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Department of Chemical Engineering

Identification of flood risk areas in an open storm-water system with MIKE URBAN – Senai Town, Malaysia

Master's Thesis by

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Picture on front page:

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1. Main channel in the open storm-water system in Senai Town, Johor State, Malaysia. (L. Reuterwall)

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List of abbreviations

CGCM1 – Coupled General Circulation Model
CRS – Cross Section
CSIRO – Commonwealth Scientific and Industrial Research Organisation
DEM – Digital Elevation Map
DHI – Danish Hydrological Institute
DMP – Drainage Master Plan
EPA – Environmental Protection Agency
ESRI – Environmental Systems Research Institute
GCM – Global Climate Model
GIS – Geographical Information System
IPASA – Institute of Environmental & Water Resource
IPCC – Intergovernmental Panel on Climate Change
MMD – Malaysia Meteorological Department
MASMA – Manual Saliran Mesra Alam Malaysia (Urban Stormwater Management Manual For Malaysia)
MOUSE – Model for Urban Sewers
m.a.s.l. – Meter Above Sea Level
NAHRIM – National Hydraulic Research Institute of Malaysia
PVC – PolyVinylChloride (Plastic)
RDI – Rainfall Dependent Infiltration
SRES – Special Report on Emisson Scenarios
SUDS – Sustainable Urban Drainage Systems
SWMM – Storm-Water Management Model
ToC – Time of Concentration
UTM – Universiti Teknologi Malaysia

Summary

By the year of 2020 Malaysia is prospected to become a developed nation due to twenty years of rapid socio-economic growth. As strong urbanization will take place, runoff will increase as a result of growth and spread of impervious surfaces. The study area in this project is in Senai Town which is situated in an important economic centre in the mid-southern region of Johor State in South-East Malaysia close to the border of Singapore. Flash floods, water pollution and ecological damage are associated with storm water in Malaysia. To solve future problems with flooding in the region, the Government of Johor carried out a Drainage Master Plan (DMP) for Bandar Senai (DID, 2005a). The purpose of the DMP was to indentify existing drainage problems and propose long-term improvements with a projected year of 2020. The objective of this study is to identify areas with risk of flooding today and in the future.

A rainfall-runoff model was created in the computer program MIKE URBAN in order to forecast the future situation in the drainage system. The necessary information to create the model was taken from the DMP and collected from onsite observations. Quantitative data such as rainfall and water level was recorded in order to perform a calibration of the model during the 24th of October to the 18th of November 2008. The tributary Cabang Sungai Senai Fasa 1 is the object of this study which has a catchment area of about 33 hectares and a length of almost 1 kilometre. The drainage network is almost entirely an open drainage system and consists of concrete lined channels and culverts of different dimensions. At low-lying areas in the Sungai Senai catchment, flash floods have occurred in the past due to insufficient capacity in the drainage system. Additional cause is the backwater effect from the river Sungai Skudai. In the region of the study area the climate is tropical with an annual average temperature of 27°C and annual precipitation of 1500 to 3500 mm. Due to the ongoing global warming the temperature on the Earth's surface is increasing steadily. The Intergovernmental Panel on Climate Change (IPCC) demonstrates the effects of global warming to have adverse consequences on the Asia/Pacific region. Based on forecasting using climate models, future changes in precipitation are projected.

Four scenarios were defined to evaluate the drainage system's capacity and future function. These scenarios are based on future changes such as projected increased precipitation, backwater effects from connected rivers, some suggested improvements of the drainage network found in the DMP and effects of exploitation around the study area. In order to simulate the four scenarios, the DHI computer program MIKE URBAN has been used to create a rainfall-runoff model which consists of a hydrological and a hydraulic model. A calibration was performed using the collected rainfall- and water-level data. The calibration optimizes the model so when the recorded rainfall data is put into the model and is simulated, the out coming result graph of the water level is made as equal to the graph of the recorded water level as possible.

The recorded rainfall was utilized in the simulations which showed that two sections had a large risk of flooding with today's situation. The results of the simulations of the future scenarios indicated a small impact of increased precipitation on the drainage system. Backwater effects from the rivers had a large impact on the water level in the low-lying parts of the drainage network. The suggested changes by the DMP resulted in a lowering of the water level in the overall system. Future exploitation was simulated by increasing the catchment, which resulted in severe flooding in the upstream part of the drainage network. None of the scenarios indicate any additional areas in risk of flooding in the future compared with today's situation.

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1 Introduction

1.1 Background

By the year of 2020 Malaysia is prospected to become a developed nation due to twenty years of rapid socio-economic growth (DID, 2000a). The expected population is 30 million compared to today's 21 million. This will be the result of an increased number of births within the country as well as an increased number of immigrants from the bordering countries. With an annually increasing internal migration from rural to urban areas and industrial centers with good infrastructure, cities and towns are expected to reach 55-60% of the total population (DID, 2000a). As the urban and industrial areas are increasing and the daily life-quality of the urban citizens is improving, the hydrological and ecological stresses on the environment are increasing as well.

When land use changes from rural to urban, the runoff will increase as a result of growth and spread of impervious surfaces. This increased runoff has an impact on receiving waters due to its content of nutrients, heavy metals, oil, grease and bacteria. Together with frequent heavy rainfalls the situation has become ever more problematic and possibly worse in the future (DID, 2000a). Flash flooding, water pollution and ecological damage, traffic disruption and accidents, garbage and floating litters are all associated with storm water in Malaysia. This is forcing Malaysia to plan for a sustainable urban storm-water management. However, the research in Malaysia on the effects on increased amount of impermeable surfaces due to urbanization is inadequate. The reason is lack of satisfactory data such as quantity, quality and length of record for reliable design (DID, 2000a).

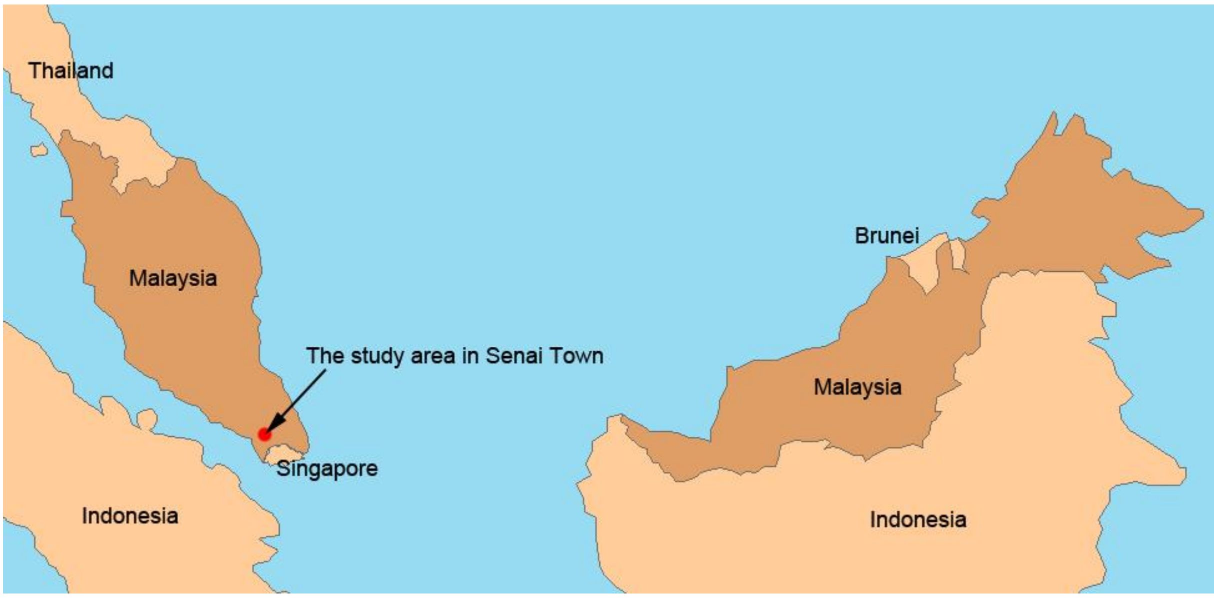

Figure 1. The image illustrates where the study area in Senai Town is situated in Malaysia in South-East Asia (Reuterwall & Thorén, 2009).

The study area in this project is Senai Town which is situated in an important economic centre in the mid-southern region of Johor State in South-East Malaysia, see Figure 1. It is a part of the river basin Sungai Skudai and together with several other notable river basins, it suffers from increased development pressure on the water environment at an alarming level. During the past decades, flood damage and deterioration of the water quality have occurred frequently and now been recognized as failures of the planning, design and management of storm-water systems in urban areas (DID, 2000a). High water levels in the river courses near Senai Town coinciding with heavy rainfall have in the past resulted in flash floods in housing estates. As the urban areas in Senai Town are developing rapidly, runoff will increase as the amount of impermeable surfaces increase, creating further risks of flooding problems (DID, 2005a). The river Sungai Senai is discharging into river Sungai Skudai, close to Senai Town (see figure 3 on page 14). Downstream Sungai Skudai is a weir, which is possible to close if the tide is too high. However, this can cause backwater effects in river Sungai Skudai, which also affects Sungai Senai (DID, 2005a).

To solve future problems with flooding in the region, the Government of Johor carried out a Drainage Master Plan (DMP) for Bandar Senai (DID, 2005a). Estimated future land use data was collected from the Structure Plan for Johor Bahru 2002 to 2020 (Kulai Municipal Council, 2002). The aim of the DMP was to identify existing drainage problems and propose long-term improvements with a projected year of 2020. The improvements were presented with both new drainage alignments and cross sections (DID, 2005a).

1.2 **Objective**

There are two major objectives of this thesis. The first objective is to locate areas in the drainage system in Senai Town with high risk of flooding with today's situation in a created MIKE URBAN model. The second objective is to see how these sensitive parts of the system will stand the effects of future climate changes, as well as to look at the future effects on the total drainage system. In addition, proposed improvements by the DMP and assumed expansion of the catchment area will be applied and analyzed in the model.

1.3 **Method - Overview**

This chapter is an overview of the method in this study and for more details see chapter 3. A rainfall-runoff model was created in the computer program MIKE URBAN in order to forecast the future situation in the drainage system. The rainfall-runoff model consists of a hydrological and a hydraulic model. The hydrological model is a surface model that uses the "Time-Area Method". The hydraulic model mainly consists of an open drainage system.

The necessary information to create the model was taken from the Drainage Master Plan for Senai Town and from onsite observations. The author of the Drainage Master Plan is hereinafter referred to as the consultant. The Drainage Master Plan (DID, 2005b) includes details about the drainage alignment, dimensions and slopes from the existing drainage system, which were directly used in MIKE URBAN to construct the hydraulic model. Information about land use was interpreted from an aerial photograph. This knowledge is important in order to define surfaces with different permeability. From onsite observations, information about the catchment area's boundaries was gathered. The flow direction in the drains helps to identify these boundaries.

Quantitative data such as rainfall and water level was collected in order to perform a calibration of the model. The measuring equipment for recording the rainfall data was a tipping bucket. In order to record the water level data, equipment which measures the pressure in the water was used. The provided computer program converted the pressure to water depth. Detailed information about the measuring equipment can be found in Appendix 1. During the calibration the constructed model was simulated with the recorded rainfall data. The curve of the simulated water level was compared to the recorded water level curve. In order to make the curve fit the recorded water level curve, some parameters were adjusted. More details about this procedure can be found in chapter 3.6 Calibration.

Four different scenarios were formulated and simulated in MIKE URBAN to test the drainage system's capacity and future function. The underlying information for these scenarios were taken from a literature study of the prospected future climate changes in the region, from the result of the Drainage Master Plan of the area, from the Structure Plan for Johor Bahru 2002 to 2020 and from onsite observations.

The results of the simulations for each scenario were analyzed individually in order to evaluate the possible risks of future flooding in the area.

Figure 2 gives a schematic understanding of the strategy of the work procedure of this study to accomplish the objectives.

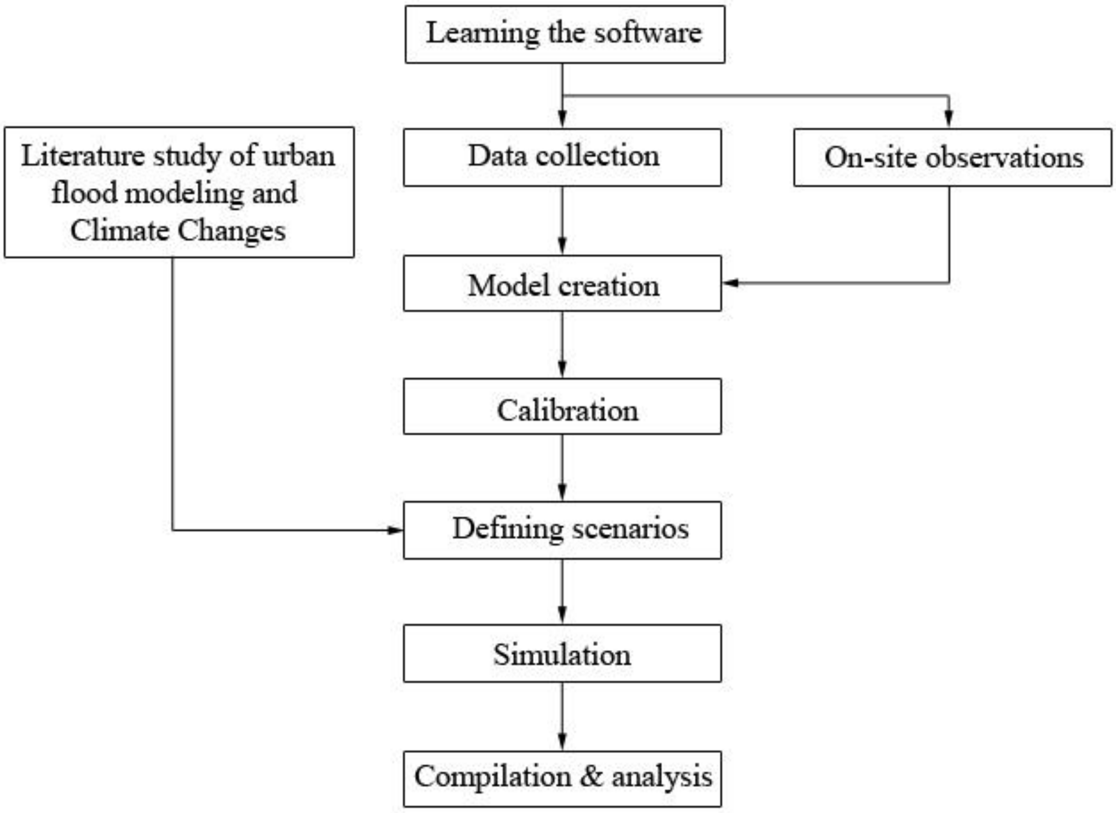

Figure 2. Flow-scheme to illustrate the work procedure of this study (Reuterwall & Thorén, 2009).

1.4 **Limitations**

The study area is a residential area in Senai Town in the state of Johor. The rainfall-runoff model is restricted to this residential area.

The scenarios of the future situation are based on the projected changes in precipitation in South-East Asia, assuming it to be applicable in the region of the study area.

The chosen limits for the catchment area's geographical borders are due to the decision of making the area as urban as possible as the hydrological model "Time-Area method" in MIKE URBAN is more suitable for urban areas.

Fourteen rainfall events were noted during the recording period. The majority of them did not have sufficient rainfall depth in order to be useful for the calibration and validation. This is because they showed none or small response in the recorded water level. There were only five useful rain events. As the number of useful rainfall event was not sufficient for both calibration and validation, the validation was not possible to perform. Out of these five useful rainfall events only two is used for presentation in this report. These two rainfall events had a large rainfall depth and where the most suitable to use for presentation. They also showed a distinct difference in properties, since one of the rainfall events had two distinct peaks.

1.5 Assumptions

The rainfall data was collected on a school area close to the study area but outside of the catchment boundary. This way the equipment was under supervision by the school staff, reducing the risk of it being stolen. This rainfall data is assumed to be applicable also inside the catchment.

Location of roads, residential areas and commercial areas were based on existing data in form of GIS-layers provide by Universiti Teknologi Malaysia (UTM), which are assumed to have the accurate coordinates.

Alignment, slope and dimensions of the drainage network were taken from the Drainage Master Plan for Bandar Senai (DID, 2005b), which is assumed to be accurate.

The scenarios of the future situation are based on the prospective changes in precipitation made by the Intergovernmental Panel on Climate Change (IPCC) along with a study made by the National Hydraulic Research Institute of Malaysia (NAHRIM), assuming the information to be appropriate for this study.

Water losses in form of evaporation are assumed to be small and are therefore neglected in the model. The effects of litter and garbage in the drainage system are assumed be small and therefore neglected.

Observed differences between the real and model hydraulic structures that are difficult to simulate but are assumed to have small impact on the result have been neglected by assuming that:

- Drains between the manholes have uniform slope.
- Drains have the same profile between the manholes.
- The drain construction material is concrete.
- Manholes are circular in shape with the diameter set to the width of the drain.

2 Previous studies on urban flooding and climate change

Computer models for urban drainage networks are created to replicate rainfall events. This is useful when evaluating the function and capacity of the network. Computer models can also be utilized in order to simulate urban flooding. The models give an overview of the drainage network when evaluating flood risks in urban areas. Different scenarios regarding for example increased precipitation and urbanization can be simulated in the model to give a forecast of the future situation. As infrastructure is expensive to construct and maintain, this type of simulation and analysis can emphasize the focus on the most critical points of the drainage network.

Many studies have been made on the subject of urban flooding and a few specific studies have been chosen to demonstrate different procedures when performing computer modeling of urban flooding. There are several approaches to assess urban flooding and one method is one-dimensional modeling. This approach uses rainfall-runoff models which consist of an artificial hydrological model and a hydraulic model. Computer software that can be utilized to construct a rainfall-runoff model is for example MOUSE (Model of Urban Sewers) or MIKE URBAN by DHI and SWMM (Storm-Water Management Model) by EPA. Two studies made on one-dimensional modeling can be found in chapter 2.1. Another approach is to use two-dimensional surface modeling, where flooding can be simulated by overland flow. These types of models can give a clear overview of the locations of flooding as the flooding can be presented as a two-dimensional model. It is also possible to combine one-dimensional models and two-dimensional models to get a better understanding of the connection between the surcharged drainage network and overland urban flooding. Three studies made on two-dimensional modeling can be found in chapter 2.2.

After reading these studies, the intention of this study was to perform a one-dimensional rainfall-runoff model combined with a two-dimensional surface model. This would make it possible to identify locations in risk of flooding and assess the spreading of any flooding. There would also have been a possibility to present the results on a two-dimensional surface, including houses and streets. This would have made the presentation of the results easy to visualize and comprehend. Detailed information about the elevations is important when creating a two-dimensional elevation model (Mark *et al*. 2004). It is also important to choose the appropriate method to implement the houses in the elevation models (Schubert *et al*., 2008). Elevation data and information about the slope in the area is also important in order to simulate the spreading of flooding (Schmitt *et al*., 2004). However, the necessary information such as detailed elevation data was not available and thereby a creation of a two-dimensional model was not possible. Therefore, a one-dimensional model was utilized to simulate the urban flooding in the study area.

The literature studies show that one-dimensional modeling to simulate urban flooding is a conventional approach which can give promising simulation results (Mark *et al*., 1998). A one-dimensional model can also be extended in the future to include a two-dimensional model or a statistical tool to assess failure probabilities of different part of the drainage network (Thorndahl, Willems, 2008). No appropriate study was found about simulating open drainage network with a one-dimensional model, but several studies where found made on closed underground drainage networks. So simplifications that can be made in the model, when simulating an open drainage network with different types of cross sections, were not found in any studies. These simplifications could be for example how to simulate open unpaved manholes in the drainage network and how to construct the cross sections of the drains.

As the climate changes can have a substantial impact on the amount of urban runoff, projected climate models are useful in formulating scenarios of the future situation (Semadeni-Davies *et al*., 2008). Increased precipitation and urbanization are two examples of common scenarios of the future. Global climate models are used to project the climate changes for the whole earth, but they are incapable of capturing extreme rainfall events in adequate resolution. Therefore the global climate models are downscaled into a regional climate model. The downscaling method influences the effects of climate changes on extreme rainfall events and can lead to uncertainties (He *et al*., 2006). These uncertainties can affect the regional model's suitability in describing extremes at time-scales that are relevant to urban drainage (Grum *et al*., 2006). It can therefore be hard to apply predictions of extreme rainfall events in a rainfall-runoff model. These uncertainties are important to keep in mind when simulating the effects of future climate changes.

The result of a study in the United Kingdom was a large reduction in the return period of extreme precipitations, meaning that extreme precipitation will become more common in the future (Senior *et al*., 2002). Another study made in Denmark, suggests that compared to the past decades, extreme precipitation events that affect urban drainage and cause flooding will occur at least twice as often as a result of climate change (Grum *et al*., 2006). Two studies made on the impact of climate changes on modeling of urban flooding and on extreme events can be found in chapter 2.3 and 2.4.

2.1 One-dimensional modeling on urban flooding

Dhaka, Bangladesh
A MOUSE model was created in order to simulate flow and pollutant transport in the city sewer system in Dhaka (Mark *et al*., 1998). There were big problems with flooding in the city and the flooded water depth could in some places be 30 – 50 cm. The flooding occurs even at low rainfall depth and this creates large infrastructural problems when roads are flooded (Mark *et al*., 1998). Flooding causes long-term economical and environmental damages to the infrastructure, such as basement flooding which is a common problem during flooding. The model simulates the flow inside the sewer system and also flow on the streets (Mark *et al*., 1998).

The model was verified against prior flood records in the city (Mark *et al*., 1998). After the verification the model could be used to test suggested improvements to the system so the best and most cost efficient solution could be chosen. The result of the simulations was presented using geographical information system (GIS) in the computer software ArcView.

The results of the modeling in Dhaka showed that the model performed a good reproduction of the flooding in the city according to the flood records (Mark *et al*., 1998). The model will in the future be used to optimize the sewer system in Dhaka.

Frejlev, Denmark
In the Danish town Frejlev, a MOUSE model was created and was with a statistical tool called "first-order reliability method (FORM)" (Thorndahl, Willems, 2008). The aim of combining a MOUSE model with a statistical tool was to find probability of failure of specific component in the sewer system. Such failure can be overflow to receiving water, surcharge or flooding. In Frejlev the sewer system is an underground system that has the possibility to overflow to a nearby stream. In the sewer system, detention storage has been built in order to prevent overflowing of the system (Thorndahl, Willems, 2008). The catchment area is 87 ha and there are approximately 2000 inhabitants in the city.

The conclusion from this study was that the implementation of FORM was applicable when trying to estimate the probability of failure in the sewer system. An advantage compared to traditional methods is that the simulation time can be reduced to 1% of the simulation time in the traditional method (Thorndahl, Willems, 2008). But the simulation with FORM only presents results from one manhole at a time whereas the traditional method presents results from all manholes in the model.

The implementation is only verified against a catchment where the transport of water is done by gravitational forces and not with a catchment with many pumps (Thorndahl, Willems, 2008).

2.2 Two-dimensional modeling on urban flooding

Potential and limitations

The problems with urban flooding are from minor to large ones, ranging from water entering the basements of some houses to major cities being flooded for days. In the industrialized part of the world these problems are mainly due to insufficient capacity in their sewer system during heavy rainstorms (Mark *et al*., 2004). Regions in South/South-East Asia suffer more often of much heavier local rainfall and lower drainage standards. Together with the fact that cities in these regions are growing rapidly without the funds to adapt their existing drainage system, these problems are becoming more urgent (Mark *et al*., 2004).

In history there are several examples of urban flood problems. For example, In Mumbai in India in 2000, 15 lives were lost when the water depth reached 1.5 m, 17.000 telephone lines ceased to function after flooding occurred and electricity was cut off. Bangkok was flooded for 6 months in 1983 which caused both the loss of lives as well as infrastructural damages of about $146 million (AIT, 1985). In 2002, Jakarta in Indonesia suffered from heavy rainfall which extended floods to the city centre, forcing 200,000 people from their homes and killing 50 people nationwide (Bangkok Post, 2002).

The view on damage when water flows on urban surface varies. König *et al*. (2002) divides damages into categories:

- *Direct categories* – typically material damage caused by water or flowing water.
- *Indirect damage* – e.g. traffic disruptions, administrative and labour costs, production losses, spreading of diseases, etc.
- *Social consequences* – negative long term effects of a more psychological character, such as decrease of property value in frequently flooded areas.

As well as damage on properties and goods, urban flooding can cause massive infrastructural problems and enormous economic losses regarding production. (Mark *et al*., 2004)

In the strive for understanding and reducing urban flooding many cities in the developed part of the world use computer-based solutions to manage local and minor flooding problems. Using software such as MOUSE, InfoWorks and SWMM it is possible to create computer models of the drainage or sewer system in order to understand the complex relation between rainfall and flooding (Mark *et al*., 2004). As the existing conditions have been analyzed it is possible to evaluate a mitigation scheme and implement the optimal scheme. Few studies have been made on urban flooding with a combination of conditions in the surcharged pipe network and the flooding on the surface of the catchment (Mark *et al*., 2004). The ones made have dealt with urban flooding as a one-dimensional (1D) problem and a 2D model can be considered as a benchmark for the 1D model (Schmitt *et al*., 2002). Currently, a model that combines 1D pipe flow model with a 2D hydrodynamic surface flood is being developed (Alam, 2003).

