Polder system Can Tho City

Impact of the urban polder on Can Tho City

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Preface

This report is written by students of different master programs of the faculty of Civil Engineering at the Delft University of Technology, for the course CIE4061. This course is an opportunity to study abroad with a group of Dutch students. It is a contribution to bring the theoretical knowledge into the real world problems.

The group collaborated with the Dutch Technical University, the Can Tho University, the Thuy Loi University and the Can Tho Resilient Office. This is the group who helped us to gather data and showed us around in the problem area. There were several meetings with the Dutch students and one of the Universities or the Office. The World Bank project also provided us a lot of data.

The objective of the report is to define the resiliency of the city and to describe the effects and impacts of the World Bank project. The city centre of Can Tho city struggles with flooding in the current situation. The polder designed by the World Bank is helping the environment protecting the city centre from floods. First, the current situation is and the future situation is analysed by two different models, the hydraulic part and the transport part. The validity of the current situation ensures the availability of the future situation models. By implementing the scenario analysis, recommendations of can be made about the future for Can Tho City, based on the flood problems.

This multidisciplinary team consists of 5 students, Reinier Frölke, Watermanagement; Berend Meijer, Structural Engineering; Oscar van den Heuvel, Offshore & Dredging Engineering and Nadieh Maarse and Eveline Frouws of Transport, Infrastructure and Logistics. By combining the different background an integrated solution and analysis of the above described objective can be made. The team lived in Ho Chi Minh City during the months September and October. The team made several trips to the case area.

The team was not able to go to Vietnam without the supervisors, Ir. T.J. Zitman (TU Delft), Dr. ir. R. van Nes (TU Delft), Dr. ir. G. Schoups (TU Delft). The project was defined by J.D. Bricker, he brought us in contact with the University of Ho Chi Minh and our supervisor there Mister Van (Thuy Loi University) and Mister Trung (Can Tho University). They all gave us helpful feedback and provided models and data. We would like to thank all the supervisors involved in the project and Sweco, HKV-group and DIMI for providing us with financial support.

Delft, 19 February 2019

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Abstract

Vietnam is one of the five countries that is severely affected by the consequences of climate change. The extreme weather conditions and the increase of the sea level results in floods in the Mekong Delta, located in the South of Vietnam. Can Tho city, found in the heart of the Mekong Delta, is one of the cities that copes with water related issues on a regular basis. To be prepared for the future, the environmental and infrastructural issues need to be tackled. The resiliency of Can Tho got included of the World Bank program. The objective of this project of the World Bank is to reduce the flood risk in the urban core area and to improve connectivity between the city centre and the low risk urban growth areas.

A resilient city is defined as a 'city that can adapt to a variety of changing conditions and withstand shocks while providing essential services to its residents'. Resiliency concerns the land and waters of a city. Currently, the city is connected to the southern surrounding area and Ho Chi Minh City with several highways and bridges. The high availability of water in Can Tho city is usable for agriculture activities, transportation and touristic activities. However, the connectivity is limited and highly influenced by the occurring floods. With that, the frequent floods lead to significant economical damages to the city and the inhabitants. Improving the infrastructure of Can Tho is important in overcoming these issues.

In order to realise infrastructural improvements, Can Tho city is included in the *Resilient Cities Programme* of the World Bank. The objective of this programme is to reduce the floods in this area with the creation of a polder in the city. The structural solutions of the polder will be sluice gates, tidal sluice gates, the construction of river embankment, rehabilitation of the drainage system and constructing two regulation and water retention lakes. Additionally, building dykes with new roads and expanding or building new bridges will increase the connectivity of the city. All these measures will contribute on the resiliency of the city.

The aim of this report is to identify the impact of the polder on the city, considering the infrastructural and the hydraulic aspects. To measure the impact, the current situation is simulated into two models, an infrastructure model and a hydraulic model. The results of hydraulic model show whether and when locations are flooded, whereas the aim of the infrastructure model is to identify flows on the network, the connectivity of the city and the flow changes after implementation of the new roads.
The models are build with data gathered from experts and literature. A Four Step Model is used to indicate whether there will be changes in flows of the motorbike on the road network. This is validated by real-time counts during a visit of the city. To model the hydraulic system, a *Simplified Shallow Water Equation System* (SSWES) model is created using MatLab.

To achieve a view on the future, four scenarios are created with varying relevant values for environmental and economic factors. After entering these values in the respective models, conclusions are drawn. One of the main findings of the Four Step Model is a range of increase in trips on the network of 3-10% in 2050. It should be noted that an increase of trips may not serve as a positive impact on the network as the capacity of the lanes is not taken into account in the model. Future research could therefore focus on congestion on the network based on capacity of the lanes since this influences the choice behaviour of travellers on a certain route. Moreover, the execution of the counts could be improved in order to obtain more effective and more reliable outcomes. Using the hydraulic model resulted in the conclusion that the construction of a polder improves the resiliency as floods can be prevented. However, this requires a good control plan regarding the sluices. By using the extended SSWES model, it makes further research on the hydraulics of the polder more accessible and applicable.

Contents

List of Figures

List of Tables

MONRE Ministry of Natural Resources and Environment

SIWRR Southern Institute of Water Resources Research

RCP Representative Concentration Pathways

CBA Cost Benefit Analyses

IDF Intensity-Duration-Frequency

GDP Gross Domestic Product

AR5 5^{th} Assessment Report

SIURP Southern Institute of Urban and Rural Planning

GSOV General Statistics Office of Vietnam

SSWES Simplified Shallow Water Equation Solver

WTP1 Water Treatment Plant 1

AMSL Above Mean Sea Level

1
Introduction

According to the World Bank, Vietnam is one of the five countries which are seriously affected by the consequences of climate change [28]. Extreme weather conditions and an increase in sea level will result in vulnerability to flooding of settlements and economic activities. One of the most affected areas in Vietnam is the Mekong Delta region, mainly because its low elevation; the average elevation within the area is 0.8m Above Mean Sea Level (AMSL) [25].

The city of Can Tho, lying in the heart of the Mekong Delta, is the fourth largest city of Vietnam. As the socio-economic engine of the Mekong Delta, Can Tho plays multiple important roles in ensuring the well-being of its residents and the regional population of the Mekong Delta. It is a hub for financial, educational and touristic activities.

Figure 1.1: Location of Can Tho (orange dot) within the Mekong Delta region (yellow area) in the South of Vietnam.

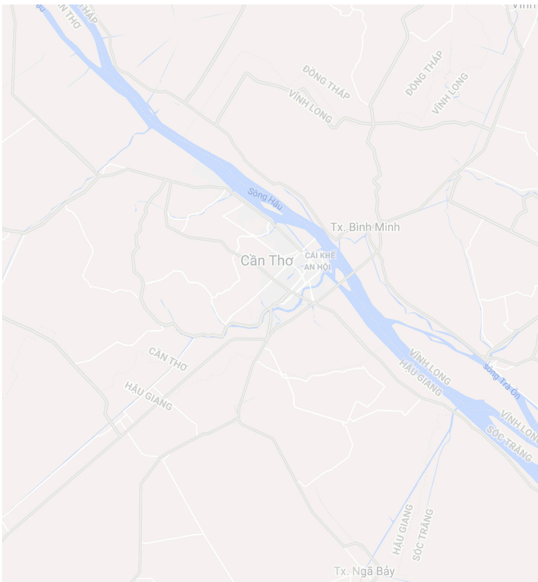

Figure 1.2: Regional view Can Tho City, Vietnam

Located in a low-elevated delta region, and on the cross-section of two rivers (the Hau and Can Tho river), the city has to deal with large volumes of water. While the water brings aesthetic and (indirect) economic value, it is proven to be a burden as well. During the monsoon season, which spans from May to November, Can Tho City gets flooded twice a day every 15 days. At these moments, the spring tide pushes water from the Vietnamese East Sea upstream to cause inundation and flooding on the streets of Can Tho, which is increased in combination with a high river flow from upstream. Furthermore, heavy rainfall and storm surges lead to heavier floods. The flooding causes significant economic losses to the city and its surroundings and hampers its ability to fulfil its potential of being an economical hub in the Mekong Delta. According to an analysis by Can Tho, the urban flooding causes direct economic damages of more than US$300 million over the last five years. On a yearly basis, the annual economic losses due to flooding were 11% of household annual income, according to interviews with the households [42].

Moreover, because of climate change and urbanisation, this problem becomes more and more relevant. According to the Mekong Delta Plan [25], created by Vietnamese ministries in collaboration with Dutch water experts, the sea level rise due to the climate change is estimated from 57 to 73 cm (average scenario) and from 78 to 95 cm (high scenario) up to 2100. This will have significant impact on the GDP of the country as 90% of the Mekong Delta region is threatened with submergence.

Another important development for the daily life in Vietnam is the current economic growth. Where this economic progress means increased wealth for the Vietnamese, it has been accompanied by rapid urbanisation, with Can Tho being no exception. The city has a population of approximately 1.25 million, and an urban annual growth rate of 5% between 2005 and 2012. While the population growth is beneficial for the city's economy, it also comes with an increase in congestion as the infrastructure is not designed for the increasing traffic rates. Besides, incompetent land use due to a lack of municipal control leads to unanticipated traffic flows.

To be prepared for the future, both the climate change and the infrastructural issues need to be tackled. Even more when considering Can Tho's goal for 2020 to become a modern city that contributes to the development of Vietnam and the South East Asia region [9]. With the resiliency of Can Tho being of increasing importance, the city got included in *The Resilient Cities Program* of the World Bank group.

1.1. Involvement of the World Bank

As one of the plans launched in December 2013, the *The Resilient Cities Program* aims to support cities in strengthening their ability to prepare for and adapt to changing conditions in the future [9]. Additionally, it helps cities to withstand and recover rapidly from disruptions related to climate change, the induced natural disasters, and other shocks and stresses. The program serves as an overarching party for delivering analysis, rationale, and support to local governments which need to make resiliency part of their urban management agendas.

In June 2014, a team of specialists from the World Bank Group worked together with local stakeholders to identify priority actions and investments that will strengthen the resilience of Can Tho to the current and future challenges. Since the city has great challenges in terms of seasonal flooding, sea-level rise, land subsidence and rapid urbanisation, enhancing the resilience has high importance. The objective of the World Bank Group is to reduce the flood risk in the urban core area, improve connectivity between the city centre and the low risk urban growth areas, and enhance the capacity of city authorities to manage disaster risk in Can Tho City. To accomplish these objectives, the project is split into three components [35]:

1. Flood risk management and environmental sanitation, to reduce flood related risks in the urban core of Can Tho.
2. Urban corridor development, to increase intra-city connectivity and encourage compact, mixed-use, pedestrian and public transport oriented urban development in the less flood prone area of Cai Rang.
3. Spatial planning platform and financial and social protection instruments, to build management systems to improve spatial planning, data and information management, post-disaster budget execution, and the responsiveness of safety nets to flood events

In this report, the focus will be on component one and two, regarding the flood risk management and environmental sanitation and the transportation management in Can Tho city. The third component is left beyond the scope of this report.
A resilient city is defined as a ”city that can adapt to a variety of changing conditions and withstand shocks while still providing essential services to its residents” [9]. Resiliency of a city is of great importance for infrastructure over land and over water, but also capability of preventing natural disasters like frequent flooding or tropical storms.

With the cities as centres of regions where most of the population and capital goods are concentrated, the cities are key to social development and economic prosperity. With the combination of urbanisation and climate change, the cities have a growing number of challenges. Regarding these challenges the cities are increasingly vulnerable for natural disasters and civilisation disasters as economic downturns, crime and violence, public health epidemics and even infrastructure failure. Logically, these shocks can have a deep and lasting impact on human development.

Furthermore, cities are complex systems. A city depends on multiple constituents and a larger organisation, therefore the city’s resilience is affected by the resilience of multiple smaller and larger systems. Focusing on one goal, such as only flood protection, without considering other aspects of a city, could lead to undesirable outcomes. Building a resilient city therefore needs to take multiple disciplines into account and requires a comprehensive approach.

1.2. Problem definition

1.2.1. Urgency

Can Tho City is vulnerable to climate change and hydro-metrological disasters, particularly flooding. Flooding has significantly impacted the socio-economic development of the city and the entire Mekong Delta, the surrounding region of Can Tho City.

The City is susceptible to flooding caused by Mekong alluvial overflow, high tides, and extreme rainfall events. Seasonal flooding typically impacts 30 percent of the city area, but has recently increased to 50 percent. Close to 95 percent of the total land area is less than 1 m above mean sea level, except for the built-up urban area located along the bank of the Hau River, which is about 2 m above mean sea level.

Vietnam’s economic progress has been accompanied by rapid urbanisation, sustaining a three percent annual urban population growth rate from 1999 to 2011. Can Tho has a population of approximately 1.25 million, and an urban annual growth rate of five percent between 2005 and 2012. As the 4th most populated city in Vietnam and the largest city in the Mekong Delta, it is an engine of economic growth for the region. Recent flooding in Can Tho has affected an average of 2,000 ha (about 69 percent of the total core urban area) and more than 200,000 people each year. In addition to the serious damages to assets, flooding also interrupts economic activities in these core urban areas.

Rapid and inadequately planned urban growth in Can Tho has caused that the development of urban transport has become a priority. Transport infrastructure in Can Tho is predominantly dependent on roads, rendering the transport sector vulnerable to disruptions caused by seasonal flooding. While the city has proactively assessed transport investments based on flood risks, the link between transport and urban land-use planning is not fully taken into consideration. Over 85 percent of manufactured goods are transported through roads in Vietnam, while an increasing number of bottlenecks are hampering the movement of goods and people.

Direct beneficiaries of the World Bank project in Can Tho will be residents in the project area, based on the population estimates in 2013 it will directly benefit about 420,000 people [28]. In addition, people from other provinces in Mekong Delta region as well as within the country will benefit from the project, consisting of students, immigrants working in Can Tho and tourists.

1.2.2. Objective

In collaboration with the World Bank and the university of Can Tho City, plans are made addressing economic, social, environmental and financial dimensions of the resilience of Can Tho[28]. A polder approach will be taken for flood mitigation, which can be expressed as a structural system consisted of a: i) closed "ring embankment with tidal sluicegates/valves" to protect the area from high water on outside rivers (river and tide floods); and, ii) drainage system including open canals, sewers, storm rainwater retention, and pumps (if needed). Tidal gates are designed for "embankment function" during closed time and "water discharge function" during gate opening.

Figure 1.3: Polder area Can Tho City

By creating a polder around the city centre of Can Tho City, multiple aspects are taken into consideration:

- The change of the infrastructure in and around the city centre and with that the logistics of goods and services
- The polder management regarding the water quality and quantity
- The design of the dykes around the polder and the sluicegates, weirs, quay etc.

The area of Can Tho City outside the polder area has less priority in the World Bank project given the land use and population density. For this area a plan is created which is outside the scope of this study. Ultimately, the research question states:

How can the urban polder contribute to the resiliency of Can Tho city, regarding the control of water within the polder and the impact on transport and infrastructure?

1.3. Scope

The geographical scope of this project is limited between the planned embankments surrounding the polder area illustrated in Figure 1.3. Between those embankments, the urban core of Can Tho City have to be protected against flooding.

This research focuses on the resiliency of the urban core of Can Tho City. The polder area should be completed in 2020. When successful, in the future, areas outside the urban core could be protected against floods as well. For now, different scenarios will be created to estimate the possible situations in the year 2050, regarding climate change and economic growth.

1.4. Methodology

This section describes the different methodologies that are used in the project. The project is divided into two parts, the infrastructure part and the hydraulic part. In order to draw a conclusion about the resiliency of Can Tho City, the current state analysis is split in both aspects. The hydraulic system is analysed using MATLAB and the infrastructure is analysed using a 4-step model. After obtaining data about the current situation, there is a future analysis according to the World Bank plans and investments. The both models are tested with the values of created scenarios so that conclusions can be drawn about the resiliency of the city. Analysing the scenarios is important to be able to make recommendations on the polder design and to have expectations about the futures maintainability of the polder. The scenarios are created using literature and the future projections of different aspects in Vietnam.

1.5. Outline

In this introduction, the background and the relevance of the project is described, including the research objective and methodology. In the second chapter the current state of the city is discussed for both parts, the road aspects and the water aspects. This chapter also includes the plans of the World Bank. In the third chapter the hydraulic system is discussed and the model is explained. Chapter four contains the created transport model. In the fifth chapter the scenario analysis is done and implemented in the both models to give an insight of the future. In chapter six the results of the implemented scenarios in the models are described. In the last chapter, chapter seven, the conclusions about the research are drawn and the future research is discussed. The appendices start with a site visit report of Can Tho City, and remaining appendices are elaborations of information discussed during the report.

2

Current state

In this chapter the current state of Can Tho city will be described. Firstly, a demographic introduction to Can Tho is given as well as information about the current networks within and around the city. After this, information about the city's hydraulic system will be presented. Thirdly, Can Tho's involvement in national programmes and policies will be specified. After this, an elaborate view on the components of the World Bank *Resilient Cities Programme* will be given. At last, a brief conclusion on the current state of Can Tho is presented.

2.1. Demographic introduction

Can Tho city was created in the beginning of 2004 by a split of the former Can Tho Province into two new administrative units: Can Tho city and Hau Giang Province. Can Tho City is a major urban centre in the Vietnamese part of the lower Mekong Delta. The city is connected to the rest of Vietnam by National Route 1A and the Can Tho International Airport.

There are five urban districts; Binh Thuy, Cai Rang, Ninh Kieu, O mon and Thot Not and four rural districts; Co Do, Phong Dien, Thoi Lai and Vinh Thanh. The five urban districts with their population density [28] is depicted in the figure 2.1. The districts that are affected by the polder are Ninh Kieu (96 %) and partly Binh Thuy. As described in the scope, section 1.3, only the Ninh Kieu disctrict will be taken into account in this study.

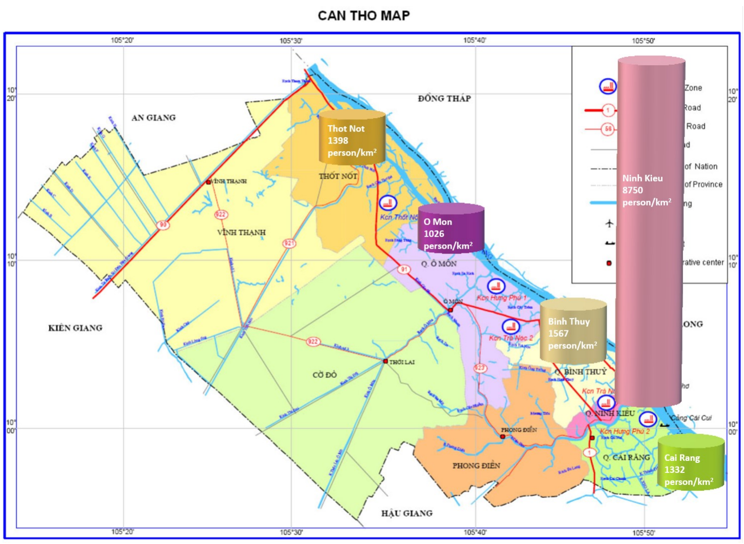

Figure 2.1: Population density

2.2. Population and land use

With a population of approximately 1.34 million and a yearly growth rate of ±2% found in 2018 [10], Can Tho city is a rapidly growing city. A wide range of studies and documents show varying numbers of the population in the future. However, the General Statistics Office of Vietnam (GSOV) presents expected values until 2034, where a population of 1.58 million is anticipated. These values will be used for further calculations. While the exact numbers for the further future are uncertain, it is sure that Can Tho is expanding. Besides, recent studies stated that the urban development, as shown in figure 2.2 is uncontrolled [40].

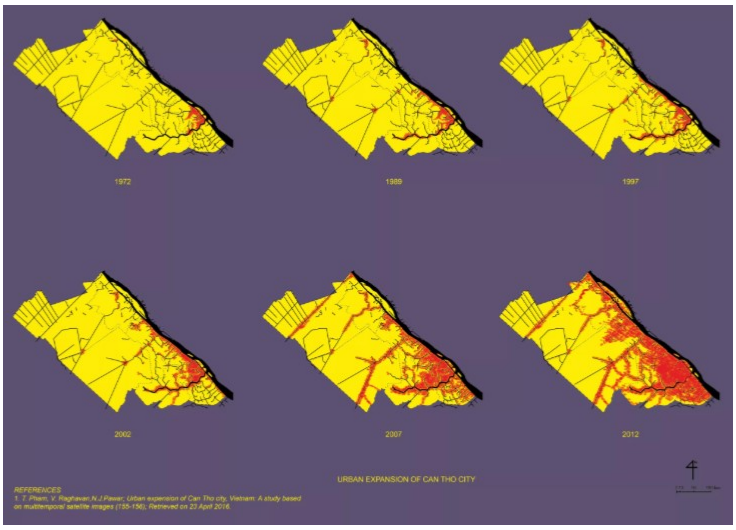

Figure 2.2: Urbanisation of Can Tho, 1972-2012. [40]

Planned urbanisation in the eastern direction and other higher elevation rural regions needs to be encouraged in order to provide safer living conditions. The urban centre is Ninh Kieu - Binh Thuy, located in the South-Eastern part, is being surrounded by new settlements within the city borders. By locating new residential and industrial areas further away from the river, the impact of urban pollutants on surface water quality will be reduced and the resilience to river flood events will increase [19]. Conducted from GSOV, the land use of Can Tho is specified in 4.6. Can Tho has the economic focus from traditional agriculture to industry, trade, services, tourism, and agro-businesses [28]. With its industries, the city has the potential to become the regional hub for high-tech agro-industrial production and aquaculture, food processing, and export.

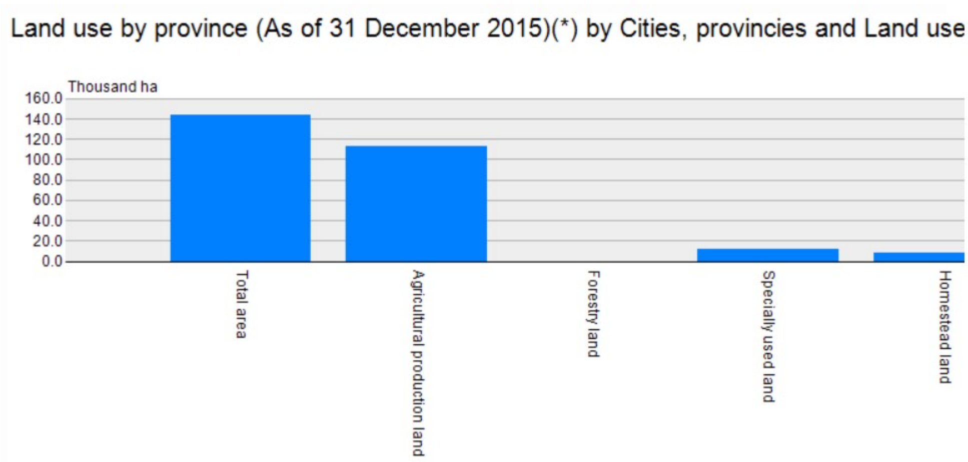

Figure 2.3: Land use [10]

2.2.1. Road network

Can Tho city has several highways that connect the city with all surrounding regions, but mostly the lower Mekong Delta as and Ho Chi Minh city. The total length of the provincial roads is 184 km [28]. The road conditions has recently improved, as 82 percent of the provincial roads and 50 % of the district roads are paved. This is higher than the national average. In 2015 the road density reaches 1.3 - 1.5 km/km^2 [33]. When observing travels in and around Can Tho, multiple routes with different purposes can be found First of all, approximately 45.000 students travelling by motorbike or car to the university every day. Besides, there are a lot of people going to their work by motorbike. Moreover, touristic routes such as inter-provincial tourism routes, national tourism and inner city tourism routes are located in the city. Figure 2.4 gives an overview of the road network in Can Tho City.

Figure 2.4: Road map Can Tho City

2.2.2. Bridges

There are three bridges to ensure the connection between Can Tho City and the southern surrounding area over the Can Tho river. These are the Cai Rang bridge, Hung Loi bridge and the Quang Trung bridge. The northern part of Can Tho City is connected via Cau binh Thuy 1, 2 and 3. The east side of the city is the connection for traffic from and to Ho Chi Minh City. This bridge is called the Cau Can Tho and is the largest bridge in the region. The above picture shows the location of the bridges in Can Tho, figure 2.4.

2.2.3. Water transportation network

Can Tho City is dissected by many small and larger rivers. The abundant network has a total length of 3,405 km, of which 1,157 km is used for transportation. Only 619 km of the rivers and channels can be used by transportation vessels with a loading capacity from over 30 tons. The most important inter-regional and international river ways include the Hau river branch from Cambodia crossing Can Tho to the sea, the branch linking Ho Chi Minh City with Can Tho City and Ca Mau, the branch crossing Can Tho and Kien Luong. However, due to deposit of silt and sediment, only small vehicles with average capacity lower than 250 tons can move regularly. The port system includes Can Tho port (Hoang Dieu port) with a yearly capacity of 2.5 million tons. However, the currently used capacity is only 0.5 million tons per year and there is difficulty in transportation through canals to the sea. This underutilised port located in relatively close proximity to the Can Tho Bridge, and there is an extensive system of canals throughout the area. Although the overall Delta has over 30,000 km of rivers and canal, port infrastructure in the region is weak and usually operates below capacity. This is mainly due to the lack of connectivity between the inland waterways, ports, and road networks. The Mekong region has seven seaports, 31 harbours, and 57 inland ports in Mekong Delta. Despite this, around 80 percent of the goods are still transported by land to seaports in the region. The Can Tho Port has a convenient location, within a radius of 200 kilometres, the Port can be connected with the production of goods centres, industrial parks and large consumer centres of the region through roads and waterways. To keep up with the increase of tonnage freight carried by waterways, the government has to invest in increasing port capacity to stimulate the use of the water network. [28]

2.2.4. Importance of infrastructure

Over 85% of manufactured goods are transported through roads in Vietnam, while an increasing number of bottlenecks are hampering the movement of goods and people [35]. Thus, improving the efficiency of road freight transportation is critical for the city. Urban corridor development was introduced to connect backbones of the town, promoting connectivity among new and existing residential areas in the city centre, enhance connectivity among inter-regional urban areas and public transport option of Can Tho City.

2.3. Water system

The city of Can Tho has multiple benefits from the water in and around the premises of the city. Because of the water availability, the surrounding rural area is suited well for agricultural activities. Secondly, the water serves as a mode of transport within and through the city. Not to forget the touristic value of the water; the boat tours through the Mekong delta and visits to the floating market are the touristic highlights of Can Tho city. Lastly, the water is a pleasant natural cooler in the warm tropical climate.
Besides the advantages of the water, it is also considered a burden. As mentioned in 1.2, floods lead to significant economical damages to the inhabitants and their businesses.

The city centre has a dense system of canals and creeks, consisting of primary, secondary and tertiary canals. In cases of high water these canals can lead to completely flooded roads. With a high number of people travelling to Can Tho City for work in the morning, traffic jams are every day's business and are increasing even more during floods.

The city of Can Tho has various aspects regarding water management. At first, more information about the floods will be presented. Secondly, the water quality will be revised; various factors within the city determine the quality of the surface water. Thirdly, the water quantity will be discussed, as it plays an important role in providing storing capacity.

2.3.1. Floods

Regular floods trouble the daily lives in Can Tho city. There are a number of factors that contribute to these floods:

Heavy rainfall Can Tho is located in a tropical monsoon area. This is accompanied by high precipitation values and high intensities. On a yearly basis, a total rainfall of 1,5000-1,800mm is measured. Of this total number, 90% is found during the wet season, from June to November [19].

Tidal influence Due to the low elevation of the Mekong delta, the rivers are heavily influenced by the tidal effects. Therefore, the Hau river has a tidal regime as well; even though Can Tho city if located ±80km upstream, the river experienced a tidal range of 1 meter during the day. Besides, storm surges can find their way upstream to heighten the water levels for a short period of time.

Poor drainage The sewer systems in the city are generally old and of insufficient capacity to deal with high rainfall events, while many parts of the city do not yet have drainage systems. Due to low capacities, the sewers are often overflowed, causing both water and odour nuisance.
Besides, rapid and uncontrolled urbanisation has resulted in encroachment on many

natural canals, significantly reducing water drainage capacity of the city drainage system.

