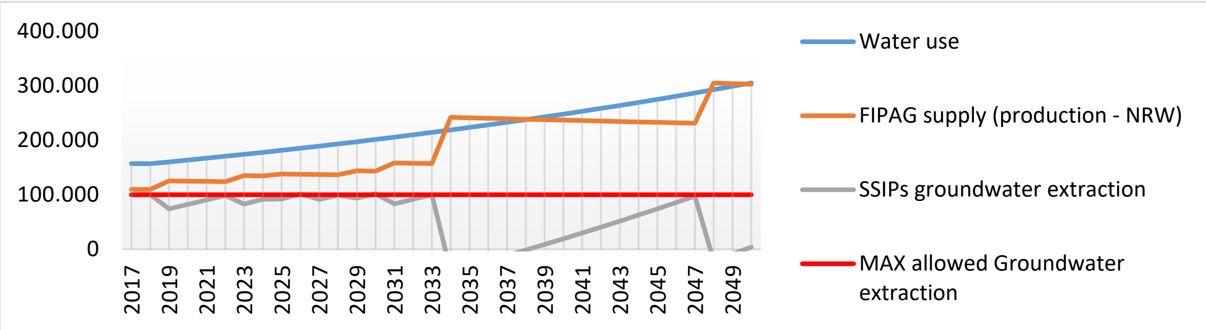


Figure 23 Model results for strategy 3 with Scenario 2.

In Table 28 it becomes clear that in scenario 2 the cost of strategy 3 are still quite high compared to the other strategies. However, it is illustrated that the construction of Corumana or Moamba Major are not vital in creating a sustainable freshwater supply for Greater Maputo, especially in case of slow development of external influences.

Table 28 Table of impacts and costs for strategy 3 in scenario 2

Strategy 3 in scenario 2	Impact				Years in violation of max GW	Cost *(million US$)*
	Drinking water	*Surface water*	*Sanitation*	*GW quality*		
Limit non-essential DW use (-5%)	+	o	o	o	o	Policy.
Decrease NRW in current network FIPAG (-10%)	+	o	o	+	o	10
Decrease NRW in SSIPs networks (-10%)	+	o	o	+	o	10
Decrease NRW in current network FIPAG (-20%)	+	o	o	+	o	30
Rehabilitate current network and WWTP Infulene	o	+	+	+	o	50
Water-fit-for-use: additional treatment of water at Infulene	+	-	o	o	o	20
Masterplan: drainage network for WW and storm water	o	o	+++ (++)	+	o	P1: 735 (P2: 437)
Masterplan: treatment WW and FS to surface water quality	o	+++ (++)	++ (+)	o	o	P1: 238 (P2: 189)
Water-fit-for-use: additional treatment MP effluent	+++ (++)	- - - (- -)	o	+++ (++)	o	P1: 70 (P2: 50)
Strategy 3 total	+++++ +++	o	+++++ +	+++++ +++	0 years	1.163

8. Discussion and conclusions

In this chapter findings from the DAPPs analysis are discussed, next conclusions are drawn by answering both the sub-research questions and the main research question. After the conclusion, notice is given to the general limitations about this research.

8.1. Discussion of findings from DAPPs analysis

Findings of Scenario 1

Strategy 1, the traditional approach does not meet the requirements for the extraction of GW during almost half the years until 2040, nor does it create an acceptable future situation until 2040. This approach is focussed solely on DW production and appears similar to what actors in Greater Maputo are expecting to happen over the coming years. This research modelling shows that with rapid developments, additional action is required to meet this the growing demand for DW.

Strategy 2, improving the traditional approach with actions that decrease the NRW in the FIPAG network proves to be an approach that does meet the requirements of limiting GW extraction over the timeframe until 2038. However, this strategy shows that combining improvements of the FIPAG network with additional resources as Corumana, Moamba Major and desalination still does not offer much guarantees for 2040, as in this scenario of rapid developments, the GW extraction threshold is violated during 3 years.

Strategy 3, shows that by taking additional actions, it is possible to postpone the construction of Corumana WTPs by 4-5 years and the effectiveness of Corumana could be prolonged beyond 2030. This strategy also shows that the construction of WW and storm water networks from Phase 1 of the Masterplan, are expensive, but could very well save the effort and cost of constructing the Moamba Major dam and WTPs. Although strategy 3 is more expensive than the other strategies, it will create a longer term sufficient DW capacity and it will have the huge additional benefit of improved sanitation in Greater Maputo (with over 62% of the Masterplan in place).

Table 29 Summery of Impacts and cost of the strategies in scenario 1

		Impact				Years in violation of max GW	Cost *(million US$)*
		Drinking water	*Surface water*	*Sanitation*	*GW quality*		
Scenario 1	Strategy 1	+++++ ++	+++	o	+++++ ++	6 years + last 5 years	1.216
	Strategy 2	+++++ +++++	++	o	+++++ ++++++	1 years + last 2 years	1.256
	Strategy 3	++++++ ++++(++)	+	+++++ +++(+)	++++++ ++++(++)	last 3 years (0 years)	1.413 (2.089)

Findings of Scenario 2

Strategy 1, shows that with slow population growth and economic development the traditional approach is sufficient beyond 2040. However, even without desalination, the costs of this strategy are still high.

Strategy 2, improving the traditional strategy with network improvement actions would make it possible to postpone the necessity of Moamba Major beyond 2040) in scenario 2, with significant cost savings. Within this scenario alternative routes are possible depending on actual actions available, but it illustrates the potential of combining several types of actions.

Strategy 3, shows that in case of slow developments, upgrading the supply networks first will allow to postpone construction of new supply capacity until after 2030, making it possible to replace both Moamba Major and Corumana for a WW and storm water reclamation solution. The combined cost of these actions show that water reclamation and fit-for-use reuse are expensive solutions, even when new dams are not necessary on short term. Innovative solutions become economically viable when DW use is increasing quickly and alternatives become more expensive as well. Replacing Moamba Major and desalination plants with WW reclamation proves to be a better option (from a financial perspective) than replacing Corumana.

Table 30 Summery of Impacts and cost of the strategies in scenario 2

		Impact				Years in violation of max GW	Cost *(million US$)*
		Drinking water	*Surface water*	*Sanitation*	*GW quality*		
Scenario 2	Strategy 1	+++++	+++++	o	+++++	0 years	1.016
	Strategy 2	+++++	++	0	+++	0 years	290
	Strategy 3	+++++ +++	o	+++++ +	+++++ +++	0 years	1.163

Discussion the value of this DAPPs analysis for the case of Greater Maputo

The DAPPs have shown to be a useful tool to compare the future sustainability of three solutions strategies. An additional advantage of DAPPs in practise is that it allows visualising the multitude of future opportunities. This makes them specifically suitable to bring together groups of decision makers, that are active in the system and have different roles, capacities and interests. An added value of DAPPs is that it can enable the sharing of information and interests, to find pathways to a sustainable future combining the capacities of various decision makers. The DAPPs analysis conducted in this report brings together the challenges and possible actions in the sanitation and DW sector. It is a testcase for the applicability of DAPPs in this sector in Greater Maputo. As a results of this analysis it is found that DAPPs can be useful and that it is possible to apply DAPPs for the case of sustainable freshwater supply and sanitation service in Greater Maputo. However, as this research does not contain an assessment of various methods applicable for a similar analysis, judgement on whether this is the best methodology is not possible..

Another important notion to understand the potential value of DAPPs analysis is that the construction of such model is data dependent and author specific: the information used for the cost and benefits of solutions could be interpreted in many different ways, including for example yearly cost of solutions or the time value of money. Also the assumption made for this DAPPs model could vary significantly between different researchers. That means that the outcomes of this research have not yet been tested on robustness to changing of any of these assumptions or interpretations.

For this research DAPPs where selected as a tool to deal the with longer term flexible planning of solutions in a context of high uncertainty. DAPPs are suited for exactly this kind of environment. The current situation in water and sanitation sector of Greater Maputo complicates the application of the DAPPs. DAPPs are normally used in a situation where the current situation is acceptable and it is possible to determine an unacceptable future that the policy makers try to prevent from happening. In Greater Maputo the current situation in sanitation is far from acceptable and immediate action is needed for an acceptable situation. Starting from 2017 every year requires action, this is contradictory to the DAPPs approach of multiple solution pathways with various years that require action. However, from the perspective of the shared denominator between sanitation and water sector, the available water, it is unlikely that sanitation actions will be chosen as a short term solution. The actions in the sanitation sector create available water on a longer term, as short term sanitation action will deal mostly with direct challenges for sanitation and not focus on the large scale collection of water. The complexity of creating the DAPPs for Greater Maputo is that there are three areas of challenges to be dealt with, available water, sanitation services and groundwater quality. The consequence for this analysis is that applying the DAPPs results in sanitation being a side benefit to the creation of an additional water resource, while specific actions purely focussed on improving sanitation services are missing because they don't offer value for the creation of water supply.

In evaluating the strategies the cost benefit analysis is fragmented because strategies 1 and 2 have no value for sanitation and strategy 3 does. A consequence is that costs and benefits of each strategy are difficult to compare, depending strongly on the value assigned to sanitation. The findings from this approach are that water reclamation can contribute significantly to creating a sustainable freshwater supply. It is a viable option in terms of potential volumes of water and in terms of cost it is comparable to strategy 1 (with sole focus on additional supply). However, this DAPPs analysis is a comparison of different pathways towards a sustainable freshwater supply, potentially including sanitation actions, it is not a comparison of different pathways towards sustainable sanitation. The comparability of the strategies could be improved by including actions that only benefit sanitation services to strategies 1 and 2. That would enable a cost benefits analysis in which benefits and cost that are more comparable.

8.2. Conclusions

The sub- and the main-research questions will now be answered.

- *SRQ 1: What is the current situation for drinking water supply, water resources and sanitation services and what solutions have been proposed in the last decade?*

In DW supply the formal provider FIPAG is struggling to provide enough water to the households connected to its network, as surface water resource and DW supply capacity are limited. SSIPs provide DW produced from GW at significantly higher prices (1.5-2 times the normal price) to their clients. In the current situation there is a limited amount of DW supply available, as surface water is becoming increasingly scarce, a situation that is expected to deteriorate in the future considering climate change. Meanwhile a growing demand for DW is increasing the pressure on GW extraction as a source for DW. At the same rate over-extraction is reducing the quality of GW resources, particularly due to salt water intrusion and pollution (e.g. nitrate). Alongside this, the growing population has an increasing need for sanitation services that is not dealt with because of a lack of both budgets and organisational capacity at public and private actors in the sanitation sector. These developments have been known in the past decade, but short-term breakthrough improvements appears unlikely to happen.

As an answer to the challenges at stake, in the past decade the main response in sanitation has been privatisation, resulting in minor improvements in services. For the development of water resources and DW supply the most serious propositions have been the Corumana and Moamba Major dams, two solutions that will provide additional DW supply for Greater Maputo. As both of the proposed dams are located more than 90 km from Maputo, not only the construction itself, but also the supply networks will be very expensive. For the current supply networks, improvement project has been conducted for the FIPAG network and some minor projects with SSIPs have been proposed. However, as the general expectation is that Corumana and Moamba Major will serve the growing future water demand, these alternative solutions have not received much focus of actors in Greater Maputo.

- *SRQ 2: Why (or why not) have these proposed solutions been implemented?*

Implementation of the Corumana dam has been delayed for years, as the cost for the project where high and had to be financed by donors. The high NRW rates in the FIPAG network posed a challenge to attract foreign capital for the construction of supply solutions like Coruman and Moamba dam. As an FIPAG employee explained, "Try telling a foreign investor that 65% of the DW produced with this 250 million project will be lost as NRW". To tackle this, in the past decade reduction of the NRW rates in FIPAG network has been achieved. Another delaying influence for the projects implementation was the limited organisational capacity at FIPAG. A process of further professionalization over the past 15 years has made FIPAG able to bear the responsibility of managing projects like Corumana and Moamba Major to successful revenue. Currently implementation of Corumana is under way, but for Moamba Major construction has not been planned nor has financing of the project been secured. Even though Moamba Major is far for certain as a solution, local actors see it as the only serious possibility to serve the growing need for DW in Greater Maputo.

- *SRQ 3: What solutions have been proposed for the coming decades and which alternative solutions are possible towards creating sustainable sanitation services and freshwater supply?*

The solutions that have been proposed are aimed at creating additional DW supply, from short to long term they are Corumana, Moamba Major and desalination of seawater or GW. The creation of new DW supply is one of the essential elements in creating a sustainable freshwater supply for Greater Maputo. However, these supply solutions do not contribute to sanitation, nor do they improve the performance of supply networks.

For the sanitation services in Greater Maputo three proposed actions have been identified. One short-term solution, the rehabilitation of the current WW and drainage network, and the WWTP at Infulene. This solution will be the start in creating sustainable sanitation services (from a perspective of finance, health and environment), as it will cover a first part of Greater Maputo. However, the challenges in sanitation are far greater, two proposed solutions for the medium- and longer-term are the execution of the Masterplan for Drainage and Sanitation, constructing drainage networks as well as treatment plants to reclaim WW and FS at surface water quality. These solutions are not only essential in creating sustainable sanitation services for Greater Maputo, they will also result in a significant volume of surface water that becomes available to be further reclaimed and reused.

Consequentially, an alternative possible solution is fit-for-use water reclamation for industries. Providing water-fit-for-use reduces the amount of DW needed by these industries, and that DW in turn becomes available to supply households. However, all of these solutions accept that in the current system 45% of the water is lost as NRW. That means that any solutions (traditional or innovative) can be made significantly more financially profitable by reducing the NRW rates in the supply network. In terms of creating a sustainable freshwater supply, reducing NRW can increase the effectivity of these solutions. Another alternative solution is a policy action to limit non-essential DW use, by prohibiting certain types of water use or by raising public awareness about water scarcity.

- *SRQ 4: What strategies of (combined) solutions are possible towards sustainable freshwater supply and sanitation services for Greater Maputo?*

The analysis has shown that there are several solution strategies that can lead to a sustainable freshwater supply. However, for sustainable sanitation and freshwater supply for Greater Maputo the innovative approach is the best option. In order to deal with the significant growth in DW use, the improvement of the current supply networks has proven to be an unreplaceable solution in any strategy. This must be combined with the creation of dams at great distance or with the WW collection and reclamation as water-fit-for-use inside Greater Maputo. The most important notion is that with the objective the creating sustainable future situation, the actors should consider more than just new supply sources.

- *SRQ 5: How could the application of DAPPs help in reducing the uncertainty in the potential benefits of (combinations of) proposed and alternative solutions?*

The conducted DAPPs approach contains a (limited) quantification of the external influences of population growth, economic growth and climate change on the water and sanitation system in Greater Maputo. Additionally, in the DAPPS approach these external influences have been used to created two development scenarios, this provides a better understanding of the possible implications of the uncertainties about climate change, population and economic growth. The actual implications of population and economic growth can be that a proposed solution might only create sufficient DW supply for 3 years instead of more than 10 years as generally expected. The added value of using DAPPs is that they provide insight in the bandwidth of the impacts of uncertain external influences, combined with a flexible planning diagram that can be used to test different strategies to deal with these impacts.

- *SRQ 6: How could the application of DAPPs help to maximize the probability of implementation of these (alternative) solutions?*

The limited improvements in the water and sanitation sector appear to be related to the actors narrow view toward responsibilities and a lack of (cross-)sectoral leadership. The sector should start planning together with (cross)-sectoral timelines, to make clear who needs to take action on short term, so that long term solutions by others can be of maximum value. As this analysis has shown, it is probable that only creating new dams with donor support will not be enough for a sustainable future.

As this analysis has shown the application of DAPPs is data and assumptions dependent. Therefore both the successfulness and reliability of the approach depend on the open sharing of information from different actors. As a lack of information sharing and cooperation are problems in the current implementation of solutions in Greater Maputo, the application of DAPPs could bring actors together, require information sharing and increase the probability of implementing solutions in general. Specifically, applying DAPPS with actors active in drinking water and sanitation can potentially improve cross-sectoral interaction and create an overview that could incentive short-term actions for WW collection to create future reclamation opportunities. However, it is noted that the DAPPs approach is merely a tool that can help actors to visualise solutions strategies together. DAPPs as a tool is not a solution to the (underlying) problems causing limited cooperation or the lack of information. The actual added value of DAPPs has been subject of discussion in Section 8.1 and the limitations in Section 8.3.

