Sustainable Dala

Showcase for a sustainable water infrastructure

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TU Delft

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TU Delft Delft University of Technology

Preface

Dear reader,

Before you lies the report of our multidisciplinary project in Myanmar: 'Sustainable Dala'. This project was carried out as part of our masters program at the Delft University of Technology and in preparation for the Amsterdam International Water Week 2017, where the result will be presented. From 28 August until 20 October 2017 we worked in Yangon, where we could visit the area of study, Dala, and where we were in contact with local experts. We were very impressed by the things we saw in the Dala Township. The problems regarding drinking water were visible, and the stories we heard from inhabitants were daunting.

This led us to work towards an innovative design that could be solve the problems and be feasible to implement in the area of Dala. We hope that, although the scope of the design is limited, some valuable ideas and information can be found in this document by local stakeholders.

We would like to give a special thanks to Daw Tin Tin Kyi, Daw Nyein Aye, Daw Saw Sandar Oo and Daw Khaing Moe Nyunt from the Yangon City Development Committee for showing us around in Dala, giving us feedback on our findings and joining our workshop. We also want to thank UNESCO-IHE alumni U Cho Cho, U Khin Lat and U Aye Myint from the National Engineering and Planning Services for their thorough knowledge and elaborated feedback on our report and workshops. Furthermore we want to thank the Dutch and Burmese experts from the Young Expert Programme and the students, both from Maritime Myanmar University and Yangon Technological University, for their input during our workshops. We want to especially thank Ir. Tanya Huizer and Ir. Alwin Commandeur from the Young Expert Programme for guiding us in Yangon and introducing us to the right people. Likewise our supervisors in the Netherlands, Dr. Ir. Martine Rutten and Dr. Ir. Adam Pel, who gave answers to our questions and advise us via e-mail and Skype while being in Yangon, and helped us setting up the project. Thank you for your time, involvement and expertise during the project. Furthermore, we would like to thank our sponsors for making this project possible and our followers on social media for their interest. You really motivated us to work on this project even harder to achieve better results. We would also like to thank our families for their love and support. Your phone calls, motivating messages and kind words kept us going.

We hope you enjoy reading our report.

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Yangon, October 2017

"Don't spend money as water, spend water like money" - U Cho Cho

Abstract

The goal of this project is to develop a design for Dala's water system that deals with challenges of the township in a sustainable way. Dala is a township of Yangon, Myanmar's economic centre. It is located directly South of the central business district (CBD), across the Yangon river. The area is now largely underdeveloped, but in 2021 it will be directly connected to Yangon's CBD by a bridge, after which rapid urbanization and growth is expected. Current water infrastructure is already lacking heavily, making the need for a full new system even more imminent for the future.

In an 8 week field research period, a full design cycle was conducted with input from several local experts and stakeholders. The final advice is to implement a new system focused on rainwater harvesting, large-scale storage in reservoirs and a dual reticulation system for water supply to the consumer. Other water infrastructure, such as drainage, sewage and treatment is designed to fit these focal points.

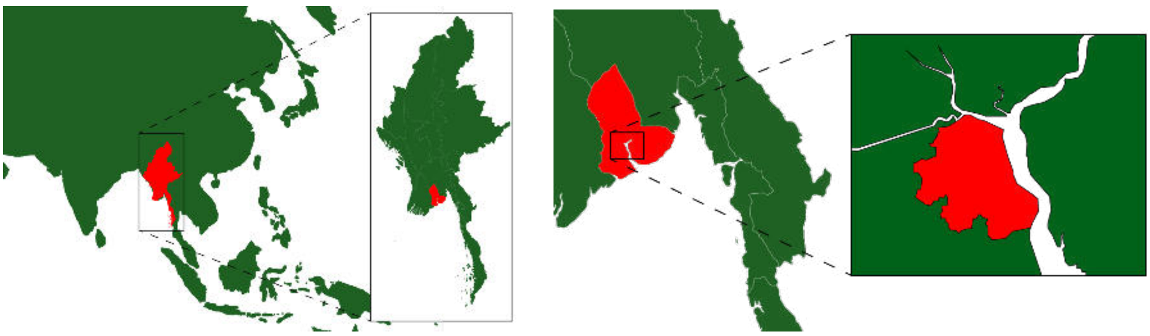
This system is more sustainable than commonly used methods, as the resource is not impacted and energy is saved on treatment and transport. Furthermore, it caters for all expected water needs in 2040, making Dala fully self sufficient in closing the water circle.

Contents

1
Introduction

Water supply and sanitation are some of the most serious impediments in developing countries [106]. Even in areas where large, sometimes overflowing rivers and a monsoon season brings in more than enough water, people are facing shortage of drinking water. Yangon is one such regions. Situated in the Ayeyarwady delta and subject to a monsoon season of almost four months, the region has an abundance of water. However, not all of Yangon's inhabitants can benefit from this. They lack adequate water infrastructure and become dependent on donations.

One such areas is Dala (see Figure 1.1). Located at the South bank of the Yangon river, directly opposite Yangon's central business district (CBD), it forms a sharp contrast to the rest of the city. Facilities such as a large scale water supply system, sanitation and drainage are barely present. Residents collect drinking water directly from the rainwater reservoirs, but when these dry out towards the end of the dry season, they become dependent on water donations from Yangon. As described by inhabitants of Dala in Appendix E, section E.1, due to the poor state of the road infrastructure, the donated water, which is transported by truck in tanks, cannot reach all residents. Salt water intrusion and risk of land subsidence make use of more abundant water resources such as the river and groundwater difficult.



(a) Location of the Yangon State and Myanmar in South-East Asia

(b) Location of Dala and Yangon in the Yangon State

Figure 1.1: Location of Dala

Next to these current challenges, Dala is facing rapid changes in the future. According to plans made by Japanese and Korean funds for the Yangon City Development Committee (YCDC) to promote economic growth in the area, a bridge will be constructed linking Dala directly to the CBD by 2021 [48]. This bridge will be part of an economic corridor running from the CBD through Dala to a future ring road linking all current and future economic zones of Yangon. The improved connectivity and location of Dala will likely make it very attractive for people to live and industry to settle. Therefore, rapid growth and urbanization of the township is expected. This will have major consequences for the entire water cycle in Dala.

The goal of this project is to develop a design for Dala's water system that deals with current and future challenges of the township in a sustainable way. In order to do this, knowledge is needed about the parties involved in governing Dala's water system, the spatial development of the township, the water needs and possible sustainable and innovative measures. Therefore the main research question is:

Which steps need to be undertaken to develop a sustainable, future-proof water infrastructure for the Township of Dala?

This research question can be answered by addressing the following sub-questions:

How can the actor framework governing Dala's water system be characterized?

How can the expected spatial development of Dala be characterized?

How can the resulting water needs in Dala be characterized?

How can these water needs be tended to in a sustainable and innovative way?

A two month field research period was conducted during which three visits were made to the research area, Dala. The research period was also used to conduct interviews with stakeholders such as Dala inhabitants, Dala local government and the YCDC. Besides this, workshop sessions and interviews were arranged to gain insights from students from the Yangon Technological University (YTU) and Myanmar Maritime University (MMU), local experts from the Young Expert Programmes (YEP) and experts from other relevant organizations such as the National Engineering and Planning Services (NEPS) and the National Water Resources Committee (NWRC).

In order to develop the design, a design cycle was followed containing a number of structured steps and a number of iteration cycles between those steps. The model that this approach was based on is called the V-model. It was developed by Paul Rook [89] for software projects, but it is often used to offer structure in large design projects of all sorts. Figure 1.2 shows the v-model as it was adapted for this design cycle. The arrows are not to be taken too strictly, as more iteration steps were made during the design cycle.

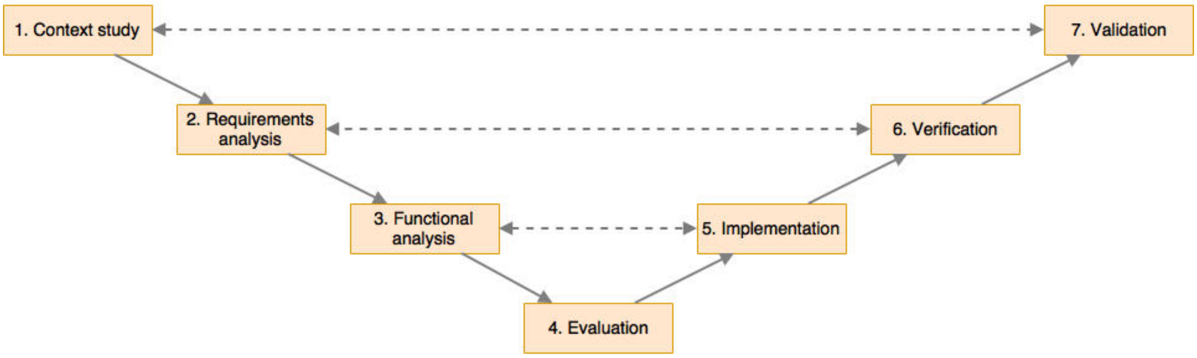


Figure 1.2: V-model adapted for this design cycle

The report chapters largely follows the design steps. First, in chapter 2 background information is presented about the current situation in Dala and the relevant stakeholders, and a number of scenarios for the future development of Dala are sketched. Then, the requirements to which the design needs to comply are defined in chapter 3. However, as these requirements are subject to the rapid development of the area, a land-use model describing those dynamics was constructed as presented in chapter 3. The functions of the water system were defined, a morphological chart was made to find solutions for these functions and by combining these solutions, three alternative designs were generated, all of which is presented in chapter 4. Using the previously defined requirements, the alternatives were evaluated and their best characteristics were combined, as presented in chapter 5. The final design that followed is presented in chapter 6. In chapter 7 a verification and validation of the design is presented. Finally chapter 8 contains a round up with answers to the research questions, discussion and proposed further research.

2 Context

When designing a system, it is important to have a clear picture of the context in which the system will be implemented and operative. In this chapter that context is presented. First a short introduction is given of Dala in its current state, then the scope and assumptions bounding this project are presented, after this an analysis of the relevant stakeholders is given, and finally the scenarios for the future development of Dala are presented.

2.1. Introduction to Dala

Dala is a township on the south bank of the Yangon River, opposite of the Yangon CBD. The area has a surface of 224 km^2. A map of Dala and its surroundings are shown in Figure 2.1. This section will give background information on the current situation of Dala. Its demographic, economic, housing and infrastructural situation are sketched, after which an overview is given on current projects in and around Dala.

Figure 2.1: Dala and its surroundings

Demography

Dala is home to around 173.000 inhabitants, of which most live in the urban area, in the north of Dala [20]. Table 2.1 depicts the basis demographic information of Dala.

Table 2.1: Demographic data Dala in 2014 [20]

Total inhabitants	Male	Female	In urban area	In rural area
172,860	84,670	88,190	119,370	53,490

Economy

In comparison to Yangon, Dala stayed behind with respect to economical growth [9]. From observations, made during field work in the urban area of Dala, it can be stated that commercial activities within Dala are limited to the retail of products used in the area itself. A large portion of the total area of Dala is used for agricultural purposes [48, p.13]. Lastly, a large amount of the inhabitants of Dala are dependent on work in Yangon, and rely on the ferry service to commute to Yangon each day, as stated in Appendix E, section E.4. This is supported by the fact that about 30.000 people make use of the ferry between Dala and Yangon each day [48, p.77].

Housing

During field work in Dala, it was observed that most of the houses are built with waste materials on land which is not owned by the residents themselves, as seen in Figure 2.2a. Although this form of squatting is officially illegal in Myanmar, the government does not take any action against it. As stated in Appendix E, section E.4, interventions are not undertaken by governmental institutions. This is because any actions will lead to squatters reallocating themselves. Instead of solving the problem of illegal settlements, this would replace the problem. Therefore Dala is currently attractive for squatters.

(a) Houses of squatters in Dala

(b) Crowds at the Dala ferry

Figure 2.2: Photos of housing and the ferry in Dala

Infrastructure

In the last ten years several improvements have been made. The largest improvement has been to the infrastructure of Dala, as stated by inhabitants in Appendix E, section E.1. With these improvements, the main roads have been paved. However, within the wards most of the roads are not paved, this results in accessibility problems for motorized vehicles. Transport between Dala and Yangon is done by ferry, providing a connection for approximately 30.000 commuters per day [48, p.77]. With only two ferries operating, this facility can get crowded, as seen in Figure 2.2b. When foggy conditions occur in the dry season, the ferry is not operating. This results in long waiting lines for the smaller, unsafe, boats, as can be seen in Figure 2.3a.

(a) Dala inhabitants waiting for small boats to cross the river

(b) Officials inspecting a dried out pond in Dala

Figure 2.3: Photos of Dala, made by U Tin Hla

Water facilities

There are almost no drinking water treatment plants or wastewater systems present in Dala. The current water facilities in Dala are almost non-existent. Only 12 % of the total population in Dala is connected to a water supply system [9]. The remaining 88% needs to rely on other methods in order to have access to water. This portion of the population needs to rely on the distribution of water via trucks, water donations and harvesting through communal ponds. A small portion of this population is able to buy water which comes from Yangon in water tanks. However, the remaining portion of the population relies on water from the water ponds. This water is harvested during the wet season and is stored until the dry season. However, some years, the water in these ponds dries up as can be seen in Figure 2.3b. When this happens the local population are dependant on water donations from Yangon as can be seen in Figure 2.4a. Figure 2.4b shows the local people of Dala queuing in line to fill there water bottles with water from donations.

(a) Truck in Dala delivering water donations from Yangon

(b) People in Dala queuing up for filling water bottles

Figure 2.4: Photos of Dala, made by U Tin Hla

Current and future projects

As already described in chapter 1, foreign funds are involved in the development of Greater Yangon. Next to the plans of the Koreans and Japanese, other companies are setting up projects to treat water to produce drinking water, as described in Appendix E. From the plans described in JICA and YCDC [48, p. 80] namely infrastructure projects are already implemented. Water treatments projects in Dala will be executed, starting from November 2017, described in Appendix E, section E.3.

2.2. Scope and assumptions

The case under study is quite multifaceted and can be approached in different ways. Many aspects of Dala's water system can be researched in-depth, but doing so may take several months, if not years. Therefore, it is important to define a scope and a number of assumptions that are being used for the project.
The scope of the project is defined by the following boundaries:

- This project looks at infrastructure supporting the water cycle. Development of other types of infrastructure in Dala is outside the scope of this project
- The system will treat and supply the water with a certain quality and not with a certain temperature.
- The flood risk of the area is acknowledged. However, flooding is not the focal point of this project. Therefore, flood prevention will only be included at a global level.
- The project focuses on water for domestic and industrial use, water for agriculture falls outside the scope.
- Dala is currently already struggling with a gap between supply and demand in terms of water. YCDC is working on solutions to bridge this gap until a better, large scale water infrastructure is implemented, as mentioned in Appendix E, section E.3 and section E.6. Solutions to bridge this gap fall outside the scope of this research.
- The project area is bounded by the geographic boundaries of Dala region, published by Brinkhoff [12], and JICA and YCDC [48] depicted in Figure 2.5 with the dark blue line.

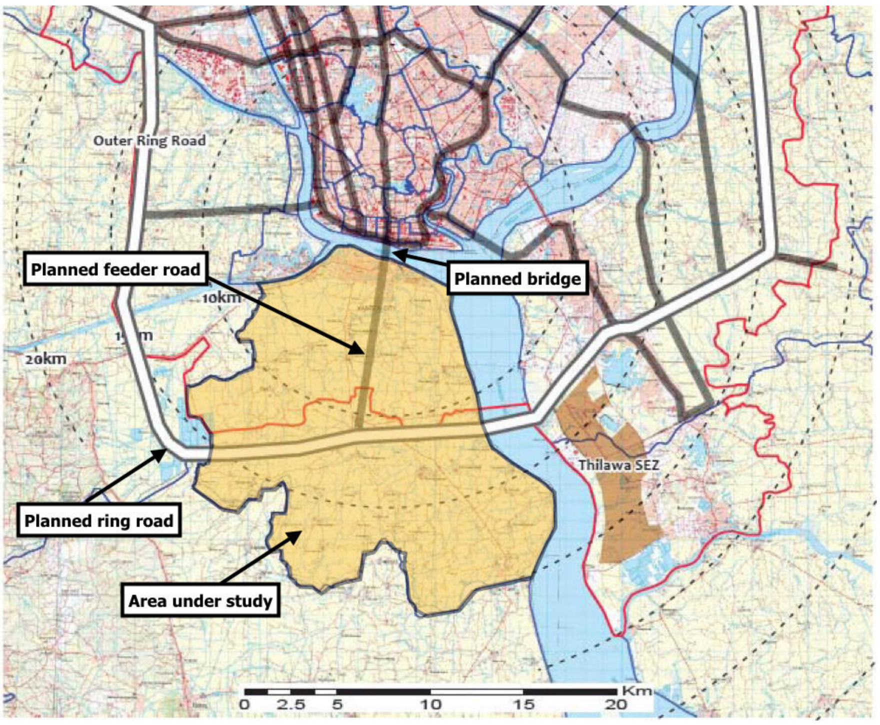


Figure 2.5: Area under study [48, p. 57]

The assumptions that are made are as follows:

- By the year of 2021 there will be a connection (bridge or tunnel) between Yangon's CBD and Dala [107].
- By the year of 2035 there will be an outer ring road connecting the southern part of Dala with Thilawa [48, p.86].
- The landing of the connection will be roughly $1km$ inward from the river bank. The Dala landing will be at the intersection of Bo Min Yaung rd. and Dala-Twante rd.
- By the year of 2030 there will be a connection (bridge or tunnel) [48, p. 87] between Dala and Thilawa
- The population of the Yangon region will increase with 2,6% each year [48, p.44].
- Although sources can be found on the negative influence of climate change on the investments for industrial activities [68, p. 24], the assumption is that Dala is still considered as a potential location for these activities. This is supported by multiple news articles that speculate on foreign investments on activities in Dala and testimonies from representatives of YCDC and NWRC, as can be seen in Appendix E, section E.5 and in Win [121] and Mon and Nyein Aye [67].
- No heavy industry will settle in the Dala region, as explained in section E.5.
- A large share of the riverbank of Dala will be developed for recreational use, as explained in section E.5.
- A public transport connection will arise between Dala and Yangon.
- Other infrastructure, such as electricity supply, will increase proportionally with the population and industry.
- Businesses servicing the population (eg. banks, convenience stores) will increase proportionally to the population.

2.3. Stakeholder analysis

To form a complete picture of the environment in which the problem plays and the design should be implemented, a stakeholder analysis was conducted. The aim of a stakeholder analysis is to map any and all parties that are affected by or can affect the problem or the solution. Dala, as it is being analyzed and designed for in this research, should be seen as a socio-technical system: people interact with technology and infrastructure. Technology determines the success of human endeavours and human behaviour determines the success of technological solutions. Therefore, it is important to analyze stakeholders' interests, opinions and resources. This helps to see under which conditions the solution will be successful and which stakeholders need to be actively or passively involved.

For this case, 22 relevant stakeholders were identified. A full list and analysis can be found in Appendix A. Following a study of the stakeholders' interests and resources, a power-interest grid was constructed. This is a graphic tool that classifies stakeholders according to their interest in the case and their power to enforce their interest. The grid, as found in Figure 2.6, can be used to identify stakeholders that require minimal effort (lower left quadrant), stakeholders to keep satisfied (upper left quadrant), stakeholders to keep informed (lower right quadrant) and the so-called 'key players' (upper right quadrant) [71]. A further explanation of the power-interest grid can be found in Appendix A.

Some important general acknowledgments prevailed from the analysis. Firstly, Myanmar has a large spectrum of governmental bodies at different levels (national, regional, local, township). This means that responsibilities for the water system are not only scattered, they are also overlapping between different bodies [112]. Secondly, international funds and investors have a large interest and high amount of power in the area due to large investments and penetration in the upper governmental layers of Yangon [121]. And finally, Dala's local government, its inhabitants, and possible future inhabitants and companies have a high interest and positive attitude towards urban development in Dala, but little power to do anything themselves. Below, the 'key players' [71] are further described.

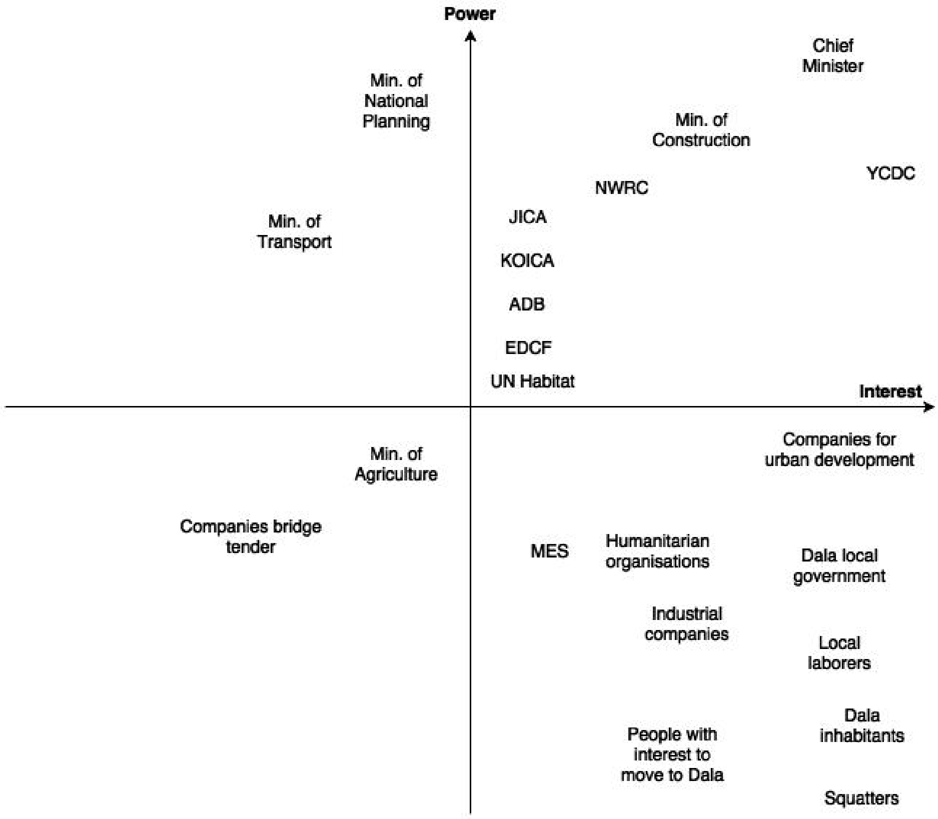


Figure 2.6: Power-interest grid of stakeholders

YCDC

The YCDC is the municipal government and the problem owner for this research. Their main goal is the welfare of the city of Yangon for which they have drawn up a plan in cooperation with JICA: The Strategic Urban Development Plan of the Greater Yangon [48]. From this plan, the intention to build the bridge in order to connect (new) economic centres and the intention to improve water infrastructure were derived. In terms of water management the YCDC is responsible for the quality of drinking water and sanitation in Yangon [112].

Chief Minister Yangon region

Myanmar has 14 regional governments with each a Chief Minister as their chief executive [69]. The regional government's main task is to implement projects that fall within the union government's policies. Yangon region's Chief Minister, Phyo Min Thein, has grand plans for the Yangon region for his period in office. His goal is to improve living conditions and connectivity to ensure economic growth. Roads and bridges of regional significance fall under the regional government's jurisdiction [112].

National Water Resources Council (NWRC)

As Myanmar has many governmental bodies who have (overlapping) water topics in their jurisdiction, the NWRC was established in 2013 and formulated a National Water Policy (NWP) in 2014 [113]. This policy acknowledges that an integrated water resources management approach is needed to exploit Myanmar's abundant water resources to its fullest while mitigating problems with water, such as water quality, water supply and flooding. The NWRC receives advice from an advisory group of water management professionals chaired by U Cho Cho [112], one of the water management experts who were involved in this project.

Ministry of Construction

This ministry is, among other things, responsible for building and maintaining the transport infrastructure. Next to this, they are also responsible for ensuring proper drainage of the system, and planning and developing sanitation systems in new settlement areas [5, 48].

International funds and loans

A number of international funds have invested money and knowledge in the development of the Greater Yangon region. Together, these funds have invested more than $1,2 billion in Myanmar, mainly aimed at improving the infrastructure [1, 49, 53]. First and foremost, there is the Japanese International Cooperation Agency (JICA), who have not only administered a significant loan to the government of Myanmar to invest in water and transport infrastructure projects, but have also cooperated with YCDC in a long and intensive research to create The Strategic Urban Development Plan of the Greater Yangon [48]. Second, the Korean International Cooperation Agency (KOICA) who have attributed their resources to write a master plan for several areas of economic interest in Yangon, of which Dala is one [38]. The South Korean Economic Development Cooperation Fund (EDCF) have administered a loan for the construction of the bridge between Yangon and Dala [53]. Lastly, the Asian Development Bank (ADB), helps YCDC with investments in creating labour and infrastructure investments [1]. They are also involved in the construction of water management solutions to bridge the current gap in Dala. These funds have similar interests, namely economic development of the region. By doing this, they can also improve the competitive position of companies from their country. Japanese and Korean companies already have a large share in the new Special Economic Zone (SEZ) in Thilawa [41] and for the bridge construction tender only Korean companies were invited to participate [53].

UN Habitat

UN Habitat is a UN programme working on better living conditions in urban areas [105]. In Myanmar they advised the government on urban planning and consequences of climate change [104]. These two topics are very relevant for Dala as it is now included in the urban plans for greater Yangon and because its location makes it sensitive to the effects of climate change.

2.4. Scenarios

One difficulty for this design is that it is not being made for the current context or for a future context that can easily be extrapolated from the current context. In fact, the future development of Dala is very uncertain and probably very different from the current situation.

In order to enable decision making and to clarify present actions and consequences, scenarios regarding the future development of Dala area are built. The primary purpose of scenario building is to create an integrated picture of how the future might evolve according to the interaction among different factors and actors that can influence the development of the area [78]. The resulting figures will become the context for planning, developing, and testing new ideas.

For this context, the year of 2040 is chosen as a target year. This year is taken as the target year for the plans presented in JICA and YCDC [48]. The design for Dala, as presented in this report, will have to provide the water infrastructure for the situation of 2040. It is assumed that urban and economic growth, which will be given an impulse with the construction of the CBD-Dala connection, have stabilized by this year.

The scenarios were developed following the Ratcliffe method [86]. This method follows five steps:

1. Task identification and analysis
2. Exploring driving forces and key decision factors
3. Ranking driving forces
4. Alternative projections
5. Scenario development

After the first three steps, which are described more in detail in Appendix B, three external factors with high impact and high uncertainty were identified: population growth, industrial activity and climate change. Below, a summary of the alternative projections for these factors will be given, after which the conclusion about the resulting scenarios will be presented. Further elaboration on each step of the Ratcliffe method can be found in Appendix B.

2.4.1. Influencing factors

Above, three external factors with high impact and high uncertainty were identified for the basis of the future scenarios for Dala. In this section, a summary is given of the various trajectories that were identified for these factors. As mentioned, an elaboration and calculations can be found in Appendix B.

Population growth

Population growth is of main importance, since the number of inhabitants will have a relevant influence on the demand of water and on the design of the infrastructure in Dala. It is thus crucial to estimate the coming growth rate of Dala population in order to provide a design able to satisfy the needs of the Township in 2040.

To make an assumption about the population growth, a distinction is made between the period before the connection with the CBD is constructed, until 2021, and the period after the connection is constructed. The growth after 2021 is calculated based on the yearly growth of Yangon area and the percentage that will move from Yangon to Dala due to the increased attractiveness caused by the connection.

An estimation is made of 6% population growth in the period before 2021. For the period after 2021 a comparison is made with Bangkok and Ho Chi Minh City [18]. This resulted in a 7,8% grow annually.

It is not assumable that the growth of 7,8% will stay the same for 20 years. Therefore, for the first three years after the connection is completed, the 7,8% population growth is assumed, after which the growth will gradually go down to 2,6% in seven years, which is equal to the yearly population growth of the Yangon area [48, p.44]. This means that after ten years there is no extra influence of the bridge anymore on the population growth of Dala with respect to the growth of Yangon region. The total population in Dala in 2040 will be in this base case around 560.000 inhabitants.

Based on the this estimate, three scenarios for the population growth in Dala can be defined. The plus-minus scenario (+/−) is taken equal to the base case described above, the plus (+) scenario is calculated considering 20% higher population in 2040, thus 670.000 and the minus (−) scenario expects a final number of inhabitants 20% lower then the base case, thus 448.000. In the scenarios the difference in population growth rate starts from 2024, as also shown in Figure 2.7. The 20% difference in the final population is spread over the years after the construction of the connection.

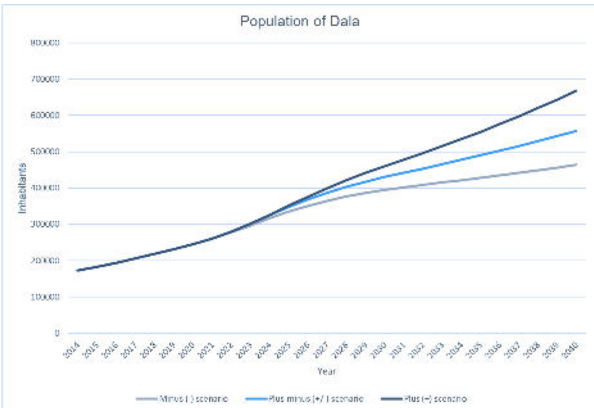


Figure 2.7: Population of Dala per scenario

Industrial activity

Industrial activity is of great importance of the Dala region. First of all, it will directly influence the water demand. Secondly, industry will generate wastewater which might have to be treated differently from domestic wastewater. Besides this, the industrial activity will generate jobs, which will make Dala a more attractive place to live. Therefore, industry also imposes an indirect increase in water demand for domestic use. The growth of secondary sector in Dala will also have a significant influence on the future landscape of the township which directly affects the area's water cycle. For these reasons, it is not only relevant to consider the actual water consumed by industry but also account for the effects that these activities have. Besides this, infrastructural improvements in the region, needed for the logistics bound to the industrial activity, will further increase the attractiveness of Dala as a residential area [125, p.7-2], again increasing water demand.

Currently there are no secondary sector companies located in the Dala Township. The SEZ in Thilawa, in which the first factory opened in 2015 [48, p. 86], is expected to grow towards a secondary sector hub with a total labor population of 204.000. Since Thilawa is already connected to surrounding parts of the city of Yangon, and Dala is still not, it is unlikely that development in the secondary sector will commence before the completion of connections between Dala and its surroundings. However, new connections between Dala and the CBD as well as the proposed outer ring road could make Dala an attractive place for activities within the secondary sector. In Appendix B, subsection B.3.2 different cases of predicted industrial growth are explored. The results are shown in Table 2.2 and Figure 2.8.

Table 2.2: Industrial development in 2040

Scenario	Labor population	Industrial area $[km^2]$	Water consumption industry/total $[\%]$
Minus	0	0	0
Plus-minus	60.000	7,4	30
Plus	149.000	18,3	74,5

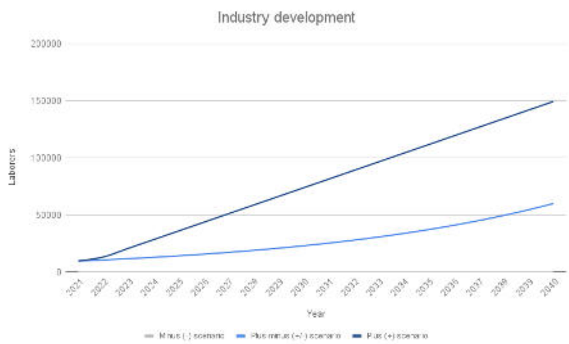


Figure 2.8: Industry development of Dala per scenario

Table 2.2 shows the different scenarios for the industrial growth. As can be seen for the minus scenario, no industrial growth is predicted. A labor force of 60.000 and an industrial area of 7,4 km^2 is expected for the plus-minus scenario. In this case, 30% of the total municipal water consumption will be used for industry. For the plus scenario, it is predicted that Dala will have a labor population of 149.000 and industry will require a surface area of 18,3 km^2. In this scenario, the industrial water consumption will require 74,5% of the total yearly municipal water production.

Climate change scenarios

Myanmar is expecting significant impacts from climate change. Indeed, due to its geographic location and geological characteristics, Myanmar is exposed to several extreme natural weather events which have shown an increasing trend in frequency and intensity over the last 6 decades [68, p.9]. According to Sönke Kreft, David Eckstein [94], Myanmar is the second country most affected by extreme weather events between 1996 and 2015. A map of the *Global Climate Change Risk Index 2017* is shown in Figure 2.9.

The expected climate change is relatively similar in the whole Southeast Asia region. However, Myanmar is currently much less prepared to deal with the challenges caused by climate change [94, p.4]. Therefore, it is more vulnerable compared to neighbouring countries.

The general observed changes include: temperature increase, rainfall variability, sea level rise, increase in magnitude and frequency of drought and heavy rainfall. The last is the most concerning climate issue for Dala due to its vulnerability to pluvial flooding. Furthermore, Dala lays in the delta area of the country which is particularly vulnerable to tropical cyclones and intense storms during the wet season (June to October) [43]. Additionally, the increasing temperature combined with the predicted

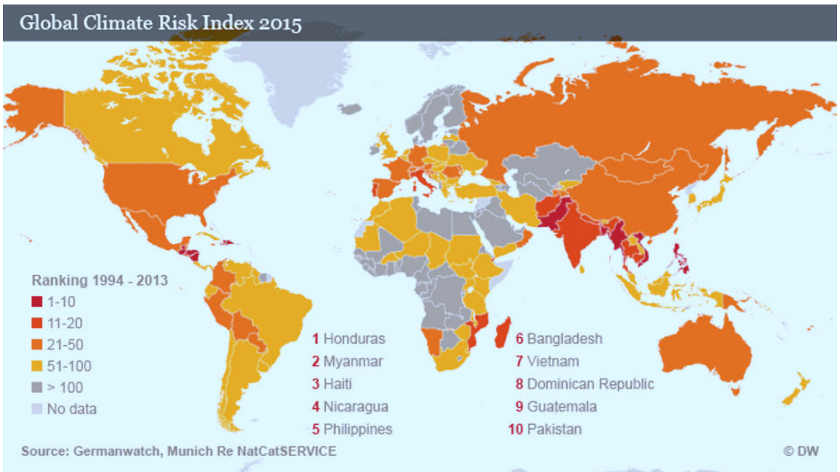


Figure 2.9: Climate change risk index 2015: [94]

decrease of the average duration of the monsoon (already recorded over the last 50 years [68]) will further stress the Dala water resources during the dry season. These elements could have a direct impact on the future industry growth and urbanization rate in the southern area of Greater Yangon.

Climate change is, therefore, an important factor which should be taken into account when designing different scenarios. However, due to it's uncertain nature it is very difficult to predict. To come up with reasonable scenarios, data from the Intergovernmental Panel on Climate Change (IPCC) is used. In Appendix B, subsection B.3.3 the precipitation and temperature change for two different periods (2011 - 2040 and 2041 - 2070) were calculated, these results are shown in Table 2.3 and Table 2.4. This change in climate will be taken into account when designing a solution.

Table 2.3: Predicted change in precipitation and temperature due to climate change for the period 2011-2040 [40, p.79].

	Hot Season	Wet Season	Cool Season
Precipitation [%]	4,5	6,5	-6,5
Temperature [$^{\circ}C$]	0,9	0,8	1,1

Table 2.4: Predicted change in precipitation and temperature due to climate change for the period 2041 - 2070 [40, p.79].

	Hot Season	Wet Season	Cool Season
Precipitation [%]	6	15,5	2,5
Temperature [$^{\circ}C$]	2	1,65	2,7

2.4.2. Scenario description

Based on the factors described above, plausible scenarios are formed. One scenario is used for the basis of the design while the others will be used to verify the robustness of the design. According to Ratcliffe [86], the ideal amount of scenarios should be between two and four. However, as each factor can vary along three levels, a total set of 27 scenarios will be obtained combining the three driving forces identified above (population growth, industrial activity, climate change).

To reduce the number of possible combinations, scenarios are generated only coupling population growth and industrial activity. In this way only 9 scenarios are obtained. After that, the 4 most probable scenarios are selected and developed. The resulting scenarios for population growth and industrial growth can be found in Table 2.5. In all the generated scenarios, the 'plus-minus' scenario for climate change is considered. The variability of climate change and it effects on the final design will be verified separately.

A description of each of these scenarios can be found in Appendix B. The scenario that was found to be most probable to occur in Dala is 'Relieving Yangon'. A description of this scenario is given below as well as the core figures.

Table 2.5: Scenarios

Scenario	Population growth	Industrial activity
Relieving Yangon	**+**	**+/-**
Residential township	+	-
Industrial potential	+/-	+/-
Economic corridor	+/-	-

Relieving Yangon

The connection with the Yangon CBD makes Dala a very convenient place to live for people working in and around the CBD. Commuters can easily access the connection that crosses the Yangon river. The outer ring road on the South as designed in JICA and YCDC [48] connects Yangon to Thilawa, making Dala a popular place to live when working in Thilawa. Dala will also develop some industrial activities, across the river from Thilawa. Since Thilawa is the appointed SEZ, the industry in Dala will be smaller, and for example more focused on textile. This industry will generate labour, attracting new residents to Dala. All the new residents of Dala that work either in CBD, Thilawa or Dala's new industry also generate service jobs in Dala. This newly generated labour will in turn attract more new residents to Dala. As land prices have already gone up significantly in anticipation of the bridge project [66], it is assumed that average welfare will rise in Dala as new residents move in. This will increase the need for high quality facilities.

To evaluate whether the potential sources can provide enough water to the future urban area, the water demand in 2040 has to be estimated. In this section, the distinction between drinking and domestic water need is not considered.

The water consumption of the township is in agreement with the rest of Yangon and is estimated to be 150 litres per inhabitant per day [123, p.4-2]. This results in a total water demand of 100.300 m^3/d. This number, however, does not take into account the industrial water consumption. This is estimated to be equal to the 30% of the total private water demand in Dala according to the assumptions made in subsection 2.4.1 and results in a demand of 30.100 m^3/d. Finally, to estimate the real daily demand that the water sources have to satisfy a value of 10% of non-revenue water (NRW) was considered truthful and consistent with the YCDC objective set for the NRW reduction [123, p.4-2], which leads to a final estimate of around 144.000 m^3/d for the average daily water demand. The resulting core figures for this scenario are presented in Table 2.6.