Land subsidence As the soil in deltas is highly compressible, it makes it vulnerable to subsidence [36]. Especially when the groundwater table is lowered by groundwater extraction, subsidence becomes an issue as the water-carrying layers are compacted. The industrial area in the O Mon district, located north of Ninh Kieu, has been pumping out groundwater for the last decades, contributing to the subsidence in the case area. In the period of 1993–2013, the soil of Can Tho city subsided with 17.1 mm per year [38].

When heavy rainfall and tidal influence conjure during the wet season, the city experiences heavy floods. Poor drainage and land subsidence are considered factors with a longer term period, without peak moments.

2.3.2. Current water management

Water quantity

Before the collaboration with the World Bank started in 2015, there was no flood protection; sluices, gates and dykes were absent. As observed during site visits (see Appendix A), a large part of the urban population are still protecting their houses by embankments made of crates or wood. Sometimes sand sacks are used. The only measures protecting the population in the rural area are small self-built dykes made of clay or sand. Currently, the embankments are being built at a few locations.

Water quality

In 2009, a large research performed by Neumann et al. found the surface water to be of poor quality. An overall trend over the period 1998-2008 showed a general increase for all the measured pollutants. For a few of the parameters, one of them being COD, the proportions even doubled in the 10-year period [19]. One of the main contributors to the poor surface water quality is the effluent from households. At the moment, 70% of the households in Ninh Kieu is connected to the sewer systems [6]. The other 30% are loosing their domestic wastewater into the canals, which has a considerable impact on the quality. Besides the households, there are agricultural-, fishfarming- and processing industries that diminish the water quality.

Besides contaminated water, households loose their solid waste into the channels as well. In the urban areas of Can Tho City, there are 650 tones/day of waste produced. 470 tones/day are residential waste. The remaining 180 tones/day are produced from markets and industrial areas. Only 20 % of the waste are collected per day in the central districts. The rest is dumped directly into the canals and ditches[7]. This leads to bad surface water quality, especially when the flow in the canals are not continuous. . The estimated amount of waste in 2020 is about 2500 tones/day of which 60 % is residential waste. The rest will be produced by industrial areas. In the future it is even more important to collect all the waste produced and made sure that waste is treated. That is why the long-term objective of Can Tho City in 2020 is to collect 90 % of the domestic waste produced in the urban core of the city. Outside the urban core, less waste will be collected which is estimated around 70 %.

2.4. National programmes and policies

Besides the World Banks *Can Tho Urban Development and Resilience Project* (as introduced in Chapter 1.1), Can Tho is and has been subject to various other policies and programmes. These are and were applied on the city in order to enhance the city's liveability and resiliency. Examples are the *National Strategy for Natural Disaster Prevention, Response and Mitigation to 2020*, the *Vietnam Urban Upgrading project (VUUP)* and the followup program *Vietnam Urban Upgrading project (VUUP2)*.

National Strategy for Natural Disaster Prevention, Response and Mitigation to 2020 Approved by the Prime Minister in 2007, this national strategy aims to prepare Vietnam for future natural disasters [1]. The National Strategy promulgates tasks, solutions and plans for implementation, on which the 63 provinces and 12 ministries base their strategic action plans. For the Mekong Delta region, the approach is to ”live with flood”, with the following relevant solutions: Establish plannings of flood control and be proactive in flood prevention; create specific measures for flood and salinisation control and to proactively take advantages of flooding (e.g. research and invest to explore the flood events).

Vietnam Urban Upgrading project (VUUP) Running from 2002 to 2012, the objective of the VUUP was to reduce poverty in urban areas by improving the living and environmental conditions. This was done with participatory planning methods and influencing planning methods to become more supporting for the lower income classes. Can Tho was one of the four cities involved in the project.

Vietnam Urban Upgrading project (VUUP2) As the follow-up from *VUUP*, active between 2012 and 2017, the objectives were the same as its predecessor. In an attempt to improve the living conditions of the poor urban population in selected cities, the urban management capacity and planning was improved. Meanwhile, the knowledge and urban management capacity at the national level was strengthen.

2.5. Urban Development and Resilience Project (World Bank)

The project with the most impact on the resiliency of Can Tho is the *Can Tho Urban Development and Resilience Project* by the World Bank. After the initial start in 2013, a report on the decisions concerning the flood control and infrastructural aspects were published in the Environmental and Social Impact Assessment (ESIA) in 2015 [28]. As stated earlier, the project consists of three components:

- Component 1: Flood risk management and environmental sanitation (Bank financing: US$139.5 million);
- Component 2: Urban corridor development (Bank financing: US$102 million);
- Component 3: Urban infrastructure information management systems and financial and social protection (Bank financing: US$18 million).

2.5.1. Component 1: Flood risk management, and environmental sanitation.

The objective of this component is to *reduce the flood related risks in the urban area of Can Tho.* This component includes implementing structural measures for flood protection, drainage and sanitation. The solution will be a combination of ’low-regret’ solutions: measures that will meet the requirements of being effective in combination with low operation costs and with a minimum of negative impacts on flooding and environment to the adjacent areas. Additionally, it would be built with the other future uncertainties taking into account such as climate change, land subsidence and urbanisation.

Subcomponent 1.1: Priority Flood Control Investments in Urban Core (Ninh Kieu and Binh Thuy districts)

For this sub-component, a design is made based on a 1 in 100 year flood event. A system of embankments, combined-use roads and tidal gates will create a ”ring-dyke” to protect the urban area from the river and tidal flooding and will create a manageable system to control the amount of water in the urban area.

Subcomponent 1.2: Drainage and Waste Water Systems

The existing sewer system in the urban core is out-of-date and with that, the capacity of the system has been significantly reduced in time. Additionally, Can Tho faces challenges as tidal intrusion in its canal system and serious issues with disposal of solid and industrial waste in its canal system. This sub-component will finance the rehabilitation and improvement of the current canals, drainage and sanitation infrastructures and management systems involved. The solution will take into account the storm water drainage, tidal water intrusion and waste water outlets.

Subcomponent 1.3: Planning and operation of an integrated flood risk management system
Currently, key authorities of the city are operating the flood risk management system independent of each other. This results in fragmentation and overlap and therefore makes it challenging to plan, implement and operate the flood risk management system. Improving the flood risk management system will help the city operating the current and planned flood control, as well as the drainage systems.

2.5.2. Component 2: Urban Corridor Development

The objective of this component it to increase intra-city connectivity and encourage compact, mixed-use, pedestrian and public transport oriented urban development in the less flood prone area of Cai Rang.
With this component, the connectivity of the urban transport system of Can Tho will improve significantly. This results in increased transport-related efficiencies and reducing transport costs.
The current urban transport system is oriented in vertical and horizontal axes, but with only a few links between the horizontal and the vertical axis. With the vertical axes far apart form each other, the inter-connectivity is limited resulting in transport flows through the urban core. This results in economic consequences due to increased transport costs and subsequently product costs, reducing investment attractiveness and competitiveness. Moreover, the non-linked transport infrastructure is affecting the economic development capabilities as well as the access of residents to social infrastructure.
This component will include organising the urbanisation by increasing the attractiveness of low risk areas on higher ground due to the increased accessibility and connectivity.

Figure 2.5: Location of Cai Rang district, south-west of Ninh Kieu

Subcomponent 2.1: Road and Bridge Links
With investments in transport infrastructure the inter-connectivity between the vertical axes will be increased. The following road links will be constructed:

- Quang Trung Bridge crossing the Can Tho River
- Tran Hoang Na Road, including NH1 side roads from Tran Hoang Na to IC3 intersection
- Cach Mang Thang Tam to PR 918/Bui Huu Nghia road (dual purpose by providing flood protection)

The three transport links will be designed with a *POD* (Pedestrian Oriented Design), creating a walkable and dense road.

Subcomponent 2.2: Construction of the Residential Area for Resettlement
Included in this subcomponent is the construction of a residential area for resettlement of the affected households, including facilities ensuring good living conditions for residents.

Subcomponent 2.3: Effective Transport Systems Management and Equipment
This subcomponent would support feasibility studies regarding a *Bus Rapid Transit* (BRT) pilot, the establishment of a Public Transport Authority and opportunities for POD.

2.5.3. Component 3: Spatial Planning Platform and Financial and Social Protection Instruments

This component is mostly about building management systems, forming a smart city of Can Tho and post-disaster management of flood events.

Subcomponent 3.1: Risk Informed Spatial Planning Platform
This subcomponent includes building a web-based geospatial database which will house in the People's Committee to improve the accessibility of data sharing. Besides, usage will put an end on the current paper-based organisation.

Subcomponent 3.2: Disaster Responsive Social Assistance System
In this subcomponent the city's existing social protection system will be adapted using additional investments in social protection resilience. With this, the city becomes "disaster-responsive", resulting in a more complete engagement and resilience.

2.5.4. Proposed flood control system

The chosen flood control system includes embankment at the Can Tho river, road systems along the Cai Son and Muong Khai rivers, and linking Cach Mang Thang Tam to Bui Huu Nghia road. The last of these road links will serve the dual purpose of providing flood protection for the urban core as well as providing a path for transportation. This control system also includes rehabilitation and upgrade of canals in the centre and the construction of a water drainage system. The total protected area within the polder is 29.25 km^2.

The structural solutions are presented below [2]:

- Construction of embankments at Can Tho river with a length of 5.5km with tidal protection elevation, combined with urban landscaping.
- Constructing two tidal sluice gates combined with a ship lock at Cai Khe and Dau Sau channels on Can Tho river.
- Constructing tidal sluice gates/valves along Cai Son, Muong Khai and link between Cach Mang Thang Tam (NH91) and Provincial Road 918 to close the system.
- Upgrading and rehabilitation of 17 primary canals to improve drainage capacity, storage volume during heavy rain and high tide, and improve sanitation. Besides, the upgrades will enhance the effectiveness of structures from the VUUP 1 and 2 projects (previous resiliency projects in Can Tho) due to a better connectivity to the rest of the network.
- Rehabilitation of the drainage system in Ninh Kieu urban centre, the urban district of Can Tho. In total 27 proposed roads with length of about 11 km in Ninh Kieu and about 10km in the remaining areas of the catchment.
- Constructing two regulation and water retention lakes with a surface area of 12ha.

With these solutions the flooding area is reduced to about 3.6 km^2, scattered in low-lying areas, lakes and ponds; locations used for temporary retention during heavy rain combining with high tide. The flooding time is reduced from 3-4h to 1h and areas with elevation above +0.78m will not experience anymore floods. Implementing this set of solutions will not have

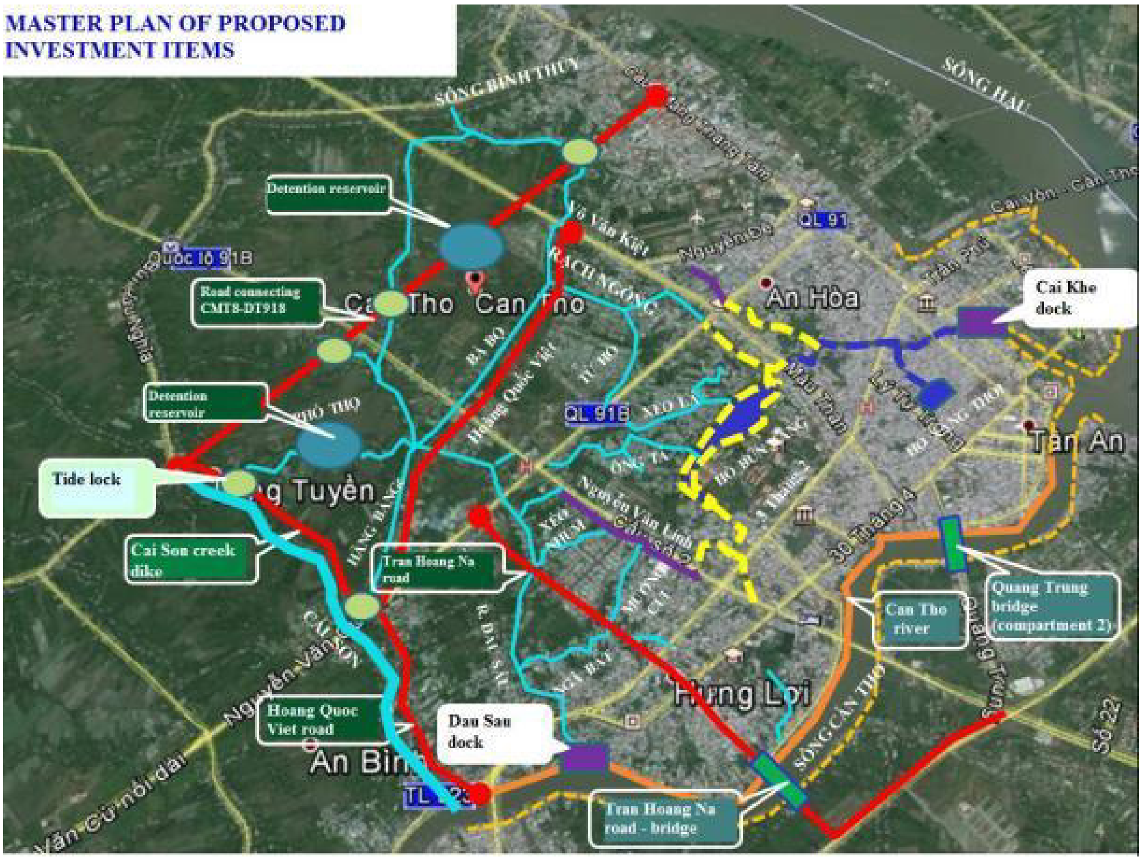

Figure 2.6: Master plan proposed investment [28]

any negative influence on the water level of the surrounding area. As indication, the estimated costs of this solution are 131.74 million USD.

Several measures are elaborated below.

Embankment structure The embankment structure along the Can Tho river and Cai Son canal is built as a gravity concrete embankment wall, topped by a roof reinforcing embankment with precast concrete. This structure is commonly applied in protection works in the Mekong Delta and has relatively low costs.

Construction road and park behind embankment Proposed is a construction with a cross section of 23m wide along the route with road surface of 15m and pavement of 6m per side. The capacity of the road proposed for the project is suitable with the development objectives and the current traffic flow. It is necessary to be consistent with the need for vehicles in the future and to facilitate smooth travel connections with existing roads. The construction will be combined with the park and the Can Tho River embankment forming a highlight for Can Tho City.

Dau Sau and Cai Khe Tide Sluice Gate For the tide sluice gate structure, a deviation from the traditional option in the Delta is selected. For abutment, an enclosure frame is chosen. This is a relatively new technology but it is used in the flood prevention project of Ho Chi Minh City as well. For the moving part of the valve gate, a lower axis turning gate is selected.

Ship locks The proposed flood control system will include five ship locks for controlling the corridor positions intersecting with the canal surrounding the polder. This includes the channels of Sao, Ba Bo, Suc, Pho Tho and Hang Bang. The design choice is focused on the flood control possibilities, from which the ship lock with hydraulic lifting equipment is selected. With this design, the water level can be controlled at a certain level and it will help maintain a clean and safe water system.

Environmental sanitation This component contains improving the drainage system for storm water in the centre of the Ninh Kieu district. The selected system is to collect storm water maximally at the Xang Thoi Lake and a smaller volume trough the canal from the Mau Than bridge to the Cai Khe channel.

This plan includes an expansion of the Xang Thoi Lake with a zero slope canal on the current De Tham Road to the Hoa Binh Avenue. The hydraulic slope will be created by a flood control pumping station at the Xang Thoi Lake.

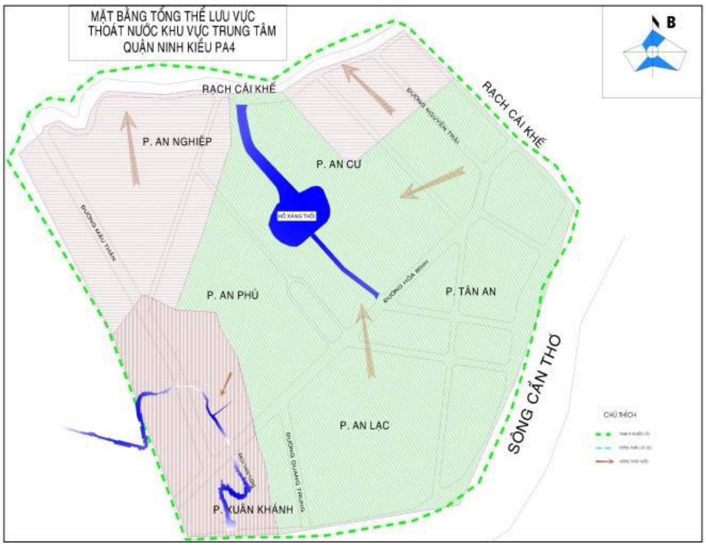

Figure 2.7: Drainage plan Xang Thoi lake [28]

Tidal sluices The proposed master plan includes the construction of twelve sluices. The tidal sluices are designed regarding a water level outside the polder with a maximum of +2.29m and a minimum of -1.54m. And inside the polder with a maximum of +1.42 and a minimum of -0.71m.

2.6. Conclusion

The city of Can Tho is a rapidly growing urban centre in the Mekong Delta. Can Tho is a hub for financial, educational and touristic activities. The Mekong area is experiencing a fast process of urbanisation and economic growth. Meanwhile the city is seriously affected by the consequences of climate change and thereby, heavy floods and rainfall increases the vulnerability of the city.

Promoting connectivity among new and existing residential areas in the city is done by implementing two new roads. For resiliency reasons and the importance of a robust infrastructure system an extension of the road network is planned by the World Bank to handle the large amount of transported goods via roads in Can Tho. Moreover, the water network of Can Tho is a dense system of canals and creeks which is used to touristic reasons and the water serves as base from agricultural and transport mode. The four factors regarding the contribution to the floods in the city are heavy rainfall, tidal influence, poor drainage and, land subsidence. The proposed flood control system is based on sluices, gates and retention lakes which will regulate the water level in the city. This system will reduce the flooding area with 3,6 km^2.

Therefore, a model of the hydraulic aspect as well as the transport/infrastructural aspect based on the traffic flows in the city is needed to gain insight in how the issues can be handled and what the impact will be.

3 Hydraulic system

For the Can Tho City urban development and resilience project, several years of research determined the measures that have to be taken to prevent frequent flooding. For example, the Southern Institute of Water Resources Research (SIWRR), located in Ho Chi Minh City, has developed a hydraulic model of the water flow through the city of Can Tho. This includes simulating flooded areas when taking drainage systems like sewers and open channels into account. The main objective for their model is to map the causes of a flood. Secondary objectives are: simulating the flooded areas of Can Tho City in a certain condition, giving recommendations on the tidal control works and renovations of the drainage system, determining design criteria for tidal control systems and developing a Cost Benefit Analyses (CBA) for the investment projects.

The polder system, including the dykes, tidal works and sewer system that have to be constructed or improved, is designed using the SIWRR model. However, in order to achieve optimal control of water within the polder even in the future, a simple and open-source hydraulic model is created to visualise the current and future urban water behaviour for different scenarios. These future scenarios (2050) are discussed in Chapter 5. The model is able to calculate the water levels and discharges in the canals. The output data can be used for future research, to do recommendations on adaptions of the polder system.

First the schematisation of the polder area is discussed, then the methodology and inputs in the model are described, including the rainfall input, the Hau River water level input and the Household effluent. In the last section the outputs are discussed and a conclusion of the water model is drawn.

3.1. Assumptions

To develop a simple model, several assumptions have to be made. These assumptions are given below:

- The polder area is located for 96.3 % in the Ninh Kieu district, where this model assumes that 100 % does. [28]
- The model is developed as a 1D shallow water equations model, making use of the conservation of mass and the conservation of momentum (See Section 3.3).
- Only primary canals are included, secondary and tertiary canals are neglected. The model assumes that canals are rectangular with constant depth.
- The polder area is divided into several watersheds to assume the flow of for example rainfall inside a particular watershed ends up in the corresponding canal (See Section 3.2.1)

- The sewer system is neglected because of its limited capacity, bad maintenance and malfunctioning. Particularly in the Ninh Kieu district this results in the incapability of draining flood waters [4].
- The future dyke system is capable of preventing floods, therefore the focus is on the water flow through the canals.
- Inputs used in the model are rainfall, tidal range of the Hau River translated to the polder area and household effluent. Further description of the inputs are given in Section 3.4.
- Retention lakes are modelled as channels with the depth and area of the retention lakes. Wave effects will be negligible due to the size of the lakes.
- A flood is assumed when the water depth is larger than +1m AMSL. This assumption is made as most of the surface elevation within the polder area lies around +1m [19].

Figure 3.1: The polder area of Can Tho City is surrounded by the orange line.The blue lines indicate the modelled canals, with the nodes depicted as black circles. The red pin points at the border of the polder area are tidal gates only, while the blue pin points are tidal sluices including ship locks where ships can pass by. The retention lakes are shown as blue circles connected to node 3,4,5 and 9. Figure made using Google MyMaps.

3.2. Schematisation

The polder area as given in Figure 3.1 is only a small part of Can Tho City province. However most of the population lives in the polder area and this part of the city is most vulnerable to floods. As can be seen, the polder area consist of a lot of canals and creeks. For modelling the polder area and calculating water height or discharge at certain location, not every canal can be modelled to prevent long computational time.

The canals that are used in the model are depicted in blue lines. These canals are the primary canals which indicates their storage capacity and play a major role in managing the water system. An important part of the polder system are the tidal sluices and gates. These can be opened or closed when needed in case of high and low water respectively. The tidal sluices and gates are shown as red and blue pin points. To check if these structures are capable of preventing floods in the city, the model should contain the canals that are directly connected to these tidal sluices or gates, which are included.

Canals can be connected to nodes, that can be used to model a sharp turn or intersection between canals. In a node, retention lakes can be added to model storage capacity of the water. As shown below, the model consist of 11 canals, 12 nodes and 4 retention lakes.

An overview of the different canals and retention lakes and gates together with their characteristics, that are used in our model are described in Appendix C.

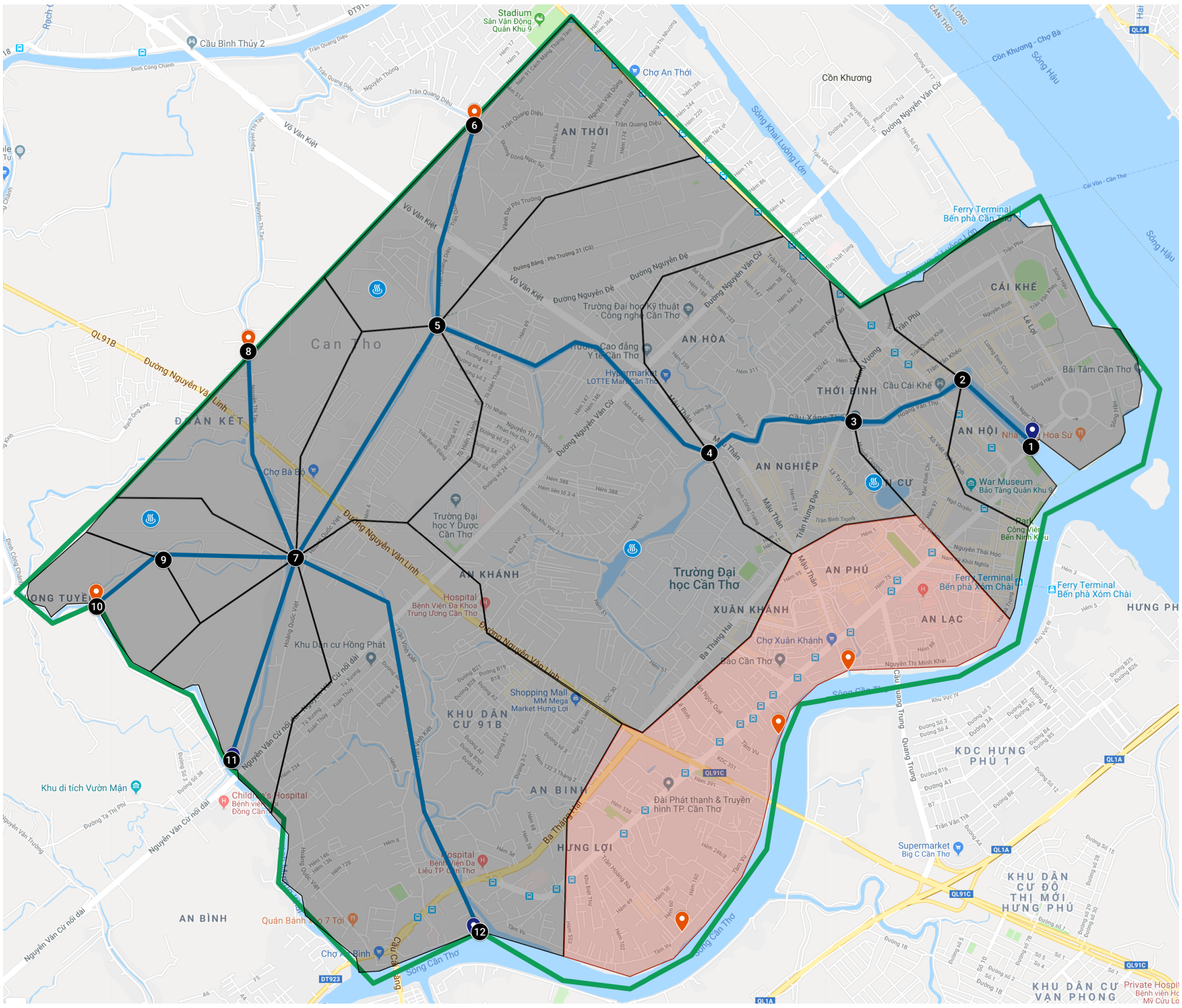

Figure 3.2: Overview of the project area including the watersheds, canals, nodes, tidal sluices and retention lakes. The polder area is surrounded by the green line. The watersheds are bounded by the black lines. The red watershed is the watershed which is not included in the model calculations. The blue lines represent the canals, with the nodes depicted as black circles. The retention lakes are shown as blue circles connected to node 3, 4, 5 and 9. The red pin points at the border of the polder area are tidal gates only, while the blue pin points are tidal sluices including ship locks where ships can pass by. Figure made using Google MyMaps.

3.2.1. Watersheds

The model uses watersheds where is assumed that, for example, rainfall which is not infiltrated by the soil (runoff) ends up in the corresponding canal. For all inputs, described in

Section 3.4, the area of the watersheds are used to define the water quantity that have to be added to each canal.
The watersheds are created using a elevation map of the Can Tho City province [28]. The borders of the watersheds are defined by the highest point close to a canal, assumed that water will flow from the highest point to the canal in a watershed.
The contribution of the red watershed depicted in Figure 3.2 is neglected in the model, as well as the three tidal sluices located in this area, since the absence of primary canals where is assumed that water will flow directly in the Can Tho river.

3.3. Methodology

In order to model the water behaviour in the polder area, a Simplified Shallow Water Equation Solver (SSWES) model is created. The SSWES model is created in 2011 by the Hydraulic Engineering section from the TU Delft and is commissioned by the North Holland province to investigate bank protection possibilities. For this research, a simple model for calculating water heights and flows within a water system turned out useful, and the SSWES was created. This existing SSWES model is extended to be applicable for the study area of Can Tho City.
The equations used in the SSWES are derived from the Navier-Stokes equations and are called the 'shallow water equations' or the Saint-Venant equations:

- Conservation of mass

$$B\frac{\partial d}{\partial t} + \frac{\partial Q}{\partial x} = 0 \tag{3.1}$$

- Conservation of momentum

$$\frac{\partial U}{\partial t} + U\frac{\partial U}{\partial x} + g\frac{\partial d}{\partial x} + \frac{c_f}{R}|U|U = 0 \tag{3.2}$$

Where:

B: width of the canal $[m]$
d: depth of the canal $[m]$
Q: water discharge $[m^3/s]$
U: flow velocity $[m/s]$
g: gravitational constant $[m/s^2]$
c_f: friction coefficient ($c_f = g/C^2$, see Appendix D)
R: hydraulic radius $[m]$
t: time $[s]$
x: streamwise coordinate $[m]$

The canals in the SSWES model are a combination of finite length segments between which the two equilibrium conditions are considered to determine the changes in time within the segments. Canals are modelled as rectangular blocks with constant depth. The equilibrium conditions can only be met with enough boundary conditions. These boundary conditions are applied at ends of the canals, where either a water height or a flow is defined. The canals in the schematisation connected to the 'outside world' have a defined spillway function at the concerned node, this is used to model the sluices. Within the spillway function, a crest height is defined and with a defined water height on both sides of the crest a flow is calculated. This is added to the equilibrium of the volume balance within a node. Using the spillway function, the sluices can be managed by adding rules for the height of the crest depending on the water height outside the sluice.