Physical processes such as the hydrological process, the hydraulics of the drainage system, the digital elevation model (DEM), the flow exchange between the streets and the pipe system are all involved in urban flooding (Mark *et al*., 2004). The digital elevation model gives information about the land elevation and requires detailed spot elevations. It is recommended for the intervals of the spot elevations to be in the range of 10-40 cm in order to obtain a good resolution and cover important details in the area (Mark *et al*., 2004). Other technical requirements that are necessary can be summarized as:

- *Dynamic flow description:* by using a dynamic wave model, the model includes backwater effects and surcharge from manhole including rapid change of water level.
- *Parallel flow routing:* when surface flooding takes place, it is not necessary that the flow direction on the streets have to be the same as the flow direction in the pipe system.
- *GIS interface:* GIS is an important tool in order to provide input data and to display the results of simulation of urban flooding. The application of GIS together with the DEM of the study area, it is possible to calculate the surface storage. The results of the simulation can be readable in flood inundation maps which are produced by overlaying of water surface and DEM, giving the flood depth map.

(Mark *et al*., 2004)

These facts have also been pointed out by Maksimović and Prodanović (2001).

Other physical processes like evaporation and infiltration are important to consider if they influence the conditions of the urban flooding (Mark *et al*., 2004). A comparison of accumulated evaporation to accumulated rainfall during the period of rain and flooding is necessary in order to know whether evaporation should be included in the model simulation. Evaporation does not affect the simulated maximum flooding if there is only a small evaporation compared to the accumulated rainfall. When it comes to drawbacks and limitations the most important inaccuracy is the dealing with street channels as prismatic and of the flow as one-dimensional (Mark *et al*., 2004).

Some simplification is always involved when engineering predictions are made. Urban flooding is a complex phenomenon and it is impossible to include all details in the modeling (Mark *et al*., 2004). However, this should not hinder from make attempts in using a 1D approach, especially when internal floods are caused by heavy rainfall. Accurate simulations of local conditions on a small scale are difficult to perform. On the contrary, promising results are likely to be achieved when simulation of urban flooding on a larger scale (Mark *et al*., 2004). The combination of 1D hydrodynamic modeling and GIS is believed to be a cost efficient system for drainage systems suffering for urban flooding when it comes to planning and managing (Mark *et al*., 2004).

As 1D modeling approach is sometimes insufficient, future approaches may use a hydrodynamic pipe flow model beneath ground in combination with a full 2D hydrodynamic model in order to be able to describe the surface flow (Mark *et al*., 2004).

Erzhütten, Germany

A dual drainage model called RisUrSim was created to be able to simulate interaction between flow in the underground sewer system and overland flow when the sewer system is surcharged (Schmitt *et al*., 2004). Flooding can occur even if there is no overland flow. Backwater effects from the sewer system cause these types of flooding in the basement of the nearby houses. Wastewater from the sewer system goes into the basements via the outgoing wastewater pipe that is connected in the bottom of the basement. Produced wastewater in the building cannot exit the house, which will increase the flooding of the basement. These types of flooding mostly occur when the sewer system is combined, meaning that the drainage water and wastewater is lead in the same pipe.

Surface flooding depends on local constraints in the sewer system. The spreading of these flooding depends on ground slopes and walkway curb heights. These properties are harder to simulate because it requires a large amount of data in the model, which is often not available (Schmitt *et al*., 2004).

The conclusion of this study was that to simulate urban overland flooding in an underground drainage or sewer system, an underground hydraulic structure must be directly linked to an overland flow routing model (Schmitt *et al*., 2004). This allows the hydraulic structure to flood via the manholes in the hydraulic structure. When the water has exceeded the hydraulic structure the water is routed in the overland model. The water that is routed overland can enter the drainage or sewer system again via the manholes when they are not surcharged (Schmitt *et al*., 2004). If possible, the water can also flow overland to other manholes in the drainage or sewer system. These manholes can be upstream or downstream the original manhole that was flooded. To get an accurate description of this flooding routing to other manholes, the overland model must be detailed.

Glasgow, Scotland

An overland flow model was constructed in order to simulate the flow of water in an urban catchment in Glasgow (Schubert *et al*., 2008). Using remote sensing technology the different types of surfaces were identified. A finite element method was used to generate a mesh structure, where each mesh triangle represents a specific surface (Schubert *et al*., 2008). Two different methods were used to simulate the properties of buildings in the catchment area. The "building-hole method" deletes the mesh where the buildings are represented after the mesh is created (Schubert *et al*., 2008). This means that the flood is not calculated in these meshes because they are deleted. The second method is called "building-block method" and instead of deleting parts of the mesh it increases the elevation of the mesh where the buildings are represented (Schubert *et al*., 2008). This way the flooding is simulated around the building but the flooding must be severe in order to flood the whole house. These two methods were combined with three different sizes of the mesh structure.

The conclusion was that both methods were equally good at reproducing flooding in Glasgow (Schubert *et al*., 2008). The difference was that building-hole method was 30% faster to compute than the building-block method (Schubert *et al*., 2008). However, when the mesh was coarser the building-hole method presented the best result.

A “non-building method” was also evaluated together with the building-block method and the non-building block method showed a good result at coarser mesh (Schubert *et al*., 2008). The building-block method was therefore better to used when the mesh was smaller.

2.3 Climate change impact on urban flooding modeling

Helsingborg, Sweden

In 2007 a study was made on the impacts of climate change and urbanization on drainage in the coastal city of Helsingborg, south of Sweden. The relative impacts have been assessed both separately and together by creating and simulating different scenarios. The storm-water flows were simulated with the DHI (Danish Hydrological Institute) software MikeSHE and MOUSE (Semadeni-Davies *et al*., 2008). The authors want to point out that “futurology is a dangerous game in that a scenario is a picture of a possible future rather than a prediction”. Therefore, the results of the study should be interpreted as magnitudes and directions of possible impacts (Semadeni-Davies *et al*., 2008).

Two climate scenarios and two urbanization scenarios have been created to simulate the city’s future drainage system. Based on future gas emission scenarios projected by the IPCC (Intergovernmental Panel on Climate Change) and the regional climate model by SMHI (Swedish Meteorological and Hydrological Institute) the climate scenarios were put up (Semadeni-Davies *et al*., 2008). The simulations for urbanization and planned subdivision into residential and industrial properties were made by modifying model parameters to imitate trends in demographic and urban water management (Semadeni-Davies *et al*., 2008).

The study shows that climate change effects on the current drainage system increases the problems without any development of the city (Semadeni-Davies *et al*., 2008). The cause is increased precipitation and surface runoff. The scenario of further urbanization increases flood risk in some parts of the system. A combination of the scenarios shows increased peak flow volumes and the potential to cause the worst drainage problems. Another finding was that in order to mitigate the impact of urbanization, source control and increased storage capacity is a solution (Semadeni-Davies *et al*., 2008). However, this is not likely to be enough to eliminate the combined effects of city growth and climate change. The study also brings up the general positive effects of installing SUDS (Sustainable Urban Drainage Systems) in urban environments (Semadeni-Davies *et al*., 2008).

Calgary, Canada

In Calgary, Canada, simulations of the drainage system were performed in order to evaluate new design practices that consider climate changes (He *et al*., 2006). The design of drainage network has traditionally been based on historical rainfall records. These design practices assume that the climate does not change, which if the climate changes will yield more intensive precipitation can lead to that the drainage system is under dimensioned. Because drainage system is a large investment in the infrastructure and is assumed to be in working condition for many years, there is a large economical benefit of taking climate changes into account when designing a drainage system. New design rainfalls were calculated and used in a simulation of the drainage system in Calgary, to see if the drainage network would pass the new design criteria (He *et al*., 2006).

The conclusions of this study were that the effects of climate changes on the extreme precipitation events are dependent on the downscaling method from the global climate model and its projected climate variables (He *et al*., 2006). This study can be used to assess the effects of climate change to existing or new drainage systems. Then each design procedure can be modified in order to assess the impact of climate change to the design practices.

2.4 Climate change effects on extreme precipitation events

United Kingdom

Senior *et al*. 2002 wanted to simulate the changes of extreme precipitation and affects of an increased mean sea level to the occurrence of extreme sea level. Both global and regional climate models were used in the study. A regional model was created over the United Kingdom in order to evaluate the consequences of an increased extreme precipitation and an increased extreme sea level at already flood sensitive areas (Senior *et al*., 2002).

The conclusions of this study were that changes in extreme precipitation are hard to evaluate from global climate models, because they do not have enough resolution to accurate capture extreme events (Senior *et al*., 2002). The regional models gave better result in capturing extreme events. These models were used to simulate extreme precipitation in the end of the 21st century. The result was a large reduction in the return period of these extreme precipitations, meaning that extreme precipitation will become more common in the future (Senior *et al*., 2002). The global models indicate that the speed hydrological cycle will increase in warmer climate, generating more precipitation in these parts of the world.

One must keep in mind that the regional models require data from a global climate model. This data are dependent on climate feedback, climate variability and different types of scenarios (Senior *et al*., 2002).

Copenhagen, Denmark

A study has been made in order to look at the effects of climate changes on extreme precipitation events (Grum *et al*., 2006). Predictions from a regional climate model were used and simulations for both present and future climate to reflect the predicted climate change were made by a methodology of comparing and transforming rain gauge measurements (Grum *et al*., 2006).

The study was made in three steps. The first one is about making an average of the hourly rainfall intensities from 16 point rain gauges. This is made in order to create a rain gauge equivalent intensity corresponding to one grid cell in the climate model. Secondly, projection of the hourly extreme statistics of the rain gauge surface into the future is made by looking at the differences between present and future in the climate model. The third part performs a downscale of the future extremes of the square surface area in order to give future point rainfall extremes (Grum *et al*., 2006).

The results of the study are presented as changes in the return periods of extreme events. A halving of the return periods for hourly intensive extreme events is suggested in the conclusion of the study. The study suggests that compared with the past decades, extreme precipitation events that affect urban drainage and cause flooding will occur at least twice as often as a result of climate change (Grum *et al*., 2006). Even though the results of the study are clear, it is necessary to understand the uncertainties to the analysis. These uncertainties are based on the regional model’s suitability in describing extremes at time-scales that are relevant to urban drainage (Grum *et al*., 2006).

3 Study area

3.1 General

The study area of Senai Town is within the Sungai Senai catchment in the state of Johor in the southern part of Malaysia in South-East Asia. Sungai Senai catchment is one main river system in the region and has an area of about 3250 hectares (DID, 2005a). Anak Sungai Skudai is another main river system in the region which also has problems with flooding similar to Sungai Senai. The river Sungai Senai is discharging downstream into river Sungai Skudai which later is discharging into Selat Johor between Malaysia and Singapore. Selat Johor is connected to the Andaman Sea in between Malaysia and Indonesia (DID, 2005a).

Cabang Sungai Senai Fasa 1 is a tributary of Sungai Senai and is the object of this study. It has a catchment area of 32.91 hectares and a length of 0.83 kilometers (DID, 2005a).

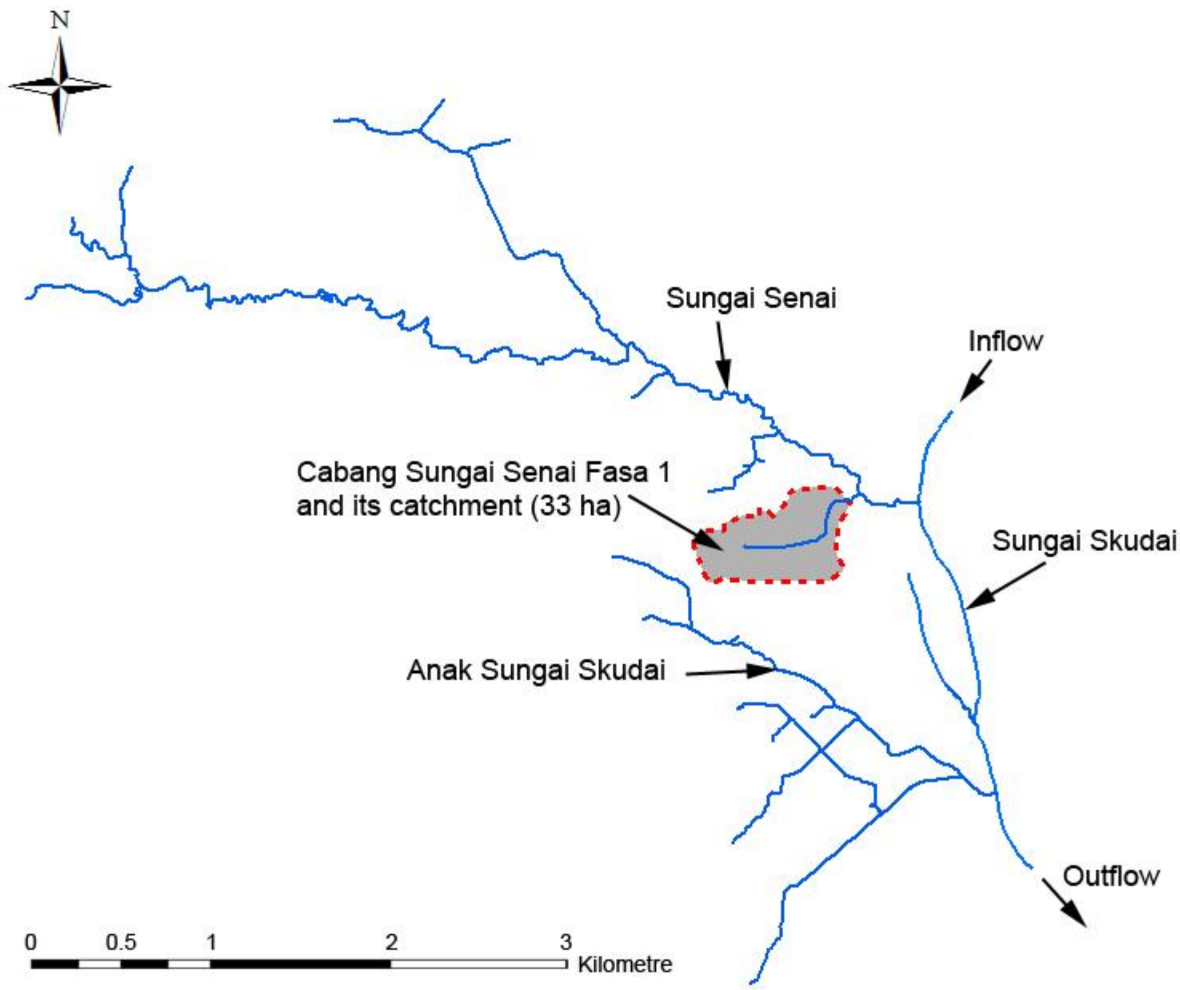

Figure 3. The river system in Bandar Senai in the state of Johor, Malaysia. The river Cabang Sungai Senai Fasa 1 and its catchment is the object of this study (Reuterwall & Thorén, 2009).

3.2 Climate

In the region of the study the climate is tropical (DID, 2005a). The humidity is high with a monthly relative humidity varying between 70 to 90%, depending on place and month. Malaysia is close to the equator and it receives an average of 6 hours of sunshine per day (MMD, 2008).

The temperature during the year is uniform, as Malaysia is an equatorial country (MMD, 2008). The average temperature is 27°C with an annual variation of less than 2°C (DID, 2005a). However, the daily range can vary between 5°C to 10°C. Local topographic characteristics together with seasonal wind patterns affect the rainfall patterns over the country (MMD, 2008). Monsoons influence the climate and rainfall distribution during the months from November to March (northeast monsoon) and during May to September (southwest monsoon). The annual rainfall varies between 1500 and 3500 mm (DID, 2005a). This study is performed during September to November 2008.

3.3 Topography and land use

The area of the study is hilly and has a general slope running from North-West to South-East. The area is almost entirely urbanized with estates consisting of residential houses, commercial buildings, health centers and schools.

3.4 Existing drainage system

The drainage network for storm water is almost entirely an open drainage system and consists of concrete lined channels and culverts in different dimension. The system has a main channel running from west to east, see Figure 4 in chapter 4.3 on page 23. Channels with smaller dimensions are leading the water from the residential houses, other buildings and green areas to the main channel. The drainage water is further lead into river Sungai Senai.

3.5 Present flood problems

At low-lying areas in the Sungai Senai catchment, flash floods have occurred due to insufficient capacity in the drainage system. Additional cause is the backwater effect of the river Sungai Skudai (DID, 2005a). In relation to the study area, flash flood areas are situated near the Senai town centre, along the middle reach of Anak Sungai Skudai and at the lower reach of Anak Sungai Skudai. In the most problematic areas (the low-lying areas) along the river, water rises up to 1.0 meter during heavy precipitation (DID, 2005a).

The Department of Irrigation and Drainage (Jabatan Pengairan dan Saliran Johor) has performed some attempts to improve the river conditions in the past in order to mitigate the problems of flooding. However, the effects were adverse because of the rapid siltation of the river (DID, 2005a). The improvements are not specified in the Drainage Master Plan.

The Government of Johor carried out a Drainage Master Plan in 2002, to identify existing drainage problems and propose long-term improvements with a projected year of 2020. According to the plan there are four main reasons why flooding occurs in the area:

- Insufficient capacity in the existing water course to handle the increased runoff due to urbanization.
- The culverts are too small for outlets and under road crossings.
- Some cross sections of the drainage network have inappropriate hydraulic properties which reduce the water transporting capacity.
- Clogging due to poor maintenance of the drainage system.

(DID, 2005a)

The downstream part of Cabang Sungai Senai Fasa 1 has experienced flooding in the past. The cause is inadequate capacity of the hydraulic structures and backwater effects from the river Sungai Senai (DID, 2005a).

3.6 Climate changes in the region

Among many other sources, the scientific intergovernmental body IPCC states that the Earth is standing before an extensive global climate change. This is mainly due to the human's usage of fossil fuel as energy source which is increasing the greenhouse gases (IPCC, 1997). As these concentrations are increasing the temperature on the Earth's surface is raised steadily, with 0.8°C since the 1950s. The IPCC projected in 2001 an increase of global mean temperature of 1.4-5.8°C by the year 2100 along with an increased sea level of 9-88 cm (CSIRO, 2006).

The IPCC demonstrates the effects of global warming to have adverse consequences on the Asia/Pacific region. Already, areas in tropical Asia are subject to climate extremes such as floods and cyclones (CSIRO, 2006). Observations of rainfall trends have showed inter-seasonal, inter-annual and spatial variability in all of Asia (IPCC, 2007).

Water and agriculture are the most vulnerable sectors to the effects of climate changes in Asia. Areas in tropical Asia are expected to be increasingly exposed to extreme events such as typhoons, tropical storms and floods (IPCC, 2007). Tropical cyclone intensities are expected to rise with 10 to 20% in South-East Asia due to an increased sea-surface temperature of 2 to 4°C. Along with the rise of cyclone intensities the sea-level is expected to rise. Before entering the 22nd century the sea-level will reach 40 cm higher than today, causing the risk of annual amount of flooded people in the world to increase from today's 13 million to 94 million. (IPCC, 2007)

Regarding the changes in rainfall in the region, climate models give different results and vary significantly between different areas. However, the central estimations are reduction of rainfall in west South-East Asia of less than 10% by 2030 and by 2070 less than 20-30%. These reductions will vary along with the seasons of the year, with increasing rainfall with the region's summer monsoon. These percentages are to be interpreted as directions and not magnitudes. Extreme monsoons have caused flooding and crop damages. The risk of extreme rainfall any given year is increased as the climate change increases the variability of monsoon rains. (CSIRO, 2006) In tropical Asia increased precipitation intensity can increase flood-prone areas, especially during summer monsoon (IPCC, 2007).

In order to project future climate it is common to use climate models. This is done by collecting existing information about the climate system of the Earth and simulating it using quantitative methods. The IPCC has projected the changes of precipitation for seven sub-regions in Asia and uses two emission levels to classify the future scenarios. Pathway SRES A1F1 has used the highest future emission and pathway B1 uses the lowest emission. The time periods are 2010-2039, 2040-2069 and 2070-2099 compared to the time period 1961-1990. The projected changes of precipitation in the sub-region of South-East Asia and the region of the study of this report are presented in Table 1 below. (IPCC, 2007) It shows that IPCC predicts a 12% increase of precipitation in the end of the 21th century.

Table 1. This table shows IPCC's projected changes of precipitation (%) in the sub-region of South-East Asia between the years of 2010 to 2099 in comparison to the years of 1961 to 1990 (IPCC, 2007).

2010 – 2039			**2040 – 2069**			**2070 – 2099**		
Season	A1F1	B1	Season	A1F1	B1	Season	A1F1	B1
Dec-Feb	-1	1	Dec-Feb	2	4	Dec-Feb	6	4
Mar-May	0	0	Mar-May	3	3	Mar-May	12	5
Jun-Aug	-1	0	Jun-Aug	0	1	Jun-Aug	7	1
Sep-Nov	-2	0	Sep-Nov	-1	1	Sep-Nov	7	2

A more local study of the impact of Climate Change on Peninsular Malaysia was performed in 2005 by the National Hydraulic Research Institute of Malaysia (NAHRIM). Two climate models were used in the study, namely the major Global Climate Model (GCM) and simulations of Coupled General Circulation Model (CGCM1) of the Canadian Centre for Climate Modeling and Analysis. The result of the study shows that there is a small decrease of precipitation in southern region of Peninsula Malaysia. At the same time there is an increase of maximum monthly precipitation. When comparing the maximum monthly precipitation during 1993-1994 and the simulated during 2041-2050, there is an increase of 2.9%. (NAHRIM, 2005)

Based upon these two studies, Scenario 1 is formulated with three different precipitation levels. The first increase is with 3% based upon the study made on the southern region of Peninsula Malaysia in 2005. In addition, increases of 5% and 10% respectively are simulated based upon the projected changes over South-East Asia made by the IPCC in 2007. Read more about this in Model scenarios, chapter 3.8.

The increase of monthly precipitation is assumed to correspond to increased intensity of short term rainfall. This assumption was made because no other information about future rainfall intensity changes was found during this study.

4 Runoff modeling

4.1 Hydraulic construction

In this study the DHI computer program MIKE URBAN has been used to perform the hydrological and hydraulic calculations. MIKE URBAN computes pipe flow with both free surface and pressurized flow (DHI, 2008). The program is computing the pipe flow using the Saint Venant free surface flow equation in a finite difference numerical solution (DHI, 2008). Calculations can be performed on both subcritical and supercritical conditions, also including backwater effects.

The two types of differential equations are used in MIKE URBAN to calculate the conservation of mass and conservation of momentum, see equation 1 and 2. The equations are solved for several points inside the pipes and inside the manholes. A computer program called MIKE VIEW is used to present the result of the simulation and present the result in graphs or animations. Because the differential equations are solved for a large number of points along the pipes it makes the illustration of for example back water effects inside MIKE VIEW to appear more natural.

$$\frac{\delta Q}{\delta x} + \frac{\delta A}{\delta t} = 0$$

Equation 1. Conservation of Mass – continuity equation that is used in the computation in the computer program MIKE URBAN (DHI, 2008).

$$\frac{\delta Q}{\delta t} + \frac{\delta\left(\alpha\frac{Q^2}{A}\right)}{\delta x} + gA\frac{\delta y}{\delta x} + gAI_f = gAI_0$$

Equation 2. Conservation of Momentum – momentum equation that is used in the computation in the computer program MIKE URBAN (DHI, 2008).

The variable definition of equation 1 and equation 2 is explained below (DHI, 2008):

Q = discharge [m^3/s]
A = flow area [m^2]
y = flow depth [m]
g = acceleration of gravity [m/s^2]
x = distance in the flow direction [m]
t = time [s]
α = velocity distribution coefficient
I_0 = bottom slope
I_f = friction slope

Nodes

In MIKE URBAN, manholes in a sewer or discharge network are called nodes. In this study, the nodes do not consist of manholes. Instead they represent locations where open drains change dimensions or constructed open holes in the ground. Pipes and canals, called links, can only be defined between two nodes. One or more links can be connected to a node, creating a junction of links. Nodes must be defined with x and y coordinates, which can be put in manually, imported or edited using the integrated GIS tools in MIKE URBAN. Furthermore the ground level and invert level must be defined. Invert level is the level of the bottom of the node. Local head loss in the node can be modified depending on the link outlet of the nodes, which yields a loss in energy when the water passes out from the node. This simulates the loss in energy due to for example turbulence when the water passes through the node.

There are five types of default outlet head loss, but in this study only two of them will be utilized. The two utilized head losses are “MOUSE Classic (Engelund)” and “No Cross Sectional Changes” (DHI, 2008). The MOUSE Classic head loss gives an energy loss to the water when it passed through a node, simulating the change of diameter between the link and the node. No Cross Sectional Change means that the cross section is not changed between the links and the nodes and there is no energy loss in the water.

There are four different types of nodes, called “Manhole”, “Basin”, “Outlet” and “Storage node” (DHI, 2008). This report will only use two types of nodes, “Manholes” and “Outlet”, because there are no basins or storage in the drainage network. An outlet node is where water can exit the model and a manhole node is utilized when the links change direction or when the dimension of the links change. In this type of drainage network there are no manholes by definition, because real manhole lye underground. But there are no other definitions of nodes that are not manholes in MIKE URBAN, so the definition of “manholes” must be utilized. In this study the drainage network is partly open and partly closed. When the drainage network is open so are the “manholes” and the outlet head loss definition of MOUSE Classic (Engelund) is used. However, when the drainage network is underground, the “manholes” are also underground and thereby they are no longer “manholes”. They are more like locations where the links change direction and at the same time the dimensions stay the same. The drainage network is then closed and the definition of outlet head loss No Cross Sectional Change is utilized.