Research question: How can the Dynamic Adaptive Policy Pathways approach be applied to characterize the challenges towards sustainable freshwater supply and sanitation services for Greater Maputo, and be exploited to quantitatively compare the potential paths to address these challenges?

The model underlying the DAPPs includes assumptions about the relations between GW quality and extraction for use, surface water and the supply of DW in the water sector, as well as the influence of the external factors climate change, population and economic growth in Greater Maputo. The DAPPs approach allows to bring freshwater and sanitations services together to their common denominator water (whether it is potable, polluted or reclaimed). Additionally requirements about the system are included in the DAPPs model, to prevent loss of GW quality, a maximum acceptable level of GW use and necessary extraction has been defined. With the addition of water supply network efficiency and the influence on the amount of DW that actually becomes available for use, the

DAPPs create an overview of the sector makes it possible to include a wide range of alternative action to improve the current situation.

Solutions for water or sanitation services have been scored for their cost or benefits in multiple impact criteria relevant in the system (DW supply, surface water, sanitation and GW quality). These scores and the DAPPs model together allow to compare different strategies quantitatively in their effectiveness to deal with the challenges towards sustainable freshwater supply and sanitation services in Greater Maputo. Specifically the DAPPs approach allows for testing and comparison of many alternative solution pathways within solution strategies. The different external development scenarios can be applied to tweak strategies to the need of (un)expected external influences. Additionally, this allows policymakers to determine a general development strategy that can be altered year-by-year to adapt to external developments as they have actually happened in reality.

8.3. Limitations

The following limitation are noted as important for assessing the values of the obtained results and conclusions.

Continuous development of external influences

In this model the external influences of climate change, economic growth and population growth are assumed to be constant percentage. In fact research has shown that the influence of climate on the amount of rainfall and the consequential river discharges varies strongly over cycles of years, making the expected amount of surface water increasingly hard to predict and existing resources increasingly unreliable. Similar notes have to be made for population and economic growth. Population growth has been steady over the past 10 years in Greater Maputo. However, longer before that the civil war has had significant contribution to migration into the region. Recent unrest in the centre provinces of Mozambique or neighbouring countries could very well lead to new increases or incidental migration in future years. The same goes for economic growth, which has been steady over the past years. However, political problems and difficulties with international donor organisations have the potential to significantly influence the economic growth from year to year in a donor dependent country like Mozambique.

Percental development of external influences

In this model percental increases are used as external influences on DW use and available surface water. On a longer term timeframe, as is used in this research (25-35 years), it is possible that those percentages will not be fair assumptions after 10 or 20 years. Hence, along with the uncertainty about external developments, the uncertainty about the effectiveness of actions will increase strongly as they are projected further in the future.

Side benefits of actions excluded from analysis

In this research the side benefit of both the Corumana and Moamba Major are excluded from the impacts/cost assessment. As noted in chapter 6, both dams have benefits for local agriculture, flood prevention and even power generation. However, it is noted that although these aspects are considered important, they are both too vaguely defined in development plans to incorporate in the analysis and to far outside of the research scope of this thesis. For the action that include benefits for sanitation and strategies that do not address the challenges in sanitation, the consequentially prevented or necessary cost for health care and other socio-economics cost of improved or lacking sanitation are excluded, as this analysis is focussed on including the common denominator, water.

Simplification of several relation between GW extraction and FIPAG DW supply

There appears to be a strong replaceability between both sources of DW. However the percentage is highly uncertain. Examples like hotels or businesses sending tanker-trucks to SSIPs to provide drinking water shows a strong relation, however it does not mean the additional water is provided via the SSIPs network, hence adding uncertainty about the percentage of NRW in SSIPs supply.

Limitations to cost: estimations, operational cost and time-value of money

It is noted that for the cost of the actions in this analysis only rough estimates of the investment cost of each action are included. This has the potential to improve the assessment of solutions that are expensive during operations. Also, the time value of money was excluded, cost made in 2018 or in 2040 are considered the same in this analysis.

Unreliable or contradictory information

Data and information from interviews used in this research could be unreliable in the sense that people have different interpretations of the situation. An example is the unsuccessful creation of a faecal sludge transfer station (FSTS), where arguments vary strongly from; it was ill-reasoned resistance against a harmless FSTS, versus; it was the obstruction of an undesired smell causing digester and FSTS). Another example are the different opinions on the limiting factors in the current capacity of drinking water supply, FIPAG representative argue that; it is the unreliability of energy supply form South Africa, versus; the limited surface water available is poorly management.

8.4. Recommendations for future research

The following recommendation for future research are made.

Explore the applying DAPPs in practise in Greater Maputo

It is recommended to explore the attitudes of different actors in water and sanitation sectors in Greater Maputo, to indicate whether they are interested in exploring the possibilities of the DAPPs approach in practice. It is noted that the DAPPs in this research are quite general and there are limitation to the reliability of the results. However, the approach could open the eyes of actors to increased cooperation, information sharing and even to considering alternative future solutions for their own organisation.

Comparison of DAPPs analysis to other pathways analyses

In this analysis the choice of applying the DAPPs has been based on a limited literature review. Hence a literature review of alternative possible methodologies could establish better whether this is in case the best approach to deal with the challenges at stake in Greater Maputo. As explained in the answers to the research question and in the limitations, DAPPs are data dependent and both the reliability and availability of data can be serious problems in Greater Maputo. An interesting topic for further research could be to determine if methodologies exist that suit the data availability as well as the challenges at stake in the water and sanitation sector in Greater Maputo.

Improvement to DAPPs

Comparability of strategies: The creation of strategies with cost and benefits that are more comparable on the several impact criteria, so that a comparison could lead to a more detailed recommended strategy within the possible pathways. To do this, a possibility could be to include alternative actions for the sanitation sector and include them as a baseline of actions to improve the sanitation in Greater Maputo. This presents decision makers the choice between actions that create networks for water reclamation (scores high on surface water availability) or actions that focus on creating additional FS disposal services (scores high on sanitation services).

Time value of money: In the current analysis no value is given to the actual year in which an investment is necessary. Including the time value of money means that with regard to interest rates and potential revenue on capital, an investment of 1 million in 2017 is more expensive than the an investment of 1 million five years later. Including this element could have the implication that postponing a solutions like Moamba Major would financially become more attractive if postponed, for example by implementing other smaller and cheaper solutions first.

Cost during operation of solutions: The cost for the implementation of a solution is one element. However, for a solution like desalination of seawater, the most important cost kick in during the operational phase, when the required amounts of energy encompass a large part of the final price of DW. Including the yearly operational cost for each action would improve the reliability of the cost comparison for the three strategies in this analysis.

Increasing capacity of solutions: The flexibility of the strategies researched in this analysis could be improved by including the ability to increase the capacity of individual DW supply or reclamation actions. For example, the Moamba Major Dam will create far more surface water capacity than the planned DW production and supply capacity. The same goes for reclamation actions, as the use of DW is expected to keep increasing, it is likely that the amount of water collected in a WW network will also increase over the years. That would mean that some years after the construction of a reclamation plant, more treatment capacity should be added to avoid polluted effluent and more water could be reclaimed as water-fit-for-use.

Recommended additional DAPPs analyses

DAPPs for sanitation: Conducting a separate DAPPs analysis for the sanitation sector in Greater Maputo. In which strategies for the development of the sanitation sector can be compared and adjusted to changing uncertain future developments in the sanitation sector. For example uncertainties like, the (dis)continued inhabitation of a certain area of Greater Maputo, the development of new business districts like Matola or development of areas with resorts and hotels like Costa del Sol. Many different development pathways or sequences could be possible within the execution of the Masterplan, but especially when considering alternative solutions or actions like water reclamation and reuse. Impact criteria for a sanitation DAPPs analysis could be, for example: number of inhabitants served, volume of WW/FS collected or possible revenues (social, e.g. health care or economic, e.g. business models like selling dried FS as fertiliser).

DAPPs with a focus on flexibility: Conduct the DAPPs analysis with a focus on the creation of robustness against unexpected future development. This DAPPs analysis uses constant developments for the external influences of climate change and population growth. It would be interesting the conduct research into different strategies with more sudden and unexpected developments included in the development of these influences. This could show the potential of DAPPs to deal with suddenly changing uncertain environments. As an example, it could provide decision makers with insight in which strategy would be best suited to deal with an immediate rise of population, or what would be most effective in dealing with a potential period of sever draught between 2025-2030.

References

Ahlers, R., Güida, V. P., Rusca, M., & Schwartz, K. (2012). Unleashing Entrepreneurs or Controlling Unruly Providers ? The Formalisation of Small-scale Water Providers in Greater Maputo, Mozambique, (November 2012), 37–41. http://doi.org/10.1080/00220388.2012.713467

AIAS Employee 1. (2016). *Interview AIAS Employee 1*. Maputo.

AIAS Employee 2. (2016). *Interview AIAS employee 2*. Maputo.

ARA-Sul. (2014). Water Allocation Models for the Umbeluzi River Basin, Mozambique, *31*(December), 66.

ARA-Sul Employee 1. (2015). *Interview ARA-Sul Employee*. Maputo.

Bäuerl, M.-M. (2015). *ASSESSMENT OF ATTITUDES AND PRACTISES REGARDING ONSITE SANITATION MANAGEMENT IN MAPUTO, MOZAMBIQUE*. University of Natural Resources and Life Sciences, Vienna.

Bhatt, J. (2014). Comparison of small-scale providers' and utility performance in urban water supply: The case of Maputo, Mozambique. *Water Policy*, *16*(1). http://doi.org/10.2166/wp.2013.083

Caltran, I. (2014). *Characterization of the central wastewater treatment plant of Maputo (Mozambique)*. Delft University of Technology.

CIA. (2015). CIA World Factbook. Retrieved May 12, 2016, from https://www.cia.gov/library/publications/the-world-factbook/geos/mz.html

Cooley, H., Ajami, N., & Heberger, M. (2013). *KEY ISSUES IN SEAWATER DESALINATION IN CALIFORNIA: Marine Impacts.* Retrieved from www.pacinst.org/publication/desal-marine-impacts

dos Santos Silva, T. (2014). *The discursive production of the urban waterscape - An insight into Maputo City , Mozambique*. UNESCO-IHE Institute for Water Education.

Dutch Sustainability Unit. (2015). *Climate Change Profile MOZAMBIQUE*.

ENGIDRO, HIDRA, & AQUAPOR. (2015a). EXECUTIVE SUMMARY - Sanitation and Drainage Master Plan for the Greater Maputo - SOLUTIONS IDENTIFICATION, (6).

ENGIDRO, HIDRA, & AQUAPOR. (2015b). *Institutional Development Studies Of Matola And Boane - Sanitation And Drainage Master Plan For The Greater Maputo Metropolitan Area*. Matola.

ENGIDRO, HIDRA, & AQUAPOR. (2015c). *PLANO DIRECTOR DE SANEAMENTO E DRENAGEM DA ÁREA METROPOLITANA DE MAPUTO*.

ENGIDRO, HIDRA, & AQUAPOR. (2015d). *Sanitation and Drainage Master Plan for the Greater Maputo - SOLUTIONS IDENTIFICATION*.

Enserink, B., Hermans, L., Kwakkel, J., Thissen, W., Koppenjan, J., & Bots, P. (2010). *Policy analysis of multi-actor systems*.

FIPAG. (2013). Environmental and Social Studies for Greater Maputo Water Supply Scheme - Executive Summary of the Environmental and Social Impact Assessment Final Report, (January).

FIPAG Employee 1. (2016). *Interview FIPAG Employee 1*. Maputo.

FIPAG Employee 2. (2016). *Interview FIPAG Employee 2*. Maputo.

Foster, S. S. . (2001). The interdependence of groundwater and urbanisation in rapidly developing cities. *Urban Water*, *3*(3), 185–192. http://doi.org/10.1016/S1462-0758(01)00043-7

Gell-Mann, M. (2002). What Is Complexity? In A. Q. Curzio & M. Fortis (Eds.), *Complexity and Industrial Clusters: Dynamics and Models in Theory and Practice* (pp. 13–24). Heidelberg: Physica-Verlag HD. http://doi.org/10.1007/978-3-642-50007-7_2

Haasnoot, M., Kwakkel, J. H., Walker, W. E., & ter Maat, J. (2013). Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. *Global Environmental Change*, *23*(2), 485–498. http://doi.org/10.1016/j.gloenvcha.2012.12.006

Haasnoot, M., van Deursen, W., Middelkoop, H., van Beek, E., & Wijermans, N. (2012). An integrated assessment Metamodel for developing adaption pathways for the Rhine Delta in the Netherlands. In R. Seppelt, A. A. Voinov, S. Lange, & D. Bankamp (Eds.), *International Environmental Modelling and Software Society (iEMSs)* (pp. 1743–1751). Retrieved from http://www.iemss.org/society/index.php/iemss-2012-proceedings

Hallegatte, S., Shah, A., & Lempert, R. (2012). Investment Decision Making Under Deep Uncertainty. *World Bank Group*. Retrieved from http://www-wds.worldbank.org/servlet/WDSContentServer/WDSP/IB/2013/01/09/000158349_20130109112237/Rendered/PDF/wps6193.pdf

Heylighen, F. (1999). The Growth of Structural and Functional Complexity During Evolution. *The Evolution of Complexity - The Violet Book of {`Einstein} Meets Magritte'*, 17–44. Retrieved from http://pespmc1.vub.ac.be/Papers/ComplexityGrowth.pdf

HYDROCONSEIL. (2008). *Improving water services in the periurban areas of Maputo, Mozambique: the role of independent providers*.

Hydroconseil, & WE Consult. (2011). *Sustainable Management of the Groundwater Quantitative and Qualitative Aspects*.

Jenkins, P. (2000a). City profile Maputo, *17*(3), 207–218.

Jenkins, P. (2000b). Environment and Urbanization management in Maputo. http://doi.org/10.1177/095624780001200110

Jenkins, P. (2001). Regularising "informality": turning the legitimate into legal? Land reform and emerging urban land markets in post-Socialist Mozambique. *Paper Prepared for the N-AERUS Workshop*, 1–14.

Jenkins, P. (2009). Xilunguine, Lourenço Marques, Maputo – structure and agency in urban form: past, present and future. In *African Perspectives 4: The African city centre (re-)sourced*.

Katz, D. (2015). Water use and economic growth: Reconsidering the Environmental Kuznets Curve relationship. *Journal of Cleaner Production*, *88*, 205–213. http://doi.org/10.1016/j.jclepro.2014.08.017

Kingdon, J. W. (1995). *Agendas, alternatives, and public policies (2nd Edition)*. *Policy* (Vol. 2). http://doi.org/10.2307/3323801

Kooy, M. (2014). Developing informality: The production of jakarta's Urban waterscape. *Water Alternatives*, *7*(1), 35–53.

Maliva, R., & Missimer, T. (2012). Managed aquifer recharge. In *Arid Lands Water Evaluation and Management* (pp. 559–630). Springer.

Matola Employee. (2016). *Interview Employee Municipality of Matola*. Matola.

Matola Inhabitant. (2016). *Interview Matola Inhabitant*. Matola.

Montibeller, G., & Belton, V. (2006). Causal maps and the evaluation of decision options - a review. *Journal of the Operational Research Society*, *57*(7), 779–791. http://doi.org/10.1057/palgrave.jors.2602214

Mwanza, D. (2015). *Serviço de Abastecimento de Água pelo Sector Privado*.

NEPAD. (2013). *Country Water Resource Profile Mozambique*.

Paulo, M., Rosário, C., & Tvedten, I. (2011). *" Xiculungo " Revisited Assessing the Implications of PARPA II in Maputo 2007-2010*.