Rainfall runoff is added to the model as an extra inflow at nodes between the segments. The total runoff to a canal is divided into the amount of segments within a canal to add the result to each node within the canal. An graphic overview of the model can be seen in figure 3.3.

Eventually, water flow and water height data will be exported. This data is used to evaluate the polder model of Can Tho. In this way we are able to determine vulnerable spots where flooding can occur.
That is why the main goal is to:

- Model the water flow in the polder, using SSWES, in order to get a general view on the behaviour of the water system.

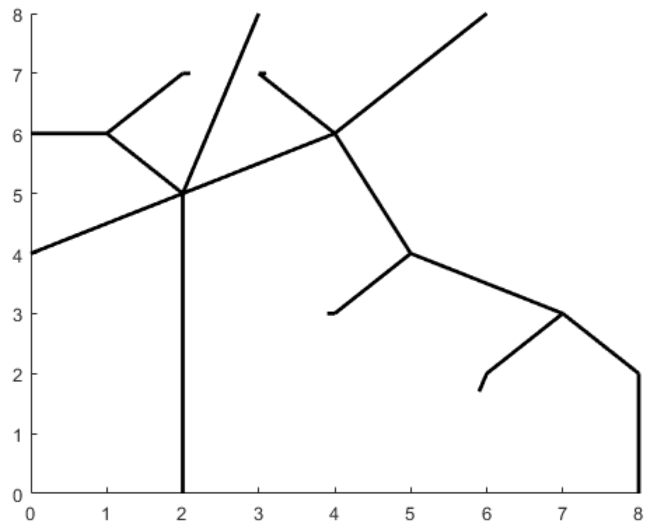

Figure 3.3: The canal network in SSWES

3.4. Inputs

The inputs that are used in the model are described in this section. These inputs influence the water quantity and quality. Data used for the inputs are:

- Extreme hourly rainfall including runoff of Can Tho City.
- Hau river waterlevel translated to Can Tho City in dry and rainy season.
- Direct household effluent in polder area.

In the model, a discharge in m^3/s can be added to a desired canal. In addition, constraints in water heights can be added to desired tidal gates/sluices. How these values are determined are described in the following sections:

3.4.1. Rainfall

Rainfall can have a significant influence on the water quantity in river or canals. Especially in the Mekong Delta, heavy rainfall can contribute to frequent flooding of urban en rural areas. Precipitation is partly infiltrated in the soil and partly discharged into existing water systems. First, for the model, the expected extremes need to be known to evaluate the polder design. The World Bank has determined that the urban core of Can Tho City will be protected against flooding due to rainfall for a 10-year return period case as a result of their investments [35]. In the Project Development Objective of the World Bank, the drainage system will be designed based on the following parameters: 90 minutes of localised heavy rain with a 10 year return period for open canal. Therefore, for this model, the same design rainfall is needed.
To determine the relevant rainfall for Can Tho, the Intensity-Duration-Frequency (IDF) relationship for the area of Can Tho is needed. The rainfall IDF relationship is one of the most commonly used tools in water resources engineering, either for planning, designing and operating of water resource projects, or for various engineering projects against floods.

A paper study of the Can Tho University determined the IDF relationship of rainfall in Can Tho [16]. Historical rainfall data from 1978 to 2015 is used to establish parameters for existing models, see Figure 3.4. The results show that Pearson III distribution is most suitable for building the Cumulative Distribution Function (CDF) curve for the rainfall in Can Tho. Thenceforth, the suitable IDF for each meteorological rainfall in Can Tho is calculated and selected based on the comparison of IDF from DCF with IDF constructed form empirical formulas. The basis for comparison was to use the average standard error (RMSE) and

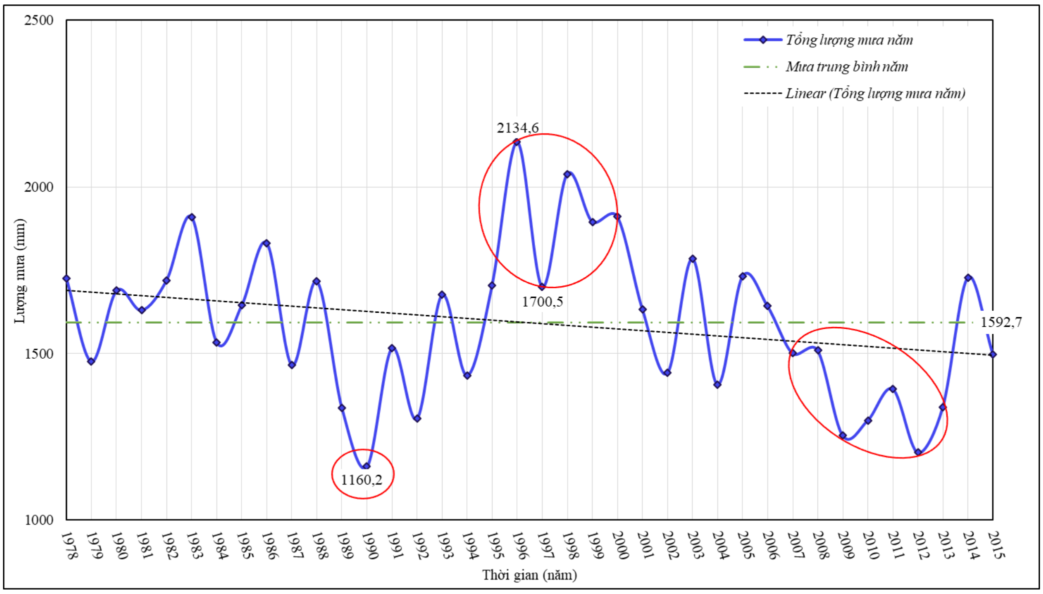

Figure 3.4: Total rainfall in the period from 1978 to 2015 in Can Tho[16]

the efficiency coefficient (EI). The result shows that the following parameters of the Vietnam Standard (TCVN 7957:2008) are appropriate for the studied area: A = 9594, C = 0.5, b = 26, n = 0.96. These values are well suited to rain monitoring points in each period (0.84 ≤ EI ≤ 0.93 and 2.5 ≤ RMSE ≤ 3.2). These values in implemented in the following formula:

$$q = \frac{A * (1 + C * \log(P))}{(t + b)^n} \tag{3.3}$$

where
q: rainfall intensity
P: rainfall return period, 0.1, 0.2, 0.5 and 1.0 for the 10, 20, 50 and 100 year return period respectively
t: duration of rainfall

With this information, the IDF curve depicted in Figure 3.5 is created.

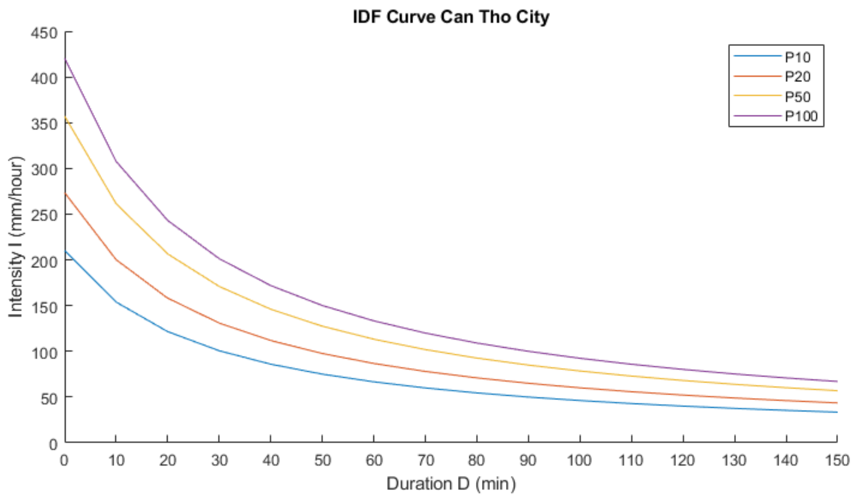

Figure 3.5: IDF Curve Can Tho City

With the World Bank design parameters, 90 minutes of localised heavy rain with a 10 year return period (P10), results in a related rainfall intensity of 50 mm/hour. Therefore, the design rainfall used in our model is 90 minutes of 50 mm/hour each 10 years, based on historical data of 1978 to 2015. This results in a total rainfall of 75 mm over 90 minutes. This design rainfall is used to calculate the runoff to the canals which can be implemented in the model.

Rainfall runoff

In the model it is assumed that the runoff will flow into the canals with use of the watersheds mentioned in Section 3.2.1. First, the area of the watersheds have to be estimated to eventually calculate the discharge in m^3/s. This is done by using Google MyMaps.
For the calculation of runoff into the canals it is assumed that for residential areas the runoff is 100%, so there is no infiltration in the soil. For green areas, there is infiltration which have to be calculated. To estimate the amount of green and residential area in a watershed, Google MyMaps with satellite view is used.
Secondly, the infiltration in green areas have to be calculated. This is dependent on soil properties. According to Appendix E properties of sandy clay are used in the calculation. Using this data, the runoff can be calculated as:

$$runoff = P - I \tag{3.4}$$

Where:
P = rainfall in mm/h
I = infiltration in mm/h

The runoff is calculated as 37.06 mm/h according to Appendix F. With this value, the discharge $[m^3/s]$ in each watershed to the canals can be calculated using the area of the watershed. These values can be implemented in the model to add the runoff in certain branches. The rainfall runoff is distributed over a period of 3 hours in the model.

3.4.2. Hau river water level

Shown in a study is that the sea level has significant influence on the Hau River water level at Can Tho [37]. Because Can Tho is located close to the Hau river which is directly connected to the ocean, the ocean tide determines a large part of the tidal amplitude of the Hau river. Since the river flow causes different tidal damping in rainy and dry seasons, the extreme months for both high and low water levels of the Hau river have to be estimated. After that, the phase difference of the tidal range between different locations at the polder area have to be estimated and taken into account in the model to find the water heights outside the model at each border of the model.

Using hourly water level data from the Hau river from the period between 2001 and 2011, the extreme days are found to schematise the outside water levels of the model. From the data, the highest and lowest mean water level per day is determined and two extreme days are found. The day with the lowest mean water level is 18 May 2005, and the highest mean water level is found on 27 October 2011. For these days the hourly data is collected during the 24 hours. With this data functions are fitted using Matlab curve fitting with a sum of sines to implement these water levels in the SSWES model, see appendix G.

Figure 3.6 shows the water level fluctuations in a day for these two different extremes. These water levels are going to be used in the model as an input at the sluices at the polder entrance. After fitting the tidal range of the Hau river per 24 hours in October and May, the phase difference between the Hau water level and the inputs of the model (the gates) have to be estimated. It have to be proven if this phase difference between different gates have to be included or can be neglected in the model. First a fixed point, located in the Hau river, have to be chosen from where distances are measured to the gates. This point is depicted in white in Figure 3.1. Using the sinusoidal tidal data of October and May, the period and eventually the wave velocity is calculated. With the distances and the wave velocity, the phase difference as a function of time is estimated for all the gates. It has been shown in Appendix H that the

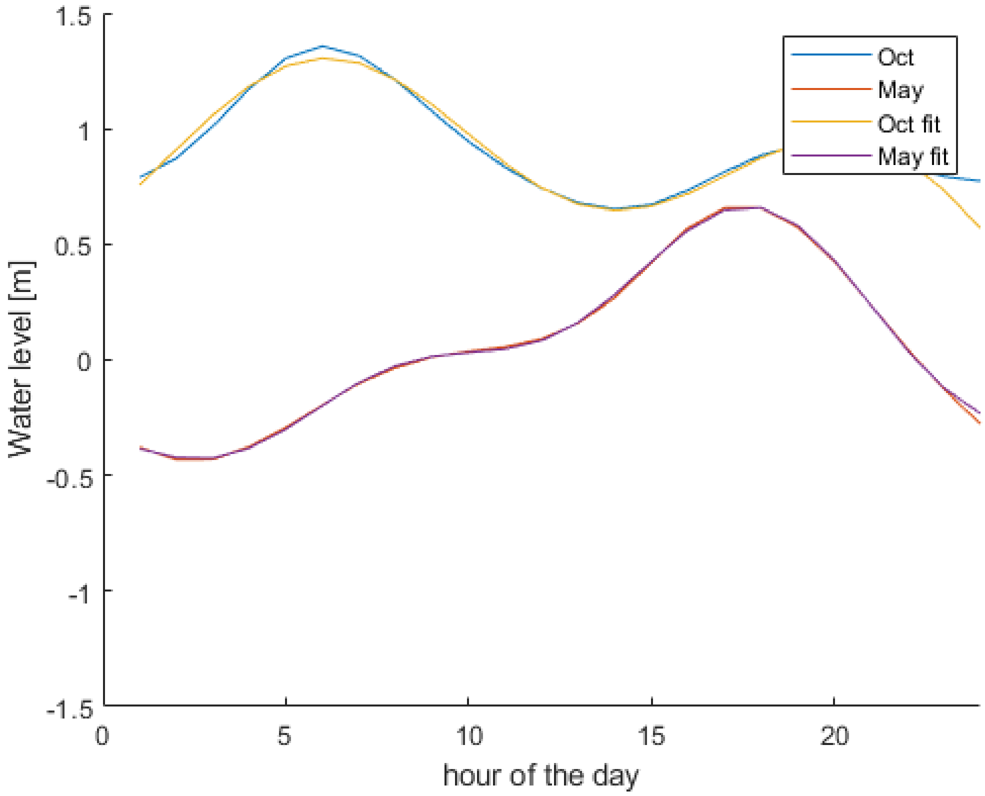

Figure 3.6: Hau water level during the day in dry season and wet season

phase difference between the Hau water level and specific gate water level can be neglected and that the water level estimated at the Hau river can be used for every gate used as input for the model.

3.4.3. Household effluent

Not every household in Can Tho City can collect their waste water by using the public sewer system or septic tanks, the remaining effluent is directly discharged into nature. Every form of waste water collection results in a discharge into nature. The difference is when it ends up in the polder system or outside the scope of the project. As mentioned before, the capacity of the sewerage systems are neglected in the model and here is assumed that the waste water collected by the sewers will end outside the polder into bigger rivers. For the remaining waste water, it can be assumed that it will enter the water system inside the polder which affects the water quality more than the water quantity. However, in this report only water quantity is implemented in the model. For further research, the values for waste water discharge into nature can be used to give an estimation of water quality inside the polder area, which was not included in the model of SIWRR.

In the current situation, ±70% of the households within the polder area are connected to the sewer system [6]. Which means that 30% of the households discharge their waste water directly into nature. This not only leads to the decrease of water quality in the city, but also contributes to a small increase in water level in the canals.

To calculate the discharge of waste water into the canals, the billed water volume and the served people have to be known. After that, this information needs to be scaled to the current population in the polder area assuming that 100% of the population has access to piped water [6]. The calculation of the current and predicted total discharge of waste water in the polder area is given in Appendix I.1. The current total discharge of waste water in the canals is calculated to be $0.198m^3/s$. This value is of no significance regarding the size of the system and for example the rainfall runoff added to the system. Therefore, the household effluent will not be taken into account in this model.

3.4.4. Sluices

In the wet season, the sluices are set to close if the Hau water level is higher than +1.05m. If the Hau water level is under the +1.05m, the height of the sluices is set to +0.75m, as this is the mean water level during wet season). In the dry season, the sluice is set to a height of 0m AMSL.

3.5. Outputs

By running the SSWES model using the right parameters, a calculation is made to find the water height and water flow at each node during a predefined time period. Figure 3.7 presents the values for one day during the wet season in the current situation at one of the twelve nodes in the system. The upper section of the graph represents output of the model: the water height at the node and the flow through the node. The lower section shows the variable input of the model, being the water level of the Hau river and the runoff, caused by rainfall.

The rainfall runoff is defined in the model at the most inconvenient moment for this run. The peak of the Hau water level is around 6AM. With a distribution of the 50mm over 90 minutes rainfall the runoff is distributed over 180 minutes, with the peak at 90 minutes. To match the peak of the Hau water level, the start of the runoff is set at 4:30AM. More inconvenient is the closure of the sluices during the runoff period, that is why a slight increase in water level can be seen during the runoff period between 4:30AM and 7:30AM.

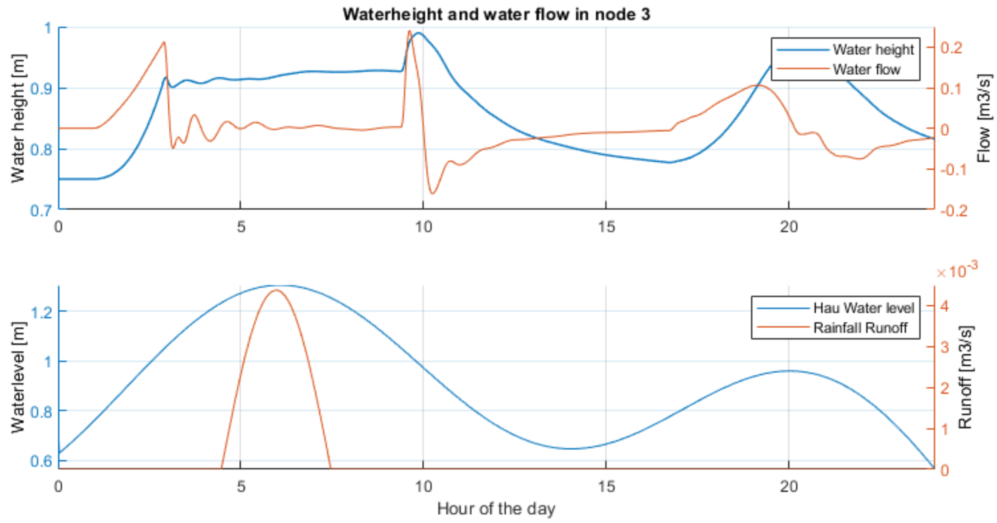

Figure 3.7: Water height and water flow in node 3 during wet season (current situation)

For the dry season a simulation is done with the dry season Hau water level and no rainfall (runoff). See figure 3.8.

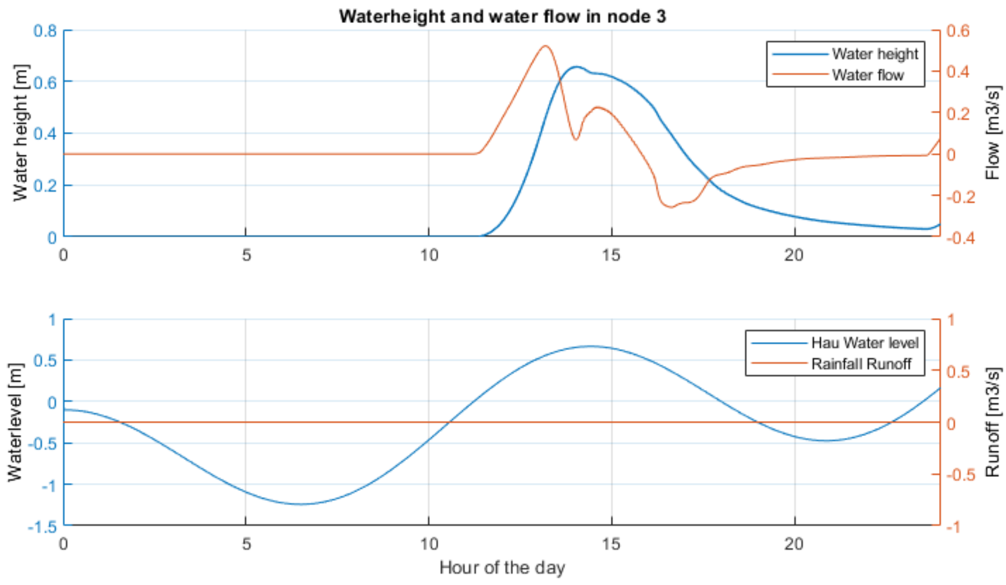

Figure 3.8: Water height and water flow in node 3 during dry season (current situation)

3.6. Conclusion

The used SSWES model of the TU Delft is successfully validated, the extended SsWES model used in this research could not be fully validated. Therefore, results should not be believed directly but should be understood and checked critically. With the model as a combination of many variables, the results are realistic and can be used for a general overview of the behaviour of the water system. The output of the model can be logically linked to the input, where the link is based on the equilibrium conditions. Moreover, the script is highly customisable and applicable for many situations and water systems. Rules can be added to create a management plan for a system, as the sluice openings can be dependent on the water heights for example. This could be extended for many possibilities.

It should be taken into account that the model is a schematisation of the reality; assumptions described in Section 3.1 need to be considered.

To draw conclusions for the future, the model is used in a scenario analysis. Here, different input parameters followed from scenarios will be used in the model to find the behaviour of the system in these situations. Together with the infrastructure model conclusions can be made for different scenarios to see what the impact of the polder will be on Can Tho City.

4

Transport and infrastructure

4.1. Relevance

The rapid urbanisation in combination with the flood risk results in a high risk environment for the city of Can Tho. Due to economic growth close to the canals and rivers, citizens mostly life closely to their work and this impacts the safety of these households. The current knowledge about the transportation in the city is not sufficient yet. Transport modelling provides numerous benefits in traffic and the transportation industry, and can be used as a basis for future planning purposes [29]. A transport model clarifies the relationship between the road network and land uses within the intended area of modelling. Moreover, it can analyse the impacts of existing infrastructure and predicting future traffic volumes on the road network.

Consequently, this project has led to the development of a transport model which will be further elaborated and explained in section Four Step Model. Thereby, the objective of this model is to contribute to transport modelling by presenting a transport model for the city of Can Tho. As mentioned before, the focus is on component 2. The urban corridor development objective for this study is to analyse the road network of the flooding area of the city and the connection with the surrounding of Can Tho city. Thereby, sub-component 2.1, road and bridge links, will be taken into account. With the investments in transport infrastructure the inter connectivity between the vertical axes will be increased. Figure 4.4 shows the location of the new road in the map. The following road links are included:

1. Quang Trung Bridge crossing the Can Tho River
2. Tran Hoang Na Road, including NH1 side roads from Tran Hoang Na to IC3 intersection
3. Cach Mang Thang Tam to PR 918/Bui Huu Nghia road (dual purpose by providing flood protection)

The general understanding of an urban corridor to be bundles of infrastructure that links two or more urban areas [44]. It concerns connections that use different transport modes and carry both passenger and freight. Considering a corridor as an economic development axis, a relationship is supposed between opportunities for economic development and major traffic axes. This point of view assumes that the spatial results of functional economic activities are strongly determined by the infrastructure network.

Accessibility and the infrastructure network are closely related. Accessibility refers to people's ability to reach goods, services and activities, which is the ultimate goal of most transport activity [15]. Many factors affect accessibility, including mobility (physical movement), the quality and affordability of transport options, transport system connectivity, mobility substitutes, and land use patterns. Accessibility can be evaluated from various perspectives, including a particular group, mode, location or activity. The level of accessibility is an important factor for economic growth [5].

In order to support the objective of this project, a research question with sub-questions are formulated.

- **What effect does sub-component 2.1 have on the traffic flow of Can Tho City?**

  How will the traffic flow behave in the base year of 2018?

  How will the traffic flow behave in the future year of 2021?

  What are the differences and similarities of both modelled years?

The study is used for the development of a transport model for a small scale network. Since this order of magnitude is chosen and the lack of data, the level of detail is relatively limited.

4.2. Structure

First, the methodology of the development of the transport model is elaborated. The first sections describes the general outcomes and gives an overview of the step that need to be taken. Then, a detailed analysis of the Four Step Model is performed and outlined. The assumptions, input data and model specifications are included. Consequently the conclusion draws together the predicted traffic flows in Can Tho City for 2021.

4.3. Methodology

The framework of demand modelling is the traditional procedure utilised for transportation forecasts. The Four Step Model allows a prediction of the volume of traffic by means of a given transportation element in the future [30]. It follows a sequential procedure of four steps.

The first step in the Four Step Model is forecasting the trip generation. The goal is to estimate the number of trips that are produced or originate in each zone. The output is the number of trips per zone. Subsequently, the matches or movements between origins and destinations are developed in the next step; trip distribution. Trip ends are linked to create complete trip in the study area. The output is a flow matrix between zones with the number of trips. Mode choice or modal split is the third step to determine what travel mode is used for each trip. It predicts the choices that travellers make in selecting their mode. The order of the Four Step Model can differ. Initially, the traffic model opted to merge the trip generation with the mode choice. In that case, the mode choice can not influence the later stages of the process figure 4.1. The last step contains the route choice to assign trips to the network. The article of Immers is used to describe and analyse the steps of the Four Step Model.
This procedure is consequently iterative and converges towards a solution, often measured as the minimal transportation cost considering a given travel demand and the characteristics of the existing transportation network [30]. Using this method leads to a forecast of the number of trips on each link of the network.

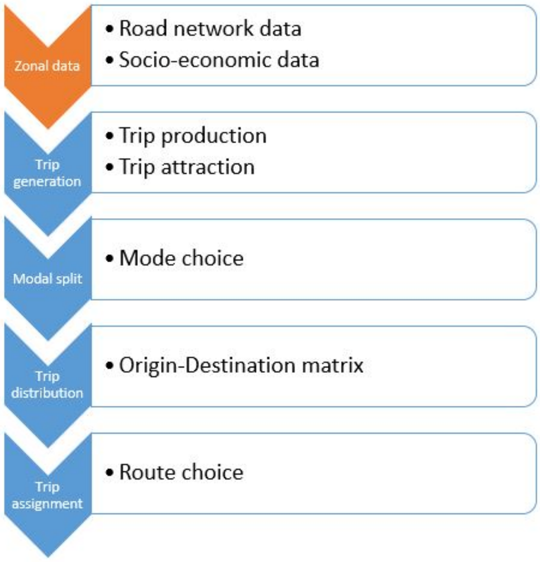

Figure 4.1: Four Step Model for Can Tho City

4.3.1. Counts

Referring to the first step of the model, the estimation of the number of trips of zones can be done via zonal data. The characteristics of a zone by means of socio-economic data can be used for the zones located in the study area. However, a significant part of the traffic flows may have their origin or destination outside the study area. It is also possible that traffic crosses the study area, this is called through traffic. To cover these flows, an external zone is added. The method to obtain data for these flows from or to outside the study area, is via counts [13]. Counts on a cordon (a closed ring around the study area) are performed during the visits of Can Tho City. Detailed information about this part of the model is defined in section J.

4.4. Four Step Model

This section contains the elaboration of the Four Step Model. Appendix L contains an overview of the used model conducted from excel. First, the zones of the road network of Can Tho City and the networks are defined. Subsequently, an excel format is used to determine the traffic flows of the network.

4.4.1. Zoning and networks

A traffic model relates to a specific study area. It includes the following parts;

1. Zoning; the study area will be divided in a number of zones and the movements are from and to a zone start/end in a centroid.
2. Networks; the transport system of Can Tho City consists of levels. This network is a simplification and abstraction of the real network since the level of detail depends on the availability of data and time.

The following sections aim to explain the guideline for the zoning and network specification of the city.

Zoning

The study area and the catchment area consists of internal and external zones. The traffic flows from and to each zone specifies the study area. On the other hand, the catchment area focuses on those flows that have their origin or destination within the study area. As mentioned before, each zone has a centroid in the center of the area. This point of gravity is expected to be the departure and arrival point of all traffic. Each centroid is connected to the rest of the network by one or more connectors. The traffic movements between two zones is the interzonal traffic and movements within a zone is called the intrazonal traffic.

Focusing on the scale and purpose of this study, the amount of zones is chosen so that reliable conclusions can be made. That is why this study deviates from guidelines to small-scaled studies. The zoning of Can Tho City is in line with the availability of socio-economic data such as employment and population density.

An external cordon (zone L) is included to obtain information on the trips originating outside the external cordon having origins within the external cordon or passing through the study area [31]. The external cordon line is chosen so that the trips crossing it can be easily measured. Therefore, zone L is divided in five centroids; L1, L2, L3, L4 and L5. The area inside the cordon line is studied extensively, whereas the area outside the cordon line is studied in a smaller degree of detail [23]. The overview of the zoning of Can Tho City is depicted in figure 4.2.