Also, different functions such as weirs, orifices, pumps and valves can be connected to nodes in MIKE URBAN (DHI, 2008). However, no function will be added to any nodes in the model in this study. Because there are no parts of the drainage network that needs to be simulated with a function.

More detailed information about individual nodes in the model, such as invert level, ground level, diameter, outlet head loss, node type and coordinates can be found in Appendix 2.

Links

Pipes and canals in a sewer or discharge network are, in MIKE URBAN, called links. All links in the model must be connected with two nodes. Information of pipes and canals cross section is taken from drawings and figures in the Drainage Master Plan for Senai Town (DMP Vol. 3, 2005). There are six different cross sections for the links in the drainage system inside the study area. They are circular, rectangular or U-shaped.

There are three methods of defining cross sections in MIKE URBAN. The first one is to use a circular cross section, where only the diameter must be defined. The second alternative is to define the cross section as rectangular, where the height and width must be defined. The third option is to use the CRS (Cross Section) method, where all types of symmetrical or unsymmetrical cross sections can be defined. Using the CRS method, it is also possible to define open and closed cross sections. Because one can create rectangular cross sections also in CRS, the method of defining rectangular cross sections where not used. Those cross sections that where rectangular, were instead defined with the CRS method.

CRS cross sections can be edited in four different ways. First, one must define if the drain is open or closed. Then, it is possible to choose between defining the cross section with height and width or x and y coordinates for each of these cases, depending on if the section has a symmetrical shape and how the available data is organized. If the data of the cross sections can be stored according to a coordinate system, the method of defining the cross section with x and y coordinate must be utilized. If the data is stored with width as a function of height the definition of the cross section must be according to height and width. As all cross sections in this project are symmetrically shaped with the data according to height and width, the CRS has been defined with height and width for open or closed cross sections.

The Manning's number can be changed when choosing the links material and it is preset for most common pipe or canal construction materials, such as concrete, plastic and ceramics. The material setting that is chosen in this study is "normal concrete". These numbers can be changed manually or one can create own materials. The height of the water path in the links can be put in manually or be automatically set by the invert level of the nodes they are connected to, using the "AutoAssign wizard".

The AutoAssign wizard can help to assign all types of properties to nodes or links using properties from nearby nodes or links to assign data for the nodes or links that are missing these properties. Even topographical data in form of DEM (Digital Elevation Map) can be used when automatically assigning properties to nodes or links. Nearby nodes and links can be diversified depending on if they are connected to the node or link which properties are about to be changed, i.e. processed. For example a node that doesn´t have a value of ground level can use the information from a close upstream or downstream node, that is connected to this node through a link, using a linear or distance weight method. The node is then not using information from others nodes that could be closer but not connected through a direct link to the node that is going to be processed.

More detailed information about individual links in the model, such as upstream or downstream level, length, slope, type and geometry can be found in Appendix 2.

4.2 Hydrological construction

Hydrological models

In MIKE URBAN one can choose between two different types of hydrological models, surface models and continuous hydrological models (DHI, 2007). Surface models only calculate the overland surface runoff and give a discontinuous hydrograph as output. This means that runoff is only generated during a rainfall event. These types of models are suitable to use in densely urbanized areas, where most of the runoff is generated from impervious surfaces (DHI, 2007). Therefore a surface model is chosen to be used in this study because the study area is urban with most of the surfaces being impervious. Surface models are also the better choice if simulating short design rainfall events or rainfalls with a specific return period. The rainfalls that will be put in the model in this study are actual recorded rainfall from the study area and they do not have a specific return period. The rainfall events are short and most of them have duration of less than 1 hour.

When the study area is rural a continuous model is better to use. It gives a more realistic result for rural areas because it calculates runoff using a precipitation volume balance, including overland and sub-surface generated runoff. The model has a "hydrological memory", which means that the model remembers the hydrological situation from the previous rainfall event

(DHI, 2007). This memory is essential when simulating over a longer time period. However, this is not the case in this study because a surface model was chosen.

The surface models included in MIKE URBAN "Time-Area Method", "Kinematic Wave", "Linear Reservoir" and "Unit Hydrograph Method" (DHI, 2007). The Time-Area Method is chosen as the hydrological model in this study, because it is suitable for urban catchments, requires a small amount of input data and is easy to modify. The included continuous hydrological model is called MOUSE RDI (Rainfall Dependent Infiltration) (DHI, 2007). There is a possibility to combine a surface runoff model with MOUSE RDI, but in that case it must be done for all catchments. However, this possibility will not be utilized in this study.

The Time-Area Method requires a minimal amount of input data and is a very simple type of surface model (DHI, 2007). The behavior of the generated runoff can be manipulated by changing a few parameters. The parameters are grouped together in sets that can be saved with a name and can be associated to one or several catchments. First of all the model must know the initial loss of the rainfall. This setting is necessary in order to simulate the wetting of the impervious surfaces. A total hydrological reduction factor can also be set to simulate the overall reduction of the rainfall. Time of concentration can be modified to simulate the amount of time it takes for the whole catchment area to contribute to the runoff. To consider the shape of the catchment a time-area curve can be changed. The curve defines the amount of the catchment area that is contributing as a function of time. By default these parameters is set to all catchments, but can easily be changed for each individual catchment. (DHI, 2007)

For each individual catchment one must define the total catchment area and the amount of impervious surfaces in percentages. People equivalents and additional flow can be defined for each individual catchment, however it is optional (DHI, 2007). When drawing the catchment in MIKE URBAN the total catchment area is automatically defined, because MIKE URBAN calculates the area from the polygon that is drawn. Changing the value of the drainage area can modify the value of the catchment area, if the catchment is only drawn for presentation purposes.

Catchment creation

By using the integrated GIS tools in the computer program ArcMap from ESRI, catchments can be defined by either drawing them, or by using an existing GIS layer or by using a DEM (Digital Elevation Map). In this study the catchments were drawn manually as polygons in ArcMap based on onsite observations. The polygons were later used in the "Catchment Delineation Wizard" to be converted into MIKE URBAN catchments.

The tool Catchment Delineation Wizard is used in order to define catchments. When drawing the catchments manually it is preferred to have an existing GIS layer as background, which can be used to locate important features such as roads, houses and green areas. Predefined features that must be available when dividing different catchments with the Catchment Delineation Wizard are points or lines. The points are by default chosen to be the manholes whereas the polygon (lines) is the links between nodes. However, one can use any existing GIS layer with points or lines. The division of the catchments between these points or lines is done by Thiessen polygons. An important note is that delineation of catchments, with an existing GIS layer, is only done to the selected polygons and if a point or line is located within these selected polygons. When using DEM delineation, predefined points or lines are not needed because the catchments are created according to the topography. The numbers of catchments that are created are also depending on the topography.

When the catchments are created they must be connected to manholes, otherwise the model will not work. This can be done manually by using the graphical editing tools or automatically with the Catchment Connection Wizard. When connecting the catchment automatically one can choose to connect all catchments or only the selected catchments, to the closest node. If the catchments have been connected to the wrong node, this can be modified with the graphical editing tools (DHI, 2007).

The last catchment tool is the “Catchment Processing Wizard”. This wizard helps to calculate imperviousness and hydrological parameters for the catchments. In the calculation of imperviousness one can set a fixed value or use different existing GIS layers representing different surfaces with individual imperviousness. The latter method is useful when one has access to GIS layers representing buildings and roads, because they contribute to the largest amount of runoff. In the calculation of the hydrological parameters the mean surface velocity can be set to calculate the time of concentration. Individual reduction factors and initial loss can also be set here for each individual catchment (DHI, 2007). In addition, the wizard can calculate the most appropriate time-area curve for each individual catchment or set a fixed Time-Area curve for all catchments. However, in the model in this study, all catchments will utilize the same Time-Area curve in order to avoid complexity when calibrating the model.

In this study only tool which calculates the amount of impervious surfaces where used in the Catchment Processing Wizard. This is because the tool which calculates the hydrological parameters did not work in the computer program MIKE URBAN. The wizard just did not work when this tool was used so this tool was switched off and only the amount of impervious surfaces where calculated using the wizard. No other solution to this program was found. The hydrological parameters were therefore calculated manually. Values of imperviousness were taken from Publication 90, written by Swedish Water (Svenskt Vatten, 2004). This publication is used when dimensioning drainage systems in Sweden.

The values of imperviousness for different types of surfaces were set to:

- Roof – 90%
- Roads – 80%
- Others – 10% (later changed to 40%, see chapter 3.6)

More detailed information about individual catchments in the model, such as area, amount of impervious area and time of concentration can be found in Appendix 2.

4.3 Description of the MIKE URBAN model

The MIKE URBAN model that was created in this study has a total catchment area of 33 hectares, see Figure 4. After onsite observations, looking at the flow direction in the smaller drains of every street in the catchment area 24 different sub catchments could be defined. They were defined according to flow paths after onsite observations, where runoff from each sub catchment has the same discharge point into the hydraulic structure. Later one virtual catchment is added in one of the simulation scenarios which give a total number of 25 catchments. The hydraulic structure is describing the main drain, positioned in the middle of the overall catchment. Because the hydraulic structure only describes the main drain and not the smaller drains in each street, the 24 sub catchments have very large areas. If the smaller drains were to be included, there would have been a larger number of sub catchments with a smaller area.

The mean value of the amount of impervious surfaces is 74% of the 32,91 ha catchment. This could be set in the perspective to the dimensioning value of 40 – 60% impervious surfaces of a similar catchment in Sweden (Svenskt Vatten, 2004). Apart from the intensive rainfalls in Malaysia, a larger amount of impervious surfaces yields a larger runoff, which increases the risk of flooding.

Alignment, dimensions and slopes for the hydraulic structure are taken from Drainage Master Plan for Senai Town (DID, 2005b). The cross section of the drain varies along downstream. Due to the topographical situation in the catchment area the slopes of the drains are steep, which leads to a high velocity of the water. The drain consists of prefabricated sections joined together onsite with concrete. At the far most upstream the sides cross section is V-shaped but with a flat bottom, going into a big U-shaped drain that is three meter wide. When the drain goes underground it either goes into having a circular or rectangular cross section with smaller cross sectional area, where water is gathered during high intensity rainfalls, creating backwater effects.

Notice the definition of "Section 1" and "Section 2" in Figure 4. Thus it is in these sections where flooding will occur in the simulations and much of the explanation in the results and conclusions is referred to these two sections. Therefore it is important to especially remember these two sections.

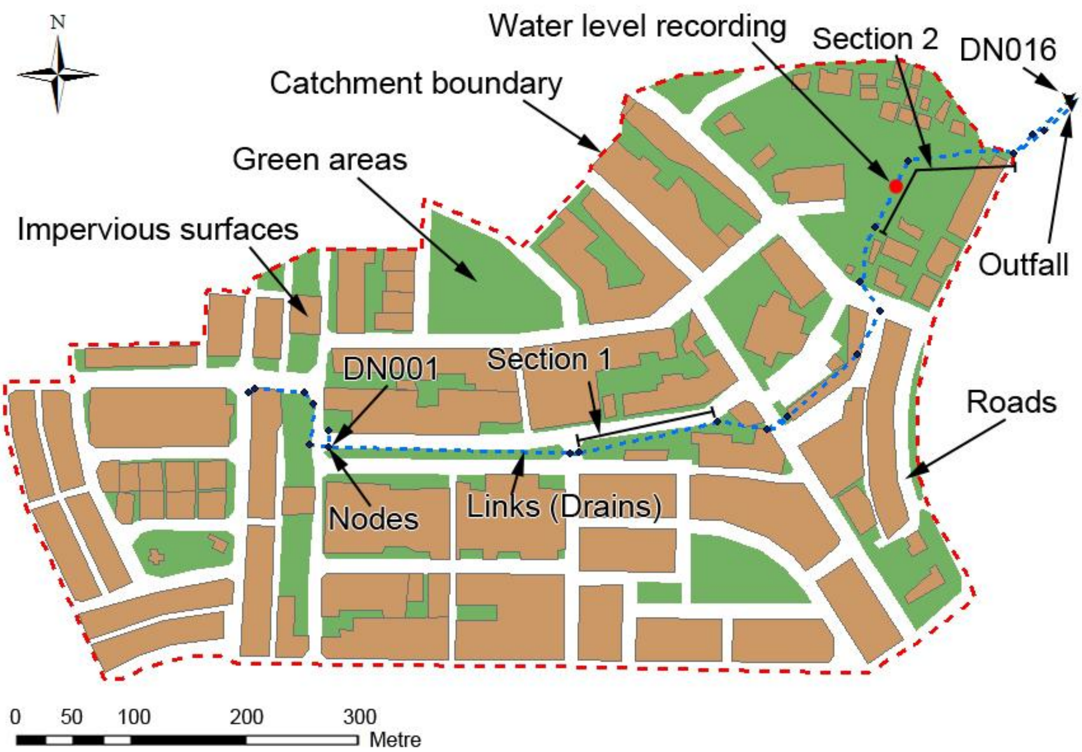

Figure 4. Overview of the catchment area, presented in GIS-layers. Notice the definition of "Section 1" and "Section 2" where flooding will occur in the simulations (Reuterwall & Thorén, 2009).

4.4 **Input data**

Quantitative data such as rainfall and water level was collected in order to perform a calibration of the model. Rainfall data is the only varying input data. Collection of this data was done with a rain gauge using a so called “tipping bucket”. The equipment consists of a cylinder made of stainless steel. On the top of the equipment a funnel collects the water and leads the water into the cylinder and fills up the bucket. When the bucket is full it tips over and a logger registers the time of this event. One tip of the bucket is equal to 0.2 mm of rain. More details about the equipment can be found in Appendix 1.

In order to be able to calibrate the model parameters and to get a more realistic result, the water level in the drainage network must be monitored. This was done by installing a water level recorder, which records the water pressure and converts this to water depth. The resolution of the water level recordings was set to one minute, because the recorder could store 40.000 values. With this resolution, the number of available days for recording was almost 28 days. It was calculated like this:

40 000 values / 60 values / h = 666 h
666 hours / 24 hours / day ≈ 28 days

Placement of the equipment was chosen at a point where the channel flow can be assumed to be uniform, with a small bottom slope, rectangular cross section of concrete and small or no backwater effects. See the location of the water level recorder in Figure 4 on page 23. The channel flow was assumed to be steady state, meaning that the water depth is not changed with time, within the recording interval. The recorded water level is not an average value but a point-value of every minute. Originally, two water level recorders were installed. The second recorder was placed in section 1. However, this one was stolen and therefore data was only recorded in section 2.

Rainfall and water level was recorded from the 24th of October to the 18th of November 2008. During this period there were fourteen rainfall events of which five had enough rainfall depth to be used in a calibration of the model. To make the presentation of the results easier two rainfall events are utilized for presentation in this study. These rainfall events occurred during the 5th and 12th of November 2008 respectively, see Figures 5 and 6. The water level recordings, during the rainfall event during the 5th of November 2008, had two distinctive peaks which is an interesting property. But this property also makes a good calibration result harder to achieve. Therefore this rainfall event was used for presentation. The return period for this rainfall event could not be calculated by the design principles in MASMA 2000, because the calculation parameters were only available for return periods equal or larger than two years. The rainfall depth on the 5th of November 2008 was lower than the rainfall depth for a rainfall event with a return period of two years with equal duration. The rainfall event during the 12th of November 2008 had the largest rainfall depth of all recorded rainfall events and was therefore chosen for presentation. According to the design principles in MASMA 2000, this rainfall event has a return period of about two years in Johor Bahru (DID, 2000b). The simulation result for the other useful rainfall events, with belonging water level recordings, showed the same pattern as for these two rainfall events that were used for presentation.

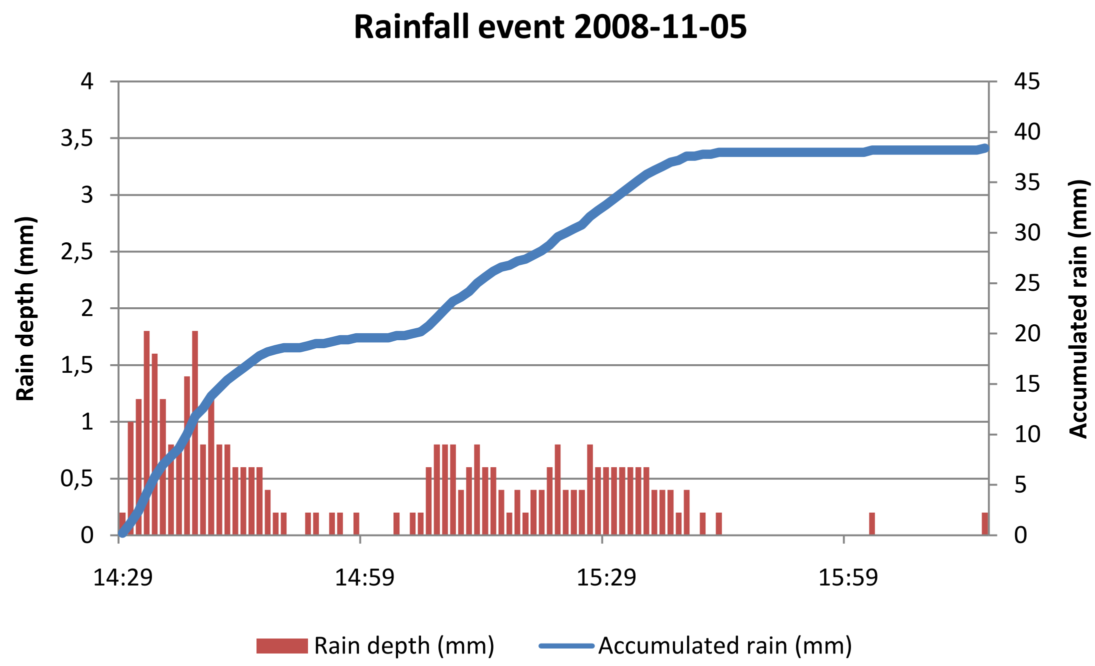

Figure 5. The result of the measured rainfall on the 5th of November 2008 presented both as a hydrograph and accumulated rain depth. Notice that the rainfall has two peaks.

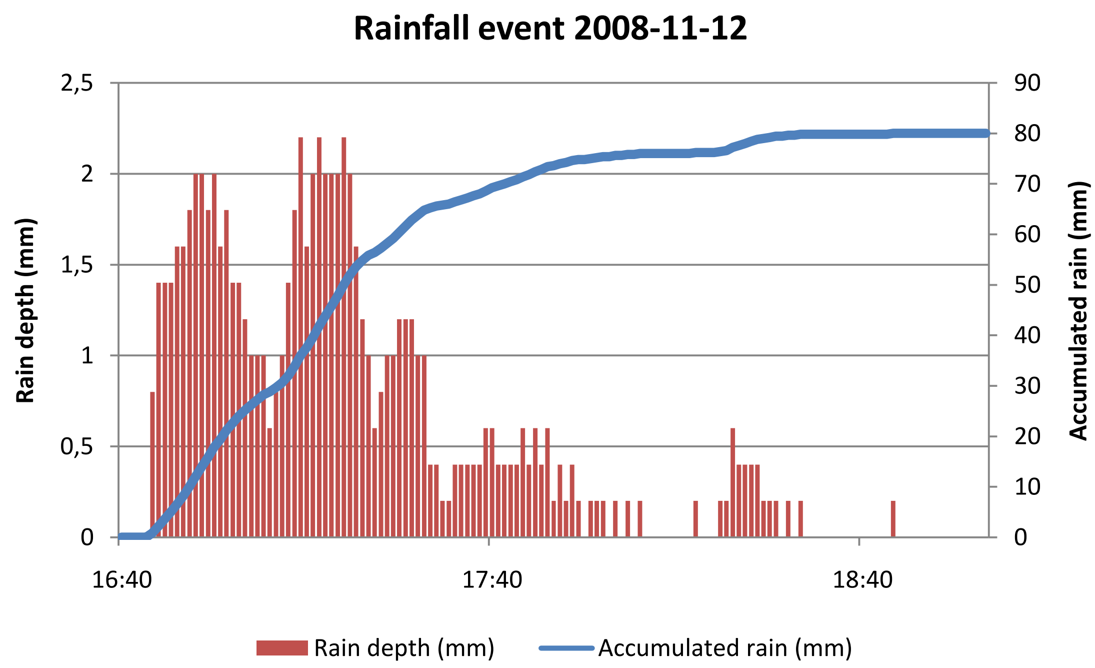

Figure 6. The result of the measured rainfall on the 12th of November 2008 presented both as a hydrograph and accumulated rain depth.

4.5 **Source of errors**

Values of elevation in the drainage network were taken from the Drainage Master Plan. Unfortunately no exact coordinates where these measurements had been taken were specified.

Position of the drainage alignment was instead drawn with help of GIS-layers and aerial photographs. This does not give the exact alignment of the drainage. However, it should not give a larger error than a couple of meters, considering the size of the overall drainage network. This can be considered to have a small effect on the result.

GIS-layers that have been utilized do not always coincide with the reality, such as planned areas that have not been built yet. This was noted during onsite observations. This is the situation especially in the northeast part of the catchment, where houses seem to have been built without proper planning. The location of the actual houses that have been built was identified by looking at aerial photographs.

The measuring equipment for the water level recording was installed inside a PVC-pipe, which was attached to the wall of the drain, see Figure 7. Prefabricated concrete sections build up the drain and between these sections there are some gaps. This gave the perfect support for the PVC-pipe to stay in place when the water level was high in the drain. However, because the PVC-pipe was installed inside this gap there might have been some differences of elevation between the inside of the pipe and the bottom of the drain, see Figure 7. Because the measuring equipment was lowered into the pipe via a nylon string and the exact elevation of the bottom inside the pipe is unknown there might by some difference in elevation. But by manually measurements of the water level and comparing it to the recorded values this error can be considered to be less than 1 cm.

Figure 7. This picture illustrates the installation of the water level recorder in a drain in Senai Town. A PVC-pipe (plastic pipe) was installed in between prefabricated concrete sections in order to provide support for the pipe. The water level recorder was installed with a string, inside and at the bottom of the pipe. Left: The pipe is attached to the concrete wall with nails and steel string. Right: The picture is taken from above the drain, looking down along the PVC-pipe (Reuterwall & Thorén, 2009).

As many pipes and culverts are situated underground and blueprints over the drainage network were not found, the actual catchment area might be larger than the total catchment area defined in this study as pipes and culverts possibly are crossing the defined catchment boundary. The area where this error possibly would occur is in the eastern part outside of the defined catchment area, where the ground is more flat and many culverts and pipes are placed underground. However, if this error should occur, it would probably not influence the measured water level, because the discharge of the eastern part most likely would be done further downstream than the location of the water level recording.

The model is not considering at the direct impact of evaporation. This phenomenon has a small impact on the output results because the model only uses small time periods and reflects an urban area with large amount of runoff, which is generated rapidly from the impervious surfaces. However, one parameter that could have an impact of evaporation is the definition of initial loss. This loss is used to simulate the amount of water that is needed for wetting of the ground to such an extent that runoff is created. If the ground is dry it takes more water to wet the ground than if the ground is already wet. This impact should also be small as the initial loss is only used in the beginning of the simulation.

Many properties of the drainage network are hard to reproduce in a model, such as the construction of the nodes. Most nodes are square-shaped but are for practical reasons modeled as circular, with a diameter equal to the width of the drain. The bottoms of the nodes are often unpaved in reality, see figure 8. In the picture, loose material on the bottom of the node can be seen. As water removes the loose material in the bottom, the actual volume of the node can vary with time. These errors associated with the nodes should not have a large impact of the out-coming result, as it is only an error of the storage capacity of the nodes.

Figure 8. This picture illustrates the ground conditions found at several nodes in the drainage network in Senai Town. Loose material, rocks and garbage are some obstacles in recreating these nodes in the model completely (Reuterwall & Thorén, 2009).

Garbage is commonly thrown in the drainage network and it settles in nodes and junctions, reducing the water transporting capacity, see Figure 9. This phenomenon is difficult to include in the model, because it varies in both time and space. A better approach to this problem is to have it in mind when evaluating the results of the simulations. A discussion of the impact of garbage to the water transporting capacity should be performed.

The measured rainfall data was not corrected for the influence of wind. If there is a lot of wind at the time of the rainfall, the actual water depth can be larger than the measured value. The placement of the rain gauge was located on a flat roof between two buildings in a school area (Senai Sekolah). The flat roof was situated above a walkway, giving protection against rainfall. This also made it easy to install the rainfall measuring equipment and no advanced installation construction was needed. This way the equipment was also under supervision by the school staff, reducing the risk of it being stolen. The whole catchment was within a 1 km radius from the rain gauge, see Figure 10. One of the buildings was two-storey height and the other one was one-storey height. To give a smaller influence of wind, the rain gauge was not placed in the middle of the roof. It was placed closer to the building with one-storey height, so the two-storey height building was not acting as a rain protector to the rain gauge.

Figure 9. This picture is illustrating the common situation with large amounts of garbage in the drainage system in Senai Town. The garbage can reduce the water transporting capacity in the drains. However, due to the complexity to take it in consideration in the model, it is not included, but discussed when evaluating the results (Reuterwall & Thorén, 2009).

Figure 10. The placement of the rain gauge and its distance to the catchment area. The whole catchment area is within 1 km from the rain gauge (Thorén, 2009).

There was a small base flow in the drain that was produced by a wastewater treatment plant that is situated inside the catchment area. This base flow was considered to have a small contribution when the water level is high. It normally gave a variation from 0-4 cm in the drain at dry-weather conditions.