Table 2.6: Core figures 'Relieving Yangon' in 2040

Parameter	Value
Population [#]	670.000
Municipal water consumption [m^3/d]	100.300
Laborers in Dala industry [#]	60.000
Industrial area [km^2]	7,36
Industrial water consumption [m^3/d]	30.100
Total daily water demand [m^3/d]	144.000
Total annual water demand [m^3/d]	52.333.00

3 Requirement analysis

After the stage in which the system will operate has been sketched, the next step of the design process is to define requirements to which the system needs to conform. By defining these requirements early on, the functions for the design can be derived from them. Furthermore, it is possible to return to them later for evaluation and verification purposes. By doing a requirement analysis, performance of the system is ensured. Usually a requirement analysis consists just of a list of constraints and requirements. However, it should be acknowledged that the environment in which the system will operate is dynamic, making the requirements dynamic as well. To capture this dynamic behaviour, a land use model was made.

3.1. Requirements of the system

In this section, the requirements that were defined for the system are listed. Three types of requirements are distinguished: constraints, functional requirements and non-functional requirements. Constraints are conditions that the system absolutely has to comply to, otherwise it has no use. These can be checked with a simple yes or no. Functional requirements are things the system has to do. They determine the degree to which the system serves its purpose. Non-functional requirements are attributes that the system must have. They are performance measures that do not directly relate to the purpose of the system, such as price, sustainability or reliability. The requirements were first generated by means of a brainstorm, involving local experts, as shown in Appendix F, section F.1. Then they were supplemented and adjusted during a number of iteration steps in the design cycle.

3.1.1. Constraints

- The system shall provide water for all water demanding activities in Dala.
- The system shall collect wastewater of wastewater creating activities.
- The system shall protect the area against pluvial flooding.
- The system shall protect the area against fluvial flooding.
- The system's capacity shall match the projected population growth.
- The system's capacity shall match the projected industrial growth.
- The system shall provide drinking water according to World Health Organization(WHO) quality standard reported in [35].
- The system should treat the wastewater which is collected.

It should be mentioned that Dala is a flood prone area [48, p.13]. Cyclones can cause severe damage to Dala, and its water infrastructure. The water infrastructure as presented in this report should be protected from these forces. Therefore the protection from fluvial flooding should be a constraint for the design of the water infrastructure. However, the design of flood protection is not part of this design. The work presented in Nientker et al. [72] is used as a reference for the requirements on making Dala protected against fluvial flooding. Any consequence induced by the measures to make Dala flood proof should be taken into account in the design for Dala's water infrastructure.

3.1.2. Functional requirements

- The system should ensure a maximum of 10% non-revenue water.
- The system should provide each Dala inhabitant with clean drinking water at no more than 500 meters distance from their home [101].
- The system should preserve the quality of the water sources.
- The system should preserve the capacity of the water sources.
- The system should allow for the harvesting of resources from wastewater.
- The system should limit the pollution of industry wastewater.
- The system should ensure as little waste of water as possible during consumption.

3.1.3. Non-functional requirements

- The system should consume less energy compared to traditional methods.
- The system shall be as safe as possible.
- The system shall reduce the environmental impact of the Dala urbanization.
- The system shall be climate change-resilient.
- The system shall have as little greenhouse gas (GHG) emissions as possible.
- The system should have an as high mean time to failure (MTTF) as possible.
- The system should have an as low mean time to repair (MTTR) as possible.
- The system should provide affordable water for every inhabitant of Dala.
- The system shall be implementable by local laborers.
- The system shall be maintainable by local laborers
- The system shall allow for flexible, step wise implementation.
- The system shall allow for investments to be spread over time and parties.

3.2. Land-use model

In order to design a system that tenders to the water needs as defined in the requirements, it is important to know how Dala will develop spatially after 2021. In other words, it is important to know how the land is used, what the densities will be and what the patterns behind these developments are. If Dala is divided into a number of zones, land-use tendency, density and therefore water needs can be defined per zone. This provides valuable insights for the design of the water infrastructure. The zonal land-use is not only a given that needs to be taken into account when designing the water infrastructure, it can also be influenced by the design. Therefore, the land-use itself can not be given as a scenario. It is only important to understand the relationships between relevant factors that influence the design and that can in turn be influenced by the design. Therefore, in this chapter a conceptual model is proposed outlining relationships between factors that are relevant for this case. This conceptual model is then visualized for the zones as defined for Dala.

3.2.1. Conceptual model

The land-use development of the zones comprising the area under study can best be described by two theories commonly used in land-use modeling: Wegener's Circle of land-use and transport interaction [118] and Lowry's model [54] describing the agglomeration effect. Wegener's model sketches the circular relationship between the transport network and land-use in a zone [118]. Wegener found that investments in infrastructure and therefore improvement of the accessibility and attractiveness of a zone will attract investors and eventually more residents and businesses. These generate more activities, causing an increased load on the network, which means that the travel times will be higher and accessibility will decrease. This way, after each infrastructure investment in a zone, an equilibrium will be found between accessibility and activities. The circle and therefore the equilibrium can be influenced at each point. However, in practice it is often done via infrastructure investments and enhancing the attractiveness of the area. In Figure 3.1 the relationships in Wegener's circle are depicted.

The "moves" that follow from the increased attractiveness of the zone and the construction of real estate are further taken under the loop by Lowry's model [54]. Lowry argues that regional growth is a function of the expansion of the basic sector. With the basic sector, Lowry means the amount of jobs in the primary and secondary sector. For this project, the primary sector in Dala is defined as agriculture and the secondary sector is defined as any type of industry. This sector has an impact on the developments in both the residential and service sectors in and around the zone under study. The

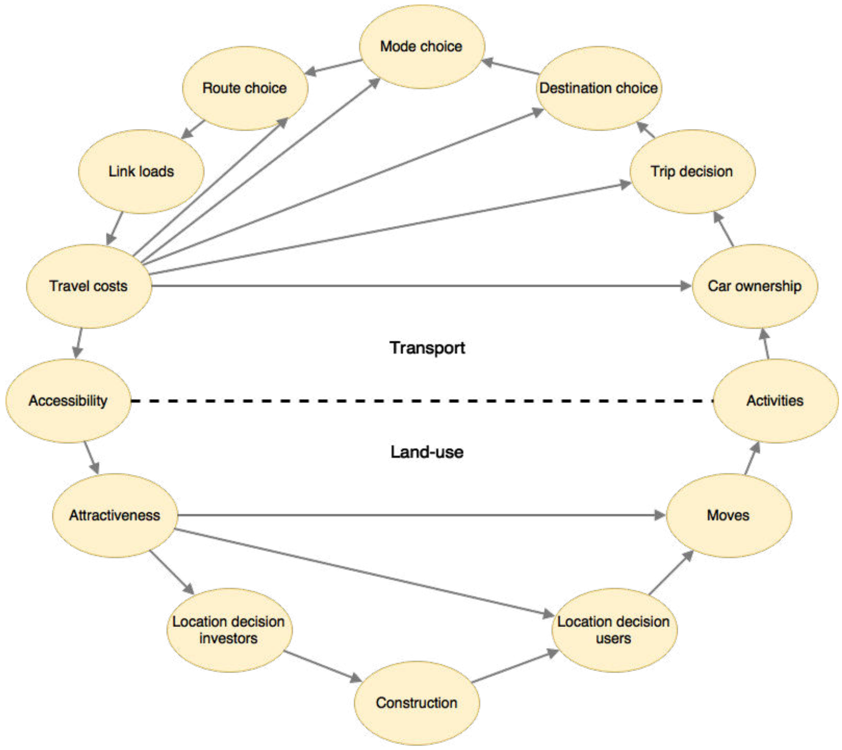


Figure 3.1: Wegener's Circle of land-use and transport [118]

residential sector is here defined as the amount of people living in the area and the service sector is defined as the amount of tertiary sector jobs, or service jobs, in the area. A certain amount of basic sector jobs will attract residents to the zone itself and the zones around it depending on the accessibility and attractiveness of each zone. This in turn generates service jobs in the respective zones which will in turn attract residents. In Figure 3.2 Lowry's model is depicted.

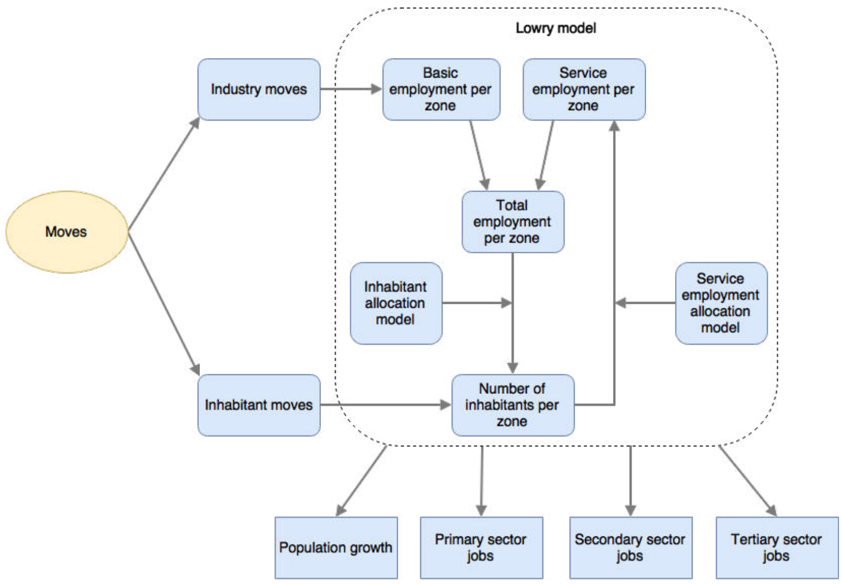


Figure 3.2: Lowry's model of basic jobs, residents and service sector jobs [54]

As was said, when something changes in the land-use and transport circle, this is usually the result of infrastructure investments and enhancing the attractiveness of the zone. In the case of Dala, the road infrastructure investments are seen as a given. That is, the bridges between Yangon and Dala, and Dala and Thilawa are assumed to be built. Furthermore, as stated in the Master Plan for Greater Yangon [48], further infrastructure investments in Dala are expected, such as the outer ring road, the feeder road from the Dala - Yangon CBD connection to the outer ring road, improved public transport and an improved road network, reducing travel costs. In Figure 3.3 the influence of these assumed investments on the conceptual model is shown.

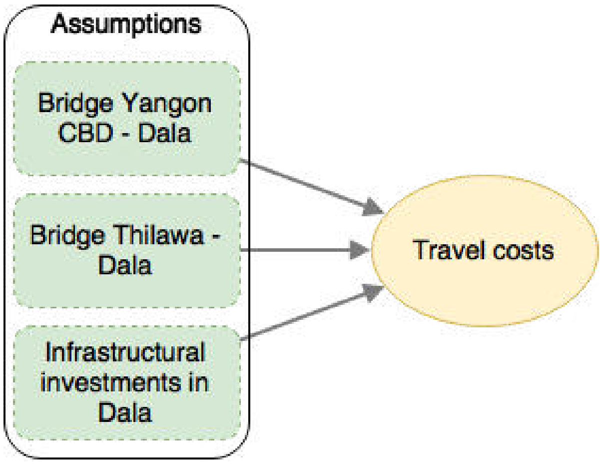


Figure 3.3: Assumptions on infrastructure investments influencing Wegener's Circle for Dala

Next to the travel costs and accessibility, there are other factors influencing the attractiveness of a zone. It is important to acknowledge that any plans implemented by the YCDC in Dala that influence the attractiveness of a zone will therefore also affect the input factors which they are based upon. For example, an improved water infrastructure will make the area more attractive for investors [125, p.7-2], attracting more residents and industry, which in turn increases the water demand. On the other hand, YCDC can also take measures that influence the input factors for their plans. By issuing construction permits and strategically locating "hotspots" such as hospitals and schools, the population, and therefore the water demand, can be steered to the most advantageous locations. These possible influences are depicted in Figure 3.4.

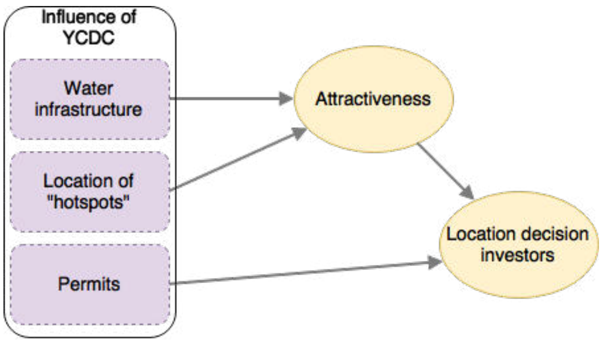


Figure 3.4: Influences YCDC can have on the attractiveness of a zone

The relationships described above come together in a conceptual model for the land-use in Dala that will be used as reference for the design. As data and time are limited, the relations will not be quantified using this model. However, it is important to acknowledge the dynamics that play a part in the spatial development of Dala in order to make a resilient design. The complete overview of relationships (a combination of the above highlighted components) can be found in Figure 3.5.

3.2.2. Zonal map of Dala

Based on the relations as sketched in subsection 3.2.1, Dala can be divided in areas that have similar developing potential characteristics. This division in zones provides a spatial translation of the conceptual model. Furthermore, the zones can be used for a more detailed specification of the water

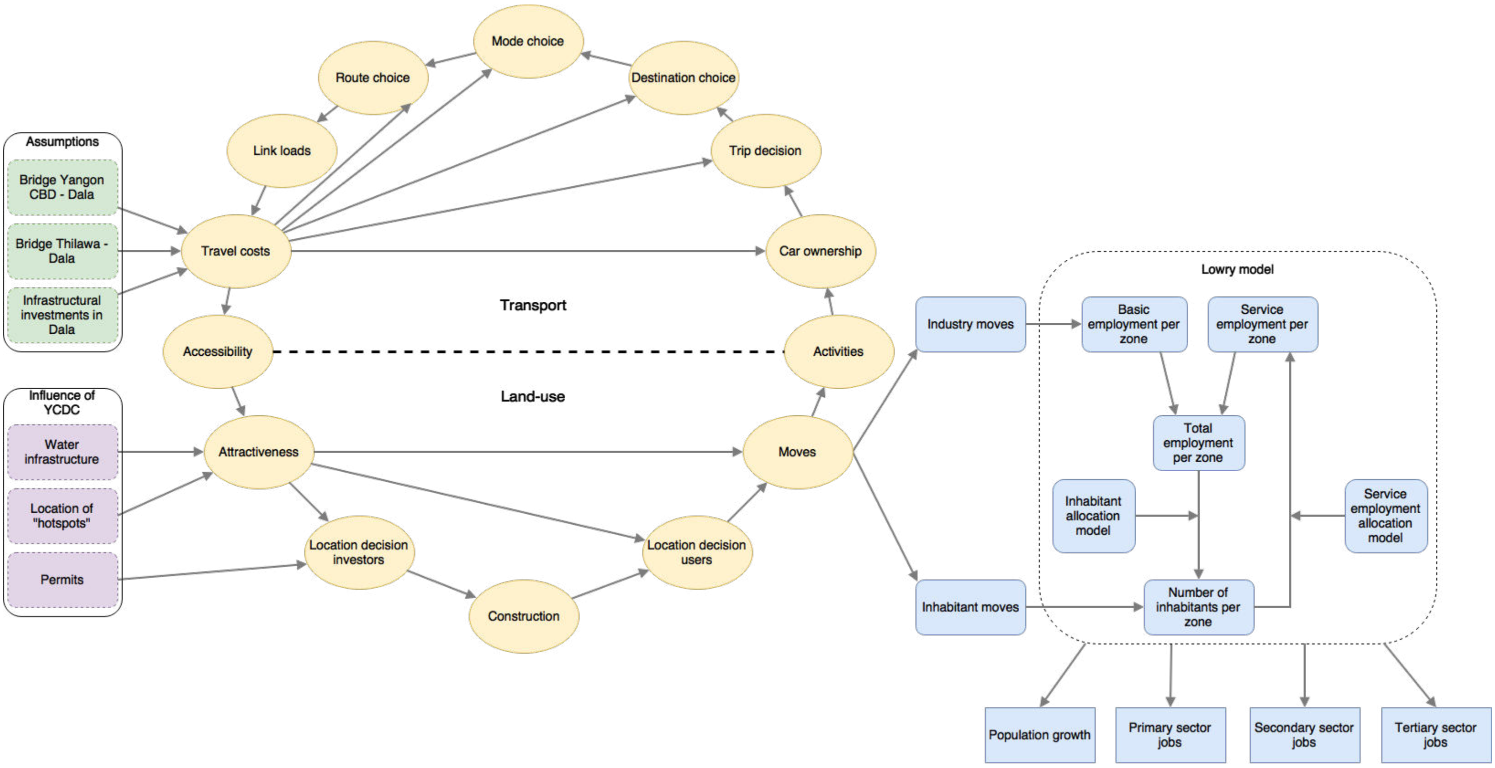


Figure 3.5: Conceptual model of land-use in Dala in full

needs of certain areas in Dala. This is done for both population developments, and developments in industrial activity. More information about the calculation of the attractiveness of the zones can be found in Appendix C.

Population

As reasoned in subsection 3.2.1, investments in infrastructure will make areas more attractive. This statement is sustained for the case of the Yangon region by YUTRA [125, p.7-2], which shows that land value is determined partly by the vicinity of major infrastructure. Since JICA and YCDC [48] indicate the construction of two major infrastructure investments, i.e. the outer ring road, and the connection between Dala and Yangon CBD, attractiveness of the land adjacent to these roads is high. The area around the T-junction which connects these two major roads will be even more attractive for the same reason.

YUTRA [125, p.7-2] indicates a land value increase for the vicinity of the Yangon CBD as well. For Dala this means that the area near the landing point of the connection will have an increased attractiveness. Furthermore, infrastructure in Dala in the existing urban area will have an attractive effect. The region adjacent to the current urban area of Dala is relatively easy accessible for new infrastructural improvements, which puts an attractive force on this area as well.

Industry

For any investments in the secondary sector, vicinity of infrastructure will have an attractive effect. Here it needs to be taken into account that the river can fulfill a valuable infrastructural task as well, because imported goods used in industry are most likely transported through the port of Yangon, since 90% of the national cargo volume is processed here [48, p.28]. Furthermore, the riverside is situated across the Thilawa SEZ, making the river bank on the Dala side the most obvious place for investments in the secondary sector. However, it should be noted that YCDC has plans to invest in recreational zones along the riverside. Where these recreational zones are placed, there will be no room for industrial activity, as stated in Appendix E, section E.5. For these recreational zones, it is assumed that only the riverside north of the outer ring road will be used. South of the outer ring road, industrial activity can develop.

Furthermore, the outer ring road will have an impact on the attractiveness of zones. One of the main purposes of the ring road is to create an outer ring where industry can settle, while keeping areas closer to the city of Yangon free for residential and tertiary sector purposes [48, p.19]. For this reason the road connecting Dala with Yangon CBD is assumed to be less of an attraction factor on secondary sector activity, in comparison with the outer ring road.

As described in subsection 3.2.1, the agglomeration effect of Lowry [54] will lead to more inhabitants and service jobs in areas that are connected to areas with secondary sector jobs (i.e. basic jobs). Therefore, the attractiveness as a residential area or a commercial area of connected zones will increase due to the industrial activity that is expected.

In Appendix C, Table C.1, the influence of all factors that are described in this Section are coupled to the zones of Dala. The factors taken into account are:

- Connection road Dala - Yangon CBD;
- Outer ring road;
- Yangon CBD, being the landing point of the connection between Dala and Yangon CBD;
- Existing urban area;
- River south of the ring road;
- River north of the ring road;
- Adjacency to the zone that is directly influenced by the factors mentioned.

Figure 3.6 graphically depicts the relations between zones and attraction factors as described in this section. Relative attraction weights were used to determine population density and industrial activity density per zone. The methods used to derive these figures are described in Appendix C. The land-use model was also evaluated by YCDC officials, among which the Director of the Urban Planning Division. They agreed with the chosen attraction factors as being important for the development of the Dala area. A summary of this meeting can be found in Appendix E, section E.5.

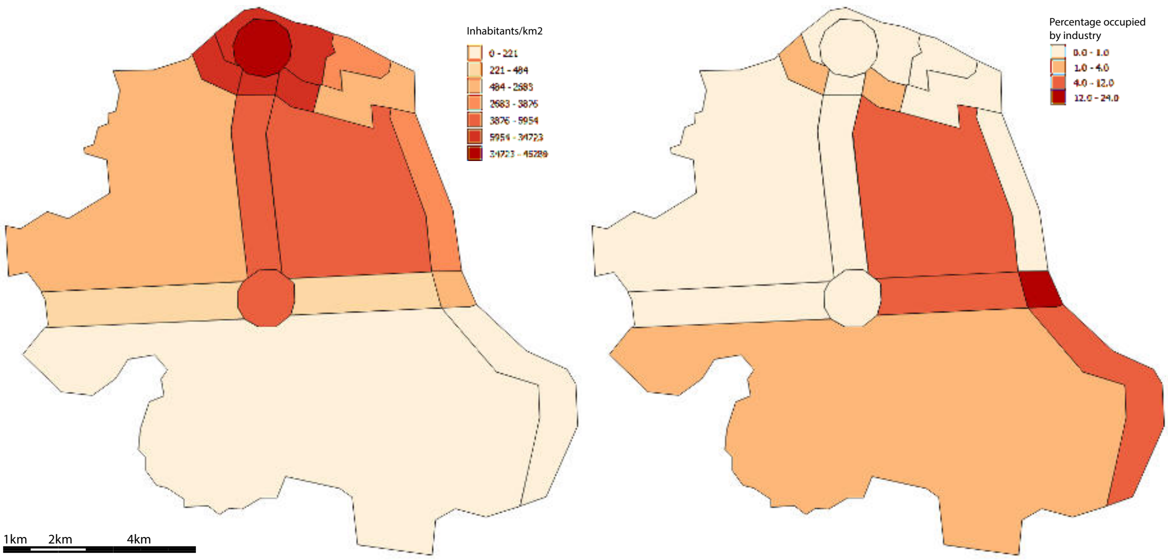


Figure 3.6: Relative density of population and industrial activity

The maximum density for population can be found in zone 2, which is the zone where the landing point of the connection with Yangon CBD is expected. The population density here is 45.000 $inhabitants/km^2$. This density is comparable with Pazundaung Township, Yangon. This township in Yangon CBD that is characterized by buildings with a height from 3 to 12 stories. Zone 1 yields a density of 35.000 $inhabitants/km^2$, which is comparable with the density of San Chaung and Latha, which are located next to, and in the CBD respectively. No zone in Dala yields the density of the densest zone in CBD, Kyauktada, accounting for a population density of 70.000 $inhabitants/km^2$ [20]. The lowest densities, as projected by the model, can be found in zones 16 and 17, yielding around 200 $inhabitants/km^2$. These figures are comparable with Htanbin, Kyauktan, Thongwa and Twantay [20], which can be characterized by low urbanization.

The maximum density for industry can be found in zone 15, yielding a surface occupation of 24%. Furthermore, zone 11 attracts industry up till a surface occupation of 12%. The rest of the zones are a lot less attractive and all yield surface occupation rates between 0% and 6%. Although it is hard to give a reference case for this occupation rate, it can be concluded that the water demand for industry in zones 15 and 11 will be the highest

Urban area

For calculations on the drainage system, a figure for the urban area should be derived. Where this figure is not directly derived from the land-use model, some assumptions have to be made. Deuskar [21] states the most common threshold used for identifying an area as urban, lies at 2000 inh/km^2. When this figure is used for the zones of Dala, 63 km^2 is identified as urban. Industrial area should also be taken into account. As stated in subsection 2.4.1, the surface for industrial area is projected to be 7,36 km^2. Besides these areas, the area of Dala will be provided with two major infrastructure projects, connecting the industrial areas and the residential areas. Furthermore, the water infrastructure that is presented in this report also needs to be drained. To be on the safe side for the calculations of the to be drained area, it is assumed that 50% of the total area of Dala needs to be drained, and is identified as urban area. This results in 112,5 km^2.

4

Functional analysis

After having defined the requirements of the system, a functional analysis can be conducted. Based on the requirements, a number of functions of the system can be defined. Using morphological design, as many potential solutions as possible are then identified for these functions. The first step that was taken to narrow down these solutions to a design, is generating three alternative designs with one or a set of solutions per row of the morphological chart. The themes that were chosen for these alternative designs are economic sustainability, environmental sustainability and social sustainability.

4.1. Definition of functions

From the constraints and functional requirements as defined in the previous chapter, a number of functions were derived which were used to generate a design. The goal of dividing the system up into a number of functions is to enable the design of 'bite-sized' subsystems. These will afterwards be unified in an integrated design. The functions were defined as follows:

- Harvesting of water/resource
- Storage of harvested water
- Treatment of household- and drinking water
- Quality control of drinking water
- Supply (bringing to consumer) of drinking water
- Collection of wastewater
- Limiting pollution of wastewater
- Monitoring water consumption
- Treatment of wastewater
- Protection against pluvial flooding
- Collection of run-off water

4.2. Morphological design

When the functions have been defined, they can be used to generate a number of designs. This is done using a morphological chart. A morphological chart is a tool that can be used for functional design brainstorms. The functions are listed below each other and methods to fulfill these functions can be filled in for each of them. In the end, alternative designs can be generated by combining solutions for all the functions. The full morphological chart, which can be found in Appendix D, was generated by means of multiple internal brainstorm sessions and an external brainstorm session with experts from the YEP network and students from MMU and YTU. A detailed account of the external brainstorm can be found in Appendix F, section F.1. The goal of these sessions was to generate as many ideas as possible. These ideas were then filtered down to a number of feasible ideas based on some preconditions inherent to the area. After further research regarding the feasible solutions, combinations of solutions were selected to generate three alternatives, which are described in section 4.3.

This section gives an overview of the current situation for all the functions as listed in section 4.1. After explaining the current situation, the alternative designs are sketched, giving insight in the changes that will occur when implementing an alternative design in Dala.

4.2.1. Harvesting of water/resource

Dala is located in the lower part of the Ayeyarwady Delta. This area is particularly rich in surface water. However, due to the proximity of the sea, the majority of the streams that flow in the lower delta are characterized by a high level of salinity [124, p.2-18]. For this reason, river water is not currently used in Dala for drinking purposes. According to Aung [7], the Toe river, located 46 km Southeast of Dala, is potentially suitable to produce drinking water for the growing Yangon region. Compared to other rivers in the area, the Toe combines a high basic discharge during the dry season with a relatively low salt content, as stated in Appendix E, section E.3, and YCDC and JICA [124].

Groundwater (GW) is a source that has been used in Dala area over the last decades. The pipe system currently present in Dala uses GW extracted in the Pauk Yangon village [7, p.34]. Furthermore, YCDC is planning the construction of 3 small GW treatment plants to provide water to the most remote wards in Dala, as described in Appendix E, section E.3. This can be seen as a controversial solution due to the link between groundwater extraction and land subsidence in the surrounding areas [111]. This phenomenon can be mitigated by increasing the natural infiltration of the rainwater or through artificial infiltration [83]. The groundwater in Dala is also characterized by a relatively high salt concentration, as reported in section E.3, section E.6. The production of freshwater from it implies the employment of high energy consuming treatment (e.g. reverse osmosis filtration) and the production of a waste brine which is usually hard to dispose of.

The average yearly rainfall in the Yangon Region is around 2.700 mm [7, p.24], most of which is concentrated during the wet season (June to September). This currently represents the main water source for Dala during most of the year. At the moment, there are 323 rainwater ponds located in Dala [9]. This system is inadequate as it cannot provide the population of Dala with enough water to last the dry season [9]. However, the extraordinary amount of rainfall makes it interesting to look into the potential use of rain as main water source also for the future urban expansion of Dala. Furthermore, The YCDC plans to forbid air-polluting industries to settle in Dala, as stated in Appendix E, section E.5, can prevent the contamination of the rainwater.

4.2.2. Storage of harvested water

Currently Dala makes use of 323 rainwater reservoirs for water storage [8]. However, this does not provide the residents with enough water to last the entire dry season. Not only do the reservoirs have insufficient capacity, a large part of the stored water also evaporates. Using data from Aung [7], it was calculated that only in the dry season the potential evaporation is roughly 1 meter in the Great Yangon region.

Further, in some ponds the quality of the water is too poor and can not be considered drinking water due to its level of contamination, as stated in Appendix E, section E.4. This is partly due to different methods of water collection, as can be seen in Figure 4.1a and Figure 4.1b. However, the extremely poor population does not have a choice and end up drinking the contaminated water.

When the reservoirs run out, Dala becomes dependent on water donations from Yangon. To make Dala self-sustaining, a storage system needs to be designed with enough capacity to provide Dala residents and industry with enough water year-round. Further, the storage system should comply to the requirements as defined in chapter 3. These notions gave starting points for filtering the multiple ideas that came out of the brainstorm.

4.2.3. Treatment of household- and drinking water

There is no information about the treatment steps of the water currently supplied by YCDC in Dala. The water taken from the ponds is usually not treated for financial reasons, as reported by Appendix E, section E.4. In some cases, the community which lives around the reservoirs pours aluminum salt as coagulant into them to reduce turbidity and improve sedimentation, as state in Appendix E, section E.4.

4.2.4. Quality control of drinking water

Currently no basic standard for drinking water quality exists, and there is a lack of appropriate monitoring facilities in the whole Greater Yangon metropolitan area [122, p.4]. Therefore, there is no regular monitoring and surveillance data for water quality control to test the quality in Dala. The quality control

(a) Reservoir with electric pump

(b) Reservoir with bucket collection

Figure 4.1: Rainwater reservoirs with different types of water extraction

per source is operated by different organizations: the reservoirs are under observation of the irrigation department, while the YCDC tests the quality of the groundwater and the river is under custody of department of meteorology and hydrology [99].

4.2.5. Supply of drinking water

In 2016 only 12% of the inhabitants were supplied by the pipeline system in Dala [9], the rest of the inhabitants have to collect the water themselves or are dependent on transport in another way. A map displaying the current pipeline infrastructure is shown in Figure 4.2. The supply of water to remote areas is mostly done by trucks with water bottles from the area of Yangon city. Due to the poor quality of the road, not every inhabitant can be reached. Especially during the dry season, this is a big problem for the area of Dala, as inhabitants stated in Appendix E, section E.1. It is the goal of the YCDC to solve the drinking water problem in Dala [9]. Therefore, this should be an important part of the design.

Figure 4.2: Map of current pipeline system in Dala

4.2.6. Collection of wastewater

There is currently no large scale wastewater collection system present in Dala. The fact that most of Dala is still undeveloped allows for complete freedom when designing a solution for this problem.

4.2.7. Limiting pollution of wastewater
No information can be found on any measures taken in Dala to limit the pollution of wastewater. Limiting the pollution of wastewater can make the wastewater treatment process easier and cheaper, and is therefore a valuable function to take into account.

4.2.8. Monitoring water consumption
Currently there is no system to monitor the water consumption per household in Dala, a system only exists in Yangon [58, p. 26]. It is important to include this function in the general design to make the system more efficient. Indeed, the development of a monitoring system for Dala is also part of the future goals of YCDC for the Greater Yangon [48, p.123]. Compared with other countries, the drinking water tariff of YCDC is much cheaper. Therefore, user awareness on water savings is low. This water tariff has to be reconsidered, since it cannot cover the investment cost for the construction of new water facilities [48, p.30]

4.2.9. Treatment of wastewater
Currently in Dala most of the residents discharge grey and black water into a hole in the ground. Waste, heavier than water, will sediment to the bottom of this hole, while water will 'float' on top of this waste. When the hole overflows only water and light particles will leave the hole. In this way, a share of pollutants in the wastewater is not discharged. The effluent will either infiltrate into the ground around the hole, or flow into nearby water bodies. Although the wastewater loses a part of the solid fraction, the effluent can still contain a large amount of pathogens, causing health risks. Besides this, pathogens in the effluent can affect the flora and fauna of the area. The ground in which the wastewater infiltrates, or the water body in which the wastewater ends up, might be a water source used by the inhabitants, which again causes health risks.

4.2.10. Protection against pluvial flooding
There are currently no specific protection measures in place to protect Dala against pluvial flooding. The only measures which have been observed are the creation of natural retention area in which the excess rainwater is collected and stored, and the heightening of buildings and roads. The entrance of the building is about half a meter higher than the surrounding area, a similar height difference is also observed with the roads. As assumed by Nientker et al. [72], these houses and roads where specifically constructed at a higher level to prevent the occurrence of flooding.

4.2.11. Collection of run-off water
There is currently no actual drainage system implemented in Dala. The runoff generated during storm is collected in trenches located beside the streets or in natural water retention areas.

4.3. Alternative designs
As mentioned before, the morphological chart can be used to generate multiple alternative designs by combining solutions for the functions. These solutions can be chosen using certain pillars. In this case three pillars for sustainable development as defined by UNESCO [80] were chosen: economic sustainability, environmental sustainability and social sustainability. A compressed morphological chart with only the solutions that were chosen for these alternatives can be found in Table 4.1. The resulting three alternatives were generated by combining the solutions which for their own function were either the most economically, environmentally or socially sustainable. In that respect, these designs are 'extremes' and their functional solutions do not necessarily fit well together. Therefore, in chapter 5 a synthesis will be formed.

4.3.1. Economic sustainability

This alternative focuses on creating an economically sustainable solution for the Dala region. This means that this alternative should allow for industrial growth of Dala, generation of jobs, the engagement of local companies and allow for the agricultural sector in Dala to become more efficient.

The economic alternative consists of the collection of water from two main sources, the groundwater and the river water from the Toe river. In order to survive the dry period, the water needs to be stored. On a large scale the water will be injected into aquifers or allowed to infiltrate naturally, while on a smaller scale the water will be stored in small tanks for personal use. The use of these tanks will benefit the economy because they can be manufactured and supplied by means of a large project engaging local businesses to come up with the best and cheapest design. The water will be treated using reverse osmosis and later re-mineralized. This technique has already been implemented in industrial areas in the Yangon region [45] and is therefore easier to operate by locals. Private groundwater withdraw allows industries to directly extract the needed amount of water. This results in more flexibility and autonomy for the industrial activity, making the area more attractive for investors.

The supply of water to the local population will be done using a separate pipeline system for household water and drinking water. The collection of wastewater will also be done with the use of pipes, which will consist of a separate, gravity-based system for 'black' water and runoff water. The use of pipes to supply and collect water can indirectly benefit the economic growth of the Dala region by protecting the natural environment as well as increasing the quality of life, resulting in an increased attractiveness for the Dala region. Since the drinking water is supplied in a different system, the amount of water that has to be treated is reduced. The quality of the water should be checked on a regular basis to ensure safe drinking water. This will be done by implementing a Citizen Science Project which consists in promoting the use of smartphones to collect and analyze water quality data. This system allows the local government to collect enough information to keep track of the water quality. The improvement of the water quality will also result in the increase of the attractiveness of Dala. The consumption of water will be monitored by a 'pay for usage' system where water is supplied only to costumers who have paid beforehand. This can be implemented by using a prepaid card system. In this way, money is only deducted when water is consumed. This system ensures that all the water consumed is charged, supporting the economic sustainability of the design.

To prevent the occurrence and consequences of severe pluvial flooding in the Dala region, a drainage system will be used to collect run-off water. The drainage system implemented will be similar to the one operating in Yangon. This system consists of elevated sidewalks covered with concrete slabs under which the rainwater can be collected and drained. This drainage system will be easy to construct, but it will require regular maintenance to prevent clogging, which in turn will provide the local population with jobs.

Lastly, the treatment of wastewater needs to be discussed. In order to reduce the amount of wastewater to be treated, the amount of pollution present in the wastewater should be limited. This can be done by putting sanctions on exceeding pollution standards such as fees or criminal prosecution. This option is opted for because the other option, reuse of wastewater for own usage, will bring extra costs to companies. This will reduce the attractiveness of the area for investments. Before discharged, wastewater is treated by means of phytodepuration. The wastewater treatment will be implemented and maintained by local laborers. This will be possible thanks to the simplicity of the employed method.

4.3.2. Environmental sustainability

This alternative has the following focus points for Dala: protecting the fauna and flora; minimizing emission of greenhouse gasses as well as the impact on natural resources, and keeping the interruption of natural cycles, mainly water, as small as possible.

This alternative includes the use of rainwater harvesting as main water source. The rainwater will be directly harvested on the reservoirs or collected from the surface runoffs. This solution requires less transport and therefore has a smaller emission during operation than using the Toe river or groundwater. Further, by using rainwater harvesting as resource, the harvesting itself does not affect the resource. Big reservoirs are needed on a large scale to store enough water for the dry season. To cope with the problem of the evaporation of the water, solutions on two scales will be implemented. On a large scale, the currently used reservoirs will be deepened and new deeper reservoirs will be built. On a local scale underground cisterns are going to be constructed. In order to prevent seepage loss and contamination by the salty groundwater in the reservoirs, an impermeable layer has to be included in the reservoir design.

The supply of drinking water can be done by a separated pipeline system, namely one for drinking purpose and one for domestic use. This makes reuse of water easier since it allows to reuse grey water (for instance for flushing the toilet) without any treatment. This results in less treatment needed for the water and therefore less energy. Since the supply system will consist of two separated pipelines, the quality does not have to be the same for drinking water and domestic water. Therefore, another source can be used to supply for domestic use to prevent the depletion of one source completely. By using a system where users pay before they get the water, it is not only known who is consuming the water, but the consumer is also aware of their water usage.

To ensure the quality of the water, a Citizen Science Project will be set up where the inhabitants help to collect the data by using a prepared test kit. The data can be sent by smartphones to affect the environment as little as possible. However, it has to be taken into account that the used test material has to be recycled or reused.

The collection of used water the system is divided in two parts: drainage water and wastewater. This separation facilitates potential reuse of grey water. The rainwater is collected by a drainage system which is in part directly connected with the reservoir. To reduce the pollution of the runoff water and make it suitable for drinking water production, the drainage system is designed to already provide a partial treatment and prevent the contamination of the reservoir. That can be done by letting the water percolate in a soil layer before being collected in the drainage system. To minimize the risk of flooding and increase the groundwater recharge, urban agriculture and green roofs will be promoted among locals. The wastewater is collected by a central vacuum sewage system which helps to minimize the negative environmental effects, such as soil and groundwater contamination.