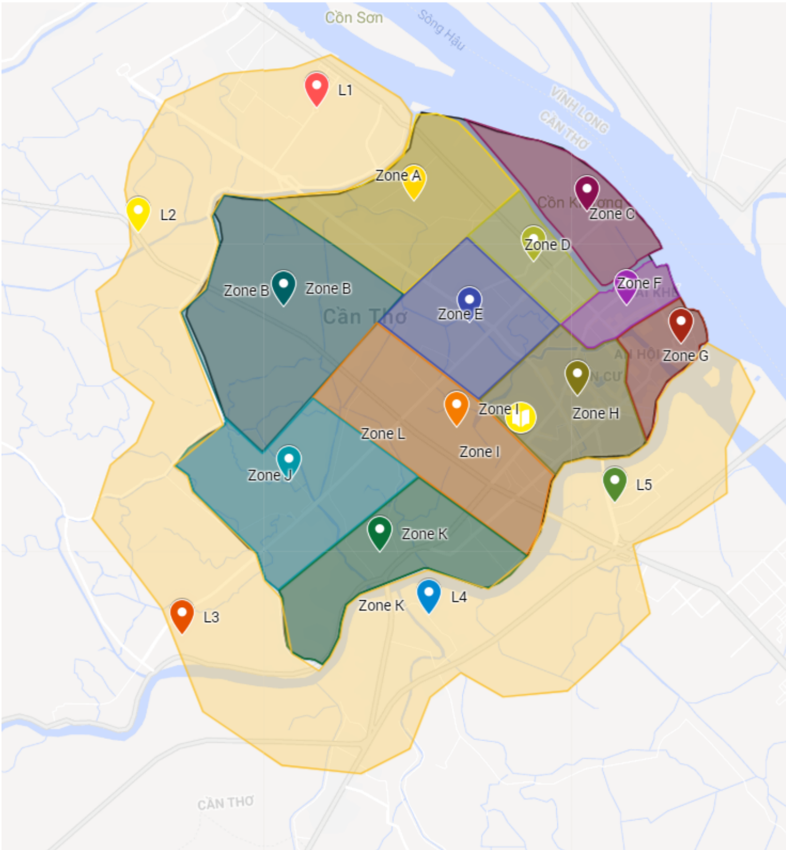

Figure 4.2: Zoning of Can Tho City

Networks

The transport system of Can Tho City has its network which includes nodes and links. Figure 4.3 shows the simplified overview of the base year road network. Subsequently, the overview of the future year network including new roads and bridge is showed in figure 4.3. In figure 4.4 the network is shown in combination with the zones. The road network of Can Tho City is mainly used by motorbike drivers. According to [6], the percentage of motorbikes in Ninh Kieu is 98,6% and in Binh Thuy 98,3%. Due to these high usage of motorbikes, the model is specified on motorbikes *ONLY*.

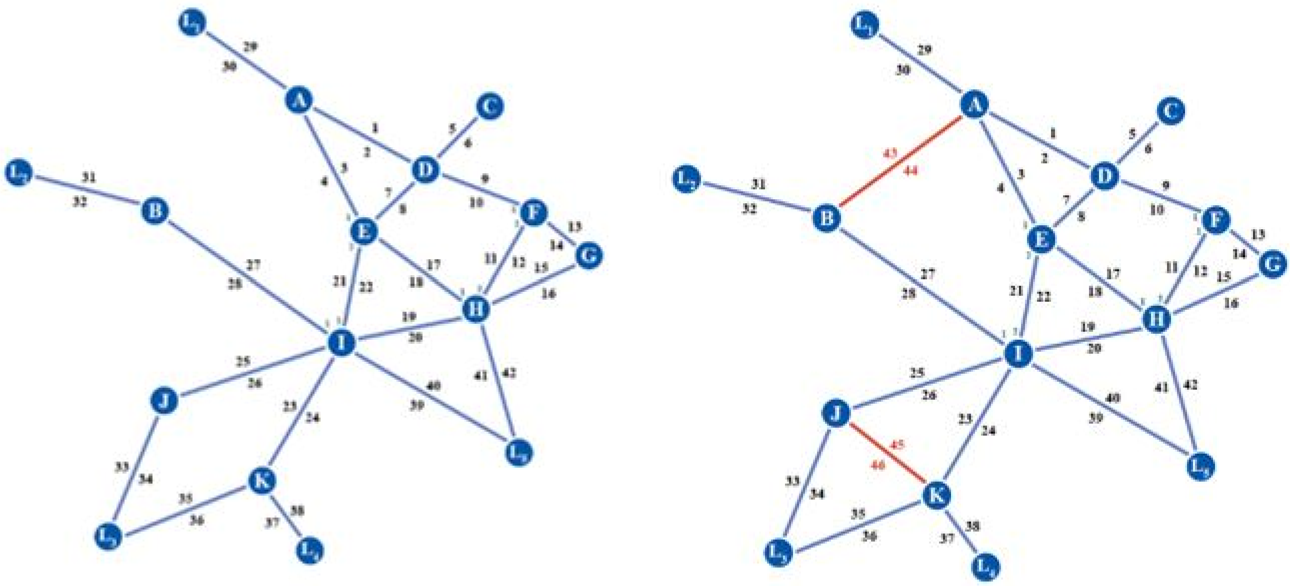

Figure 4.3: Network 2018 - 2021

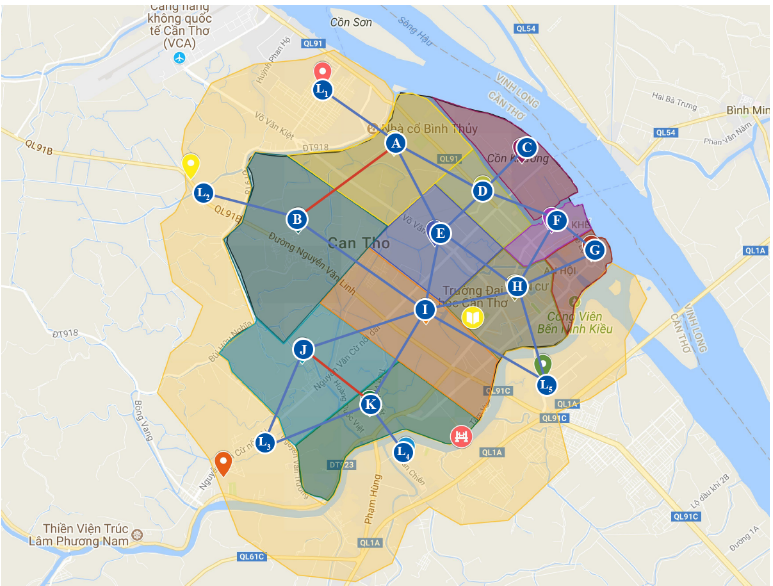

Figure 4.4: Network and zoning

4.5. Trip generation

Estimating the trip generation can be done via various ways. This section aims to predict the total amount of produced and the total amount of attracted trips per zone and over a specific period of time in the study area. Before focusing on Can Tho city, the concept of trip generation will be elaborated.

A **tour** is made due to the activities of people such as work, social and education. Activities are widely distributed in the city. It is possible that a tour consists of more trips. Trips are originated in a certain place A and have its destination in B, so a trip has an **origin** and a **destination** and it will use only one mode, figure 4.5. The definition of origin and destination differs for **production** and **attraction**. Production means the number of trips departing at each zone whereas the attraction is the number of trips arriving at each zone.

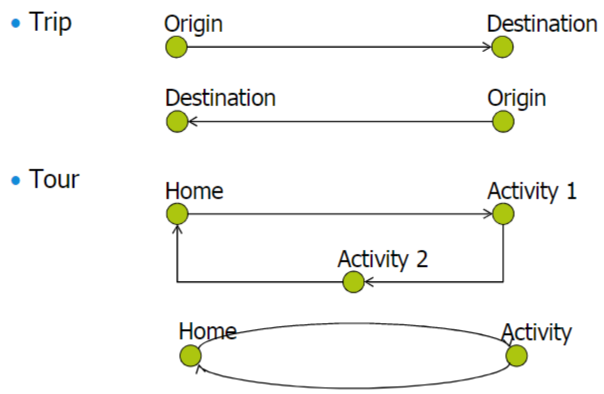

Figure 4.5: Difference trip and tour

4.5.1. Trip purpose

There are two different tours, **home-based** and **non-home-based**. There are different purposes to make a trip, compulsory trips (working trips, education) and optional trips (social, recreational). The table gives an overview of purposes and kind of trips.

Tour	Trip purpose	Kind of trip
Home-based	Work	Compulsory trip
	Education	Compulsory trip
Home-based other	Shoppings	Optional trip
	Social/recreational	
Non-home-based		Non-home-based

4.5.2. Time of day

A distinction is made between the trips in peak period, morning or evening, or not in peak period. The trips in peak period are mostly mandatory trip, to work or education. The decision to make optional trips can be postponed or cancelled. The model of Can Tho City is based on 24 hours.

Peak hour from	Peak hour to	Purpose
6.00 a.m.	7.30 a.m.	going to work
11.30 a.m.	1.30 a.m	having lunch
4.30 a.m.	6 a.m.	going home for evening

4.5.3. Possible influence factors

Possible factors that might influence production are, income, car ownership, household structure, family size. For attraction there are different possible factors such as office space, retail space, employment, households and student capacity. The trip purposes for Can Tho City are based on employment and households due to lack of data of a wider range of factors.

4.5.4. Trip generation based on regression analysis

The regression analysis is the most commonly used method to calculate the productions and the attractions of a specific zone. The linear regression method predicts a variable Y as a linear function of factors of that variable.

As mentioned before the regression method used for Can Tho City is based on employment and households. Since the model is a 24-hour model the assumption of attraction and production are equal holds.

$$Y = 6,5 \times X_1 + 2,9 \times X_2 \tag{4.1}$$

X_1: amount of households
X_2: employment
Due to lack of information, the zonal information is based on estimations and assumptions.

4.5.5. Assumptions and information about current situation

The land-use information is used to develop the model as the model input is from the latest available data provided by GSOV (2017) and Ms. So Sen La of the University of Can Tho.

The surface per zone is measured via Google maps. Providing an estimation for the amount of inhabitants in each zone, the density per district in Can Tho City is used to gain overview of the density for the zones [28]. Since the layout of the zones is not the same as the districts of Can Tho City, zone C and I are estimated. By multiplying the density and the surface of each zone, the inhabitants are calculated. Thereby, the number of households is determined by using a households size of 3,8 persons [32].

The total density of the study area is approximately 5 times (18%) higher compared to total density of Can Tho City. This percentage is taken into account for the correction of the non-agricultural employees since a higher density of inhabitants can be in line with a higher employment for non-agricultural sector. This can not be applied for the agricultural employment. Using this correction factor the total amount of working people is 85% of the inhabitants. The statistics of Vietnam mentioned 54%, however that is only people who are trained and registered, so the actually percentage might be a lot higher.

The employment and the surface (ha) for both agricultural and non-agricultural sectors, are known [10]. Subsequently, an estimation is made to obtain a density (employment/ha) for both sectors, that can be applied in each zone. The land use map [10] which is depicted in figure 4.6, shows the layout of sectors in Can Tho City. The combination of this map and the density per sector resulted in the employment per zone.

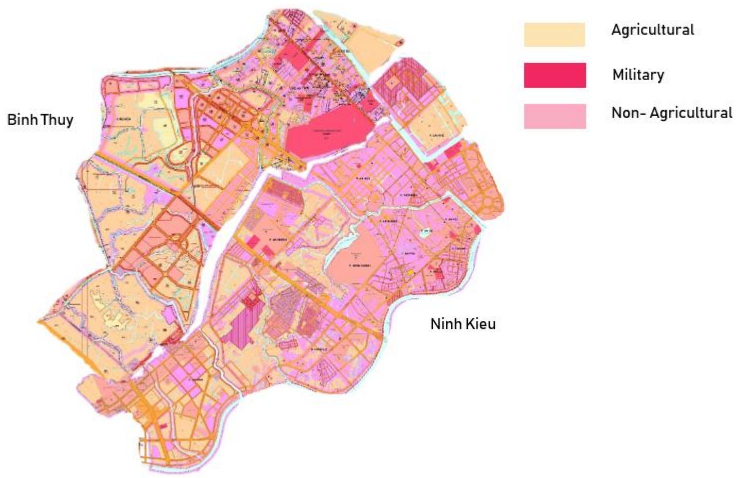

Figure 4.6: Land Use of Can Tho City

The motorbike share that is used in the model 98,45% [6]. That is why the total estimated production is multiplied by the motorbike share to obtain a model that only focuses on motorbikes.

As mentioned before in the methodology part, the production for the cordon zone is estimated via counts, Appendix J. The counts are applied in the morning peak (06.00am-07.30am). A correction factor is used to have a reliable amount of production for the 24 hour model. The morning peak is approximately 8% of the daily movements to and from the cordon. Thus, a factor of 12,5 is used to obtain the total production of the cordon zone.

4.5.6. Assumptions and information about future situation

The traffic model for the future year 2021 is quite similar as the base year model. This means that the model is adjusted with data that is relevant for the future situation. For example, the future construction plans (the new roads) and expected economic developments in number of jobs or the growth of the population. To achieve a reliable production for the future, the amount of inhabitants are multiplied with the inhabitants growth factor for 2021 (see figure 5.1. Next to that, the employment is multiplied with the economic growth factor for 2021 [11]. The future situation is not elaborated with the other effects of the polder, only the new roads.

4.5.7. Routing

An assumption is made to define the route from origin to destination. Dijkstra's Algorithm is used to determine the shortest path chosen by the travellers and this is explained in the Appendix K. For the accuracy of the model it is taken into account that there are multiple routes possible from and to a certain zone.

The inter-zonal travel times are calculated based on the speed of the lane and the distance of the lane from one zone to another. During the visits of Can Tho City, our experience of the maximum allowed speed of the lanes is not the speed people actually drive because of the amount of traffic lights and exits. That is the reason why an adjustment is made to the free-flow speeds.

The intra-zonal travel times are based on assumptions. Intra-zonal trips means trips that have their origin and destination within the same zone. However, travelling between zones (inter-zonal trips) are based on travel times from one centroid to another measured via google maps. With the intra-zonal trips that is not possible.

Some OD-pairs are not included in the model since these trips will not cross the study area. In particular the trips from a centroid in the cordon zone to another centroid in the cordon zone. This also appears for trips from a zone close to the cordon zone to the cordon zone. To cover this is the model, the travel time is set to 99999. The section of trip distribution will explain this in more detail.

The two new roads in the study area will lead to a change in travel time for some OD-pairs. In terms of route choice this indicates different routes since shorter travel time may be available. The speed of these roads will be the original designed speed of 60 km/h.

4.6. Trip distribution

The previous section explained and analysed the production and attraction for the different zones. Yet, it is not known what the origin(O) or destination(D) is for a trip within the area. This chapter focuses on the distribution of the trips from a certain zone to all destinations and the trips with destination in a certain zone over all origins.
The pattern of trips will be displayed in a matrix which includes the number of trips going from each origin (i) to each destination (j). The OD-matrix is two-dimensional with 16 rows and 16 columns since the study area of Can Tho City is divided into 16 centroids. This confirms that each zone is an origin, as well as a destination. The diagonal contains the intra-zonal trips and the rest of the cells are the inter-zonal trips.

4.6.1. Computation method

Many methods have been suggested for OD-matrix estimation which describes an average traffic situation. Synthetic models have been introduced for the trip-distribution step to bring the actual travel behaviour of commuters into the trip-distribution techniques. These models aim to have resistances such as distance, time and costs, and apply them to trip distribution. The gravity model method illustrates the macroscopic relationships between places and this is the most well-known method for the distribution of trips. Alternatively, growth factor models and logit models can be used.
For this project, the gravity model is used. It states that the force of attraction between two zones depends on time, distance and costs at an aggregate level. The detailed information in this project is about the travel time between the centroids of each zone. Thereby a distribution function is used to support the forces between zones.

For accurate transport modelling, and in order to incorporate the impact of distance and time on human travel behaviour in Can Tho City with motorbikes, the resistance of each zone is expressed via travel time from and to each zone as shown in the previous section. However, some trips have multiple routes, as explained in the previous section of routing. These trips are assigned with the shortest travel time using the shortest path algorithm (Appendix K).

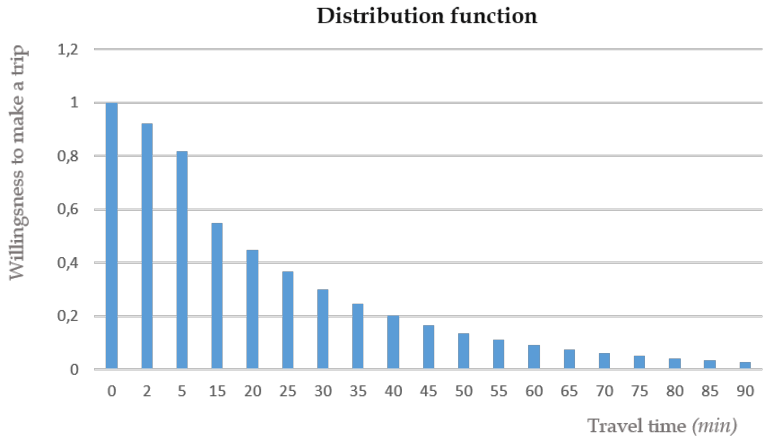

Figure 4.7: Trip distribution function

The effect of the used function is shown in figure 4.7. The number of trips will decrease as the travel time (resistance) to that destination increases. This effect can be expressed by the distribution function (see function 4.2).

$$F(ij) = e^{-0,04*traveltime(ij)} \tag{4.2}$$

However, there are many different formulations of mathematical formulations to give the relation between travel-time and resistances. Using the above function, the trips with a travel time between 0 and 30 minutes have a relative high willingness to travel by motorbike. Since the travel times of some OD-pairs is set to 99999, this function makes sure that these OD-pairs will be valued to zero trips. The values 99999 are the trips that are not crossing the study area.

The next step in the trip distribution is the matrix with all F(ij) equations for each OD-pair. This is performed in an iterative process until a matrix close enough to the target. To complete the first iteration, all rows are multiplied with the production of that zone (iteration to production). In fact, it will appear that the column totals will not correspond to the expected attractions. Therefore, the iteration to attraction is applied. This process is performed sequentially to converge the production and attraction and obtain the trip distribution of all OD-pairs.
The results of the distribution calculation provide the input of the next phase. It must be clear that these amount of trips are on a 24-hour base.

4.7. Trip assignment

The last step of the Four Step Model is the assignment of the distributed trips to the lanes in the road network. The amount of flow per lane is also known as the intensity. There are several methods and approaches to assign the trips to the network. Choice modelling is the most suitable method for estimating the travellers willingness to travel for a specific route based on the travel time [8].
As mentioned before, some OD-pairs have the option to choose multiple routes. These routes are assigned via the Logit Model approach. The formula that is used to determine the choice between routes is;

$$LaneIntensity(tt1) = \frac{exp^{-0,04\times tt1}}{exp^{-0,04\times tt1} + exp^{-0,04\times tt2}} \times totalflow \tag{4.3}$$

To make clear, this transport model is a static assignment model, the model is not dependent on traffic demand and network attributes are not changing in time. This means the model is a steady-state model and flows are not changing in time. All or nothing (AON) assignment is the simplest approach and it assumes that trips from any origin zone to any destination zone can simply be assigned onto the fastest route [3]. The AON assignment assumes that vehicles are able to drive the free-flow speed and that users have precise knowledge of the travel times on the links. As earlier discussed, adjustments has been made for the free-flow speed. Moreover, there won't be interruptions on a specific route, so travel times will always be the same between a specific origin and destination. The model also assumes that travellers are aware of all distances/travel times and possible routes and they will all make the same kind of choices based on distances/travel times.

By contrast, a congested corridor might change the route of a traveller to take a different route with a longer distance but same travel time. According to the transport model of Can Tho, congestion will not be taken into account. However, to obtain more reliable outcomes for a situation where there are two routes available, the usage of equation 4.3 makes sure that the total flow is divided based on the travel time of both routes. *tt1* refers to the travel time of the first route, and *tt2* refers to the travel time of the second route to arrive at a certain zone. In order to have a reliable representation of the choice between the two routes, a logit coefficient of 0,04 is used. By using this coefficient, lower travel times results in a higher amount of travellers on that route compared to a longer travel time.

The assumptions for AON assignment:

1. All vehicles are driving free-flow speed
2. No interruptions of the travel time for a specific route
3. Travellers know all the routes and travel times/distances

The trips of future year model are assigned in the same way as the base year model. The base year model outcomes are shown in Figure 4.8. The numbers at the lanes can be interpreted as the amount of trips between the zones.

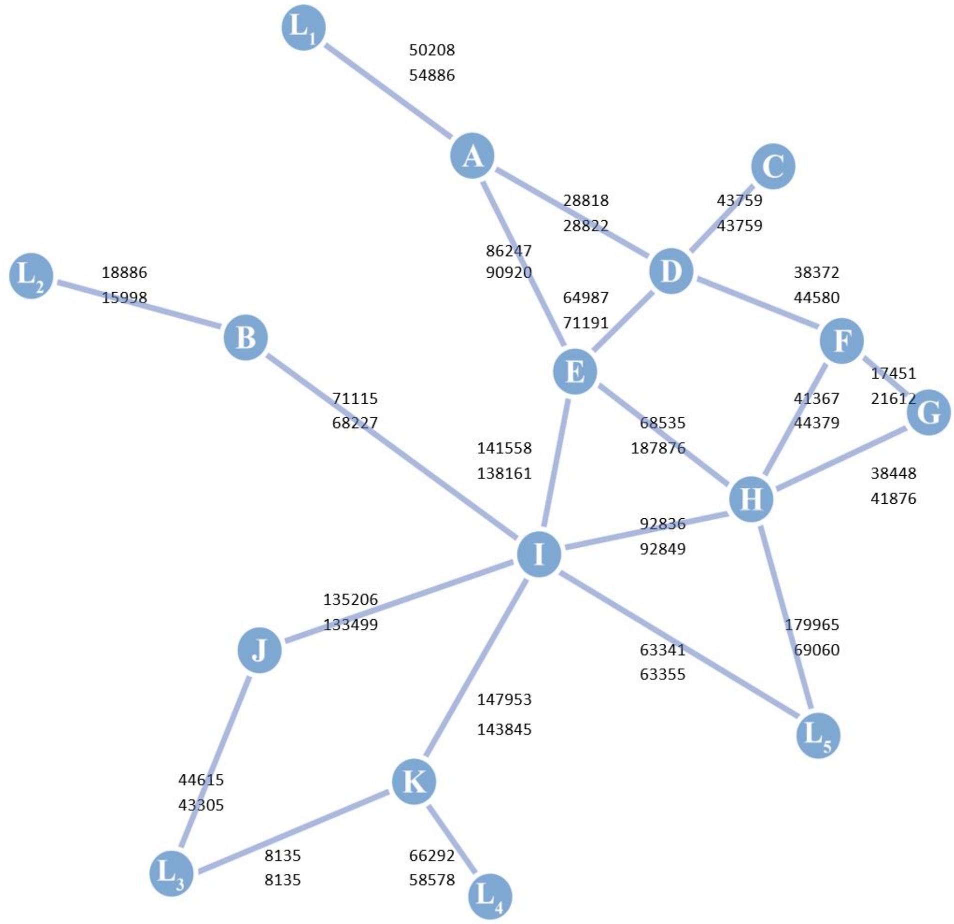

Figure 4.8: Flow network 2018 base year

4.8. Future traffic flows

Yet, both models base year and future year, are developed. Moreover, the models are validated and verified (Appendix M). Based on the outcomes, this chapter illustrates the changes in flows as a result of the new roads. The data used in the model represents a situation where the dykes and sluices are not implemented yet. The two new roads are the leading factor for changes in flow of the network.

It should be clear that the accuracy of the predictions for 2021 decreases as the future year increases since many factors are out of the scope of this project. The model does not take into account any changes in other factors towards making the trips.

The following figure shows the changes in amount of trips comparing the base year and the future year with the new roads and the assigned lane intensities.

It can be noted that the amount of travellers which supposed to use A-E-I-B, will now use A-B. Therefore, a reduction of flow is assigned to lanes A-E-I-B. The outcome of the model confirmed this behaviour. Subsequently, the addition of J-K confirms the hypothesis of flow changes.

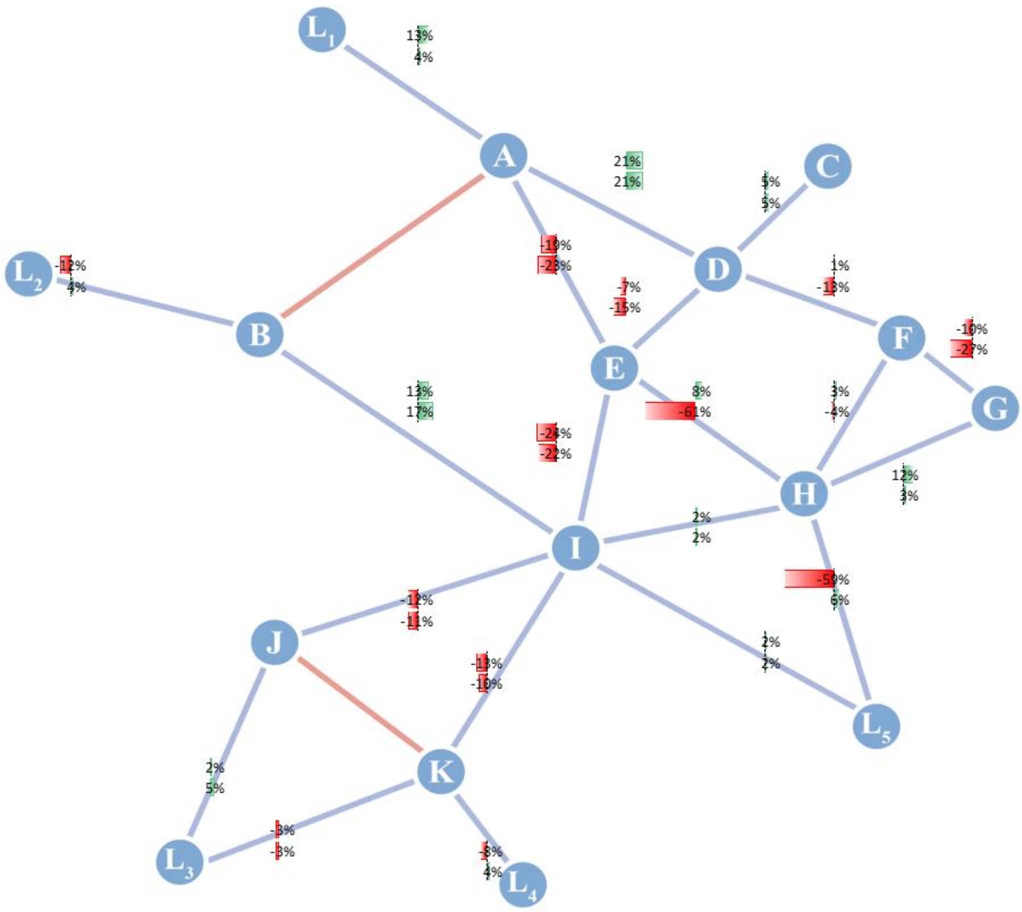

Figure 4.9: Flow changes 2018-2021

4.8.1. Route changes

Because the two new roads are included in the model, the trips are distributed in a different way. Travellers have the option of choosing a faster route to their destination. As demonstrated in table below, a total of five OD-pairs changed in route choice. Compared to the base year, it is expected that travellers will use the study area to travel from A to L2.

Route changes
A - L2
A - B
B - L1
B - L3
J - K
J - L4

4.9. Conclusion

The development of the Four Step Model has provide answers to the research questions of the transport part. The aim was to determine the changes in flow and trips of motorbikes in order to gain information about the distribution of the city in future years. It has to be clear that many assumptions had to be determined.

As a result, an iterative process of the model provided the flows across all lanes. The method to obtain the current flows is done via real-time counts. The counts are applied in the morning peak to determine the production of the cordon zones. Moreover, the counts are used to validate the calculated production of each zone.

To reflect on the research question; *What effect does sub-component 2.1 have on the traffic flow of Can Tho City?* it can be concluded that the flows in the year of 2021 which includes the new roads and bridges has led to a change in flows in the network. This appears since there are changes in travel times for some OD-pairs. It is assumed that all travellers opt for shortest path this indicates different routes since shorter travel time are available.