Pitcher, M. A. (2006). Forgetting from Above and Memory from Below: Strategies of Legitimation and Struggle in Postsocialist Mozambique. *Africa*, *76*(1), 88–112. http://doi.org/10.2307/40026158

Republic of Mozambique. (2001). *ACTION PLAN FOR THE REDUCTION OF ABSOLUTE POVERTY (2001-2005)*

(PARPA).

Republic of Mozambique. (2005a). *Report on the Millennium Development Goals - Mozambique*.

Republic of Mozambique. (2005b). *REVIEW OF THE ECONOMIC AND SOCIAL PLAN OF 2004*.

Republic of Mozambique. (2006). *ACTION PLAN FOR THE REDUCTION OF ABSOLUTE POVERTY 2006-2009 (PARPA II)*.

Republic of Mozambique. (2011). *POVERTY REDUCTION ACTION PLAN (PARP) 2011-2014*.

Salim, I. C. (2016). *Assessing water and nutrients flows in the city of Maputo, Mozambique*.

SEED. (2010). *Formulation of an outline strategy for Maputo City citywide sanitation planning*.

Sousa, O. (2014a). Presentation: The Challenges of Implementing the Delegated Management Framework in Secondary Cities and Towns in Mozambique (pp. 1–11).

Sousa, O. (2014b). The Challenges of Implementing the Delegated Management Framework in Secondary Cities and Towns in Mozambique (p. 1).

SUWASA. (2010). REFORM WORK PLAN - Support for Sustainable Small Scale Maputo and Matola.

TAC Economics. (2016). MDG Track Mozambique, *2011–2016*.

Tauacale, F. (2002). Water resources of Mozambique " and the situation of the shared rivers." Nairobi Kenya.

The Republic of Mozambique the Republic of South Africa and the Kingdom of Swaziland. (2002). TRIPARTITE INTERIM AGREEMENT. Retrieved from http://www.dwaf.gov.za/Docs/Other/IncoMaputo/INCOMAPUTO_AGREEMENT29082002.pdf

The World Bank. (2013). *Greater Maputo Water Supply Expansion Project*. Retrieved from http://www.worldbank.org/projects/P125120/greater-maputo-water-supply-expansion-project?lang=en

UN. (2015). SDGs - Goal 6: Ensure access to water and sanitation for all. Retrieved October 1, 2016, from http://www.un.org/sustainabledevelopment/water-and-sanitation/

UN-HABITAT. (2008). *Global Atlas of Excreta, Wastewater Sludge, and Biosolids Management: Moving Forward the Sustainable and Welcome Uses of a Global Resource*. *Un-Habitat*. http://doi.org/10.2175/193864709793846402

UN-HABITAT. (2009). *Climate change assessment for Maputo, Mozambique: a summary.*

UNICEF, & WHO. (2015). 2015 Update and MDG Assessment - 25 years Progress on Sanitation and Drinking Water.

UNM, & FCD. (2015). *POST 2015 DEVELOPMENT AGENDA - NATIONAL CONSULTATION COUNTRY REPORT*.

van Esch, M. S., & van Ramshorst, J. G. V. (2014). *The sewer system of urban Maputo*.

ViaWater. (2017). Smart water meter reading, Mozambique. Retrieved February 15, 2017, from https://www.viawater.nl/projects/smart-water-meter-reading-mozambique

Walker, W. E., Haasnoot, M., & Kwakkel, J. H. (2013). Adapt or perish: A review of planning approaches for adaptation under deep uncertainty. *Sustainability (Switzerland)*, *5*(3), 955–979. http://doi.org/10.3390/su5030955

WaterAid. (2010). Mozambique: 2010-2015 Country Strategy, (July 2010).

WaterReuse Association. (2011). Seawater Desalination Power Consumption, 16.

WE Consult. (2014). Market Assessment of Faecal Sludge Emptying and Transport Services in Maputo, Mozambique.

WHO, & Unicef. (2013). Progress on Sanitation and Drinking Water 2013 Update. *World Health*, *1*(October 2004), 1–40. http://doi.org/http://apps.who.int/iris/bitstream/10665/81245/1/9789241505390_eng.pdf?ua=1

World Bank. Delegated Management of Urban Water Supply Services in Mozambique (2009).

WSP. (2014). Caracterização do Saneamento em Maputo.

WSP. (2015). Developing Business Models for Fecal Sludge Management in Maputo, (June).

WSUP. (2013). *Getting to scale in urban sanitation*.

WSUP Employee. (2016). Interview WSUP 2 Employees. Maputo.

Zuin, V., Nicholson, M., & Davis, J. (2012). Water access, service quality, and consumer satisfaction in peri-urban Maputo: A beneficiary assessment, 1–65.

Appendix A. System Analysis – Means ends diagram

This research is conducted within the project 'Sustainable freshwater supply in urbanizing Maputo, Mozambique', that is why in the following means-end diagram (Figure 24) the top 'end' is formulated as *the creation of a sustainable freshwater supply for Maputo*. The perspective for this diagram is an independent research group, instead of a single actor, this allows for the inclusion of cross sectoral means (actions) that would in practise be attributed to different or multiple actors.

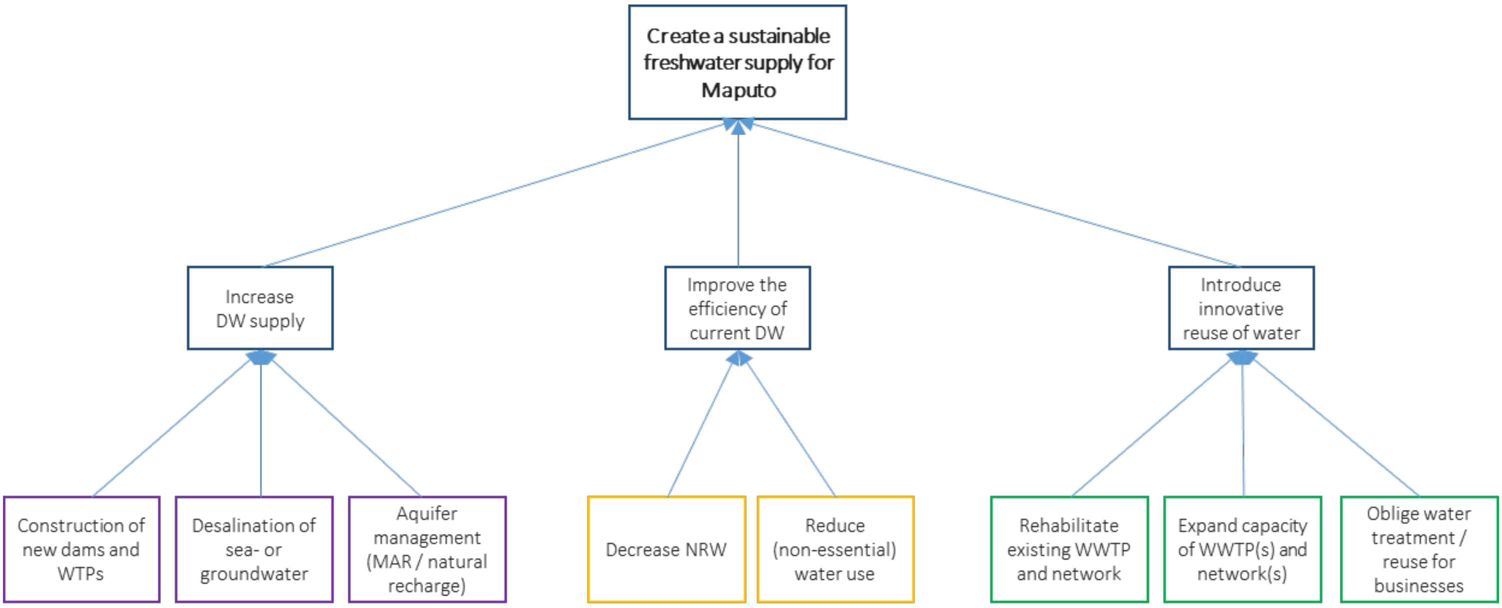


Figure 24 Means-end diagram with the perspective of an independent research group[18].

The perspective for this diagram is an independent research group, instead of a single actor, this allows for the inclusion of cross sectoral means (actions) that would in practise be attributed to different or multiple actors. Three means to obtain the main end are formulated. The first, that can be considered the current paradigm in Maputo, entails a more traditional approach to increase water availability, traditional is interpreted in a sense that all these techniques focus solely on the creation of additional supply. The second is focused on improvements of the efficiency of the existing DW capacity and the use of this water. Third are innovative solutions in which water reclamation and reuse are applied, these are considered innovative because these are not current practise in water supply in Greater Maputo and are not considered in the current paradigm. These three means for creating a sustainable water supply, are revised as ends and provided with means to obtain them. This results in concrete actions that can be taken in Greater Maputo to obtain the envisioned main objective.

The traditional approaches that aims to increase the water availability are; building new dams and water treatment plants (WTP) to supply water (from far); desalination of groundwater or seawater (creating a new water supply resource from non-potable water); managed aquifer recharge (where aquifers are artificially recharged with pre-treated surface water).

The means to improve the efficiency of current DW system and use are twofold; first focus on the reduction of non-revenue water (NRW), which includes various types of unbilled authorized consumption, apparent losses and real losses (Figure 25); secondly it's possible to focus on decreasing the amount of water used on non-essential things (e.g. excessive landscaping or swimming pools).

Within innovative solutions we also include the rehabilitation of the current wastewater network and WWTP to allow for water reclamation; a second action is the expansion of the existing sanitation infrastructure or the construction of new networks and WWTPs to allow the reclamation of water for DW use, industries or farmers; another option is to oblige the reuse of water at water intensive industries or businesses like car washes.

[18] In this case the research group is the project: Sustainable freshwater supply in urbanizing Maputo, Mozambique.

System Input Volume (corrected for known errors)	Authorized Consumption	Billed Authorized Consumption	Billed Metered Consumption (including water exported)	Revenue Water
			Billed Unmetered Consumption	
		Unbilled Authorized Consumption	Unbilled Metered Consumption	Non-Revenue Water (NRW)
			Unbilled Unmetered Consumption	
	Water Losses	Apparent Losses	Unauthorized Consumption	
			Customer Metering Inaccuracies	
			Systematic Data Handling Errors	
		Real Losses	Leakage on Transmission and Distribution Mains	
			Leakage and Overflows at Utility's Storage Tanks	
			Leakage on Service Connections up to point of Customer metering	

Figure 25 Explanation of various types of Non-Revenue Water (NRW)[19]

[19] Non-Revenue Water diagram retrieved from:
http://www.awwa.org/portals/0/files/resources/water%20knowledge/water%20loss%20control/iwa-awwa-method-awwa-updated.pdf

Appendix B. System Analysis – Objectives Tree

The objective tree analysis will allow us to translate the main objective into measurable criteria. We use the following objectives, as retrieved from the project website[20], that have been formulated for the project: Sustainable freshwater supply in urbanizing Maputo, Mozambique:

- "Work with local community-based, governmental and non-governmental organizations to address the issues that the city's population faces. In particular, saline intrusion, groundwater contamination, access to safe DW, inappropriate sanitation services and unsafe and unplanned WW reuse;
- Develop integrated social and technological knowledge, models, robust technologies and methodologies. These should enable the development of a sustainable and more innovative water resources management program for the city of Maputo;
- Produce open-source knowledge that can be replicated in other parts of Mozambique and in other countries facing similar challenges."[20]

These objectives, combined with the SDGs (Chapter 2), are translated into the following tree of objectives (Figure 15). This objective tree consists of a main objective and multiple sub-objectives, on the lowest level in the tree measurable criteria are defined for each sub-objective. These measurable criteria will enable researchers to assess the expected effectiveness of their actions.

The main objective (SDG 6) is to ensure availability and sustainable management of water and sanitation for all (top-level of Figure 15), alongside this objective the envisioned solution from this research group. This objective is split into three sub-objectives, the *Availability of water*, *Sustainable management of water* and the *Availability and sustainable management sanitation.*

Water availability is characterized by two factors that together define the number of people that can be served from the water resources available for central DW:

- Amount of DW resources available (criterion: amount of water available for central DW system, in 10^3 m^3/year) and
- Per capita water usage (criterion: amount of DW used per person, in m^3/year).

Sustainable water management is defined by two factors:

- Surface water pollution (criterion: Volume of wastewater (WW) discharged without treatment, in 10^3 m^3/year) and
- Groundwater pollution (criterion: Volume of WW or faecal sludge (FS) lost from collection systems, in 10^3 m^3/year).

The availability and sustainable management sanitation is defined by two factors:

- Population with access to improved sanitation (criterion: Population with access to improved sanitation, as % of total population) and
- The fraction of WW and FS safely collected (criterion: fraction of treated WW and FS, as % of the total).

[20] Objectives retrieved from: https://sustainablewatermz.weblog.tudelft.nl/

These criteria at the bottom of Figure 25 will be used to assess the effects of measures (bottom row of the means-end diagram, *Figure 23*) in the systems diagram (Figure 13).