After being collected the wastewater is treated by an Upstream Anaerobic Sludge Blanket Reactor (UASB). The UASB reactor can be made with local material, and has low energy requirements due to the natural flow in the tank. At the same time biogas and other resources are harvested. These can be reused for energy production and for agricultural purposes [103]. To limit the amount of polluted water that has to be treated, the local industry are stimulated to reuse their wastewater.This is done making them more aware of their consumption as well as urge them to increase the quality of their wastewater. Together with reusing the water, putting the treated water back into the ground and the reuse of the nutrient waste, this alternative really focuses on closing the water circle.

4.3.3. Social sustainability

The social alternative focuses on promoting social equity, diversity, cohesion and democracy, as well as increasing the welfare of the Dala region.

In this design water will be stored in two different ways: on a large scale and on a medium scale. On a large scale, rain will be collected in reservoirs. These large reservoirs can serve as community ponds stimulating social interaction and cohesion in local communities. On a medium scale, a Bhungroo system can be used. In this system rain water is collected and injected into the groundwater table for storage and in the dry months this water can be extracted and used for agricultural purposes [97]. This system has been implemented in India and is specifically designed for poverty stricken areas.

Drinking water will be supplied to communities to one main distribution point. These distribution points will help to minimize the consumption and waste of drinking water due to the social pressure created by the community as well as create a system in which the consumer only 'gets what he needs'. In order to minimize the water consumption, household surveys can be given to all inhabitants of Dala, increasing awareness about the problems faced due to large consumption as well as teach the local population how to optimize their water use. The local population will be in charge of testing the quality of the water, stimulating social cohesion. This will be done using the Citizen Science Project, using smartphones. This system will be easy to implement. Thanks to the recent technologies boom, most of the local population is already familiar with smartphones and apps. Therefore, only a brief explanation will be needed to use these devices to test their water quality.

In order to minimize the probability and damage caused by pluvial flooding, a main drainage system is needed, as well as an increased amount of 'green' in the streetscape. This increased amount of 'green' will help to absorb some of the water during peak flow and allow for recharge of the groundwater. Adding 'green' in the streetscape can be achieved by either constructing an urban garden or planting urban agriculture. An urban garden creates an area for the community to come together and relax, stimulating social cohesion. An urban farm will benefit the local community by providing the Dala population with an increased income as well as provide the possibility for every inhabitant to have access to food, because it is locally produced.

For the collection of run-off water, a main drainage system will be needed. The drainage of this water will minimize the damage to the infrastructure as well as protect the public from outbreaks of diseases due to the development of stagnant ponds with mosquitoes. The use of pipes to collect wastewater will make living conditions of the poorer population safer, instead of living in contact with their own bodily waste. This promotes equality among the inhabitants of Dala. In order to limit the pollution of the wastewater, the company or individual should be forced to reuse their own wastewater. This provides the company and individual incentive to produce less wastewater as well as improve the quality of the wastewater produced. Finally, the wastewater will be treated using a septic tank system in combination with Phytodepuration. The phytodepuration can take place decentralized, bringing the water treatment closer to inhabitants. This creates more awareness about water usage. Furthermore, implementation of the phytodepuration infrastructure combined with other green in the city can promote social health and community cohesion [116].

Table 4.1: Compressed morphological chart for three alternatives. Yellow: economic; green: environmental; orange: social

Function	1	2	3
Water harvesting/ resource	Ground water	Rainwater	Toe river water
Storage of harvested water	Aquifers	Rainwater reservoirs	Domestic storage
Treatment of drinking water	Reverse osmosis	Traditional treatment	
Quality control of drinking water	Citizen science project	Smartphones	
Supply of drinking water	Separated pipelines	Pipeline to collection point	
Collection of waste water	Gravity sewer system	Vacuum sewer system	
Limiting pollution of waste water	Reuse by same company/person	Fine for exceeding limit	
Monitoring water consumption	Pay for usage	Household survey	
Treatment of waste water	Septic tank	Phytodepuration	UASB
Discharge of waste water	Use for agriculture	Reuse for drinking water	Close water circle
Protect against pluvial flooding	Drainage system	Add green to streets	Green roofs
Collect runoff water	Main drainage system	Urban canals	Heightened sidewalks

5

Evaluation

After the alternative designs have been defined, they can be evaluated in a structured manner after which a synthesis can be formulated. The evaluation, as described in this chapter, includes two steps: an internally conducted requirements evaluation and an expert evaluation. Before starting the requirements evaluation, all of the alternatives were checked against the constraints mentioned in subsection 3.1.1 to see if they were met. All constraints were met by all of the alternatives. In the requirements evaluation the different alternatives are scored for each of the different functional and non-functional requirements. Based on this evaluation, a few focal points are established. These different focal points were discussed with local experts in a workshop session and are analyzed in section 5.2

5.1. Evaluation of the alternatives

As can be seen in section 4.3 summaries were written which explain the different alternatives and how each of these alternatives are sustainable. Based on these different summaries each group member analyzed these alternatives and gave a score of -1, 0 or $+1$ to each of the requirements. The scores for each requirement were then added together and the tables below show the result for each of the different alternatives.

Table 5.1: Functional requirements compliance per alternative ($-1/0/+1$)

Functional requirement	Economic sustainability	Environmental sustainability	Social sustainability
Ensure 10% non-revenue water	4	4	2
Provide drinking water at 500 meters	3	3	-2
Preserve quality of water source	-3	4	4
Preserve capacity of water sources	-3	5	5
Allow for harvesting of resources from wastewater	-1	5	0
Limit pollution of industry wastewater	2	4	4
As little water waste as possible during consumption	-1	3	3
Sub total	**1**	**28**	**16**

Table 5.2: Non-functional requirements compliance per alternative($-1/0/+1$)

Non-functional requirement	Economic sustainability	Environmental sustainability	Social sustainability
Consume less energy compared to traditional methods	-3	4	3
As safe as possible	-2	1	2
Reduce environmental impact of urbanization	-2	4	5
Climate change resilient	-2	4	4
As little GHG emissions as possible	-2	4	3
As high mean time to failure (MTTF) as possible	4	1	2
As low mean time to repair (MTTR) as possible	0	-5	-1
Affordable water for residents	-2	-1	3
Implementable by local laborers	4	-3	3
Maintainable by local laborers	3	-3	3
Allow flexible implementation	4	3	3
Low initial investment resulting in spread over time and parties	1	-3	2
Sub total	**3**	**6**	**32**

Table 5.3: Final scores of the analysis of the alternatives

	Economic sustainability	Environmental sustainability	Social sustainability
Sub total functional requirements	1	28	16
Sub total non-functional requirements	3	6	32
Total score	**4**	**34**	**48**

As can be seen from Table 5.3, the socially sustainable alternative scores highest followed by the environmentally sustainable solution, while the economic solution scores the lowest. In the next subsections the different alternatives will be evaluated.

5.1.1. Economic sustainability

As can be deduced from the requirements evaluation, the economic sustainability alternative forms the least satisfying solution for the previously defined requirements. This poor result is related to the use of groundwater as the main water source for industry and domestic use. The withdrawal of groundwater, combined with the increasing load exercised on the land surface due to the area urbanization, could cause land subsidence. Since it has been recorded in several surrounding areas, this phenomenon can also be expected in Dala. This problem can be solved by ensuring a sufficient recharge of the aquifer. However, the urbanization of the area is expected to badly impact the infiltration capacity of the area. Even though solutions have been given for the future urban development to limit the effects of urbanization on the infiltration capacity. The reduction of the ground level is usually a relevant issue for flood prone cities in urban areas. In this type of territory, the land sinking associated with the expected rise of sea level and frequency of heavy rainfall can easily increase the inundation risk and thus reduce the township safety. Furthermore, as mentioned in subsection 4.2.1 the groundwater in Dala is characterized by a relatively high iron and salt contents when compared to other water sources (river and rainwater). Therefore the production of freshwater from this source implies the employment of high energy consuming treatment (e.g. reverse osmosis filtration) and the production of a waste brine which is usually hard to dispose of without threatening the environment.

In this solution, the use of the (Toe) river water as support source for satisfying the future Dala demand is considered. However, the source's optimal intake point is located 46 km away from Dala, where the Toe is not affected by salt contamination[124, 3-19]. Therefore, the transport of the water will involve high energy costs and significant investments. The reduction of the river discharge during the dry season and the increase of the water demand can cause a decline of the river flow downstream in the dry season. This could lead to potential problems for the ecosystem and the sediment transport. This last issue, however, occurs only if a significant amount of water intake from the river is needed.

The economic sustainability design scores higher in the requirements related to the feasibility and flexibility of the system. This is due to the implementation of solutions already employed in the country (e.g. reverse osmosis treatment and gravity sewage system). For this design less training is needed for system operators. Since the laborers are already partially familiar with the implemented technology, a higher MTTF is also expected.

5.1.2. Environmental sustainability

According to the requirements evaluation, the environmental sustainable solution is able to successfully meet most of the requirements. The harvesting of rain as main water source will not only minimize the impact of the water supply on the environment but it will also decrease the pluvial flooding risk in the area. In this solution, the water needs to be collected and stored in big reservoirs and private tanks placed within the urban area. These facilities play an important role in increasing the total buffer capacity of the township, improving its resilience to climate change threats.

Furthermore, this alternative, compared to the design where river- or groundwater is employed, can potentially reduce the stress on the sewage and treatment system. That follows from the fact that this alternative is not dependent on any external water streams in the natural cycle of the study area. The maximization of green area and the institutional promotion of urban agriculture create favorable conditions for water to infiltrate, making the area more flood resistant.

Nevertheless, this design also has some important drawbacks. The majority of these are related to the feasibility and deploy-ability of the solutions involved. Most of the concepts present in this design require an expert and well-trained labour force, or are ideas that involve technologies and knowledge which are hardly applied on a large scale in more developed countries (eg. vacuum sewage system). This weakness of the system is reflected in the poor result scored by this alternative in the non-functional requirements where the feasibility and the reliability of the system are assessed in the specific Dala context.

5.1.3. Social sustainability

The evaluation shows that the social sustainable design has the highest score. This alternative focuses on making a design which will benefit all of the inhabitants. This solution uses rainwater as the main source. Rainwater harvesting makes it possible to preserve both the capacity and the quality of the water source as well as limit the probability and impact of pluvial flooding on the area. By harvesting water which is already part of the natural system of Dala, further pressure on the water system caused by additional water input in the water cycle is prevented. This protects the system from having to cope with the additional stress of water being added to the system.

The social sustainable alternative also scores high on reducing the environmental impact of urbanization. This will be done by adding 'green' to the streetscape, constructing urban gardens and creating urban agriculture. Normally urbanization changes the whole water cycle of the area. However, with the implementation of these systems water will be allowed to follow its original path, therefore minimizing the impact of urbanization on the environment. Introducing plants and gardens will also help to minimize the concentrations of GHG in the atmosphere.

The alternative scores relatively high on climate change resilience. This is because the system already incorporates a sustainable water source, as well as allowing the natural water cycle to continue during the urbanization of Dala. This solution scores highest for the requirement of producing affordable water, because the system will provide drinking water to communities at one main location. The use of one distribution point will also minimize the loss of non-revenue water, because having one main distribution system will allow for more accurate measurements. This is because less meters need to be checked and the probability of one meter breaking without the water company knowing is reduced. This central system will also help to limit the unneeded waste of water, because residents need to collect drinking water themselves and will be less likely to waste it.

The main source of water will be located within the Dala region, minimizing the cost of the transport of water from the source to the location where it will be needed. The social sustainable system will consist of dual pipeline systems, supplying separately potable and domestic water. The drainage system will collect surface run-off of as well was wastewater from households. It will be easy to construct, maintain and repair for the local population since these systems are already present in Yangon. The gravity sewage system is much easier to implement than the vacuum system of the environmental alternative and can therefore be installed by local laborers, promoting more equality.

5.1.4. Focal points

After evaluating the requirements, three main focal points were identified. They are, the harvesting of rainwater, storage in reservoirs, and the dual pipeline system for the water supply and collection. Both the environmental and social sustainable alternative score very high in the requirement evaluation and this is in part due to the fact that rainwater will be used as a main source to produce drinking water. It should be noted, however, that this source should be paired with a high capacity storage system. The separation of pipes came out as the best solution from the morphological design for all of the different alternatives and therefore this should also be a focal point. It is expected that these focal points will allow for the most innovative solutions to be designed and will therefore be discussed in a workshop with local experts.

5.2. Expert evaluation

A workshop was organized on 28 September 2017 to get valuable input about, among others, the focal points that were chosen and described in the previous section. The participants of the workshop were distinguished guests from YCDC, alumni from NEPS, NWRC and the TU Delft, students from YTU and MMU, and local experts from YEP. The full attendance list and the setup of the workshop are presented in Appendix F,section F.2. In this section, a summary of the most relevant outcomes of the workshop is provided.

The participants agreed that rainwater harvesting is one of the solutions which has the smallest effect on the water cycle. However, the harvesting of rainwater will affect the amount of water which can infiltrate into the ground, which in turn can lead to subsidence. Calculations have to be made to give an educated opinion about this topic. Furthermore, multiple experts indicated that the use of rainwater as the only source for water supply is probably not enough for all water consumption in Dala. Participants also named the Toe river as a good water source with potentially more capacity.

The separation of the supply system into domestic and drinking water, to reduce the energy consumed for treatment, was not directly accepted by everybody. A critical influencing factor was identified in the water source quality. Looking to drinking water, it was mentioned that the Toe river is almost potable and therefore almost no treatment is needed. This means that separating the pipelines would not be convenient anymore. The use of rainwater results in more treatment needed, which could make a separate pipe system effective in reducing energy usage. Regarding the energy costs and reductions of energy consumption, the participants advised to come up with rough calculations of the energy consumption within the total water system. Drinking water treatment might not be the part of the water cycle that consumes most energy. Supply might be a more energy intense part of the system. In this case it would not be efficient to split the system since this would increase the energy demand for the supply. Moreover, the cost of the pipelines have to be accounted. The investment costs are higher for a separated pipe system with respect to a single system. Therefore, the payback time is expected to be longer. A more practical issue of separated system is the implementation, since locals are not familiar with this concept.

An important issue is the awareness of consumption of water. The proposed idea coming from the evaluation of the alternative designs is that this can be improved by making people responsible for their own water by storing water on local scale. Inhabitants of Dala can be encouraged with personal incentives. YCDC has found that assigning responsibility at community level does not work, because of a lack of water conservation awareness. For example, community ponds are often not well maintained, meaning drinking water quality will drop. Therefore, assigning personal responsibility works better. However, the economic feasibility of local storage is questioned. Besides this, the feeling of responsibility for storing the water might not always be present among inhabitants. To solve this and to create more awareness, education has to be improved on the storage of water as well as on how to save water and efficiently harvest water. Lastly, the laws and regulations about water consumption, water quality and wastewater production were mentioned. These laws are at least 50 years old, from back when Dala only had a few inhabitants. They are outdated and need to be adapted to the current consumers and standards.

To improve the water system an economic option was proposed, namely: make the drinking water free of charges and set this margin on domestic water to cover the expenses for the total water consumption of Dala. In this way, all inhabitants will have access to drinking water. Completely free drinking water was not the best option according to the experts, since people will use drinking water for other purposes to save money. Alternatives were proposed from which the community can earn money, for example with tourism, so the water for the poor people can be paid.

5.3. Synthesis

As argued in the previous paragraphs, each of the three alternative designs combines beneficial solutions with significant drawbacks. The main objective of the synthesis is to find a suitable combination of the measures discussed for each alternative in order to come up with an integrated design able to synthesize the main positive findings and minimize the weaknesses addressed in the three different designs. The focal points presented in subsection 5.1.4 will be used to pivot the rest of the design around.

As mentioned in subsection 5.1.4, rainwater harvesting will be used as the main source for water. As pointed out in section 5.2 the amount of rainwater harvested should consider the needed recharge of the GW table in order to minimize the land subsidence. Based on the output of the requirements evaluation and the expert evaluation, the storage of rain will be one of the main challenges. This is because, the variability of rain throughout the year is large. The main storage system will consist of either a few large reservoirs in which the rain water will be collected or the combination of reservoirs and small scale storage points. The current reservoirs in Dala are shallow and highly vulnerable to evaporation losses. It is therefore recommended to make the reservoirs deeper. A rough feasibility study will be done in subsection 6.1.2 to determine which storage system is the most suitable. An impermeable layer will be applied to the base of the reservoirs to prevent seepage losses and groundwater salt intrusion.

Since the needed treatment processes are influenced by the quality of the source and the storage method (and time), a customized treatment process will be defined once information on the water source quality characteristics are better defined.

Initially the quality control of the water will be performed by specialized operators using smartphones and a small quality control device. In the long term, the objective is to make the users perform quality tests on their own tap water. The local consumers can connect their smartphones to a quality testing device to regularly assess the quality of the drinking water in Dala.

The water will be supplied to households by using a dual pipeline system. There will be one pipe system which supplies only water for domestic purpose and another pipeline which will provide drinking water to the different users in Dala. The consumption of the two water types will be monitored and charged through a 'pay for usage' system.

The collection of wastewater and run-off water will be performed by separate sewage systems. 'Grey' and 'black' wastewater will be collected and treated together. This stream will be independent from the run-off drainage system. The run-off stream consists of all the water that is considered too polluted to be efficiently used to produce drinking water (e.g. street water run-off). This water will be treated and then discharged in the environment.

The roof runoff will be collected, stored and treated together with the water collected in the reservoirs and uncontaminated green area to produce drinking and domestic water. The implementation of a complete drainage system as well as the increase of green to the urban landscape will aid in protecting the Dala from pluvial flooding. Adding trees, urban agriculture, urban farming and other green area will smoothen the peak flows on the drainage system during heavy rainstorms.

In order to limit the pollution of the water, standards on quality of the discharge will be set and reuse of wastewater will be mandated to any company that exceeds this limit. The wastewater will be treated using combination of an Upstream Anaerobic Sludge Blanked Reactor (UASB) and phytodepuration/wetlands. This combination positively impacts the sustainability of the system and provides a good quality effluent [103]. The UASB reactor has relatively low energy demands, and produces valuable by-products like biogas and sludge. Biogas can be used to reduce the energy cost of the treatment while the sludge is suitable for agricultural purposes [103]. The relatively high and constant temperatures in the Greater Yangon Region allows for the UASB reactor to achieve high efficiency rates. However, UASB technology needs to be operated and implemented by skilled and trained laborers, which are not readily available in Dala. The wetlands that are proposed in subsection 4.3.3 are able to get rid of excess pathogens and nutrients, that the UASB reactor did not filter out of the wastewater [103].

Furthermore these wetlands will bring more green area to Dala, giving an aesthetic bonus. They are easy to construct and maintain. The high temperatures in Dala go well with the wetlands.

Lastly, the treated wastewater and runoff water will be made available for reuse in agriculture. Here it can be used for irrigation of the crops, making Dala's paddy fields more productive while it can also evaporate into the atmosphere and return to the system as rainwater. Here it should be noticed that water taken directly from the UASB reactor suits the agricultural use better, due to the nutrients that are not yet filtered out by the wetlands.

6

Final design

From the previous design steps a synthesis of all the functions of the water infrastructure was done. The synthesis was based on three focal points to which the rest of the functions were adjusted. This is however not yet a design. Extensive measurements and calculations will be needed to design the full water infrastructure of Dala and give dimensions of the major parts of the design. However, conducting all these measurements and calculations is not realistic within the time available for this project. Therefore, choices had to be made about the level of detail. It was decided that the focal functions (resource and harvesting, storage, and supply, as presented in subsection 5.1.4) will be elaborated on in more detail. For the rest of the functions, their chosen methods and how they fit in with the system will be described more generally.

Feasibility and details of the chosen methods for the focal functions will be assessed and presented in section 6.1. The design for the additional functions will be presented in section 6.2. A graphical overview of the total design will be presented in section 6.3.

6.1. Focal functions

As was explained before, the chosen solutions for the focal functions as presented in subsection 5.1.4 will be designed in more detail. This section presents the considerations that were made while assessing the feasibility and the considerations which should be made when deciding the design parameters. In Appendix G the calculations that support the assessment and decisions are presented.

6.1.1. Water harvesting and source

In this section, solutions that originate from urban planning regulations and harvesting techniques are analyzed to assess if this source can autonomously provide enough water for the future Dala area. In Appendix G calculations on the potential harvested water in Dala shows that this source would be enough to satisfy the predicted water demand for Dala in 2040.
Three major forms of rainwater harvesting (RWH) can be identified [39]:

- In situ RWH: collecting the rainfall on the surface where it falls and storing it in the soil. In this point the in situ RWH in reservoirs can be included as well.
- External water harvesting: collecting runoff originating from rainfall over a surface elsewhere and storing it off site.
- Domestic rainwater harvesting (DRHW): collecting runoff water from roofs, streets and courtyard areas by residents.

Storage of in situ rainwater in the soil is hard to implement in the Dala territory due to the salt intrusion in the aquifers, as stated in Appendix E, section E.6. In situ RWH in reservoirs is possible. Since this method overlaps with the chosen storage method, this form of RWH is described in subsection 6.1.2. The external and domestic water harvesting can be seen as important potential methods to increase the water source of the Township. In the following sub-paragraphs calculations to quantify the water actual harvested by the system are carried out.

Roof rainwater harvesting

The collection and storage of rainwater for drinking purposes from individual household roof catchments is a technique which is already applied by some of the Dala inhabitants. An example of this is shown in Figure 6.1a. The limited capacity of the storage and the poor management of the harvesting technique makes this resource only available during the wet season. Nevertheless, as stated in the previous paragraph, the abundance of precipitation during the wet season could potentially satisfy the growing demand of the area.

Several studies show that rainwater is a good quality source, usually within the WHO 'low risk' category [29, p.1]. However, poor collection and maintenance practices reduce the quality considerably. This emphasizes the need for proper design and maintenance strategies to minimize the contamination of potable roof-collected rainwater supplies. There are several factors which influence the quality of roof runoff, of which the principal are [29, p.4]:

- Roof material: chemical characteristics, roughness, surface coating, age, weather ability.
- Pathogens present in animal excrement.

(a) Local rainwater harvesting

(b) Metal roofs seen in San Chaung, Yangon

Figure 6.1: Roof rainwater harvesting

Most substances show a distinct "first-flush phenomenon": the pollutants concentrations are high in the first minutes of a rain event, and decrease later towards a constant value [56]. Therefore, to significantly reduce water pollution with a very low investment, first-flush devices can be implemented. Doyle [23] gives a complete overview on the different first-flush devices that can be installed. For the Dala case an automatic intensity-dependent device is suggested. The working of this device is based on the fact that low-intensity precipitations does not cause enough flow to wash contaminants from the roof. Once the intensity of the rain rises it is much more likely that the particulate matter will be carried off the roof. This mechanism is particularly efficient in areas with high intensity precipitation, as is the case in Dala. The implementation of this devices leads to a relevant improvement of the collected water quality. However, it reduces the total amount of water harvested by the system. This is taken into account by reducing the amount of water harvested from the roofs with 10%. Further studies are needed to evaluate which specific design can better fit with the Dala situation and to give a more specific estimation of the amount of losses in the harvesting process.

Regarding the roof material, Mendez et al. [61] shows that rainwater harvested from metal roofs tends to have lower concentrations of fecal indicator bacteria as compared to other roofing materials. In the same study, it is stated that the quality harvested from concrete tiles and cool roofs is comparable to that from the metal roofs. This indicates how these materials are as suitable for rainwater harvesting applications as the metal roofs. However, metal roofs are recommendable in this design, considering the current large use of metal roofs in the area, as seen in Figure 6.1b and the higher runoff-coefficient of around 0,9 [23].

To estimate the total capacity of this harvesting method, the roof surface for the future Dala Township is assessed assuming a roof surface per capita rate equal to 19,4 m^2/inh, as explained in section G.1. An efficiency factor of 0,75 is considered to account for the losses during the harvesting process.

Using the assumptions stated above and the formula explained in section G.1 the average water yearly harvested from the roof is estimated around 25 million m^3.

The roof harvesting system is installed during the edifice constructions by real estate companies. The water, collected from roofs, is directly transported and stored in the main reservoirs. This is done with the help of pumps, or with a gravity system. The choice between these two options is determined by the proximity of the reservoir, and the height of the roof used for harvesting. The harvesting and transport systems are installed by local construction companies and financed by public institution. YCDC is responsible for the maintenance of the roofs.

Green area rainwater harvesting

A rough calculation is carried out to assess the potential contribution of a *Bioretention Basin (BB)* design to the total water harvesting. Singapore has been taken as a reference case, providing green areas in an area prone to fluvial flooding, to estimate the total green area in Dala. It was estimated that 40,2 km^2 of Dala will be green area, of which 20% will be the catchment area for the Bioretention Basins. As a result, it is estimated that around 5.6 million m^3 of water can be harvested by implementing 0,13 km^2 Bioretention Basins in Dala. This infrastructure can be installed by local companies under the supervision of foreign partners. A scheme of a classic BB design is shown in Figure 6.2. More background on how the results are derived can be found in section G.1.

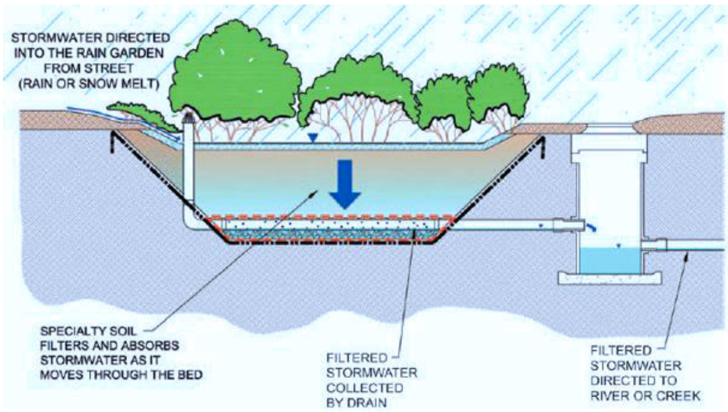


Figure 6.2: Bioretention Basin scheme [16]

Water harvesting from air

Since a large part of the Yangon CBD consists of multistory buildings, of which a large share is supplied with air-conditioning units, the idea arose to harvest the condensed water produced by air-conditioning systems. Based on the report by Siriwardhena and Ranathunga [93], between, 0,38 to 1,14 litres of condensate per ton of cooled air is produced every hour [93, p.1]. The quality of the water which is produced by an air-conditioner is relatively high. It has a low amount of suspended solids, a neutral to slightly acidic pH and a low temperature [93, p.1]. This type of water can be easily used in irrigation systems, as well as for toilet flush water, in fountains or in industrial cleaning applications [93, p.3].

The harvesting of this water will not be very difficult. A small hose will connect the back of the air-conditioning unit to the gutter system. Making it possible for this water to be collected and treated together with the harvested rainwater. Since this water source is very hard to quantify for the Future Dala township, it was not considered in the water balance calculation. However, since it can be easily combined with the rainwater harvesting system, further research should be done on it potential contributions for the harvesting of water.

Conclusion on rainwater harvesting

The results of the previous explained calculations for the different water harvesting methods are summarized in Table 6.1. The methods that give the result for the RWH on the reservoir surface are described in subsection 6.1.2.

Table 6.1 shows that the total harvested rainwater from the system is equal to 49 million m^3 per

Table 6.1: Total rainwater harvested

	Surface [m^2]	Potential yearly volume [m^3]	Actual yearly volume [m^3]
Roofs	12.999.000	36.558.000	24.677.000
Green areas	40.200.000	113.066.000	5.650.000
Reservoir surface	10.500.000	29.532.000	22.688.000
Total	64.198.000	179.156.000	49.016.000

year. This number is slightly smaller than the yearly consumption calculated in Table 2.6. However, the reservoir will have a filling time of four years, this will create a large buffer which will be able to suffice the water demand for the Dala region up until 2070. If the population increases significantly after 2040, the reservoir will not be able to supply the amount of water which is demanded. Dividing the 49 million m^3 by the total precipitation that falls on Dala, results in only 7,8 % that is harvested.

6.1.2. Storage

Whether or not a storage system is needed to provide Dala with drinking water during the dry season is dependant on the source. Three different water sources were evaluated in section 4.3, groundwater, Toe river water and rainwater. These three different sources will quickly be discussed in the next section.

Feasibility

As mentioned above, the source of water depends whether or not a storage system is needed. groundwater harvesting does not need a storage system. This is because groundwater is already being stored and is only pumped up when needed. Secondly, if the Toe river was used as a source, it is expected that no additional storage would be needed. However, no further research has been done to see if the Toe river is able to suffice the demand required in the dry season. Lastly, the distribution of rain in Myanmar is very uneven, in a few short months high amounts of precipitation is present. Therefore, in order to effectively use rainwater as a source a large storage system will be needed to be able to supply the demand for the dry season. Since rainwater has be chosen as the most sustainable solution, the next sections will discuss the large scale storage of rainwater in reservoirs. An example of a reservoir can be seen in Figure 6.3a, while Figure 6.3b shows the storage of rain water on a local scale.

(a) Central reservoir in Dala (b) Local rainwater storage

Figure 6.3: Water storage possibilities

Reservoirs

The storage of rainwater plays an important role in being able to provide the expected 670.000 inhabitants of Dala with drinking water harvested from rainwater in 2040. A total daily consumption of around 143.000 cubic meters is expected in Dala in 2040, as presented in Appendix B, subsection B.4.1. The storage system needs to have a large enough capacity to provide the population of Dala with water during the dry season. The dry season is defined as a seven month period starting in December and ending in June. Since the dry season is defined for a period of seven months, this already takes into account the shift in the duration and length of the monsoon period due to a changing climate in the future as described in subsection 2.4.1.

A rough calculation has been made where the necessary storage capacity for the population of Dala for the year 2040 is estimated on 30,5 million m^3, see Appendix G, section G.2. If the reservoir has a maximum depth of 10 meters this will result in a surface area needed of 3,05 km^2. However, this calculation does not take into account whether or not this amount of water harvesting is possible.

In subsection 6.1.1, it was concluded that the harvesting of water from the urban area of Dala together with the precipitation falling on the surface of the reservoir will not result in enough water to meet the demand of the dry season.

Additional calculations were made to not only have a reservoir which was large enough to harvest water, but also have a system that can cope with the increase in population and the change in climate. Reservoirs will be built with a total surface area of 10,5 km^2 and have a maximum depth of 10 meters resulting in a total storage capacity of 105 million m^3. These reservoirs will be built by 2020 and will require a period of less than 4 years before being able to be used. Once these reservoirs are in use they will be able to supply the demand of water for the growing population. Up until the year 2040 a growth in the population is predicted, after 2040 a relatively stable population size is predicted. This reservoir size will provide the stable population with drinking water for at least another 30 years. The calculation takes into account the yearly losses due to seepage and evaporation. It is assumed that the yearly evaporation losses can be decreased by 25% resulting in a evaporation loss of 1 meter per year. This decrease in evaporation losses is due to the use of implementing wind breakers. These wind breakers should be placed on the windward side of the reservoir [92, p.37]. After these 30 years additional measures will be needed to provide the population with sufficient water in the dry season. However, if the population experiences a significant growth after 2040 additional measures may be necessary to provide the population with enough water.

Evaporation losses

High evaporation loss is one of the main problems of a reservoir system. However, if the evaporation losses can be decreased by even more, for instance 50%, a significantly smaller reservoir can be used which will be more effective and require a shorter filling time before being completely operational.

To minimize the evaporation, different solutions are discussed. The solutions which could be easily implemented are the use of floating covers, wind breakers, shadow structures and biological covers [11, 92, p.5-6, p.33]. Both shade structures and wind breakers will be the cheapest and easiest to implement because, these structures can just consist of trees and will already aid in minimizing the loss due to evaporation.

Seepage losses

The soil composition in Dala causes a risk of loss of water due to seepage and a risk of pollution and salt water intrusion from the ground. In order to minimize these risks, the base of the reservoir should consist of an impermeable layer. A high plasticity clay layer should be used and will result in a yearly seepage loss of 33 mm [77, p.2]. This value was taken into account when calculating the required volume of the storage system.

6.1.3. Water supply

For supplying drinking water towards households, the implementation of a dual reticulation system is proposed. This measure consists of dividing the system in two separated pipelines for the supply of domestic and drinking water and has the goal to save energy and costs for the treatment of drinking water. This section will compare a dual reticulation system with a single pipeline system. Figures derived to assess the performance of the dual reticulation system are purely meant to compare against the performance of a single pipeline system. To compare the two systems, simplifications are made.

Although simplifications might lead to dimensions of the system which are not realistic, the assumption is made that the comparative figures for the dual reticulation system in relation to the single pipeline system will hold.

A dual reticulation system is not new. Many cases exist around the world, of which the most can be found in the US [36, p.69]. Grigg et al. [36] presents 37 case studies of dual reticulation systems in the US. Only a few of the systems supply grey water for domestic use, whereas most of the systems focus on reusing wastewater for landscape irrigation. In most of the cases, the reticulation was installed due to a water shortage. When harvesting water from new sources is complex, expensive or has a big impact on the environment, the dual reticulation system is seen as a possible solution. Energy reductions on the water treatment are not mentioned as an argument to opt for a dual reticulation system.

To determine whether a dual reticulation system is in fact contributing more to the goal of the report, set for this design, than a single pipeline system, the pipeline characteristics, installation, operation and maintenance are considered.

Pipeline diameter

Due to lower quality constraints for domestic water, the velocity in the pipeline system for domestic water supply can be lower. This results in a bigger diameter for the pipeline, which supplies the domestic water, in comparison to a single pipeline system. The resulting diameter for the pipeline supplying domestic and drinking water in the case of a dual reticulation system is 1,12 meter and 0,21 meter respectively. The diameter for a single pipeline system will be 0,82 meter. For this calculation a peak flow per hour of 1,8 times the daily demand is assumed. Full calculations can be found in Appendix G, section G.3. It should be noted that the calculations are underestimating the peak in the water demand, by omitting the industrial water use and non-revenue water.

Pipeline length

To roughly calculate the pipeline length, a grid system was drawn with a surface comparable to the service area of the water system for Dala. The requirement of supplying water at a distance of maximum 500 meter was taken into account, for a case which considers equal distribution of households over the surface. An increase in pipeline length is seen with the addition of extra storage facilities. This is due to an increase in primary distribution lines, which serve the branches (secondary distribution lines) that transport the water towards 500 meter maximum from every household. The method used can be seen in Appendix G, section G.3. An average of 190 km pipeline length is obtained, which is used in further calculations in this chapter. For the dual reticulation system this means that the total pipeline length is two times the pipeline length of a single pipeline system, resulting in 380 km.

Pipeline material

The results of the pipeline diameter and length determine the total material needed for the pipelines. The material used is PVC, as recommended in Commercial Industry Supply [17], with 12.800 m^3 for the single pipeline system, and 24.750 m^3 for a reticulation system.

Installation

The parts of the installation that mostly influence the costs are the transport of the pipelines, the digging of the ditch, the burial of the pipelines and the chance of cross connection [44, p.5]. It was concluded that the costs for the dual reticulation system is higher on all parts. Only during the installation, the digging and burial of the two pipes can be done together, so this will not give the biggest difference per meter pipe.

Power demand

A pipeline is modeled with the characteristics as derived in the paragraphs before. A simplified straight pipe is considered to calculate head losses. With these calculations it is derived that the dual reticulation system uses less energy than a single pipeline system, which can be explained by the lower velocity needed in the pipeline for the domestic water supply. Power needed for pumping of a single pipe system yields 1,35 MW, while the two pumps needed for the dual reticulation system use 0,58 MW.

Maintenance

According to Grigg et al. [36, p.45], maintenance costs are induced due to cross connection control, leakages and spills and extra quality control on the supplied water. These induced costs can also be expected for the case of Dala. Furthermore, maintenance issues can be expected when the demand for reticulated water is low, due to biological growth [36, p.246]. This problems occurs for example in Tampa, where reticulated water is used mainly for landscape irrigation. This demand for irrigation water will depend on the precipitation, which in the case of Tampa results in a drop in demand in the wet season [108]. These issues are not expected in Dala, since water demand for domestic use as well as for drinking water is quite stable, if assumed that these figures are comparable with the figures of Yangon [124, Table S 10].

Conclusion on dual reticulation system

An overview of the comparison between the dual reticulation system and the single pipeline system is given in Table 6.2. It can be concluded that extra material will be needed to build the dual reticulation system. This will cost more money and energy. However, the decreased energy use due to lower power needed for pumping installations is significant. Besides this, the decrease of energy needed for the treatment of the water also yields significant differences, as seen in subsection 6.2.1. Therefore the dual reticulation system is opted for in this design, supplying domestic and drinking water separately.

Table 6.2: Comparison single pipeline system with dual reticulation system

	Single pipeline system	Dual reticulation system
Pipeline diameter	0,82 m	1,12 m and 0,21 m
Pipeline length	190 km	380 km
Pipeline material	12.800 m^3	24750 m^3
Installation	One time transport	Two times transport
	One trench	One trench
	No cross connections	Chance on cross connections
Power demand	1,35 MW	0.58 MW
Maintenance	Normal costs	Extra costs for checking
	No chance on cross connections	Cross connections
	One water quality to check	Two water qualities to check

Communal facilities

As discussed in Appendix E, section E.4, a large share of the people currently living in Dala do not own the land they live on. These 'squatters' build their own houses with cheap or waste materials. The design in this report suggests distribution to each household. However, it is not feasible to construct distribution facilities to all houses of squatters. This is due to the induced land value that can be expected if water facilities are upgraded [125, p.7-2], which is the goal of the design presented in this report. Induced land values will lead to more investments, earlier explained in Figure 3.1, which will make the land owners reclaim their land. In this process squatters will have to move, and will resettle elsewhere. The squatters will resettle in unused land, which will not provide supply facilities for drinking water.

To supply all people in Dala with drinking water, while coping with the resettlement of squatters, public supply points are proposed. Public or communal supply facilities will provide water to squatters within a range of 500 meter. This solution will not make the area significantly more attractive for investments, while supplying squatters with safe drinking water.