5 Scenarios

For the resiliency of Can Tho city, it is important to consider multiple scenarios to cope with uncertainties. With these scenarios, the models can be tested for different situations in the future. In this report, two uncertain components of the future are chosen to create scenarios; *Economic growth* and *Climate change*. As the economy is predicted to grow fast and steadily in the coming years, the *Economic growth* is included as it is relevant for the increase in population and wealth in Can Tho. The component *Climate change* is used as it affects two aspects that have a high influence on the system, being the rainfall intensity and the Hau river water level. Economic growth is considered For both components, two outcomes in the future are considered, being a positive and a negative (or less-positive) situation.

The scenarios will be sketched for the year 2050. This time span gives a fair view on the long-term future. Per scenario, future predictions are made using references and assumptions in relation to the current situation.

In this chapter, the factors that influence the situation of Can Tho in 2050 will be specified. At first, values relative to the

5.1. Climate change

In 2016, Ministry of Natural Resources and Environment (MONRE) published their latest report on the possible results of climate change in Vietnam. These climate change projections are built upon the 5th Assessment Report (AR5) of the Intergovernmental Panel on Climate Change. Using different scenarios, named RCP, different futures are sketched with varying severeness of climate change. MONRE extended the outcomes of the different scenarios with local (observed) data to make them more specified for Vietnamese regions [18].

Four RCP's are presented in the AR5; RCP2.6, RCP4.5, RCP6 and RCP8.5. The numbers behind the abbreviation officially indicate the increase in radiative forcing (W/m^2) in 2100 relative to pre-industrial times, and can be regarded as the severeness of a climate change scenario. In most literature, including the MONRE report, RCP4.5 and RCP8.5 are used for analyses and conclusions about climate change in the Mekong delta and Vietnam as a whole [18] [34] [12] [20]. Therefore, these will be the climate scenarios that are used in this report.

Important aspects of the polder system affected by climate change are rainfall and sealevel rise. Rainfall intensity is an significant contributor to floods, while the sealevel rise influences the water level at the Hau river. One of the consequence of the floods is the availability of the roads. The combination of the rainfall and the sealevel rise, together with the new designed polder influences the average speed of the roads.

5.1.1. Rainfall

The depth of annual rainfall in Vietnam increased slightly in the period between 1958 and 2014. When taking a closer look at different climatic regions within Vietnam, it is found that the Northern part has decreased rainfall values while the South has an increase in rainfall. The latter includes the Lower Mekong Delta, where over the last 57 years, an increase of 6.9% mm is found [18].

Due to the distinct difference between the dry and rainy season in terms of hydrological characteristics, AR5 presents predictive values for both periods. These values are given as the percentual difference relative to a baseline period of 1986-2005. This rainfall, and its increase is, assumed to be the same for the present situation as well. The increases in rainfall for the Can Tho region, in both RCP4.5 and RCP8.5 are presented in 5.1. As of Vietnam presents projected values for all four annual seasons, the extreme values are taken for both the dry and rainy season. For the dry season this is the month of May, for the wet season, October is taken.

When looking at this table, a substantial percentual increase in rainfall is predicted in the dry season. These numbers may seem high, but given the low precipitation rates in dry season, the absolute increase will be relatively small. The percentages will be used to find the new values for the design rainfall as determined in 3.4.1.

5.1.2. Sea level rise

On average, the sea level along the coastline of Vietnam increased with a rate of 3.50mm/year with a deviation of 0.7mm over the last decades. With the global trend of increasing sea levels, the water level in the Vietnam East Sea will experience further increase in the future as well.

Since the Hau river regime at Can Tho, being 80 kilometre upstream, is dominated by tidal influence of the East Sea, the increase in sea level will affect the water near the city. For both RCPs, the increase in sea level in the Vietnam East Sea is presented in 5.1.

To find values for the increase in the Hau river water level at Can Tho caused by sea level rise, a comparable case area is reviewed. For this, a recent study in the Betna river is used. The Betna river is flowing through the Ganges delta in Bangladesh, and was studied to find the relation between sea level rise and the resulting increase in water level upstream [14]. As a result, the percentual increase in water level relative to the baseline year of 2014/2015 was found.

This percentual increase of water level in the Betna river is assumed to be usable for the Hau river, as they have several comparable characteristics:

- The Betna river regime is dominated by tidal influence;
- The Betna river (and point of measurement) is located in a low elevated delta area, as it lies ±3m above mean sea level;
- The rise in sea level of the influencing water body (northern Bay of Bengal) is predicted to be 0.1 to 0.3m in 2050, as stated in the AR5. This rise in sea level is comparable with the Vietnam East Sea, where a rise of 0.23m (RCP4.5) or 0.26 (RCP8.5) is projected;
- The measuring point in the Betna river lies ±100km upstream of the Bay of Bengal, where the distance between Can Tho and the Vietnam East Sea is 80km.

Given the similarities in both river systems, the percentages found for the Betna river are assumed to be valid for the Hau river as well. Where Islam et al. make a distinction between water level increase for ebb and flood tide, this is generalised to one daily value for the Hau river.

	Rainfall (%)		Hau river water level (%)	
	Dry season	*Rainy season*	*Dry season*	*Rainy season*
RCP4.5	43.8 (11.4÷72.7)	22.5 (9.6÷36.4)	10.9 (10.6÷11.3)	11.4 (11.1÷11.7)
RCP8.5	77.3 (33.3÷122.7)	21.0 (13.8÷28.3)	14.2 (13.9÷14.5)	15.5 (15.1÷51.8)

Table 5.1: Percentual increase for *Rainfall* and *Hau water level* in 2050 per RCP. Rainfall values are given relatively for the period 2046-2065; assumed for 2050 [18]. Water level river increase values are relative to baseline year 2014-2015.

5.2. Economic growth

Vietnam has the potential to be one of the worlds fastest growing economies over the period 2016-2050 in terms of Gross Domestic Product (GDP) per capita [11]. In the period to 2050, the average annual GDP growth per capita in Vietnam will be approximately 5%. This GDP growth per capita is estimated with steps of 10 years. The following percentages are predicted:

- 2016-2020 6.2 %
- 2021-2030 5.6 %
- 2031-2040 5 %
- 2041-2050 4 %

As shown above, the increase rate of the GDP per capita is declining over the years, however an annual growth remains until 2050 at least. With this high potential in Vietnam, it can be assumed that the estimated economic growth will be experienced in Can Tho city as well. Hence, a differentiation in positive economic growth is chosen for defining the scenarios.

Two projections regarding economic growth will be used for the creation of scenarios; a projection with a slight increase in GDP and a projection with high increase of GDP. This results in projection *Economic growth* +, where a slightly lower GDP growth rate per capita is projected and projection *Economic Growth* +++, where a larger economic growth rate is projected.

The polder system is affected by economic growth, as it influences the number of inhabitants. The number of inhabitants has an impact on the traffic flows as well as the volume of household effluent into the canals. Besides, a healthy economy will increase the possibility of connecting more houses to the urban drainage system.

The simulations for the scenario's are done with two estimated values for the economic growth. Since there is EG+ and EG+++ it is most reliable to to use 4% and 6,2% based on the predicted percentages shown above.

5.2.1. (Urban) population growth

The GSOV measured the population of Can Tho City to be 1.34 million in 2018. In the same year, percentage of the inhabitants living in urban areas (urban population) was found to be 67% [19]. Both numbers have increased over the past years, and are predicted to continue increasing [24]. With an empirical relation shown in the past, and expected in the future, it can be assumed that the increase in population and urbanisation are closely related. For the scenarios, it is important to estimate the population in Can Tho city until 2050. The GSOV has projected the number of inhabitants in Can Tho until 2034. By creating a second order polynomial fit, the data is extrapolated until 2050 (Figure 5.1). Since this gives the total population number, the population density estimated in Appendix B is necessary to compute the population numbers in the polder area.

Urbanisation

In Vietnam, a two-way causal relationship between urbanisation and economic growth is found; growth in economic wealth is caused by the urbanisation and vice versa [21]. However, if the urbanisation is increasing too rapid, this can have a negative effect on the economic

growth. According to Nguyen and Nguyen, if the urbanisation level is below 70%, the annual economic growth will be affected positively. However, when the threshold of 70% is exceeded, the annual economic growth will decline. This is presumably caused by the fact that local infrastructure can not handle the growing need for transport and logistics.
The urbanisation level is calculated as:

$$URB = \frac{P_U}{P_U + P_R} \tag{5.1}$$

with
URB: Urbanisation level [%]
P_U: Population in the urban area
P_R: Population in the rural area

As mentioned above, the current URB in Can Tho City is approximately 67%. It can be assumed that the URB, together with the population growth, keeps increasing and exceeds the threshold of 70% in 2050. Therefore, it is likely that the annual economic growth will decline. This can be confirmed with the estimated GDP-growth percentages presented in Section 5.2. As the polder area is mostly located in Ninh Kieu, which is an urban area, the urbanisation levels in the polder are assumed to be equal to that of Can Tho city. With this information the population can be estimated with a varying economic growth.

For the situation *Economic Growth* +++, the population should be less than the baseline projection (labelled *Median* in 5.1) since a larger economic growth is related to a smaller level of urbanisation (and thus population growth). The other way around, for the situation *Economic Growth* +, the population is assumed to be higher as the degree of urbanisation stays below 70%.

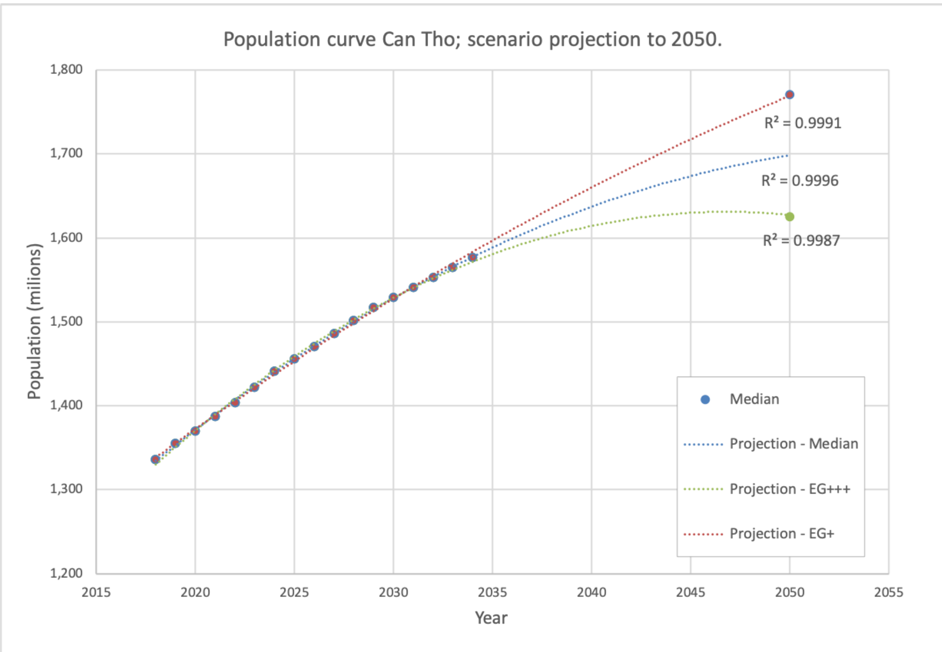

Figure 5.1: Projection of Can Tho city population for different economic pathways using second order polynomial fit in Excel.

Compared to the base year 2018 (labelled *Median*), the population will grow with 22% in the future with *Economic Growth* +++ and with 33% in the *Economic Growth* + situation. The calculations are found in Appendix B. These values are determined with different population growth scenarios by GSOV.

5.2.2. Connection to urban drainage system

As mentioned in Section 3.4.3, the waste water discharge of households can affect the water quality and quantity inside the polder area. With a general rise in prosperity within the city, it is assumed that more funds will be available to increase the livability. One of the urban aspects to improve is the grade of connectivity to the urban drainage system, as this has been mentioned in the current World Bank project as well as previous policy programmes. It is of importance as higher connectivity of houses to the sewer system will lead to more living comfort indoor and better conditions on the streets, since odour nuisance is prevented.

The current waste water discharge into the canals was calculated as 0.198 m3/s (see Appendix I). As the sewer system in Can Tho city is going to be improved and expanded, it is difficult to estimate the percentage of households that is going to be connected to the sewerage system in 2050. The goal is to connect all households to the sewerage system by 2050, but the plans of construction may be subject to change and there is a chance on delay. Therefore, different numbers are estimated.

For *Economic Growth* +++, it is assumed that a large amount of households will be connected, with an estimated value of 95%. When the economy grows, more people can afford access to the sewer system. The calculated waste water discharge for the future situation is given in Appendix I.2. Logically, it can be assumed that for the scenario *Economic Growth* +, the connectivity is lower compared to the *Economic Growth* +++ projection, but still higher than the current situation. The in this connectivity is estimated on a connectivity of 85% (See Table 5.2).

Situation 2050	Population	Household connectivity
Economic Growth +++	+21.68%	95%
Economic Growth +	+32.55%	85%

Table 5.2: The two pathways regarding economic growth, *EG*+++ and *EG*+ and their values for population (relative to 2018) and household connectivity.

5.3. Possible futures

With the identification of two important aspects of the future, with each generating two pathways, four scenarios can be created. As shown in Figure 5.2, on the vertical axis the scenarios for climate change are sketched. The most favoured pathway is RCP4.5, where the climate change related to water level rise and rainfall is less severe than in RCP8.5. Still, both of the scenarios on the vertical axis are related to negative effects on climate change, as it is assumed that the greenhouse effect will develop in the coming years till 2050.

The variations in economic growth are sketched on the horizontal axis. The most desired economic growth is *EG*+++, which corresponds with being one of the largest growing economies in the world for the period 2018-2050. On the other side of the axis, *EG*+ is found, with a lesser economic growth.

The four scenarios (tagged *I, II, III and IV*) will differentiate on the vertical axis with values for rainfall and Hau river water level (influenced by sea level rise) and the speed of the roads. On the horizontal axis, the population growth and household effluent (influenced by household connectivity) will define values for the scenarios. The values per scenario are presented in 5.2. Note that the values for the design rainfall in the dry period is neglected, as it is assumed zero.

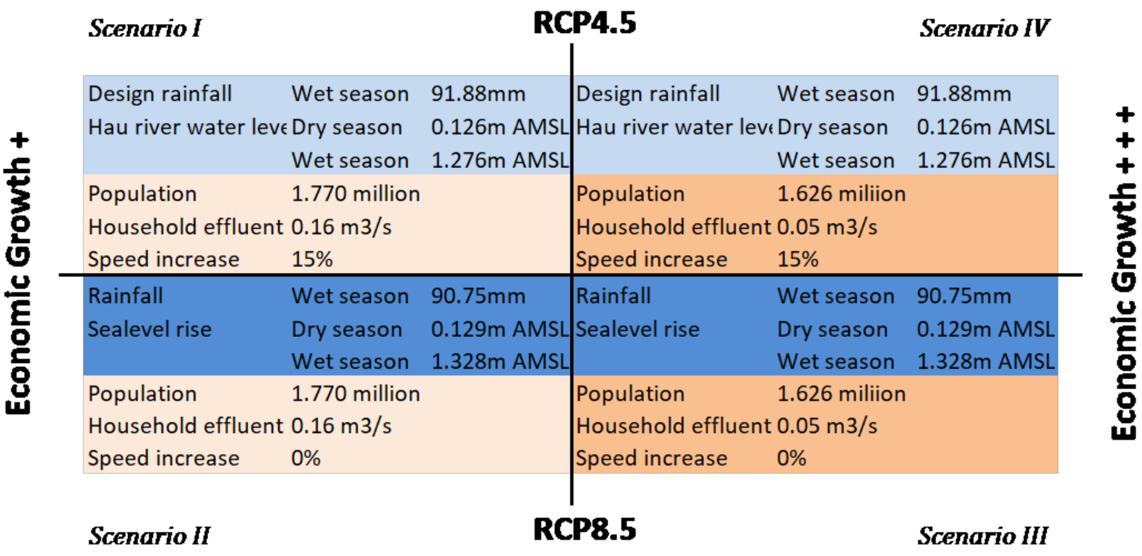

Figure 5.2: Creation of four scenarios, using two pathways on two axes.

6 Results

Four scenario's are simulated in the hydraulic model and the Four Step Model. This chapter discusses the outcomes and relations between the rainfall, floods, and the accessibility of the study area. Scenarios I and IV represent a future environment where less water is involved. On the other hand, heavy rainfall is included in scenarios II and III.

The Four Step Model simulates the water level difference in the study area as a difference in speed on the roads. The higher the watter level in the city, the lower the speed will be. In this case, the flow of the network changes due to travel time differences. As mentioned before, the future model in section 4.9 of the transport model represents a flow which only includes the two new roads. In order to have more reliable outcomes, the scenario analysis uses data where dykes and sluices can regulate the water quantity in order to have less floods. The following sections elaborates and discusses the four different scenario's. Appendix N show the used numbers for economic growth and inhabitant growth, the new speed limits and, the result graphs of the lane intensities of the four scenario's.

The SSWES model will be used to check the water depth and height at one specific point in the case area. The chosen test point lies at the location where the tributary of the Cai Khe canal flows towards the Xang Thoi lake, and is labelled with *node 3* in the model and Figure 6.1. This location is chosen as it lies in the flood-prone urban area and is known to be inundated regularly [41]. Both the results of the wet and the dry season will be inspected.

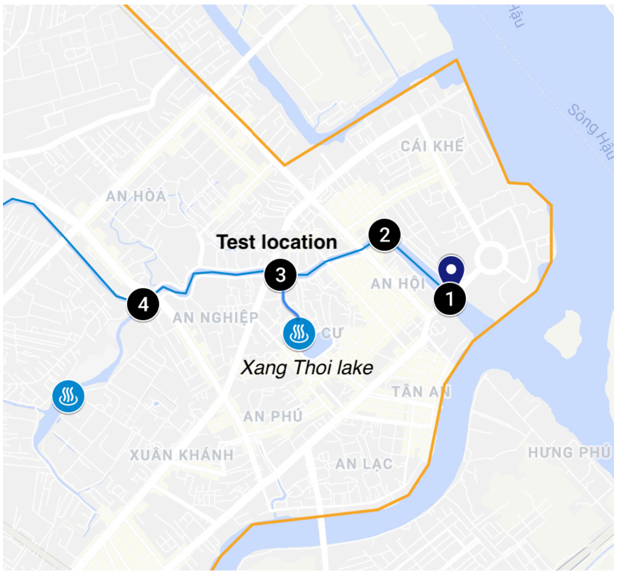

Figure 6.1: Location of test node in hydraulic model. Retrieved from Google MyMaps.

6.1. Scenario I

The scenario simulating an economic growth of 4% and an inhabitant growth of 32,5% with a speed increase of 15% provides the highest total flow of traffic in the city of Can Tho compared to the other scenario's. The impact of the flood dynamics in a situation where less water needs to be regulated intensifies the amount of trips. Model results indicate that the construction of the dykes and sluices has a great effect on the traffic flow of the city. Dykes and sluices prevent water from entering the roads of the study area of Can Tho and this suggests that more trips will flow over the roads. The simulations, however, could not determine what roads are affected more due to less floods. Besides, a larger amount of trips results in a higher pressure on the network. Since the capacity of the road network is not taken into account, the effect of the larger amount of trips on the network could not be determined. No study has yet analysed what the capacity of the road network is.

The relationship between GDP growth and demand for infrastructure can be structured as follows. A GDP growth results in an increase in traffic demand and this requires changes in traffic supply. Moreover, in low income countries, basic infrastructure such as water and irrigation are more important. Studies have also revealed that generally around 6.5 percent of the total value added is contributed by infrastructure services in low income countries. However, infrastructure has a two-way relationship with economic growth. One, infrastructure promotes economic growth, and two economic growth brings about changes in infrastructure.[17] Overall the distribution and trip assignment provides useful information in order to determine the new pressure on the network. This is the case for all scenario's.

For the hydraulic aspect, the details in node 3 are presented in figures 6.2 (dry season) and 6.3 (wet season). In this scenario, the RCP4.5 is used as the climate change pathway. The inflow starts around 11AM when the Hau river water level is above the +0M as the sluices are defined. With this inflow, the water level inside the polder is starting to increase. When taking a look at the water height of node 3, it shows that it has a maximum water height of +0.7m AMSL. This means that no flood occurs at node 3, as the threshold is set to +1m (see 3.1). With this, no floods are assumed in the polder area and therefore the speed of the traffic on the network is at highest. This is expected, as the Hau river water level is relatively low and the rainfall runoff is equal to zero over the day, as shown in the lower part of Figure 6.2.

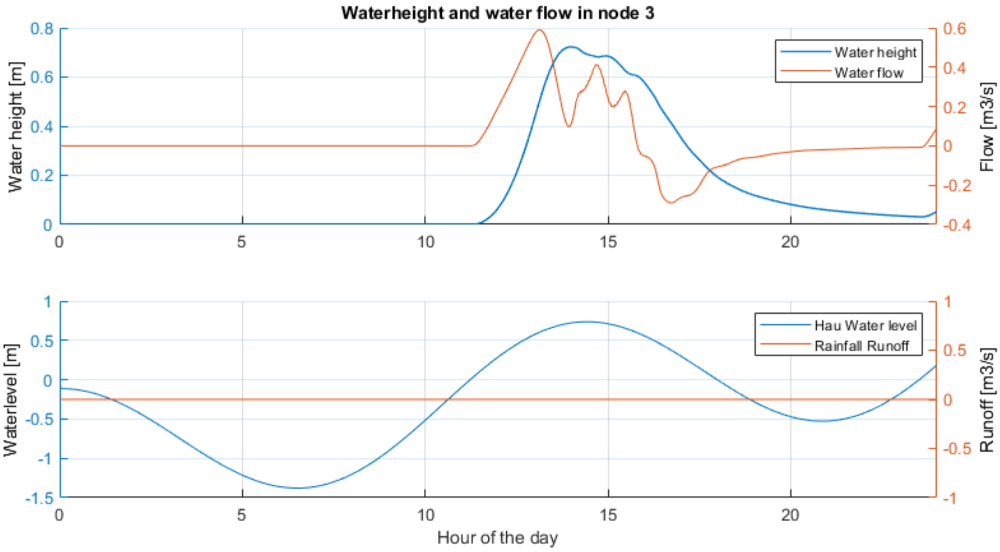

Figure 6.2: Water height and water flow in node 3 during dry season (RCP4.5)

During the wet season the Hau water level is higher and has a different curve, this can be seen in the lower part of figure 6.3. Also, rainfall enters the polder area, starting at 4:30AM. The runoff of this rainfall, can be found as a sinusoidal shape over three hours in the graph. Around the 3rd hour, the Hau river water level exceeds the threshold value of +1.05m AMSL. This can be seen at the stagnation of the water height and the dip in flow. Only a result reaction of the direct stop of the flow is working in the system as minor waves. Again, no floods are observed as the maximum water height is at 0.97m AMSL.

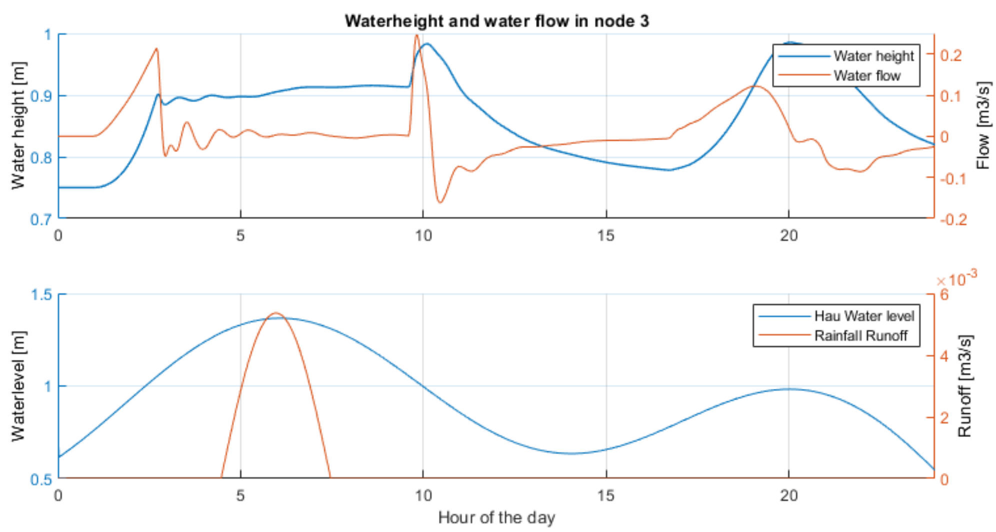

Figure 6.3: Water height and water flow in node 3 during wet season (RCP4.5)

6.2. Scenario II

The model of scenario II uses data which focuses on an economic growth of 4% and an inhabitant growth of 32,5%. In comparison with scenario I, less trips are assigned on the network. The impact of the flood dynamics where the network needs to cope with more water due to heavy rainfall, is determined via the same speed on the lanes as in the base year. This results in a total amount of trips of 3.169.636 which is 10 percent higher than the base year.

For the hydraulic aspect, the details in node 3 are presented in figures 6.4 (dry season) and 6.5 (wet season). In this scenario, RCP8.5 is the present pathway of climate change.

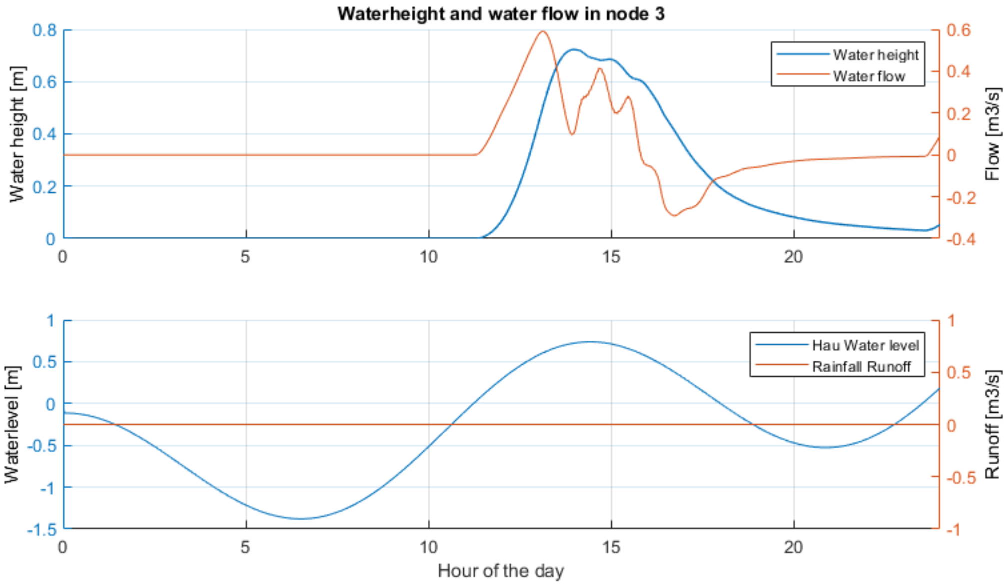

Figure 6.4: Water height and water flow in node 3 during dry season (RCP8.5)

In the dry season, the water levels are under control. No floods are found, as the water height remains under the threshold value of +1.05m AMSL. All the water flows naturally through the centre.