4.6 **Calibration**

George Edward Pelham Box said that “Essentially, all models are wrong, but some are useful” (Box and Draper, 1987), which is very important to keep in mind when performing a calibration or using a model. No matter how good and precise the model is, it can never describe the complete complexity of the nature. By performing a calibration of the model, it can get closer to describing the behavior of nature, sometimes resulting in a model that is useful.

To calibrate a simple rainfall-runoff model using Time-Area method as the hydrologic model, the most essential input is onsite measured rainfall depth. The output of the model in form of simulated water level is later compared to the onsite recorded water level. Even better is if output data of water discharge from the drainage system is available. Important is that the measured data is from the same time period. Otherwise it is impossible to compare the simulated water level from the model and the recorded water level. Important is also that the resolution of the recorded measurements are adequate. The possibility to measure with an adequate resolution can be dependent on properties like memory capacity of measurement equipment. The resolution of measurements in this study was set to 1 minute, because the measurement equipment could store 40 000 measurements in its memory. This gave a maximum continuous measurement period of about 28 days, which is roughly the actual length of the measurement period used in this study.

Calibration is a time consuming task. For every run of the model, the settings of the model are slightly changed and the simulated water level is compared the recorded water level. If the changes of settings gave a better match between the curve describing the recorded water level and the curve describing the simulated water level, the changes of settings are kept. Otherwise they are changed back to their original settings. This is done many times until the match is satisfying. The resulting data are opened in the DHI computer program MIKE VIEW, which can present the results in profiles and graphs. The resulting data can also be extracted and analyzed in other computer programs.

In rainfall-runoff models there are some basic phenomena to calibrate, which are peak height, peak timing, peak shape and, if aiming at a very precise model, base flow. The parameters chosen to calibrate against depend on the objective of the model. In this project the three first phenomena are the most essential and the base flow was neglected. However, when the total volume of water is of interest, the base flow must be estimated. As the base flow is not considered, it is the peak height and peak timing in the curves describing the output water level and the recorded water level that should have a fit.

In MIKE URBAN there are different settings that can be modified in order to achieve a satisfying output result. In this project, properties like time of concentration, amount of impervious areas and time-area curve were changed before achieving this. The default setting of time of concentration in MIKE URBAN is set to 7 minutes, which is the time it takes until the whole catchment is contributing to the runoff. Because the catchments have different size and shape, the time of concentration should vary between the sub catchments. When the time of concentration is modified the shape and timing of the output water level peak are changed.

At first in this study the peak was simulated too early, meaning that the time of concentration should be increased. The time of concentration was calculated for each individual sub catchment by measuring the length of the flow path in the catchment and multiplying it with 1 m/s (Svenskt Vatten, 2004). This resulted in 24 different values, which were grouped into six different groups to make the model easier to maintain and supervise. In order to simulate the time from when the rain fell on the roof until it entered the smaller drains in the sub catchment, five minutes were added to the time of concentration, see Table 2.

Table 2. The different groups the sub catchments were divided into depending on the Time of Concentration (ToC).

Groups (ToC)	Assumed ToC	Final ToC
0 – 4	4	9
4 – 8	8	13
8 – 12	12	17
12 – 16	16	21
16 – 20	20	25
20 – 24	24	29

ToC = Time of Concentration

If full satisfaction with the timing of the peak is not achieved after modifying the time of concentration, the “time-area” curve can be changed. This curve describes the relationship between the amounts of area in the sub catchment that is contributing to the runoff at a specific time after the rainfall. By default this relationship is linear. But if the peak of the runoff needs to be held forward in time, a smaller amount of area can be set to contribute to the runoff in the beginning and then rapidly increase in the end. The curve was modified to achieve a move of the peak in time. The peak needed to be simulated later and therefore the time-area curve was modified until it gave a satisfying effect on the simulation result. The modified time-area curve in Figure 11 is used for all catchments in this study.

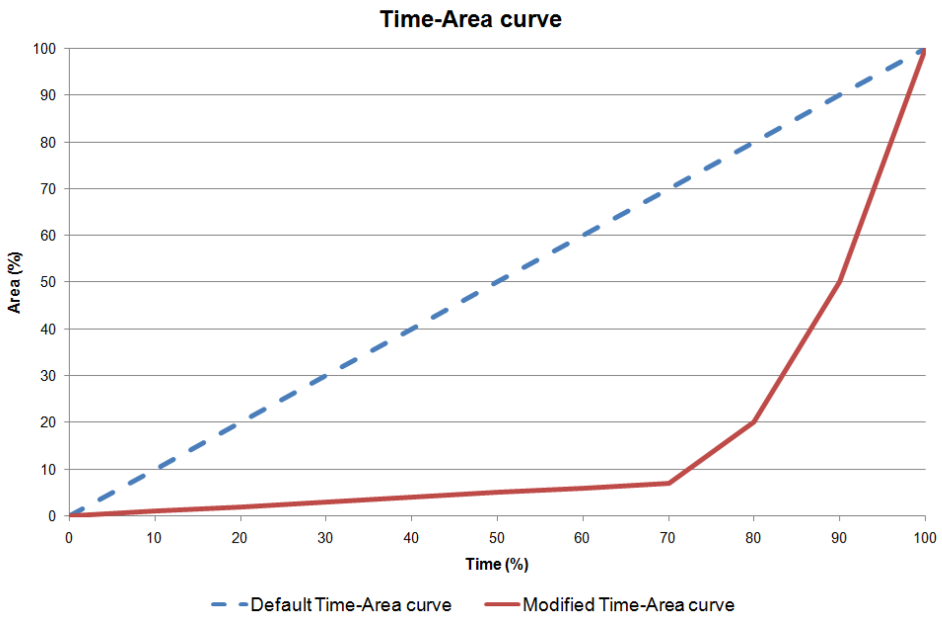

Figure 11. The default and the modified Time-Area curve for this study. The modified Time-Area curve is the one that is used in the simulations for all catchments. The relationship simulates the time in percentage it takes for a specific percentage of the catchment area to contribute to the runoff. The Time-Area curve was modified to improve the result of the calibration and no physical explanation can be made about the shape of the curve.

To increase the height of the peak, GIS-layers describing roads and houses were modified to span over a larger area, as it was underestimated when first drawn. This underestimation was noted because the simulated water level was much lower than the recorded water level. This increase in area will yield a larger runoff from the sub catchments. The peak will also increase, as the amount of impervious areas becomes larger. If this action is not enough to raise the peak height, the percentage of runoff from different surfaces can be modified. In this project the runoff from the surfaces called "others" were changed from 10% to 40% to simulate higher water content in the soil.

The simulation was cancelled by the model when the nodes in section 1 or 2 were flooded. The model does not know how to deal with this situation and cancels the simulation. To overcome this problem the cross sections of sections 1 and section 2 were modified. The height of the drain was increased with 1 m and the overlying part of the cross section was also widened with 2 m on both sides. This way the model was able to continue the simulation even if the sections were flooded.

4.7 **Validation**

In order to see if the calibration has been successful, an independent period of rainfall and water level measurements in the area should be tested in the model. If the output result of this period yields the same satisfying result in the calibration, the model calibration can be assumed to be successful. If the validation gives a very poor result, it might be necessary to redo the calibration.

To make a proper calibration and validation the recorded period of rainfall and water level must have a satisfying amount of rainfall events. Fourteen rainfall events were recorded during the measurement period and five of them were useful for calibration. The non-useful rainfall events had too small rainfall depth or gave small response in the recorded water level and were hence considered not useful. Five rainfall events are too few to perform both a calibration and validation against. Therefore, the decision to only perform a calibration was made. The calibration was made with these five useful rainfall events. Only two of these five events are used for presentation purpose. Because all rainfall events gave the same result in the simulations, but these two were selected because one of them had two peaks and the other had the largest rainfall depth.

4.8 Model scenarios

To solve the study objectives, four scenarios were defined and simulated in the model. The situation after the model was calibrated is used as a reference. Deterioration or improvements are compared to this situation.

Scenario 1
The monthly precipitation is expected to increase with about 3% by the year of 2050 according to a study made for the southern region of Peninsula Malaysia in 2005 (NAHRIM, 2005). By applying this increase in precipitation to the measured rainfall data, a rough estimation of the future situation can be simulated in the model. The future situation with 5% and 10% increase in precipitation is also simulated, in order to see how sensitive the hydraulic system is to a larger increase in precipitation. These two projected increases are made based on a study by the IPCC in 2007 over South-East Asia (IPCC, 2007).

The three simulations in scenario 1:

- 3% increase of rainfall
- 5% increase of rainfall
- 10% increase of rainfall

Scenario 2
Backwater effects can have an effect on the water level recording. Therefore, a scenario was put up with an increased outfall water level. The term inside MIKE URBAN is to increase the external water level. This external water level was increased from 8.64 meter above sea level (m.a.s.l) and the range is from +1 to +2.5 m.

The four simulations in scenario 3:

- +1 m increase of external water level (9.64 m.a.s.l)
- +1.5 m increase of external water level (10.14 m.a.s.l)
- +2 m increase of external water level (10.64 m.a.s.l)
- +2.5 m increase of external water level (11.14 m.a.s.l)

Scenario 3
Some sections in the drainage network have the water transporting capacity smaller than the 100-year flow. Therefore, the consultant presented some suggestions of changes to the hydraulic structure in the Drainage Master Plan for Senai Town (DID, 2005a). The changes are:

- In the section 350-370 m in the drainage system, a circular cross section with diameter 1.2 m is changed to a box culvert of 3.0 x 1.5 m (width x height)
- In the section 470-520 m in the drainage system, a box culvert of 2.0 x 1.4 m is changed to a U-shaped drain of 3.0 x 1.5 m
- In the section 760-780 m in the drainage system, a circular cross section with diameter 1.2 m is changed to a box culvert of 3.0 x 1.8 m

Based on these suggestions, there are two formulated simulations in scenario 3:

- Changes proposed by the consultant in DMP
- Changes proposed by the consultant in DMP and +2 m (10.64 m.a.s.l) increase of the external water level

Scenario 4
As Senai town grows, more runoff will be generated from the increased impervious surfaces. Partly based on the Structure Plan for Johor Bahru (Kulai Municipal Council, 2002) and partly based on onsite observations the size and location of this increase of impervious surfaces is estimated. In order to simulate the growth of the town, a scenario with an increased catchment area is put up. The catchment area will be increased with 5 and 10 hectares, which is an increase of about 15% and 30% respectively. Amount of impervious surfaces in these catchments is assumed to be 60%. It is not certain how and where this runoff will be discharged, but it is assumed to be discharged in the catchment of this study. For more information about the increase of catchment area, see Appendix 3 (Catchment 1).

There are two simulations in scenario 4:

- 5 hectares of increased catchment area with 60% amount of impervious surfaces
- 10 hectares of increased catchment area with 60% amount of impervious surfaces

5 Results

Calibration
Notice the definition of "Section 1" and "Section 2" in Figure 12. Thus it is in these sections where flooding will occur in the simulations and much of the explanation in the results and conclusions is referred to these two sections. Therefore it is important to especially remember them.

After the calibration there were two flooded sections, in section 1 and 2, see Figure 12. This is mainly due to insufficient dimensions directly downstream section 1 and 2. Section 1 consists of open U-shaped drain, 3 m wide and 1.6 m high. Downstream section 1 the section consists of a circular pipe with a diameter of 1.2 m. This section have a significantly lower water transporting capacity then section 1 and therefore large amounts of water is built up in section 1 which causes the flooding. The same problem is causing the flooding in section 2.

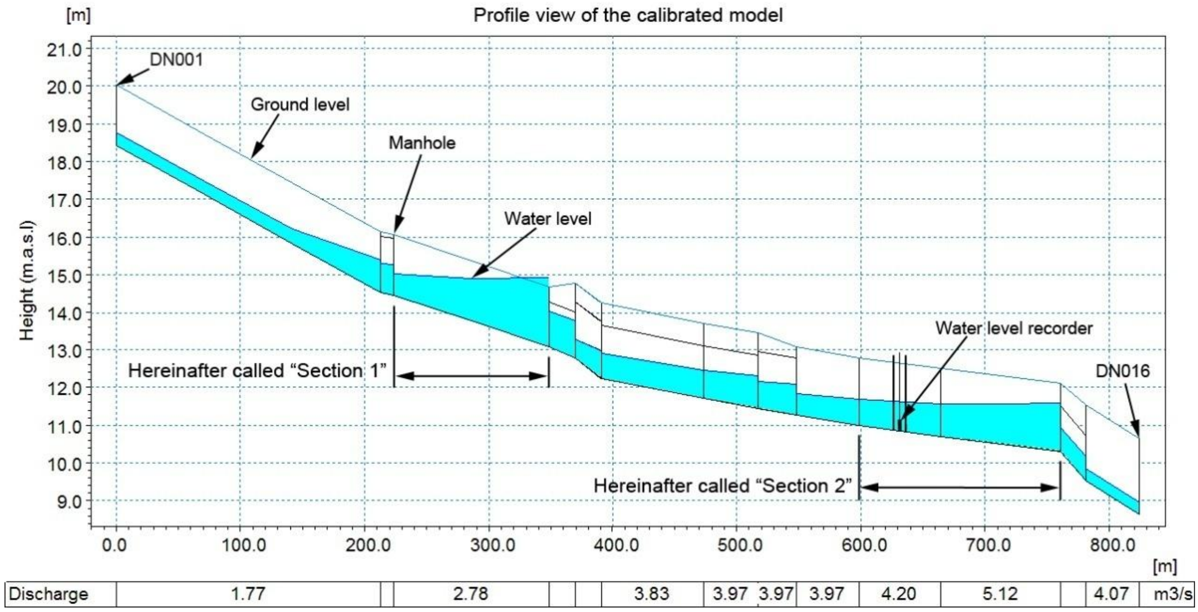

Figure 12. A profile-view of the drain after the rainfall on the 12th of November 2008. Notice the definition of "Section 1" and "Section 2" in the figure. Location of nodes DN001 and DN016 can be found in Figure 4.

The overall look of the simulated water level, compared to the recorded water level, is that the level is simulated too low, see Figure 13. The timing of the simulated peak is fitting well in the beginning, but not in the end of the peak.

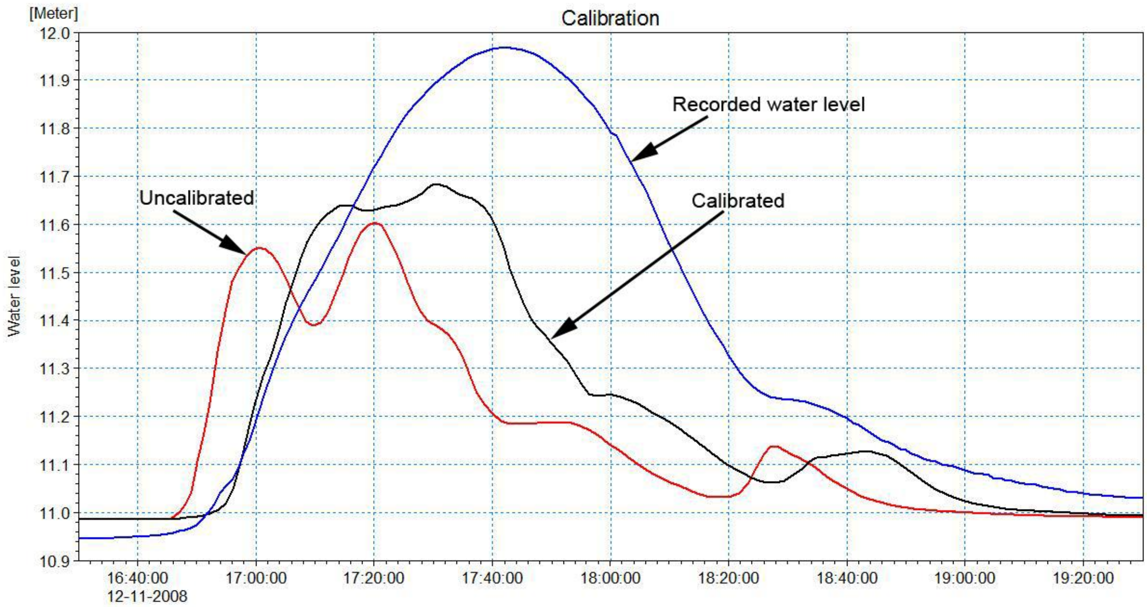

Figure 13. Calibrated, uncalibrated and recorded water level in section 2 after the rainfall event the 12th of November 2008. The calibrated water level is still simulated too low. Several attempts have been made to increase the water level and at the same time to do realistic changes, but this did not improve the performance of the calibration. The location of the water level recorder can be seen in Figure 4.

In order to evaluate the simulated flow it is possible to compare it with onsite measured flow. If the fit between simulated and measured flow is good, the model can be assumed to be useful. The Institute of Environmental & Water Resource Management at Universiti Teknologi Malaysia provided measurements of flow and water depth. Data was collected in December 2007 (Fai, C., 2007) at a point some 50 m upstream the location of the water level recording in section 2. These measurements were compared to the simulated values of flow and water depth at the location of water level recording, see Figure 14. The simulated values were extracted from MIKE VIEW.

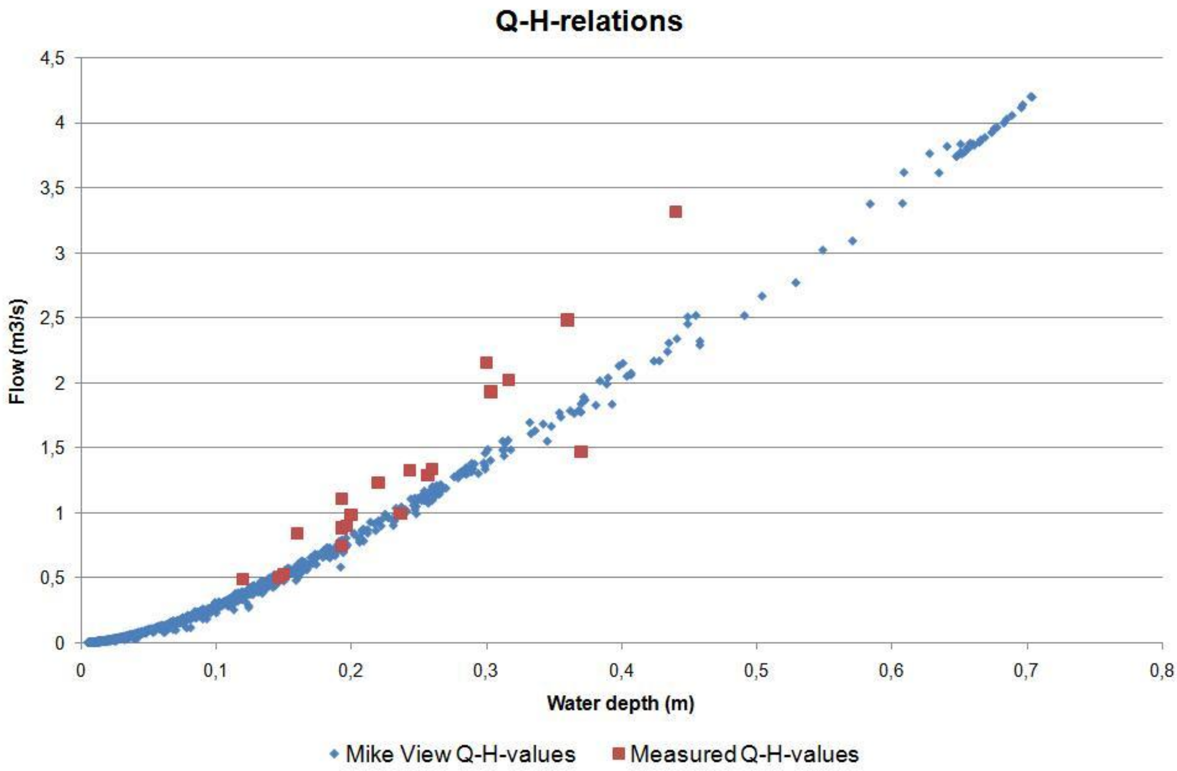

Figure 14. The Q-H (Flow-Height) relationship between measured flows (Fai, C., 2007) in drain and the simulated flows in MIKE URBAN.

Scenario 1

The graph in Figure 15 illustrates the future scenario with increased rainfall as a result of the ongoing climate changes. The chosen increases are 3%, 5% and 10% based on previous studies, see chapter 2.6.

The different increases are reacting uniform and have a similar shape as the calibrated curve. As expected, the highest increase (10%) in precipitation is resulting in the highest peak. The results of increased rainfall are not showing until the rain is at its maximum values. However, the increases of precipitation do not lead to high water levels. In the most extreme case of 10%, the curve is not near the recorded water level curve. Compared to the calibrated water level the 10% increased rainfall is resulting in 8 cm increased water level, which is about 9% increase. So for the simulated curve to fit the recorded water level curve the precipitation has to increase with almost 100%.

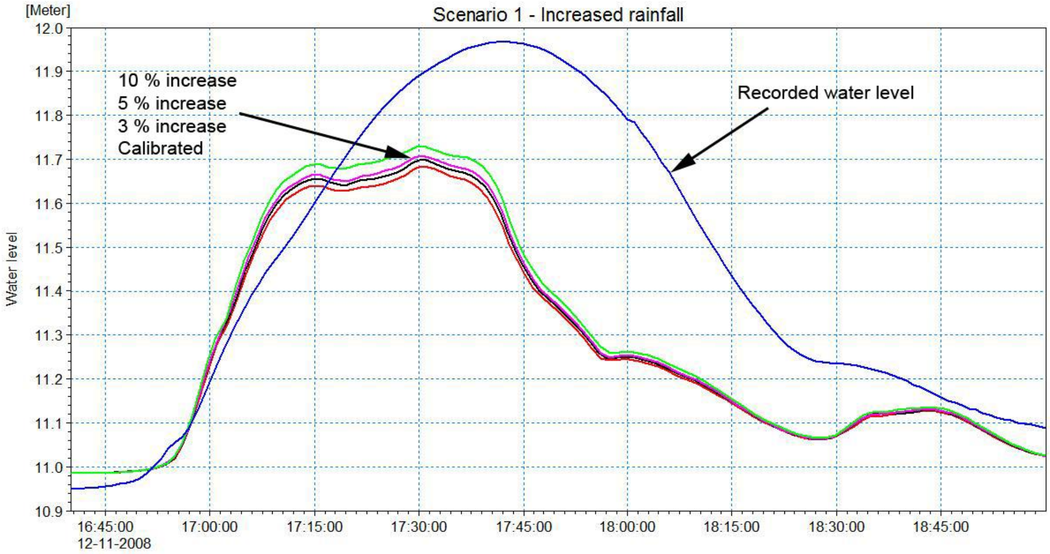

Figure 15. This Figure illustrates scenario 1 when the future possible climate changes are considered. The rainfall is increased 3%, 5% and 10% and compared to the calibrated and recorded water levels. The rain event is from the 12th of November 2008. The curves are from the top: recorded water level, 10% increase, 5% increase, 3% increase and calibrated curve. The location of the water level recorder can be seen in Figure 4.

Figure 16 illustrates the profile section with a rain event from the 12th of November 2008. It shows how the scenario with increased rainfall of 10% leads to its maximum water level in the system. Is possible to see in the figure how the water level is exceeding the ground level in section 1. The dimension of the following link is smaller and almost full.

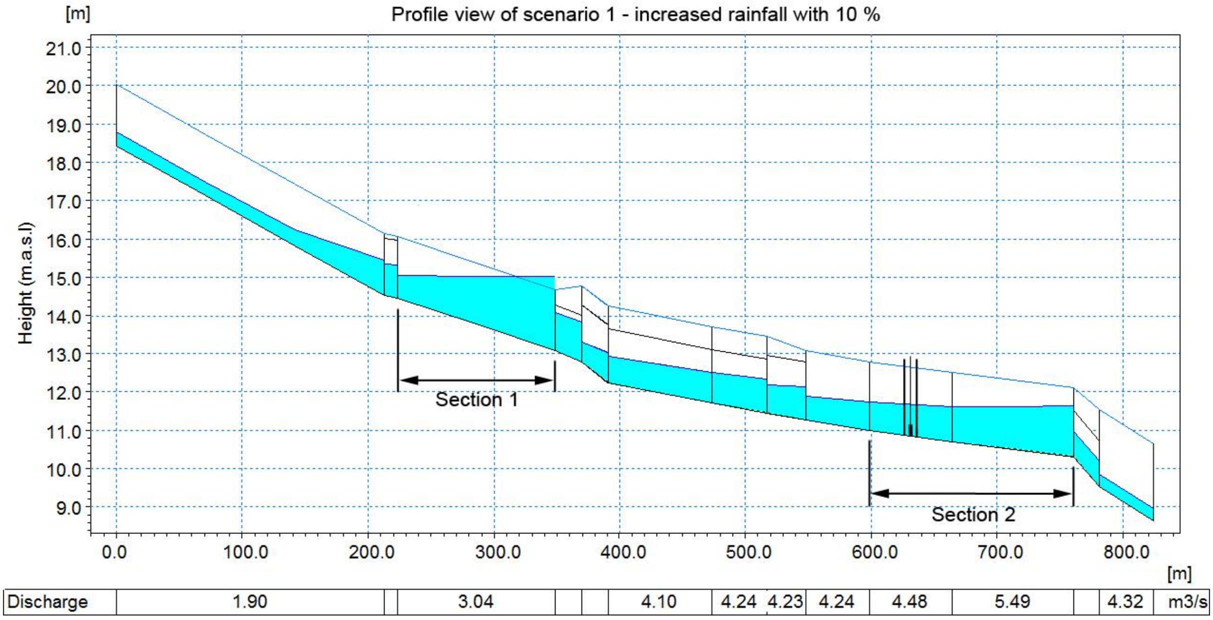

Figure 16. This is the worst case in scenario 1, when the rainfall is increased with 10%. The rain event is from the 12th of November 2008.