6.2. Additional functions design

Next to the focal functions, nine other functions were identified and elaborated in the previous chapters. These functions are equally as important as the focal functions in closing the water circle in Dala, but will be designed for in less level of detail. In this section, the methods that were chosen in the synthesis in section 5.3 will be elaborated on and linked to the rest of the design. Furthermore, some considerations for the institutional, legal and social framework surrounding this design will be presented.

6.2.1. Drinking water treatment

As mentioned in subsection 6.1.1, rain is generally considered as a non-polluted, or at least not significantly polluted, source of water. The main contamination of rainwater will occur during the collecting process. However, in subsection 6.1.1 specific measures and recommendations (e.g. first-flush device, regular maintenance of collecting surface) to reduce the contamination of the water are included in the design. In addition, the resident time of the water in the reservoir can lead to a further improvement the water quality [88, p.1]. From these considerations a high quality of the source water is already expected before the treatment.

The design is characterized by a dual supply system where the waters for drinking and domestic purposes are split, as discussed in subsection 6.1.3. Due to this design choice, the possibility to only partially treat the domestic water arises. In this chapter the set of needed treatment steps for the two water types are defined. After that, the investment and operational cost and energy savings are compared for the dual and single supply system.

A traditional drinking water treatment is chosen for the design. This system is considered easy to operate and maintain for local laborers and it usually has a lower energy consumption than membrane systems [109, p.1]. The drinking water treatment consists of the following steps and it was designed to accomplish the WHO standards set in [35]:

1. Pre-filtration
2. Coagulation-Flocculation
3. Rapid-sand filtration
4. Ultra Violet disinfection
5. Granular Activated Carbon (GAC) filtration
6. Chlorination

The domestic purpose water does not necessarily have to go through steps 4 and 5. This leads to a reduction in investment cost, CO2 emissions and operational costs in the treatment. In order to estimate the magnitude of these advantages, the software *Kostenstandard* as designed by *Royal HaskoningDHV* was employed. The cost and the emission difference between the single and dual supply system are presented in Table 6.3 and they refer to the Dutch market prices of energy in 2008. To calculate the costs, the same discharge as considered in subsection 6.1.3 is used as an input in the software.

Table 6.3: Treatment cost and CO2-emission reduction by implementing dual pipes system

	Investment cost [€]	Operational cost [$€/y$]	Energy use [Wh]	Emission [$tonCO2/y$]
UV Disinfection	1.268.000	444.000	301.000	816
GAC Filtration	16.111.000	2.097.000	N/A	127
Total	17.380.000	2.540.000	301.000	943

The total treatment costs for a single reticulation supply system is reported in Appendix G, section G.4, Table G.11. Comparing these with the results from Table 6.3, the dual reticulation system leads to the following advantages:

- 35% reduction of investment cost of the plants.
- 40% abatement of operational cost for the plants.
- 11% reduction in CO2 emission, during the life cycle of the treatment plants.

6.2.2. Quality control of drinking water

A combination of an already proven method in the Netherlands [117] and an existing and used mobile application in Asia [4] will be used to ensure that on the long term the control of the water quality will be sustainable.

The idea used in the Netherlands is the Citizen Science Project (CSP) which involves the local inhabitants to check their own water quality. This projects makes the local people more aware of the water quality, stimulates the inhabitants to control the water quality themselves and on the long term reduces work for the employees of the water treatment company. Before this is possible, sessions and lectures are needed where information is given about the use of the app and the different test devices. Therefore on the short term the quality control will be done by qualified operators, who can also inform citizens about how the different techniques work.

By combining the CSP with a mobile application, the measurements can be done by using smartphones. Data can easily be stored in an online database. This reduces the consumption of paper and makes the information directly accessible. The application Akvo Caddisfly from Akvo [4] makes use of water test strips only, as the one shown in Figure 6.4 and the camera of the phone. These strips have to be put in the water, where they react with the different chemicals in the water. Then a picture has to be made from the strip, where the application compares it with the different possible outcomes.

An interview with a local expert on community involvement with smart applications was conducted to see whether this could be a good method for quality control. From the interview, as found in Appendix E, section E.7, it became clear that engagement with such a method is achieved by physically visiting the community and showing how the application works. Furthermore, it is important to show people how their lives can improve by sending the data. It should, however, be ensured that the application does not use too much mobile data, otherwise people will not use it.

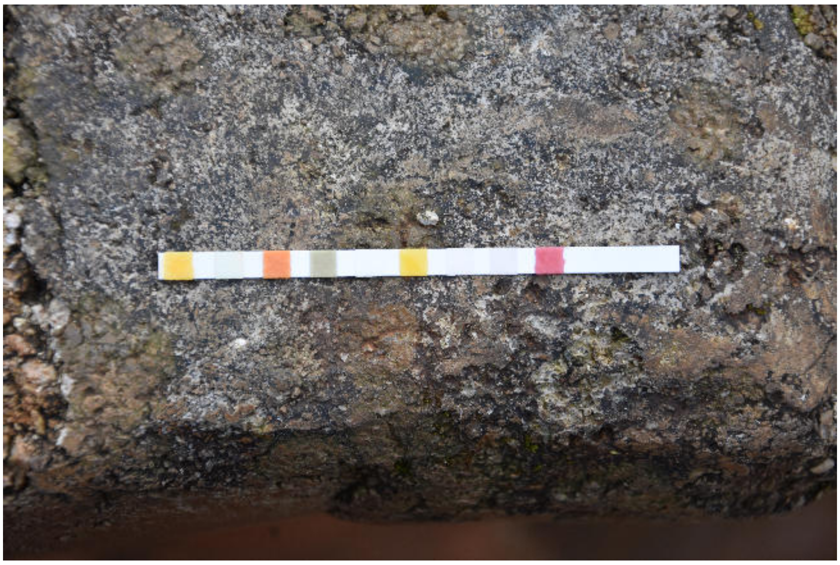


Figure 6.4: Water test strip

6.2.3. Collection of wastewater

As mentioned in section 5.1, the 'black' and 'grey' water are collected together and transported to a treatment plant. This system consists of a separate pipe system which does not have to cope with the drainage of street runoff water. A gravity flow system is used to collect and transport wastewater. This type of system utilizes the gravity gradient to transport the wastewater to the WWTP [73]. When this gradient is too small pumps are used to create a height difference. Force mains are also used in low lying areas to prevent sedimentation in the pipe network.

6.2.4. Limiting pollution of wastewater

To ensure that the wastewater of Dala can be treated as efficiently as possible, it is important to ensure a certain maximum pollution level. If there are only a few sources which produce heavy polluted water, eliminating these sources could save a lot of energy on the treatment.

As was mentioned in section 5.3, the chosen method to limit the pollution is setting a pollution limit and mandating any user that exceeds this limit to reuse their own wastewater. However, monitoring individual pollution levels for all inhabitants, industry and agriculture is an impossible task. Therefore it is best to monitor only the sources that will most likely produce wastewater with the highest pollution levels. For Dala, this will probably be the industry. Globally, industry is one of the most important sources of water pollution [50]. Furthermore, the textile industry produces the most polluted water of all industries worldwide [114]. As was stated in section 2.4, this is exactly the type of industry that is expected to settle in Dala.

Standards need to be incorporated in local water laws setting limits to certain substances in the wastewater. Veenstra et al. [115] researched common pollutants, standards and techniques used to limit the pollutants. Furthermore, TBW [98] defined some requirements for the water inserted in the UASB, which will be the main treatment technology. Together, the common standards and the requirements for the UASB lead to the values for water parameters as stated in Table 6.4.

Table 6.4: Standards for the most common industrial wastewater pollutants [98, 115]

Parameter	Standard
pH	$6,3 - 7,85$
Temperature [$°C$]	$35 - 38$
Chemical oxygen demand (COD) [mg/l]	> 250
Suspended solids [mg/l]	< 400
Heavy metals [mg/l]	< 10
Cadmium [mg/l]	< 100
Cyanide [mg/l]	< 2
Sulphate [mg/l]	< 1.000
Oil and grease [mg/l]	< 100

Compliance to these standards needs to be monitored for industry. This can be done by requiring a report of the wastewater composition before allowing a company to settle in Dala, and after they have settled conduct regular inspections. Companies that do not comply to the standards will be asked to reuse their own wastewater and disconnected from the municipal system. Companies that claim to not exceed the limit, but turn out to be in violation upon inspection, are fined and disconnected from the municipal system. Companies are allowed to reorganize their processes such that they establish a less polluting water stream which can then still be discharged in the municipal system.

Next to keeping the pollution of the wastewater in the municipal system to a limit, it is also expected that because of the the water reuse, companies become more aware of the pollutants they add to the water. Wastewater reuse can be conducted in several ways [76]. Firstly, a company can reuse untreated water for purposes that require water of lower quality, such as fire protection, washing and pH adjustment. Secondly, they can reuse untreated water within a group of companies, also known as industrial symbiosis. This allows for businesses to exchange byproducts, share utilities and share ancillary services. Thirdly, if the water is too polluted, companies can set up their own treatment system tailored specifically to their needs. They can do this individually or again within a cluster of companies. For all of these methods, the reuse of the water costs less energy than when treated in municipal treatment plants. Therefore, these methods will be promoted amongst industrial companies settling in Dala.

Next to saving energy on treatment, wastewater reuse has a number of added advantages that make this a very sustainable method [76]. It reduces the amount of water that is withdrawn from the water resource, increases the productivity per water input, limits the amount of wastewater in the system and it could save the companies money on the long term. As the water is being kept in the system, this part of the water circle for Dala will be closed.

6.2.5. Monitoring water consumption

As stated in subsection 4.2.8 there is currently no adequate way of metering and billing in Dala. Therefore a new system will be implemented in Dala to monitor the consumption of water by using a prepaid system. As depicted in section 5.3, the consumption of water is monitored by a 'pay for usage' system where only water is supplied to people who have paid beforehand. With this prepaid system the users can only collect water if the balance on their account is positive.

New houses will be connected to the piped system and will have a meter in their house to monitor the consumption and gives a warning when their balance is negative. With this system, money is deducted when the tap is opened and the water consumption is administrated in a remote database. For the communal points, the same system is used. In the public collecting points people can pay with their account before the water is supplied. With this system it is known who is consuming water, how much this person is consuming and at what time. The information is digitally stored so paperwork is reduced and it is freely available online for the supply company and costumers.

Mcintosh [58, p.43] states that it is not always the case that the poor are not willing to pay, but most of the time the governments are unwilling to charge. It is believed that a correct pricing and charging system can have a positive influence on lowering of the water consumption. For this reason, a pricing system is introduced. This system is designed to make water affordable for everyone and, at the same time, discourage unnecessary consumption of water. This can be realized by making the price per liter increase in steps. The first 10 liters of drinking water, based on the drinking water demand [42], are free. After this threshold the price for drinking water will increase rapidly to discourage the overuse. Also for domestic water the price increases in steps but starting with a base price. This compensates for the difference due to the free drinking water. A schematic graph of the pricing can be seen in Figure 6.5.

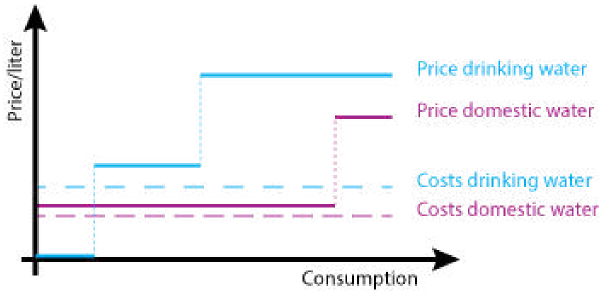


Figure 6.5: Schematic graph of the pricing system

6.2.6. Treatment of wastewater

As was mentioned in section 5.3, for the wastewater produced and the resources available in Dala, a combined wastewater treatment system is the most suitable and sustainable solution. The wastewater treatment system will be a combination of an upstream anaerobic sludge blanket reactor (UASB) and phytodepuration in wetlands.

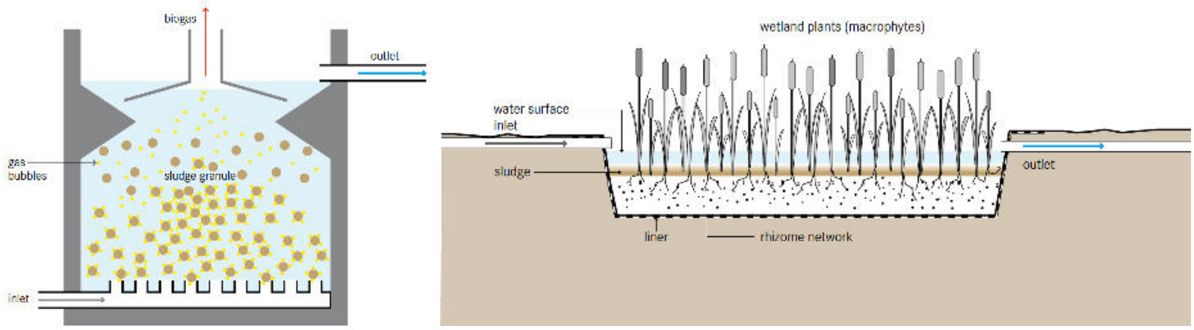
The UASB is a centralized treatment technology, meaning that Dala could do with just one treatment plant. However, to save energy on wastewater transportation, multiple plants can be built. No primary settling of the water is needed, so the domestic and industrial wastewater can be directly inserted into the UASB. As will be explained in subsection 6.2.4, pollution levels of this wastewater will be limited such that the treatment is done as efficiently as possible.

As depicted in Figure 6.6a, the grey, brown and black water is inserted in the bottom of the tank and flows upward. It is then filtered by a suspended sludge blanket [103]. To ensure a constant upstream velocity of 0,7 - 1,0 m/h in order to keep the sludge blanket suspended, an electricity supply and constant water inflow are needed.

The UASB is a highly appropriate and efficient treatment method for the wastewater in Dala, but it should be noted that this comes at a cost [103]. The plant needs expert design and construction, which should be outsourced to a company specializing in UASBs. Further, the operation and maintenance of the plant requires well-trained personnel who need to constantly monitor the state of components and maintain the balance between upflow and settling rates. It is advised to either outsource this to an expert company or select local laborers to undergo a well-designed training by an expert company.

The outputs of the UASB are biogas, sludge and effluent [103]. The biogas can be used to generate energy, and can therefore be sold to energy companies. The sludge can be made available as fertilizer for agriculture [90]. As will be discussed in subsection 6.2.7, the effluent needs to be further treated before it can be discharged. Also, the runoff water that is collected from the streets needs some treatment before it is discharged, but does not need to go through the UASB [103]. Both types of water will be treated by phytodepuration in wetlands.

The type of wetland that is chosen is the free-water surface constructed wetland [103]. This artificial wetland attempts to replicate the processes that take place in its natural counterparts. After laying an impermeable base covered with rocks, gravel and soil, native vegetation is planted on top. Using an inlet designed to distribute the water evenly, the wetland is flooded to 10-45 cm with wastewater. As particles of the wastewater flowing through the wetlands settle, pathogens are destroyed and the vegetation utilizes the nutrients in the water. The desired amount of nutrients and pathogens to



(a) UASB (b) free-water surface constructed wetland

Figure 6.6: Schematic representation of two wastewater treatment methods. Source: Tilley et al. [103]

be removed from the water should be defined on beforehand, so the amount of compartments with separate flow paths can be determined. After covering all the flow paths, the water exits through the outlet and can be discharged. Figure 6.6b shows a schematic representation of the processes in a wetland.

Laborers should be employed to regularly maintain the wetlands. This is needed to avoid short-circuiting of the water due to waste, fallen branches or other blockages. It should be noted that the system needs quite a large area and should be constructed well in advance of being used as the vegetation needs to grow. Also, the wetlands need expert design and construction, which is recommended to be outsourced to a specialized company.

6.2.7. Discharge of wastewater

Both the effluent water treated by the UASB and the sludge that comes out of the UASB are rich of nutrients and therefore fit for usage in agriculture [90]. For that reason, they can be made available directly after the UASB treatment for irrigation and fertilization purposes. This will increase the productivity of Dala's rice paddies, generating more profit for farmers and increasing overall welfare in Dala. Next to that, the water will be kept in the system and used efficiently, making this a very sustainable solution.

However, as most of the land is already fully irrigated by rainwater during the monsoon season [70], during this time of the year the water will need to be discharged elsewhere. During this time, a number of options for the wastewater discharge are possible [103]. The water can be discharged into surface water bodies, in this case that would most likely be the river, it can be used to recharge the aquifers and it can be infiltrated in the ground. A combination of these methods can be used, but it should noted that the ground is likely to be saturated with water during the wet season, so discharging the water there may increase flood risk. This makes discharging it in the river more attractive, but that does not lead to a closed water circle. For any method used during the wet season, it should be noted that additional treatment after the UASB is needed to remove harmful nutrients (which is not the case when used for agriculture) [103]. As mentioned in subsection 6.2.6, this will be done using phytodepuration in wetlands. Further, when the water is discharged in the river, the distance between the discharge point and the next harvesting point should be sufficient [103].

In short, during the dry season both wastewater and sludge can be made available for use in agriculture directly after treatment by the UASB. During the wet season, a combination of discharging in the river, recharging the aquifers and infiltrating in the ground can be used. During this period, any sludge and nutrients that are retrieved from the water can still be used for agriculture. Also, in this case the water needs additional treatment by phytodepuration in wetlands before being discharged.

6.2.8. Protection against pluvial flooding

As mentioned in section 5.1, pluvial flooding is a serious problem in the Dala region. In order to minimize the occurrence of pluvial flooding, two measures where proposed. The first measure which was proposed was the adding of a complete drainage system which can cope with the peak flows and allow for the proper discharge of the rainwater. The second measure which was proposed was the adding of green to the streetscape. The harvesting of rainwater is also a measure which helps protect the Dala region against flooding. However, this system isn't primarily constructed to aid in flood protection but to supply the system with drinking water. The rooftop harvesting aids in reducing the magnitude of the peak flow in the drainage system as well as the volume of water which needs to be drained.

The construction of a complete drainage system will allow for the rapid removal of water from the urban area during high precipitation levels. However, these drainage systems will require regular cleaning and maintenance, so that they can be used to their full capacity. Adding green to the streetscape will aid in minimizing the chance of flooding because these green systems allow for water retention. The retained water can later be drained during a moment of little or no precipitation. These green areas can consist of either parks, urban gardens or urban farms. These green areas also allow for the infiltration of water, re-supplying the groundwater table and also minimizing the chance of subsidence due to water extraction [79], which is important due to the fact that increased levels of subsidence induce the risk of flooding.

6.2.9. Drainage system

In this section the discharge of the drainage system will be calculated. In order to calculate the maximum discharge that the drainage system has to cope with, the Wet Weather Flow (WWF) is needed. This is the flow of water which needs to be harvested from the urban area to prevent the occurrence of flooding.

Wet Weather Flow

To estimate the Wet Weather Flow, which is defined as the flow of water which needs to be drained to make sure the area does not suffer from flooding.

$$Q_{WWF} = i \cdot C \cdot A \tag{6.1}$$

Equation 6.1 show the Wet Weather Flow, in which, i is the rainfall intensity $[mm/hour]$, C is the runoff coefficient and A is the surface area $[km^2]$ of the catchment area.

Runoff coefficient

Depending on the land use different runoff coefficients are considered for the future Dala case. Butler and Davies [13, p.229] provides a table which includes values for runoff coefficients in urban areas. Table 6.5 show the values chosen for each of the different areas. These runoff coefficients are based on Butler and Davies [13].

Table 6.5: runoff coefficients and surface areas of the different surfaces in Dala

Type of surface	runoff coefficient C
City center	0,85
Green areas	0,30
Green areas with rainwater harvesting	0,00
Roofs	0,10

As mentioned in subsection 6.1.1, 90% of the roof runoff will be harvested for drinking water production. The remaining 10% of water will end up in the drainage system. This 10% derived from the installation of first-flush devices. Green areas will also aid in the harvesting of rainwater and the production of drinking water. The green areas will have a total surface area of 40,2 km^2, 20 percent of this will be used to harvest rainwater and the remaining 80 percent will be regular green areas which have a relatively high runoff coefficient due to high soil saturation rate which can be expected in the wet season.

Surface area

As derived in section 3.2, it is assumed that the urban area of Dala will have a total area of 112,5 km^2. This whole area includes green areas, roofs and paved surface (e.g. streets and parking lots). The size of these surfaces can be found in Table 6.6.

Table 6.6: Size of the different areas with a different surface in Dala

Type of surface	Area $[km^2]$
Paved surface	59,3
Green areas	32,16
Green areas with rainwater harvesting	8,04
Roofs	13

Intensity

Based on the rainfall intensity duration frequency curve a rainfall intensity of 88.9 $mm/hour$ with a return time of once every 25 years [120, p.5] will be used. This value can correctly be used for catchment areas smaller than 0,65 km^2 [120, p.5]. Win and Win [120] presents these figures for the case of Yangon, which justifies the use of these figures for Dala. The choice of designing with a high return period takes into account the expected increase of intensity and frequency of extreme events due to climate change, as described in subsection 2.4.1.

Table 6.7: Wet Weather Flow of Dala

Type of surface	WWF $[m^3/h]$
City center	4.481.000
Green areas	857.000
Green areas with rainwater harvesting	0
Roofs	116.000
Total	5.454.000

Based on all of the above mentioned input parameters the Wet Weather Flow will result in a total discharge of 5,5 million $m^3/hour$ for the urban area of Dala.

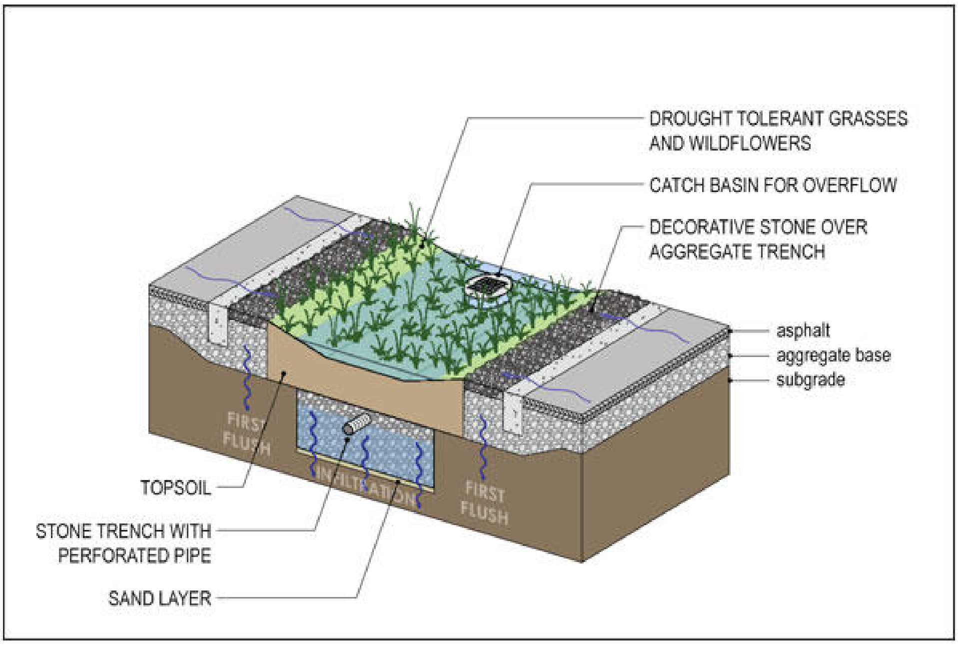


Figure 6.7: Cross section rain garden scheme [26]

However, since no clear map exists with the distribution of the urban areas, green areas and the road infrastructure. This area cannot be split up into many small catchment areas for which the peak flow and pipe diameter per area can be estimated.

Based on the previously calculated hourly peak discharge of the urban area, the rainfall intensity of 88,9 $mm/hour$ can only be used for catchment areas smaller than 0,65 km^2. When the actual layout of the drainage system will be defined, it is wise to design catchment areas smaller than 0,65 km^2.

This drainage has to be designed to cope with discharge of 5,5 million $m^3/hour$. The drainage system is separate from the wastewater sewage, as mentioned in section 5.3. In this way, the WWTP can more efficiently treat the wastewater thanks to the more concentrated and constant incoming flow. The collected runoff water can be only partially treated before discharge, lowering the operational and investment cost of the WWTP. Separating the runoff flow to the wastewater stream, also reduces the environmental pollution in case of overflow of the drainage system.

To reduce the runoff which the system has to cope with, high porosity asphalt and cross section rain garden, as the one schematized in Figure 6.7, are recommended in the Township future landscape.

6.2.10. Protection against fluvial flooding

As mentioned in section 2.2, the risk due to fluvial flooding is acknowledged and will only be examined on a global level. Based on Nientker et al. [72], the occurrence of an extreme high water event of + 10 meter will have a return period of 1/350 years. This value is based on the probability of both High Water Spring tide (HWS) and the occurrence of a strong cyclone hitting Myanmar [72, p.213]. Therefore it is wise to include a fluvial protection measure such as a dike or an integrated flood wall to minimize the effects of fluvial flooding. The dike should be constructed near the river edge along the whole of the Dala Township and enclose the Dala area. It should be high enough to withstand 10 meter high flood levels. When constructing the dike enough land should be left surrounding the dike to allow for heightening and reinforcement of the dike, should this be required in the future.

6.2.11. Institutional, financial, legal and social framework

The proposed system will only work when supported by an advantageous environment. This is ensured by designing arrangements that take into account the actors involved and the people that will make use of the system. These arrangements will not be discussed very much into depth here, as the focus of this research is the technological design. However, it is important to acknowledge that this technological design should be accompanied by the appropriate institutional, financial, legal and social measures.

Institutional measures

As was described in the stakeholder analysis in section 2.3, institutions governing the water system in Myanmar are abundant. Responsibilities in terms of water are often overlapping, not well defined or even assigned to ”the community” [8]. This does not support effective and efficient governance. As was pointed out in the expert evaluation in section 5.2, it was found that assigning responsibility at community level does not promote adequate water conservation. Appointing clear responsibilities is key to successful water management [82], as was also confirmed by the experts. Therefore, the responsibilities for all functions of the system should be appointed to actors that have an interest in having a successful system. It then remains the question how the responsibilities should be divided.

As with many infrastructural systems, it is common to distinguish between vertical and horizontal unbundling [65, p.54]. Vertical unbundling occurs when two activities, of which one is an input factor of the other, are institutionally separated. In the case of Dala this could be, for example, separation of water harvesting and water treatment. In horizontal unbundling activities are separated based on markets. This can be geographical or in the case of Dala, for instance, domestic and industry. For all arrangements counts that combinations of private and public entities is possible. Therefore, this is not only relevant for public stakeholders, but also for private stakeholders. The most appropriate arrangement for Dala's water system needs to be further researched and constructed in close cooperation with relevant ministries, such as the Ministry of Construction.

Further, it was pointed out in the expert evaluation in section 5.2 that adequate knowledge and professional training needed to develop and maintain a water system as the one proposed is lacking in Dala. Further education and training of responsible authorities and laborers is needed to ensure the system is constructed and maintained in the right way. This was underlined by a member of Dala's local government during a visit to Dala. As illustration he showed a groundwater well, see Figure 6.8b, which has been unusable for some time already. It was donated by a humanitarian organization, but because people had no knowledge of how to use or maintain it, the water quality rapidly deteriorated.

(a) Poorly maintained groundwater pump (b) Poorly maintained groundwater well

Figure 6.8: Out-of-order water facilities due to poor maintenance and operations

Financial measures

The system as proposed here, requires some significant investments. As YCDC in itself does not have a large amount of money to spare, it is important to spread the investment over time and parties. As mentioned above, the responsibilities for the system need to be spread over governmental bodies and private companies. This includes financial responsibility. YCDC can choose to allocate funds to these parties to enable them to make the necessary investments.

The next question is how YCDC can finance these organizations. As was mentioned in section 2.3, several international funds have shown interest in the development of Yangon. Among them are the Japan International Cooperation Agency (JICA), the Korean International Cooperation Agency (KOICA), the South Korean Economic Development Cooperation Fund (EDCF) and the Asian Development Bank (ADB). Together, they have invested more than $1,2 billion in Myanmar, mainly aimed at improving the infrastructure [1, 49, 53]. If approved by these funds, YCDC can allocate some of this money towards investments in Dala's water infrastructure.

Legal measures

The design that is proposed assumes some form of structure in Dala in terms of built environment and behaviour. However, as was pointed out in the expert evaluation in section 5.2, the laws governing water management in Dala are more than 50 years old. They are not equipped for the size that Dala has now, let alone the size it will have by 2040. Since in 2010 the UN General Assembly made the decision to declare the right to clean drinking water and sanitation a basic human right, the pressure on governmental bodies to formulate adequate laws and policies has risen [81].

In terms of explicit drinking water and sanitation laws and policies, the appropriate governmental body (either YCDC or Dala's local government) will need to promote WHO norms on drinking water quality, safe use of wastewater and safe recreational water environments [81]. Next to that, as was suggested in subsection 6.2.4, restrictions on the pollution of wastewater need to be imposed on industry in order to ensure efficiency in wastewater treatment. As was mentioned in the stakeholder analysis in section 2.3, Myanmar has established a National Water Resources Committee (NWRC) that attempts to ensure consistency in water policy. For this, they have written a National Water Policy (NWP). The local government can use the NWP as a basis to write their local policy. Hereby it is important that these policies are consistently enforced.

In order to make the design successful, a policy for the water standards is not enough. As the performance of the water system is dependent on the built environment that is yet to be developed in Dala, policy needs to be written that ensures favourable conditions. For example, if rainwater harvesting from roofs is to be employed on a large scale, then policy must be implemented that prevents construction companies or individuals from using materials that harm the water quality during the roof water harvesting process. This, and the guarantee that enough space is left for water infiltration, can be ensured by issuing building permits.

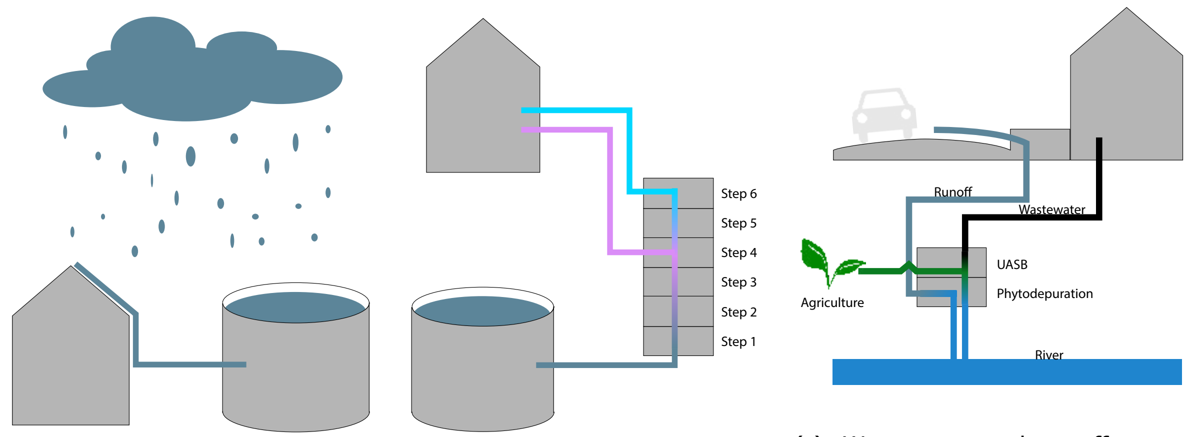
Social measures

Laws, policies and institutional arrangements aimed at enabling a communal system rarely work without awareness of the people who will make use of it. As was pointed out by the experts in section 5.2, people in Dala are insufficiently aware of their water usage and the effect of their actions on the water quality. Therefore, it is important to adjust people's attitude and behaviour towards water.

Multiple methods can be used to raise awareness. Embedding water consumption, preservation and good sanitation in the educational system is what was proposed by the experts during the workshop. Other methods that can be used are school campaigns, such as the hand washing campaign set up by UNICEF [55], media campaigns and promoting corporate social responsibility [96]. Another effective method is to enable influential people, such as ward leaders, to promote water conservation, preservation and good sanitation.

6.3. Design overview

Figure 6.9 depicts the main parts of the water cycle as described in this chapter. Harvesting, storage, drinking water treatment, drainage, sewage, wastewater treatment and discharge are shown. A full overview of all functions is found in Figure 6.10



(a) Water harvesting scheme (b) Water treatment and supply (c) Wastewater and runoff water treatment and discharge

Figure 6.9: Overview of parts of the water cycle

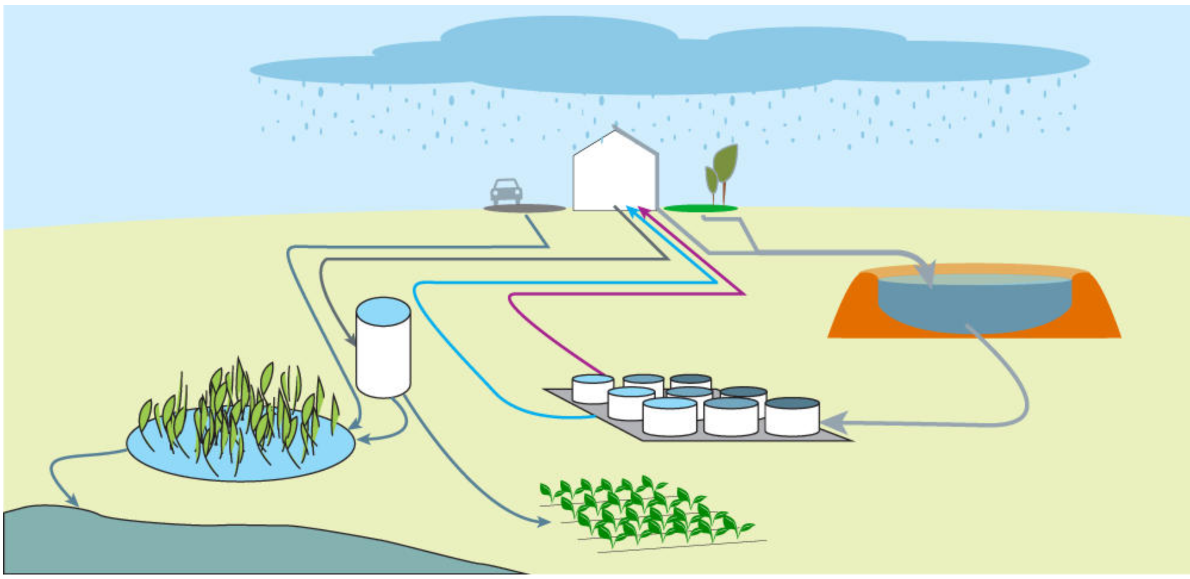


Figure 6.10: Schematic overview of the full water infrastructure system

6.4. Implementation phases

The above described design is very extensive and above all formulated for a water demand that is expected in 2040. It is necessary to distinguish a number of comprehensive implementation phases that are meant to make the design practicable and gradually build up the system proportionally to the population and industrial growth. For the design implementation phases, a distinction is made between short-term, medium-term and long-term. Short-term is now until 2020, medium-term is 2020 until 2025 and long-term is 2025 until 2035. Next to the phases determined for the implementation of this design, solutions that are suggested to bridge the gap between supply and demand in the mean time are described. These are however not part of the design that was developed here.

6.4.1. Bridging the gap

Before the designed system is operational, temporary solutions have to be implemented to battle the drinking water shortage currently faced in Dala. These solutions are not part of this design, and are therefore not elaborated in this report. The main characteristic of these systems is that they have to be implementable in a short period to bridge the gap before the completion of the design. These short term solutions are designed as 'quick fix' solutions and should not be implemented as a long term solution. This is because these solutions are not considered to be sustainable and for this reason the designed system should prevent these solutions to become definitive. To supply water for the Dala inhabitants during the dry season small mobile RO plants are implemented. These systems are fed with the water from the Twante canal (West of Dala's downtown) and groundwater wells and will not be combined with a pipe supply system, as stated in Appendix E, section E.3 and section E.6. This means that the drinking water is supplied only through collecting points close to each treatment plant.

6.4.2. Short-term: now-2020

The first order of business is to get the institutional and legal framework set up. As mentioned in subsection 6.2.11, setting up the institutional framework is all about assigning responsibilities and providing the necessary education. This needs to be done on the short term so parties involved can start making their own tactical and operational plans, assessing resources and training personnel. As stated in subsection 6.2.11, the legal framework deals with water management standards and guidelines. This needs to be established on the short term since industrial and water management companies need to be aware of the restrictions before they start operating in Dala. Further, on the short term, legal measures should also be written that govern the development of the built environment. Before developers start buying land and building on the area, it is important that they are aware of the requirements for the rainwater harvesting and the required green area. These institutional and legal measures can then be supplemented with social measures to raise awareness about water consumption among the inhabitants and industrial companies. This is easy to implement on the short term and is already relevant now, because there is a large gap to bridge between supply and demand.

As described in subsection 6.2.2 the inhabitants have to be involved in the quality control as soon as possible. This involvement will also result in raised awareness which can be beneficial in reducing water consumption and waste of water in the future.

As mentioned in subsection 6.1.2 the construction and the completion of the total reservoir plays an important part in allowing the water supply for Dala to be sustainable. This is because, in order for the rainwater harvesting to be sufficient the reservoir requires a buffer volume. This buffer volume will be acquired and explained in the next subsection. In this period, rooftop harvesting systems should be implemented as well as the pipe system which is required to transport the harvested water to the reservoir should be constructed.

6.4.3. Medium-term: 2020-2025

The volume of water which is needed as a buffer, will require a little less than 4 years to be harvested. This takes into account the yearly increase in volume of water which can be harvested. This yearly increase in volume is dependant on the relative growth of the urban area. After four years, the reservoir can be used as a source to provide drinking water. Therefore, the needed infrastructure to allow for this should also be constructed. This means that the pipe system which supplies the water to the different households should be laid as well as the construction and completion of the drinking water and wastewater treatment plant.

A number of parts of the system need trained personnel for operation and maintenance: the drinking water treatment facilities, the drainage system, the dual reticulation system, the UASB and the wetlands. For these systems it is best to hire a foreign specialized company to work together with local laborers to construct the systems. By working alongside with foreign experts on the construction and initial operations of the systems, the local laborers become familiar with it and will soon be able to operate and maintain the systems themselves. The drinking water treatment plant and the wastewater treatment facilities will need to be constructed between 2020 and 2024 to be fully operative by the time that the water supply is ready. This means that personnel can also be trained during this period and be ready to independently run the facilities by 2024. The drainage system and the dual reticulation system will be built gradually with the development of real estate. For this system, laborers can also be trained between 2020 and 2024 to make them fully able to continue construction, operation and maintenance by 2024. For all of the above systems, it should be taken into account that it can take some time from the start of construction until the system is operative. Especially creating the right conditions in the UASB and growing the vegetation in the wetlands can be time-consuming.