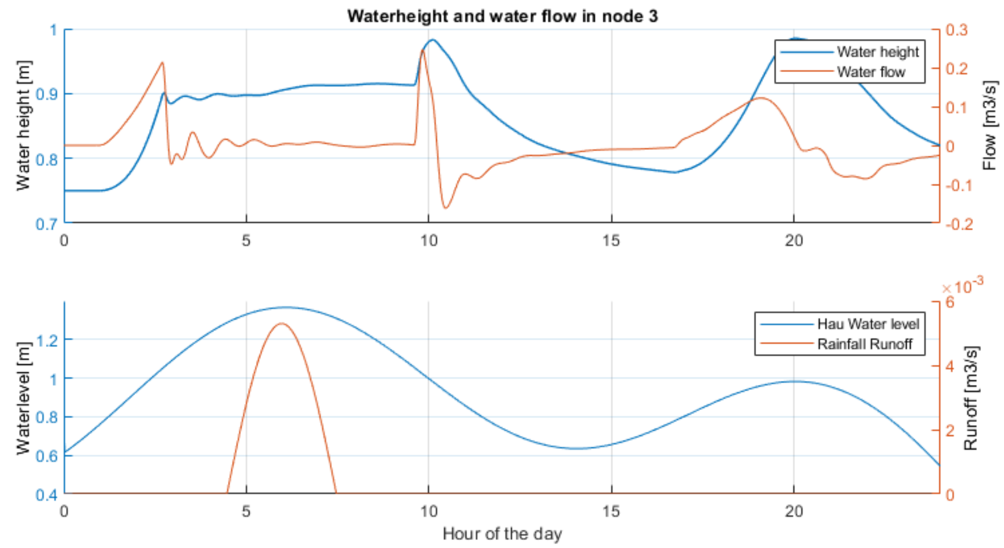

Figure 6.5: Water height and water flow in node 3 during wet season (RCP8.5)

The wet season brings a higher Hau water level is higher and heavy rainfall. Like the wet season in the RCP4.5 pathway (Section 6.1), there are no floods to be detected as maximum water height is at 0.97m AMSL.

6.3. Scenario III

Scenario III represents a future situation where inhabitant growth of 21,7% and an economic growth of 6,2%. The scenario includes a higher flood risk than scenario I and IV and resulted in the lowest predicted amount of trips. This scenario is based on a situation where an increase in rainfall is observed which allows travellers to have an average speed on the network. Although the economic activities increased, the influence on the network based on the employment, is limited.

In this scenario, the parameters for the hydraulic model are the same as in *Scenario II*. Therefore, the outcomes are identical and can be found at Section 6.2.

6.4. Scenario IV

A growth of 21,7% of inhabitants and an economic growth of 6,2% results in an amount of trips of 3.042.443, which is 4 percent higher than the base year. The infrastructure does not suffer from disturbances since the city is cut off from flooding, the speed of the travellers is slightly higher than the base year. Despite the rapid expansion of the economic activities in the city, the changes in amount of trips is limited.
In this scenario, the parameters for the hydraulic model are the same as in *Scenario II*. Therefore, the outcomes are identical and can be found at Section 6.1.

6.5. Conclusion

To sum up on the outcomes of the Four Step Model, Figure 6.6 shows that the amount of trips per scenario differs. Relating the outcomes of the simulated scenario's and the base year flows, an increase for all cases is noted which is depicted in Figure 6.7.

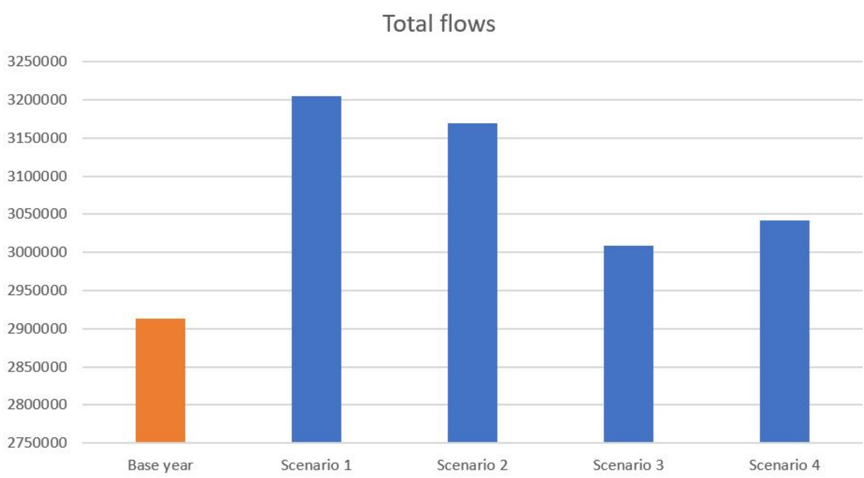

Figure 6.6: Total flows per scenario

The hydraulic model shows that between the two pathways, the difference in maximum water height is ±0.27m. Besides, a conclusion can be made about the flood risk in the dry season; in neither of the scenarios there is a threat to the water safety.

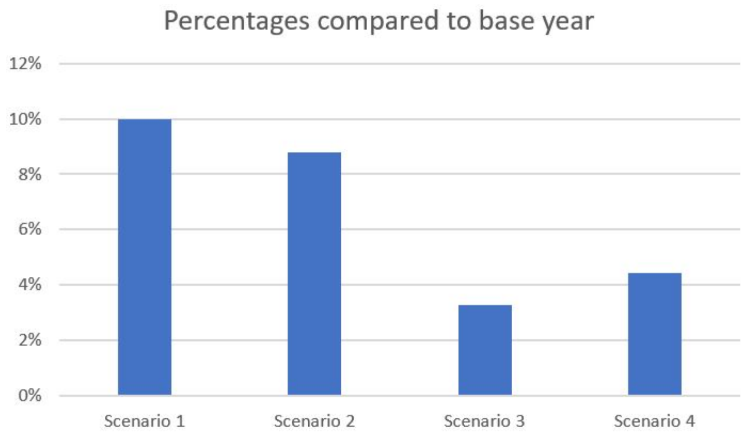

Figure 6.7: Difference percentages

7 Conclusion

Heavy rainfall, tidal surges, poor drainage and land subsidence cause floods in the city of Can Tho on a regular basis. The last five years the floods have led to damages of more than US$300 million. For this reason, the World Bank launched plans to improve the resiliency of the city by supporting cities which have to cope with heavy floods. Therefore, this research is focused on the development of a polder system, which manages the floods with tidal sluice gates, retention lakes and embankment structures. By creating this polder system, a change in infrastructure in and around the city consists of new bridges and roads in order to improve the resiliency and economic growth.
Therefore, this research is used to analyse the following question: **How can the urban polder contribute to the resiliency of Can Tho city, regarding the control of water within the polder and the impact on the transport and infrastructure?**

In the current state analysis, both hydraulic and transport factors are analysed. It became clear that the main focus points which is needed to be studied are, the proposed flood control systems based on sluices, gates and retention lakes. These systems will regulate the water level in the city. Besides that, the impact of the traffic flow on the planned infrastructure implementation proposed by the World Bank was analysed. Therefore, a model of the hydraulic aspect, as well as the transport/infrastructural aspect was created to model traffic and water flows.

In this study, it is shown that the hydraulic system regarding water height and water discharge of connected canals in the polder area can be modelled using a SSWES. This solver uses Saint-Venant equations to simulate the water flow in the primary canals of the proposed polder in Can Tho City. Tidal sluices or gates can be implemented as a spillway at variable heights depending on the water height outside the polder area. The model shows that the proposed polder system, with proper control of the tidal gates, contributes to an improvement in flood control even for high water levels and extreme rainfall. There is a difference in maximum water height of 0.27m between the scenarios. As the rainfall is almost the same in both climate change pathways, it can be concluded that the difference in maximum water height is caused by the increase of sea level rise.

The transport model showed that the implementation of the new roads and bridge lead to a change in routes. Travellers have the option to use a faster route to their destination where the All Or Nothing trip assignment is used. In the surroundings of the two new roads, the flow changed and travellers opt to use the new roads which have a speed limit of 60 km/h.
Scenario analysis in four situations provided information for the amount of trips where inhabitant growth and economic growth together with flood risks are determined. This resulted in a range of increase in trips on the network of 3-10%. It should be noted that an increase of trips may not serve as a positive impact on the network as the capacity of the lanes is not taken into account in the model.

To conclude, infrastructure and hydraulic structures for the proposed polder system will contribute to an improved resiliency of Can Tho City in base year and the future regarding road connectivity and flood control. However, to keep improving the resiliency of Can Tho City, investments in infrastructure for both hydraulic and transport structures have to be made for years past 2050.

7.1. Discussion

After obtaining the conclusions of the hydraulic model and the Four Step Model, it is important to describe the validity of the models and point out the limitations. Besides, recommendations for further research are composed.

7.1.1. Limitations transport model

The transport model is based on a couple assumptions and should be analysed critically. Firstly the Four Step Model, where it has to be stated that the used data is not fully representative to the real population. The assumptions on the population are made using Google Maps to measure important information. The measured information has been mixed with data about the density of parts of Can Tho City which was also based on assumptions. Furthermore, a distinction between the age of the population is missing and therefore conclusions about the population are generalised.
Moreover, the employment of Can Tho city is also based on assumptions. Due to the lack of data about socio-economic factors of the city, the total amount of trips depends in this study only on the inhabitants and the employment.
Besides that, the determination of the modal split of motor bikes and cars is done via an assumption which is applied for the defined study area, so that the amount of motorbikes is generalised.
Further criticism to the data may relate to the fact that the counts are done during high tide. This affected the average travel speed of many roads which can lead to changes in travel behaviour and therefore detours could be chosen. The calculated results of the model are generally higher then than the real-time counts. This can be explained by possible counting errors that can occur during manual counting [43]:

- Counting error: there is a difference between the number of vehicles counted and the true number of vehicles in the same interval
- Classification errors: the number of vehicles which have been classified in the wrong classes

To avoid the second error, every vehicle on the road is counted and multiplied by a percentage of the motorbikes.
In the end, the results of this study has shown large differences between the base year and the future year of 2021. It should be noted that this research is based on the upcoming three years and the only differences in the model are the new roads, economic growth and population growth. Besides, congestion and capacity is not included in the Four Step Model due to the lack of data. Step 4 of the Four Step Model includes the trip assignment. To determine the routes, travellers choose to reach their destinations, however a congested corridor might change the chosen route.

7.1.2. Limitations hydraulic model

The hydraulic model contains a few limitations. Firstly, the rainfall is inserted in the model as runoff. The runoff is calculated using area characteristics and estimations of flow directions. As the runoff can be very complex a more precise calculation is needed for a more accurate model.
Secondly, the research area is schematised using only the primary canals in the area. Secondary and tertiary canals are neglected to decrease the computational time. For a more advanced model, these canals should also be taken into account.

Thirdly, rough information about the elevation of the research area is used. Based on this information, the height of the land around the canals is estimated on +1.0M. This height is taken as boundary condition for a flood to occur, but can be very different along the canals. More information about the elevation of the area is needed to determine the possibility of flooding.
Besides, the current capacity of the sewer system in the research area is not sufficient and therefore not taken into account in this research. If the capacity is increased, it could have influence in the runoff of the rainfall and should be taken into account.
At last, the future increase in water height of the Hau river is only based on the sea level rise. Not only this relation can be doubted as it is based on a research from an other river with different characteristics, because of the lack of data and future projections about the Hau river. The Hau river height is also influenced by upstream rainfall, which should be taken into account in the future Hau river height.

7.1.3. Validation

As mention in Section 3.6 more extensively, a full validation of the hydraulic model is not done and comprehensive to realise. A validation of the basic model is done by the TU Delft, which is extended in this research. The results of the model with the different scenarios are realistic and logical, which contributes to a success full validation of the model. However, all outcomes should be looked at critically.

A validation for transport model is done by comparing the counted data with the estimated data on socio-economic activities. These values did not match well, which can be explained by possible counting errors together with the assumptions that have to be made in the model. All the outcomes should be looked at critically.

7.2. Future research

This section provides suggestions or future research that could improve the outcomes related to the improvements of the resiliency of Can Tho City.

Research focusing on the counting method of the traffic flows can be very effective for more reliable outcomes. One could look at the inductive loops since this method avoid the double counting principle. Further research could also focus on the implementation of a model where congestion and the capacity of the lanes is taken into account. This will gather information in the trip assignment when changes in routes occurs. The model is only based on motor bikes, further research can introduce the modal split. In addition, it is recommended to gather more reliable data about the inhabitants of the city and the employment of these people to obtain more factual results of the trip distribution.

Further research based on the hydraulic part of this report could focus on the water quality of the city. For the developed model the sewage discharge in the canals was of no significance and is not included but can be included if it has a significant capacity. Additionally, other factors that influences the water quality of Can Tho City can also be taken account. For example, the data obtained in this study about household effluent can be used to estimate the amount of added contaminated water to the system. Together with basic qualitative observations, that quickly determine if water is not safe, the hydraulic model regarding water quality can be improved. Furthermore, noncontinuous flow of water could lead to a decrease in water quality which affects the health of the inhabitants. By using SSWES, it should be able to indicate spots where water flow is not continuous or even a canal that is dried out. In combination with domestic waste and waste water discharged directly into the canals, waste will get stuck or will not leave the affected area due to a larger percentage of untreated waste water. When improving the hydraulic model with water quality aspects, the model can be of greater significance for simulating the whole polder system.
The rainfall in the polder area is taken into account as runoff in the canals. The runoff input is simplified and will need a more precise calculation as it is dependent on multiple variables

around the canals. In the schematisation of the research area, only a distinction is made between green (partly infiltration, partly runoff) and residential (100% runoff) area for the infiltration/runoff rate. Also, an estimation is made for the runoff duration and distribution. A comprehensive runoff calculation is needed in the future to obtain a more precise model, especially if the runoff is more significant.
The water heights around the polder are, regarding the relatively small distances, assumed to be equal at every input gate. However, these heights are dependent on more factors than only the distance. However, this assumption for a simple model is valid, for further research on improving the model it is advised to include these additional factors.
With the SSWES model, a control plan for the polder system can be created to optimise the working of the polder. Sluices can be scripted with rules of their opening and closing times and pumping stations can be added in the model to find their influences and possibilities in the system. In addition, the capacity of the sewer system can be added to obtain a more complete hydraulic model in the future. This can only be done if the capacity of the sewer system is sufficient to capture rainfall and cope with high tides.

A

Site visit Can Tho City

Appendix A contains the site visit of Can Tho City at 10-09-2018 till 12-09-2018 and 10-10-2018 till 12-10-2018.

A.1. Site visit 1

The objectives of the first site visit are given in Table A.1. The overall objective of the first site visit was an introduction to the resilience group of Mr. Trung at the Can Tho University. In the meeting with Mr. Trung we were able to obtain information about the current status of the project.

Objective	Methodology
1. Inspection of the current state of the project	Interviewing
2. Inspection of the flooding	Renting motorbikes Photographing Video taping
3. Mapping the project area	Renting motorbikes Photographing Video taping

Table A.1: Site visit 1

A.1.1. Observations

1. Mr. Trung showed us a map of the geographical scope of the constructed polder before 2020 and the expanded version before 2030. Some parts of the dykes were already in construction, however most of the dykes are going to be built in the coming years. Different locations for planned sluices/gates are also shown during the meeting with Mr. Trung.

2. During high tide the team went to several spots were flooding was going to occur. Here we witnessed flooding of approximately <30 cm. Several houses were flooded. An important observation is that mostly poor people are affected by these flooded areas.

3. Renting motorbikes to inspect the construction of the dykes and sluice gates. The dykes are not what we expected. The constructed dykes were bricked walls at the riverside to protect the urban area against high tide. Traditional Dutch dykes made of sand or clay are not possible to build here, because a lot of people are living directly at the riverside.
We also drove towards different locations were sluices/gates are going to be build. No sluices were found. So construction of the sluices are not started yet.

A.2. Site visit 2

The objective of the second site visit is to count motorbikes and cars in different areas in the polder. For two days, the traffic is counted in the morning rush hour. With the counted traffic a model can be developed to map the traffic flows in the urban core of the city. Besides counting traffic, the construction of several parts of the polder and flooded areas are inspected.

Objective	Methodology
1. Counting traffic	Using counters at zone intersections
2. Inspection of the construction	Renting motorbikes Photographing Video taping
3. Inspection of the flooding	Renting motorbikes Photographing Video taping

Table A.2: Site visit 2

A.2.1. Observations

1. Splitting the group in the morning rush our from 6:00 till 7:30am and place them at the zone intersections to count the in- and outflow of traffic towards the different zones. At every intersection, several times for a duration of 1 minute, traffic is counted by using our mobile phones. Cars and motorbikes are included in the counting. Important to mention is that we observed more traffic coming into the city than going out of the city, presumably caused by people who have a job in the urban core of Can Tho City.

2. By using a more detailed map of the construction works planned for the polder, a day is picked to drive around these spots by motorbike. Clearly observed are the dredging works and expansion of the biggest retention lake Bun Xang just behind Can Tho University. Works of the tidal sluices and gates were not started yet. However, at some spots enormous signs were placed with the drawings of the planned construction works and the executor companies. Here is indicated that the construction is going to be started soon.

3. During our second visit in Can Tho City, there was a very high tide. The floods compared to the one observed before was clearly more fierce. Water came up to half a meter. Every time high tide came in, the water started overflowing in the sewers, which indicates the poor capacity of the sewer system. Residents were protected from the water, by building barriers made of benches or sand sacks.

B

Population in case area

B.1. Current situation

It is difficult to obtain data about the current population density in the polder area. This is because several documents with plans about the polder area are published in 2015. Therefore, this appendix gives an estimation of the current population density in 2018.
First the most accurate estimation have to be found. This value is given in a document by the World Bank. The estimated population density in the polder area (Ninh Kieu district) is $8737 people/km^2$ in 2015 [28]. The surface area of Ninh Kieu is $29.27 km^2$. Around 21% of the population in Can Tho lives in the Ninh Kieu district [6]. If we assume that this percentage is still correct in 2018, we can estimate the current population in Ninh Kieu.
The population in 2018 is derived from the report of the GSOV with a value of 1,336,000 [27].

Now we can calculate the population in Ninh Kieu using:

$$Population\ NK = 0.21 * 1336000 \tag{B.1}$$

After that the current population density in the polder area is estimated as:

$$Population\ density\ polder = Population\ NK/29.27km^2 \tag{B.2}$$

This gives a population density in the polder area of approximately $9585 people/km^2$.

B.2. Future situations

Using the projection data of Figure 5.1, the estimated population growth in the period 2018-2050 is grown by a factor 1.27. This growth is based on a trend line with population values from 2018 to 2034, and does not take the different economic pathways into account. Table B.1 shows the values for total population, Ninh Kieu population and Ninh Kieu population density for the two economic pathways.

Pathway	Growth rate	Pop. Can Tho [-]	Pop. NK [-]	Pop. dens. NK [people/km^2]
Median	1.27	1,698,165.3	424,541.3	14,504.3
EG+	1.33	1,770,833.7	442,708.4	15,125.0
EG+++	1.22	1,625,595.0	406,398.8	13,884.5

Table B.1: Population values for different economic pathways.

The urbanisation is likely to grow according to Section 5.2.1. Using the same formulas as presented above, the population densities in 2050 are calculated. In this calculation, the urbanisation grade is assumed 25%, saying that a quarter of the overall Can Tho population lives in Ninh Kieu compared to the 21% in 2018.

C

Characteristics hydraulic model

In Table H.1, the characteristics of the canals, retention lakes and tidal gates/sluices used in the hydraulic model are presented. Note that every canal is modelled as a rectangular block with constant depth. This canal depth is taken from the SIWRR model, mentioned in Chapter 3. For the estimation and description of the Chezy coefficient, see Appendix D.

Canal	Name	Length [m]	Average width [m]	Bottom level [m]	Chezy coefficient [$m^{1/2}/s$]
1	Cai Khe 1	640	110	-3.5	41
2	Cai Khe 2	800	40	-3	40
3	Cai Khe 3	1130	40	-3	40
4	Cai Khe 4	2398	25	-3	40
5	Sao	1510	6	-2	37
6	Ba bo	1810	10	-2	37
7	Suc	1560	20	-2	37
8	Lang Dai Hoc 1	600	10	-2	37
9	Lang Dai Hoc 2	1230	10	-2	37
10	Hang Bang	1500	15	-2	37
11	Dau Sau	3366	19	-2	37

Retention lake	Name	Area [m^2]	Bottom level [m]
1	Xang Thoi lake	45000	-2.5
2	Long Hao lake	67774	-2
3	Lang Dai Hoc lake	51931	-2
4	Bun Xang lake	18000	-2

Node	Gate name	Type
1	Cai Khe	Tidal sluice with shiplock
6	Sao	Tidal gate
8	Suc	Tidal gate
10	Pho Tho	Tidal gate
11	Hang Bang	Tidal sluice with shiplock
12	Dau Sau	Tidal sluice with shiplock

Table C.1: Characteristics of the canals, retention lakes and tidal sluice/gates used in the hydraulic model.

D
Chezy Coefficient

The model needs the Chezy coefficient of the canal to eventually calculate the water height or discharge at a certain node. This coefficient is needed to calculate the flow velocity in a channel. To estimate the Chezy coefficient, the Manning roughness coefficient is used in the following formula:

$$C = \frac{1}{n} R^{\frac{1}{6}} \tag{D.1}$$

with
C: Chezy coefficient [$m^{1/2}/s$]
n: Manning roughness coefficient [-]
R: Hydraulic radius (water depth) [m]

The Manning roughness coefficient can be looked up in tables and is assumed to be the same for every canal. This coefficient is estimated as 0.03.[39]

E

Soil properties Can Tho City

According to soil data test in Mekong Delta soils, most of the samples are composed out of silty clay with sandy textures [22]. These samples are taken of agricultural fields distributed over a large area. Using SoilGrids, the soil in Ninh Kieu District is composed of 34% clay, 26% silt and 40% sand. Using Figure E.1, sandy clay matches the obtained data best. In conclusion, for further calculation of the infiltration in the polder area, soil properties composed of sandy clay are used. For detailed description of the calculations, see Appendix F.

Soil Texture	Porosity	Hydraulic Conductivity (m/d)	Irreducible Water Content	Displacement Pressure Head* (m)	Pore Size Distribution Index
Clay	0.38 (0.09)	0.048 (0.10)	0.068 (0.034)	1.25 (1.88)	0.09 (0.09)
Clay loam	0.41 (0.09)	0.062 (0.17)	0.095 (0.010)	0.53 (0.42)	0.31 (0.09)
Loam	0.43 (0.10)	0.25 (0.44)	0.078(0.013)	0.28 (0.16)	0.56 (0.11)
Loamy sand	0.41 (0.09)	3.5 (2.7)	0.057 (0.015)	0.081 (0.028)	1.28 (0.27)
Silt	0.46 (0.11)	0.060 (0.079)	0.034 (0.010)	0.62 (0.27)	0.37 (0.05)
Silty loam	0.45 (0.08)	0.11 (0.30)	0.067 (0.015)	0.50 (0.30)	0.41 (0.12)
Silty clay	0.36 (0.07)	0.0048 (0.0260)	0.070 (0.023)	2.0 (2.0)	0.09 (0.06)
Silty clay loam	0.43 (0.07)	0.017 (0.046)	0.089 (0.009)	1.0 (0.6)	0.23 (0.06)
Sand	0.43 (0.07)	7.1 (3.7)	0.045 (0.010)	0.069 (0.014)	1.68 (0.29)
Sandy clay	0.38 (0.05)	0.029 (0.067)	0.100 (0.013)	0.37 (0.23)	0.23 (0.10)
Sandy clay loam	0.39 (0.07)	0.31 (0.66)	0.100 (0.006)	0.17 (0.11)	0.48 (0.13)
Sandy loam	0.41 (0.09)	1.1 (1.4)	0.065 (0.017)	0.13 (0.066)	0.89 (0.17)

Figure E.1: Mean (standard deviation) values of soil water retention parameters used for infiltration calculation obtained from Carsel and Parrish, 1988

F Runoff calculation

For calculating the runoff and infiltration, the Green-Amp infiltration model is used. The defined constants are summed op below using the parameters of sandy clay:

P: Rainfall = 50 mm/h
K_s: Hydraulic conductivity = 0.029 m/d = $29/24$ mm/h
θ_r: Irreducible water content = 0.1
θ_i: Initial soil moisture content = 0.17
n: Porosity = 0.38
ψ_b: Displacement pressure head = 0.37 m
λ: Pore size distribution index = 0.23

First we have to check if the hydraulic conductivity is lower than the rainfall, otherwise everything will infiltrate and there is no runoff. In this case

$$K_s < P \tag{F.1}$$

which means we have to calculate the runoff.
The next step is to calculate t_p which is the time that the soil is saturated and runoff will start. t_p is calculated as:

$$t_p = \frac{aK_s}{P(P - K_s)} \tag{F.2}$$

To calculate t_p, the parameter a is needed and is calculated as follows:

$$a = (y_s - y_f)\Delta\theta_i \tag{F.3}$$

With:
$y_f = -\frac{(\psi_b/2)(2+3\lambda)}{(1+3\lambda)}$: water pressure at wetting front
$y_s = 0$: if it is assumed that there is no ponding of water on land surface
$\Delta\theta_i = n - \theta_i$

With all this formulas, t_p can be calculated. The last step is to calculate the cumulative infiltration and runoff which have to be solved iteratively for I (infiltration) in the following formula:

$$I - Pt_p - a\ln\left(\frac{I + a}{Pt_p + a}\right) = K_s(t - t_p) \tag{F.4}$$

This is done using MATLAB, which gives I = 12.94 mm/h and runoff = 37.06 mm/h

G

Hau river water level data fit

Using hourly water level data from 2001-2011, data from the extreme days in this period is collected to use in the SSWESS model. The found days are in May 2005 (dry season) and October 2011 (wet season). Since the water level during a day behaves like a sinusoidal curve, this curve is used as base for the fitting. This base is also not too complex and therefore easy to implement as function in the model.

Fitting
To fit the dry season water level a sum of sine curve is used with 3 terms:
General model Sin3:

$$f(x) = a1 * sin(b1 * x + c1) + a2 * sin(b2 * x + c2) + a3 * sin(b3 * x + c3) \quad (G.1)$$

Coefficients (with 95% confidence bounds) (Goodness of fit RMSE: 0.008944):
a1 = 0.1225 (0.07371, 0.1713)
b1 = 0.4166 (0.3465, 0.4867)
c1 = 0.2975 (-0.4053, 1)
a2 = 0.1191 (0.07033, 0.1679)
b2 = 0.6376 (0.577, 0.6983)
c2 = -3.625 (-4.268, -2.982)
a3 = 0.4497 (0.3788, 0.5207)
b3 = 0.2148 (0.1767, 0.253)
c3 = -1.912 (-2.244, -1.579)

The result of this fit can be seen in figure G.1.

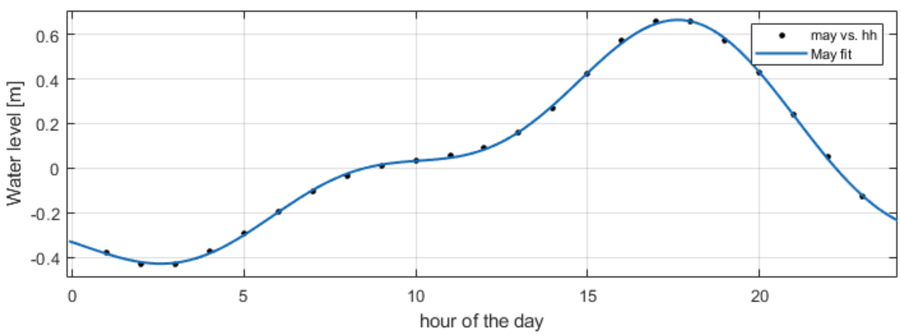

Figure G.1: Dry season water level data and fitted curve

To fit the wet season water level a sum of sine curve is used with 2 terms:
General model Sin2:

$$f(x) = a1 * sin(b1 * x + c1) + a2 * sin(b2 * x + c2) \quad (G.2)$$

Coefficients (with 95% confidence bounds) (Goodness of fit RMSE: 0.03402):
a1 = 1.02 (0.9939, 1.045)
b1 = 0.07071 (0.05225, 0.08917)
c1 = 0.9808 (0.6477, 1.314)
a2 = 0.299 (0.26, 0.338)
b2 = 0.4122 (0.3804, 0.444)
c2 = -0.8578 (-1.31, -0.406)

The result of this fit can be seen in figure G.2.