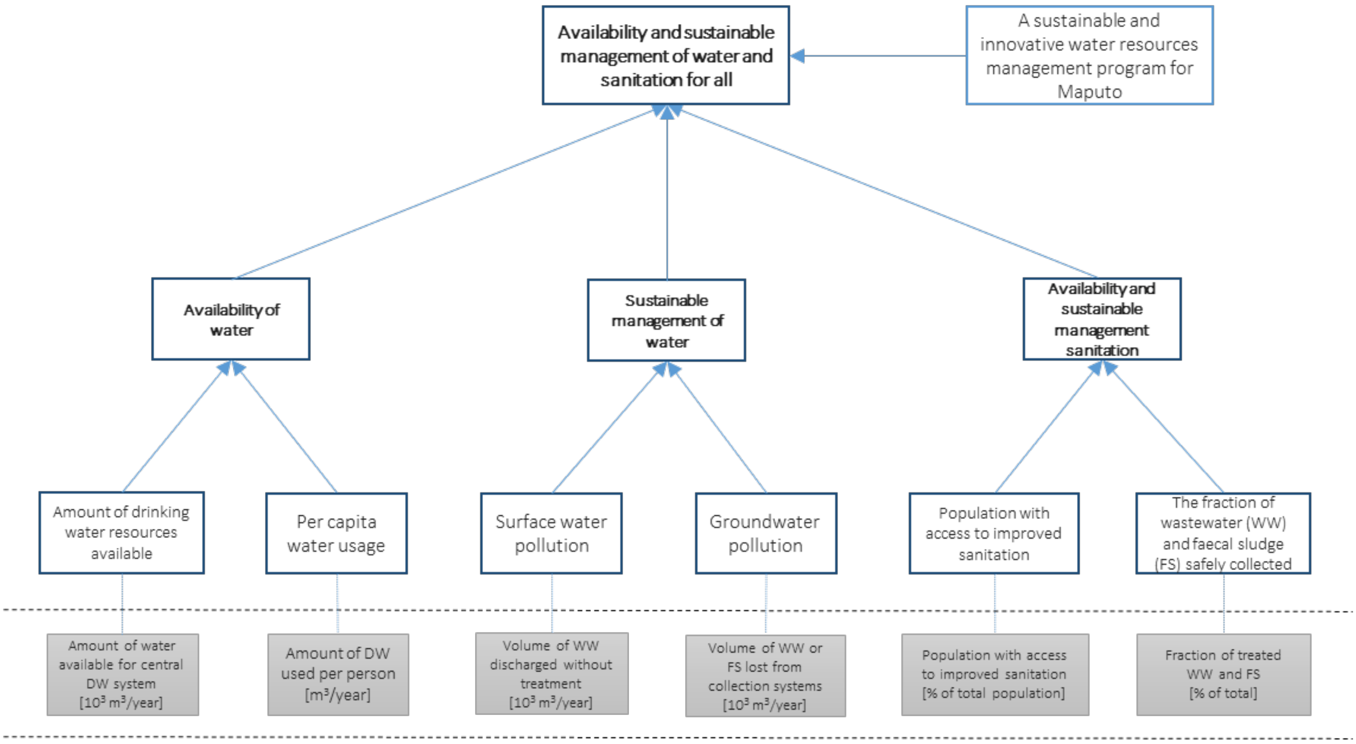
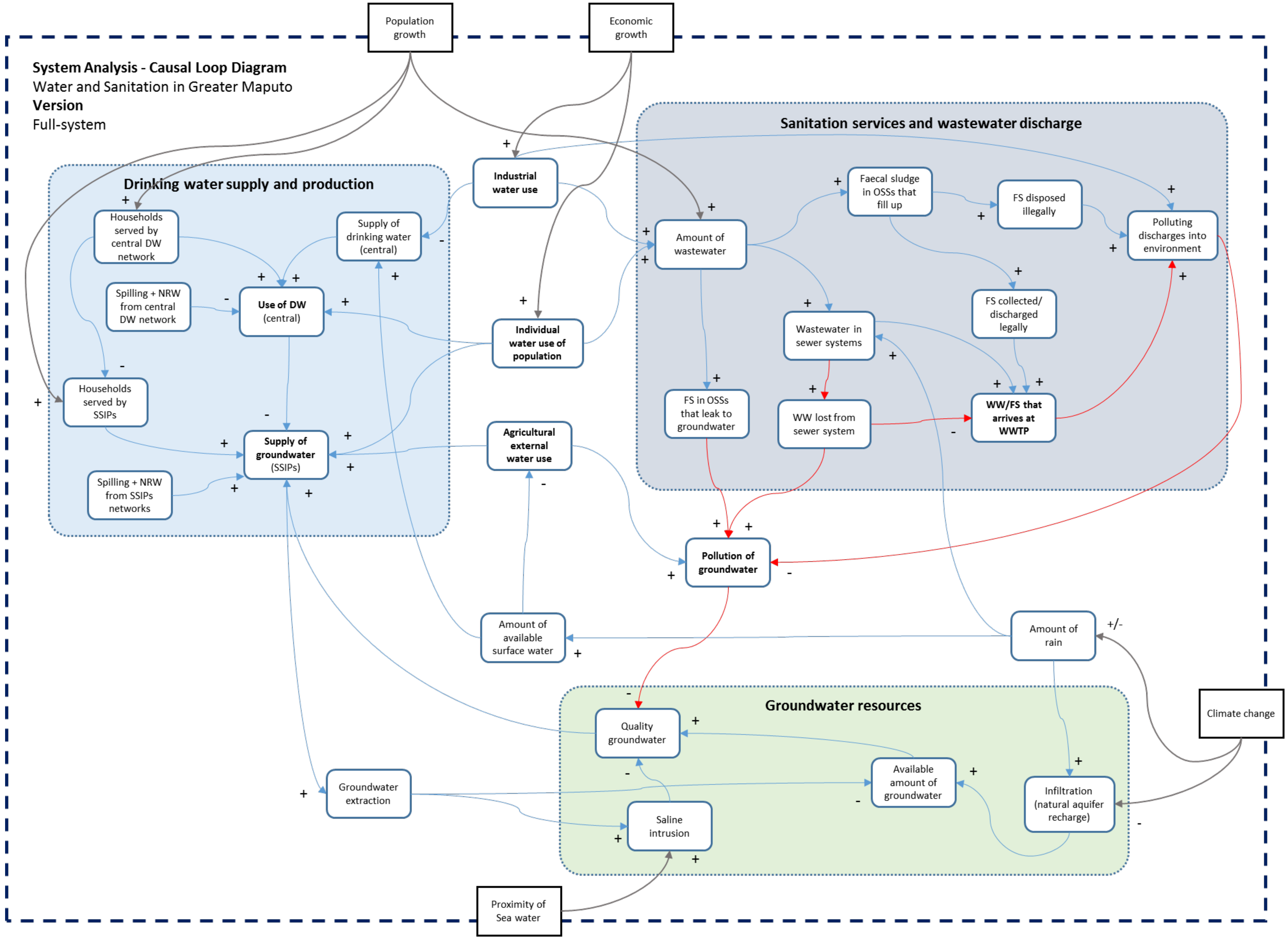


Figure 26 Objective Tree for drinking water and sanitation in Greater Maputo of this research group[21].

[21] In this case the research group is the project: Sustainable freshwater supply in urbanizing Maputo, Mozambique.

Appendix C. System Analysis – Causal Loop Diagram

Figure 27 CLD of the integrated systems of water and sanitation in Greater Maputo



Description of Causal loop diagram

The following table contains a description of the factors in the system diagram displayed in Figure 26.

Table 31 Description of factors and causal relations in Causal Loop Diagram in Figure 26.

Water supply system	
Factor + Description	*Causal relation (negative/positive) to factor + explanation*
Supply of DW (central) This represents the amount of water that is produced and supplied by AdeM.	Use of DW (centrally provided) (+) The water from the central network is the cheapest in Maputo, consequently an increase of the amount of available water will increase the domestic use of this water.
NRW from central DW network This represents the amount of water that is lost in the production and supply process of DW via the central network. In this factor these element are taken together because the supply of DW is limited, and NRW that is reduced can always be supplied officially.	Use of DW (centrally provided) (-) The more water is lost form the network, less DW can be used/consumed – negative relation.
Use of DW (centrally provided) This is the amount of DW that both households and business are using from the central network, to provide in their need for DW, household activities and sanitation.	Supply of groundwater(SSIPs) (-) The DW from the central system is the preferred option for costumers that can choose, as it is cheaper and of better quality. That is why citywide, if more DW from the central system is available, less groundwater will be used.
Supply of groundwater (SSIPs) The amount of groundwater extracted to provide to households, business or agriculture, by SSIPs or FIPAG standpipes.	Groundwater extraction (+) In case more groundwater is used, more will have to be extracted from the ground.
NRW from SSIPs The amount of water that is lost in the extraction and supply process of groundwater for DW.	Supply of groundwater (SSIPs) (+) An increase of the water lost from the networks, means more water needs to be extracted to provide in the same amount of use.
Households served by central DW network The number of households and businesses (with DW only for personal use) that have a connection to the central DW network and use it as their primary source of water.	Households served by SSIPs (-) SSIPs operate in areas where the central network does not exist yet; hence it is assumed if the central network expands, SSIPs connections in place might persevere but the new connection will be the main connection. If the number of households that are served by the central DW network increases, less households will be served by SSIPs. Use of DW (central) (+) The more households are served by the central network, the more DW will be used.
Households served by SSIPs The number of households served by SSIPs.	Supply of groundwater (SSIPs) (+) An increase in the amount of households that are served by SSIPs, will increase the amount of groundwater used.
Industrial water use The amount of water used by industries. These industries usually have contracts with the central DW provider which gives them a preferred position in the allocation of the water supply.	Supply of DW (central) (-) In case the demand for industrial water increases via contracts with the DW provider, the amount of water left available to supply as DW to the city decreases. Amount of WW (+) The amount of water industries use, positively influences the amount of WW they produce.

Water supply system	
Factor + Description	*Causal relation (negative/positive) to factor + explanation*
Individual water use of population The amount of water a person uses for personal reasons such as drinking, sanitation, cooking etc., at home/work.	Use of DW (central) (+) If the population starts consuming more water this will increase the demand for and use of DW from the central system. Supply of groundwater (SSIPs) (+) If the population starts to use more water on average this will increase the demand for and use of DW from groundwater. Amount of WW (+) The amount of water people use, positively influences the amount of WW they produce. This can be in the form of showers discharging in the sewer (more WW), but also includes people using pour-flush toilets that used traditional latrines before (more FS).
Agricultural external water use The amount of water that is used in agriculture from a managed water source. The most common source are either surface water (rivers and rain) or natural spring water that surfaces near their land. In case these sources are insufficient agriculture makes use of managed source of groundwater from SSIPs.	Supply of groundwater (SSIPs) (+) If the agriculture uses water from a managed sources, more groundwater will be extracted in order to supply the water necessary.
Economic growth The growth of the national gross domestic product GDP is enabling more people to access water services and sprouting more businesses in Greater Maputo (more explanation, Chapter 5).	Industrial use (+) More business means more business and industrial use of DW water (more explanation, Chapter 5). Individual water use of population (+) More people can afford more water means an increase of individual water use (more explanation, Chapter 5).

Natural surface water and groundwater resources	
Factor + Description	*Causal relation (negative/positive) to factor + explanation*
Groundwater extraction The amount of water that is extracted from the ground by SSIPs and FIPAG standpipes. This amount is influenced by the demand for water, and at the moment not well managed.	Available amount of groundwater (-) If more water is extracted from the ground, less groundwater will remain available for extraction. Saline intrusion (+) If more groundwater is extracted, the amount of saline sea water that will intrude the ground and groundwater shall increase as well.
Available amount of groundwater	Quality groundwater (+) Will decrease the quality of groundwater and consequently lead to an increase the use of DW central.
Quality groundwater Quality is whether or not the groundwater is fit for potable purposes, meaning the amount of contaminants (e.g. salt, nitrates and faecal coliforms) should as low as possible.	Supply of groundwater (SSIPs) (+) Groundwater abstraction for DW and irrigation will decrease if the quality of DW significantly decreases.
Saline intrusion	Quality groundwater (-)

Natural surface water and groundwater resources	
Factor + Description	*Causal relation (negative/positive) to factor + explanation*
The movement of saline water into freshwater aquifers, which can lead to contamination of DW sources.	The increase of saline intrusion, can lead to contamination of groundwater and will therefor decrease the quality of groundwater.
Available amount of surface water The amount of surface water in rivers and basins that is available for both DW production and irrigation.	Agricultural external water use (-) The amount of surface water that is naturally available for agriculture, decreases the need for the use of external water. Supply of DW (central) (+) The amount of water that is available for DW and agricultural water, is leading in the amount of DW that is produced and supplied by FIPAG.
Amount of rain The amount of precipitation or rain.	Infiltration (natural aquifer recharge) (+) A part of the rain will recharge aquifers; an increase in rain means an increase in recharge. WW in sewer systems (+) Part of the rain will reach the sewer system. More rain means more WW in the sewer. Agricultural external water use (-) More rain also means that agriculture needs less other sources of water, so less external water is required.
Infiltration (natural aquifer recharge) Leachate is the natural infiltration of atmospheric water or rain that eventually reaches the underlying aquifers.	Available amount of groundwater (+) The amount of natural recharge of unpolluted rainwater directly influences the available amount of groundwater positively.
Polluting discharges into environment This contains the pollution from industries and households reaching the river (downstream of the WTP) and the sea. This is called the environment instead of surface water, because this surface water is currently not used for either agriculture or DW production.	Pollution of groundwater (+) Water from polluted rivers seeps into groundwater (be it in lesser amounts), the more polluted this environment becomes, the more polluted groundwater resources will become.
Climate change Climate change is the complex alternation of the climate on the planet, it is an external factor to the system that does influences the amount of rain in Greater Maputo.	Amount of rain (-)/(+) Climate change causes more rain during the wet summer season and less rain during the dry winter.

Sanitation system	
Factor + Description	*Causal relation (negative/positive) to factor + explanation*
Amount of WW The total volume of WW and FS produced in Greater Maputo.	FS in OSSs that fill up (+) The more FS is produced, the more FS will end up in on-site systems. WW in sewer systems (+) The more WW is produced in the city, the more will reach the sewer system. FS in OSSs that leak to groundwater (+) More FS, means more FS in OSSs that are not closed and that will leak polluted water into groundwater.

Sanitation system	
Factor + Description	*Causal relation (negative/positive) to factor + explanation*
FS in OSS that fill up The amount of FS that ends up in on-site sanitation systems (OSS), that fill up and that need to be emptied or abandoned after some years.	FS disposed illegally (+) At this moment an unknown percentage of FS is disposed from OSSs illegally. This can be emptying them in a hole dug in the ground, or disposing of the FS in the sea or at a garbage disposal. The more FS is produced, the more people will find the need to dispose of it in an illegal way. FS collected / discharged legally (+) The total amount of FS in OSSs that fill up influences the amount of FS collected by and discharged legally as well. Increase of FS will increase the demand for these legal services.
WW in sewer systems The amount of WW that is discharged into the sewer system. The main sources are the connected households that discharge from their connected septic tanks, also some industries discharge their effluent in the sewer.	WW lost form sewer system (+) The amount of WW entering the sewer system is positively related to the amount of WW that is lost through leaks etc. The more water flows by the leaking parts, the more water is lost. WW/FS that arrives at WWTP (+) The more WW enters the system, the more will be conveyed to the WWTP.
FS in OSSs that leak to groundwater The amount of FS that ends up in OSS, that do not have a closed reservoir and leak into groundwater.	Pollution of groundwater (+) The more water leaks form OSSs, the more groundwater is polluted.
WW lost form sewer system Due to clogged or broken sewer pipes WW in the network is lost and leaks into the ground.	Pollution of groundwater (+) The more WW is lost from the sewer system, the more groundwater will be polluted with nutrients WW/FS that arrives at WWTP (-) The more WW is lost from the sewer system the less WW be conveyed to the WWTP.
WW/FS that arrives at WWTP The amount of WW and FS that arrives at the WWTP through the sewer network or via collection trucks that dispose at the WWTP.	Polluting discharges into environment (+) In the current situation the WWTP is not operation, which means the effluent is still polluted, and the more water that arrives at the WWTP will increase the amount of polluting discharges is released into the environment.
Pollution of groundwater The amount of pollution that the groundwater resources in Greater Maputo are being subjected to.	Quality groundwater (-) The quality of groundwater is negatively related to the pollution of groundwater. More pollution means a decrease in quality of the groundwater.
FS disposed illegally At this moment an unknown percentage of FS is disposed from OSSs illegally. This can be emptying them in a hole dug in the ground, or disposing of the FS in the sea or at a garbage disposal site.	Polluting discharges into environment (+) The more FS is disposed of illegally the more pollution will reach the environment, as the larges part of the FS is still disposed directly into the environment.

Appendix D. System Analysis – CLD on sub-systems level

Figure 28 Causal Loop Diagram on sub-system level of the integrated systems of water and sanitation in Greater Maputo. In the diagram only the relations between individual factors have a +/-. Because factors cannot have relations with a sub-system itself, but only with one or more factors inside the sub-system.

First the sub-system of Water production and supply, contains the production of DW from surface and groundwater resources.

- Groundwater extraction is a connecting factor (to the sub-system of groundwater resources), it is influenced by the production of groundwater as DW and influence the availability of groundwater.
- The groundwater resources, the quality and availability, also influence the supply of groundwater as DW, hence the connection between both sub systems.

The sub-system of groundwater resources contains the natural relations between rain, soil nutrients, groundwater resources and the relations between availability, quality and pollution.

- The sub-system is directly influenced by the external factors of the proximity of sea water and nutrient concentration.
- Additionally the amount of rain (influenced by climate change) has an effect on the groundwater resources, as it influences the amount of natural recharge.
- The groundwater resources are connected to the sanitation sub-system via pollution.
- Groundwater is affected by the amount of WW and FS that leaks from OSS or spills from the WW network (e.g. high Nitrate and faecal coliforms concentration) and by farming, due to use of fertilizers.

The sub-system sanitation services and WW discharge entail the systems and management of WW and FS.

- The sub-system influences not only the pollution of groundwater, but also the availability of surface water via the pollution of surface water. This happens because of industrial and domestic WW that reaches surface water untreated.
- The pollution can be directly (industrial WW discharged into rivers) or indirectly, as discharged water reaches surface water untreated via the sewage network or a (non-operational) WWTP.
- The available surface water influences the production of DW.
- The individual use of DW of the population and by industries both influence the sanitation sub-system, because their WW or FS has to be handled.
- Both also influence the drinking water sub-system, the individual use influence the amount of central DW is needed, and how much demand for groundwater still results.
- The industries often use DW in their production process, hereby limiting the amount of DW available for domestic use.