Scenario 2

Figure 17 illustrates the scenario when increasing the external water level with +2 m and +2.5 m. The difference in maximum height in comparison to the calibrated water level is 16 cm and 23 cm, respectively. When the external water level is increased with +2.5 m there is a constant water level increase of 15 cm at the location of the water level recorder, even if there is not any runoff. The maximum value of this curve is simulated 15 cm higher than the recorded water level. Both simulated curves in the scenario are uniform with the calibrated curve and the main difference is the peak height.

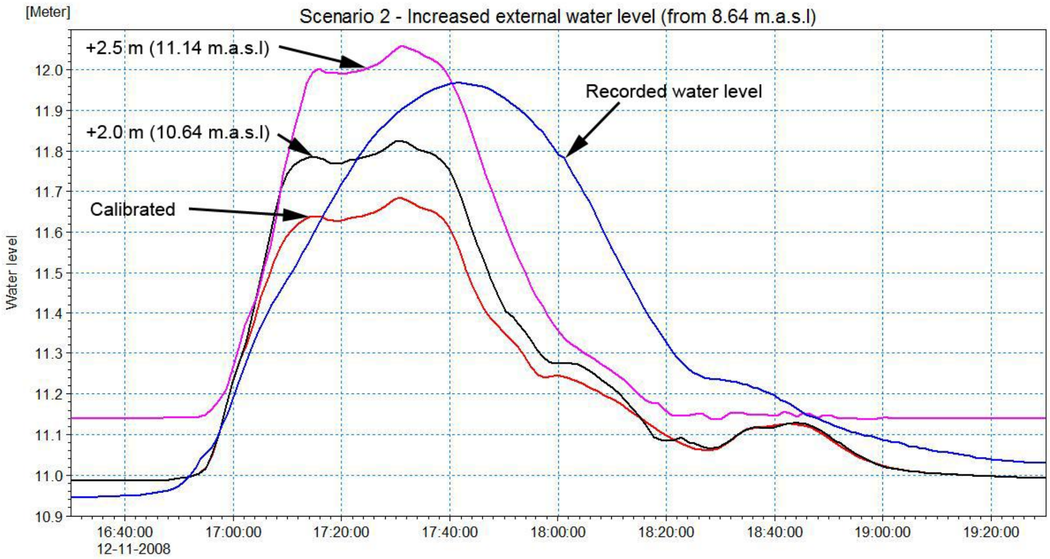

Figure 17. This figure illustrates scenario 2 when increasing the external water level with 2 meters and 2.5 meters respectively. They are compared to the calibrated and recorded water levels. The rain event is from the 12th of November 2008. The location of the water level recorder can be seen in Figure 4.

When increasing the external water level with 2 meters, the profile looks like in Figure 18. Section 1 is full as the dimension of the pipe directly downstream is too small. Water is built up in section 2 because of backwater effects from the increased external water level. The pipe directly downstream section 2 also has a too small dimension and the water cannot be discharged fast enough out from the drain to avoid backwater effects. The other sections of the system are not in risk of being flooded.

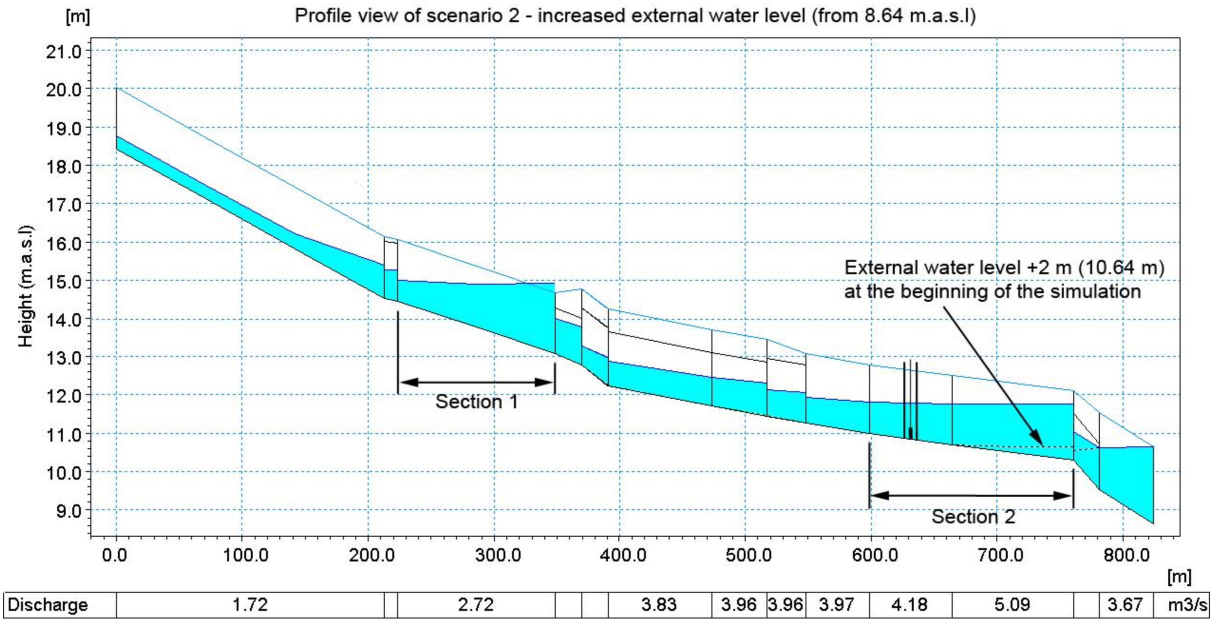

Figure 18. This figure illustrates the profile section when simulating scenario 2 when the external water level is increased with 2 meters. The rain event is from the 12th of November 2008.

Scenario 3

The suggested changes by the consultant improved the situation in the drain. The water level in the drain was lowered, which is particularly noticeable in section 1 and 2, see Figure 19 and 20. The water level in section 2 was decreased with 9 cm during the rainfall event the 12th of November 2008. Some water was still built up in section 1, but the water level was significantly lowered. Section 2 showed only small backwater effects after the changes.

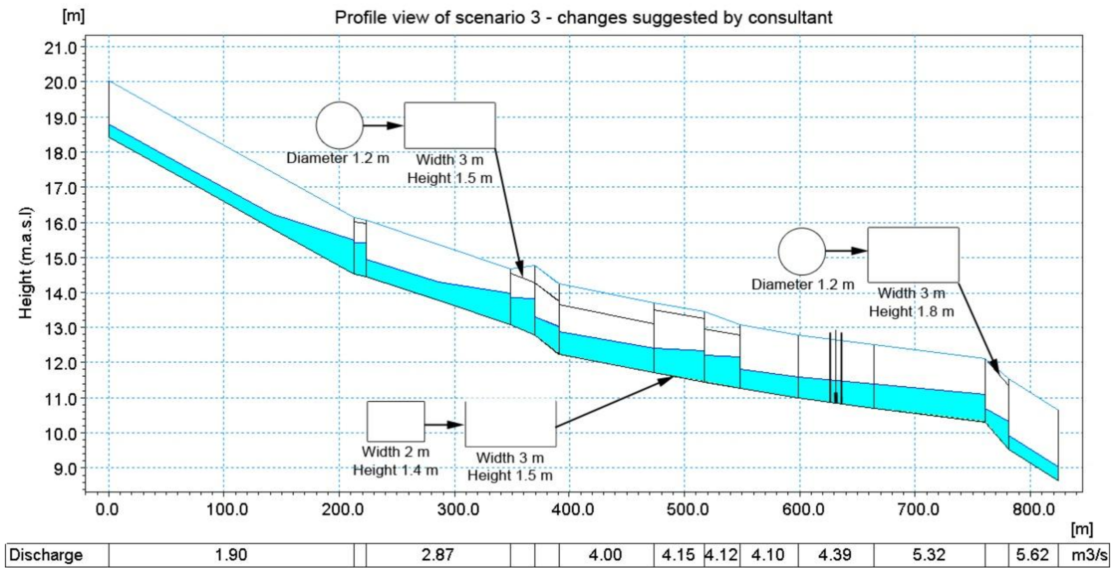

Figure 19. This figure illustrates the proposed dimension changes in scenario 3, together with a profile-view of the drain in the situation after the rainfall event the 12th of November 2008 in scenario 3. There were three proposed changes, with the original dimension presented to the left and the proposed dimension to the right.

When a higher external water level was taken into account, the improvements had a smaller effect in section 2 and no or little effect in section 1, see effects in section 2 in Figure 20. The external water level was increased with +2 m above the outfall (10.64 m.a.s.l). The simulated water level in section 2 was then only 5 cm lower than the calibrated water level.

The shape of the simulated curve still has the same look as the calibrated curve, it is just simulated lower. After increasing the external water level, the changes of the simulated water level gave almost the same result as without the suggested changes. However, the water level in section 1 was still lowered by the suggested changes.

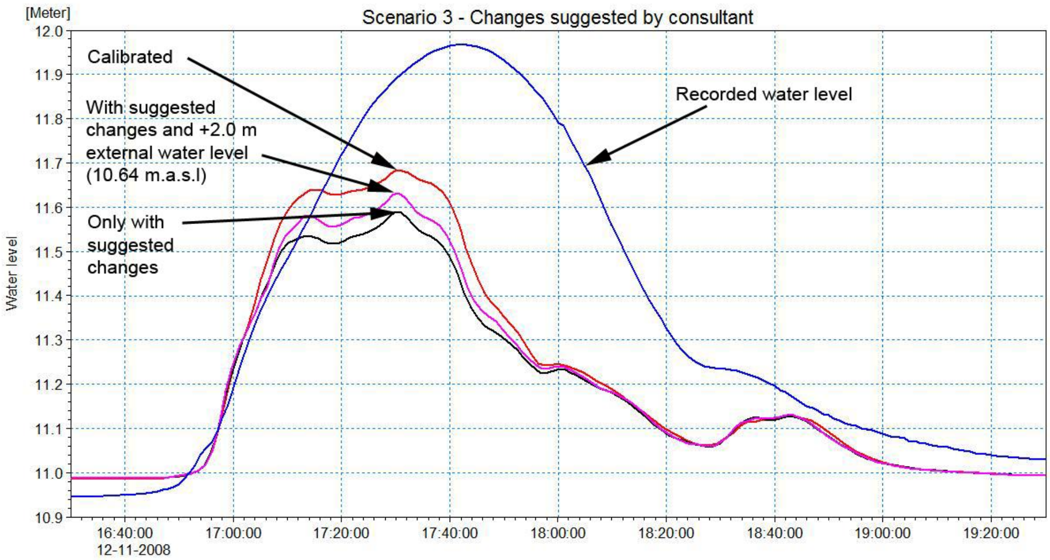

Figure 20. The graph shows the calibrated water level together with the two simulated water levels in scenario 3, after the rainfall event the 12th of November 2008. The location of the water level recorder can be seen in Figure 4.

Scenario 4

An increase of the catchment area gave, not surprisingly, an increase of the water level in the overall drainage system. Because the new catchment was connected to the hydraulic model upstream section 1, it was also in section 1 that the water level increased the most, see figures 21 and 22. Directly downstream section 1, is a circular pipe with a diameter of 1.2 m. It has a much lower capacity to transport water than the drain in section 1. This is the reason why a large amount of water is built up in section 1. Some severe flooding would take place in section 1 because the cross sectional area above the ground level is significantly increased in the model in section 1. The height of the drain was increased with 1 m and the section above ground was also widened with 2 m on both sides. This means that the illustration is underestimating the flooding in Figure 21, because it is a perspective view.

There is only a slight increase of the water level in the overall drainage system, apart from section 1. Actually there is none or very small increase of the water level in section 2.

The increased catchment area is added to the west part of the original catchment area. The amount of increased area is 5 and 10 hectares, simulated separately. The areas are assumed to have 60% impervious surfaces.

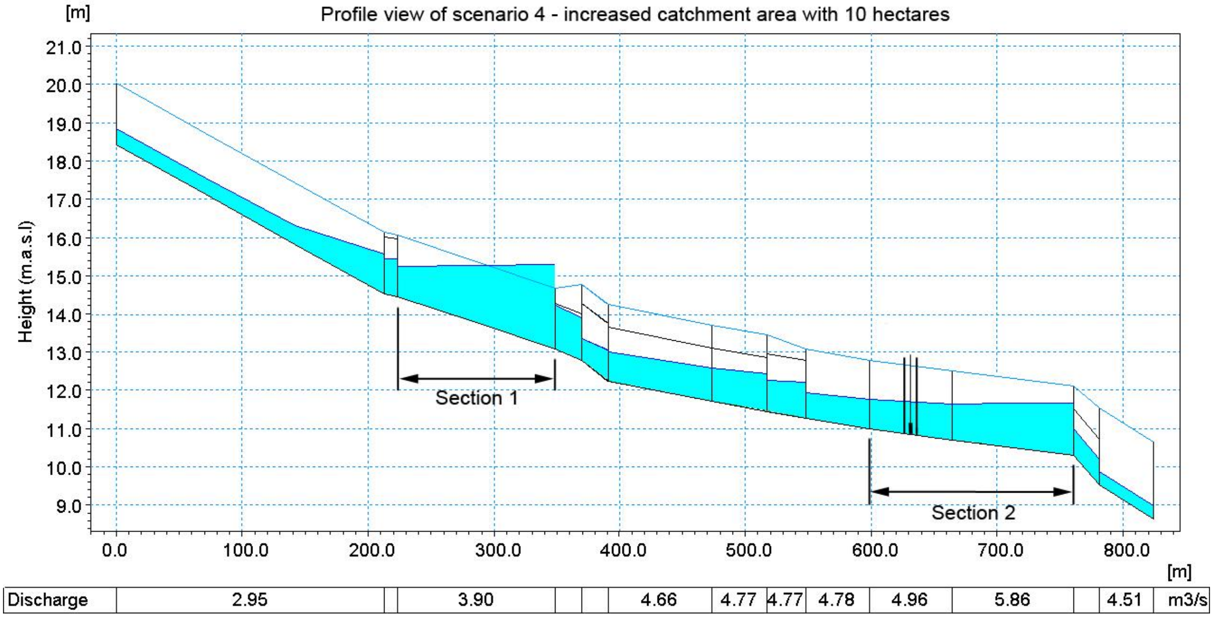

Figure 21. This figure is a profile-view of the drain after the rainfall event on the 12th of November 2008 in scenario 4. Notice the increased water level in section 1.

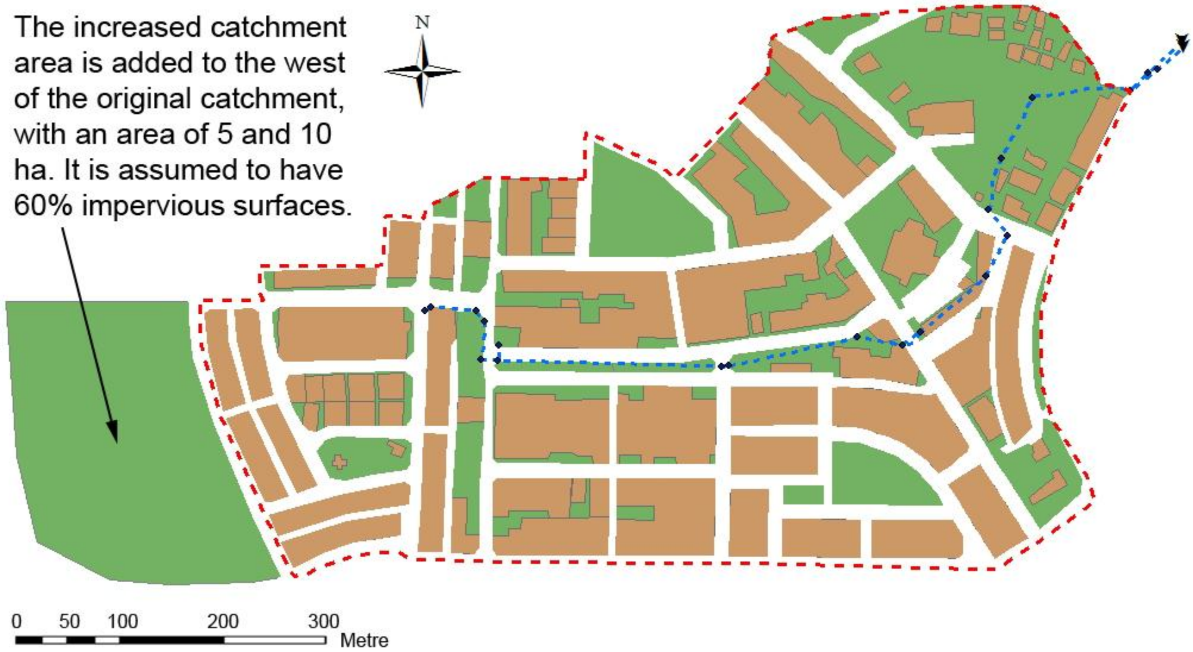

Figure 22. An overview of the catchment area with the increased catchment area to the left of the original catchment area (Reuterwall & Thorén, 2009).

When studying the water level after the rainfall event on the 5th of November 2008 in section 2, the left peak in Figure 23 seems to be correct simulated. However, the right peak is simulated too low. So an increase in catchment area could not improve the performance of the simulation of the right peak. The definition of the original catchment area is likely made correctly and the input rainfall data is then probably incorrect for the right peak.

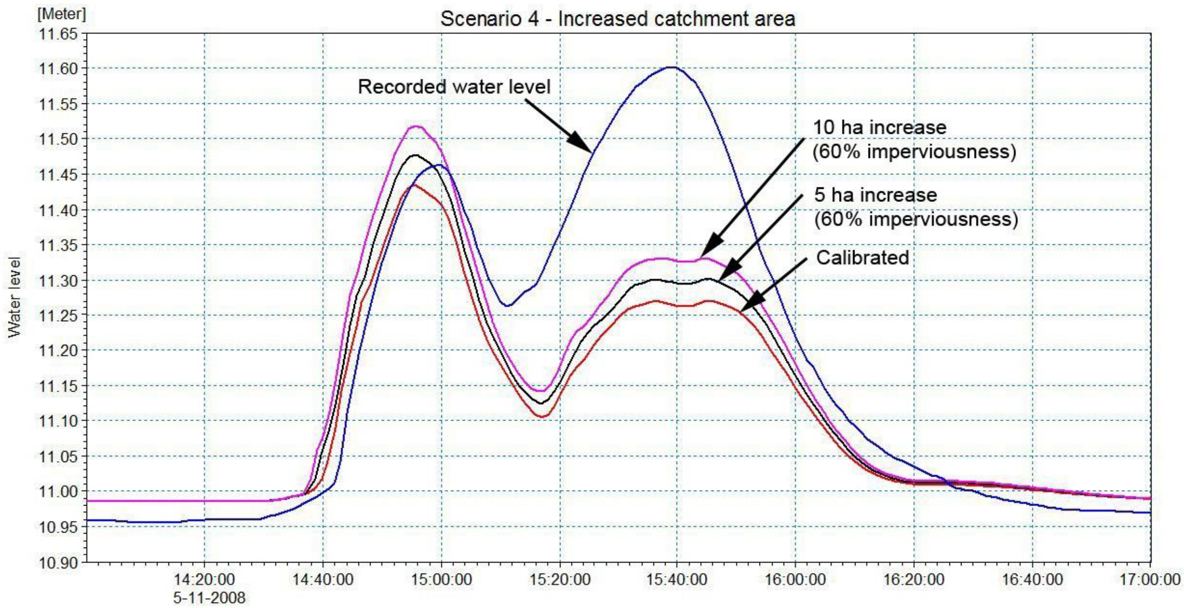

Figure 23. The graph shows the calibrated water level together with the two simulated water levels in scenario 4, after the rainfall event on the 5th of November 2008. Notice that even though the catchment is increased, the performance of the simulated water level in the right peak is not improved significantly. The location of the water level recorder can be seen in Figure 4.

6 Discussion

Calibration

The overall look of the simulated water level, compared to the recorded water level, is that it is simulated too low. Several attempts have been made to increase the simulated water level and at the same time to do realistic changes in the model. There seems to be other properties that affect the measured water level in the drain. These properties could be the water level in the outfall river Sungai Senai, soil moisture in the green areas and underestimation of the catchment area. If the water level in Sungai Senai is higher than 1.67 meters above the outfall level it gives backwater effects in section 2. High soil moisture in green areas could generate more runoff and thereby increase the water level in the drain. An attempt was made to simulate this feature by increasing the runoff percentage from 10% to 40%, but it gave a moderate impact. No measurements of the soil moisture were made and one could always speculate if 40% is realistic or unrealistic, but this was only made to test the impact of increasing soil moisture.

Other properties that could impact the water level in the drain are underestimations of the catchment area. The boundary of the catchment area was defined by onsite observations. By observing in what direction the water flows in the smaller drains it was easy to determine the catchment boundaries where the topography was hilly. However, this method could lead to an over- or underestimation of the catchment area when the topography is almost flat. In this case an underestimation could be the cause of the problem, especially in the North-Eastern part of the catchment. That part of the catchment was more flat and lots of green areas with few or no roads, made it difficult to estimate the catchment boundaries.

During the calibration an interesting property was that the rainfall events often seemed to have two peaks. This could also be seen in the “Urban Stormwater Management Manual For Malaysia” (DID, 2000b). It was understood during the calibration that this property was hard to mimic in the simulations. In Figure 26 there seems to be a good match with the left peak but the right peak is simulated very low compared to the recorded water level. As the left peak fits well, the misfit of the right peak is probably due to an error in the input data for the right peak. This error is possibly caused by clouds that passed the rain gauge in different alignments, see Figure 27. The fit of the left peak indicates that the model is performing a satisfying result and the calibration is therefore stopped.

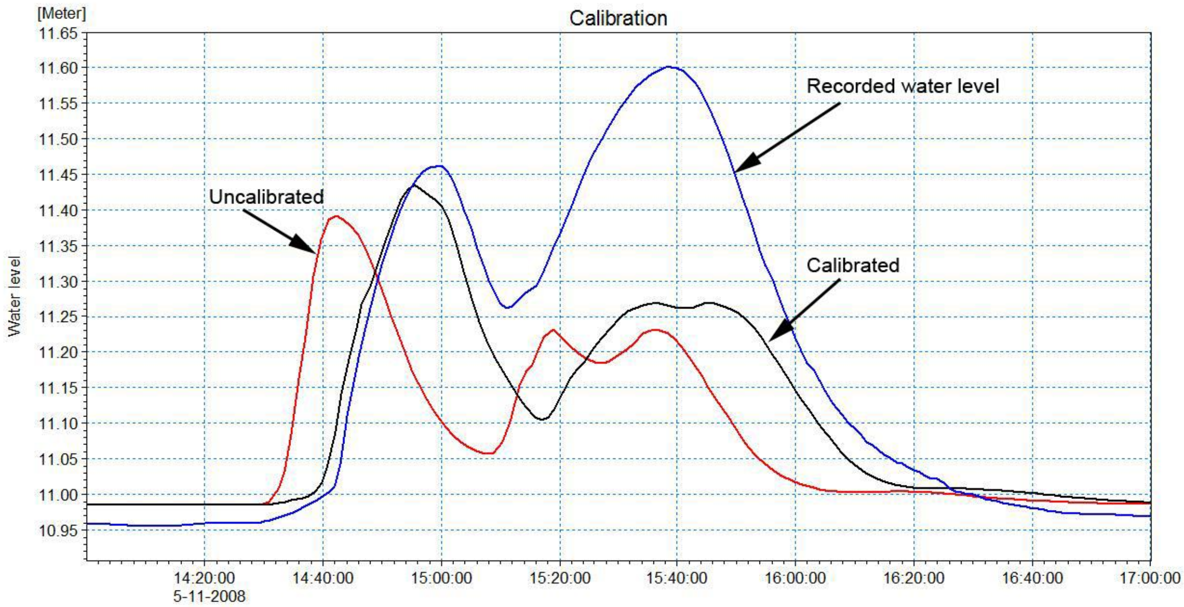

Figure 24. Calibrated, uncalibrated and recorded water level after the rainfall event the 5th of November 2008. The left peak of the calibrated water level has a good fit to the recorded water level and at the same time the right peak have a very poor fit. An explanation could be that the clouds have not been aligned to the rain gauge at the time of measurement, see Figure 25. The location of the water level recorder can be seen in Figure 4.