Lastly, in this term public facilities should be constructed such as toilets and water taps. These facilities should be constructed before the drinking water and wastewater systems are implemented. This is because these systems should be connected to these networks and provide the extremely poor population access to these services. For example, if the extremely poor population of Dala is not able to access a toilet which is connected to the wastewater network, this waste will be disposed of in another manner such as dumping at a specific site. This can result in contamination of the groundwater and surrounding area.

6.4.4. Long-term: 2025-2035

Since rainwater harvesting is partly done in the urban area, the catchment area of rainwater harvesting will increase with increased urbanization. The expected growth of the urban area of Dala will lead to more rainwater harvesting from roofs and green space. With this the water harvesting scales with the urban growth.

Treatment facilities for drinking water as well as for wastewater will have to be scaled up as well with the growth of population in the area. The location chosen for these facilities should take into account that additional facilities will be placed.

Supply and collection pipelines to newly urbanized areas will be built where necessary. These new branches will be coupled to the primary supply and collection infrastructure, so digging new trenches is minimized.

7

Verification and validation

The final design described in the previous chapter, has to be verified and validated on several aspects. First of all, the design has to comply with the initial goals of the project. Therefore, it is compared with the requirements described in section 3.1. Furthermore, the design has to be resilient for different scenarios, as set up in section 2.4. Another verification is done by looking into the interests and resources of various stakeholders stated in section 2.3. Verification of the requirements, scenarios and stakeholders will be done in section 7.1. In addition, to see if the project is implementable, section 7.2 describes the validation with local experts of the final design and its implementation.

7.1. Verification

The verification is an important step in the design of the total solution. It reflects back on what is said earlier in chapter 2 and chapter 3 to see whether the design complies to these statements.

7.1.1. Requirement verification

In section 5.1 a MCA was conducted on the different alternatives with respect to the constraints, the functional and the non-functional requirements. In this section, a critical assessment is conducted on the different requirements.

Functional requirements

Ensure 10% non-revenue water

The use of a system in which water consumption is closely monitored allows for any discrepancies between production and actual supply to quickly be discovered. This minimizes the amount of revenue lost due to water which has not been accounted for, and it allows for quick discoveries of leaks in the system. The implementation of a dual reticulation system allows to reduce the minimum flow velocity, and thus pressure losses, in the domestic water pipeline, as described in subsection 4.2.5. For this reason, the average pressure in the pipes will be lower. As a result, less leakages are expected during the transport and distribution of water for domestic use when the dual reticulation system is employed [51, p.9].

Provide drinking water at 500 meters

The pipeline supply system makes it possible to serve water to every Dala inhabitant within 500 meters. However, since a detailed design of the urban area is not yet defined, this requirement can be fully verified only during the actual construction of the system. This is particularly relevant when communal distribution points are allocated.

Preserve quality of water source

The system does not affect the quality of the water source. Rainwater contamination is prevented by the YCDC policy which avoids the settle of air polluting industries in the south of Yangon, as explained in Appendix E, section E.5. The choice of rainwater as principal source prevents the use of other sources which have a bigger impact on the Dala water resources, as explained in subsection 4.2.1. For example, excessive extraction of groundwater can eventually lead to salt water intrusion and deterioration of groundwater quality.

Preserve capacity of water sources

Only 7.8% of the yearly amount of rain falling on Dala is harvested for drinking water purposes, as described in subsection 6.1.1. This ensures the annual recharge of the groundwater table. Furthermore, the system is designed to reintroduce the used water in the natural water cycle. Wastewater treatment is included in the design to not impact the quality of the water body that receives the effluent, as mentioned in subsection 6.2.6.

Allow harvesting of resources from wastewater

During the treatment of wastewater, by-products are produced. The UASB reactor produces biogas, sludge and water. Biogas can be used as an energy source. The sludge which is produced in the settling tank can be used as a fertilizer by the local farming population, as mentioned in subsection 6.2.7. In the dry season the water which comes out of the UASB reactor can be directly be used for irrigation, because it contains nutrients.

It cannot be said that the harvesting of resources is maximized, since other ways of wastewater treatment will harvest other resources more efficiently. However, the combination of harvesting sludge, effluent and biogas is quite unique for the UASB facility [103].

Limit pollution of industry wastewater

Industrial companies are encouraged to reuse their own wastewater. The standards companies have to comply with the standards that are given in subsection 6.2.4. These standards are based on the requirements to have an efficient UASB treatment system.

The strictness with which the standards are preserved will influence the limit of pollution highly. If wastewater is regularly checked on pollution levels, the design as proposed in this report will limit the pollution of industry wastewater.

As little waste of water as possible during consumption

Increasing the awareness of the local population, with respect to water consumption, helps to minimize the waste of water. The use of a 'pay for usage' system reduces the waste of valuable water as well as makes each person more aware of the amount of water they are consuming/collecting. Furthermore, the reuse of wastewater as promoted for industry in subsection 6.2.4 not only directly reduces the consumption of resource water, it also generates awareness among companies about their consumption.

Non-functional requirements

Consume less energy compared to traditional methods

The main reason for splitting the pipeline systems for supply and waste-/runoff water was based on the assumption that it would consume less energy. After rough calculations, it was indeed shown that during the supply and treatment, less energy is consumed with respect to a single pipeline system. Implementing separate sewer systems for the collection of wastewater and the collection of runoff water reduces the energy consumption of wastewater treatment as stated in subsection 6.2.6. This also increases the treatment efficiency and bio-gas production of the UASB reactors.

As safe as possible

Implementing underground pipelines, a closed treatment area and a secured storage area are all decisions that reduce the risk of infection of the water. Not choosing for open systems like canals and limiting pollution reduces the risk of accidents. The promotion of green areas, bioretention basins and rainwater harvesting reduces the risk of pluvial flooding in the urban area as mentioned in section 5.3.

Reduce environmental impact of urbanization

The use of rainwater as a water source reduces the impact of the water demand rise on the Dala water resources. Using roof surface for harvesting is even an example of making positive use of the urbanization. The treatment of wastewater before reintroducing it into the local environment minimizes the impact of the water use on the river ecosystem and the groundwater level. Introducing measures which reduce the pollution of wastewater, supports the development of environmentally friendly activities in the area.

Climate change resilient

In this report, change in precipitation and temperature, depicted in subsection 2.4.1, are taken into account with respect to climate change. Regarding precipitation, the variability of the monsoon and the increase in precipitation intensity are considered in the design of the volume of the storage system. The first aspect is covered by designing for a dry season which lasts for 7 months instead of the current 6 months. The second aspect is taken into account by designing a drainage system for rainfall data with a higher return period. However, the increase in rates of evaporation due to higher mean temperatures is not taken into account in the design of the storage.

As little GHG emissions as possible

Components of the designed system produce GHG emission during fabrication and operation. Choosing for a dual reticulation system results in more material used for the pipelines. On the other hand, this solution is expected to have a lower energy consumption, and thus less emission, during operation. It is not certain whether in the long term the lower energy consumption overcomes the GHG emitted for the material production. Institutional measures promoting the efficient use and reuse of water, leads to a reduction of GHG emissions. Finally, the employment of natural and low energy demanding treatments, for domestic-, drinking- and wastewater, reduces the overall emissions of the system.

As high mean time to failure as possible

By making use of proven technologies and providing extensive training, the system can be easily deployed and maintained by local laborers. It is expected to reduce the frequency of failure. However, variations in precipitation and unexpected increase of the water demand could threaten the system capacity and reliability. Also, the double reticulation system doubles the length of the pipelines, heightening the probability of failure.

As low mean time to repair as possible

As mentioned in subsection 6.1.3 the dual reticulation system brings several benefits. However, problems can arise during maintenance and repair due to its complexity. The implementation of these systems is done under guidance of foreign expert partners. These companies are also responsible for educating the local laborers on the new implementation. This measure is included in the design in order to overcome the lack of knowledge minimizing the time required to repair the system.

Affordable water for residents

The system makes a distinction between drinking water and domestic water, listed in subsection 6.2.5. The first 10 liters of drinking water are made free for everyone, sufficing in the basic needs for drinking water. These free liters are economically compensated by an increased price for using drinking water over this threshold. With this, drinking water is made affordable for everybody in Dala.

Implementable by local laborers

Not all parts of the design can be implemented solely by local laborers, because knowledge in the Dala is lacking. However, the entire new system is planned to be implementable by local work-force in cooperation with, and under supervision of foreign specialists.

Maintainable by local laborers

The new system will be implemented by local workers. When new techniques are used, the local labor force will be working under guidance of foreign specialists. The same foreign partners are responsible for educating local laborers to operate, maintain and repair the system independently.

Allow flexible implementation

Parts of the solution allow for flexible implementation while others do not. When implementing the design, the first step is to setup an institutional and legal framework. This needs to be done in the beginning of the implementation so that throughout the development this framework is followed. This part of the solution is not flexible. Secondly, the whole storage capacity need to be constructed before 2020, which is not flexible. This is because then a buffer can be created so that the reservoirs will be able to satisfy the growing water demand of Dala for a much longer period of time. On the other hand, all of the infrastructure needed to supply the different systems with water, will expand in correlation with the growth of the population. Therefore, this allows for flexible implementation.

Investment spread over time and parties

Since the total surface area of the reservoir needs to be constructed at once, the capital expenditure can not be spread over time by building the reservoirs in steps. The supply, the collection and the treatment systems will require lower initial investments because these systems are dependent on the population growth. Therefore the total capacity is not needed in the beginning and the system will expand over time. As mentioned in section 2.1, foreign funds have been granted to water projects in and around Dala. Similar funds will aid in minimizing the initial investment costs of the responsible parties.

7.1.2. Scenario verification

The final design is based on a scenario with high population growth and moderate industrial activity, described in subsection 2.4.2. This part of the verification tests the design on its resilience against changes in the driving forces which affect the development of the Dala area.

First, the resilience of the design is tested for changes in the three main driving forces. After that, the resilience to other forces, as listed in Appendix B, section B.1, are assessed.

Population growth

The scenario for which the water infrastructure in this report is designed takes into account the plus scenario for population growth, with a total population of 670.000 people in 2040. When testing the design against lower rates of population growth, the design will still cater to the water needs of these people. Some overcapacity can be expected, which is undesirable due to the investments that are not used to their full potential.

The choice to harvest rainwater from roofs results in less harvesting for the minus scenario on population growth. The same counts for harvesting water from green area within urban areas. However, the choice made to store drinking water in open reservoirs provides a catchment area for rainwater harvesting that is not dependent on the amount of inhabitants. Since the catchment of water on the reservoir surface accounts for a significant share of the total water harvested, the decrease of harvested rainwater is smaller than the decrease in water demand.

The choice to store drinking water in open reservoirs, which are designed to store water for 670.000 people, will generate a surplus of storage capacity for lower population growth scenarios. The choice to build all reservoir capacity in 2020, in order to create enough buffer capacity, implies that this design for the storage is not scale-able. Since this is not violating the constraints given in subsection 3.1.1, this does not result in a non-functioning design. However, investment costs needed for the construction of the reservoirs, are not used to their full potential, which is undesirable.

Drinking water and domestic water supply facilities will be constructed towards areas that are about to host residential functions. Considering the conceptual land use model as presented in subsection 3.2.1, a lower amount of moves towards Dala can be related back to a lower attractiveness of an area. This lower attractiveness will cause investors to construct less residential functions in Dala. Water supply facilities directed at areas which are not attractive will not be constructed, and therefore lower investments will be made for the supply system. The primary pipelines, however, will have a dimension that takes into account the population growth towards 670.000 inhabitants. These pipelines are therefore overdimensioned, and therefore lack cost-effectiveness.

The treatment of drinking-, domestic- and wastewater will be scaled up according to the population and industrial growth. Only sudden drops in these growth rates will result in the construction of overcapacity on these facilities.

Although deemed unlikely, in Appendix B it is also stated that a higher population growth than expected could occur in Dala. In this case, the storage lacks capacity to suffice the water needs of the total population. In this case the design as presented in this report does not comply with the constraints of subsection 3.1.1. However, rainwater harvesting is a practice that can be easily extended or coupled with other water sources. Therefore, the capacity of the system could be easily enlarged including a complementary sources and/or increasing the storage capacity.

Industrial activity

The design as presented in this report is aimed to facilitate the plus-minus scenario of industrial activity. The scenarios in section 2.4 describe second option to be a case in which Dala does not attract any industrial activity. In this case, the total water demand drops with 30%. As seen in subsection 7.1.2 this reduced demand causes overcapacity.

The roof surface per capita is taken as input value to calculate the roof rainwater harvesting. In this figure not only roofs of residential buildings are taken into account, but the roofs of other functions, like industry, as well. Lower industrial activity will lead to less roof surface for industry, and therefore less roof surface per capita. Lower industrial activity therefore leads to less rainwater harvesting. However, it is expected that industry uses more water than can be harvested on the roofs of buildings with industrial functions. Therefore, no shortage in water harvesting is expected.

As described in subsection 7.1.2, the lower water demand causes the storage to be overdimensioned. This does not violate any constraints, but causes undesirable overcapacity.

Industrial activity will mainly settle in different zones than the population, as seen in Figure 3.6. This will mean that industrial areas will be served with a primary supply pipeline that is not the same as the one leading to residential areas. If no industrial development will take place in Dala, this primary supply will not be constructed. In this way, the supply can cope with any absence of industry, without spilling investments.

Any case of lower industrial activity will require less facilities to treat drinking-, domestic- and wastewater. The design takes into account that these treatment facilities will scale up according to the growth of population and industry. In this way the treatment facilities as designed are able to cope with growth rates lower than the growth rate as taken into account in the chosen scenario.

The plus scenario for industrial activity was assessed to be less likely than the plus-minus or minus scenario. However, if this situation does occur, the system will be affected. The high case for industry projects a water demand of 74,5% of that of the demand of the population. This will impose an increase in the total water demand on the system of 34%. The system as designed is not able to cope with this induced demand. Storage and harvesting facilities will not be able to supply the water for this intensity of activity.

Climate change

The water infrastructures of this report are designed for a climate change scenario which takes into account climate variation according to a RCP scenario calculated between the 4,5 and the 8,5. This resulted in an average precipitation increase of 4.5% and temperature increase of 0,93 $^{\circ}C$ between 2011 and 2040. Since rainwater harvesting is the main source, a changing climate can significantly impact the volume of water which can potentially be harvested. In the design, the effect of evaporation was taken into account. However, the change in evaporation rates due to an increase in temperature was not accounted for. A constant evaporation rate was assumed for the 2011-2040 period.

Minus scenario (RCP 4,5)

If a lower RCP value is chosen, the precipitation will decrease by 12% while the temperature will increase with 0,63$^{\circ}C$ between 2011 and 2040. The increase in temperature is slightly lower than in the plus-minus scenario. It can be assumed that the average evaporation will not be higher than the evaporation experienced in the chosen scenario. The precipitation is significantly lower than in the plus-minus scenario. This can potentially create a serious problem in the dry season, because not enough water can be harvested. Upscaling of the solution can be done to solve this problem

The drainage system will not be impacted by lower levels of precipitation. Lower levels of precipitation will only result in a longer return time of the predicted intensity of rainfall, which may cause the drainage system to be overdimensioned.

Plus scenario (RCP 8,5)

Both the temperature and precipitation levels would increase for a higher RCP value. The precipitation would increase on average by about 14,7% and the temperature by around 1$^{\circ}C$ between 2011 and 2040. This increase in precipitation will greatly influence the amount of water which can be harvested each year. The temperature increase is not much more than in the chosen scenario, so it can be assumed that the evaporation will not increase significantly. The combination of more precipitation and a slightly higher rate of evaporation will allow the storage system to be just as effective with a smaller surface area as well as allow for a shorter filling time to create the buffer.

Higher precipitation levels will also have an impact on the drainage system and the occurrence of pluvial flooding. It is expected that the intensity of the individual rainfall event will increase. This is because the onset of the monsoon season is increasingly later and finishes at the same time [40, p.49]. The designed drainage also takes into account the expected increase of intensity and frequency of extreme events due to climate change, depicted in subsection 2.4.1. However, this system is able to cope with a 1/25 year occurring rainfall intensity of 88,9 $mm/hour$ which is higher than the common occurrence of 1/2 year [120, p.5].

Other driving forces

Population density

The design does not include any regulations on the maximum density of an area. Therefore, some parts of Dala potentially yield high density figures in the future. This high density will result in a lower roof surface per capita, leading to lower harvesting of rainwater. When not compensated in other areas, this leads to a shortage of water.

Industrial density

To limit pollution of wastewater, the design in this report stimulates reuse of wastewater for industrial companies. However, high densities of industrial activities might not allow for the space required to install wastewater treatment facilities. In this case, wastewater treatment might take place outwards from this industrial center.

Agricultural growth

If agricultural growth is high, less land is available for urban development. The opposite can be said if the agricultural sector will decrease, more land will be available for urban development. An optimum can be reached, where the agricultural sector can benefit from population growth. The wastewater from urban areas will be treated using an UASB system. This system produces sludge which can be used as a fertilizer for the agriculture. Effluent water can directly be used to irrigate the crops during the dry season and contains high values of nutrients.

Economic welfare

Chang et al. [15] notes that income is a factor influencing water consumption. For the case of Dala, it is assumed that 150 liters of water per day is consumed per person. This might increase if welfare increases in above average rates. On the other hand, lower income might lead to less consumption than 150 liter.

Labour in rest of Yangon

The attractiveness of other areas can have a negative influence on the amount of industry that settles in Dala and on the amount of people working and living in Dala. If more people will work in other areas, less people will go to Dala. However, it has to be noted that people working somewhere else can still live in Dala, this is for example also influenced by the connection between Dala and the rest of Yangon, which is out of the scope of this project.

Squatting

The design takes into account that squatters will also live in Dala. Public toilets will be constructed so that these squatters will also have access to proper sanitation and that their bodily waste is properly removed from the area and treated. Communal systems will help subsidizing the cost of drinking water for squatters, making it possible for them to have access to drinking water.

However, if the percentage of squatters inhabiting Dala is to drastically increase, this would have a large effect on the public sanitation systems and on the drinking water. A larger population of squatters results in a larger demand of subsidized drinking water. This can in turn result in an increase in price for the regular population of Dala to be able to support these squatters.

If the number of squatters is to significantly decrease, the only effect this would have is that the community spends less money on subsidizing the water for the squatters, since less water is needed.

Technology reducing water usage in agriculture

If new technologies in reducing water usage in agriculture occur, a higher share of the water, needed for irrigation, can be supplied by the effluent of the UASB treatment, as proposed in the design. The technologies will not impose any effects on the system designed in this report. However, economic welfare might increase due to new technologies, which in turn might induce water usage of domestic and drinking water [15].

7.1.3. Stakeholder verification

In this section, a short evaluation will be conducted to see whether the interests of the 'key players', as presented in section 2.3, are served and whether all the stakeholders with the resources to ensure the success of the system are included. Further, the inclusion of other stakeholders who were not identified as 'key players' is evaluated.

YCDC

YCDC's main interest is to ensure welfare for the citizens of Yangon and a healthy economy of Yangon. It is therefore also in the interest of YCDC to serve the interest of the people in Dala and local companies, who are both less powerful stakeholders themselves. The proposed design is an adequate tool to do so while still answering to the wishes of the national and regional government to connect and improve Myanmar's economic centres, using Dala as a corridor.

Chief Minister of the Yangon Region

The Chief Minister of the Yangon Region acts as a middle man to implement national policy in the region of Yangon [69]. His main goal is to improve living conditions and connectivity to ensure economic growth. It is therefore in his interest to exploit Dala's position for economic purposes, while also improving the conditions there. Although the design succeeds at doing both, resources might have been allocated more efficiently when a less sustainable design was chosen. The Chief Minister has the power to reject the plans, and therefore he should be convinced of the necessity to have a sustainable water infrastructure instead of a cheap one.

National Water Resources Council (NWRC)

The interest of the NWRC is to ensure consistency in water policies in Myanmar through the National Water Policy (NWP) [113]. As mentioned in subsection 6.2.11, the laws governing the water system in Dala are over 50 years old and should therefore be rewritten before the new system is implemented. The role and expertise of the NWRC is acknowledged to the extent that the NWP can be very helpful in formulating policy and should serve as a basis to ensure consistency across Myanmar.

Ministry of Construction

As the Ministry of Construction is responsible for constructing and maintaining roads while ensuring proper drainage and sanitation in new settlement areas [5, 48], this is an important party to work closely together with. As mentioned in subsection 6.2.11, responsibilities for the water system should be allocated clearly and in close cooperation with the Ministry of Construction.

International funds and loans

As mentioned in section 2.3, the international funds of JICA, KOICA, EDCF and ADB have invested more than $1,2 billion in Myanmar, mainly to use towards infrastructure improvements. It was acknowledged in subsection 6.2.11 that when YCDC wants to use some of this money towards improving the water infrastructure in Dala, it should be done in communication with these funds. As their overarching goal is to ensure welfare and economic growth through infrastructural improvements in developing countries, using the money toward this cause should not be a problem. However, sustainability is not necessarily the funds' main goal, while making the system sustainable might increase the investment. Just like the Chief Minister, these funds should be convinced of the necessity to implement a sustainable system in Dala.

UN Habitat

It was mentioned that UN Habitat plays a big role in advising the Myanmar government on urban planning and climate change. These are design aspects that have been taken into account in this research. However, the specific expertise of UN Habitat on the area could have been employed more explicitly.

Other stakeholders

As mentioned in Appendix A, 22 stakeholders were identified. Only a part of them were categorized as 'key players' and taken into account in the design. However, during the design and multiple interviews, some of the other stakeholders often surfaced as important players to take into account. These are mainly less powerful stakeholders whose interests are defended by key players, but they are also worth mentioning separately.

Firstly, the local laborers. The new systems that are being proposed will generate a lot of labour for construction, maintenance and operations. This will therefore positively influence the labour market in Dala and potentially even attract people from outside Dala. Some technologies that are being proposed are quite advanced, which may cause difficulties for the laborers in their work. However, intensive supervision from expert companies is planned to be implemented in the starting phase.

Secondly, Dala's local government. In interviews with Dala's local government, as seen in Appendix E, section E.4, they expressed their concern with the current state of the water supply in Dala and their inability to cope with more people, meaning more demand. Their expectation is that the bridge will be supplied with a water pipeline from Yangon, supplying Dala with all the water they need in the future. This design does not incorporate that idea, but offers a more sustainable solution for tending to Dala's future water demand. Although this design would need a lot more planning in Dala itself than a pipeline from Yangon would, the expectation is that Dala's local government would grasp any opportunity to increase the water supply.

Finally, Dala's inhabitants and industry, both current and future. It is in their interest that the water infrastructure improves in Dala. This would raise the overall standard of living, attract more labour to the area and improve people's health. However, the proposed design does require some cooperation of the local people and companies. It must be ensured that they are willing to cooperate in order to improve the situation in Dala.

7.2. Validation

Once the internal check, the verification, is performed, it is important to perform an external check: the validation. To be able to make a design in 8 weeks time, reductions and assumptions had to be made. The validation is meant to check whether our design still fits with the actual real-world system that it was created for. Normally, this can be done by comparing output with real-world measurements. However, this real-world system is a future situation, which is still very uncertain. Therefore, the method chosen to validate the design, is conducting expert interviews. The local experts, that were chosen to interview, know a lot about the situation in Dala, possible water infrastructure systems in Myanmar, and urban development.

Two expert interviews were planned for the validation of the design. For the first interview, two water management experts from the National Engineering and Planning Services (NEPS), who are also part of the advisory group for the National Water Resources Council (NWRC), were invited. For the second interview, four officials from the urban planning department of YCDC (of which one is the director of the department) were invited. However, this last interview was cancelled from their part due to a visit from the Minister of Construction and attempts to reschedule it failed.

7.2.1. Interview water management experts

For the validation of the design, an expert interview was organized on 13 October 2017. Before the interview, the experts had the opportunity to read the final design, check the crucial assumptions and look at the interview questions. Two local water management specialists were consulted, namely: U Cho Cho, member of the advisory board at NEPS and chairman of the advisory group for the NWRC; and U Khin Lat, senior consultant at NEPS and member of the advisory group for the NWRC. Both of them received a Master in Hydraulic Engineering at UNESCO-IHE (Delft, The Netherlands) and are considered among the most experienced consultants in the Burmese water sector. A summary of the central aspects which emerged during the interview is presented below. The integral version of the interview can be found in Appendix H. The outcome of this validation does not change the design but will be taken into account with the recommendations.

General impression/face validation

The first set of questions was aimed at getting a general face validation of the entire design. The questions concern the general impacts of the design on the principal stakeholders and the system results in terms of environmental, social and economic sustainability. Overall the two experts expressed a positive judgment on the implement-ability of the system by the local workforce. U Khin Lat pointed out the importance of a detailed urban plan to support the design. This was addressed as crucial to coping with the potential discrepancies between the actual total future water demand and the picture painted in the chosen scenario.

The main stakeholders affected by and influencing the design were identified as; YCDC, the investors, the contractors and local laborers. YCDC's role in the feasibility of the design was appointed as the most relevant. This authority can exercise a veto on companies and investors involved in the design deployment. In regard to the sustainability of the system, the only concern which emerged was related to the design effects on the rest of the southern Yangon region. Only improving the infrastructure in the Dala urban area will create an unbalanced situation in the southern Yangon zone. The development of Dala will attract people from the rural area that are looking for a better lifestyle (e.g. access to drinking water during dry season). These people will be subtracted from the laborers working in the agricultural sector. According to the experts, Yangon region is already facing a shortage of farmers and this will result in an increase in the food prices in the future. If the living conditions in rural areas are not improved at the same rate as the development of the city, the whole economic and social system of the area might collapse. This point was further highlighted later by U Cho Cho who emphasized that the design for Dala should fit in a general masterplan for the whole region, otherwise it will not work.

Harvesting and resource

After the general questions, the interview focused more in detail on the chosen source and harvesting methods. In this part, the assumptions regarding the scenarios taken in section 2.4 where discussed as well. Globally, U Khin Lat and U Cho Cho agreed on the choice of rainwater harvesting as the main source. They emphasized that this solution is consistent with the government's plan to maximize the rain source in the country. The 75% of possible water harvested from rooftops was considered as a good estimate. In contrast, for the green area harvesting, the efficiency of 25% was evaluated as being too high, due to the significant infiltration capacity of the existing soil in Dala. With regard to future water demand, they gave positive feedback on the values used for water demand calculations. However, the two specialists expressed some doubts about the low industrial development scenario chosen for Dala, in contrast to most other experts in this project. Finally, U Cho Cho remarked that educating people about rain harvesting techniques and water-use is a fundamental aspect for the success of the entire design.

Storage

The third part of the interview was a more in-depth analysis of the design choices taken with regard to the water storage. During this part, the two experts provided their ideas on the storage design and gave important suggestions on how to improve the reservoirs' efficiency. Both experts agreed on the values used for the calculation of the seepage and evaporation losses. For reducing the latter, it was suggested to not use only trees. This is because the leafs could cause deterioration of the water quality once fallen into the reservoir. U Cho Cho recommends applying a 'green-net' on the water-body surfaces during the dry season in order to minimize the evaporation and the contamination, a small scale example is shown in Figure 7.1. Through this improvement, they thought that a value below 1 meter of evaporation per year can be achieved.

Supply

Finally, questions regarding the dual reticulation water supply system were asked. U Cho Cho was not convinced about the feasibility of this system. He stated that the drinking water flow is too low to justify the installation of a separate additional pipe system. He suggested how this issue can be partially overcome by implementing drinking water collecting points instead of serving drinking water from domestic taps. He also questioned the possibility to extend the system in the whole southern Yangon area. U Khin Lat did not fully share U Cho Cho's idea. He was convinced that the energy saved by splitting the pipeline can make the implementation of a second parallel supply system for drinking water more affordable. According to him, the presence of the domestic system will also allow the possible reuse of wastewater within the Township. However, U Khin Lat did not agree on the choice to centralize the storage system. He remarked that by making local water tanks accessible to private users, the energy demand for transport and treatment will drop.

Figure 7.1: Covered rainwater collection point

8
Conclusion

The goal of this project was to develop a design for Dala's water system that deals with challenges of the township in a sustainable way. This chapter is meant to reflect on whether this goal was achieved. First, the research questions will be answered while revisiting the methodology that was applied. Then, any limitations to this research will be presented. Finally, some suggestions will be made for further research.

8.1. Design cycle

As Dala, with regards to its water infrastructure, is a socio-technical environment, it is necessary to first identify the most important stakeholders before designing a new system. It was found that both municipal and local government are pushing to infrastructural developments, such as the bridge between Yangon CBD and Dala, that help improve Yangon's economy. While Dala's location makes the area in this regard more of a tool than a goal in itself, the governmental parties also acknowledge the need for an improved water infrastructure to enhance quality of living there. In this, they are supported by multiple international funds that have invested large sums in infrastructural and water projects, for which they expect advantages for companies from their country in return. Responsibilities for different aspects of the water infrastructure are scattered over a multitude of governmental bodies, with many overlaps. Therefore, the NWRC has formulated a National Water Policy (NWP) aimed at reaching consistency across water policies in Myanmar and exploiting its abundant water resources while mitigating problems with water such as quality, supply and flooding.

The region is expected to undergo rapid changes in the coming decades after construction of the CBD - Dala bridge in 2021, and a bridge connecting Dala to the Thilawa SEZ in 2035. As the extent of these changes is quite uncertain, but the success of the water infrastructure depends on the future state of the area, a scenario analysis was conducted. It was concluded that next to a significant population growth due to increased connectivity with Yangon and Thilawa, some industry can also be expected to settle in Dala. Through the amount of labour, the industry generates more population growth, while this population in turn generates labour in the service sector, and therefore more population growth. Furthermore, it should be noted that improved facilities, such as a water infrastructure, may also attract more population. At the point where the existing infrastructure reaches its limit, population growth is expected to come to a halt. The resulting expected 670.000 inhabitants and industry in 2040 have a significant impact on the entire water circle in Dala. This means that the township should rapidly transform from an area where almost no water infrastructure is available to an area where all needs are met by a single system in a sustainable way.

The land-use models also shows the spread of the developments in both population growth and industrial activity. This gives information on the locations where water should be supplied towards. A conceptual model led to a zonal map, which, in combination with attraction factors per zone, gave insight into the relative densities for population and industry of the zones in Dala. A super-linear distribution of the total amount of inhabitants, expected in Dala for the year of 2040, provided insight in the absolute densities expected per zone. This yields relatively high densities of population for the zones near the landing point of the connection between Dala and Yangon CBD, with a maximum of 45.000 $inhabitants/km^2$. For industrial activity, the highest density can be expected near the connection with Thilawa, at the outer ring road, yielding a surface occupation of 24%.

To meet the needs of Dala in 2040, solutions were generated for water harvesting, water storage, drinking/domestic water treatment, water supply, quality control, monitoring the consumption, wastewater collection, wastewater treatment and disposal, limiting the pollution of wastewater, runoff water collection and protection against pluvial flooding. From these solutions, three alternative designs were generated: an economically sustainable, an environmentally sustainable and a socially sustainable alternative. From an internal evaluation, it was concluded that the final design should pivot around three focal points in order to attain adequate sustainability while working as a well-integrated system. These focal points are rainwater harvesting, storage in reservoirs and a dual reticulation system for the supply. These focal points were checked by means of an external evaluation with local experts, which led to valuable considerations towards the final design.

The result is a design for the full water circle which can provide enough water to cater to the future municipal and industrial demand using only rainwater. This is more environmentally sustainable than the use of any other water resource because harvesting it does not affect the resource itself, and limited transport and treatment is needed. Furthermore, it also increases the storage capacity of the urban area reducing the risk of pluvial flooding. High capacity reservoirs will ensure that Dala has enough water to supply the dry season demand. The water supply will be more efficient as domestic use water and drinking water are delivered through separate pipelines. This does not only save energy on treatment of domestic water, it also saves energy on transportation of water. The system is completed with methods for other functions of the water circle that do not only complement the focal points, but also perform well on sustainability measures. All in all, this system will make Dala fully self sustaining in terms of water while allowing for rapid growth of the township. Besides this, the solutions chosen in Dala will not affect the fresh water source availability in the rest of Great Yangon area.

8.2. Limitations

One of the main limitations is the short time frame in which the whole project needed to be realized. Therefore, it was decided that the focus of this research would be on three focal points, as mentioned in the previous section. Further research should be done on the remaining functions to accurately decide whether or not these solutions are actually feasible in Dala.

The lack of a detailed and official urban development plan on Dala limits the accuracy of this project. This is because certain assumptions were made (based on the available information) which can influence the magnitude of some of the different design variables. When a complete spatial plan for the development of Dala exists, more detailed calculations can be performed which will result in a more complete design.

The land-use model as presented in this report uses relative attractiveness for each zone to estimate population densities and density of industrial activity. A super-linear relationship is assumed between the attractiveness of a zone, and its density. Although the distribution of densities over zones gives an idea on where to expect relatively high densities, the model lacks underlying data which can provide reliable absolute numbers with respect to these densities.

This research focuses on developing Dala as a system which is independent of the rest of southern Yangon region. However, as mentioned in the expert interview in subsection 7.2.1, in order for this design to work, it should fit into the masterplan for the whole region South of Yangon. As this region was not included in the scope of this research, it was not assessed how the described design for Dala can be integrated in this masterplan.

The scarce amount of available data on water quality and soil composition made it difficult to create an accurately worked-out design. Most of the assumptions which were made during the design phases, were based on hearsay of local experts. The difficulty with hearsay is that it is hard to verify whether or not the information given is correct.

One of the assumptions which was made was that there will be a connection between Dala and Yangon and Dala and Thilawa. However, this research has shown that, here in Myanmar, large infrastructure projects take quite a long time before being approved and then finally constructed. Therefore, the assumptions made about the completion dates of these connections can limit the implement-ability of this research.

During the design was assumed that the population will have reached a peak in 2040 and after this the population will no longer grow anymore. This assumption limits the adaptability of the design with respect to a storage system. The use of reservoirs will be able to suffice the demand for drinking water for a relatively long period of time (30 - 40 years). However, it must be realized that this storage system of the source is exhaustible for a constant population of 670.000. This means that the reservoir will eventually empty over time, if no additional measures are taken to increase the storage capacity.

8.3. Further research

This section is based on the conclusion and limitations explained in the previous two sections. During this project the main struggle was the short time frame in which this project was realized. This resulted in making many assumptions throughout the project, which limited the amount of detail of certain design aspects. In the next few paragraphs, some recommendations will be given for further research.

One of the possibilities for further research is the coupling of the designed system with a different sources. This new system could, for instance, combine the water from the Toe river with the water from rainwater harvesting. This will create a system with two 'independent sources'. This solution could become especially interesting if the demand is higher that the one used in the final design. Further research on this combination would be suggested also because plans are already in place to construct a complete water supply system to provide water to Yangon from the Toe river. This was mentioned in the interview with AG Resources Myanmar, found in Appendix E, section E.6.

Rainwater harvesting was chosen above groundwater extraction, partly because of the risk of land subsidence. However, in the evaluation in section 5.2 it was pointed out that harvesting the rainwater may have an effect on the amount of water that will infiltrate in the ground, which might cause land subsidence. As data about the soil composition was missing, this effect was not further researched. It was only argued that there will probably be little effect on the groundwater table, as only 7,8% of rainwater is harvested. However, when rainwater harvesting is to be implemented, this should be research more in detail.

Further, a more detailed plan of the implementation phases of the system can be explored. This plan should focus on prioritizing which parts of the solution should be implemented first.

In this project, the only effect of climate change which was taken into account was the changing length of the monsoon period and the intensity of the precipitation in this period. Additional research can be done on the other effects of a changing climate. For example the effects of the temperature change on the evaporation rates and the consequences of the sea level rise.

The possibility to implement the concepts described in the designed (e.g. rainwater harvesting and dual reticulation system) system to the whole Yangon should be further research. It should be done in such a way that the water scarcity in the Yangon region can be eradicated as a whole. By doing this, a solution can be made which fits into the master plan of Yangon on the short and long term.

More research can be done in the field of storing the water during dry season, where the focus can be on reducing evaporation of the stored water in reservoirs. Other ways of storage can be researched, for example injecting water in the ground. This requires more information about the soil, which is inadequate right now, as mentioned before.

Rough calculations are made to address the different options and the feasibility of the chosen solutions for the focal points. When more data is available, the validity of the calculations needs to be checked, the demand for treatment of drinking water and wastewater have to be sharpened, and the feasibility for other solutions, for example the bio-retention basins, has to be calculated.

In this report, a land-use model is used to determine the water demand in the defined zones of Dala. Attraction factors found in literature and articles are used to compare the attractiveness of different zones. On the base of this relative attractiveness, population is distributed (super-)linearly over the zones. However, combining data on population densities in relation to land value figures, as currently observed in Yangon, might give more insight into the relationship between the attractiveness of a zone, and its population density.

Unfortunately, the planned validation interview with officials from YCDC's urban planning department could not take place. Therefore, the design had to be validated only using the input from other experts. However, before any of the plans in this design are further worked out, it is important to have approval of YCDC. Not only can they make a good estimation of what will work and what not, they also have the power to decide whether or not something will be executed in Yangon.

A

Appendix: Stakeholder analysis

To form a complete picture of the environment in which the problem plays and the design should be implemented, a stakeholder analysis was conducted. The aim of a stakeholder analysis is to map any and all parties that are affected by or can affect the problem or the solution. Dala, as it is being analyzed and designed for in this research, should be seen as a socio-technical system: people interact with technology and infrastructure. Technology determines the success of human endeavours and human behaviour determines the success of technological solutions. Therefore, it is important to analyze stakeholders' interests, opinions and resources. This helps to see under which conditions the solution will be successful and which stakeholders need to be actively or passively involved.

In this appendix, the identified stakeholders are first briefly described. Based on the stakeholder description and the general impression of the stakeholder, they are evaluated in the stakeholder evaluation table. This table is then used as input for the power-interest grid which is used to identify the most important stakeholders, or 'key players'.