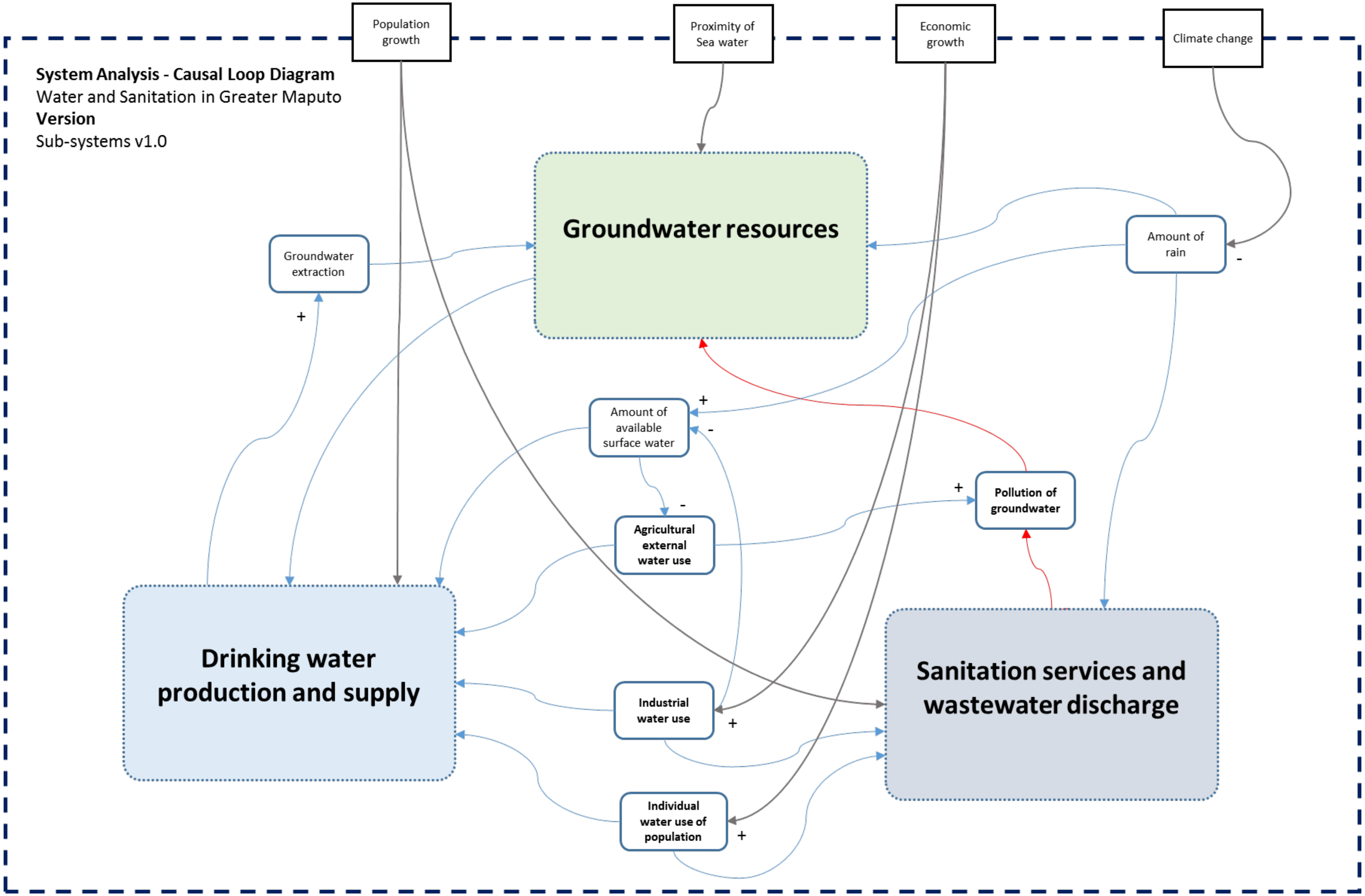


Figure 28 CLD on sub-system level of the integrated systems of water and sanitation in Greater Maputo

Appendix E. Actor Analysis

Actors in DW and water resources

National Directorate of Water (DNA) in Portuguese: Direção Nacional de Águas	
Type of organisation	Public, part of Ministry of Public Works and Housing (MOPH)
Establishment/ history	DNA was established in 1970s. DNA used to be responsible for maintenance and operation of the WWTP and sewerage network in Maputo. However, they transferred this responsibility to the municipality of Maputo around 10 years ago (DNA Employee, 2016). During the execution of this research the institutional setup of DNA was subject to alternation, however for the efficiency of this thesis the implication of this change are left outside the research scope.
Based:	Maputo
Sector	Water resources, water supply and sanitation.
Responsibilities:	The organisation sets overall strategic direction for the development of the water and sanitation sectors. Develops all policy and monitoring programs for water services and manages the nation's water resources (SUWASA, 2010).
Services:	DNA services are planning, strategic development, fundraising, monitoring, policy making in the water and sanitation sectors. In Greater Maputo they are especially involved in the attracting of large investments in DW infrastructure and storm water drainage.
Challenges:	- Municipalities are responsible for collecting taxes for services like sanitation and storm water drainage. However, in case they do their autonomy allows them to appropriate these funds to other sectors. DNA is trying to ensure that municipal budgets on water and sanitation are appropriated correctly (DNA Employee, 2016).

Southern Regional Water Authority (ARA-Sul) in Portuguese: Autoridades Regionais de Águas Sul	
Type of organisation	Public
Based:	Mozambique is divided in five geographical areas and the water resources in each area are managed by one water authority, or ARA. In the South (Sul, in Portuguese) of Mozambique, ARA-Sul is the responsible authority.
Sector	Water resources and hydraulic structures.
Responsibilities:	- To enable sustainable management and self-sufficient water resources in Mozambique in the area south of the Save River. - Construction and maintenance of new dams. ARA-Sul manages three major dams (Pequenos Libombos, Corumana and Massingir) and a large weir (Macarretane in the Limpopo basin), as well as some smaller dams, dikes and other hydraulic structures and a network of hydro-climatological stations.[22] - Collection of information on quality of groundwater resources (ENGIDRO, HIDRA, & AQUAPOR, 2015b).
Services:	- Planning, ensuring the availability and balanced distribution of water resources (surface and underground). - Control of use and reclamation of surface and groundwater, effluent discharges and other activities affecting water resources. - Grant rights of usage and the imposition of related fees.

[22] Source ARA-Sul website, date of access 9-12-2016: http://www.ara-sul.co.mz/MenuPrincipal/SobreNos/CriacaoEAtribuicoes.html

	- Construction and maintenance of new dams - Register groundwater extraction, by licensing SSIPs that extract groundwater (Hydroconseil & WE Consult, 2011).
Challenges:	- Currently there is no service regulation on tariffs, service quality and monitoring of groundwater (SUWASA,2015). - Conflicting claims on the freshwater in currently existing and the planned reservoirs, for agricultural, industrial (such as MOZAL) and domestic use (supplied via FIPAG treatment and network). - Groundwater pollution from (pit) latrines threatens the aquifer quality, while limited regulation exist to prevent this (Hydroconseil & WE Consult, 2011).

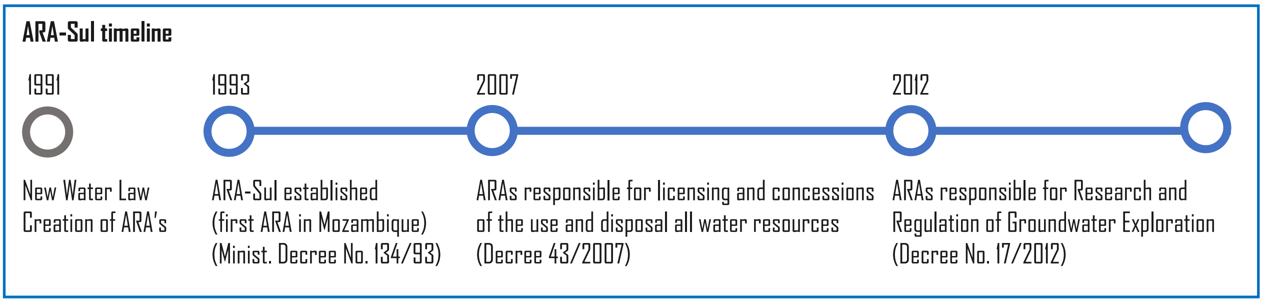


Figure 29 Institutional timeline ARA-Sul (own illustration).

Water Regulating Counsel (CRA) in Portuguese: Conselho de Regulação do Abastecimento de Água	
Type of organisation	Public
Based:	Maputo
Establishment/ history	Initially established to regulate water supply services in the five service areas where services that are operated under delegated management and provide regulatory advice for the nine FIPAG services receiving managerial technical assistance. Under Decree nr. 18/2009 of May 13, the mandate of CRA was expanded to non-FIPAG towns and now includes sanitation services (SUWASA, 2010, p. 9).
Sector	Water and sanitation
Responsibilities:	CRA is responsible for regulatory oversight in water related sectors (including DW and sanitation) in Mozambique. With a mandate to protect consumers, regulate service quality, approve changes in tariffs, and promote and improve the delegated management framework (SUWASA, 2010, p. 9).
Services:	- Regulatory licencing of AdeM for water supply. - Regulation of the sector of small independent water supplier.
Challenges:	CRA for years did not regulate the private water operators as they thought this was the responsibility of the main operator. CRA gave a license to AdeM to provide water in the Maputo metropolitan and assumed that AdeM should therefore regulate any person providing water in their service area.

FIPAG, the National Urban Water Investment and Asset Holding Fund, in Portuguese Fundo de Investimento e Património do Abastecimento de Água	
Organisation type	Semi-public. A state-owned enterprise (SUWASA, 2010).
Based:	Maputo
Establishment/ history	Established in 1998 as the asset holding and investment fund to define the management structures for the 13 largest urban centres including Maputo, Beira, and Nampula, among others. Seven other urban centres were added to their portfolio in May 2009 (SUWASA, 2010). From the start-up, limited organisational capacity was a problem at FIPAG, but the in the past 15 years FIPAG has professionalized.
Sector	DW production and supply.
Responsibilities:	- Production of DW. - Investment in and maintenance of DW infrastructure. - Expanding the national coverage of access to water supply service.
Services:	- Construction and maintenance of DW networks. - For the case of Maputo, FIPAG delegates network management to an operator - DNA provides FIPAG with national targets that can be realised at any location that FIPAG selects.
Challenges:	- The Pequenos Limbobos reservoir (river discharge) and the WTP have reached the maximum DW supply capacity, there is not enough water to expand. Therefore FIPAG cannot connect more households or increase service hours (FIPAG Employee 1, 2016). - The high NRW rates in the FIPAG network posed a challenge to attract foreign capital for the construction of supply solutions like Coruman and Moamba dam, as it limits the profitably of operations. A quote from an FIPAG employee is illustrative "Try telling a foreign investor that 65% of the DW produced with this 250 million project will be lost as NRW" (FIPAG Employee 1, 2016). - Expansion to the peri-urban areas of Maputo means competition with local SSIPs. - In the peri-urban areas of Greater Maputo the average income of the population is lower increasing the risk of payment problems that decrease revenues on water services (FIPAG Employee 2, 2016). - The unreliable electricity supply to the city severely limits the possibly for FIPAG to keep its reservoirs in the city full. As a consequence the number of hours that households have water service fluctuates (FIPAG Employee 2, 2016).

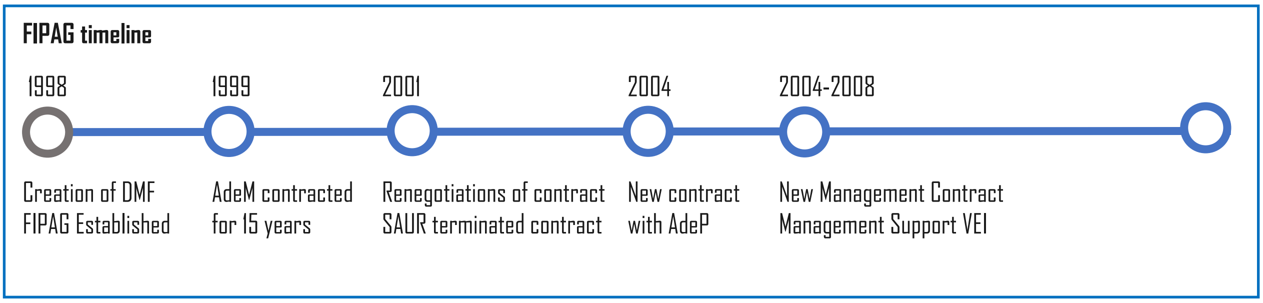


Figure 30 Insitutional timeline FIPAG (own illustration).

Water for the Maputo Region (AdeM) in Portuguese: Águas da Região de Maputo	
Type of organisation	Private company, owned partly by FIPAG (73% of the shares) and a consortium of Mozambican private investors (27%).
Based:	Maputo
Establishment/ history	Established in 1999 AdeM is the successor of the original Águas de Moçambique, the central DW provider in Greater Maputo.
Sector	DW service
Responsibilities:	AdeM is responsible for management of DW system operations within Maputo and Matola (SUWASA, 2010).
Services:	- 185,000 connections - serving over 1 million inhabitants in Greater Maputo. - operates 430 public standpipes (in reduction) - an average of 16 hours of water supply,
Challenges:	- FIPAG's network has NRW, both physical losses and unauthorized consumption, severely limiting the profitability of the operations by FIPAG and AdeM (FIPAG Employee 1, 2016). - Expansion of services to peri-urban areas, means serving people with lower incomes, increasing the risks of people not being able to pay their water bill (FIPAG Employee 2, 2016).

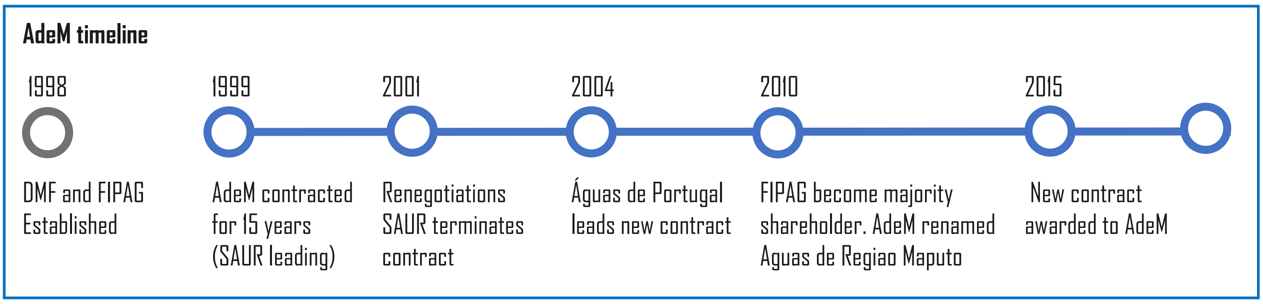


Figure 31 Insitutional timeline AdeM (own illustration).

Small Scale Independent Providers (SSIPs) in Portuguese Pequenos Operadores Privados (POPs)	
Type of organisation	Private, more than 800 independent water providers.
Based:	Peri-urban areas in Greater Maputo.
Establishment/ history	The peri-urban areas of Greater Maputo lack sufficient coverage from the AdeM network. SSIPs fill a gap left by the services of the central network and provide water to a variable number of clients. SSIPs started to provide water in the 1970s. The national government acknowledged the importance of the SSIPs in water supply in the National Water Policy in 1995. Later a formalisation process was started intended to improve service quality of SSIPs and increase the access to improved water sources (Jenkins, 2001).
Sector	Water supply (from groundwater).
Responsibilities:	The SSIPs represent an estimated 20-35 million USD in private investment.
Services:	- At 192,000 house connections - Combined water production of about 73,000 m^3/d,
Challenges:	- Groundwater quality is decreasing - FIPAG is expanding the reach of its supply network, increasing the competition. - Competition among SSIPs on a local level is increasing.