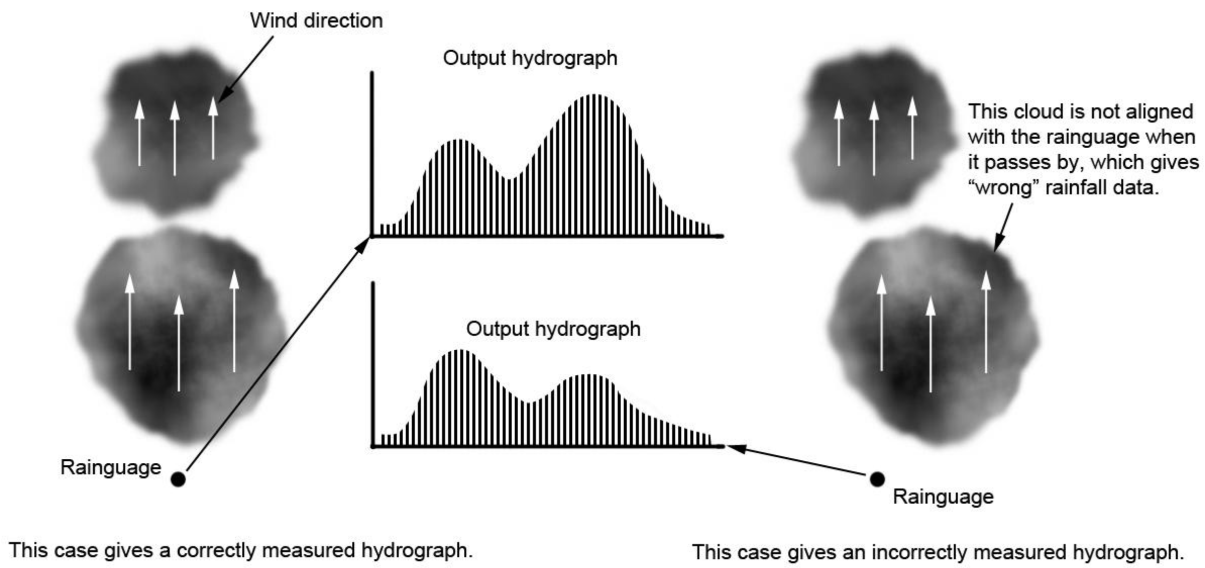

Figure 25. If the clouds have not been aligned to the rain gauge at the time of measurement, the measured rain depth is "incorrect". This could be a reason why the calibrated water level is simulated too low in the right peak in Figure 14 on page 38 (Thorén, 2009).

The fit between the simulated and measured values of height and flow (Q-H) in Figure 14 is satisfying. The hydraulic properties of the model can be assumed to be correct.

Scenario 1
The results in scenario 1 show a small impact of increased precipitation on the drainage system. Even with an increase of 10% precipitation the system there is still no flooding in the system, with the exception of section 1 where the water level goes above ground level. However, this section is sensitive in all scenarios. Roughly, the percentage of increase in precipitation is equivalent to the percentage of water level increase. So the solution of the poor result of the calibration is not solved by simply increasing the precipitation intensity as it would have been almost 100%.

Scenario 2
In scenario 2, when increasing the external water level, there is an increase in section 2 and the increase is also limited to the low-lying parts of the drainage network. If there is flooding in this section the water will most likely be transported by overland flow to the river Sungai Senai. Section 1 is still subject to flooding, in the same order of magnitude as the calibrated simulation.

Scenario 3
The suggested changes made by the consultant in scenario 3 result in a lowering of the water level. The increased dimensions lead to lower water levels in both section 1 and 2, making flooding no longer a problem. When increasing the external water level with +2 m, the positive effects of increasing the dimensions are almost gone in section 2. However, the positive effects remain in section 1 as there is still no flooding. The changes are not intended to take place in the near future. Other solutions such as detention reservoirs are planned to be constructed in the river Sungai Senai and they are expected to give a more cost efficient solution to the flood problems. The detention reservoirs can lower the water level in river Sungai Senai and keep the external water level in the study catchment low.

Scenario 4
In scenario 4 the catchment area is increased in the western part of the catchment. This results in severe flooding in section 1. The water is likely to be transported overland towards downstream drainage sections due to the topography around section 1. However, if there is an exploitation of Senai Town to the west of the original catchment area, the runoff will most likely be discharged outside the catchment in a South-West direction due to the topography.

General discussion
The amount of impervious surfaces has a big impact on the result in the model. To have access to such accurate data makes the model more reliable. However, such information was not available and an interpretation from an aerial photo was made. This results in a less accurate determination of the amount of impervious surfaces. The soil moisture content could be one of the reasons why the simulated water level often is too low. An attempt to take this into account was made. However, in Figure 14 it can be seen that the calibration reached satisfying results in the left peak and there must be some other reasons for the too low simulated water level. The reason is most likely errors in the input data, caused by phenomena such as hard wind or local rainfall.

The impact of garbage, litter and sediments in the drains are assumed to have a small effect of the out coming result and were therefore neglected in the model. There is a tool for simulating sediments in MIKE URBAN, but in order to keep the model simple this tool was not utilized. Garbage and litter are on the other hand difficult, if not impossible, to take into consideration in the model. In addition, the impact of garbage and litter is considered to be very small when the water level is high. The presence of garbage and litter is common in the sewers of the area but in relation to the size of the drainage system, the effect on the water level is small. The water will transport the garbage through the drain without losing too much energy when the water level in the drain is high. If the water level is low, the impact of the garbage will be higher as the garbage settles to the bottom of the drain, blocking the water. This will give a local small rise of the water level, but this study will only look at the situation when the water level is high.

Evaporation was neglected in the model because it is assumed to have a small effect on the result. This is because the runoff is generated from impervious surfaces where the evaporation is smaller than the soil evaporation. Even if the evaporation has a large effect on the model result this problem will be bypassed and compensated when performing the calibration. This is because the water loss in form of evaporation will be simulated as an increase of the precipitation when adjusting the amount of impervious surfaces.

The fact that the amount of impervious surfaces in urban areas in Malaysia is much larger than in Sweden increases the risk of flooding as it yields a larger runoff. In the existing urban areas it can be hard to convert the impervious surfaces to pervious, but it can be kept in mind when planning new urban areas in Malaysia.

The rain gauge was placed outside of, but very close to, the catchment area. Our own observations during our time in Malaysia are that local rainfalls are very common during this time of year. This could be one of the reasons why the calibration could not be performed with better match between the simulated and recorded water level. To achieve better calibration results it would have been better to have the rain gauge placed inside the catchment, but with a higher risk of theft. In an ideal case several rain gauges should have been used to be able to compare the different collected rainfall data. This was, however, not possible to achieve within this study.

The two water level recorders were placed in the drain in section 1 and section 2. Unfortunately the recorder in section 1 was stolen after only a few days and no recordings were retrieved from this recorder. Access to data from the stolen recorder would have made it easier to know when the calibration reached a satisfying result. This is because a high water level in Sungai Senai would definitely not have affected the recordings in section 1.

Access to information on the water level in the river Sungai Senai would have made it easier to estimate the backwater effects in section 2. This could also have been added in the model as a varying external water level. However, an installation of a water level recorder in Sungai Senai would have been difficult and time consuming. The available time for recording was at that time already hardly sufficient and the decision where taken not to do this installation.

If the time of recording of rainfall and water level data had been longer, more rainfall events could have been obtained. This could have resulted in a larger number of useful rainfall events for calibration and possibly also a validation of the model. Only the recorded rainfall events were used in the simulations. This is because after the calibration a question was found. Our thoughts to why the calibration did not perform a better fit with the recorded water level are that the defined scenarios could explain the misfit. Thereby no artificial rainfall was simulated.

7 Conclusions

Two sections are in risk of flooding with today's situation. The problem is associated with open drains with big dimensions that are connected to downstream underground drains with too small dimensions, creating backwater effects. This problem occurs especially in section 1 and 2, where large amounts of water are built up.

Climate changes in form of increased rainfall intensity have small effects on the water level in the sensitive parts i.e. section 1 and 2. Neither does it have a considerable effect on the overall drainage system. The water level increased roughly with the corresponding percentage increase of rainfall intensity in section 2.

Increased external water level of +2 m has a large effect on the water level in section 2. The backwater effect due to this external water level increase is not transferred up to section 1.

The suggested changes by the consultant in the Drainage Master Plan improved the system's water transporting capacity and the water level decreased significantly in sections 1 and 2.

An increase of the catchment area, connected upstream of section 1, will raise the water level significantly in section 1, which can cause flooding of the nearby houses. The risk of the flooding to spread is limited by the topographical situation that will lead the water to downstream drainages with larger water transporting capacity.

None of the scenarios indicate any additional areas in risk of flooding in the future. The flooding problems are limited to section 1 and 2.

8 Suggestions for further work

If further studies about urban flooding are to be performed in this study area, some suggestions to improve the performance of the simulations follows.

In order to obtain more reliable result it is necessary to use rainfall data that has been recorded during a longer period of time. The measuring time period should preferably be up to one year so that it covers the seasonal variations of rainfall in Malaysia. A longer measuring period will also give more amounts of useful rainfall events that can be utilized for calibration and validation. With a longer recording period, it may be possible to utilize a continuous hydrological model. In this type model properties such as soil moisture can be simulated. This property can have a significant influence on the runoff.

It is of high significance that the location of the rain gauge is inside the catchment area as this reduces the effects of local rainfall. It is recommended to place several rain gauges in the catchment area to be able to compare the different rainfall data.

It is preferable to use more than one water level recorder as it makes it possible to perform a better calibration and validation. One water level recorder should be placed to measure the water level in Sungai Senai. The data from this water level recorder can be put in the model as a varying external water level. Thereby the real backwater effects from Sungai Senai can be simulated. Simultaneously, the water level in the drainage network should be measured, to be used in the calibration and validation. Preferably the water level should be recorded in both sections 1 and 2. This is because section 1 will not be affected by backwater effects from Sungai Senai. Section 2 is a good location to place a water level recorder, because the slope in the drain is small and almost uniform. This makes it easier to transform data from the water level measurements to flow data.

It is advantageous to improve the system by changing the dimensions as proposed in the Drainage Master Plan. These sections are the most problematic parts of the drainage network and by changing these dimensions the risk of flooding is reduced.

As the urban areas around the study area is likely to be enlarged in the future it is recommended to investigate where the additional storm water will be discharged. Because if the storm water from these enlarged areas are discharged into the catchment area of this study there will be a great risk of flooding, especially in section 1.

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10 Appendix

1. Measuring equipment
2. Data from the hydraulic model in MIKE URBAN
3. Data from the hydrological model in MIKE URBAN
4. Resulting graphs and profiles
    a. Calibration
    b. Scenario 1 – increased rainfall
    c. Scenario 2 – increased external water level
    d. Scenario 3 – changes suggested by consultant
    e. Scenario 4 – increased catchment area
5. Article

Appendix 1. Measuring equipment

Rainfall recorder	
Device	HOBO UA-003-64 Pendant Temp/Event
Manufacturer	Onset Computer Corporation
Description	Cabang Sungai Senai Fasa 1
Model number	RG3-M
Serial number	2014979-708
Deployment number	5
Firmware Version	1.0.7

Water level recorder	
Manufacturer	Solinst Levelogger
Model	3001 (LT F30/M10)
Made in	Canada
Software Version	3.2.3
Serial number	1035860
Altitude (m)	0
Density adjustments (kg/L) (0.9-1.1)	1
Memory mode selection	Slate logging mode
Sample mode	Linear
Sample rate	60 sec
Channel 1 – unit	m
Channel 1 - offset	-0,82

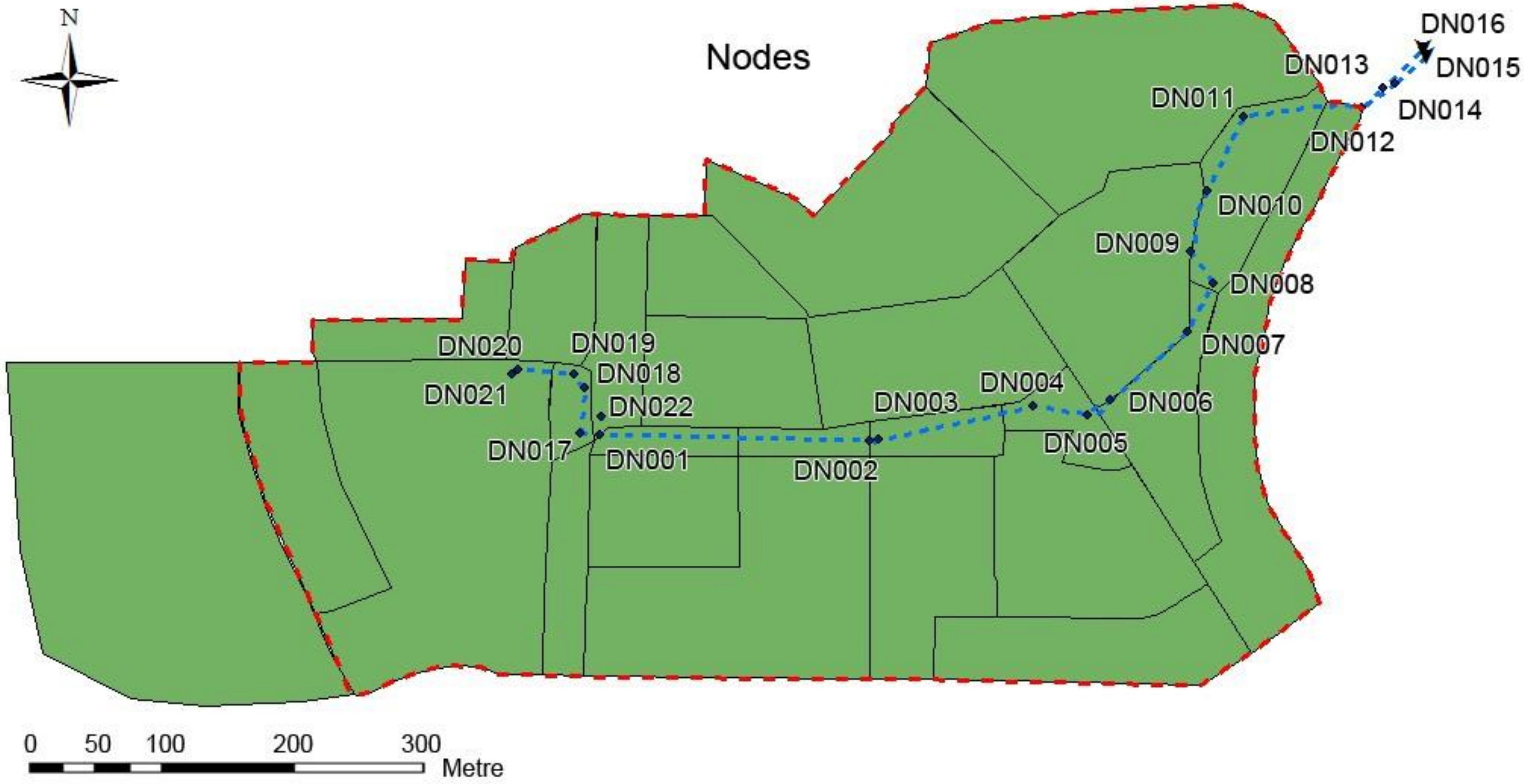
Appendix 2. Data from the hydraulic model in MIKE URBAN

Nodes

Node	Invert level [m.a.s.l]	Ground level [m.a.s.l]	Diameter [m]	Outlet head loss	X [m]	Y [m]
DN001	18.42	20.02	3.00	MOUSE Classic(Engelund)	627244.90	176947.80
DN002	14.53	16.13	3.00	MOUSE Classic(Engelund)	627457.94	176942.89
DN003	14.46	16.06	3.00	MOUSE Classic(Engelund)	627464.93	176943.97
DN004	13.07	14.67	3.00	MOUSE Classic(Engelund)	627587.39	176970.53
DN005	12.78	14.78	3.00	MOUSE Classic(Engelund)	627630.60	176963.48
DN006	12.23	14.23	2.00	MOUSE Classic(Engelund)	627647.82	176975.21
DN007	11.7	13.7	2.00	No Cross Section Changes	627709.82	177029.31
DN008	11.45	13.45	3.00	MOUSE Classic(Engelund)	627729.88	177067.86
DN009	11.27	13.07	3.00	MOUSE Classic(Engelund)	627712.06	177092.90
DN010	10.98	12.78	3.00	No Cross Section Changes	627725.09	177141.20
DN011	10.7	12.5	3.00	No Cross Section Changes	627754.23	177199.57
DN012	10.31	12.11	3.00	MOUSE Classic(Engelund)	627847.15	177206.20
DN013	9.53	11.53	2.90	MOUSE Classic(Engelund)	627864.02	177222.53
DN014	9.78	11.78	1.80	MOUSE Classic(Engelund)	627873.50	177225.87
DN015 *	8.64	10.64	3.00	MOUSE Classic(Engelund)	627898.59	177247.84
DN016 *	8.64	10.64	2.00	MOUSE Classic(Engelund)	627896.60	177253.21
DN017	19.11	20.41	1.40	MOUSE Classic(Engelund)	627228.80	176949.84
DN018	20.84	22.14	1.35	No Cross Section Changes	627232.24	176985.47
DN019	21.72	23.02	1.35	No Cross Section Changes	627224.54	176995.52
DN020	24.41	25.71	1.35	No Cross Section Changes	627180.51	176999.23
DN021	24.69	25.99	1.35	No Cross Section Changes	627175.28	176995.52
DN022	19.74	20.44	0.60	MOUSE Classic(Engelund)	627245.32	176962.50

* The node is an outlet node

Nodes


N
DN016
DN015
DN014
DN013
DN012
DN011
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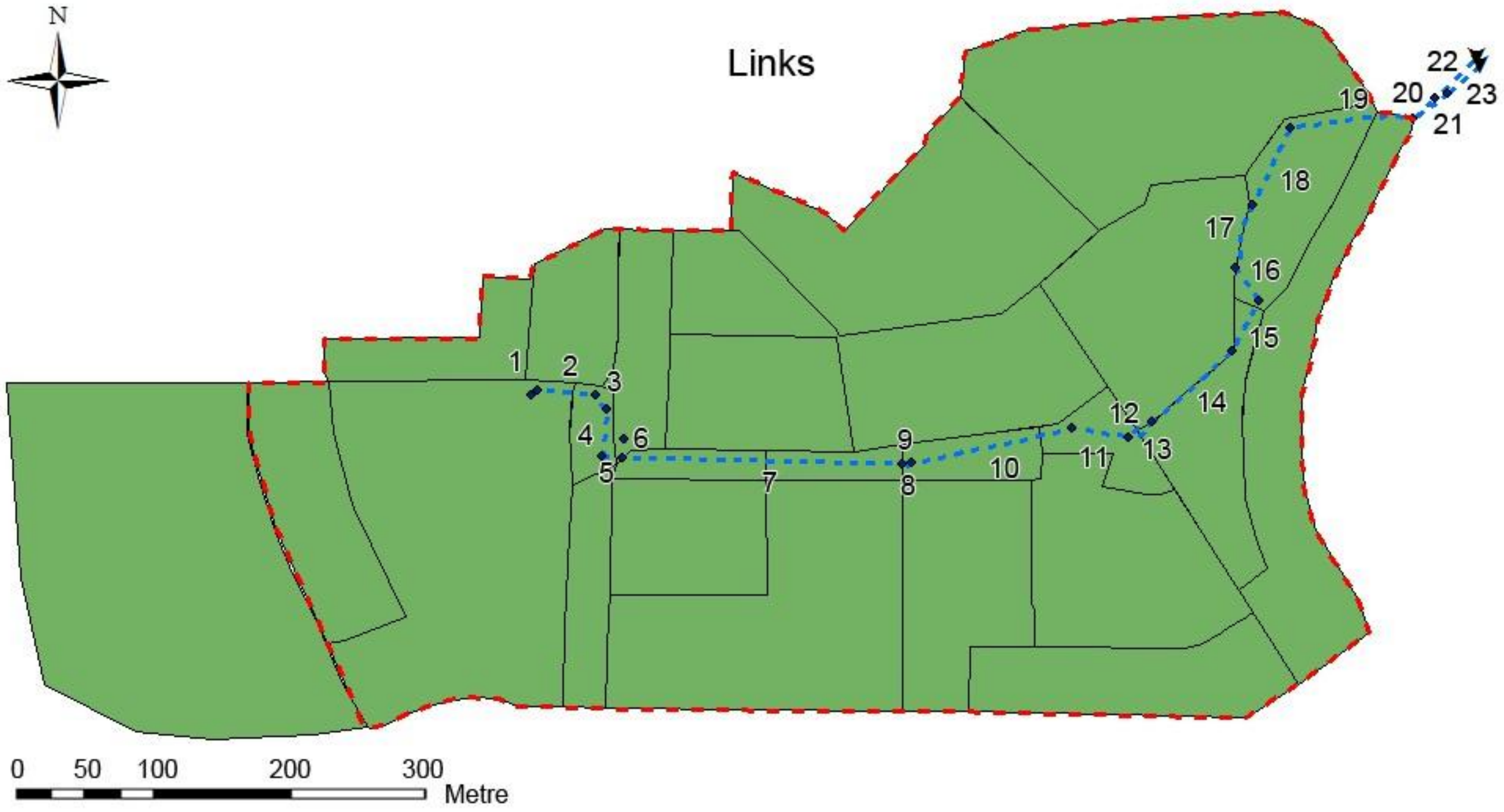
DN008
DN007
DN006
DN005
DN004
DN003
DN002
DN001
DN017
DN022
DN018
DN019
DN020
DN021
0
50
100
200
300
Metre

Links

Link	Upstream level [m.a.s.l]	Downstream level [m.a.s.l]	Length [m]	Slope [%]	Type	Diameter [m]	Width [m]	Height [m]
1	24.69	24.41	6.41	4.37	Drain	-	1.35	1.2
2	24.41	21.72	44.18	6.09	Drain	-	1.35	1.2
3	21.72	20.84	12.66	6.95	Drain	-	1.35	1.2
4	20.84	19.11	35.80	4.83	Drain	-	1.35	1.2
5	19.74	19.23	14.71	3.47	Circular	0.6	-	
6	19.11	18.42	16.23	4.25	Drain	-	1.35	1.2
7	18.42	14.53	213.09	1.83	Drain	-	3	1.6
8	14.53	14.46	7.40	0.95	Circular	1.5	-	-
9	14.53	14.46	7.39	0.95	Circular	1.5	-	-
10	14.46	13.07	125.31	1.11	Drain	-	3	1.6
11	13.07	12.78	20.88	1.39	Culvert	-	3	1.5
12	12.78	12.23	21.19	2.60	Circular	1.5	-	-
13	12.78	12.23	22.28	2.47	Circular	1.5	-	
14	12.23	11.70	82.28	0.64	Culvert	-	2	1.4
15	11.70	11.45	43.46	0.58	Culvert	-	2	1.4
16	11.45	11.27	30.72	0.59	Culvert	-	3	1.5
17	11.27	10.98	51.02	0.57	Drain	-	3	1.8
18	10.98	10.70	65.30	0.43	Drain	-	3	1.8
19	10.70	10.31	96.67	0.40	Drain	-	3	1.8
20	10.31	9.53	20.40	3.82	Culvert	-	3	1.8
21	10.81	9.78	29.81	1.78	Circular	1.3	-	-
22	9.53	8.64	42.84	2.08	Culvert	-	2.9	2
23	9.78	8.64	33.35	3.42	Culvert	-	1.8	1.8

Material: Concrete (normal)



Links
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19
20
21
22
23
0
50
100
200
300
Metre

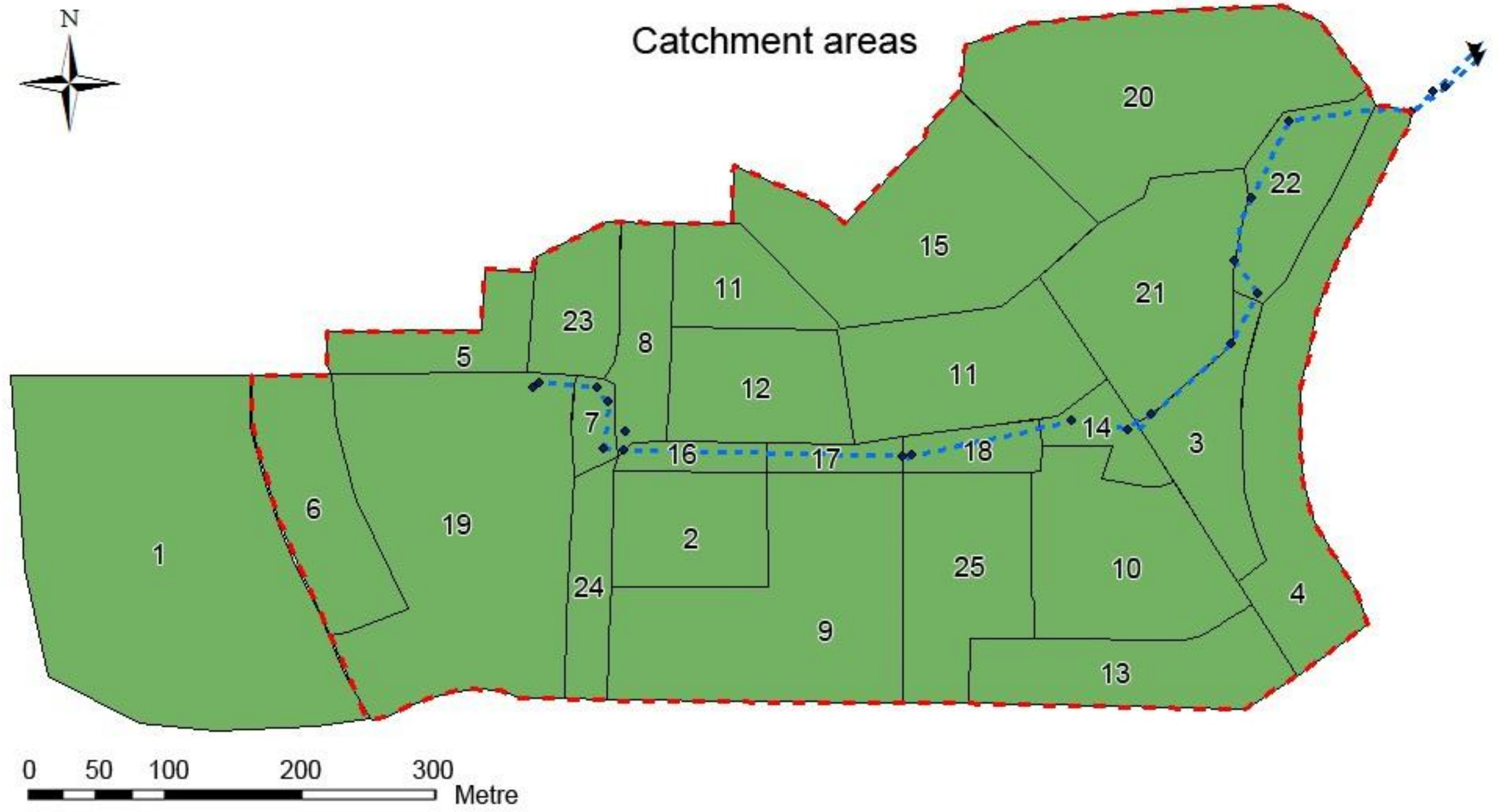
Appendix 3. Data from the hydrological model in MIKE URBAN