A.1. Stakeholder list

A full list with all the 22 stakeholders are presented.

Yangon City Development Committee (YCDC)

The Yangon City Development Committee is the problem owner for this research. Their main goal is the welfare of the city of Yangon for which they have drawn up a plan in cooperation with JICA: The Strategic Urban Development Plan of the Greater Yangon [48]. From this plan, the intention to build the bridge in order to connect (new) economic centres and the intention to improve water infrastructure were derived. In terms of water management is the YCDC responsible for the quality of drinking water and sanitation in Yangon [112].

Chief Minister Yangon region

Myanmar has 14 regional governments with each a Chief Minister as their chief executive [69]. The regional government's main task is to implement projects that fall within the union government's policies. Yangon region's Chief Minister, Phyo Min Thein, has grand plans for the Yangon region for his period in office. His goal is to improve living conditions and connectivity to ensure economic growth. Roads and bridges of regional significance fall under the regional government's jurisdiction [112].

National Water Resources Committee (NWRC)

As Myanmar has many governmental bodies who have (overlapping) water topics in their jurisdiction, the NWRC was established in 2013 and formulated a National Water Policy (NWP) in 2014 [113]. This policy acknowledges that an integrated water resources management approach is needed to exploit Myanmar's abundant water resources to its fullest while mitigating problems with water, such as water quality, water supply and flooding. The NWRC receives advice from an advisory group of water management professionals chaired by U Cho Cho [112], one of the water management experts who were involved in this project.

Ministry of National Planning and Economic Development

This ministry is responsible for planning and conducting activities that benefit the economic development of the country. One of their main projects is development of the national infrastructure for connectivity, thereby creating an 'economic corridor' [102]. These plans are further carried out by amongst others the Ministry of Transport and YCDC.

Ministry of Transport and Communications

Myanmar's Ministry of Transport has as a main goal to develop and maintain transport capacities to contribute to economic growth [62]. They are responsible for developing the desired connection of Yangon's economic centres and can assign specific tasks in this development to the Ministry of Construction [64]. In terms of relevant water management and -infrastructure, the Ministry of Transport is responsible for ensuring river water quality for domestic and agricultural use [112].

Ministry of Construction

This ministry is, amongst others, responsible for building and maintaining the transport infrastructure. Next to this, they are also responsible for ensuring proper drainage of the system, and planning and developing sanitation systems in new settlement areas [5, 48].

Ministry of Agriculture, Livestock and Irrigation

The objective of the Ministry of agriculture is to ensure proper cultivation and exploitation of industrial crop [63]. Usually this ministry bears the responsibility for providing water for irrigation in rural areas, but since Dala falls under the general responsibility of the YCDC, it is unclear whether this is also the case in Dala [112].

Japan International Cooperation Agency (JICA)

JICA is a Japanese government agency tasked with assisting economic and social development projects in developing countries [47]. JICA recently administered a loan of $800 million to the government of Myanmar to invest in water and transport infrastructure projects [49]. This makes their power in the current case quite large, because developments in the Dala region itself will likely be conducted using money from the JICA loan. Also, JICA has cooperated with the YCDC in a long and intensive research to create the Strategic Plan for the Development of the Greater Yangon Region [48].

South Korea's Economic Development Cooperation Fund (EDCF)

The EDCF is a fund operated by the South Korean government which aims to support economic development in developing countries through infrastructure investments [74]. For this reason, EDCF has administered a loan of $138 million for the construction of the bridge between Yangon and Dala [53]. This covers a large part of the expected total costs of the project. As the money is specifically intended for the bridge and not for further developments in Dala, the EDCF's power and interest in the current case are estimated to be high, but less than JICA.

Korean International Cooperation Agency (KOICA)

KOICA is a government-run South Korean agency which administers grants and assists in making plans for economic development in developing countries [22]. KOICA has attributed their resources to writing a master plan for several areas of economic interest in Yangon, of which Dala is one [38]. Their interest in the case is very similar to that of JICA.

Asian Development Bank (ADB)

The Asian Development Bank is a regional development bank which has members from all around the world. Their goal is to fight poverty in Asia and the Pacific [2]. In Myanmar they aim to do this mainly by increasing labour opportunities and improving infrastructure [1]. Yangon representatives of this bank often accompany the YCDC director of urban development on missions to Dala to inspect the region and see what can be improved. In total they have invested $292 million in Myanmar [1].

UN Habitat

UN Habitat is a UN programme working on better living conditions in urban areas [105]. In Myanmar they advised the government on urban planning and consequences of climate change [104]. These two topics are very relevant for Dala as it is now included in the urban plans for greater Yangon and because its location makes it sensitive to the effects of climate change.

(Real estate) Developers and consultants for urban development

As with the bridge, the Myanmar government is likely to put out a tender for the development of water and road infrastructure in Dala and toward the ring road. Depending on the profitability and innovativeness of the tender, this may attract consultants and construction companies from around the world. As Japan is funding the infrastructural developments, it is expected that multiple Japanese companies will place a bid.

Companies for bridge tender

In September 2017 the tender for the construction of the Yangon-Dala bridge will be open for bids and the winner will be announced in December 2017 [52]. Not only is the Myanmar government looking for a construction company, they are also looking for a consultancy company to supervise and advise this construction company [100]. As the bridge is constructed with a South Korean loan, multiple South Korean companies are expected to place a bid [53].

Myanmar Engineering Society (MES)

The Yangon-Dala bridge project and subsequent projects in the area are seen as an opportunity for engineers from Myanmar. The project also entails a training course for Myanmar engineers and it is expected that they can learn a lot from the foreign engineers that will be involved [100]. To ensure this, active involvement of Myanmar Engineers is necessary.

Local laborers

Most of the planned developments will have to be constructed, maintained and operated by local laborers. On the one hand, it is very much in their interest that new projects are started in Dala, generating more labour. On the other hand, the technologies that are being used must also be comprehensible for them, otherwise they cannot do their work well and will be facing a lot of challenges.

Humanitarian organizations

Multiple humanitarian organizations are active in Dala such as Aid Myanmar and UNICEF [3, 55]. Their main focus is on improving living conditions in Dala by providing clean water. A well-functioning infrastructure for water supply, wastewater treatment and drainage would greatly benefit these organizations.

Dala Township local government

The local government of Dala consists of a number of committees and has as main task administration, tax collection and data collection [112]. Next to this, the township government is responsible for implementing policies that have been written by higher governmental bodies. Therefore, the decision making power of the township government is very low, but a large scale development of Dala does have an impact on the work that it does. Therefore, this stakeholder needs to be kept informed and perhaps equipped with more capacity.

Industrial companies interested in Dala

Local and regional government expect that Dala's improved connectivity will attract quite some industry, despite Dala not being dubbed as one of the economic zones in the Greater Yangon plan [48]. Foreign investors are interested in the location as it is situated at the Yangon river, will have good connectivity, offers the prospect of cheap labour, and is right between Yangon's CBD and SEZ in Thilawa [121]. If industrial companies indeed choose to settle in Dala, this will create a lot of jobs for the inhabitants. However, it may also have large consequences for the water demand and possible pollution of the wastewater. Fortunately, heavy polluting industry will not be admitted by the YCDC, as the prevailing wind direction leads fumes straight to the CBD, as stated in Appendix E, section E.5.

Inhabitants that own land in Dala

On 29 August 2017 a number of interviews were conducted with inhabitants of Dala. Their largest concern is the quality of the infrastructure and facilities needed for good living conditions. Especially the supply of clean water is currently insufficient. This is mainly because the water is transported by road in containers, but the quality of the road network is insufficient. An improvement of the water infrastructure and connectivity will benefit these inhabitants greatly. Furthermore, it will bring along a boost for the labour market, bringing more prosperity to the area. A recent survey found that almost 90 per cent of Dala inhabitants are in favour of the bridge project [8].

Squatters

A large amount of the inhabitants of Dala are squatters living in slums on government land because they cannot afford better housing [28]. Some of them live on the land that needs to be vacated for the construction of the bridge and will thus be evicted very shortly. Others might also be evicted soon as the housing demand in Dala is expected to increase causing real-estate developers to buy the land. These squatters will then need to find a new place to settle which is very likely to be further away from the economic centre, making it more difficult for them to assure a livelihood. The government is giving the squatters that are being evicted for the bridge construction a small sum of money to vacate the land before October 2017, but most of these squatters do not know where to go yet, as described in Appendix E, section E.2.

People with interest to move to Dala

As the housing prices in Dala are relatively low compared to Yangon's CBD and the direct bridge connection will reduce the travel time and conditions between the two greatly, it is expected that people working in Yangon's CBD will be inclined to move to Dala. Already tens of thousands of workers commute daily to Yangon on the ferry, so it is a popular operating base.

A.2. Stakeholder evaluation

The information collected about the stakeholders was analyzed to structurally evaluate the stakeholders. To evaluate a stakeholder's involvement in a certain case, it is important to know their general interest in life, their (usually consequential) objectives in the current case, their own resources which they can use to achieve their objectives, and their attitude towards the case. This information was all derived from the above stakeholder descriptions. As the YCDC is the problem owner, "the current case" here means the plans of YCDC to develop a sustainable water infrastructure for a rapidly urbanizing Dala after the construction of the bridge. The stakeholder evaluation can be found in Table A.1.

A.3. Power-interest grid

Based on the stakeholder evaluation table, stakeholders could be categorized in a power-interest grid. This is a grid that represents the relative positions of the stakeholders in the current case. On the horizontal axis, stakeholders are positioned relative to how much the case affects their interest. On the vertical axis, stakeholders are positioned relative to how powerful their resources are to influence the case.

Consequently, stakeholders can end up in one of the four quadrants. Newcombe [71] defined how best to regard each of these resulting categories. The stakeholders in the lower left quadrants require 'minimal effort', because they have low interest and low power. The stakeholders in the lower right quadrant have high interest in the matter, but little power to do anything. Therefore, it is best to keep these stakeholders informed. In the upper left quadrant, the stakeholders are quite powerful, but have little interest in the matters. Therefore it is best to keep these satisfied. Finally, the stakeholders in the upper right quadrant will be the 'key players'.

It is important to have all key players, because all of them are needed to be successful. It is also important for the problem owner, the YCDC, to know where they themselves stand in the grid relatively to the other stakeholders. Some are more powerful and some are less powerful. All of them have smaller interest in the matter, which is logical, because they are not the problem owner. The key players will mainly be taken into account in further consideration of the stakeholders during the design cycle. The power-interest grid can be found in Figure A.1.

Table A.1: Evaluations of stakeholders

Stakeholder	Interest	Objective in current case	Own resources	Attitude
YCDC	Welfare of city of Yangon	Economic development by increased connectivity and increased welfare by improved water supply	Funds, land ownership, manpower	Positive (problem owner)
Chief Minister of Yangon Region	Welfare of Yangon region	Exploitation of Dala's location for further economic growth of the Yangon region	Funds, political power	Positive
National Water Resources Committee	Consistency in water policies	Ensure compliance to National Water Policy	Political power	Positive
Ministry of National Planning	Conduct of economic activities that benefit the development of the country	Good connection between Yangon's (new) economic centres	Political power, money	Positive
Ministry of Transport	Develop and fully utilize transport capacities to contribute to economic growth	Ensure good connections between Yangon's (new) economic centres	Political power, money, knowledge institutes	Positive
Ministry of Construction	Construction & maintenance of roads, drainage and sanitation	Build infrastructure to ring road, ensure proper drainage and sanitation	Money, human capital, tenders	Positive
Ministry of Agriculture	Efficient cultivation and exploitation of industrial crops	Ensure profitability of crops in Dala, provide water and tools for irrigation	Political power, money, knowledge institutes	Neutral
JICA	Economic and social welfare of developing countries	Support water- and transport infrastructure development in Yangon	Loan of $800 million, expertise	Positive
EDCF	Economic development of developing countries through infrastructure investments	Help Yangon attain economic development goals	Loan of $138 million at 0.01% interest	Positive
KOICA	Economic development in developing countries through grants and knowledge	Help Yangon attain economic development goals	Masterplan for potential economic zones such as Dala	Positive
ADB	Fighting poverty in Asia and the Pacific	Help Yangon increase labour opportunities and improve infrastructure	Expertise, loans, grants	Positive
UN Habitat	Improve living conditions in urban areas	Help YCDC with urban planning and preparations for climate change	Expertise, political connections	Positive
(Real estate) developers	Profit and innovation	Win bids for urban development projects in Dala (also water infrastructure)	Expertise, human capital	Positive
Companies bridge tender	Profit and innovation	Win the bridge tender at a profitable price	Expertise, human capital	Positive
Myanmar Engineering Society	Help engineers and architects contribute effectively to Myanmar's economic growth	Involve Myanmar engineers in bridge construction and related projects	Political contacts, local expertise	Positive
Local laborers	Personal welfare	Comprehensible labour tasks	Human capital	Neutral
Humanitarian organisations	Welfare of people unable to care for their own well-being	Ensure welfare of inhabitants of Dala (housing, infrastructure, water, labour)	Money, water donations	Positive
Dala township local government	Welfare for the citizens of Dala	Be able to deal with consequences of the rapid development of Dala	Capacity	Positive
Industrial companies interested in Dala	Profit	Cheap land prices, cheap labour, high connectivity to CBD and ports, good facilities	Money, jobs, choice to move to Dala or not	Positive
Landowners in Dala	Social welfare in Dala	Improved living conditions in Dala for facilities, infrastructure and labour	Land ownership, votes	Positive
Squatters	Personal welfare	Keep house	Votes	Negative
People interested in moving to Dala	Personal welfare	Low land prices, good living conditions in Dala and connection with Yangon	Money, choice to stay or move	Positive

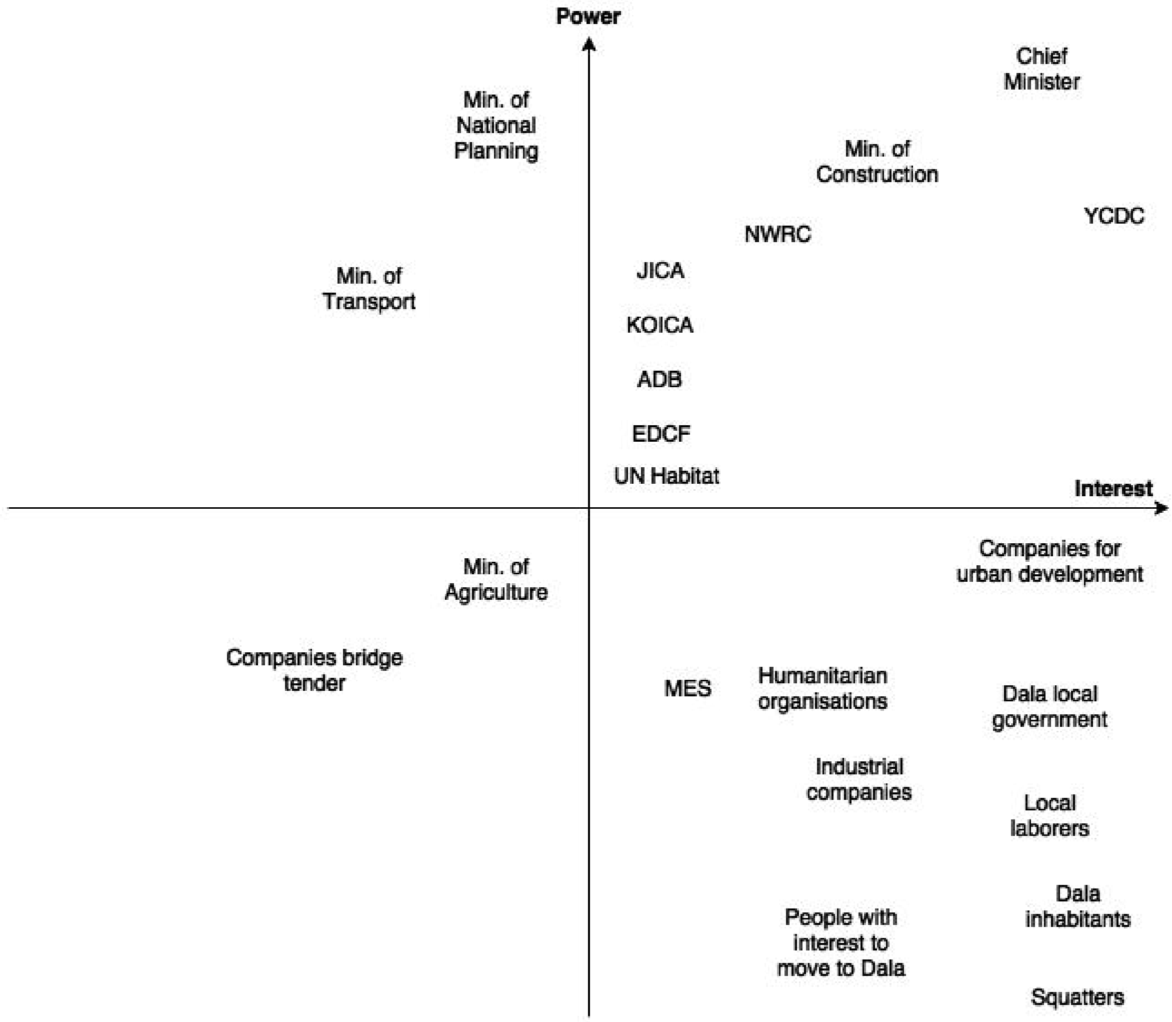


Figure A.1: Power-interest grid of stakeholders

B

Appendix: Scenario analysis

The scenarios are built following a well-defined framework explained in Ratcliffe [86]. Since this method is designed for strategic planning in a wide range of fields, to achieve better output its framework has been slightly modified and adapted to the study case. The method employed can be easily schematized in the following five steps:

1. **Task identification and analysis**
   In this step, the research or the decision that must be made is specified. In this case: Which steps can be undertaken to ensure sustainability in the development of the (water) infrastructure for Dala Township? Furthermore, the time-horizon for the scenario is set to 2040.
2. **Exploring driving forces and key decision factors**
   This step consists of specifying the key factors (or driving forces) which influence the failure or the success of the decision identified in the previous step. In this phase it is fundamental to focus on those factors related to the external and largely uncontrollable conditions. To identify these it is necessary to gather information relevant to the topic and current situation of the Dala area. This information will allow to address which uncertainties are independent of the implemented solutions but have an effect on them.
3. **Ranking driving forces**
   The next step in the process is ranking the driving forces on the basis of two criteria: the degree of impact on the success of the critical issue, and the degree of uncertainty surrounding these variables. To be systematic in this ranking process a simple impact/uncertainty matrix can be built. This step directs the outcome of the final scenarios according to the (two or three) most important and uncertain key factors. These will define the most divergent and relevant future conditions to be included in the final set.
4. **Alternative Projections**
   The results of the previous step can be employed to construct a matrix within which the different scenarios will diverge. The aim is to come up with just few scenarios whose differences lead the decision-maker to distinct choices. Ratcliffe [86] suggests to only develop two to four different scenarios. For Dala 4 scenario stories have been selected according to their plausibility and diversity.
5. **Scenario Development**
   In this final phase, the scenarios selected are further developed and described in more details. The key factors and the driving forces identified in steps 2 and 3 can now be adapted and located on the scenarios according a logic correlation.

B.1. Exploring driving forces

The external factors, or as Ratcliffe calls them: driving forces, that were identified for this case are listed below. The factors were identified by performing a brainstorm of all the factors that influence the system as defined by the boundaries in section 2.2.

- Pollution

- Sediment
- Population growth
- Population density
- Industrial growth
- Industry density
- Agricultural growth
- Through traffic demand
- Connectivity
- Mobility
- Economic welfare
- Labour in rest of Yangon
- Squatting
- Technology reducing water usage in agriculture
- Climate change

B.2. Ranking driving forces

These factors were ranked on the basis of their impact on the case and the uncertainty of their development over time. The resulting impact/uncertainty grid can be found in Figure B.1. As can be seen, population growth, industrial growth and climate change have the highest impact and uncertainty. Population and industry density are less uncertain as they can be projected in a land use model, which was done in section 3.2. Sediment has low uncertainty as the composition of different water sources is known. Connectivity, mobility and trough traffic demand also have a low uncertainty, because the bridges, ring road, feeder road and further transport infrastructure investments in Dala are seen as given. Other factors score quite average on the uncertainty/impact grid. They will need to be addressed when verifying the design, but will not be used to define the scenarios on which the design will be based.

B.3. Alternative projections

In this section, projections will be given for the driving forces, chosen to be the most important for the development of Dala. Projections will be given for population growth, industrial activity and climate change.

B.3.1. Population growth

To make an assumption about the population growth, a distinction is made between the period before the connection with CBD of Yangon is constructed, until 2021, and the period after the connection is constructed. The percentage of growth after 2021 is calculated based on the growth of Yangon area of 2,6% [48, p.44] and the percentage of this growth that will move to Dala due to the increased attractiveness of Dala because of the connection. See subsection B.3.1 for calculations and information on the population growth.

An estimation is made of 6% population growth of Dala in the period before 2021, based on the population growth of the past few years [20]. For the growth after 2021 an assumption had to be made of the percentage of immigration from Yangon area to Dala. A comparison is made with the population growth of Bangkok in Thailand and Ho Chi Minh City in Vietnam, two of the fastest growing cities in the world.

Regarding Bangkok, the population of the city grew with 1.9 million in the period of 2000 until 2010, which equals a growth of 30% in 10 years and an annual growth of 2,6% on average. The suburban growth was 2,5 million people, which equals 66% over 10 years and 5,2% annually on average, as shown in Figure B.2 [18]. This growth was not influenced by a newly built connection and the number of inhabitants of the suburban area of Bangkok was already much higher than the absolute number of the current inhabitants of Dala.

Regarding Ho Chi Minh City, a growth of 36% is found in the same period with an annual growth of 3,6% from 2002 until 2009 and 2,2% in the period from 2009 till 2012 [37]. Here the core was experiencing little or no population growth, while peripheral areas were growing much more strongly. In the years from 2004 until 2009 those areas already experienced a growth of almost 30%. This is

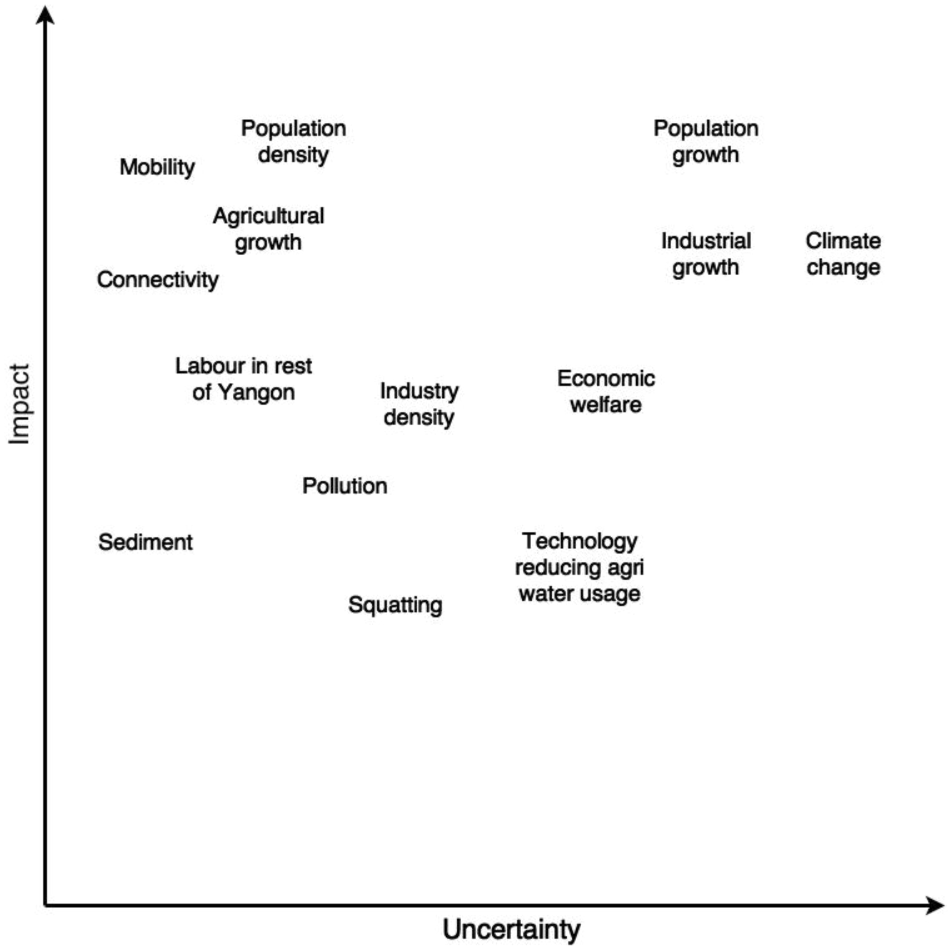


Figure B.1: Impact/uncertainty grid for the external factors

partly due to the fact that the core is already densely populated with respect to the suburban areas [19].

Based on the growth of the described reference cases of Bangkok and Ho Chi Minh City, the initial estimate for the population growth of Dala is chosen as three times the growth of the region, or 7,8%. This will result in a total number of inhabitants of around 1,1 million. However, it is not assumable that the growth of 7,8% will stay the same for 20 years. Therefore, for the first three years after the connection is completed, the 7,8% population growth is assumed, thereafter the growth will gradually go down to 2,6% in seven years. This means that after ten years there is no extra influence of the bridge anymore on the population growth of Dala with respect to the growth of Yangon region. The total population in Dala in 2040 will be in this case around 560.000 inhabitants.

Based on the this estimate, a plus and minus scenario for the population growth in Dala can be calculated. The plus-minus scenario is taken equal to the base case described above, the plus scenario is calculated as 20% higher, thus 670.000, and the minus scenario will be 20% lower, thus 448.000. The 20% difference in growth is spread equally over the 20 years after the construction of the connection.

B.3.2. Industrial growth

Industrial activity is of great importance of the Dala region. First of all it will directly influence the water demand. Secondly, industry will generate wastewater which might have to be treated differently from domestic wastewater. Besides this, the industrial activity will generate jobs, which will make Dala a more attractive place to live. Therefore, industry also imposes an indirect increase in water demand for domestic use. The growing of the secondary sector in Dala will also have a significant influence on the future landscape of the township which directly affects the area's water cycle. Therefore, different cases of expected industrial growth should be explored.

So far, no agreements have been formed about any investments for Dala's industrial sector. The

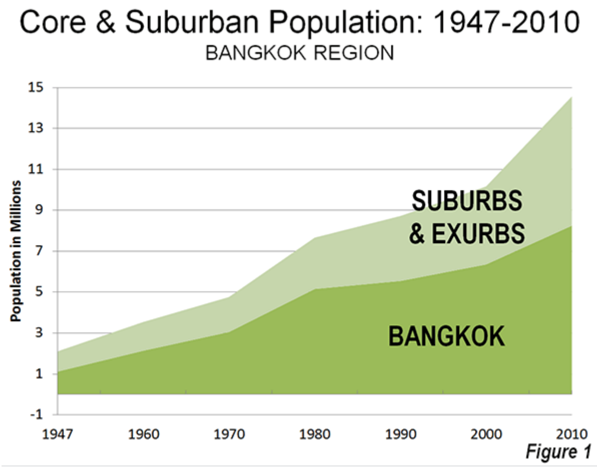


Figure B.2: Population growth of Bangkok. Source: [18]

area is not appointed as a Special Economic Zone, which makes Dala still an inconvenient place for investments. Chances are that this will not change before 2040. This is amplified by uncertainty about the connections between Dala and its surroundings. Although these connections are assumed for this report, the uncertainty itself creates a less friendly climate for investments [14]. This gives a minus scenario for industrial activity in the Dala area of 0: no activity will be undertaken in the secondary sector.

For the plus-minus scenario, the figures for national growth for the secondary sector as estimated by the Asian Development Bank [6] are used. From 2012 to 2016, this was between 8% and 12%. As Yangon is Myanmar's economic hub, the growth for Dala is expected to be higher than 8%. However, as Dala is not among the multitude of intended new industrial areas in Myanmar [75], the growth will likely not be as high as 12%. Therefore, 10% annual growth is taken as a middle value. Latest found news reports state that the bridge will be completed in 2021 [107]. Since right now there is no secondary sector activity at all, a starting value for the year in which the connection is to be completed must be assumed. For this starting value, the assumption is made that 3 companies will start business in Dala, accounting for 120 ha.[1] Projected towards the year of 2040, the most likely area covered by secondary sector businesses in Dala is 7,36 km^2. When this surface is multiplied by the average surface per laborer of all Myanmar industrial zones, this amounts to roughly 60.000 laborers. This seems like a valid plus-minus scenario, as the figure is roughly halfway between the lower and upper bound.

Recent news articles include Dala as an area which is in favour of foreign investments, for the development of secondary sector businesses [66, 121]. Plans include the construction of an airport and a deep sea harbor. The logical location for these investments is out of the scope of this research, namely South of the official Dala borders. However, the vicinity of an airport and a deep sea harbor will make the location very attractive for secondary sector businesses as well. Taken into account the construction of an airport and a deep sea terminal, it is assumed that secondary sector businesses can develop in the same rate as Thilawa SEZ. This situation is taken as the plus scenario for Dala's industrial activity. The projected growth of Thilawa accounts for 204.000 jobs in 26 years. Assuming a linear growth, Dala will have reached 149.000 jobs in 2040, and 204.000 in 2047.

The type of industry that will develop will determine the industrial water consumption. Therefore it is important to estimate the most likely type of industry to settle in Dala. The planned economic developments in Yangon has especially caught the interest of foreign parties. It is not a coincidence that JICA and KOICA played such an integrated role in writing the plans. Both Japan and Korea, as well as China and other countries have an interest in the development of the area, because once developed it is expected to bring a good return on investment [31, 121]. Therefore it can be assumed that the industrial region in Dala will mainly be used by foreign firms to place their industry in. As was found by Asian Development Bank [6] and OECD [75], most foreign direct investment (FDI) in Myanmar entailed textiles and related types of manufacturing. So it is a reasonable estimation that

[1] The assumption is made on the basis of OECD [75, Table 2.3], stating that industry in industrial zones in the South of Yangon covers 0,816 km^2 per company.

most industry in Dala will fall in this category. The actual industry water consumption in Yangon area is hard to assess due to the high rate of private water withdrawal by industry and illegal connections [46]. This makes it nearly impossible to directly relate the future industrial water demand in Dala with the present situation in the rest of the Greater Yangon. For this reason, the water consumption for the plus-minus scenario was assumed equal to a fraction of the domestic use according to the current ratio between municipal and urban industrial water (excluding water used in thermal and nuclear energy plans) consumption in South-East Asia [95]. The industrial water use in Dala was, thus, estimated to equal 30 % of the municipal water use for the plus-minus scenario. The industrial water use for the plus scenario was calculated in accordance with the rate of growth of industrial water usage in the plus-minus scenario. The plus scenario will consume 74,5% of the total municipal water production.

B.3.3. Climate change

The changing climate will have a significant impact on the Yangon region. The general observed changes include: temperature increase, rainfall variability, sea level rise, increase in magnitude and frequency of drought and heavy rainfall. In order to predict the effects of climate change, reasonable scenarios were created using data from the IPCC. The IPCC has developed a way to predict climate change known as Representative Concentration Pathways (RCP). These RCP's are based on a ranking of the outcomes of the 21 global climate models under various greenhouse gas concentration trajectories [40, p.17, p.19].

RCP's are defined as "scenarios that describe alternative trajectories for carbon dioxide emissions and the resulting atmospheric concentrations from 2000 to 2100" [30]. Due to a lack of available data for Yangon, an estimation has to be made between two RCP's, RCP 4.5 and RCP 8.5. RCP 4.5 is defined as peaking around the year 2050 and having a "smooth transition towards concentration stabilization level after 2150 achieved by linear adjustment of emissions between 2100 and 2150" [60, p.226, p.230]. RCP 8.5 is defined as continuously increasing until 2100 and having "Constant emissions after 2100, followed by a smooth transition to stabilized concentrations after 2250 achieved by linear adjustment of emissions after 2150." [60, p.226]

In Table B.1 and Table B.2 the different scenarios for the precipitation and temperature increase respectively are predicted. The minus scenario is defined as the 25^{th} percentile of these 21 global climate models under the RCP 4.5 emission scenario and the plus scenario as the 75^{th} percentile under the RCP 8.5 emission scenario [40, p.19]. The third column in each season is the average of the minus scenario and the plus scenario, resulting in the plus-minus scenario. These values will be used as a basis for our design.

In Table B.1 and Table B.2 the increase in precipitation and the increase in temperature are the projected changes in mean precipitation and temperature in 2011 - 2040 compared to the 1980-2005 averages [40, p.76, p.79]. As mentioned above, the climate change effects are not limited to increments in atmosphere temperature and variations in the amount of yearly rainfall. Storm intensity, sea level rise and precipitation distribution over the year are also factors that have a critical impact on the design. However in this section, it was preferred to only mention temperature and total annual precipitation to address the severity of climate change in the three different scenarios. Further data to characterize each scenario (for instance intensity-duration-frequency curve and expected sea-level rise) will be provided later during the design.

Table B.1: Predicted change in precipitation of the Yangon region [40, p.79]

Period	Hot Season [%]			Wet Season [%]			Cool Season [%]		
	Minus scenario	Plus scenario	Plus-minus scenario	Minus scenario	Plus scenario	Plus-minus scenario	Minus scenario	Plus scenario	Plus-minus scenario
2011-2040	-11	20	4.5	1	11	6.5	-26	13	-6.5
2041-2070	-4	16	6	5	25	15.5	-7	12	2.5

Table B.2: Predicted change in mean temperature of the Yangon region [40, p.77]

Period	Hot Season [° C]			Wet Season [° C]			Cool Season [° C]		
	Minus scenario	Plus scenario	Plus-minus scenario	Minus scenario	Plus scenario	Plus-minus scenario	Minus scenario	Plus scenario	Plus-minus scenario
2011-2040	0.7	1.1	0.9	0.6	1.0	0.8	0.6	1.1	0.85
2041-2070	1.3	2.7	2	1.1	2.2	1.65	1.2	2.7	1.95

The final design will be tested against the minus and the plus scenario of each season, to test its resilience/adaptability against the most extreme climate change scenarios.

B.4. Scenario development

Based on the factors described above, plausible scenarios are formed. One scenario will be used for the basis of the design and the other scenarios will be used to verify the robustness of the design in chapter 7. According to Ratcliffe [86], the ideal amount of total scenarios should be between two and four. However, as each factor can vary on three levels, making a full factorial set will give 27 scenarios.

Because industrial growth and population growth are correlated, as will be explained in section 3.2, a plausible set of four scenarios could be formed for these factors. As for the climate change, the design will be based on the plus-minus scenario as identified above.

Climate change can, however, not be correlated with the other factors. Furthermore, each of the above described trajectories is equally plausible for the future. Therefore, the set of scenarios could not be kept as low as four while including climate change in a realistic way. In order to work with four scenarios, the effect of climate change will be verified separately. The resulting scenarios for population growth and industrial growth can be found in Table B.3.

Table B.3: Scenarios

Scenario	Population growth	Industrial activity
Relieving Yangon	**+**	**+/-**
Residential township	+	-
Industrial potential	+/-	+/-
Economic corridor	+/-	-

Below the main scenario is further explained and core figures are provided. Using the same calculations, these core figures were also defined for the other three scenarios.

B.4.1. Relieving Yangon

The connection with the Yangon CBD makes Dala a very convenient place to live for people working in and around the CBD. Commuters can easily access the connection that crosses the Yangon river. The outer ring road on the South as designed in JICA and YCDC [48] connects Yangon to Thilawa, making Dala a popular place to live when working in Thilawa. Dala will also develop some industrial activities, across the river from Thilawa. Since Thilawa is the appointed SEZ, the industry in Dala will be smaller, and for example more focused on textile. This industry will generate labour, attracting new residents to Dala. All the new residents of Dala that work either in CBD, Thilawa or Dala's new industry also generate service jobs in Dala. This newly generated labour will in turn attract more new residents to Dala. As land prices have already gone up significantly in anticipation of the bridge project [66], it is assumed that average welfare will only rise in Dala as new residents move in. This will increase the need for high quality facilities.

To evaluate whether the potential sources can provide enough water to the future urban area, the water demand in 2040 has to be estimated. In this section, the distinction between drinking and domestic water need is not considered.

The water consumption of the township is equal the rest of Yangon and is estimated to be 150 litres per inhabitant per day [123]. This results in a total water demand of 100.300 m^3/d. This number, however, does not take into account the industry water consumption. This is estimated to be equal to the 30% of the total private water demand in Dala according to the assumptions made in subsection 2.4.1 and results in a demand of 30.100 m^3/d. Finally, to estimate the real daily demand that the water sources have to satisfy a value of 10% of non-revenue water (NRW) was considered truthful and consistent with the YCDC objective set for the NRW reduction [124]. That leads to a final estimate of 143.377 m^3/d for the average daily water demand.

The resulting core figures for this scenario are presented in Table B.4.

B.4.2. Residential township

This scenario takes into account that the industry will mainly focus in the appointed SEZ in Thilawa, just as depicted in the scenario above, and that a large part of the growth of Yangon's population will settle in Dala. Therefore the residential township will be characterized by a high population growth and no industry. Therefore, the municipal water consumption will stay the same as for the previous scenario. The added NRW of 10% will make the total water demand 110.330 m^3/d. The resulting core figures for this scenario are presented in Table B.4.

B.4.3. Industrial potential

In this scenario it is assumed that the population of Dala will grow at a somewhat larger rate than Yangon, meaning it will absorb some of the population growth of Yangon. This will be partly due to people working in CBD and Thilawa who move to Dala, but more so because of the labour created by industry that settles in Dala itself and service jobs generated by those laborers. This industrial growth will be just as high as in 'Dala relieving Yangon', so the total population growth for 'Dala industrial potential' will be less than for 'Dala relieving Yangon'.