Municipalities of Maputo and Matola	
Type of organisation:	Public
Based:	Maputo and Matola
Establishment/ history	Not relevant
Sector	DW sector
Responsibilities:	The municipalities within Greater Maputo are not responsible for DW supply but are involved creating and checking on rules for water quality (Matola Employee, 2016). The Matola municipal website states the following responsibilities (my translation): "Ensuring the management of water supply systems with specialized partners; Managing small municipal water systems" [23], indicating that the municipalities are involved in the planning of expansion of the parts of the municipality that are covered by the central DW network. Also the municipality is responsible for the creation of local legislation and guidelines for the DW sector (Matola Employee, 2016).
Services:	Matola - License the small water supply projects, perform inspection and quality control. - Authorize the opening of the boreholes, coordinate with the Ministry of Health the control of the sources and tanks of water supply at private or government institutions like schools (Matola Employee, 2016).
Challenges:	- On one hand the municipality has the responsibility to represent the interest of as many of its inhabitants as possible, urging FIPAG to expand in the peri-urban areas would be a logical consequence. On the other hand the municipality tries to create an economically attractive location for business, for which urging FIPAG and AdeM to expand to the newly developed business and tourist areas of the city is important. - Also, the role of the SSIPs in the poorer peri-urban areas is so important at this moment that the municipality has great responsibility in representing their interest in negotiations with FIPAG.

Households (consumers)	
Type of organisation	Not applicable.
Based:	Greater Maputo.
Establishment/ history	As described in the Chapter 2 there is a great difference (e.g. income and amenities) in households within Greater Maputo. Geographically the difference between households in the urban centre and peri-urban areas largely overlaps with the access to the central DW network and sewer network.
Sector	Drinking water.
Responsibilities:	The households have the ability to choose between alternative available DW services. When they do they base their decision on the DW quality, the hours of service and the price of water per m^3 (Zuin et al., 2012).
Challenges:	- It is usual for householders to pay an initial sum of money for the creation of a domestic water connection. Many households are connected to SSIPs and have paid fees for a connection, new costs for a connection to the central network of FIPAG can be constraint for them. - The group of households is diverse in number of people and water use per person. - Many households share a connection with their neighbours or friends living nearby. Others are not connected and use local standpipes connections or resellers.

[23] Source: website of municipality de Matola. http://cmcmatola.co.mz/

Actors in WW and FSM

Administration of Infrastructures for Water and Sanitation (AIAS) in Portuguese: Administração de Infra-estrutura de Água e Saneamento	
Type of organisation	Public, part of the ministry of Public works (AIAS Employee 1, 2016).
Based:	Maputo
Establishment/ history	AIAS was established in 2009 in an attempt to extend the Delegated Management Framework to secondary cities and to allocate the ownership of the sanitation networks all over Mozambique to one entity (Sousa, 2014b). The mandate includes 130 cities and villages. At this moment AIAS is expanding rapidly in organisational capacity. In terms of fulfilling their mandate AIAS currently has contracts with between 20 and 30 municipalities, and several cities are in the pipeline for investments (AIAS Employee 1, 2016).
Sector	Water, sanitation and storm water drainage. In the currently contracted cities AIAS is mainly responsible for water supply projects. In the smaller cities, their responsibility for sanitation is mostly limited to latrines, public toilet blocks and awareness campaigns (AIAS Employee 1, 2016).
Responsibilities:	Souza (2014a, p. 4) explains AIAS responsibility as to “Improve management of water supply and sanitation through delegated management of the services by either autonomous local entities or private operators to ensure sustainability, reliability and good quality customer services”. Mobilising investments for the water and sanitation sector, rehabilitates or constructs the water or sanitation network. Consecutively AIAS creates tenders to attract and contract private contractors to operate and maintain the network on a lease base. Maputo and Matola are special locations for AIAS, since FIPAG is responsible for water, their task here is sanitation and storm water drainage. However, since the municipalities work quite autonomously (especially Maputo), the process of defining clear institutional roles and regulatory frameworks take longer than in other cities (AIAS Employee 1, 2016). In Maputo, AIAS is responsible for implementing the Masterplan for Sanitation and Drainage project within the World Bank funded project ‘Cities and Climate Change’ (ENGIDRO et al., 2015b)
Services:	With respect to services Greater Maputo is a special location for AIAS: - Securing investments for sanitation and storm water drainage. - Creating the Master plan for drainage and sanitation in Greater Maputo. (AIAS Employee 1, 2016)
Challenges:	- Sanitation tariff is politically hard to establish and it is still unclear what services the municipality or AIAS will deliver in return for the potential tax contributions. - Small budget for sanitation on the national public budget. - The masterplan is needed to create a framework to embed individual project investment plans that are needed to secure project finance. (AIAS Employee 1, 2016) - The municipality is reluctant to allow DAS (as an autonomous organisation) or AIAS to collect the dedicated sanitation tax, since they prefer to keep the authority to make sure the tax is used properly. Informally, it is understood that this practically means being able to decide to use the money for other sectors that sanitation. - The Postura de Saneamento (Public Sanitation Guideline) has been installed in both Maputo and Matola, however in Maputo the intended sanitation tax was not included conform the intended national standard. (AIAS Employee 2, 2016)

Following the creation of AIAS a number of internationally funder projects and programs have been started and finished. In the following Figure 29 a timeline is presented to illustrate the development of AIAS since its establishment in 2009.

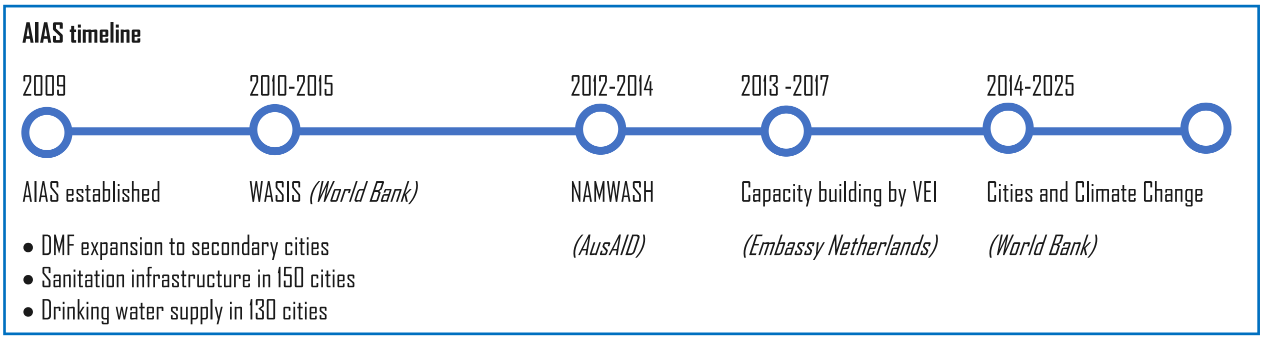


Figure 32 Insitutional timeline AIAS (own illustration).

There are three major donors involved in projects supporting the development of (the activities of) AIAS. The World Bank has conducted the Water Services and Institutional Support (WASIS) Project and has been financing the 'Cities and Climate Change' project since 2014, including the creation of the Master Plan for Drainage and Sanitation for Greater Maputo. AusAID has conducted several pilot project with water and sanitation services in smaller cities and Beira. Additionally the Embassy of the Kingdom of the Netherlands has been financing a project of capacity building for AIAS conducted by Vitens Evides International.

Municipality of Maputo In portuguese: Conselho Municipal de Maputo	
Type of organisation:	Public, Municipality.
Based:	Maputo
Establishment/ history	In 1979 the municipalities of Lourenço Marques Maputo, Matola and Machava where merged into Maputo City. Since 1987 Maputo and Matola are independent Municipalities again (Jenkins, 2000a). The Municipality of Maputo has a combined Water and Sanitation department, DAS (in Portuguese: Departamento de Água e Saneamento).
Sector	The Municipality of Maputo approved the "Postura de Saneamento" in 2016, containing guidelines related to sanitation (AIAS Employee 2, 2016). Among other things the Postura states the required dimensions of latrines or septic tanks and transfers the responsibility to connect a newly constructed house to the central WW network from the municipality to the owner of the house (AIAS Employee 2, 2016).
Responsibilities:	After Mozambican independence the responsibility for municipal services as water supply and sanitation where transferred to the central government. Around 10 years ago (DNA Employee, 2016) responsibility for sanitation was decentralised from DNA to the municipality of Maputo, the transfer was finished in 2014 (Bäuerl, 2015, p. 11). Formally, on a national level this responsibility was transferred again recently to AIAS. However the municipality, because of its status, power and seize in the country, still has large autonomy in the sanitation sector and until now has withstood attempts to share or transfer these responsibilities with AIAS (AIAS Employee 2, 2016).
Services:	- FS collection service. The municipality operates one collection truck that empties OSS free of charge. - Maintenance and operation of the WW and storm water drainage networks in Maputo. However, the sanitation department lacks the financial and organisational capacity for both (van Esch & van Ramshorst, 2014). - Maintenance and operation of the WWTP in Infulene (officially on Matola land) (van Esch & van Ramshorst, 2014). However, the sole employee at the WWTP only registers trucks disposing FS during daytime of working days (own observation).
Challenges:	- Currently there is very little municipal budget available for sanitation services, this limits both the organisational capacity as the possibilities to invest in maintenance of the existing system or trucks. - Maintenance and operation of the WWTP has been halted since the plant became out-of-operation during the large flooding in 2000, it was cleaned for the last time in 2007 (Bäuerl, 2015)

<table>
<tr><td colspan="2"><u>Municipality of Matola</u>
In portuguese: Conselho Municipal de Matola</td></tr>
<tr><td>Type of organisation:</td><td>Public, Municipality</td></tr>
<tr><td>Based:</td><td>Matola</td></tr>
<tr><td>Establishment/ history</td><td>Similar to Municipality of Maputo. Matola has a recently combined department for Water and Sanitation (Matola Employee, 2016).</td></tr>
<tr><td>Sector</td><td>Water and sanitation.</td></tr>
<tr><td>Responsibilities:</td><td>According to the municipality’s website, the water and sanitation department has the following responsibilities:
- Preparation, implementation and or tendering of the construction, maintenance and rehabilitation of water, drainage and sanitation infrastructure in Matola.[24]
- Authorizing and coordinating the release of water pipes into public roads;[25]
- The WWTP in Infulene lies within municipal land of Matola. Although the formal responsibility has been transferred to Maputo, the Matola department of water and sanitation expects to play a role in the future development and operation of the WWTP (Matola Employee, 2016).
- The municipality is responsible for quality control of projects in sanitation that could affect the public health. They work towards a sanitation objective in 2040 where no untreated water is released into the environment. The objective is to let people have septic tanks, but to eliminate the drain into the environment by connecting them to a WW network (Matola Employee, 2016).
- Matola intends to install the sanitation tax as a tariff on the water bill in 2017 for industries that are connect to drainage, for households the tax will be installed after the construction of a WW network to the WWTP. However to establish the right amount it is dependent on CRA and for public acceptance more people need to be informed and educated about the health issues related to environmental pollution (Matola Employee, 2016).</td></tr>
<tr><td>Services:</td><td>- In theory, supervising the fees charged by private operators; [26] However, no evidence is provided that this is done in practice.
- There is no existing sewerage network in Matola, so the operation and maintenance as described in the postura therefore are currently hypothetical (Matola Employee, 2016).
- The city operates one FS collection truck, however since its broken this services is also out of operation at the moment (ENGIDRO et al., 2015b, p. 8).
- The municipality collects fees from the private FS collectors active in Matola, however it is an infrastructure tax that is designated for the department of roads and infrastructures (ENGIDRO et al., 2015b, p. 8).</td></tr>
<tr><td>Challenges:</td><td>- Currently the department of water and sanitation mainly performs quality checks at water suppliers in Matola, additional budget and organisational capacity are needed to conduct similar services on sanitation (Matola Employee, 2016).
- Since there is no current WW network in Matola, implementing a sanitation tax is said not to be possible before investments in emptying services or a sewerage network are made (Matola Employee, 2016).
- The department needs state funds to invest in central sanitation infrastructure and afterwards intends to collect a sanitation fee from all users; households, industries and commercial users, dependent on the amount of water used (Matola Employee, 2016).
- Maputo municipality has hold on to autonomy on sanitation (AIAS Employee 2, 2016). It is still unclear how both municipalities are going to divide responsibilities for WWTP operation, revenues from private FS collection and revenues from the potential sanitation tax (Matola Employee, 2016).</td></tr>
</table>

[24] Source: website of municipality de Matola. http://cmcmatola.co.mz/
[25] Source: website of municipality de Matola. http://cmcmatola.co.mz/
[26] Source: website of municipality de Matola. http://cmcmatola.co.mz/

Private FS collectors	
Type of organisation	Private companies, around 25 enterprises (WE Consult, 2014, p. 15). We Consult (2014) defined 5 types of FS collectors in their market assessment: • High Capacity Private Operators (enterprises or companies) • Community Based Organizations (CBOs - supported by NGOs) • Low Capacity Private Operators (individual emptiers) • Exclusive Private Operators • Exclusive Government Operators
Based:	Maputo and Matola.
Establishment/ history	Historically FSM has been neglected in Greater Maputo, finally resulting in an out-of-operation WWTP and a poorly maintained sewerage network. Recently attention to sanitation topics has increased. However, over the past years private companies have emerged, in an attempted to capitalise on the demand for FSM services, offering a range of septic tank and latrine emptying services (WE Consult, 2014, p. 8).
Sector	Faecal sludge management (FSM)
Responsibilities:	- After reviewing a license to discharge FS at the WWTP in Infulene the collector are expected to empty OSS, charge a fee and register the disposal at the WWTP. - In the future another option is to collect FS locally at faecal sludge transfer stations (FSTS). This option is suggested in the Masterplan for Greater Maputo, but has not yet been implemented. These locations could improve the effectiveness of collection and enable the use of smaller trucks for emptying OSS in locations that are not accessible for larger trucks (ENGIDRO et al., 2015a).
Services:	- Private operators that collect FS from OSSs. For the collection several sizes of trucks with pumps are used.
Challenges:	- The private collectors dispose the collected FS either legally at the WWTP of Infulene (6% of total produced sludge) or illegally in surface water or the sea (estimated 50% of total produced sludge) and an estimated 34% is safely abandoned and covered (Bäuerl, 2015). - Many of the vacuum trucks are so large that not all locations of septic tanks are accessible (ENGIDRO et al., 2015a). - The FSTS have not been tested in Greater Maputo, one pilot project was barely used, because the owner only operated large collection trucks and the transfer station was not expected to improve revenues (WSUP Employee, 2016). Different stories exist about the successfulness of this station, as the operators suggests that is actually quite profitable for him (informal communication). - A combined FSTS and digester pilot plant has been vandalised by a local community out of fear for pollution and contamination from toxic fumes that where understood to come from the installation. WSUP indicated that, at least for the short term, they think it is unrealistic to construct a new FSTS to enhance FS collection efficiency for peri-urban areas (WSUP Employee, 2016).

Households (consumers)	
Type of organisation	Not applicable.
Based:	Greater Maputo.
Establishment/ history	The inhabitants of Greater Maputo possess several types of sanitation in their households. Including unimproved and improved latrines, shared facilities like public toilet blocks and flushable toilets with septic tanks connected to the central WW network (in Cement City). This diverse landscape of sanitation creates a wide variety of service quality within Greater Maputo. The demand for improved sanitation services is increasing with economic development. However, households still have little financial means in general, limiting their possibilities to invest in sanitation.
Sector	Sanitation systems (OSS and central network)
Responsibilities:	- The local systems fill up and have to be emptied or closed of periodically. - Septic tanks that are connected to the sewerage system still fill up and should be emptied periodically. Before independence this was obligated and enforced by the municipality, since then however this has not been enforced. As a consequence septic tanks connect to the sewer are rarely emptied and overflowing discharge cause increased risk of clogging the sewerage network (WSUP Employee, 2016).
Services:	- People with limited financial means or accessibility resort to informal emptying of latrines (90% of informal emptying is done by means of a bucket), often in unsafe conditions putting the involved people at health risks (Bäuerl, 2015). - The financial capacity a household correlates with the type of sanitation system that they choose (Bäuerl, 2015, p. 41). The type of system household have correlates with whether or not they have their system emptied or closed after it is full (Bäuerl, 2015, p. 48). From the households that have their system emptied those with simpler systems (lower incomes) significantly more often choose to empty their system informal, often discharging the FS illegally in the direct environment or the sea (Bäuerl, 2015, p. 51).
Challenges:	- A lack of proper emptying services of local systems and local circumstances causing large amount of infiltration, create a serious risk of contamination of local environment, surface and groundwater (Bäuerl, 2015). - Limited investment capacity in local households forces them to choose cheapest sanitation options, often these are unimproved pit latrines (Bäuerl, 2015), which are often even cheaper than the emptying of an existing system.