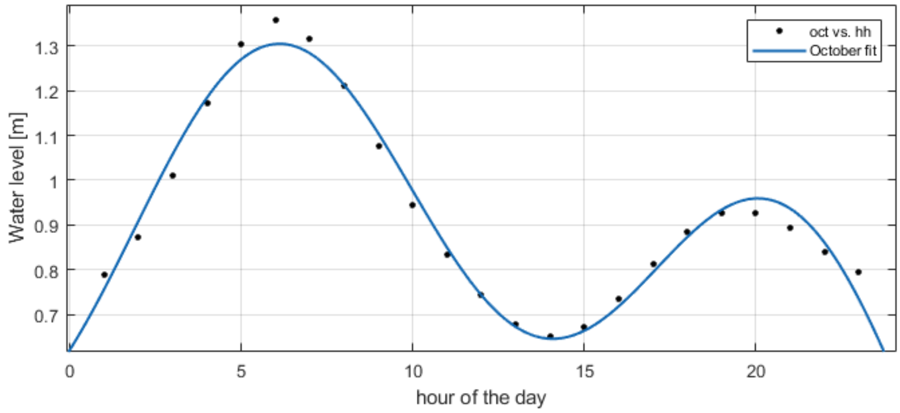

Figure G.2: Wet season water level data and fitted curve

H Phase difference calculation

The water level for the Hau river is determined and used for the outside water level of the model at each of the sluices. However, since the sluices are several meters apart, it is necessary to calculate the phase speed or the group velocity of the tidal 'wave'. Subsequently, the phase difference, resulting in the difference in water level, at the gates can be calculated. First, the shortest distances from a fixed point located in the Hau river (measured over the canals) to the gates is estimated using Google MyMaps. These are given below:

Node	Gate name	Distance from Hau river fixed point [m]
1	Cai Khe	-
6	Sao	10300
8	Suc	11350
10	Pho Tho	10620
11	Hang Bang	9060
12	Dau Sau	6200

Table H.1: Distance from a fixed point in the Hau river towards every gate used as input for the model

Second, the wave period T [s] for the graphs in Figure **??** are calculated using the difference between the two peaks. For both Figure G.1 and G.2 the wave period is approximately 14 hours or 50400 s.
Now it is important to choose the right equations to calculate the phase speed of the tidal wave. We use the Eckart (1952) formula to prove that we can use shallow water equation. The Eckart formula is given as follows:

$$kd \approx \alpha(\tanh\alpha)^{1/2} \qquad \text{with} \qquad \alpha = \omega^2 d/g \tag{H.1}$$

Where:
k: wave number [-]
α: Eckart constant [-]
ω = 2π/T: wave frequency [rad/s]
d: water depth [m]
g: gravitational constant [m/s^2]

The group velocity is given by a factor n times the phase speed c [m/s]:

$$c_g = nc, \qquad \text{where} \qquad n = \frac{1}{2}(1 + \frac{2kd}{\sinh 2kd}) \tag{H.2}$$

If the factor n goes to the value 1, then shallow water equation can be used. So, for shallow water equations holds:

$$c_g = c \tag{H.3}$$

First we need an approximation of the water depth around the polder to finish the calculation and check if we can use shallow water equations. It is found that the Can Tho river is approximately 14m deep, while the smaller canals are going to be dredged to 2.5m depth[38]. As approximately 2/3 of the gates are located at canals of 2.5m deep and 1/3 at 14m deep, the estimated average depth around the polder is 6.27m.
Now with use of the Eckart approximation, it can be calculated that n is actually equal to 1, which means we can use shallow water approximations.
For shallow waters holds:

$$c = \sqrt{gd} \tag{H.4}$$

Making use of the estimated distances from the gates to the fixed point shown in Table H.1, the phase difference in seconds can be calculated. The maximum phase difference is 0.402 hours. When implementing the phase difference of 0.402 hours in the graphs above, the maximum water height that is different from the fixed point at a certain moment is 0.05m. It is chosen to neglect the water height differences that occur at a certain moment in time for different gate locations.

I

Calculation waste water discharge

As mentioned in Section 3.2.1, the polder area is divided in smaller areas (watersheds) where is assumed that water in this particular area will flow to the corresponding canal. For the current situation (2018) and for the future (2050), an estimation of the waste water discharge in the canals is made. This information can be included in the hydraulic model.

I.1. Current situation

In Appendix B.1 is estimated that the population density in the polder area is $9585 people/km^2$. In order to estimate the current waste water discharge, some data has to be collected. The data is listed below in Table I.1

Data	Population 2018	Population density $[people/km^2]$	Served people WTP 1	Billed water volume WTP 1 $[m^3/day]$	Discharged into canals [%]
Quantity	1336000	9585	156200	41709	0.3
Reference	[27]	[28]	[6]	[6]	[6]

Table I.1: Data for estimation of the current waste water discharge into the canals for the polder area

Several steps have to be taken to calculate the waste water discharge. For every step, the calculations can be done for every watershed. The steps are listed below:

- Calculate the population in the polder area

The area of the polder, including the different watersheds, is estimated using Google MyMaps. When drawing a border around the polder area in MyMaps, the area is given. The area of all the watersheds together is $22.30 km^2$. Using the population density, the current population of the polder can be calculated. The current population is about 213760. The population in the watersheds are calculated in the same way. Per watershed, a population can be calculated assuming that the population density is equal in all areas.

- Scaling of the served people and billed water volume in Water Treatment Plant 1 (WTP1) to the current population

Data of WTP1 is taken because most of the people in Ninh Kieu are served by WTP1. For scaling, the served people in WTP1 are divided by the total population in the polder. After that, the billed water volume in WTP1 is divided by this factor just mentioned. Now the total billed water volume in the polder is known and is calculated as $57079 m^3/day$.

- Calculate the waste water discharge

When the billed water volume is known, the waste water discharge can be calculated to multiply the factor 0.3 by it. Here is assumed that the dumped waste water will end up in the canals corresponding to their watershed. The total waste water discharge into nature is calculated to be $0.19819 m^3/s$.

I.2. Future situation

For the base situation, without scenarios, it can be assumed that the area of the polder is the same in the year 2050. In Section 5.2.1 is estimated that the population from 2018 till 2050 will grow with a factor 1.27 with a total population of 1698165 in 2050. The population density is calculated as 25% of the total population divided by the area of Ninh Kieu (See Appendix B.2). All the steps in Appendix I.1 can now be followed again. The data needed is shown below in Table I.2

Data	Population base year 2050	Population density [$people/km^2$]	Served people WTP 1	Billed water volume WTP 1 [m^3/day]	Discharged into canals [%] variable
Quantity	1698165	14504	156200	41709	0.05-0.3
Reference	[27]	[28]	[6]	[6]	[6]

Table I.2: Data for estimation of the future waste water discharge into the canals for the polder area

It is difficult to estimate the discharged waste water into the canals by 2050. The goal is to connect all households to the sewerage system, but as we expect the construction of it will take years and probably will pick up some delay. For different scenarios, the percentage discharged into the canals can be changed to calculate new discharge values. It is assumed, in the best case, to be 5 % of the billed water volume in the polder area. By changing this value in Excel, for different scenarios the discharged waste water volume can be calculated and can be integrated in the hydraulic model.
The scenarios created in Chapter 5 are used to calculate different population densities in the polder area. These values together with percentage of households connected to the sewers are used to estimate the discharge of waste water directly into the canals. The calculated values are shown in Table I.3.

Pathway	**Pop. Can Tho 2050**	**Pop. dens. NK [$people/km^2$]**	**[%] discharged into canals**	**Total waste water discharge NK [m^3/s]**
Median	1,698,165.3	14,504.3	0.3	0,2998
EG+	1,770,833.7	15,125.0	0.15	0,1563
EG+++	1,625,595.0	13,884.5	0.05	0,04783

Table I.3: Future waste water discharge calculation for different economic pathways in Ninh Kieu (NK)

J

Counts of traffic model

In this project we went to Can Tho City to do the counting for the project. In two days we counted all the zone intersections. In figure J.1 the red circles are the places we counted the first day and the purple circles are the places of the second day. The counts are executed simultaneously, to prevent double counts. Since it is impossible for a vehicle to be at the same time at two different places.

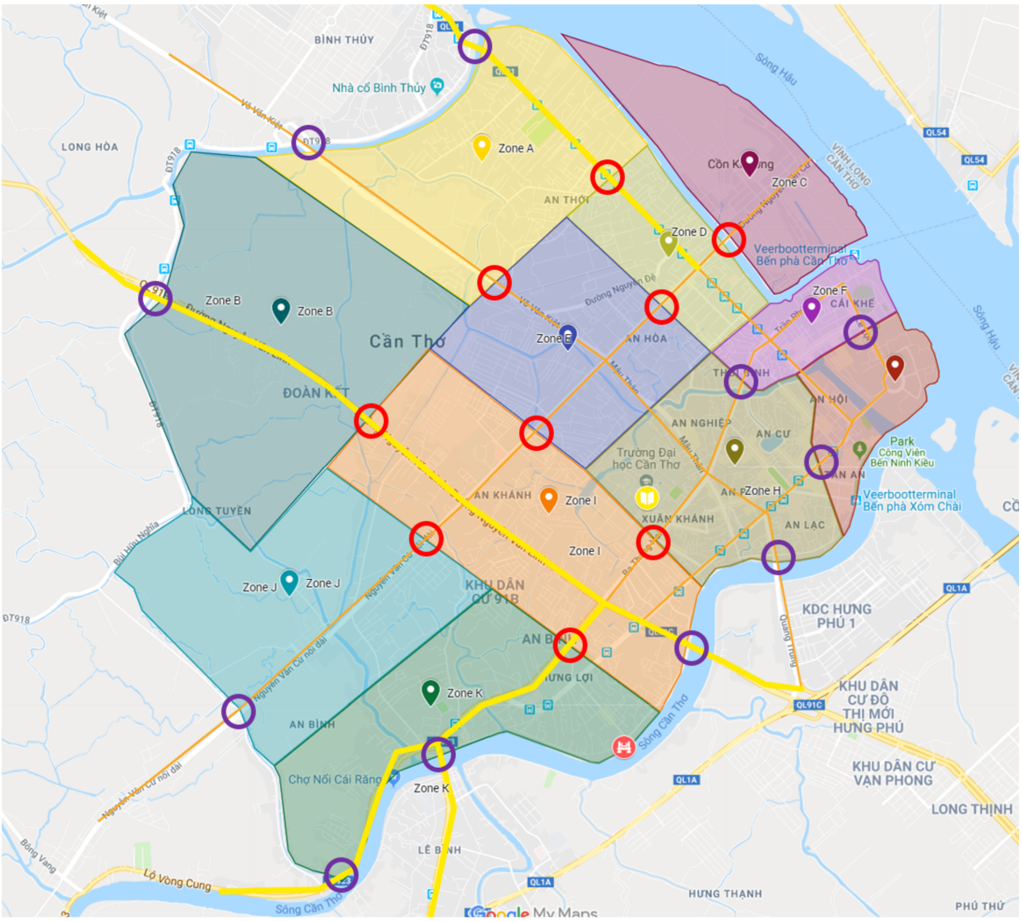

Figure J.1: Counting places

J.1. Methodology

To make the counts as accurate as we can, we counted 3 times 1 minute. In figure J.2 it is shown how the logistics of this operation has been addressed. We used table J.3 to present the outcomes.

Time indication		Berend	Oscar	Reinier	Eveline	Nadieh
06.00-06.30	Drive to location					
06.30-07.00	Counts					
07.00-07.30	Drive to new location					
07.30-08.00	Counts					

Figure J.2: Counts table

Direction	Outcome
B → I	Count 1; Count 2; Count 3;
I → B	Count 1; Count 2; Count 3;
I → E	Count 1; Count 2; Count 3;
E → I	Count 1; Count 2; Count 3;

Figure J.3: Outcometable

The counts have been used for two different purposes, estimating the cordon movements and validating the results of the model. The results of the counts have been converted to a 24-hour period, J.4. To get the counts per hour, the average of the three counts is multiplied by 60. Since the peak hour is around 8% of the total movements, the counts per hour are multiplied by a factor 12,5 to get a 24-hour period.

Zone	Production per minut	Production per hour	Production per day
A	246,7	14800	185000
B	84	5040	63000
C	18,7	1120	14000
D	246,3	14780	184750
E	209,3	12560	157000
F	272,3	16340	204250
G	240	14400	180000
H	435,7	26140	326750
I	643	38580	482250
J	128	7680	96000
K	292	17520	219000
L	424,3	25460	318250
Total:	3240,3	194420	2430250

Figure J.4: Results

K
Dijkstra's algorithm

Some trips in the network of Can Tho City can have multiple routes. For this project it is assumed that travellers will maximise their utility. This indicates that the motorbike users drive for example from zone A to zone B via the shortest path.

Dijkstra's algorithm is an algorithm for finding the shortest paths between nodes in a graph. For a given centroid in the graph, the algorithm finds the shortest path between that centroid and every other centroid.

An example of a trip between zone D and zone H is given to illustrate measurements of the shortest path.

From zone D one can travel to H via H1 and H2. Lanes 7 and 18 will be used to arrive at zone H via H1, and lanes 10 and 11 will be used to arrive at zone H via H2. Figure K.1 shows the two routes.

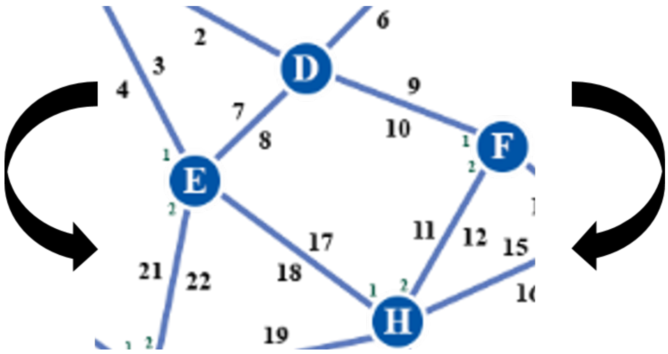

Figure K.1: Multiple routes

Both routes are included in the routing sheet of the model. To confirm the shortest path from zone D to zone H, the travel times are calculated via distance and speed. The travel time matrix will pick the lowest travel time of the two routes.

L Model description

GENERAL INFORMATION ABOUT THE ZONES								
Zone	Density per zone (/km2)	Surface (km2)	Inhabitants 2016	Inhabitants 2021	Households	Coutings	Employment 2016	Employment 2021
A	1567	4,98	7804	8102	2132		26511	28155
B	1567	7,67	12019	12478	3284		13747	14599
C	5000	2,93	14650	15209	4002		7543	8011
D	8737	1,85	16163	16780	4416		12864	13661
E	8737	3,68	32152	33379	8784		24561	26084
F	8737	1,23	10747	11157	2936		10484	11134
G	8737	1,54	13455	13969	3676		13127	13941
H	8737	3,66	31977	33198	8736		28541	30311
I	5000	5,81	29050	30159	7937		44294	47041
J	8737	5,71	49888	51793	13630		13974	14840
K	8737	4,48	39142	40636	10694		22747	24158
L1						4630		
L2						1350		
L3						4340		
L4						4942		
L5						11171		
Total			257047,1					

PRODUCTION PER ZONE PER DAY		
Zone	Production	Motorbike share
A	95507	94027
B	63680	62693
C	49247	48484
D	68322	67263
E	132740	130683
F	51374	50577
G	64322	63325
H	144687	142445
I	188005	185091
J	131628	129588
K	139566	137403
L1	57878	56981
L2	16870	16609
L3	54244	53404
L4	61771	60814
L5	139634	137470
Total	1459477	1436855

Figure L.1: General information

INFORMATION USED	
Factors:	
Housholdsize	3,8
KM2 --> HA	100
Jobfactor	2,9
HH factor	6,5
Day factor	12,5
Inhabitants growth factor	1,03817
Economic growth factor	1,062
MB share	98%

Figure L.2: Extra information

L.1. Base year

Traveltime																		
	A	B	C	D	E	F	G	H	I	J	K	L1	L2	L3	L4	L5	Production	Attraction
A	4	22	9	5	8	9	13	14	16	23	21	8	99999	28	24	18	88833	88833
B	22	5	21	18	13	18	20	13	6	13	12	99999	4	99999	14	12	59487	59487
C	9	21	4	4	8	8	11	12	15	23	21	17	26	28	24	16	46207	46207
D	5	18	4	2	4	4	7	8	12	19	17	13	22	24	20	13	63947	63947
E	8	13	8	4	4	8	11	5	7	15	13	16	18	20	16	10	124268	124268
F	9	18	8	4	8	1	3	4	12	19	17	17	22	24	20	8	48031	48031
G	13	20	11	7	11	3	1	6	14	21	19	20	24	26	22	10	60136	60136
H	14	13	12	8	5	4	6	3	7	15	13	21	18	20	16	4	135337	135337
I	16	6	15	12	7	12	14	7	5	7	6	23	10	12	8	6	175383	175383
J	23	13	23	19	15	19	21	15	7	5	13	31	18	5	16	13	123908	123908
K	21	12	21	17	13	17	19	13	6	13	4	29	16	7	3	12	130860	130860
L1	8	99999	17	13	16	17	20	21	23	31	29	99999	99999	36	32	26	54886	54886
L2	99999	4	26	22	18	22	24	18	10	18	16	99999	99999	99999	19	17	15998	15998
L3	28	99999	28	24	20	24	26	20	12	5	7	36	99999	99999	99999	19	51440	51440
L4	24	14	24	20	16	20	22	16	8	16	3	32	19	99999	99999	99999	58578	58578
L5	18	12	16	13	10	8	10	4	6	13	12	26	17	19	99999	99999	132415	132415
																total	1369714	1369714

Figure L.3: Travel time base year

Distributionfunction exp(-0,04*traveltime)																	
	A	B	C	D	E	F	G	H	I	J	K	L1	L2	L3	L4	L5	total
A	0,852	0,421	0,705	0,815	0,716	0,693	0,605	0,579	0,535	0,401	0,425	0,732	0,000	0,325	0,384	0,486	8,674
B	0,421	0,819	0,427	0,493	0,588	0,496	0,457	0,584	0,786	0,588	0,624	0,000	0,841	0,000	0,563	0,612	8,298
C	0,705	0,427	0,852	0,865	0,726	0,736	0,642	0,625	0,543	0,407	0,431	0,516	0,359	0,330	0,390	0,525	9,079
D	0,815	0,493	0,865	0,923	0,839	0,851	0,742	0,722	0,628	0,470	0,499	0,597	0,415	0,381	0,450	0,606	10,297
E	0,716	0,588	0,726	0,839	0,852	0,714	0,633	0,808	0,748	0,560	0,594	0,524	0,494	0,454	0,536	0,679	10,466
F	0,693	0,496	0,736	0,851	0,714	0,961	0,872	0,849	0,631	0,472	0,501	0,508	0,417	0,383	0,452	0,713	10,249
G	0,605	0,457	0,642	0,742	0,633	0,872	0,961	0,783	0,582	0,436	0,462	0,443	0,385	0,353	0,417	0,657	9,430
H	0,579	0,584	0,625	0,722	0,808	0,849	0,783	0,887	0,743	0,556	0,590	0,424	0,491	0,451	0,533	0,840	10,465
I	0,535	0,786	0,543	0,628	0,748	0,631	0,582	0,743	0,819	0,749	0,794	0,392	0,661	0,608	0,717	0,779	10,714
J	0,401	0,588	0,407	0,470	0,560	0,472	0,436	0,556	0,749	0,819	0,595	0,294	0,495	0,812	0,537	0,583	8,771
K	0,425	0,624	0,431	0,499	0,594	0,501	0,462	0,590	0,794	0,595	0,852	0,311	0,525	0,749	0,903	0,619	9,475
L1	0,732	0,000	0,516	0,597	0,524	0,508	0,443	0,424	0,392	0,294	0,311	0,000	0,000	0,238	0,281	0,356	5,617
L2	0,000	0,841	0,359	0,415	0,494	0,417	0,385	0,491	0,661	0,495	0,525	0,000	0,000	0,000	0,474	0,515	6,072
L3	0,325	0,000	0,330	0,381	0,454	0,383	0,353	0,451	0,608	0,812	0,749	0,238	0,000	0,000	0,000	0,473	5,559
L4	0,384	0,563	0,390	0,450	0,536	0,452	0,417	0,533	0,717	0,537	0,903	0,281	0,474	0,000	0,000	0,000	6,639
L5	0,486	0,612	0,525	0,606	0,679	0,713	0,657	0,840	0,779	0,583	0,619	0,356	0,515	0,473	0,000	0,000	8,443
total	8,674	8,298	9,079	10,297	10,466	10,249	9,430	10,465	10,714	8,771	9,475	5,617	6,072	5,559	6,639	8,443	138,248

Figure L.4: Distribution base year

iteration 1 to production																	
	A	B	C	D	E	F	G	H	I	J	K	L1	L2	L3	L4	L5	TOTAL
A	8727	4308	7221	8346	7330	7101	6193	5925	5483	4104	4355	7501	0	3331	3932	4976	88833
B	3015	5869	3059	3536	4213	3553	3277	4186	5632	4216	4473	0	6031	0	4039	4388	59487
C	3589	2172	4337	4403	3696	3746	3267	3180	2764	2069	2195	2628	1827	1679	1983	2670	46207
D	5061	3063	5373	5733	5212	5284	4608	4484	3899	2918	3096	3707	2577	2368	2796	3766	63947
E	8498	6977	8622	9965	10118	8478	7513	9597	8881	6648	7053	6224	5870	5395	6369	8060	124268
F	3249	2323	3450	3987	3346	4503	4087	3978	2956	2213	2348	2380	1954	1796	2120	3340	48031
G	3857	2915	4094	4732	4036	5562	6127	4993	3711	2778	2947	2825	2453	2254	2661	4193	60136
H	7482	7551	8079	9338	10453	10976	10124	11470	9611	7194	7633	5480	6353	5839	6893	10860	135337
I	8764	12861	8891	10276	12244	10325	9524	12166	13402	12253	13001	6419	10820	9944	11740	12754	175383
J	5661	8308	5744	6638	7910	6670	6153	7859	10575	11566	8399	4147	6990	11465	7584	8239	123908
K	5873	8618	5958	6886	8204	6919	6382	8152	10969	8211	11769	4301	7251	10349	12472	8546	130860
L1	7157	0	5046	5833	5123	4962	4328	4141	3832	2868	3043	0	0	2328	2748	3477	54886
L2	0	2217	946	1093	1303	1098	1013	1294	1741	1304	1383	0	0	0	1249	1357	15998
L3	3010	0	3053	3529	4205	3546	3271	4178	5622	7510	6934	2204	0	0	0	4380	51440
L4	3388	4972	3437	3973	4733	3992	3682	4703	6328	4737	7968	2481	4183	0	0	0	58578
L5	7620	9600	8228	9510	10646	11178	10311	13171	12219	9147	9704	5581	8077	7423	0	0	132415
TOTAL	84951	81755	85538	97779	102771	97894	89860	103476	107624	89736	96302	55878	64385	64171	66587	81006	1369714

Figure L.5: Iteration to production base year

iteration 1 to attraction																		
	A	B	C	D	E	F	G	H	I	J	K	L1	L2	L3	L4	L5	TOTAL	
A	9126	3134	3901	5458	8864	3484	4144	7750	8935	5667	5917	7368	0	2670	3459	8134	88011	0,991
B	3153	4271	1652	2312	5094	1743	2193	5475	9178	5822	6078	0	1499	0	3554	7173	59196	0,995
C	3753	1580	2343	2880	4469	1838	2187	4159	4505	2857	2983	2582	454	1346	1744	4365	44044	0,953
D	5293	2229	2903	3749	6303	2592	3084	5865	6353	4030	4207	3641	640	1899	2460	6156	61403	0,960
E	8887	5077	4657	6517	12234	4160	5028	12552	14472	9179	9584	6114	1459	4325	5603	13175	123022	0,990
F	3398	1690	1864	2608	4046	2209	2735	5202	4817	3056	3190	2338	486	1440	1865	5460	46404	0,966
G	4033	2121	2212	3095	4880	2729	4101	6530	6047	3835	4004	2774	609	1807	2341	6854	57971	0,964
H	7824	5494	4364	6107	12640	5385	6775	15001	15662	9934	10372	5383	1579	4680	6064	17752	135018	0,998
I	9164	9358	4803	6720	14805	5066	6374	15911	21840	16920	17666	6305	2689	7972	10328	20847	176767	1,008
J	5920	6045	3103	4341	9564	3273	4117	10279	17233	15970	11413	4073	1737	9190	6672	13468	126399	1,020
K	6141	6271	3218	4503	9921	3395	4271	10662	17875	11338	15993	4225	1802	8296	10972	13970	132851	1,015
L1	7484	0	2726	3815	6194	2435	2896	5416	6244	3960	4135	0	0	1866	2417	5684	55273	1,007
L2	0	1613	511	715	1575	539	678	1693	2838	1800	1879	0	0	0	1099	2218	17158	1,072
L3	3147	0	1649	2308	5084	1740	2189	5464	9161	10369	9422	2165	0	0	0	7159	59858	1,164
L4	3543	3618	1857	2598	5723	1959	2464	6151	10313	6541	10827	2437	1039	0	0	0	59070	1,008
L5	7968	6985	4445	6220	12873	5485	6900	17226	19912	12630	13187	5482	2007	5950	0	0	127269	0,961
TOTAL	88833	59487	46207	63947	124268	48031	60136	135337	175383	123908	130860	54886	15998	51440	58578	132415	1369714	1,000

Figure L.6: Iteration to attraction base year

iteration 6 to attraction	A	B	C	D	E	F	G	H	I	J	K	L1	L2	L3	L4	L5	TOTAL	
A	9176	3152	3922	5490	8938	3503	4169	7807	9047	5773	6018	7400	0	2687	3495	8257	88833	1
B	3152	4268	1651	2312	5106	1742	2193	5482	9238	5895	6145	0	1495	0	3569	7238	59487	1
C	3922	1651	2448	3010	4683	1921	2286	4354	4740	3025	3153	2695	474	1408	1832	4605	46207	1
D	5490	2312	3010	3890	6556	2689	3200	6095	6636	4235	4414	3773	663	1971	2564	6447	63947	1
E	8938	5106	4683	6556	12339	4183	5058	12648	14656	9353	9749	6142	1464	4353	5663	13377	124268	1
F	3503	1742	1921	2689	4183	2277	2820	5373	5000	3191	3326	2407	500	1485	1932	5683	48031	1
G	4166	2191	2284	3198	5055	2819	4237	6758	6290	4014	4184	2863	628	1868	2430	7148	60136	1
H	7807	5482	4354	6096	12648	5373	6762	14996	15737	10042	10468	5365	1572	4673	6080	17883	135337	1
I	9047	9238	4740	6636	14656	5001	6294	15737	21710	16922	17638	6217	2649	7875	10245	20777	175383	1
J	5773	5895	3025	4235	9353	3191	4016	10042	16922	15778	11256	3967	1691	8968	6538	13259	123908	1
K	6018	6145	3153	4414	9749	3326	4186	10468	17638	11256	15850	4135	1762	8135	10804	13820	130860	1
L1	7400	0	2695	3773	6142	2407	2864	5365	6217	3967	4135	0	0	1846	2402	5674	54886	1
L2	0	1495	474	663	1464	500	629	1572	2649	1691	1762	0	0	0	1024	2076	15998	1
L3	2687	0	1408	1971	4353	1485	1869	4673	7875	8968	8135	1846	0	0	0	6170	51440	1
L4	3495	3569	1831	2564	5663	1932	2432	6080	10245	6538	10804	2402	1024	0	0	0	58578	1
L5	8259	7240	4606	6449	13380	5684	7120	17887	20782	13262	13823	5675	2076	6172	0	0	132415	1
TOTAL	88833	59487	46207	63947	124268	48031	60136	135337	175383	123908	130860	54886	15998	51440	58578	132415	1369714	1