As for the water demand, this will be based on 560.000 inhabitants (as defined in subsection B.3.1 and an industrial water consumption of 30% of the municipal use (as defined in subsection B.3.2). As for each scenario, 10% NRW is calculated in. This leads to the core figures for this scenario as shown in Table B.4

B.4.4. Economic corridor

Just like in the 'Dala industrial potential' scenario, the population growth is somewhat higher than the population growth of Yangon, but not as high in the 'residential township' and 'relieving Yangon' scenario. Dala keeps attracting more people because of its vicinity to the Yangon CBD. However, the new connection over the Yangon River is first and foremost used as an industrial passage towards the outer ring road as designed in JICA and YCDC [48], leading to the Thilawa SEZ, where all new industry industry in Yangon will settle. Dala itself will attract no industry. The consequences for the core figures and resulting water demand can be found in Table B.4.

Table B.4: Core figures 2040 for all scenarios

Parameter	Relieving Yangon	Residentual township	Industrial potential	Economic corridor
Population [#]	670.000	670.00	560.000	560.000
Res. water use [m^3/d]	100.300	100.300	84.000	84.000
Laborers Dala indust. [#]	60.000	0	60.000	0
Indust. area [km^2]	7,36	0	7,36	0
Indust. water use [m^3/d]	30.100	0	30.100	0
Tot. daily demand [m^3/d]	143.377	110.330	125.510	92.400
Tot. annual demand [m^3/d]	52.332.605	40.270.450	45.811.150	33.726.000

C
Appendix: Land use model

This appendix gives more information on the methods used to estimate future land-use of Dala. Underlying data is provided, and assumptions are explained.

C.1. Method

For the design of a water infrastructure system, it is important to know where the future water demand will allocate. Furthermore, densities of this demand are of relevance, because relatively more facilities will be needed in smaller areas.

To derive these densities of both population and industry, six steps are undertaken:

1. Attraction factors are specified, in accordance with the conceptual model, as described in subsection 3.2.1, and in accordance with the expert interview with YCDC, as described in section E.5.
2. Zones are derived, by taking into account the specified attraction factors. For the case of the current urban area, the attraction factor creates a zone itself. However, for attraction points, like the landing point of the connection with Yangon CBD, or lines, like a road, offsets need to be determined in order to define zones. This is done by case studies in the area of Yangon. Figure C.1 and Figure C.2 show the urban development adjacent to a main road. The offset chosen for the case of Dala is 500 meter. Figure C.3 shows the industrial activities on the riverbank. For the case of Dala, the offset chosen is 1000 meter. For the circle, offsetting the point where the connection with CBD lands, and where the outer ring road and Yangon CBD connection road intersect, the size of the 'New town center' as depicted in JICA and YCDC [48, p.58] is taken as a reference. For the case of Dala, the radius of the offset chosen is 750 meter. These offsets result in the map shown in Figure C.5.
3. An influence matrix is constructed, which indicates for each zone whether a attraction factor is in play for this zone. When a factor is influencing in a zone, the corresponding cell is given a 1. When the factor does not influence the zone, the corresponding cell is left empty. The influence matrix can be seen in Table C.1.
4. An importance matrix is derived, which compares the importance for the attractiveness of a zone for each of the attraction factors that are present in the Dala area. All factors are placed as headers both in the columns and rows of a matrix. The cells will be given a 0 if the factor in the column header is more important than the factor in the row header. If the opposite is true, a 1 is given to the cell. When both factors are considered to be equally important, a 1/2 is inserted in the cell. The importance matrix can be seen in Table C.2.
5. Population and industrial densities are assigned to zones, according to the weight factors as derived with the importance matrix. This is done by multiplying the relative attractiveness with the relative surface of each zone, resulting in a weight factor for each zone. After this, for the population the weight factor is multiplied by the total number of inhabitants, as projected in section 2.4 to be 670.000, to get the number of inhabitants per zone. From this, the density can be derived by dividing the number of inhabitants per zone by the surface of the zone. Here it is assumed that the density scales proportionally to the attractiveness. For the industrial activity

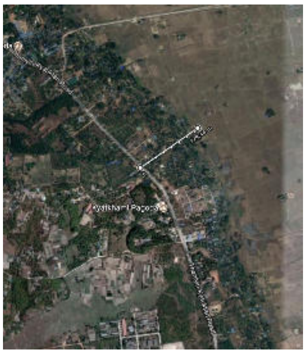


Figure C.1: Road offset 1 [32]

Figure C.2: Road offset 2 [33]

Figure C.3: River offset [34]

Figure C.4: Reference cases for determining offsets for zones Dala

accounts the same, but here inhabitants are replaced by industrial surface area. This results in the percentage of the area occupied by industrial companies.

6. After deriving the density figures for both population and industry, a scaling factor is implemented. This factor indicates the sub- or super-linearity of the attractiveness on the zones. A factor of 1 means that double the attractiveness will result in double the density. A factor lower than one, making the relationship sub-linear, means that double the attractiveness will result in less than double the density. A factor above 1, making the relationship super-linear, means that double the attractiveness will result in more than double the density These scaling factors are changed to derive at density figures that are in the order of magnitude. A scaling factor of 3 is chosen, resulting in densities that are comparable to population densities in the more busy parts of Yangon city. The same scaling factor is chosen for industry. The output of these calculations are seen in Table C.3

Table C.1: Influence matrix

Attraction factors	Importance weight	Zones																
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Population																		
Connection road CBD	9		1				1				1			1				
Adjacent to connection road CBD	5	1				1		1		1		1						
Outer ring road	6												1	1	1	1		
Adjacent to outer ring road	4 1/2								1	1	1	1					1	1
Yangon CBD	11		1															
Adjacent to Yangon CBD	9	1				1	1	1										
Existing urban area	6	1	1	1														
Adjacent to existing urban area	4				1	1	1	1										
South river	1/2								1							1		1
Adjacent to south river	1/2				1							1			1		1	
North river	7	1		1	1				1									
Adjacent to north river	3 1/2		1			1		1				1				1		
Industrial activity																		
Connection road CBD	1 1/2		1				1				1			1				
Adjacent to connection road CBD	1 1/2	1				1		1		1		1						
Outer ring road	8 1/2												1	1	1	1		
Adjacent to outer ring road CBD	5 1/2								1	1	1	1					1	1
Yangon CBD	1 1/2		1															
Adjacent to Yangon CBD	1 1/2	1				1	1	1										
Existing urban area	7 1/2	1	1	1														
Adjacent to existing urban area	4 1/2				1	1	1	1										
South river	10 1/2								1							1		1
Adjacent to south river	6 1/2				1							1			1		1	
North river	10 1/2	1		1	1				1									
Adjacent to north river	6 1/2		1			1		1				1				1		

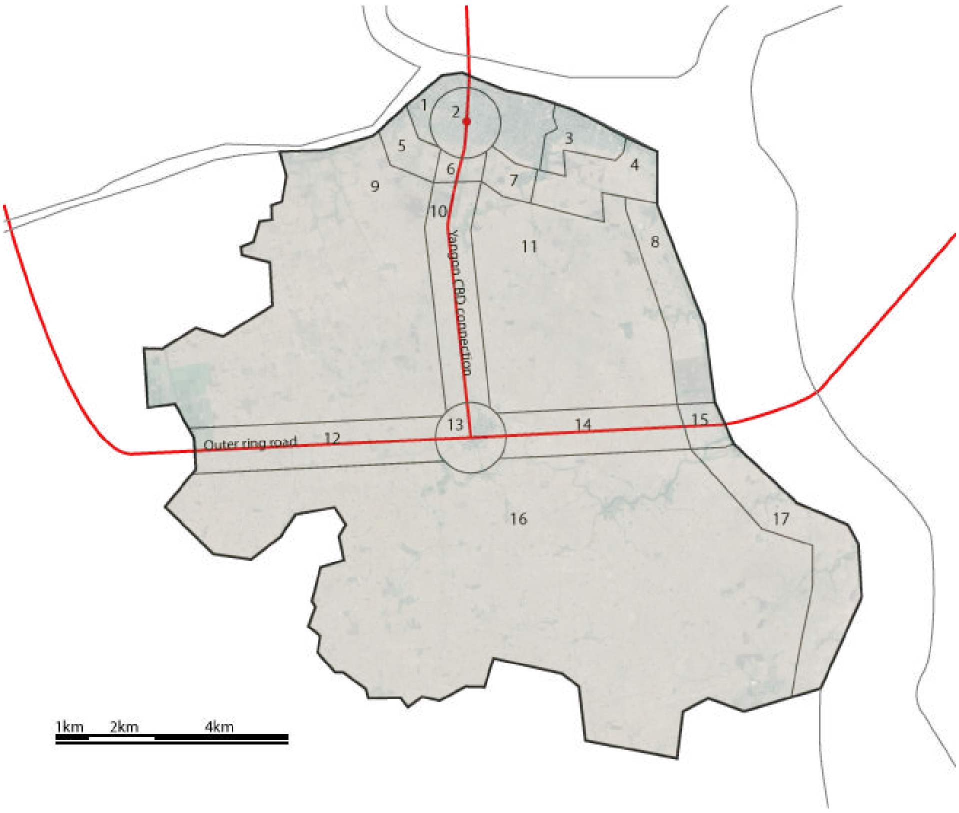


Figure C.5: Land-use zones

Table C.2: Importance matrix

	Connection road CBD	Adjacent to connection road CBD	Outer ring road	Adjacent to outer ring road	Yangon CBD	Adjacent to Yangon CBD	Existing urban area	Adjacent to existing urban area	South river	Adjacent to south river	North river	Adjacent to north river	Sum of row
Attraction for residential purpose													
Connection road CBD		1	1/2	1	0	1/2	1	1	1	1	1	1	9
Adjacent to connection road CBD	0		0	1/2	0	1/2	0	1/2	1	1	1/2	1	5
Outer ring road	1/2	1		1	0	0	1/2	0	1	1	0	1	6
Adjacent to outer ring road	0	1/2	0		0	0	0	1/2	1	1	1/2	1	4 1/2
Yangon CBD	1	1	1	1		1	1	1	1	1	1	1	11
Adjacent to Yangon CBD	1/2	1/2	1	1	0		1	1	1	1	1	1	9
Existing urban area	0	1	1/2	1	0	0		1	1	1	0	1/2	6
Adjacent to existing urban area	0	1/2	1	1/2	0	0	0		1	1	0	0	4
South river	0	0	0	0	0	0	0	0		1/2	0	0	1/2
Adjacent to south river	0	0	0	0	0	0	0	0	1/2		0	0	1/2
North river	0	1/2	1	1/2	0	0	1	1	1	1		1	7
Adjacent to north river	0	0	0	0	0	0	1/2	1	1	1	0		3 1/2
Attraction for industrial activity													
Connection road CBD		1/2	0	0	1/2	1/2	0	0	0	0	0	0	1 1/2
Adjacent to connection road CBD	1/2		0	0	1/2	1/2	0	0	0	0	0	0	1 1/2
Outer ring road	1	1		1	1	1	1/2	1	0	1	0	1	8 1/2
Adjacent to outer ring road	1	1	0		1	1	0	1/2	0	1/2	0	1/2	5 1/2
Yangon CBD	1/2	1/2	0	0		1/2	0	0	0	0	0	0	1 1/2
Adjacent to Yangon CBD	1/2	1/2	0	0	1/2		0	0	0	0	0	0	1 1/2
Existing urban area	1	1	1/2	1	1	1		1	0	1/2	0	1/2	7 1/2
Adjacent to existing urban area	1	1	0	1/2	1	1	0		0	0	0	0	4 1/2
South river	1	1	1	1	1	1	1	1		1	1/2	1	10 1/2
Adjacent to south river	1	1	0	1/2	1	1	1/2	1	0		0	1/2	6 1/2
North river	1	1	1	1	1	1	1	1	1/2	1		1	10 1/2
Adjacent to north river	1	1	0	1/2	1	1	1/2	1	0	1/2	0		6 1/2

Table C.3: Calculations population and industry density

	Zones																
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
Surface area [km2]	4,08	3,21	2,48	4,75	1,88	0,95	1,45	5,41	42,23	7,50	27,92	8,78	3,18	6,48	1,44	93,12	9,27
Population																	
Scale factor	3																
Sum of attraction factors	27	29,5	13	11,5	21,5	22	21,5	12	9,5	13,5	13,5	6	15	6,5	10	5	5
Weight (= rel attraction * rel surface)	2,5E-05	2,6E-05	1,7E-06	2,3E-06	5,9E-06	3,2E-06	4,5E-06	2,9E-06	1,1E-05	5,8E-06	2,2E-05	6,0E-07	3,4E-06	5,6E-07	4,5E-07	3,7E-06	3,6E-07
Population per zone (= pop * weight / sum weight)	141508	145329	9599	12741	32959	17871	25393	16480	63875	32532	121166	3346	18950	3138	2538	20534	2043
Population density (= pop zone / surface zone) $[inh/km^2]$	34723	45289	3876	2683	17532	18784	17532	3048	1512	4340	4340	381	5954	484	1764	221	221
Industry																	
Scale factor	3																
Industry	0	0	0	0	14	7,5	14	0	7	7	20	8,5	10	15	25,5	12	16
Weight (= rel attraction * rel surface)	0	0	0	0	6,0E-06	4,7E-07	4,6E-06	0	1,7E-05	3,0E-06	2,6E-04	6,3E-06	3,7E-06	2,5E-05	2,8E-05	1,9E-04	4,4E-05
Industry per zone (= ind * weight / sum weight)	0	0	0	0	0,08	0,01	0,06	0	0,21	0,04	3,27	0,08	0,05	0,32	0,35	2,35	0,56
Industry density (= surface ind / surface zone) [%]	0	0	0	0	0,04	0,01	0,04	0	0,01	0,01	0,12	0,01	0,01	0,05	0,24	0,03	0,06

D

Appendix: Morphological chart

An important part of the functional design phase is constructing a morphological chart. A morphological chart is a tool that can be used to generate solutions for each function of the system and by combining them, constructing alternative designs. For this project, the chart was constructed on several occasions: during two internal brainstorm sessions and during one external brainstorm session, which are fully elaborated in Appendix F, to which experts from the YEP network and students from YTU and MMU were invited to participate. The goal of these brainstorms was to generate as many solutions as possible and to think out of the box. As a result, the combined chart was very large and contained some ideas that could immediately be classified as too unfeasible or ineffective for further research. Therefore, the chart was trimmed slightly. The remaining solutions were further researched and evaluated on the basis of how well they would fit in either of the three alternative designs. The ideas that were further researched can be found in Table D.1.

Table D.1: Morphological chart

Function	Solutions							
Water harvesting/ resource	1) Rainwater ponds	2) Groundwater well	3) Direct intake Toe river	4) Waste water reuse	5) Runoff water	6) Air condensation	7) Air-conditioning condensation	8) Private rainwater harvesting
	9) Fluvial reservoirs	10) Sea water	11) Connect to water system Thilawa	12) Connect to water system Yangon				
Storage of harvested water	1) Private tanks	2) Underground cisterns	3) Water tower	4) Underground runoff water tanks	5) Wind turbine shaft	6) Large tanks	7) Bhungroo system (India)	8) Black anti-evaporation balls
	9) Rainwater community ponds	10) Aquifers with extraction wells	11) Canals	12) Deepen existing water bodies	13) Air bag water storage			
Treatment of drinking water	1) Reverse osmosis	2) Electrolysis	3) Add chemicals	4) Purify with vegetation	5) UV-purification	6) Wind-drinker	7) Green wall	8) Dunes
	9) Ceramic pot filtration	10) Traditional treatment						
Quality control of drinking water	1) Chemical testing with color change	2) Record diseases	3) Citizen science project	4) Smartphones	5) Backflow prevention			
Supply of drinking water	1) Aquaduct	2) Robot vehicles	3) Water-Wheel	4) Pipelines to collection points	5) Pipelines to homes	6) Separation of pipes (potable/ non-potable)	7) aQysta	8) Trucks
Collection of waste water	1) Central underground sewer system	2) Septic tanks under houses	3) Buckets collected by trucks	4) Canalling	5) Gravity sewer system	6) Vacuum sewer system		
Limiting pollution of waste water	1) Reuse of waste water by same company/ person	2) Fining for exceeding limit	3) Personal responsibility of director of company	4) Reject companies that exceed pollution limit	5) Clean sewer system regularly			

Function	Solutions							
Monitoring water consumption	1) Pay for usage	2) Secure water collection places	3) Household survey	4) volume harvested + δ reservoir height	5) Smart monitoring			
Treatment of waste water	1) Septic tanks	2) Sedimentation tanks	3) Phytodepuration	4) ETS-UV	5) Chlorine treatment	6) Upstream Anaerobic Sludge Blanket Reactor (UASB)		
Discharge of waste water	1) Discharge in river	2) Use for agriculture	3) Use for drinking water	4) Infiltrate in ground	5) Close circle depending on source			
Protect against pluvial flooding	1) Green roof	2) Dike	3) Sand bags	4) Drainage system	5) Houses on stilts	6) Heightened road	7) Retention basins	8) Parks that can be flooded
	9) ZOAB	10) Add green in streetscape	11) Water squares	12) Underground storage	13) Sponge city	14) Urban agriculture	15) Urban canals	16) Sand pavement
	17) Maintain current vegetation	18) Golf course						
Collect runoff water	1) Concrete road ”bak”-design	2) Heightened hollow sidewalks (as in Yangon)	3) Use sewer system/ main drainage system	4) Dig canals	5) Build Dala on hill	6) Gutter collection		

E

Appendix: Meetings local stakeholders

During the 8 week period, a number of visits, interviews, meetings and workshops were conducted. Some of them with a specific goal, such as the workshops and the validation interviews, but some of them were used as general input for this project. A number of these general input meetings are summarized in this appendix.

E.1. Dala tea shop interview - 29 August 2017

Attendants:

- Inhabitants of Dala (3)
- Pann Ei Ei Phyoe - Interpreter
- Giacomo Bandinu
- Jeroen Delfos

This interview was conducted in a local tea shop, with three inhabitants of the Dala township. The three inhabitants were working in an office in Dala itself. Questions were asked about the problems that Dala faces, and about the expected influences of the planned bridge connection between Dala and Yangon CBD.

- Is there a lot of flooding in Dala?
  - Not a lot. There is some flooding in June, July and august, but it is not destructive. There are different parts of Dala and in some areas the water will flood, like at the riverside it can come up to 4 feet in the rainy season. The area where the interview is taken, is not flooded by tide, but only by rain.
- Are you bothered by the flooding in those areas?
  - It does not matter that much, because if the tide goes down the water also flows away. It only lasts for one hour.
- Do you use the flooded water? For example for agriculture or drinking water?
  - No. Most of the people of this township have office jobs and therefore do not use it for agriculture. For the people in the villages around, they also do not use it because it is very salty. They have the water ponds which they use for drinking water.
- How do people get access to drinking water?
  - Annually there is a problem with a lack of water. In the end of the dry season, in March, April and May, the ponds dry out, and there is not enough water, although there are a lot of ponds. When the ponds dry out, there are people from Yangon that donate water for Dala. All the donations are collected at a central point in Dala, after which the water is distributed in tanks of 20 liters and some bigger.

  - During the time that the ponds can provide water, every household has to get the water manually with buckets.
- How do they transport the water?
  - Nowadays there are wider roads where water can be transported on. Donations are often not transported by boat because it's more expensive. Instead, the transportation is done by road, through Hlaing Township[1]. There are 23 quarters in Dala Township, some are really difficult to reach. There the water is really needed, because the car cannot go to the village. The roads are really a problem for transportation of the water right now.
- Is the bridge a good idea for Dala?
  - It will be good for the transportation, however more people will go to live in Dala because it is cheaper, increasing the drinking water problem already present. There is no bus right now, so transportation is done by motorbikes. It is expected that the bridge connection will result in bus lines connecting Dala.
- How is the water quality?
  - Quite okay. The water from the ponds is used for domestic purposes. However, salt water is intruded in the ground, so a lot of the pond sources are not good for drinking water.
- What changed in Dala within the last 10 years?
  - Everything is developed, electricity, the roads. Drinking water scarcity has changed for the worse, because there are more people living in Dala right now so the demand has gone up, but the harvested water has stayed the same.

E.2. Dala squatters interview - 29 August 2017

Attendants:

- Squatters (2)
- Pann Ei Ei Phyoe - Interpreter
- Giacomo Bandinu
- Lot Barendsen
- Arnout Janse
- Irene Overtoom

On the 29th of August, a field trip to Dala was conducted. A family that was currently living on the location where the bridge to connect Dala with Yangon will be built was interviewed. Most of the citizens that live in that area, including the family which was interviewed, are not the land owners, but squat on this public land. The first part of the interview is about the relocation method and compensation for the people that are living in the future bridge area. The second part of the interview investigates the occurrence of flooding in the area close to the river bank and how floods affect the local life.

Relocation due to bridge construction

- How much does the government pay you to move from this location?
  - Since we are not land owners the government only pays 300.000 MMK per family/house to remove all their goods from the public land. The government pays 10 million MMK (8.000$) to each house owner that must sell their land. The people who own the land do not necessarily have to move, they only have to sell their land to government. These are only a few houses, since most of the people in that area don't own the land on which they have built their houses.
- When do you have to remove your house?
  - They must remove their house before October 2017. This is one month after the day of the interview.
- Is the government providing a specific place for the people of Dala that have to relocate?

[1] A trip by road of about 35 km is needed to reach the Hlaing Township

  - No, we must find that by our-self.
- Are people complaining about the relocation method and payment?
  - The people who get the money seem to be OK with the compensation. There are only 1 or 2 families who do not agree with the compensation, but, since they are illegally occupying public land they do not have any right to disagree.
- When did you receive the notification that you must vacate the area?
  - Last year some authority (they do not which one exactly) told us that we must move. However, we did not have any official communication from the government. Also the notification that they have to move in October is apparently not official.
- Which organization is operating the relocation and the compensation payment?
  - We do not know, but most likely the YCDC or Dala Community Committee.

Floodings in Dala

- Are you bothered by the flooding? Is your house high enough?
  - We do not have real problems with the high water since our houses are constructed high enough to not be bothered by the flooding, even when high water occurs.
- How often does the riverbank area flood? Do you know when it is going to happen? Can you forecast the high water?
  - The high water occurs every year during the rainy season (May to September). It occurs 1 or 2 days per month during the rainy season.

E.3. YCDC - 19 September 2017

Attendants:

- Daw Nyein Aye - Assistant Director Urban Planning Division YCDC
- Giacomo Bandinu
- Arnout Janse

This meeting was intended to introduce the Sustainable Dala group and YCDC to each other. After a quick introduction about the Sustainable Dala project by the present group members, Nyein Aye gave an update of the planned and ongoing projects in Dala under the supervision of YCDC. It was agreed afterward that more appointments will follow to discuss the outcome of the project and to visit Dala.

The current drinking water for Dala is taken from a groundwater source located in Puak Yangon, $26km$ south of Dala. The capacity of this source is not big enough to cover all the households. To partially overcome this problem, a Korean donor constructed a small water treatment plant which uses local groundwater to provide wards No. 6 with drinking water.

The Japanese Fund for Poverty Reduction (JFPR) and the ADB have financed $2 million for developing projects for Dala. This will finance the construction of in total seven small treatment plants to provide drinking water in rural area of the Greater Yangon region. Three of them will be placed in Dala township in ward No. 11/14 and in Auntgui west ward. All of them will treat groundwater with reverse osmosis units. Furthermore, a public toilet project and solid waste management project in Dala will be financed by the same fund.

For the future, YCDC is looking into using the Toe River, in the south-west of Dala, as water a resource which will supply drinking water to Dala as well as to Yangon City.

E.4. Dala Community Committee - 29 September 2017

Attendants:

- Daw Nyein Aye - Assistant Director Urban Planning Division YCDC
- U Tin Hla - Member Dala Community Committee
- Dala Community Committee members
- Kyaw Nyunt Linn - Interpreter
- Kyi Kyi Thar - Interpreter

- Giacomo Bandinu
- Jeroen Delfos

During this visit to Dala, Nyein Aye (YCDC) accompanied and introduced the Sustainable Dala group to the Dala Community Committee. Different points were discussed, concerning the water use and current infrastructure. The impact of the bridge was also discussed. Lastly more in depth questions about possible design decisions were discussed.

Current water system

Currently there are three sources for water:

- Groundwater, harvested south of Dala and transported through pipelines.
  - Water is salty, and is therefore only used for domestic use;
  - it can only serve a very small part of the Township.
- Rainwater, harvested directly in ponds. Sometimes rainwater is harvested on roofs of public buildings (like schools), adjacent to ponds, and stored in the ponds.
  - The water is used for drinking water for the poor people;
  - Water is not clean. Health problems are occurring due to the quality of the water;
  - Water is not cleaned at household level. Boiling the water requires energy, which is too expensive;
  - Ponds dry up in the dry season. Depending on the storage characteristics of the pond they can empty out between February and May.
- Water from Yangon, transported by road or boat.
  - In the rainy season this is the water source for the less poor people;
  - In the dry season, when ponds are dried out, the poor people rely on water donations. People sometimes wait a whole day for this water, receiving only one or two bottles (litres) of water.

Impact of the Dala Bridge

The Dala Committee are very positive and are looking forward to the construction of the bridge. The sooner the better. Reasons for this are:

- The committee thinks the designed water pipeline will bring a more certain supply of drinking water;
- The water shortage also induces the danger of fires, since there is no water to extinguish them;
- During foggy conditions, which occur during dry season, getting across the Yangon river is problematic, obstructing commuters to work in Yangon;
- Transport for emergency situations requiring a proper hospital in Yangon need to be done by boat, which is not always available, or is brings his own safety risks.

Negative impacts of the bridge (induced water demand due to population growth, more urbanization, induced industrial activity) are not playing a role in the discussion on the bridge. When specifically asking about these negative impacts, they are largely denied, possibly to not give any reason to postpone the construction of the bridge. The Dala Community Committee wants only 'non-smoking' industry in Dala.

Possible design solutions

As said before, one of the current water sources is rainwater. Dala residents have experience with rainwater harvesting, and are used to the idea of drinking rainwater. Alternatives were also discussed with the committee:

- Groundwater is not trusted as a source for drinking water, due to the salinity of the water from the source.
- Water from the river Toe is not seen as a feasible solution, since the committee members think that the price of this water will be too high, due to the transportation costs.

Pond visit

After the meeting with the Dala Community Committee, some of the members of the Committee showed the SD group a drinking water pond in the western part of Dala. During the conversations here, some statements were made by Nyein Aye, and committee members, that give more insight in the situation of Dala.

- Some inhabitants don't have enough money even to buy a bucket, with which water can be transported to their houses.
- One pond, which is used for drinking purposes, lies adjacent to a graveyard. During heavy rainfall, runoff from this graveyard flows into the pond.
- A large share of the Dala inhabitants is housed in illegal buildings.
- The owners of the land on which illegal settlements have been formed allow this situation for now, because the land has a very low value. Any actions to remove settlements are not undertaken, because squatters will just move to a new illegal spot.

E.5. YCDC - 02 October 2017

Attendants:

- Daw Tin Tin Kyi - Director Urban Planning Division YCDC
- Daw Saw Sandar Oo - Division Head City Planning and Land Administration Department YCDC
- Daw Nyein Aye - Assistant Director Urban Planning Division YCDC
- Daw Khaing Moe Nyunt - Deputy Director Urban Planning Division
- Jeroen Delfos
- Irene Overtoom

In this meeting the land-use model as found in Appendix C was discussed. The methods used, and the resulting maps for population density and industrial activity density were presented.

Feedback on the assumptions used, and resulting figures were given by Daw Tin Tin Kyi, Daw Saw Sandar Oo, Daw Nyaing Aye and Daw Khaing Moe Nyunt:

- The listed attraction factors, used to determine the attractiveness for population growth are correct.
- A large part of the riverbank will be used for recreational space. Hence, industry can not settle here.
- Heavy, polluting industry is not welcome in Dala, due to the prevailing wind direction towards Yangon CBD.
- Non-polluting industry, like garment industry is welcome in Dala.

E.6. AG Resources Myanmar - 02 October 2017

This meeting took place so that more information could be gathered on the current progress of the plans in Dala. Attendants:

- Captain Zaw Min Win - Managing Director
- Pyaet Phyoe Aung - Operation Manager
- Lot Barendsen
- Giacomo Bandinu

E.6.1. Current situation

- Industrial wastewater is not treated.
- Yangon has 60 percent non-revenue water.
- The pipe network was constructed during the British colonization.
- YCDC has 10 tube wells in the Dala region, of which 6 can be used for drinking water. The remaining four have high iron concentration.
- These tube wells are not able to supply water 24/7 and the supply can be at any hour of the day, including the night.

E.6.2. Aim of AG Resources Myanmar

The aim of AG Resources is to supply the Dala region with drinking water. This will be done using two treatment plants. In order to bridge the time between the construction and completion of the pilot project AG has mobile RO treatment facilities which can be connected within 3 days. This system will provide the surrounding inhabitants with free drinking water until the pilot project has started. This system is able to create 20.000 liters of drinking water per day.

Pilot project - 3 million liters per day

- Reverse osmosis treatment
- Will require 4 months to build
- located 2 miles from Dala
- Water which will be treated is very dirty and polluted
- The raw water is very low in pH

50 million liters per day

- TECHKEM water from Malaysia will be responsible for drinking water treatment
- Together with partners from USA and Germany
- WHO requires 220 liters pppd.
- YCDC assumes 90 liters pppd
- This system will be able to supply 555.555 people according to YCDC standards.
- Only membrane filtration will be needed (UF)
- The source is located 19 miles downstream from the Yangon river, where the water is much cleaner.
- The test on the salinity of this potential source were carried out only during the wet season.
- Distribution system will follow the road to Dala and also provide the population of Twan Tay township (200.000) with water. The pipe network will have a length of 40 km.
- Will supply drinking water with the use of a prepaid system.
- 1000 liters of drinking water will cost approximately 855 kyat.
- The system will be completed by 2020 and will cost approximately $ 100 million.
- If its expansion is necessary an additional 3 months will be required to upgrade the system to 150 million liters pppd.
- Money will be loaned and after approximately 35 - 55 years the entire system will be donated to the local government.

E.7. Impact Terra - 06 October 2017

Attendants (phone conversation):

- Gerdien Velink - Head of External Communications
- Arnout Janse

For the quality control of water, an application has to be used by the local inhabitants. To see if this is implementable in Dala a local expert, Gerdien Velink from Impact Terra was consulted. Impact Terra has developed the application 'Golden Paddy' for farmers to improve agriculture by providing them with information about the markets. Although their application focuses more on giving information to farmers instead of asking for input, they have conducted surveys as well within their app. Therefore, she was able to give advice on how to implement a new technology with local people and share their experiences until now.

Overall, people wanted to be involved and they are curious to use new technologies to improve their life. Some points were stressed and have to be taken into account by setting up and implementing this application for water quality control:

- The application has to be easy to understand. Therefore, the application will be made in both English and Myanmar language and the use of images for the interface instead of words will the attempted.
- For the inhabitants it is important that the application does not use all of their data while uploading information. Therefore it is important to also make it available offline and to not let it consume a lot of data.

- Show the relevance for the inhabitants. If they see what can be improved for themselves they are willing to help. Therefore it is important to show that the water quality will improve if they fill it in correctly.
- To increase the usage of the application, information will be given by going to Dala in person. At Impact Terra, they saw rapid increase in usage if someone went to the area and explained to the people how to use the application. Social media can be used to stay in contact afterwards. Another option to increase the response is by rewarding people personally for their feedback.
- It is important to know what the stakes of the company are that collects the data. An example was given by Gerdien about the collection of data. If a company only wants data, they are probably not open to invest in an application that stores everything directly in a database. If they want to work more efficiently, it is a good argument to use an application.

F
Appendix: Workshops

During the project, two workshops were organized where inputs were asked from experts living and working in and around Yangon. The first workshop focused on generating ideas for the different solutions where the second workshop was for evaluating the chosen solutions for the design.

F.1. First workshop - 16 September 2017

The first workshop was set up as an open brainstorm for input on the different functions and was hosted at the office of ICCO Cooperation. The people that were attending this workshop are listed in Table F.1.

Table F.1: Attendance list first workshop

Name	Occupation
Alwin Commandeur	YEPper and river engineer at RoyalhaskoningDHV
Kyaw Hyunt Linn	Project Assistant at The Water Agency
Kyi Kyi Thar	Intern at The Water Agency
Pan Ei Phyu	Student at Myanmar Maritime University
Pyae Phyo Sein One	Student at Myanmar Maritime University
Robbert Groenen	YEPper and founder of Rockstar Impact
Tanya Huizer	YEPper and Project manager Water & Environment at Arcadis
Thet Oo Mon	Intern at RoyalhaskoningDHV
Weiyan Moe Aye	Student at MMU
Marielle Chartier	Intern urban development at Arcadis

After a short introduction and update on the Sustainable Dala project, three heterogeneous groups were formed to brainstorm about potential solutions for the several water-related issues that Dala will face in the future. In the first part of the workshop, the three teams generated many innovative ideas. The most promising ideas were chosen and worked out. Finally, each group pitched its solutions. It was interesting to observe how each team approached the problem differently and focused on different aspects. The first group presented the idea to involve the local people to let the project succeed and to create more awareness on the possible implementable solutions. The second group combined the future urban design of Dala with the water harvesting capacity of the township, really coming up with a design for a living city. The third group focused more on the total water cycle and particularly on the different possibilities to store water for the dry season.

F.2. Second workshop - 28 September 2017

The second workshop organized by Sustainable Dala took place at the embassy of the Netherlands. The attendance list can be found in Table F.2. After an introduction and sn update on the Sustainable Dala

Table F.2: Attendance list second workshop

Name	Occupation
Alwin Commandeur	YEPper and employee of RoyalhaskoningDHV
Aung Myint Oo	Employee of the embassy of the Netherlands
Daw Khaing Moe Nyunt	Deputy Director of Urban Planning Division, YCDC
Daw Nyein Aye	Assistant Director of Urban Planning Division, YCDC
Daw Saw Sandar Oo	Division Head City Planning and Land Administration Department, YCDC
Huub Buise	Deputy ambassador of the embassy of the Netherlands
Jan Jaap Pape	Researcher at Irrigation Technology Centre Bago
Khin Muyar Kyaw	Student at Yangon Technological University
Khin Myatthu	YEPper and civil engineer at Arcadis
Kyaw Hyunt Linn	Project Assistant at The Water Agency
Kyi Kyi Thar	Intern at The Water Agency
Lauren Huisman	Intern at the embassy of the Netherlands
Lindsey Schwidder	Project manager water innovations at TU Delft
Marcel Stive	Professor emeritus of hydraulic engineering at TU Delft
Marielle Chartier	Intern at Arcadis
Marjan Kreijns	Head of Project Management Department at Valorisation Centre TU Delft
Marleen Brouwer	YEPper and country coordinator Myanmar at ICCO Cooperation
Pan Ei Phyu	Student at Myanmar Maritime University
Pyae Phyo Sein One	Student at Myanmar Maritime University
Tanya Huizer	YEPper and employee of Arcadis
U Aye Mint	Senior water resources engineer at NEPS, chairman of the advisory board for NWRC and IHE-NUFFIC alumnus
U Cho Cho	Member of the advisory board at NEPS, chairman of the advisory board for NWRC and IHE-NUFFIC alumnus
U Khin Lat	Senior consultant at NEPS, member of the advisory board for NWRC and IHE-NUFFIC alumnus
Weiyan Moe Aye	Student at Myanmar Maritime University

project, four heterogeneous groups were formed all containing a discussion leader from the Sustainable Dala group. The goal of this workshop was to evaluate some of the chosen solutions by asking the attendants the following questions:

- Is rainwater the source that interrupts the water cycle the least?
- Can the responsibility for storage of water be given to the inhabitants of Dala?
- Will the separation of drinkable water and domestic water in Dala contribute to less energy consumption?
- How do we ensure economic feasibility for the water system, while making drinking water free of charge?

The questions were formulated in such a way that it would bring up a discussion about the focal points of the design. The discussion leaders wrote down the reactions after which the following summary was written.

The participants agreed that rainwater harvesting is one of the solutions which has the smallest effect on the water cycle. However, the harvesting of rainwater will affect the amount of water which can infiltrate into the ground, which in turn can lead to subsidence. A calculation has to be made to give an educated opinion about this topic. Furthermore, multiple experts indicated that the use of rainwater as the only source for water supply is probably not enough for all water consumption in Dala. Participants also named the Toe river as a good water source that possibly has more capacity.

The idea of the separation of pipeline system into domestic and drinking water, to consume less energy for the treatment, was not accepted directly by everybody. A big influence factor is the way of harvesting water. Looking to drinking water, it was mentioned that the river Toe is almost potable and therefore almost no treatment is needed. This means that separating the pipelines would not be necessary. Using rainwater as a source results in more treatment needed, which could make a separate pipe system effective in reducing energy usage. Regarding the energy costs and reductions of energy consumption, the participants advice was to come up with rough calculations of the energy consumption within the total water cycle. Drinking water treatment might not be the part of the water cycle that consumes most of the energy. Supply might be a more energy intense part of the cycle. In this case it would not be efficient to split the system since this increases the energy demand for supply. Moreover, the cost of the pipelines have to be calculated. The investment costs are higher for a separated pipe system with respect to a single system and the payback time can therefore take longer. A more practical point of separating the system is the implementation, since the inhabitants do not know the idea of a separated system.

An important issue is the awareness of consumption of water. The proposed idea coming from the evaluation of the alternative designs is that this can be improved by making people responsible for their own water by storing water on local scale. Inhabitants of Dala can be encouraged with personal incentives. YCDC has found that assigning responsibility at community level does not work, because of a lack of water conservation awareness. For example, community ponds are often not well maintained, meaning drinking water quality will drop. Therefore, assigning personal responsibility works better. However, the economic feasibility of local storage is questioned. Besides this, the feeling of responsibility for storing the water might not always be present among inhabitants. To solve this and to create more awareness, education has to be improved on the storage of water as well as on how to save water and efficiently harvest water. Lastly the laws and regulations about water consumption, water quality and wastewater production were mentioned. These laws are at least 50 years old, from back when Dala only had a few inhabitants. They are outdated and need to be adapted to the current consumers and standards.

To improve the water system an economic option was proposed, namely: make the drinking water free of charges and set this margin on domestic water to cover the expenses for the total water consumption of Dala. In this way, all inhabitants will have access to drinking water. Completely free drinking water was not the best option according to the experts, since people will use drinking water for other purposes to save money. Some options were proposed from which the community can earn money, for example with tourism, so the water for the poor people can be paid.