Catchment	Area [ha]	Impervious area [%]	Time of concentration [min]
1 *	5.00 alt. 10.00	60.00	12
2	1.04	78.26	13
3	0.91	81.60	13
4	1.93	71.20	21
5	0.67	79.88	13
6	1.26	86.64	21
7	0.22	50.60	9
8	0.70	73.22	13
9	2.87	83.55	21
10	1.82	73.42	13
11	2.38	72.68	21
12	1.18	81.30	13
13	1.30	86.27	29
14	0.38	74.58	9
15	2.63	70.38	29
16	0.25	62.13	9
17	0.24	62.49	9
18	0.36	59.05	9
19	4.05	80.83	21
20	3.18	57.72	17
21	1.88	65.76	13
22	0.89	49.46	13
23	0.70	71.32	9
24	0.57	62.31	13
25	1.49	83.85	17

Initial loss: 0.0006 meter

Reduction factor: 0.9

* This catchment is only part of the model in scenario 4


Catchment areas
N
20
22
15
21
11
23
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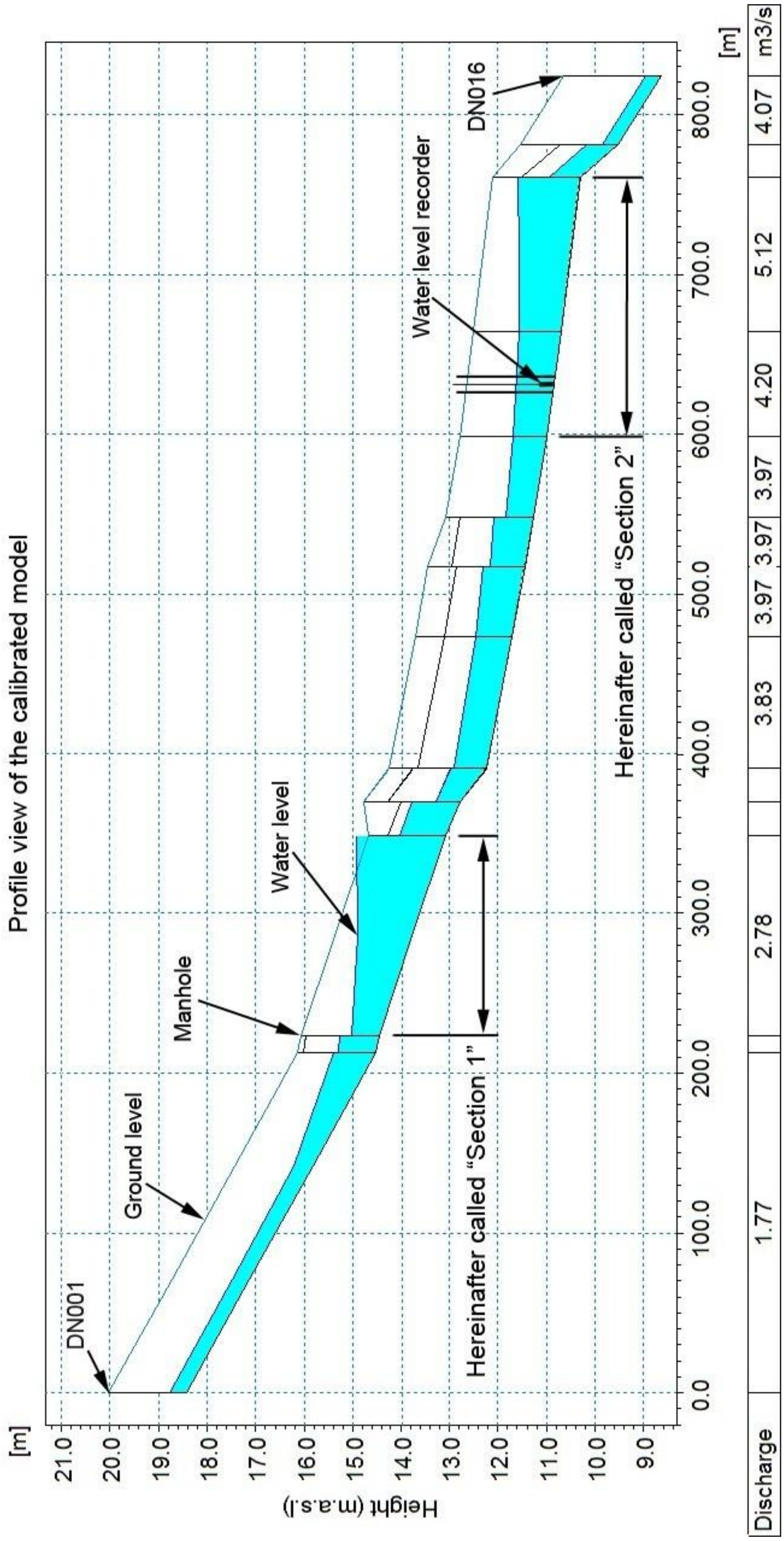
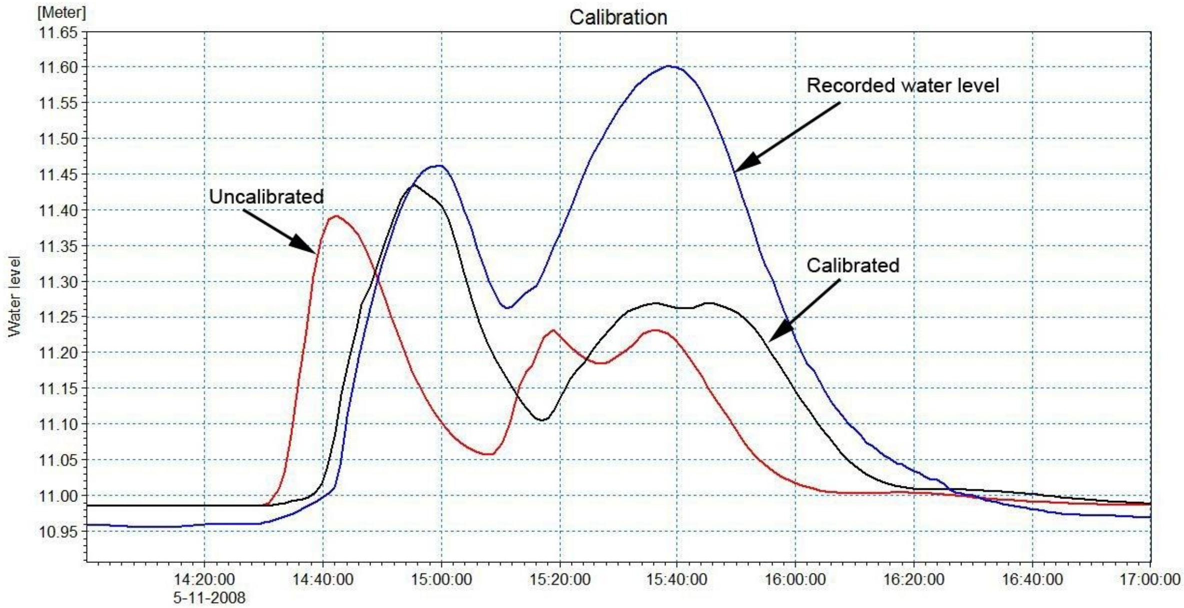
11
5
12
7
16
17
18
14
3
6
19
1
2
24
25
10
9
4
13
0
50
100
200
300
Metre

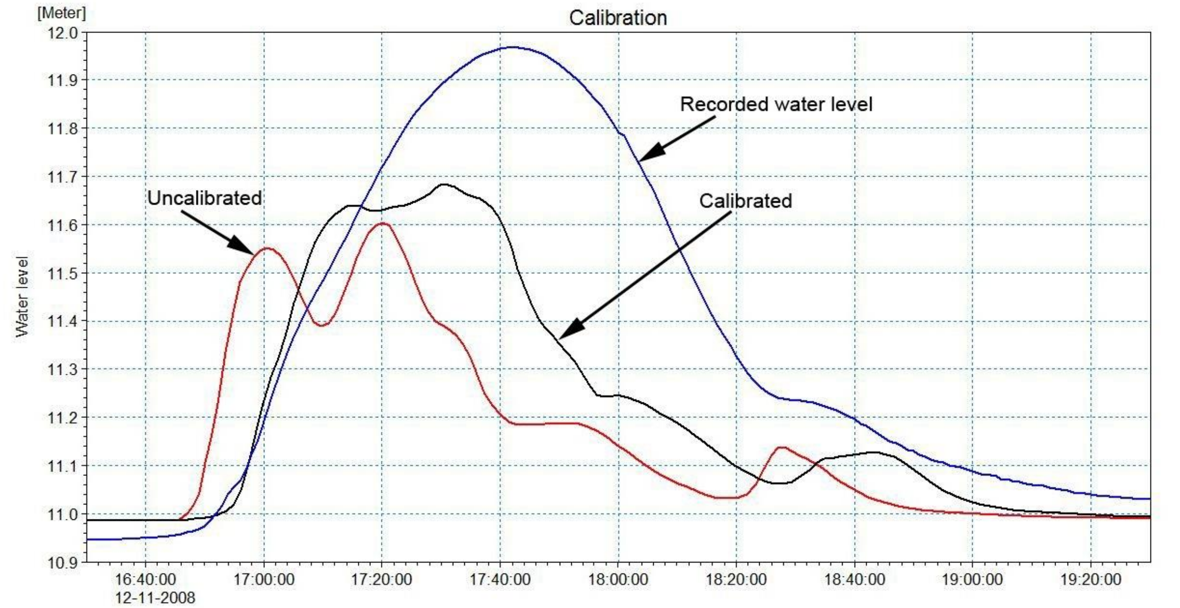
Appendix 4. Resulting graphs and profiles

Calibration



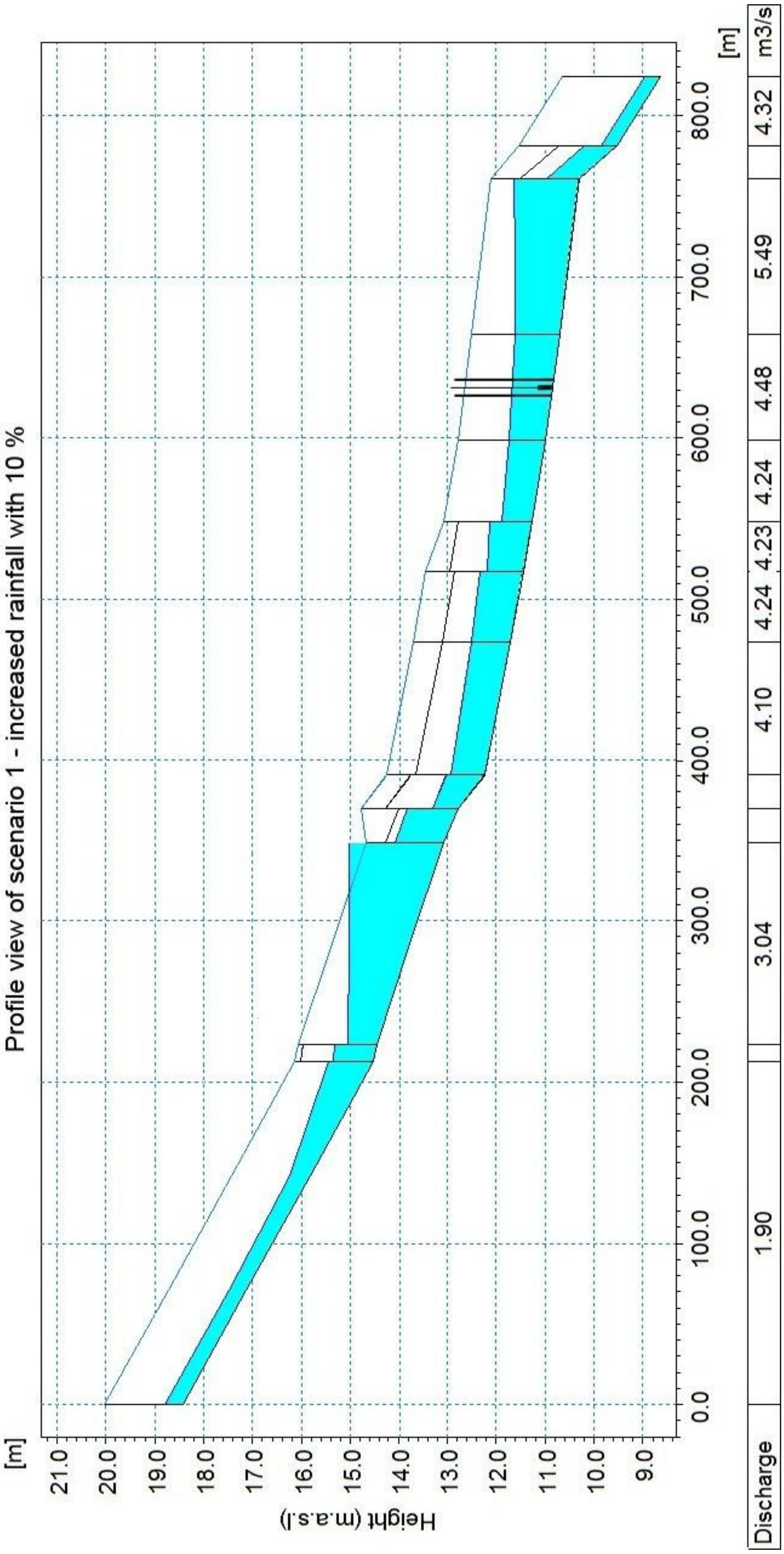


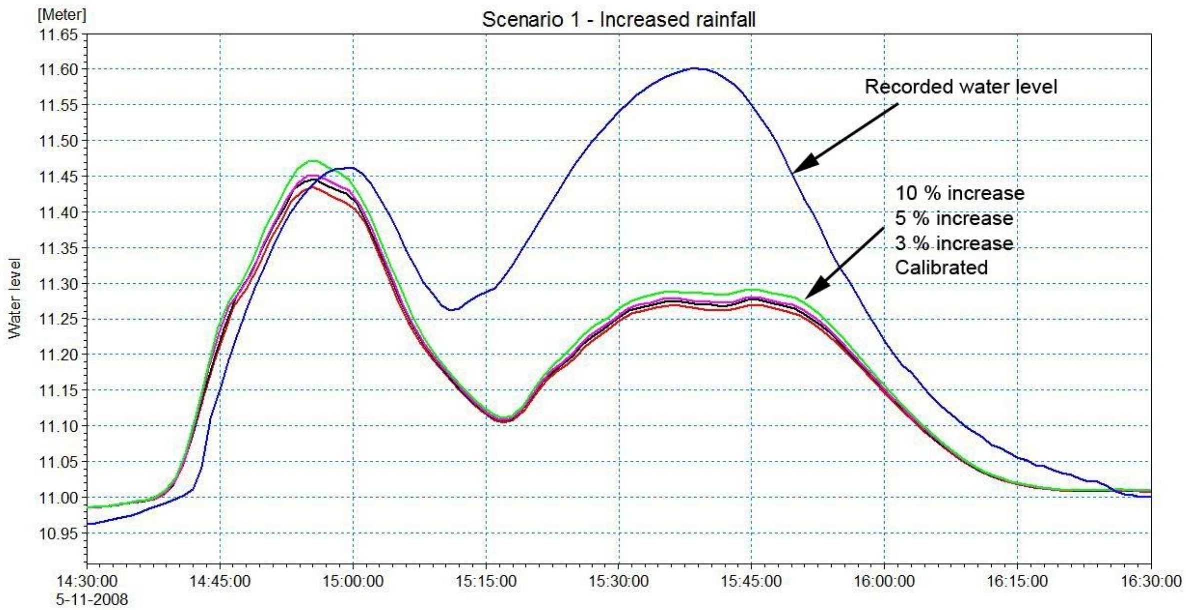
[Meter]
Calibration
11.65
11.60
11.55
11.50
11.45
11.40
11.35
11.30
11.25
11.20
11.15
11.10
11.05
11.00
10.95
Water level
Recorded water level
Uncalibrated
Calibrated
14:20:00
5-11-2008
14:40:00
15:00:00
15:20:00
15:40:00
16:00:00
16:20:00
16:40:00
17:00:00

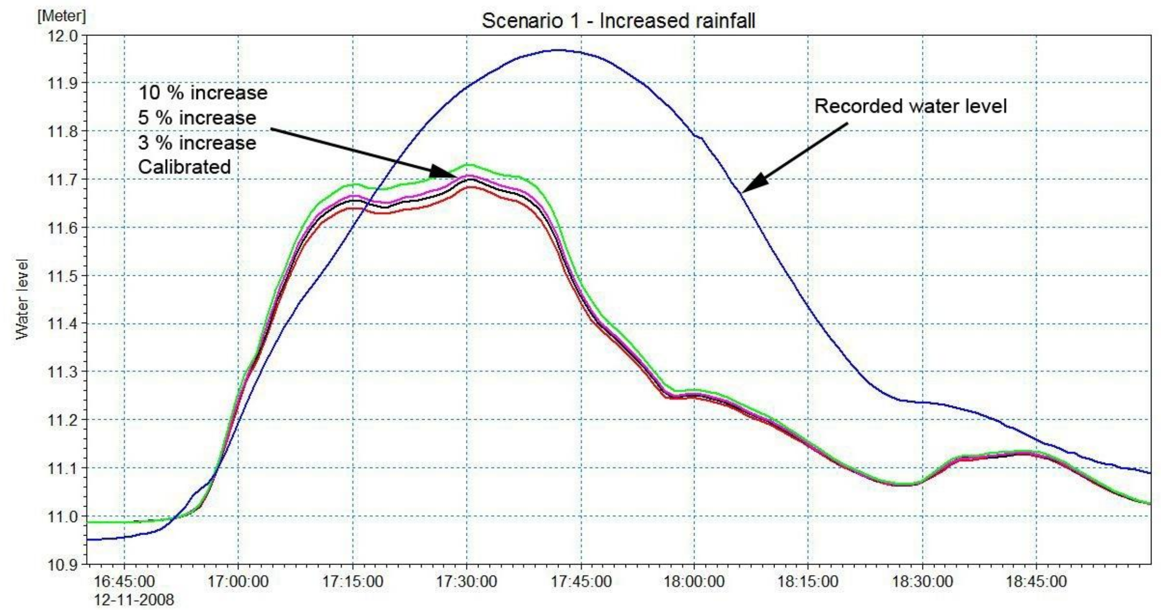


[Meter]
Calibration
12.0
11.9
11.8
11.7
11.6
11.5
11.4
11.3
11.2
11.1
11.0
10.9
Water level
Recorded water level
Uncalibrated
Calibrated
16:40:00
12-11-2008
17:00:00
17:20:00
17:40:00
18:00:00
18:20:00
18:40:00
19:00:00
19:20:00

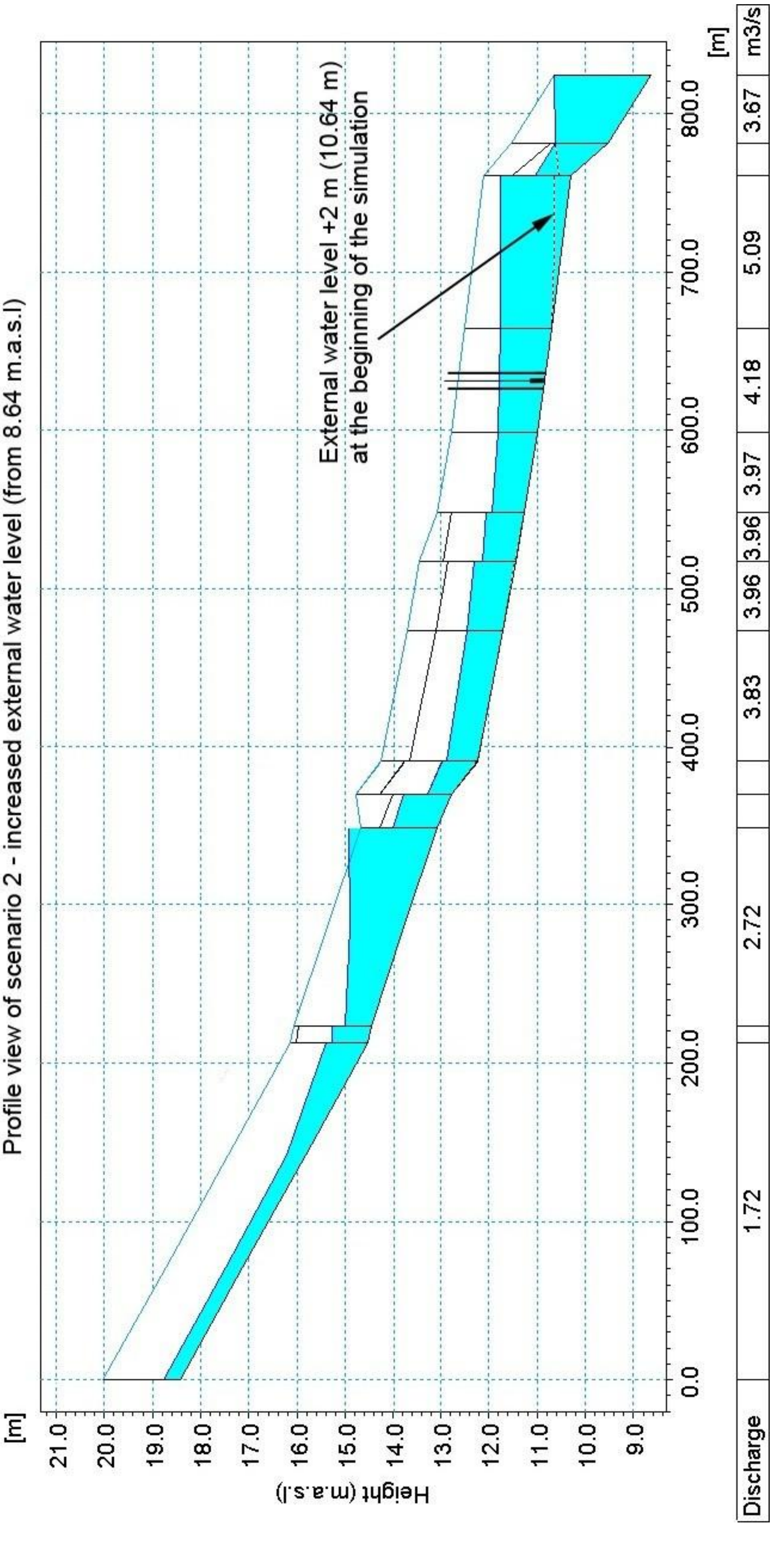
Scenario 1 – increased rainfall

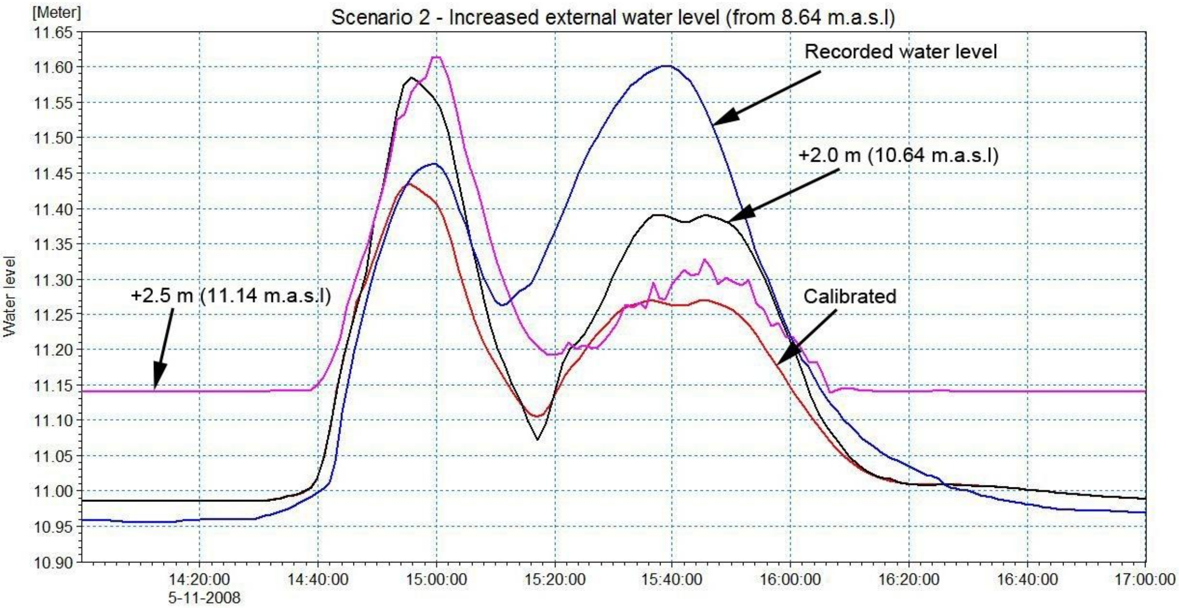



[Meter]
Scenario 1 - Increased rainfall
Water level
Recorded water level
10 % increase
5 % increase
3 % increase
Calibrated
11.65
11.60
11.55
11.50
11.45
11.40
11.35
11.30
11.25
11.20
11.15
11.10
11.05
11.00
10.95
14:30:00
5-11-2008
14:45:00
15:00:00
15:15:00
15:30:00
15:45:00
16:00:00
16:15:00
16:30:00