Appendix F. Costs drainage and sanitation Masterplan

Table 32 Cost of storm water drainage network from the Masterplan (ENGIDRO et al., 2015d)

Municipality / District	System	Total Cost (10^6 USD)	Short Term (2016-2020) (10^6 USD)	Medium Term (2021-2030) (10^6 USD)	Long Term (2031-2040) (10^6USD)
Maputo/ Marracuene	1 e 2	31.30	15.30	1.00	15.00
	3	3.00	1.50	1.50	0.00
	4	27.24	18.82	8.42	0.00
	5	141.54	89.99	33.87	17.68
	6	119.95	104.31	5.07	10.57
	Subtotal	**323.03**	**229.92**	**49.86**	**43.25**
Katembe	7	55.65	19.48	13.91	22.26
	Subtotal	**55.65**	**19.48**	**13.91**	**22.26**
Matola	8	155.70	30.23	44.30	81.17
	9	108.69	59.71	33.27	15.71
	10	68.93	10.14	6.44	52.35
	Subtotal	**333.32**	**100.08**	**84.01**	**149.23**
Boane	11	17.07	0.00	0.00	17.07
	12	16.35	0.00	0.00	16.35
	Subtotal	**33.42**	**0.00**	**0.00**	**33.42**
	Total	**745,42**	**349,48**	**147,78**	**248,16**

Table 33 Cost of WWTPs and FSTPs from the Masterplan (ENGIDRO et al., 2015d)

Municipality / District	System	Total Cost (10^6 USD)	Short Term (2016-2020) (10^6 USD)	Medium Term (2021-2030) (10^6 USD)	Long Term (2031-2040) (10^6 USD)
Maputo/ Marracuene	Infulene	162.20	67.80	22.59	71.81
	Costa do Sol	36.30	17.68	4.12	14.50
	KaTembe	150.14	37.45	32.56	80.13
	Marracuene/ Maputo Norte	7.27	7.27	0	0
	FSTS - Maputo	2.20	1.10	0.55	0.55
	TOTAL	**358.11**	**131.30**	**59.82**	**166.99**
Matola/ Boane	Matola	66.96	21.70	23.71	21.55
	Boane	1.36	1.36	0	0
	TOTAL	**68.32**	**23.06**	**23.71**	**21.55**
TOTAL		**426.43**	**154.36**	**83.53**	**188.54**

Table 34 Storm water drainage and sanitation: investment phasing by system and infrastructure type (ENGIDRO et al., 2015d)

Municipality/ District	Intervention Domain	System / Intervention	Total Cost (106 USD)	Priority Investments (2016-2020) (106 USD)	Priority Investments (2021-2025) (106 USD)	Medium Term (2026-2030) (106 USD)	Long Term (2031-2040) (106 USD)
Maputo/ Marracuene	Sanitation	1 to 4 - Infulene - WWTP	44.38	25.38	0.00	4.00	15.00
		1 to 4 - Infulene – Trunk Sewers + Pumping Station	27.82	20.23	2.39	2.39	2.81
		3 - Infulene - Networks	48.00	4.80	5.76	8.64	28.80
		4 - Infulene - Networks	42.00	4.20	5.04	7.56	25.20
		6 - Costa do Sol - WWTP	12.77	7.89	0.00	0.00	4.88
		6 - Costa do Sol – Trunk Sewers + Pumping Station	8.62	3.49	2.95	1.27	0.91
		6 - Costa do Sol - Networks	14.91	2.64	0.71	2.85	8.71
		5, 6 – Marracuene FSTP	7.27	7.27	0.00	0.00	0.00
		3 to 6 – F. Sludge Transfer Stations	2.20	0.55	0.55	0.55	0.55
		7 - KaTembe - WWTP	54.58	0.00	12.55	0.00	42.03
		7 - KaTembe - Interceptors + Pumping Station	29.73	7.47	6.17	6.70	9.39
		7 - KaTembe - Networks	65.83	5.36	5.90	25.86	28.71
		Subtotal	**358.11**	**89.28**	**42.02**	**59.82**	**166.99**
	Stormwater Drainage	1 and 2 - Cidade de cimento	31.30	14.30	1.00	1.00	15.00
		3 - Joaquim Chissano	3.00	0.00	1.50	1.50	0.00
		4 – Periurban south	27.10	6.92	11.77	8.42	0.00
		5 - North (Zimpeto + Magoanine)	113.55	20.91	48.87	28.84	14.93
		6 - Costa do Sol	95.98	51.18	30.99	8.31	5.50
		7 - Katembe	55.65	8.35	11.13	13.91	22.26
		Subtotal	**326.59**	**101.65**	**105.27**	**61.98**	**57.69**
	Municipality Total		***684.70***	***190.93***	***147.29***	***121.80***	***224.68***
Matola	Sanitation	Trunk Sewers	16.54	11.92	2.66	0.00	1.96
		Networks	42.70	2.31	9.36	11.44	19.59
		Malhampsene FSTP	7.21	7.21	0.00	0.00	0.00
		Subtotal	**66.45**	**21.44**	**12.02**	**11.44**	**21.55**
	Stormwater Drainage	8	155.70	0.70	29.53	44.30	81.17
		9	108.69	37.53	22.18	33.27	15.71
		10	68.93	5.84	4.30	6.44	52.35
		Subtotal	**333.32**	**44.07**	**56.01**	**84.01**	**149.23**
	Municipality Total		***399.77***	***65.51***	***68.03***	***95.45***	***170.78***
Boane	Sanitation	Boane	1.36	1.36	0.00	0.00	0.00
		Subtotal	**1.36**	**1.36**	**0.00**	**0.00**	**0.00**
	Stormwater Drainage	11	17.07	0.00	0.00	0.00	17.07
		12	16.35	0.00	0.00	0.00	16.35
		Subtotal	**33.42**	**0.00**	**0.00**	**0.00**	**33.42**
	Municipality Total		***34.78***	***1.36***	***0.00***	***0.00***	***33.42***
Sanitation (Total)			425.92	112.08	54.04	71.26	188.54
Stormwater drainage (Total without relocations)			693.33	145.72	161.28	145.99	240.34
Stormwater drainage (Relocations)			105.73	41.94	26.09	18.85	18.85
Mobile equipment			81.50	10.00	13.00	20.00	38.50
Training and awareness			20.00	4.00	4.00	4.00	8.00
Studies, projects and supervision			71.43	17.35	14.10	13.35	26.63
TOTAL			**1 397.91**	**331.09**	**272.51**	**273.45**	**520.86**

Appendix G. DAPPs model and specification

The causal loop diagram of the DAPPs each factor that is used in the DAPPs model is presented, the relations between these factors are presented as arrows with a + indicating that the relation is positive or a - indicating a negative relation. First the starting situation and scenarios that are input for the model are presented (Figure 33). The information is equal to what is presented in Section 7.1.

In Table 35, all variables from the model are described. Additionally, both the formulas and units used for these variables are presented.

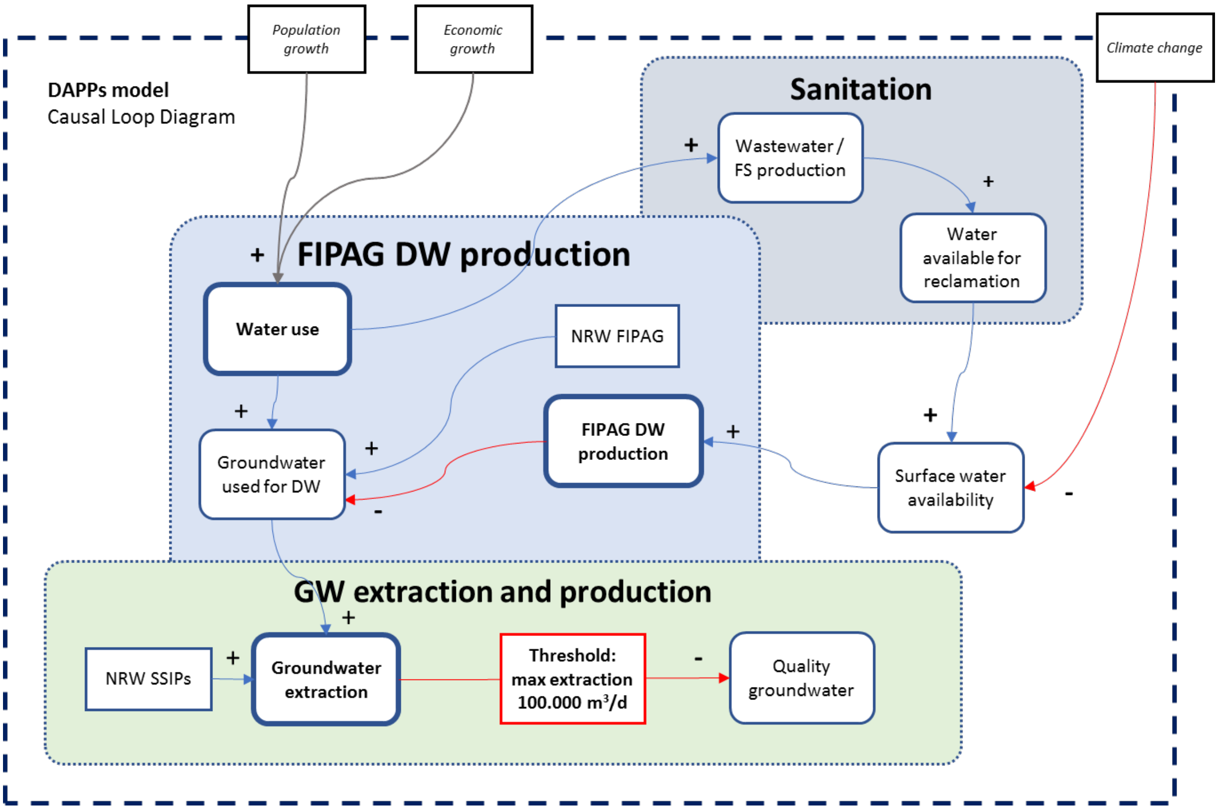


Figure 33 CLD depicting the relations in the model used for DAPPs analysis.

Model imput

	Starting value		Annual growth	%
Starting Year	2017	year	1	
Starting population	2.100.000	person	42.000 - 63.000	2-3%
Domestic water use by pop. growth	141.300	m^3/d	2.826 - 4.239 m^3/d	2-3%
Domestic water use by econ. growth	141.300	m^3/d	0 - 2.826 m^3/d	0-2%
Industrial water use	15.700	m^3/d	471 - 1.099 m^3/d	3-6%
Water use	157.000	m^3/d	3.297 - 8.164 m^3/d	2,1 - 5,2%
Surface water / FIPAG production	200.000	m^3/d	- 600 m^3/d	-0,3%
Groundwater extraction	100.000	m^3/d	-	-
WW production	4.000 - 25.000	m^3/d	84 - 1.300 m^3/d	2,1 - 5,2%

Scenario 1 Rapid climate change, population growth and economic growth			Scenario 2 Slow climate change, population growth and economic growth		
Annual change		Percentage	Annual change		Percentage
63.000	person	3%	42.000	person	2%
4.239	m^3/d	3%	2.826	m^3/d	2%
2.826	m^3/d	2%	-	m^3/d	0%
1.099	m^3/d	7%	471	m^3/d	3%
8.164	m^3/d	5,2%	3.297	m^3/d	2,1%
-700	m^3/d	-0,35%	-500	m^3/d	-0,25%
-	-	-	-	-	-
208 - 1.300	m^3/d	5,2%	84 - 525	m^3/d	2,1%

Water supply networks	Connections	NRW	Total connections	NRW
current network	175.000	45%	175.000	45%
Network expansion phase 1 (2018)	120.000	25%	295.000	37%
Network expansion phase 2 (2024)	100.000	25%	395.000	34%

	Connections	NRW
SSIPs	180.000	53%

Figure 34 DAPPs model starting situation and scenarios.

Table 35 Variables and formulas used in the DAPPs model

No.	Variable	Description	Formula	Units
1	$Water\ use$	The total volume of freshwater used in Greater Maputo, including domestic and industrial use, supplied by both FIPAG and SSIPs.	$Water\ use_{2017} \times (1 + Water\ use_{ann.increase})$	$m^3\ day^{-1}$
	$Water\ use_{yearly\ increase}$	The yearly increase is dependent on the scenario. The value for both scenarios is presented in Figure 33.	$(Domestic\ water\ use \times pop.growth) + (Domestic\ water\ use \times econ.growth) + (Industrial\ water\ use \times econ.growth)$	%
2	$FIPAG\ supply$	The volume of water supplied via the FIPAG network that is actually used. The FIPAG production minus the NRW.	$Water\ use_{2017} \times (1 + Water\ use_{ann.increase})$	$m^3\ day^{-1}$
3	$Surface\ water\ /\ FIPAG\ production$	The amount of surface water that is available for FIPAG production, decreasing yearly due to climate change.	$Surface\ water_{2017} \times (1 + Surface\ Water_{ann.decrease})$	$m^3\ day^{-1}$
4	$GW\ used\ for\ DW$	The volume of water supplied by SSIPs that is actually used as DW or for other purposes. In this model it is the difference between the $Water\ use$ and $FIPAG\ supply,$ as the GW use is seen as the buffer between demand and the formal supply.	$Water\ use - \ FIPAG\ supply$	$m^3\ day^{-1}$
5	$GW\ extraction$	This is the $GW\ used\ for\ DW$ increased with the volume of NRW that is lost in supplying the GW. NRW of SSIPs, is presented in Figure 33.	$\frac{GW\ used\ for\ DW}{(1 - NRW\ \ SSIPs)}$	$m^3\ day^{-1}$

In Table 36, Table 37 and Table 38 the data for each strategy is presented. These are the underlying data points for the diagrams presented in Section 7.6. All the actions as presented in the strategies for both scenarios are included in the year of action. The actions are highlighted green, underneath the variable that they influence. For example Corumana, is two WTPs of 60.000 m^3/d under the surface water availability. Also visible are the included NRW expansion projects, that take into effect in 2019 and 2025, as changes in the NRW that occur in every strategy and scenario.

Table 36 DAPPs model data for strategy 1, with both scenario 1 and 2.