G

Appendix: Calculations final design

To work out the core functions of the design in more detail, some calculations had to be made. The calculations that were made to support the statements in chapter 6 are presented in this appendix.

G.1. Water harvesting and source

Aung [7] calculated the annual amount of rainfall in the Yangon region based on data collected between 1993 and 2013 in the three stations of Kaba-Aye, Mingalardon, and Hmawbi. The averaged yearly precipitation recorded by these stations are 2.884 mm, 2.607 mm and 2.562 mm respectively. From this, it is possible to extrapolate that, on average, the Yangon region is showered by more than 2.680 mm every year. This large amount of precipitation makes it interesting to look into the possibility to implement a rain water harvesting (RHW) system to partially solve the drinking water problem in Dala. It is important to address that every millimetre of water harvested on a surface of one square meter is equivalent to 1 litre of potential drinkable water.

Even if this solution is extremely attractive in terms of sustainability and environmental impact, it also faces several challenges. First of all, around 80% [7, p.24] of the total annual precipitation is concentrated in a four month period, therefore the water once collected has to be stored to satisfy the demand throughout the rest of the year. Rainwater is characterized by having a very high quality. However, it can be heavily contaminated during the collection process [59]. For these reasons an elaborate design is needed to maximize the rain harvesting capacity and storage for the future Dala township. In order to do that, the first step consists of calculating the total potential water that can be collected during an entire year. This capacity can be easily estimated with Equation G.1

$$\textit{Potential Rainwater harvesting} = \textit{Dala total surface} * \textit{Yearly precipitation in 2040} \tag{G.1}$$

The result of Equation G.1 is more than 0,36 km^3. To give a comparison, this is equal to the total amount of water needed to satisfy the yearly water demand of half the population of London (UK). However, it is too ambitious to collect all the water that falls within the Dala area. This calculation gives an estimate of the potential that the rainwater source has in wet tropical regions such as the Ayeyarwady Delta.

Roof rainwater harvesting

In the following calculations, some reduction factors are employed to take into account the uncertainty related to the future landscape of the township. In this section, the land use model described in section 3.2 serves as an important tool to support the assumptions on the expected outline of the area. Wiginton et al. [119] states that there is a linear relationship between the population of an urban area and the roof surface with a correlation factor (R^2) equal to 0,993. The relation found by Wiginton et al. [119] is shown below:

$$\textit{Roof surface} = \textit{Population} * 70 + 23700 \tag{G.2}$$

The formula shows that for the Canadian urban areas the total surface of roof is 70m^2/ per capita plus a constant value of 23700 m^2. However, the average Canadian urban landscape is very different from what is expected for Dala. For this reason, the application of Equation G.2 to the Dala case gives unrealistic results. More reliable results are obtained when values from other developing countries are used. Pillai and Banerjee [85] estimates the roof surface per capita based on average roof area per person over five regions in Brazil. To do that the percentage of houses and flats in multistory residential buildings was surveyed. The results of this survey were related to the population density data and roof extent. This results in an average surface of roof per capita of 19,4 m^2/inh. This value is considered more suitable for the Dala situation. The constant term in Equation G.2 can be neglected in the case of a relatively big urban agglomerate [119].

From the previous observation, it follows that the total future roof surface in Dala can be estimated by:

$$\textit{Dala roof surface} = \textit{Dala Population} * 19{,}4 \tag{G.3}$$

The total surface of the roof allows to calculate the water that can be harvested from as follow:

$$\textit{Roof rain harvesting} = \textit{Roof surface} * \textit{Yearly rainwater} * \textit{efficiency factor} \tag{G.4}$$

In this calculation the climate change is taken into account considering the variation in yearly precipitation according subsection 2.4.1. An efficiency factor of 0,75 is used in the previous calculation. This factor accounts for losses during the harvesting process and the share of roof surface not available for rain harvesting purpose (e.g. already existing buildings).

Green area rainwater harvesting

One of the solutions which characterized the design is the promotion of green in the urban areas, as mentioned in section 5.3. The World Health Organization has suggested that every city should have a minimum of 9 square metres of green space per capita [10]. Since for Dala case, the green space area will play a fundamental role in the pluvial flooding prevention, a much higher standard should be set. For this reason, the green per capita of urban areas with similar climate where examined and set as example for the future urban development of Dala. The Siemens Green City report shows Singapore, which is the third most dense city in the world, should be a role model for spatial planning as the city has been able to combine extensive green spaces with high population density [24]. This city is characterized by a high rate of green area per inhabitant of 66 m^2/inh and an annual amount of rainfall slightly lower than Yangon. Therefore, a similar green per capita rate of 60 m^2/inh can be set as minimum requirement for the future Dala landscape. According this standard and the predicted future population of the Township, the green areas will occupy 40,2 km^2.

As explained earlier in this section, the collection of runoff water, originating from rainfall over an urban area is a possible way to increase the amount of water harvested. Epa [25] states as the storm runoff created from impervious surface in urban area (e.g. street, parking lots, walking paths) is characterized by an important concentration of several pollutants. This makes the street runoff not suitable for drinking/domestic purpose. However, the same report addresses that the runoff water generated in well-maintained green areas can be considered as a valuable source of drinking water after a basic filtration treatment. This makes it interesting to explore the possibility to collect water while creating the urban green areas.

Part of the green area in Dala can be designed as *Bioretention Basin (BB)* or *Engineering Rain Garden (ERG)* with the under laying drainage system directly connected to the drinking water reservoirs. BB landscape features low-maintenance and water-wise vegetation. They are designed with amended soils and drainage layers of gravel and sand, which absorb and naturally filter storm-water before it enters in the reservoir. BB areas can provide excellent pollutant removal for the rainwater runoff [16, p.54].

According to Phillips [84], approximately 5% of impervious area should be dedicated for construction of BB's, to allow for the drainage. Since the drainage will take place on green area, which has a runoff coefficient of 0,3, due to the probable saturation of the water in wet season [13], 1,6% of the green area should be constructed with BB's. It is assumed that 20% of the total green area of Dala has the potential to serve as a catchment area for the BB's. When the total green area is multiplied by these two figures, an area of 0,13 km^2 is derived, that have to be constructed with Bioretentian Basins, equaling a percentage of 0,32% of the total green area.

In this case, it is assumed that the 25% of the water that falls on the BB's catchment areas is collected and ends up in the drinking water reservoir. This figure is deducted from the combination between a linear rain-runoff model [87] and the expected efficiency of the drainage process in the BB. The calculation done to estimate the total water which can be harvested yearly through BB in green area is shown in Equation G.5.

$$\textit{Green area rain harvesting} = \textit{BB's catchment area} * \textit{Yearly rainwater} * 0{,}25 \tag{G.5}$$

From Equation G.5 the yearly harvested volume in the BB is around 5.650.000 m^3.

Due to the dependence on and the lack of information on the soil and territory, specific costs are hard to provide. Massachusetts Department of Environmental Protection [57] states that in general the costs for a BB area is less than or equal to that of a catch basin and underground chambers intended to treat the same area. BB areas treat and recharge storm water thereby decreasing the amount/size of piping required in the drainage system and the dimension of downstream treatment structures, which influences the price of the total system positively. However, BB areas require regular maintenance. Therefore the training of the operators needs to be planned in order to make the implementation of this solution possible.

G.2. Storage

The Dala population is expected to reach a 670.000 inhabitants by the year 2040. Based on JICA and YCDC [48] a water consumption of 150 litres per person per day will be used for domestic and drinking purposes. An additional 30% will be added to take into account the amount of water needed by industry. This will result in a yearly consumption of 52,3 million m^3 of water. In order to do the calculations for Equation G.6 and Equation G.7, a number of different input variables were needed. The most important input variables can be found in Table G.1. With this input, the lifespan of the specific reservoirs are calculated, this is shown in Table G.2.

$$\textit{Capacity} = \textit{Inflow of water} - \textit{Losses} \tag{G.6}$$

$$\begin{aligned} \textit{Change in volume} = {} & \textit{Volume in reservoir} + (\textit{Rooftop} + \textit{Green})\ \textit{harvesting} \\ & + \textit{surface area of reservoir - dry season demand - losses} \end{aligned} \tag{G.7}$$

Table G.1: Input variables to design a storage reservoir

Information	Value	Units
Population in 2040	670.000	$inh.$
Water demand in 2040	52.332.605	m^3
Volume of water which needs to be stored	30.527.353	m^3
Maximum depth of reservoir	10	m
Volume of water which can be harvested from roofs in 2040	24.676.636	m^3
Volume of water which can be harvested from green areas in 2040	5.653.296	m^3
Yearly seepage losses	330 [77, p.2]	mm
Yearly evaporation	1.330 [7, p.24]	mm
Yearly evaporation off of reservoirs	1.000	mm
Yearly precipitation	2.813 [7, p.24]	mm

The capacity of the system is defined as the amount of water which needs to be stored to supply all inhabitants with water during the dry season. The inflow of water is defined by the precipitation onto the surface of the reservoir and the added water to the system due to both rooftop harvesting and green area harvesting as can be seen in Equation G.8. The losses of the system is due to water evaporating as well as water being lost from the system through seepage as shown in Equation G.9.

Table G.2: Storage potential

	Units	2020	2025	2030	2035	**2040**	2045	2050
Water which needs to be stored for the dry season	m^3	-	19.012.737	23.537.199	26.789.027	**30.457.465**	34.628.251	29.701.176
Water which can be stored after each year	m^3	-	5.333.018	2.072.000	-271.765	**-2.915.801**	- 4.002.034	-7.419.790
Volume of water in the reservoir	m^3	-	85.333.017	101.536.234	104.947.914	**95.792.676**	81.948.994	51.860.960

$$\textit{Inflow of water} = \textit{Precipitation on reservoir} + \textit{rooftop harvesting} + \textit{green area harvesting} \tag{G.8}$$

$$\textit{Losses} = \textit{evaporation} + \textit{seepage} \tag{G.9}$$

The rough calculation using Equation G.6 results in a required storage capacity of 30,5 million m^3. If the reservoir can have a maximum depth of 10 meters, this will result in a surface area of 3,05 km^2. This figure is based on the total demand for both domestic and drinking water use. The total amount of water which could be harvested from the roofs, the green areas and on the reservoir itself was calculated. The short calculation below shows the total amount of water which can be harvested in one year on the small surface area of the reservoir.

$$\textit{Volume of water harvested on surface of reservoir} = 3,05 \cdot 1.000 \cdot 1.000 \cdot (2,813 - 1,033)$$

$$\textit{Volume of water harvested on surface area reservoir} = 5.429.000 m^3$$

The surface of the reservoir can only harvest 17,8 % of the total water which needs to be stored. This calculation shows that it is not possible to supply the population of Dala with water which has been harvested in one year. This is because the surface area of the reservoir is too small to harvest enough water and the urban harvesting cannot collect enough excess water in order to fill the 10 meter deep reservoir.

The surface area of the reservoir on which rainwater falls directly is the only factor for rainwater harvesting that is not dependent on assumptions about the growth of the urban area. If the surface area of the reservoir were to increase, the amount of water which could be collected would also increase. However, in order to suffice the yearly demand only with harvesting from the reservoir surface, an additional surface area of 14,3 km^2 would be needed to collect the required water. This solution would only work for the year 2040 and will not be able to supply the demand for the years after if the population growth continues to increase. This is because the direct harvesting of rainwater takes into account the population size of 2040 and not a larger value.

By using Equation G.7 it is expected that reservoirs will be built with a total surface area of 10 km^2 and have a maximum depth of 10 meters resulting in a total storage capacity of 100 million m^3. These reservoirs will be built by 2020 and will require a period of 4 years before being operational. Once these reservoirs are in use, they will continue to slowly fill until its maximum storage capacity. It is calculated that they can supply the demand of water for the population, that will grow up until the year 2040. Depending on the change in population, the reservoir will be functional for a period of 15 more years. This calculation takes into account the change in total precipitation and increased evaporation due to climate change as well as the total yearly losses due to seepage. After this, additional measures will be needed to provide the population with sufficient water in the dry season.

Table G.3: Growth in population and their required water usage

	Units	2020	2025	2030	2035	**2040**	2045	2050
Population	*inhabitants*	245.404	417.283	516.583	587.953	**668.466**	760.005	864.078
Water consumed in wet season	m^3	7.986.713	13.580.526	16.812.285	19.135.020	**21.755.332**	24.734.465	28.121.554
Roof top harvesting	m^3	-	15.368.853	19.026.179	21.654.779	**24.620.142**	27.991.577	31.824.689
Green area harvesting	m^3	-	3.520.928	4.358.804	4.961.003	**5.640.354**	6.412.733	7.290.880
Water which needs to be stored for the dry season	m^3	-	19.012.737	23.537.199	26.789.027	**30.457.465**	34.628.251	29.701.176

Table G.3 shows the expected population of Dala every five years starting in 2020 to 2050. After the year 2040, it is assumed that the population continues to grow. Table G.2 clearly shows that with a continuously growing population the reservoir will empty out quite rapidly. This scenario was picked to show that, if the population of Dala was to peak in the year 2040 with a maximum of 670.000 people. The reservoir will be able to cater to the demand of the population for a period much longer than if the population was to continue to grow.

Evaporation

Losses due to evaporation significantly affect the amount of water which can be stored in open reservoirs as well as the time taken to fill reservoirs. Benzaghta and Mohamad [11, p. 5-6] give a list of measures to minimize the loss due to evaporation. An overview of these measures can be seen in Table G.4.

Table G.4: Measures to limit the amount of evaporation

Type	Explanation
Floating covers	plastic(impermeable) layer covering the whole reservoir
Floating objects	work similarly to floating covers however, consist of multiple individual units.
Shade structures	reduce the amount of energy available for evaporation.
Chemical covers	cover the reservoir and need to be reapplied every 1 - 4 days.
Design features	deeper reservoirs, wind breakers
Biological covers	lily pads which limit the amount of evaporation

The different measures mentioned above will be analyzed. The advantages and disadvantages are briefly explained in Table G.5 [11, 92, p.5-6,p.28-35].

As can be seen from Table G.5, shade structures, windbreakers and biological covers are easiest to implement and use. However, these measures are not very effective. The use of a floating cover would greatly reduce the evaporation losses. For the Dala case a combination of the four mentioned measures could be used to further reduce the evaporation losses so that water can be harvested more efficiently. However, no calculation has been made to accurately quantify the magnitude of the reduction in losses.

Seepage

In order to minimize the seepage losses the base of the reservoirs needs to be built out of an impermeable layer. This layer can either be an artificial layer or a natural clay layer. If the base of the reservoir consists of a high plasticity clay the daily seepage can be as low as 0,0003 ft [77, p.2]. This will result in a yearly seepage loss of 33 mm.

G.3. Dual reticulation system

Pipeline diameter

The diameter of a pipeline, supplying water, is based on the peak flow of the water demand. The calculation of this peak flow is done by converting the daily consumption to m^3/s and multiplying this by the peak factor per hour of 1,8 [110]. The results of this calculation are shown in Table G.6. For the dual reticulation system a distinction is made between drinking water and domestic water.

The calculation of the diameter is done by dividing the discharge by the velocity of the water. For the drinking water a velocity of 1 m/s is taken [110]. For the dual system a lower value can be used since the quality has a lower standard. Therefore, the velocity of domestic water supply can be reduced. For the calculation a velocity of 0,5 m/s is assumed. Together with a D/t-ratio of 30, which is used for Schedule 40 PVC pipes Commercial Industry Supply [17], the wall thickness and the total surface area are calculated and summarized in Table G.7. Due to the lower water velocity for domestic use, this pipe has a bigger diameter with respect to the single pipeline system, for coping with the peak flow.

Pipeline length

For estimating the length of a pipeline system, a grid layout is projected on a surface, similar to the service area of Dala. Pipes in the grid are spaced 1 km apart, making all the surface complying with the requirement of having water supply at a maximum distance of 500 meter. Figure G.1 shows 4 alternatives, including 1, 2, 4 and 8 distribution points.

When measuring the pipeline length, the figures displayed in Table G.8 are obtained. An increase in the length is seen for adding more distribution points. This is due to the primary distribution pipes, which in Figure G.1 coincide with the horizontal lines of the grid.

The length of the pipes will be used for further calculations, which require a figure on the pipeline length. Turns made by the pipelines, as shown in Figure G.1, are not taken into account for the power demand.

Table G.5: Advantages and disadvantage of the different types of methods to minimize evaporation

Type	Advantage	Disadvantage
Floating covers	Very effective in reducing losses due to evaporation.	Covers can significantly impact the water quality of the reservoir.
	The cover traps the air and prevents water vapour from leaving.	On a large scale, they are very expensive and are therefore mostly used on a small scale
Floating objects	The smaller units are easier to install than the larger floating covers	Less effective in reducing evaporation that floating covers.
Shade structures	Just as effective as floating objects	Are more difficult to install than floating objects and are also more expensive.
	Have no significant effect on the water quality	
Chemical covers	Short term costs are very low	Long term costs are very expensive
		Need to be reapplied every 1 to 4 days
		Reduced environmental and health impacts.
		Less effective in reducing evaporation losses that floating covers
Design features: Deeper reservoirs	Reduce the evaporation losses by increasing the surface area to depth ratio	
	In some cases water can be harvested from a large surface area and pumped into deep reservoir to minimize evaporation losses.	
Design features: Wind breakers	Natural wind breakers can be used such as trees and should be located on the windward side of the reservoir.	
	Can be easily applied to existing reservoirs	
Biological covers	Easy to implemented	Impacts the water quality and the aquatic ecosystem.
		Only slightly reduces the losses due to evaporation

Pipeline material

The pipes consist of Schedule 40 PVC material, based on general material for supply water pipelines provided by Commercial Industry Supply [17]. With the surface area and length known, the total material can be calculated for the single pipeline system and the dual reticulation system, depicted in Table G.9. For the calculation it is assumed that the whole system uses the same diameter for the pipes. What can be seen is that the material use for the dual reticulation system is almost two times as high with respect to the single pipe system.

Table G.6: Water consumption

	Consumption $[L/day]$	Peak flow $[m^3/s]$
Single pipeline system	150 [123]	0,49
Drinking water pipe	10 [42]	0,03
Domestic water pipe	140	0,52
Dual pipeline	150	-

Table G.7: Pipe dimensions

	D $[m]$	t $[mm]$	A $[m^2]$
Single pipeline system	0,82	27	0,067
Drinking water pipe	0,21	7	0,004
Domestic water pipe	1,12	37	0,126

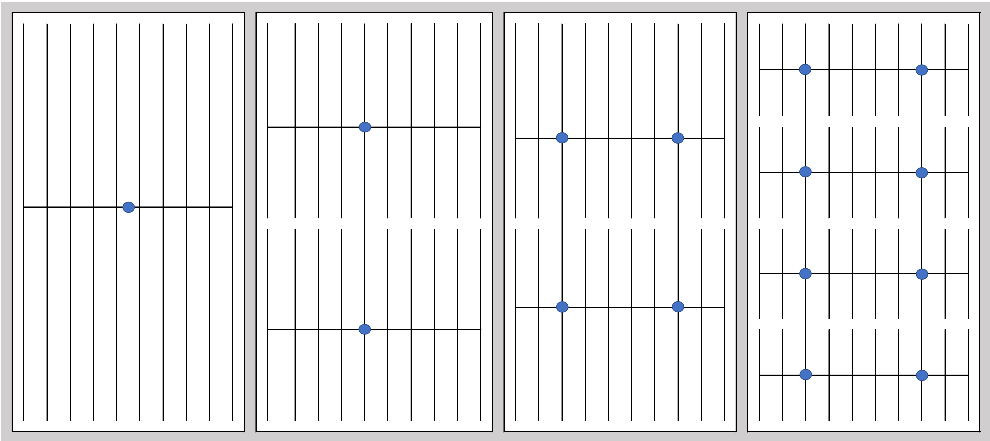


Figure G.1: Pipeline grid alternatives

Power demand

A rough calculation is made for the energy consumption during operation phase based on needed power for the pumps to overcome the head loss of the different systems. The head loss is calculated with Equation G.10, known as the Darcy-Weissbach formula [110], where the system is modelled as one pipeline with a total length of 190 km. This assumption disregards the losses that are made due to turns in the pipeline system. The results of the slope and head losses for the different pipes are shown in Table G.10.

$$\Delta H = \lambda \frac{8L}{\pi^2 g} \frac{Q|Q|}{D^5} \tag{G.10}$$

To make it independent of the length, this can be rewritten to

$$\frac{\Delta H}{L} = 0,0826 \frac{\lambda}{D^5} Q|Q| \tag{G.11}$$

Where

- D = diameter of the pipe m
- Q = discharge m^3/s
- L = length of the pipe m
- λ = 0,02 Darcy-Weissbach friction coefficient [110, Ch5 p. 3]
- g = 9,81 m/s^2

The power can be calculated by multiplying the head loss by the density of the water, the gravity acceleration, the pump efficiency and the discharge, see Equation G.12. To compare the different

Table G.8: Pipeline length

Number of storage facilities	1	2	4	8
Pipeline length [km]	184	189	189	199

Table G.9: Material use

	Area $[m^2]$	Length $[km]$	Volume $[m^3]$
Single pipeline system	0,067	190	12800
Drinking water pipe	0,004	190	850
Domestic water pipe	0,126	190	23900
Dual pipeline system	-	380	24750

systems, it is assumed that for both systems the same pump will be used with a pump efficiency of 90% [27]. The outcome of this calculation is shown in Table G.10.

$$P = \rho * g * \Delta H * \eta * Q \tag{G.12}$$

Where

- ρ = 1000 kg/m^3
- η = 0,90

Table G.10: Energy consumption

	slope $[m/km]$	ΔH $[m]$	P $[MW]$
Single pipeline system	1,25	237	1,35
Drinking water pipe	4,83	919	0,35
Domestic water pipe	0,23	43	0,23
Dual pipeline system	-	-	0,58

What can be seen is that the dual system consumes less energy for distributing the water. This is mainly due to the lower flow velocity of the domestic water supply and the bigger diameter of the system. However the investment costs are much higher for the installation and fabrication of two pipelines.

G.4. Drinking water treatment

The software *Kostenstandard* by *Royal HaskoningDHV* was employed to calculate the investment cost, operational cost and emission of the drinking water treatment. The results for each step for the single supply system solution are presented in Table 6.3. The costs refer to the Dutch market in 2008. The same discharge as considered in subsection 6.1.3 is used as input for the software. The range is +/- 30% for investment costs and +/- 20% for the operating cost estimate. CO2 emissions are calculated considering the whole life cycle of each step [91].

Table G.11: Cost and CO2-emission of drinking water treatment for a single drinking water supply system

	Investment cost [€]	Operational cost [$€/y$]	Price [$/m^3$]	Emission [$tonCO2/y$]
Pre-filtration	5.765.000	582.000	1,81	194
Coagulation-Flocculation	10.006.000	1.092.000	3,13	1.719
Rapid-sand filtration	11.621.000	1.246.000	1.589	816
UV Disinfection	1.493.000	489.000	1,4	874
GAC Filtration	18.711.000	2.358.000	6,79	136
Chlorination	154.000	496.000	1,42	3.639
Total	47.808.000	6.264.00	18,19	8.152

H

Appendix: Validation interviews

Two expert interviews were planned for the validation of the design. For the first interview, two water management experts from the National Engineering and Planning Services, who are also part of the advisory committee for the National Water Resources Council (NWRC), were invited. For the second interview, four officials from the urban planning department of YCDC (of which one is the director of the department) were invited. However, this last interview was cancelled from their part due to a visit from the Minister of Construction and attempts to reschedule it failed. In this appendix, the interview set-up is first described after which the summary of the conducted interviews is presented.

H.1. Interview set-up

In this section, the interview questions are listed and the short introduction that was given during the interviews is presented. To tailor to the functions of the interviewees, some questions were only asked to the urban development officials at YCDC and some were only asked to the water management experts at NEPS. The background questions and face validation questions were asked to all experts.

H.1.1. Introduction to interviews

To enable us to make a design in 8 weeks time, reductions and assumptions had to be made. This interview is meant to check whether our design still fits with the actual real-world system that it was created for. However, this real-world system is a future situation which is still very uncertain. Therefore we would like to ask you to critically look at our design and the underlying reductions and assumptions, and assess whether it is realistic and implementable in future Dala.

We will start with some general questions about the design as a whole. Some focal points were chosen which we worked out more in detail than others. For these focal points, we would like to know what you think about some of the quantitative assumptions and calculations. We tried to tailor these last questions to the function that you have at YCDC/NEPS.

H.1.2. Background questions

1. What is your name?
2. What is the name of your organization?
3. What is your function within the organization?
4. How long have you been working in this function?
5. What is your (academic) background?

H.1.3. General impression/face validation

1. To what extent do you think the system as presented in the design will cater to all the water needs in future Dala?
2. To what extent do you think the system as presented in the design can be constructed, operated and maintained in future Dala?
3. To what extent do you think the system is robust and flexible to cope with different ways in which the township of Dala may develop?

4. On which actors do the solutions proposed have an impact?
5. Which actors can influence the proposed system?
6. To what extent do you think the solutions proposed are environmentally sustainable?
7. To what extent do you think the solutions proposed promote a healthy economy in Dala?
8. To what extent do you think the solutions proposed promote equality amongst inhabitants of Dala?
9. To what extent do you think the system is a complete water infrastructure design?

H.1.4. Harvesting and resource

YCDC

These questions will only be asked to the officials from the urban development department of YCDC.

1. To calculate the total roof surface of Dala in 2040, a study was used that determined the average roof surface per capita in five regions in Brazil. This resulted in an average roof surface per capita of 19,4 m^2/inh. To what extent do you think this is realistic?
2. For decrease the impact of urbanization on flood risk, it is established that by 2040 a minimum of 36% of the Dala's urban area will be green area. The rest can be built area. To what extent do you think this is realistic?
3. Do you think the harvesting system as sketched in the design can be installed in Dala?
4. Do you think the harvesting system as sketched in the design can be operated and maintained by local people and laborers?

NEPS

These questions will only be asked to the water management experts from the National Engineering and Planning Services.

1. For rainwater harvesting it is assumed that of all the rainwater that falls on Dala roofs, 75% can be harvested. To what extent do you agree that this is a valid assumption?
2. Using bioretention basins for runoff water, it was calculated that 25% of the water that falls on the catchment area, which is 20% of the green area, can be harvested. To what extent do you think this is a realistic estimate?
3. For harvesting from green areas an efficiency factor of 25% has been chosen. While for the roof surface a factor of 75% is considered. To what extent do you think these are realistic figures?
4. For water that is harvested directly on the rainwater reservoir, a loss factor due to seepage and evaporation is used. This amounts to a total annual loss of 23%. To what extent do you think this is realistic?
5. The final annually harvested volume is compared to an estimated demand in 2040 which is based on a population of 670.000 inhabitants that use 150 litres per person per day and an industry water demand of 30% the amount of residents' water demand. To what extent do you think this is realistic?
6. Do you think the harvesting system as sketched in the design can be installed in Dala?
7. Do you think the harvesting system as sketched in the design can be operated and maintained by local people and laborers?

H.1.5. Storage

YCDC

These questions will only be asked to the officials from the urban development department of YCDC.

1. It is assumed that all the rainwater reservoirs can be completed by 2020 to allow them to fill over the course of 4 years. In these four years the reservoirs are not to be used. Do you think this is implementable in Dala?
2. For the reservoirs, a maximum depth of 10 meter is taken. Is this a realistic depth considering the soil in Dala?
3. Do you think the storage system as sketched in the design can be operated and maintained by local people and laborers?

NEPS

These questions will only be asked to the water management experts from the National Engineering and Planning Services.

1. An annual water demand of 52 million liter is assumed. The reservoirs have a buffer of 88 million liter. Do you think this is a realistic amount?
2. For the reservoirs, a maximum depth of 10 meter is taken. Is this a realistic depth considering the soil in Dala?
3. Do you think the storage system as sketched in the design can be operated and maintained by local people and laborers?

H.1.6. Supply

YCDC

These questions will only be asked to the officials from the urban development department of YCDC.

1. To what extent do you think having two water supplies in the house is user-friendly? (keeping in mind that currently people also don't drink the water that they use for showering)
2. Do you think the supply system as sketched in the design can be operated and maintained by local people and laborers?

NEPS

These questions will only be asked to the water management experts from the National Engineering and Planning Services.

1. It is assumed that pumping the water through the pipeline system and treatment of the water are the governing factors, determining the energy consumption. Is this a realistic assumption?
2. For the calculations, corners in the pipelines were omitted because there was no way to realistically estimate the amount of corners in the pipes. Is this a realistic assumption?
3. To what extent do you think having two water supplies in the house is user-friendly? (keeping in mind that currently people also don't drink the water that they use for showering)
4. Do you think the supply system as sketched in the design can be operated and maintained by local people and laborers?

H.1.7. Finalizing

1. Is there anything we missed that you would like to remark upon?

H.2. Interview NEPS

Below the answers from the water management experts at NEPS are presented. This interview was conducted at the NEPS office in Yangon on 13 October 2017. The interviewees had the opportunity to read the design and core assumptions on beforehand. The interview questions were also sent on beforehand.

H.2.1. Background questions

1. What is your name?
   U Cho Cho and U Khin Lat
2. What is the name of your organization?
   Both: NEPS and NWRC
3. What is your function within the organization?
   U Cho Cho: Member of the advisory board at NEPS and chairman of the advisory board for NWRC.
   U Khin Lat: Senior consultant at NEPS and member of the advisory board for NWRC.
4. How long have you been working in this function?
   U Cho Cho: Advisor at NEPS for 11 years, before that managing director at NEPS for 20 years
   U Khin Lat: Around 20 years.
5. What is your (academic) background?
   U Cho Cho: BSc Civil Engineering in Yangon, MSc Experimental and Computational Hydraulics at UNESCO-IHE (Delft)

U Khin Lat: BSc Civil Engineering in Yangon, MSc Hydraulic Engineering of Delta Areas at UNESCO-IHE (Delft)

H.2.2. General impression/face validation

1. To what extent do you think the system as presented in the design will cater to all the water needs in future Dala?
   U Cho Cho: I think that in the present situation it is doable but I am not sure that our system can cope with the rapid growth of Dala without a detailed urban planning. I share the idea to stress the need for treatment plants in Dala.
   U Khin Lat: I agree with Cho Cho about his statements.
2. To what extent do you think the system as presented in the design can be constructed, operated and maintained in future Dala?
   U Cho Cho: A bridge connecting Yangon and Dala across Yangon River is going to be constructed soon. So the demand of water for Dala will be drastically raised in the near future. For the implementation, I think that local people can do it easily.
   U Khin Lat: I agree with Cho Cho. I think you have to assume that the company has to be authorized by YCDC. It is a very important assumption to make, because in Myanmar it is hard to get the authorization of the government for these kind of things.
3. To what extent do you think the system is robust and flexible to cope with different ways in which the township of Dala may develop?
   U Cho Cho: I think that industry could be a problem. If Dala develops as an extension of the Yangon business area, a much higher water demand should be assumed.
   U Khin Lat: I think that the system is flexible as long as it is combined with a well-defined spatial urban plan for the future Dala township.
4. On which actors do the solutions proposed have an impact?
   U Cho Cho: Local communities and Yangon Regional authorities.
   U Khin Lat: Investors and contractors. Laborers that are attracted by the Dala development (I expect that these people will come from the south rural area). Also YCDC, and agriculture and irrigation people because the development of the area can reduce agriculture production.
5. Which actors can influence the proposed system?
   U Cho Cho: YCDC and Yangon Regional Government.
   U Khin Lat: YCDC can prevent companies to work on the Dala area (very important to have the approval from them)
6. To what extent do you think the solutions proposed are environmentally sustainable?
   U Cho Cho: 90% environmentally sustainable.
   U Khin Lat: Yes
7. To what extent do you think the solutions proposed promote a healthy economy in Dala?
   U Cho Cho: 80% assurance is expected for the promotion of a healthy economy.
   U Khin Lat: I think (this concept was stressed also by Cho Cho) that the development of a water infrastructure only for the Dala urban area will create an unbalanced situation in the south of Yangon area. The development of Dala will beckon in the people from the rural area that are aiming for a better lifestyle (access to drinking water). These people will be subtracted from the laborers in the agriculture sector. Myanmar already has a shortage of farmers because of the attraction of the city. If the rural areas are not developed, this will result in an increase in the food prices. I think that some reflection about how to promote a healthy economy is necessary for the design otherwise the system will collapse.
8. To what extent do you think the solutions proposed promote equality amongst inhabitants of Dala?
   U Cho Cho: 95% assures for equality among inhabitants of Dala.
9. To what extent do you think the system is a complete water infrastructure design?
   U Cho Cho: A comprehensive water infrastructure design.

H.2.3. Harvesting and resource

1. For rainwater harvesting it is assumed that of all the rainwater that falls on Dala roofs, 75% can be harvested. To what extent do you agree that this is a valid assumption?
   U Cho Cho: I fully agree. I agree with the use of rainwater as the first source. This coincides

with the plan of the Ministry and YCDC to increase the use of harvesting techniques.

2. Using bioretention basins for runoff water, it was calculated that 25% of the water that falls on the catchment area, which is 20% of the green area, can be harvested. To what extent do you think this is a realistic estimate
U Cho Cho: It would depend on the infiltration character of the existing soil. To harvest more water in the reservoirs it is possible to use plastic sheets to reduce the infiltration in the soil of the catchment areas. This will also help to reduce the buffering period to fill the reservoirs up.
U Khin Lat: I agree that the future urban plan for Dala should include green areas and that they can be used for the water harvesting.
3. For harvesting from green areas an efficiency factor of 25% has been chosen. While for the roof surface a factor of 75% is considered. To what extent do you think these are realistic figures?
U Cho Cho: Roof surface 75% is agreeable. 25% efficiency for green area depends on the nature of existing soil of the green area. this two surfaces can be used for harvesting and the estimation on the amount of water that can be harvested are good as long as local people are educated about the different harvesting technique. For the roof, you can actually aim to reach an efficiency which is even higher than 75%. I think that the 25% for the green water is too much. This is because the infiltration in the soil will be high.
U Khin Lat: I agree with Cho Cho about the efficiency of the harvesting methods. I also think that you should have designed the rainwater tanks in such a way that people can directly use the water.
4. The final annually harvested volume is compared to an estimated demand in 2040 which is based on a population of 670.000 inhabitants that use 150 litres per person per day and an industry water demand of 30% the amount of residents' water demand. To what extent do you think this is realistic?
U Cho Cho: Industry water demand will be more than 30% The construction of the bridge will have a very big impact on the population growth of Dala. The World Bank considered Dala as an agricultural area. But now the situation has changed so Dala will be an urbanized area. I think that more industry will be there. Maybe some textile industry or medium company. You should take into account more for the industry. (After explaining to him that our assumption was derived from the YCDC plan for development and on newspaper articles): If YCDC does not want to have an industry area in Dala probably your assumption is correct.
U Khin Lat: I agree with Cho Cho, and I think that the assumption of 150 litre per day is a good assumption for the future water consumption.
5. Do you think the harvesting system as sketched in the design can be installed in Dala?
U Cho Cho: Yes, I do.
6. Do you think the harvesting system as sketched in the design can be operated and maintained by local people and laborers?
U Cho Cho: Yes, I do.

H.2.4. Storage

1. An annual water demand of 52 million liters is assumed. The reservoirs have a buffer of 88 million liter. Do you think this is a realistic amount?
U Cho Cho: If Dala area is boomed up, there will be much more demand. We have to design them in a remote zone to avoid contamination from runoff. We have to consider that if we have trees the leaves can deflate the water quality. So I suggest applying a sort of green net on the water body surface to reduce evaporation.
U Khin Lat: The ponds have to be connected and only one pond has to be used as intake for the drinking water. The connection has to be by gravity. This allows energy to be saved during the transportation of the water. We can build the ponds all together. I agree on using the green net against evaporation. The pond has to be designed in such a way that people have water during the buffering period. I also suggest improving the catchment areas of the reservoirs by applying plastics layer on the surrounding surfaces.
2. For the reservoirs, a maximum depth of 10 meter is taken. Is this a realistic depth considering the soil in Dala?
U Cho Cho: It is possible to go in reach 10 meter depth, but different slope angles have to be used for the stability of the structure. Intermediate berms would be needed for stability of slope

depending on the soil properties.
U Khin Lat: I agree with Cho Cho.

3. Do you think the storage system as sketched in the design can be operated and maintained by local people and laborers?
U Cho Cho: Yes

H.2.5. Supply

1. It is assumed that pumping the water through the pipeline system and treatment of the water are the governing factors, determining the energy consumption. Is this a realistic assumption?
U Cho Cho: A water source would also be considered. I think that the two pipeline system is not practical because the flow of the drinking water demand is not big enough to justify the implementation of a complete pipe system. Since the amount of water is very small, drinking water can be distributed to a collection point. I agree that it is better to use this method (pipe system) than plastic bottles. Maybe dual reticulation can work for Dala but is difficult to spread to the rest of the south of Yangon area.
U Khin Lat: I think that it is the best way. You can save energy on treatment of the domestic water. The presence of the domestic system will also allow the possible reuse of wastewater.
2. For the calculations, corners in the pipelines were omitted because there was no way to realistically estimate the amount of corners in the pipes. Is this a realistic assumption?
U Cho Cho: A certain percentage could be added.
3. To what extent do you think having two water supplies in the house is user-friendly? (keeping in mind that currently people also don't drink the water that they use for showering)
U Cho Cho: It is not practicable. I agree on the fact that splitting the two water purposes in the system can save energy (less treatment and less pressure needed). I think that a pipe for drinking water is not needed, because people in Yangon are not used to receiving drinking water from the tap. I suggest to explore the idea of the collection points further.
U Khin Lat: I suggest to further analyze the two possibilities: using local (community) tanks or using a central tank. I think that in the present system it is not possible, but if we are able to introduce regulation on the future building design, it will become possible.
4. Do you think the supply system as sketched in the design can be operated and maintained by local people and laborers?
U Cho Cho: Yes. I suggest to increase the water price during the rainy season to increase the harvesting capacity and to make people more aware of the fact that their use of water during rainy season will impact the availability of water during the dry season.
U Khin Lat: The implementation of the policy about roofs and construction will take too much time.

H.2.6. Finalizing

1. Is there anything we missed that you would like to remark upon?
U Cho Cho: It should be noted that your plan must fit in the masterplan for the whole region South of Yangon, otherwise it will not work.

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