Figure L.7: End of iteration base year

L.2. Future year

Traveltime	A	B	C	D	E	F	G	H	I	J	K	L1	L2	L3	L4	L5	Production	Attraction
A	4	3,74	8,735	5,115	6,36	9,155	12,575	11,68	9,77	17,01	15,53	7,785	8,06	22,23	18,08	16,045	94027	94027
B	3,74	5	12,475	8,855	10,1	12,895	19,57	13,45	6,03	13,27	11,79	11,525	4,32	18,49	14,34	12,27	62693	62693
C	8,735	12,475	4	3,62	8	7,66	11,08	11,76	15,26	22,5	21,02	16,52	16,795	27,72	23,57	16,125	48484	48484
D	5,115	8,855	3,62	2	4,38	4,04	7,46	8,14	11,64	18,88	17,4	12,9	13,175	24,1	19,95	12,505	67263	67263
E	6,36	10,1	8	4,38	4	8,42	11,44	5,32	7,26	14,5	13,02	14,145	14,42	19,72	15,57	9,685	130683	130683
F	9,155	12,895	7,66	4,04	8,42	1	3,42	4,1	11,52	18,76	17,28	16,94	17,215	23,98	19,83	8,465	50577	50577
G	12,575	19,57	11,08	7,46	11,44	3,42	1	6,12	13,54	20,78	19,3	20,36	23,89	26	21,85	10,485	63325	63325
H	11,68	13,45	11,76	8,14	5,32	4,1	6,12	3	7,42	14,66	13,18	19,465	17,77	19,88	15,73	4,365	142445	142445
I	9,77	6,03	15,26	11,64	7,26	11,52	13,54	7,42	5	7,24	5,76	17,555	10,35	12,46	8,31	6,24	185091	185091
J	17,01	13,27	22,5	18,88	14,5	18,76	20,78	14,66	7,24	5	4,87	24,795	17,59	5,22	7,42	13,48	129588	129588
K	15,53	11,79	21,02	17,4	13,02	17,28	19,3	13,18	5,76	4,87	4	23,315	16,11	7,215	2,55	12	137403	137403
L1	7,785	11,525	16,52	12,9	14,145	16,94	20,36	19,465	17,555	24,795	23,315	99999	99999	30,015	25,865	23,83	56981	56981
L2	8,06	4,32	16,795	13,175	14,42	17,215	23,89	17,77	10,35	17,59	16,11	99999	99999	99999	18,66	16,59	16609	16609
L3	22,23	18,49	27,72	24,1	19,72	23,98	26	19,88	12,46	5,22	7,215	30,015	99999	99999	99999	18,7	53404	53404
L4	18,08	14,34	23,57	19,95	15,57	19,83	21,85	15,73	8,31	7,42	2,55	25,865	18,66	99999	99999	99999	60814	60814
L5	16,045	12,27	16,125	12,505	9,685	8,465	10,485	4,365	6,24	13,48	12	23,83	16,59	18,7	99999	99999	137470	137470

Figure L.8: Travel time future year

Distributionfunction	exp(-0,04*traveltime)																
	A	B	C	D	E	F	G	H	I	J	K	L1	L2	L3	L4	L5	Total
A	0,852	0,861	0,705	0,815	0,775	0,693	0,605	0,627	0,677	0,506	0,537	0,732	0,724	0,411	0,485	0,526	10,533
B	0,861	0,819	0,607	0,702	0,668	0,597	0,457	0,584	0,786	0,588	0,624	0,631	0,841	0,477	0,563	0,612	10,417
C	0,705	0,607	0,852	0,865	0,726	0,736	0,642	0,625	0,543	0,407	0,431	0,516	0,511	0,330	0,390	0,525	9,411
D	0,815	0,702	0,865	0,923	0,839	0,851	0,742	0,722	0,628	0,470	0,499	0,597	0,590	0,381	0,450	0,606	10,681
E	0,775	0,668	0,726	0,839	0,852	0,714	0,633	0,808	0,748	0,560	0,594	0,568	0,562	0,454	0,536	0,679	10,717
F	0,693	0,597	0,736	0,851	0,714	0,961	0,872	0,849	0,631	0,472	0,501	0,508	0,502	0,383	0,452	0,713	10,435
G	0,605	0,457	0,642	0,742	0,633	0,872	0,961	0,783	0,582	0,436	0,462	0,443	0,385	0,353	0,417	0,657	9,430
H	0,627	0,584	0,625	0,722	0,808	0,849	0,783	0,887	0,743	0,556	0,590	0,459	0,491	0,451	0,533	0,840	10,549
I	0,677	0,786	0,543	0,628	0,748	0,631	0,582	0,743	0,819	0,749	0,794	0,495	0,661	0,608	0,717	0,779	10,959
J	0,506	0,588	0,407	0,470	0,560	0,472	0,436	0,556	0,749	0,819	0,823	0,371	0,495	0,812	0,743	0,583	9,389
K	0,537	0,624	0,431	0,499	0,594	0,501	0,462	0,590	0,794	0,823	0,852	0,394	0,525	0,749	0,903	0,619	9,898
L1	0,732	0,631	0,516	0,597	0,568	0,508	0,443	0,459	0,495	0,371	0,394	0,000	0,000	0,301	0,355	0,386	6,756
L2	0,724	0,841	0,511	0,590	0,562	0,502	0,385	0,491	0,661	0,495	0,525	0,000	0,000	0,000	0,474	0,515	7,277
L3	0,411	0,477	0,330	0,381	0,454	0,383	0,353	0,451	0,608	0,812	0,749	0,301	0,000	0,000	0,000	0,473	6,185
L4	0,485	0,563	0,390	0,450	0,536	0,452	0,417	0,533	0,717	0,743	0,903	0,355	0,474	0,000	0,000	0,000	7,020
L5	0,526	0,612	0,525	0,606	0,679	0,713	0,657	0,840	0,779	0,583	0,619	0,386	0,515	0,473	0,000	0,000	8,513
Total	10,533	10,417	9,411	10,681	10,717	10,435	9,430	10,549	10,959	9,389	9,898	6,756	7,277	6,185	7,020	8,513	148,169

Figure L.9: Distribution future year

iteration 1 to production	A	B	C	D	E	F	G	H	I	J	K	L1	L2	L3	L4	L5	TOTAL
A	7607	7686	6294	7275	6922	6190	5398	5595	6039	4521	4796	6538	6467	3669	4331	4699	94027
B	5182	4927	3654	4223	4018	3593	2751	3514	4728	3540	3755	3795	5063	2873	3391	3684	62693
C	3633	3128	4390	4457	3741	3792	3307	3219	2798	2095	2222	2661	2631	1700	2007	2703	48484
D	5132	4419	5449	5813	5285	5358	4673	4547	3953	2959	3140	3759	3718	2402	2835	3819	67263
E	9455	8141	8855	10234	10391	8707	7716	9857	9121	6827	7244	6925	6849	5541	6541	8278	130683
F	3361	2894	3568	4124	3461	4657	4227	4114	3057	2289	2428	2461	2434	1857	2193	3455	50577
G	4061	3070	4311	4983	4250	5857	6452	5257	3907	2925	3103	2974	2583	2374	2802	4415	63325
H	8463	7885	8436	9751	10915	11461	10571	11977	10036	7512	7971	6199	6634	6097	7198	11340	142445
I	11426	13270	9173	10603	12633	10654	9827	12552	13828	12643	13414	8369	11164	10261	12113	13159	185091
J	6990	8118	5612	6486	7728	6517	6011	7679	10332	11300	11359	5119	6829	11201	10258	8050	129588
K	7459	8663	5988	6921	8247	6955	6415	8194	11026	11425	11830	5463	7288	10402	12536	8590	137403
L1	6177	5319	4356	5034	4790	4283	3736	3872	4179	3128	3319	0	0	2539	2997	3251	56981
L2	1653	1920	1166	1348	1282	1146	878	1121	1509	1129	1198	0	0	0	1082	1175	16609
L3	3549	4121	2849	3293	3923	3309	3052	3898	5246	7007	6470	2599	0	0	0	4087	53404
L4	4203	4881	3374	3900	4647	3919	3615	4617	6213	6438	7822	3078	4107	0	0	0	60814
L5	8499	9885	8472	9792	10961	11510	10616	13561	12581	9418	9992	6225	8316	7643	0	0	137470
TOTAL	96851	98327	85947	98238	103194	97907	89246	103574	108553	95157	100065	66167	74083	68557	70285	80705	1436855

Figure L.10: Iteration to production future year

iteration 1 to attraction																		
	A	B	C	D	E	F	G	H	I	J	K	L1	L2	L3	L4	L5	TOTAL	
A	7385	4901	3551	4981	8765	3197	3830	7695	10297	6156	6586	5631	1450	2858	3748	8003	89035	0,946906803
B	5031	3142	2061	2892	5088	1856	1952	4833	8062	4820	5157	3269	1135	2238	2934	6275	60745	0,968934044
C	3527	1994	2476	3052	4737	1959	2347	4427	4771	2852	3052	2291	590	1324	1736	4604	45740	0,943410038
D	4983	2818	3074	3980	6693	2768	3316	6254	6741	4030	4311	3237	834	1871	2453	6505	63868	0,94952396
E	9179	5191	4995	7007	13159	4498	5475	13556	15552	9298	9947	5964	1536	4316	5660	14100	129432	0,990427613
F	3263	1845	2013	2823	4383	2406	2999	5657	5213	3117	3334	2120	546	1447	1897	5884	48946	0,967735988
G	3943	1957	2432	3412	5382	3026	4578	7230	6662	3983	4261	2561	579	1849	2425	7521	61801	0,975934892
H	8217	5027	4759	6676	13823	5921	7501	16471	17112	10231	10945	5338	1487	4749	6228	19316	143800	1,009516448
I	11093	8461	5175	7260	15998	5504	6973	17263	23578	17218	18420	7207	2503	7993	10481	22415	187541	1,013237405
J	6786	5176	3166	4441	9786	3367	4265	10560	17617	15389	15598	4409	1531	8725	8875	13712	133402	1,029432749
K	7242	5523	3378	4739	10444	3593	4552	11269	18800	15559	16244	4705	1634	8103	10847	14632	141263	1,028096267
L1	5997	3391	2457	3447	6066	2213	2651	5325	7126	4260	4558	0	0	1978	2593	5538	57599	1,010856141
L2	1605	1224	658	923	1624	592	623	1542	2573	1538	1645	0	0	0	936	2002	17485	1,052773038
L3	3445	2628	1607	2255	4969	1709	2166	5362	8944	9543	8884	2238	0	0	0	6961	60711	1,136829202
L4	4080	3112	1903	2670	5885	2024	2565	6350	10593	8767	10741	2651	921	0	0	0	62263	1,023840622
L5	8251	6302	4779	6705	13881	5946	7533	18650	21451	12825	13720	5361	1864	5954	0	0	133222	0,969105273
TOTAL	94027,06	62693,1	48483,65	67262,66	130682,6	50577,47	63324,64	142444,7	185091,3	129588,2	137402,8	56980,87	16608,77	53403,59	60813,66	137469,5	1436855	1

Figure L.11: Iteration to attraction future year

iteration 6 to attracton																		
	A	B	C	D	E	F	G	H	I	J	K	L1	L2	L3	L4	L5	TOTAL	
A	7776	5174	3728	5233	9237	3361	4030	8111	10904	6562	7012	5912	1518	3015	3968	8488	94027	1,000000002
B	5174	3240	2114	2967	5238	1906	2006	4976	8339	5018	5362	3352	1161	2306	3034	6500	62693	1
C	3728	2114	2610	3219	5012	2067	2479	4684	5072	3052	3261	2415	620	1402	1846	4902	48484	1,000000003
D	5233	2967	3219	4170	7035	2902	3479	6575	7119	4284	4578	3390	871	1969	2591	6881	67263	1,000000003
E	9237	5238	5012	7036	13254	4519	5506	13657	15739	9471	10121	5985	1537	4352	5727	14291	130683	1,000000001
F	3361	1906	2067	2902	4519	2474	3088	5835	5401	3250	3473	2178	559	1493	1965	6106	50577	1,000000003
G	4027	2005	2477	3477	5502	3086	4673	7394	6844	4119	4401	2609	588	1892	2491	7738	63325	1,000000003
H	8111	4976	4684	6575	13657	5835	7399	16277	16987	10223	10924	5255	1460	4697	6181	19205	142445	1,000000002
I	10904	8339	5072	7119	15739	5401	6848	16987	23308	17132	18307	7065	2447	7872	10359	22192	185091	0,999999999
J	6562	5018	3052	4284	9471	3250	4121	10223	17132	15063	15250	4251	1473	8454	8630	13354	129588	0,999999997
K	7012	5362	3261	4578	10121	3473	4404	10924	18307	15250	15903	4543	1574	7861	10561	14270	137403	0,999999997
L1	5912	3352	2415	3390	5985	2178	2611	5255	7065	4251	4543	0	0	1953	2571	5499	56981	1,000000001
L2	1519	1161	620	871	1537	559	589	1460	2447	1473	1574	0	0	0	891	1908	16609	1
L3	3015	2306	1402	1969	4352	1493	1894	4697	7872	8454	7861	1953	0	0	0	6136	53404	0,999999997
L4	3968	3034	1846	2591	5727	1965	2492	6181	10359	8629	10560	2571	891	0	0	0	60814	0,999999997
L5	8490	6502	4903	6882	14295	6107	7707	19210	22197	13357	14273	5501	1908	6137	0	0	137470	1
TOTAL	94027	62693	48484	67263	130683	50577	63325	142445	185091	129588	137403	56981	16609	53404	60814	137470	1436855	1

Figure L.12: End of iteration future year

M

Validation and verification of the transport model

M.1. Verifying

To verify the model that is used to predict the flows of Can Tho City, tests are applied to the model. The tests are given in the table. Verifying means check whether to model behaves in the expected way.

Description	Expected	Result	OK
Inputdata to 0	Flows = 0	No flows at all	**PASS**
Increase the distance (100km) of a link	Not many flows	122 flows	**PASS**
Surface per zone to 0	Flows = 0	No flows at all	**PASS**

M.2. Validation

The validation of the model is done by comparing the results of the base year model with the counts. There is a difference between the outcomes and the counts, however it is in the same range.

Zone	Counts	Flow from model
A	185000	169951
B	63000	87113
C	14000	43759
D	184750	175936
E	157000	486871
F	204250	101351
G	180000	55899
H	326750	310981
I	482250	648624
J	96000	133499
K	219000	143845

N

Scenario results Four Step Model

Base year

Wegvak	Distance	Speed MB	Time MB
1	3,41	40	5,1
2	3,41	40	5,1
3	4,18	30	8,4
4	4,18	30	8,4
5	1,81	30	3,6
6	1,81	30	3,6
7	2,19	30	4,4
8	2,19	30	4,4
9	2,02	30	4,0
10	2,02	30	4,0
11	2,05	30	4,1
12	2,05	30	4,1
13	1,71	30	3,4
14	1,71	30	3,4
15	3,06	30	6,1
16	3,06	30	6,1
17	2,66	30	5,3
18	2,66	30	5,3
19	3,71	30	7,4
20	3,71	30	7,4
21	3,63	30	7,3
22	3,63	30	7,3
23	3,84	40	5,8
24	3,84	40	5,8
25	3,62	30	7,2
26	3,62	30	7,2
27	4,02	40	6,0
28	4,02	40	6,0
29	5,19	40	7,8
30	5,19	40	7,8
31	2,88	40	4,3
32	2,88	40	4,3
33	3,48	40	5,2
34	3,48	40	5,2
35	4,81	40	7,2
36	4,81	40	7,2
37	1,7	40	2,6
38	1,7	40	2,6
39	4,16	40	6,2
40	4,16	40	6,2
41	2,91	40	4,4
42	2,91	40	4,4

Scenario 1

Wegvak	Distance	Speed MB	Time MB
1	3,41	46	4,447826
2	3,41	46	4,447826
3	3,18	34,5	5,530435
4	3,18	34,5	5,530435
5	1,81	34,5	3,147826
6	1,81	34,5	3,147826
7	2,19	34,5	3,808696
8	2,19	34,5	3,808696
9	2,02	34,5	3,513043
10	2,02	34,5	3,513043
11	2,05	34,5	3,565217
12	2,05	34,5	3,565217
13	1,71	34,5	2,973913
14	1,71	34,5	2,973913
15	3,06	34,5	5,321739
16	3,06	34,5	5,321739
17	2,66	34,5	4,626087
18	2,66	34,5	4,626087
19	3,71	34,5	6,452174
20	3,71	34,5	6,452174
21	3,63	34,5	6,313043
22	3,63	34,5	6,313043
23	3,84	46	5,008696
24	3,84	46	5,008696
25	3,62	34,5	6,295652
26	3,62	34,5	6,295652
27	4,02	46	5,243478
28	4,02	46	5,243478
29	5,19	46	6,769565
30	5,19	46	6,769565
31	2,88	46	3,756522
32	2,88	46	3,756522
33	3,48	46	4,53913
34	3,48	46	4,53913
35	4,81	46	6,273913
36	4,81	46	6,273913
37	1,7	46	2,217391
38	1,7	46	2,217391
39	4,16	46	5,426087
40	4,16	46	5,426087
41	2,91	46	3,795652
42	2,91	46	3,795652
43	3,74	69	3,252174
44	3,74	69	3,252174
45	4,87	69	4,234783
46	4,87	69	4,234783

Figure N.1: Speed used for scenario I and IV

INFORMATION USED	
Factors:	
Housholdsize	3,8
KM2 --> HA	100
Jobfactor	2,9
HH factor	6,5
Day factor	12,5
Inhabitants growth factor	1,3254
Economic growth factor	1,04
MB share	98%

Figure N.2: Example factors used for scenario I

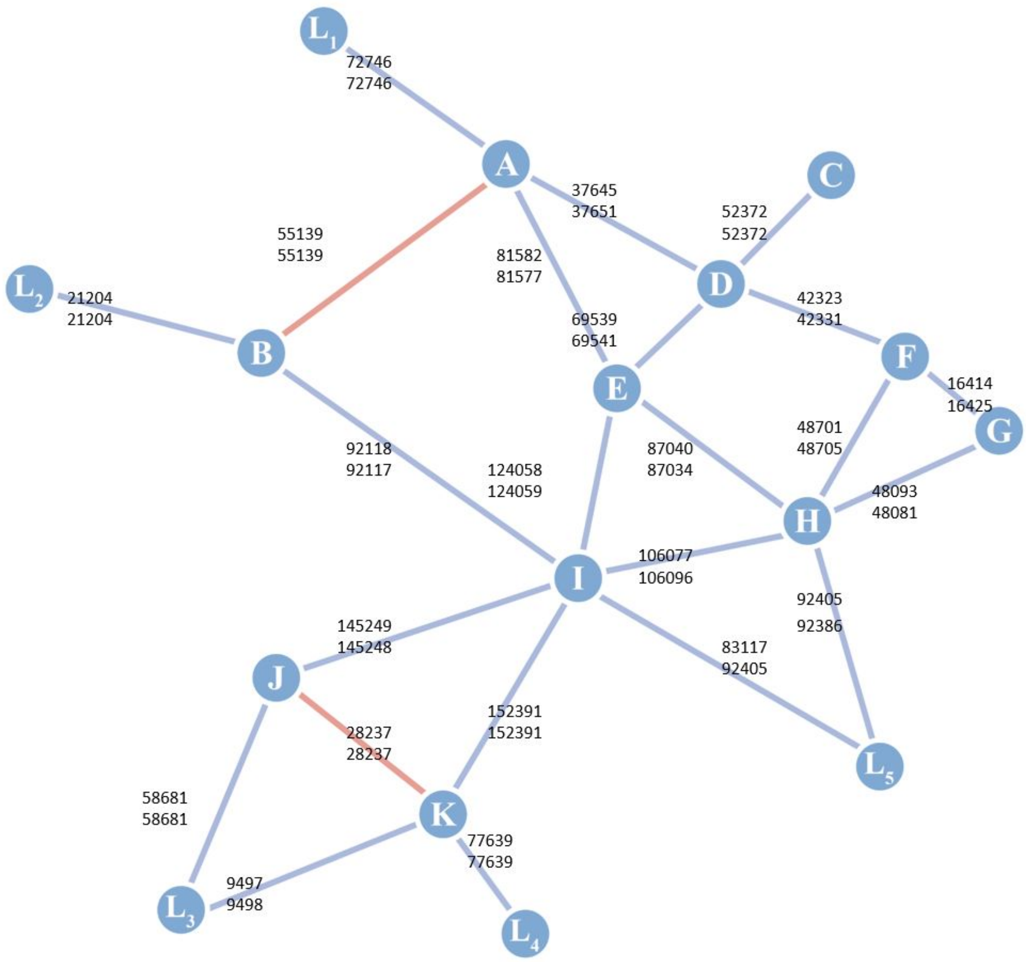

Figure N.3: Scenario 1

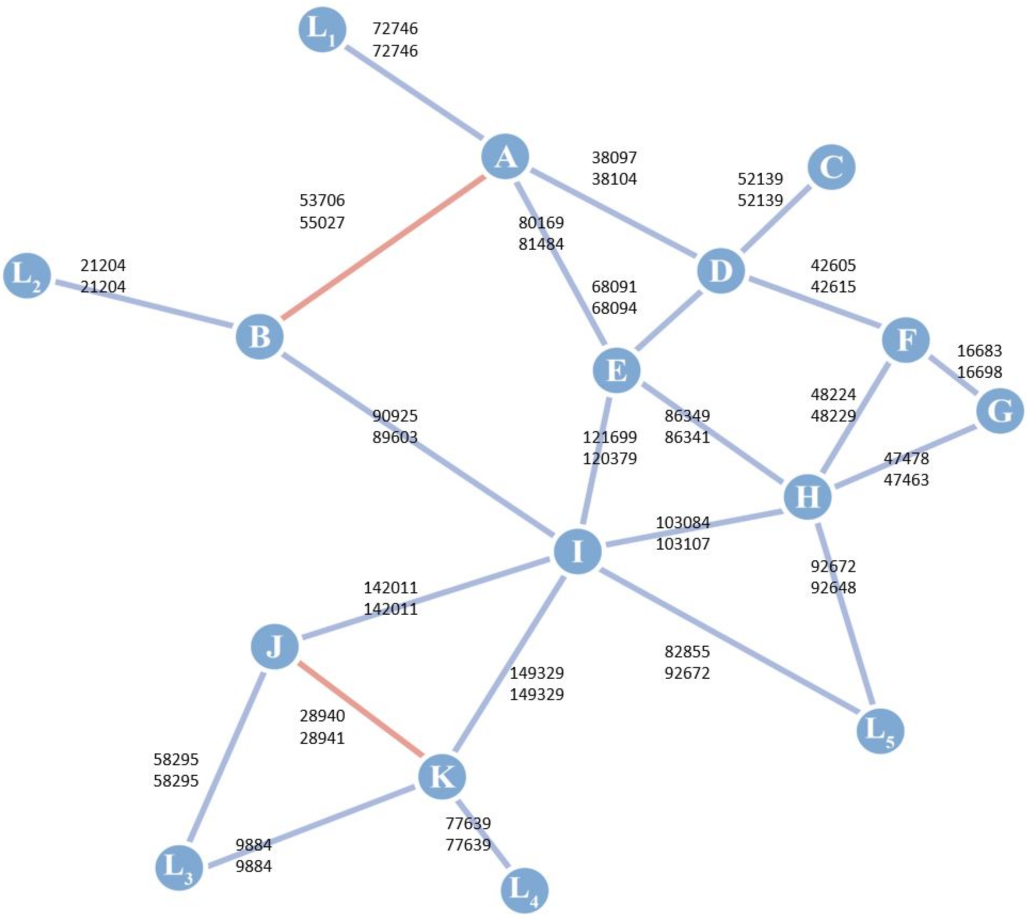

Figure N.4: Scenario 2

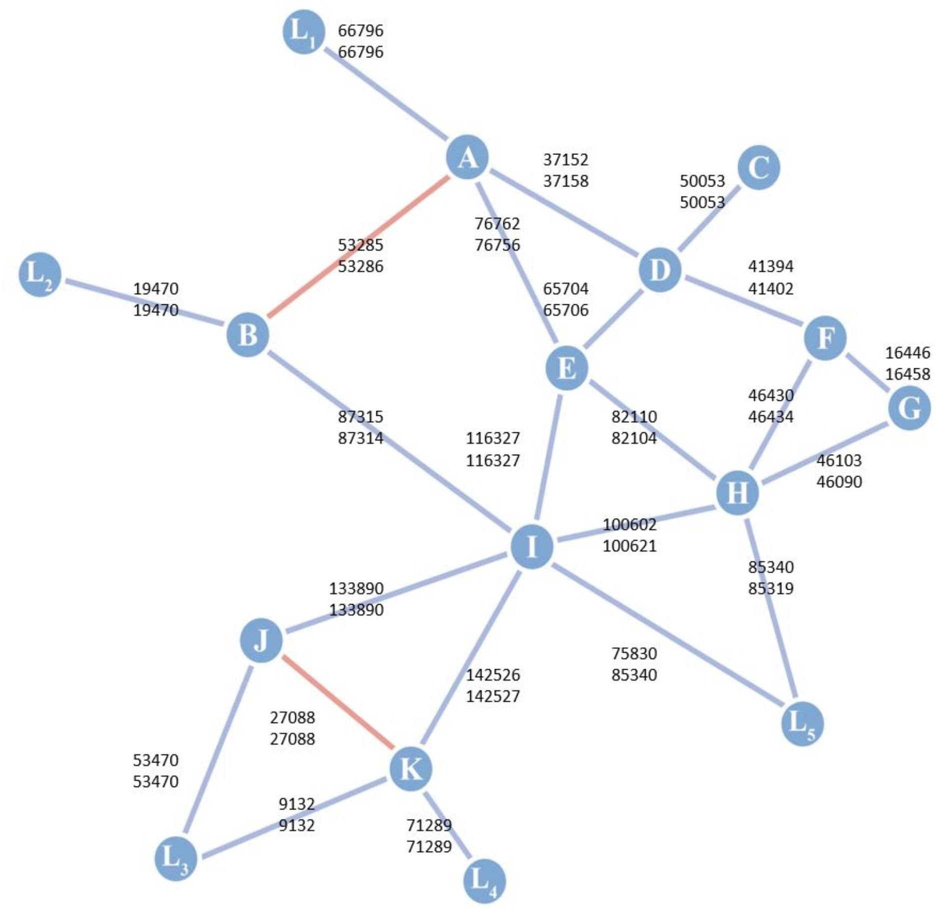

Figure N.5: Scenario 3

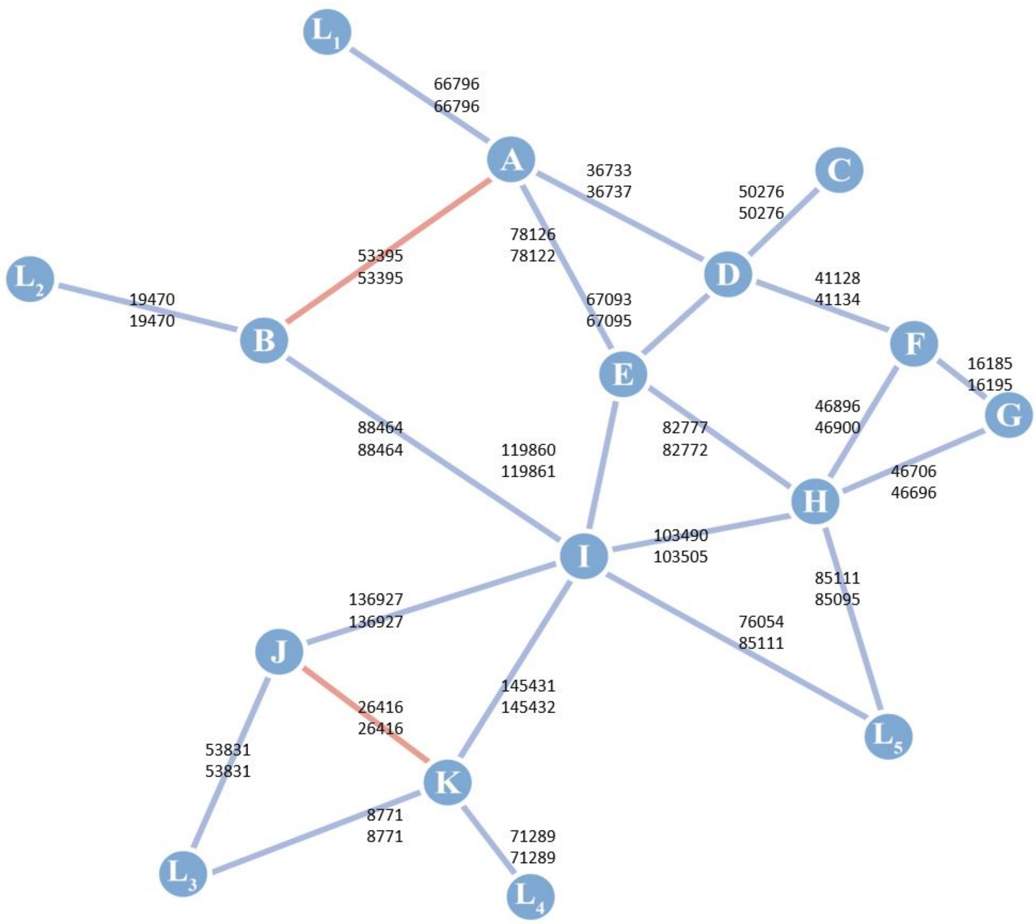

Figure N.6: Scenario 4

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