Strategy 1: Traditional approach

Scenario 1	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Water use	157.000	165.164	173.753	182.788	192.293	202.292	212.811	223.877	235.519	247.766	260.650	274.203	288.462	303.462
FIPAG supply (production - NRW)	110.000	109.615	163.270	162.699	162.129	161.562	160.996	160.433	207.161	206.436	205.713	204.993	204.276	296.156
NRW	45%	45%	37%	37%	37%	37%	37%	37%	34%	34%	34%	34%	34%	34%
Surface water / FIPAG production	200.000	199.300	258.602	257.697	256.795	255.897	255.001	254.108	313.219	312.123	311.030	309.942	308.857	447.776
			60.000						60.000					140.000
Use of groundwater	47.000	55.549	10.482	20.089	30.163	40.730	51.815	63.444	28.358	41.330	54.936	69.210	84.186	7.306
SSIPs groundwater extraction	100.000	118.189	22.303	42.742	64.177	86.660	110.244	134.988	60.336	87.936	116.886	147.256	179.120	15.545

Scenario 1	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Water use	319.242	335.843	353.306	371.678	391.006	411.338	432.727	455.229	478.901	503.804	530.002	557.562	586.555	617.056	649.143	682.898	718.409	755.766	795.066	836.410
FIPAG supply (production - NRW)	295.119	294.086	359.196	357.939	356.686	355.438	354.194	352.954	351.719	350.488	349.261	348.039	346.820	345.607	344.397	343.192	341.990	340.793	339.601	338.412
NRW	34%	34%	34%	34%	34%	34%	34%	34%	34%	34%	34%	34%	34%	34%	34%	34%	34%	34%	34%	34%
Surface water / FIPAG production	446.209	444.647	543.091	541.190	539.296	537.408	535.527	533.653	531.785	529.924	528.069	526.221	524.379	522.544	520.715	518.892	517.076	515.267	513.463	511.666
			100.000																	
Use of groundwater	24.123	41.756	-5.890	13.739	34.319	55.900	78.534	102.275	127.183	153.316	180.741	209.523	239.735	271.450	304.746	339.707	376.419	414.973	455.466	497.998
SSIPs groundwater extraction	51.325	88.843	-12.531	29.233	73.020	118.936	167.093	217.607	270.601	326.205	384.555	445.794	510.074	577.552	648.396	722.781	800.891	882.921	969.076	1.059.570

Scenario 2	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Water use	157.000	160.297	163.663	167.100	170.609	174.192	177.850	181.585	185.398	189.292	193.267	197.325	201.469	205.700
FIPAG supply (production - NRW)	110.000	109.615	163.270	162.699	162.129	161.562	160.996	160.433	207.161	206.436	205.713	204.993	204.276	203.561
NRW	45%	45%	37%	37%	37%	37%	37%	37%	34%	34%	34%	34%	34%	34%
Surface water / FIPAG production	200.000	199.300	258.602	257.697	256.795	255.897	255.001	254.108	313.219	312.123	311.030	309.942	308.857	307.776
			60.000						60.000					
Use of groundwater	47.000	50.682	393	4.401	8.480	12.630	16.854	21.152	-21.762	-17.144	-12.446	-7.668	-2.807	2.139
SSIPs groundwater extraction	100.000	107.834	836	9.365	18.042	26.873	35.859	45.004	-46.303	-36.477	-26.482	-16.315	-5.971	4.552

Scenario 2	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Water use	210.020	214.430	218.933	223.531	228.225	233.018	237.911	242.907	248.008	253.216	258.534	263.963	269.506	275.166	280.944	286.844	292.868	299.018	305.298	311.709
FIPAG supply (production - NRW)	295.443	294.409	293.379	292.352	291.329	290.309	289.293	288.280	287.271	286.266	285.264	284.266	283.271	282.279	281.291	280.307	279.326	278.348	277.374	276.403
NRW	34%	34%	34%	34%	34%	34%	34%	34%	34%	34%	34%	34%	34%	34%	34%	34%	34%	34%	34%	34%
Surface water / FIPAG production	446.699	445.135	443.577	442.025	440.478	438.936	437.400	435.869	434.343	432.823	431.308	429.799	428.294	426.795	425.302	423.813	422.330	420.852	419.379	417.911
	140.000																			
Use of groundwater	-85.423	-79.979	-74.446	-68.821	-63.104	-57.291	-51.382	-45.373	-39.263	-33.050	-26.730	-20.303	-13.764	-7.113	-347	6.538	13.542	20.670	27.924	35.306
SSIPs groundwater extraction	-181.752	-170.168	-158.395	-146.428	-134.263	-121.897	-109.323	-96.539	-83.539	-70.318	-56.873	-43.197	-29.286	-15.135	-738	13.910	28.814	43.979	59.412	75.119

Table 37 DAPPs model data for strategy 2, with both scenario 1 and 2.

Strategy 2: Traditional approach with improvement to the current system

Scenario 1	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Water use	157.000	156.906	165.065	173.648	182.678	192.177	202.170	212.683	223.743	235.377	247.617	260.493	274.039	288.289
		-5%												
FIPAG supply (production - NRW)	110.000	109.615	125.120	136.556	136.078	177.002	176.382	175.765	180.227	189.714	234.050	233.231	232.414	231.601
NRW	45%	45%	37%	31%	31%	31%	31%	31%	29%	25%	25%	25%	25%	25%
Surface water / FIPAG production	200.000	199.300	198.602	197.907	197.215	256.524	255.627	254.732	253.840	252.952	312.067	310.974	309.886	308.801
						60.000					60.000			
Use of groundwater	47.000	47.291	39.945	37.092	46.600	15.175	25.788	36.918	43.516	45.664	13.567	27.262	41.624	56.688
SSIPs groundwater extraction	100.000	100.619	84.990	78.920	99.149	32.288	54.868	78.550	92.588	97.157	28.866	58.005	88.563	120.613

Scenario 2	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Water use	157.000	152.282	155.480	158.745	162.079	165.482	168.958	172.506	176.128	179.827	183.603	187.459	191.396	195.415
		-5%												
FIPAG supply (production - NRW)	110.000	109.615	125.120	124.682	124.245	123.810	123.377	134.654	138.072	137.589	137.108	179.228	178.600	177.975
NRW	45%	45%	37%	37%	37%	37%	37%	31%	29%	29%	29%	29%	29%	29%
Surface water / FIPAG production	200.000	199.300	198.602	197.907	197.215	196.524	195.837	195.151	194.468	193.787	193.109	252.433	251.550	250.669
												60.000		
Use of groundwater	47.000	42.667	30.361	34.064	37.834	41.672	45.581	37.851	38.056	42.238	46.496	8.231	12.795	17.440
SSIPs groundwater extraction	100.000	90.781	64.597	72.476	80.497	88.664	96.980	80.535	80.970	89.868	98.927	17.514	27.224	37.106

2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
303.280	319.050	335.641	353.094	371.455	390.771	411.091	432.468	454.956	478.614	503.502	529.684	557.227	586.203	616.686	648.753	682.489	717.978	755.313	794.589
335.790	334.615	333.444	332.277	331.114	404.955	403.538	402.125	400.718	399.315	397.918	396.525	395.137	393.754	392.376	391.003	389.634	388.271	386.912	385.557
25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%
447.721	446.153	444.592	443.036	441.485	539.940	538.050	536.167	534.290	532.420	530.557	528.700	526.850	525.006	523.168	521.337	519.512	517.694	515.882	514.077
140.000					100.000														
-32.510	-15.565	2.197	20.817	40.341	-14.184	7.553	30.343	54.238	79.299	105.584	133.159	162.090	192.449	224.310	257.751	292.854	329.708	368.401	409.032
-69.171	-33.116	4.675	44.293	85.833	-30.179	16.071	64.559	115.401	168.720	224.647	283.317	344.873	409.466	477.255	548.406	623.095	701.505	783.833	870.280

2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
199.519	203.709	207.986	212.354	216.814	221.367	226.015	230.762	235.608	240.556	245.607	250.765	256.031	261.408	266.897	272.502	278.225	284.067	290.033	296.123
177.352	176.732	176.113	175.497	174.882	184.088	183.444	227.802	227.005	226.210	225.418	224.630	223.843	223.060	222.279	296.501	295.463	294.429	293.399	292.372
29%	29%	29%	29%	29%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%
249.792	248.918	248.047	247.178	246.313	245.451	244.592	303.736	302.673	301.614	300.558	299.506	298.458	297.413	296.372	395.335	393.951	392.572	391.198	389.829
							60.000								100.000				
22.166	26.977	31.873	36.858	41.931	37.278	42.571	2.960	8.603	14.345	20.189	26.135	32.188	38.348	44.618	-23.999	-17.239	-10.362	-3.366	3.752
47.162	57.398	67.816	78.420	89.215	79.316	90.577	6.297	18.304	30.522	42.955	55.607	68.484	81.591	94.932	-51.062	-36.678	-22.047	-7.162	7.982

Table 38 DAPPs model data for strategy 3, with both scenario 1 and 2.

Strategy 3: Innovative approach combining limiting water use, with water reuse of wastewater

Scenario 1	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Water use	157.000	156.906	165.065	173.648	182.678	192.177	202.170	212.683	223.743	235.377	247.617	260.493	274.039	288.289
		-5%												
FIPAG supply (production - NRW)	110.000	109.615	125.389	136.556	136.078	135.602	176.527	175.909	180.375	179.743	221.714	220.938	220.165	231.755
NRW FIPAG	45%	45%	37%	31%	31%	31%	31%	31%	29%	29%	29%	29%	29%	25%
Surface water / FIPAG production	200.000	199.300	198.602	197.907	197.215	196.524	255.837	254.941	254.049	253.160	312.274	311.181	310.092	309.006
							60.000				60.000			
Use of groundwater	47.000	47.291	39.676	37.092	46.600	56.575	25.643	36.774	43.368	55.634	25.903	39.555	53.874	56.534
NRW SSIPs	53%	53%	53%	53%	53%	43%	43%	43%	43%	43%	43%	43%	43%	43%
SSIPs groundwater extraction	100.000	100.619	84.417	78.920	99.149	99.255	44.988	64.516	76.085	97.604	45.444	69.395	94.516	99.183

Scenario 2	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Water use	157.000	156.906	160.201	163.565	167.000	170.507	174.088	177.743	181.476	185.287	189.178	193.151	197.207	201.348
		-5%												
FIPAG supply (production - NRW)	110.000	109.615	125.389	124.950	124.513	124.077	135.127	134.654	138.072	137.589	137.108	136.628	143.820	143.317
NRW	45%	45%	37%	37%	37%	37%	31%	31%	29%	29%	29%	29%	25%	25%
Surface water / FIPAG production	200.000	199.300	198.602	197.907	197.215	196.524	195.837	195.151	194.468	193.787	193.109	192.433	191.760	191.089
Use of groundwater	47.000	47.291	34.812	38.615	42.487	46.430	38.960	43.089	43.404	47.698	52.070	56.523	53.387	58.032
NRW SSIPs	53%	53%	53%	53%	53%	53%	53%	53%	53%	53%	43%	43%	43%	43%
SSIPs groundwater extraction	100.000	100.619	74.068	82.160	90.398	98.787	82.894	91.679	92.348	101.485	91.352	99.163	93.661	101.810

2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
303.280	319.050	335.641	353.094	371.455	390.771	411.091	432.468	454.956	478.614	503.502	529.684	557.227	586.203	616.686	648.753	682.489	717.978	755.313	794.589
253.690	377.231	375.911	374.595	373.284	371.978	370.676	479.658	477.979	476.306	474.639	472.978	471.322	469.673	468.029	466.391	464.758	463.132	461.511	459.895
25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%
338.253	502.975	501.215	499.460	497.712	495.970	494.234	639.544	637.305	635.075	632.852	630.637	628.430	626.230	624.038	621.854	619.678	617.509	615.348	613.194
30.328	165.906						147.039												
49.590	-58.181	-40.270	-21.501	-1.829	18.793	40.415	-47.190	-23.023	2.308	28.863	56.706	85.905	116.531	148.657	182.363	217.730	254.846	293.802	334.694
43%	43%	43%	43%	43%	43%	43%	43%	43%	43%	43%	43%	43%	43%	43%	43%	43%	43%	43%	43%
87.001	-102.072	-70.649	-37.721	-3.209	32.971	70.904	-82.789	-40.391	4.049	50.637	99.485	150.711	204.440	260.802	319.935	381.983	447.099	515.443	587.182

2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
205.577	209.894	214.301	218.802	223.397	228.088	232.878	237.768	242.761	247.859	253.064	258.379	263.805	269.345	275.001	280.776	286.672	292.692	298.839	305.114
158.233	157.679	157.127	241.910	241.064	240.220	239.379	238.541	237.706	236.874	236.045	235.219	234.396	233.575	232.758	231.943	231.131	304.959	303.892	302.828
25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%
210.978	210.239	209.503	322.547	321.418	320.293	319.172	318.055	316.942	315.832	314.727	313.625	312.528	311.434	310.344	309.258	308.175	406.612	405.189	403.771
20.558			113.777														99.515		
47.343	52.214	57.174	-23.108	-17.667	-12.132	-6.501	-773	5.055	10.985	17.019	23.160	29.409	35.769	42.243	48.833	55.541	-12.267	-5.053	2.286
43%	43%	43%	43%	43%	43%	43%	43%	43%	43%	43%	43%	43%	43%	43%	43%	43%	43%	43%	43%
83.059	91.604	100.305	-40.541	-30.995	-21.284	-11.406	-1.356	8.869	19.272	29.858	40.631	51.595	62.753	74.110	85.671	97.440	-21.521	-8.865	4.011

Appendix H. General DAPPs diagram

In Figure 35 depicts the complete pathways diagram. The lighter lines are actions that are impossible or highly unlikely at that time. From all the other pathways decision makers can choose those that they find most desirable. The two timelines on the bottom are the development scenarios, showing how long an action are expected to be sufficient under rapidly and slowly changing external influences.

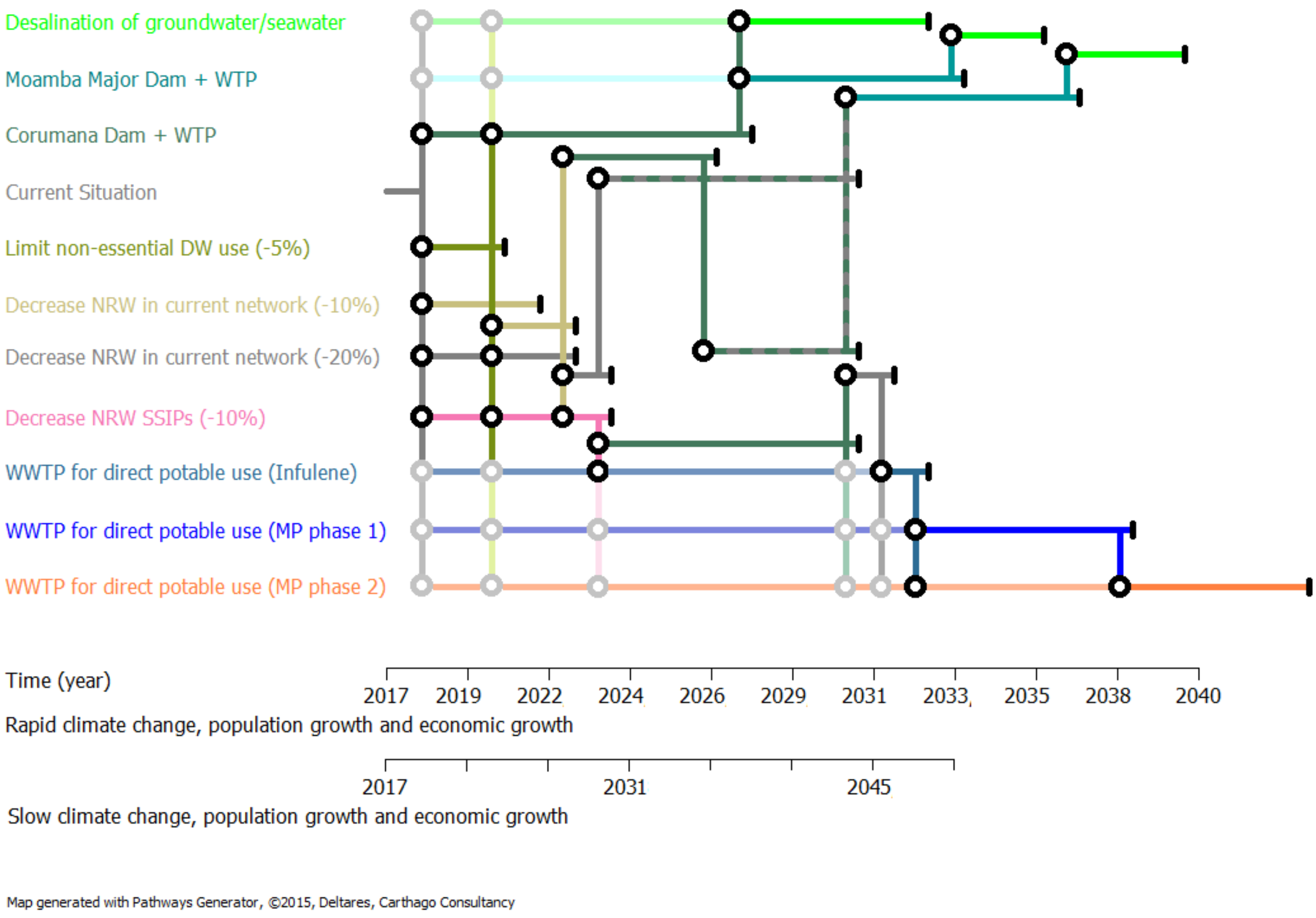


Figure 35 DAPPs Diagram for both scenario's with full possibilities presented.