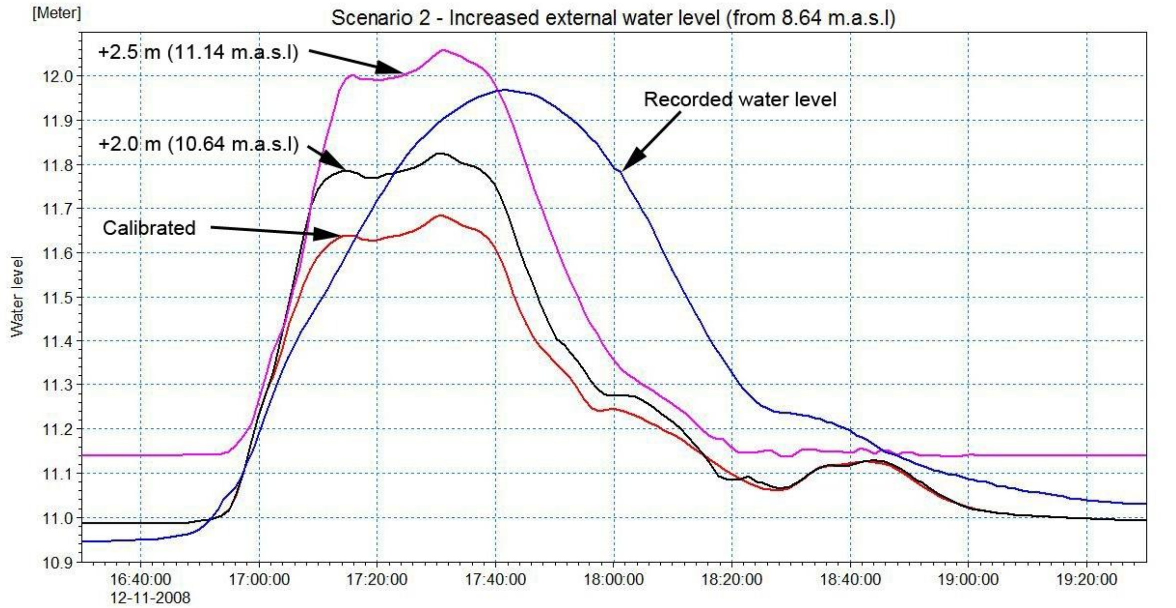

[Meter]
Scenario 1 - Increased rainfall
Water level
10 % increase
5 % increase
3 % increase
Calibrated
Recorded water level
12.0
11.9
11.8
11.7
11.6
11.5
11.4
11.3
11.2
11.1
11.0
10.9
16:45:00
12-11-2008
17:00:00
17:15:00
17:30:00
17:45:00
18:00:00
18:15:00
18:30:00
18:45:00

Scenario 2 – increased external water level



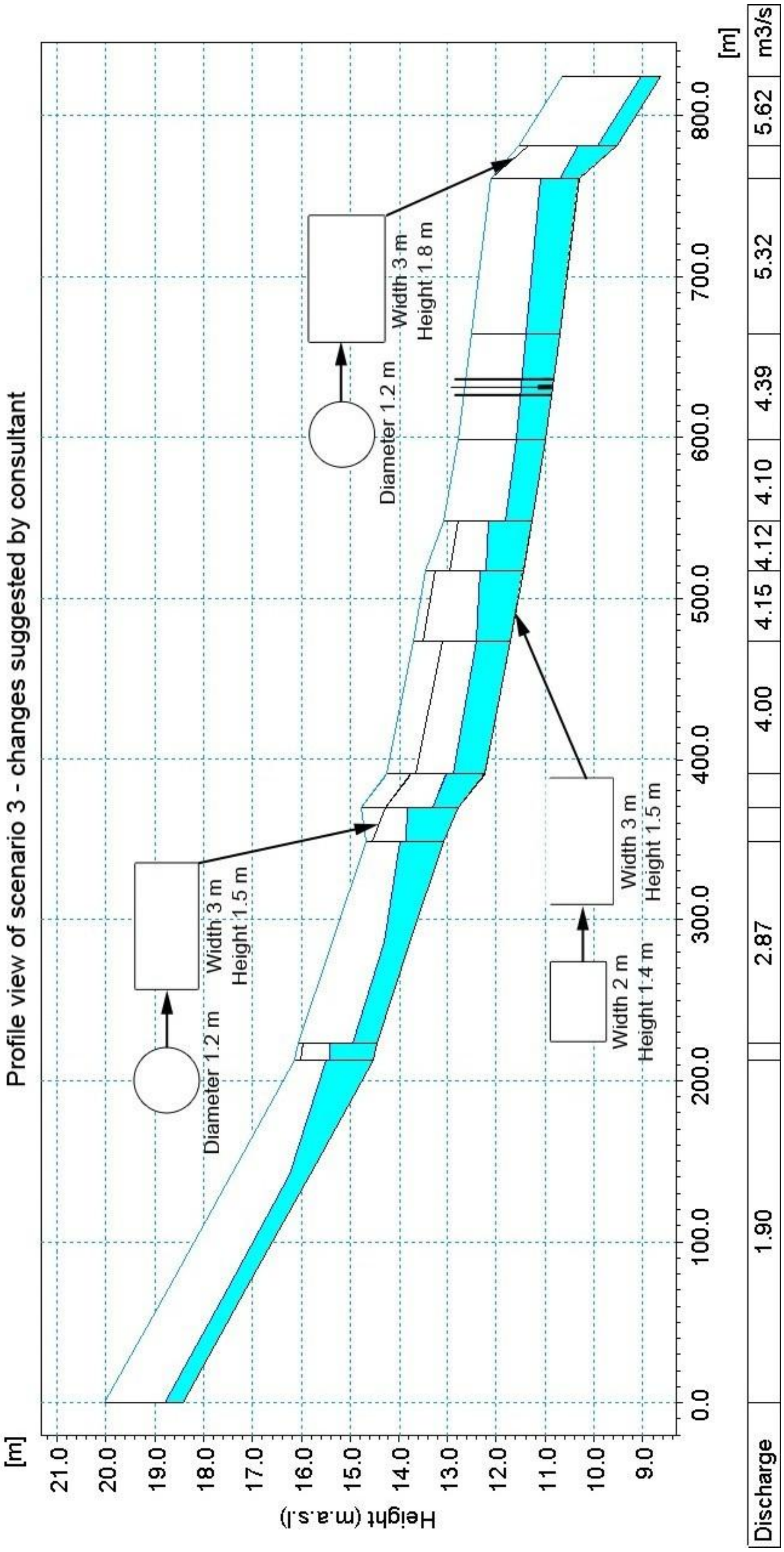


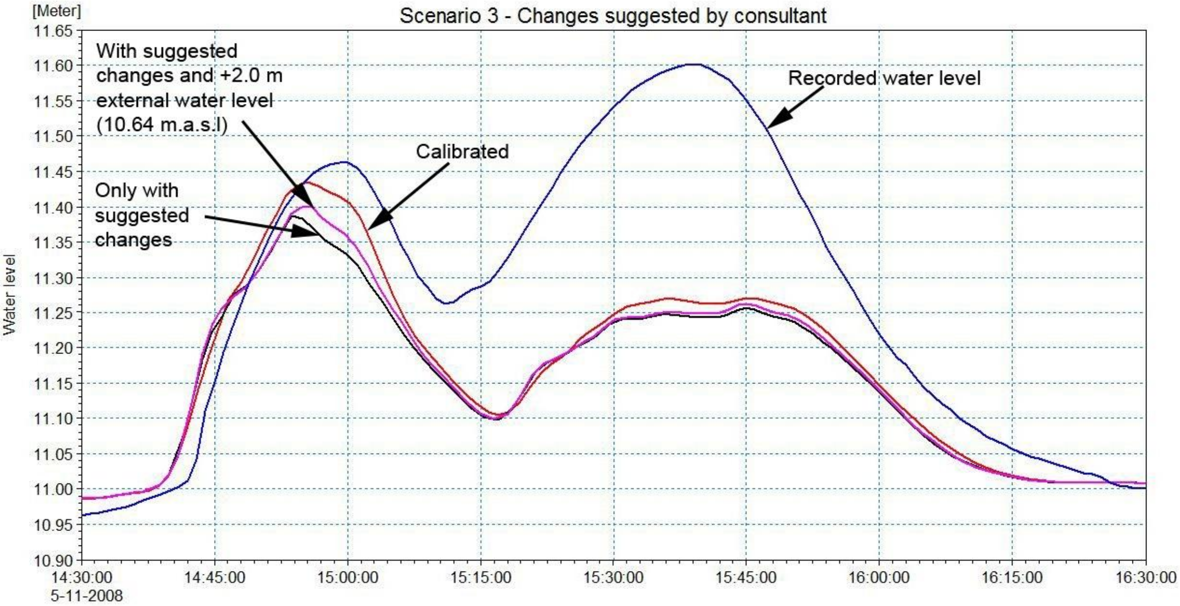
Scenario 2 - Increased external water level (from 8.64 m.a.s.l)
[Meter]
Water level
Recorded water level
+2.0 m (10.64 m.a.s.l)
Calibrated
+2.5 m (11.14 m.a.s.l)
11.65
11.60
11.55
11.50
11.45
11.40
11.35
11.30
11.25
11.20
11.15
11.10
11.05
11.00
10.95
10.90
14:20:00
5-11-2008
14:40:00
15:00:00
15:20:00
15:40:00
16:00:00
16:20:00
16:40:00
17:00:00



Scenario 2 - Increased external water level (from 8.64 m.a.s.l)
[Meter]
Water level
+2.5 m (11.14 m.a.s.l)
Recorded water level
+2.0 m (10.64 m.a.s.l)
Calibrated
12.0
11.9
11.8
11.7
11.6
11.5
11.4
11.3
11.2
11.1
11.0
10.9
16:40:00
12-11-2008
17:00:00
17:20:00
17:40:00
18:00:00
18:20:00
18:40:00
19:00:00
19:20:00

Scenario 3 – changes suggested by consultant





[Meter]
Scenario 3 - Changes suggested by consultant
With suggested changes and +2.0 m external water level (10.64 m.a.s.l)
Recorded water level
Calibrated
Only with suggested changes
Water level
11.65
11.60
11.55
11.50
11.45
11.40
11.35
11.30
11.25
11.20
11.15
11.10
11.05
11.00
10.95
10.90
14:30:00
5-11-2008
14:45:00
15:00:00
15:15:00
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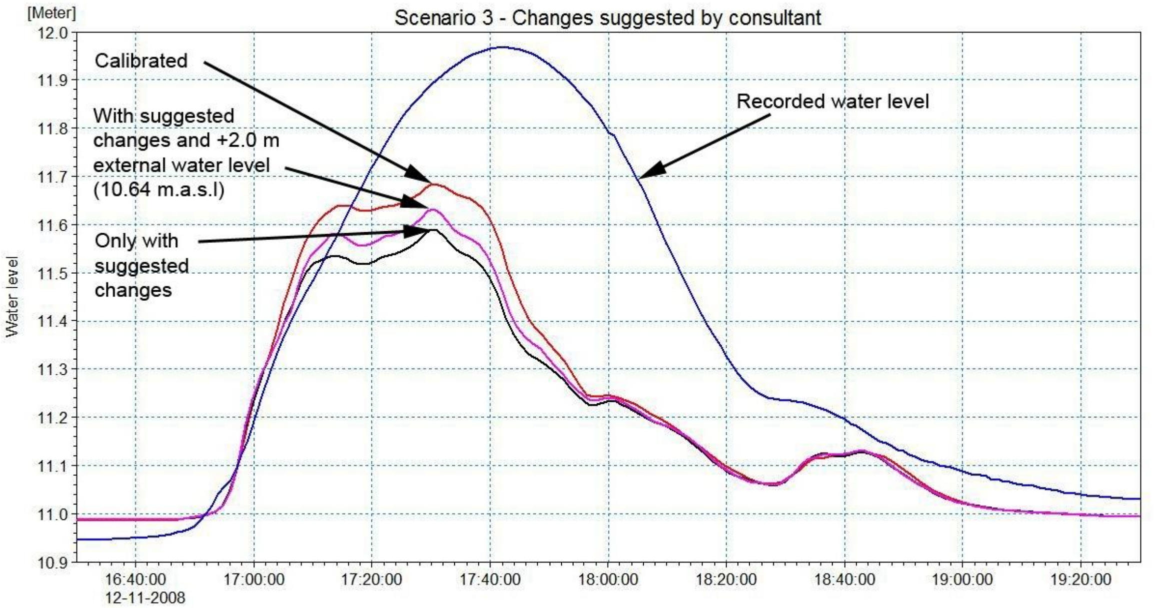
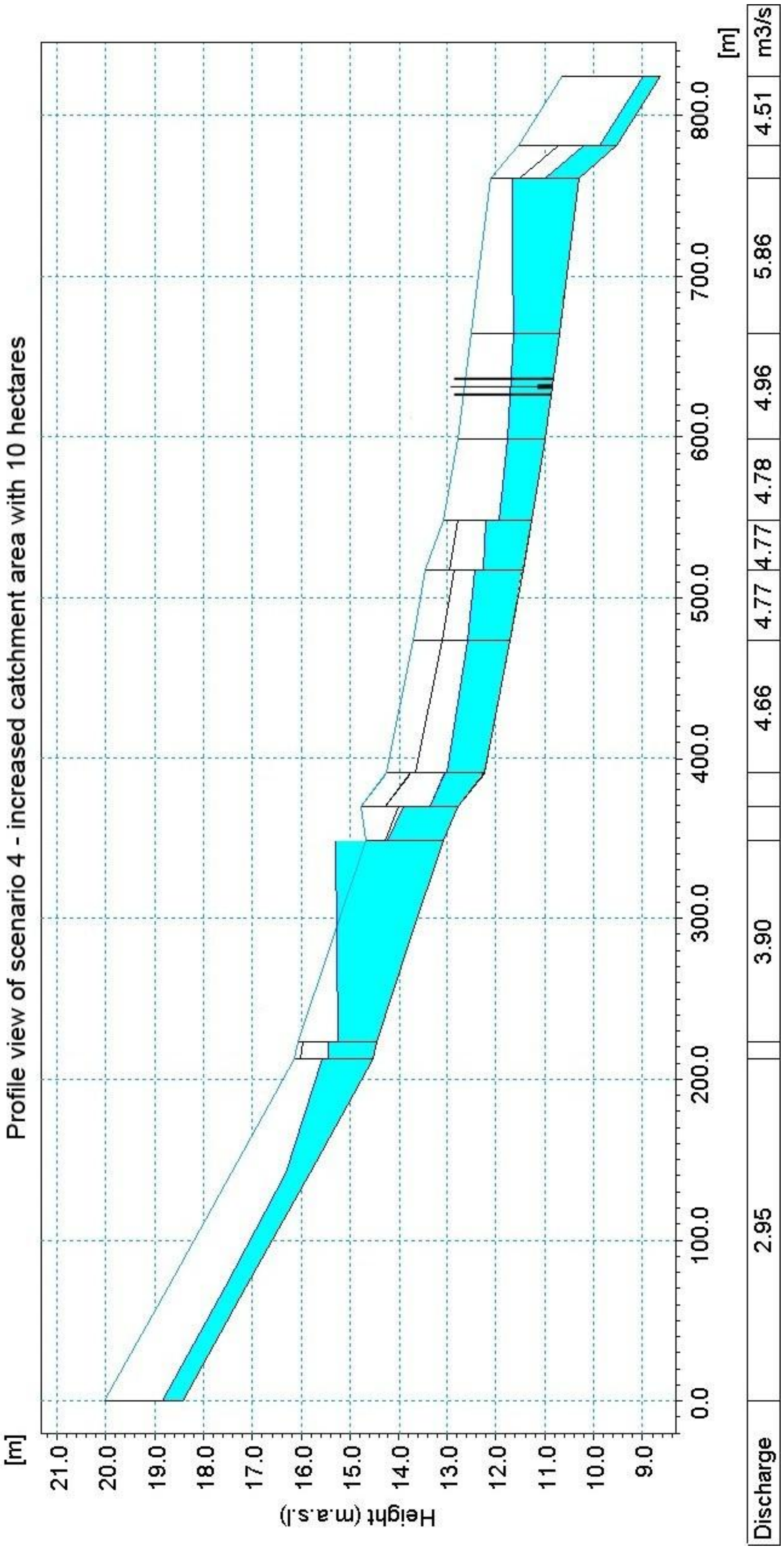
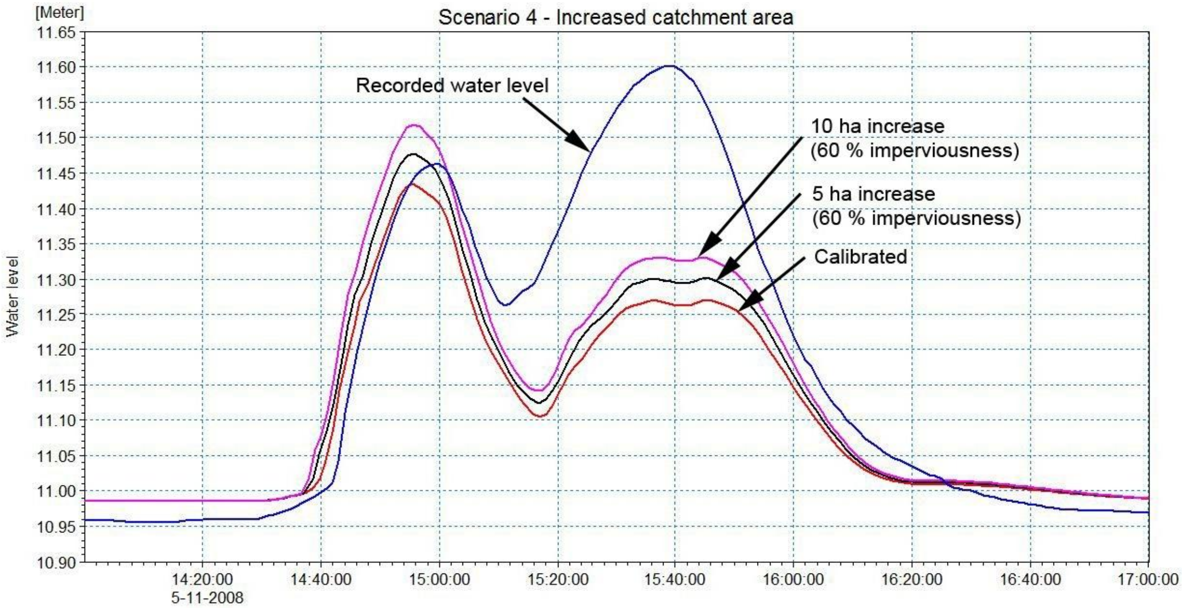
16:00:00
16:15:00
16:30:00



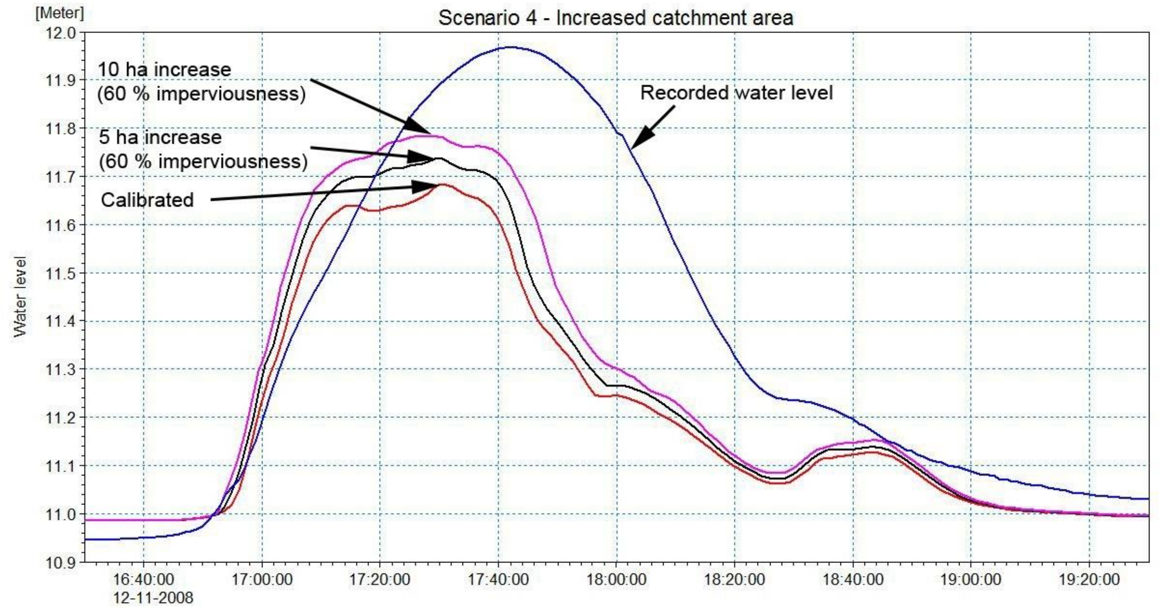
[Meter]
Scenario 3 - Changes suggested by consultant
Calibrated
Recorded water level
With suggested changes and +2.0 m external water level (10.64 m.a.s.l)
Only with suggested changes
Water level
12.0
11.9
11.8
11.7
11.6
11.5
11.4
11.3
11.2
11.1
11.0
10.9
16:40:00
12-11-2008
17:00:00
17:20:00
17:40:00
18:00:00
18:20:00
18:40:00
19:00:00
19:20:00

Scenario 4 – increased catchment area





[Meter]
Scenario 4 - Increased catchment area
11.65
11.60
11.55
11.50
11.45
11.40
11.35
11.30
11.25
11.20
11.15
11.10
11.05
11.00
10.95
10.90
Water level
Recorded water level
10 ha increase
(60 % imperviousness)
5 ha increase
(60 % imperviousness)
Calibrated
14:20:00
5-11-2008
14:40:00
15:00:00
15:20:00
15:40:00
16:00:00
16:20:00
16:40:00
17:00:00



[Meter]
Scenario 4 - Increased catchment area
12.0
11.9
11.8
11.7
11.6
11.5
11.4
11.3
11.2
11.1
11.0
10.9
Water level
10 ha increase
(60 % imperviousness)
5 ha increase
(60 % imperviousness)
Calibrated
Recorded water level
16:40:00
12-11-2008
17:00:00
17:20:00
17:40:00
18:00:00
18:20:00
18:40:00
19:00:00
19:20:00

Identification of flood risk areas in an open storm-water system with MIKE URBAN – Senai Town, Malaysia

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Water and Environmental Engineering, Department of Chemical Engineering, Lund University, Sweden

Abstract

Malaysia is expected to develop rapidly in the coming decades which will lead to urbanization with an increased amount of impermeable surfaces and runoff. The study area in Senai Town is densely urbanized and has experienced flooding in the past. In order to forecast the future situation, a rainfall-runoff model was created to identify areas in the open storm-water system with risk of flooding. Four scenarios were formulated based on the expected urbanization and the effects of climate changes in the region. By simulating the scenarios in MIKE URBAN it was found that two sections are risk of flooding today. Increased catchment area resulted in severe flooding in the upstream part of the drainage network and backwater effects from nearby rivers also have a large impact on the water level. Increased precipitation has small effect on the water level. None of the scenarios indicate any additional areas in risk of flooding in the future compared with today's situation.

Keywords: Urban flooding, MIKE URBAN, storm water, computer modeling

Introduction

By the year of 2020 Malaysia is expected to become a developed nation after twenty years of rapid socio-economic growth. The population will be about 30 million compared to today's 21 million as a result of an increased number of births within the country as well as of immigrants from the bordering countries. As the urban and industrial areas are increasing and the daily life-quality of the urban citizens is improving, the hydrological and ecological stresses on the environment are increasing as well. When land use changes from rural to urban, the runoff will increase as a result of growth and spread of impervious surfaces. This increased runoff has an impact on receiving waters due to its content of nutrients, heavy metals, oil, grease and bacteria. Together with frequent heavy rainfalls the situation has become even more problematic. Flash flooding, water pollution and ecological damage, traffic disruption and accidents, garbage and floating litters are all associated with storm water in Malaysia. This is forcing Malaysia to plan for a sustainable urban storm-water management (DID, 2000).

The study area is Senai Town which is situated in an important economic centre in the mid-southern region of Johor State in South-East Malaysia. The study is performed during September to November 2008 and the annual rainfall is in a range between 1500 and 3500 mm (DID, 2005). The drainage network is almost entirely an open drainage system and consists of concrete lined channels and culverts of different dimensions. The drainage water is further lead into river Sungai Senai. High water levels in the river courses near Senai Town coinciding with heavy rainfall have in the past resulted in flash floods in housing estates. To solve future problems with flooding in the region, the Government of Johor carried out a Drainage Master Plan (DMP) for Bandar Senai. The aim of the DMP was to identify existing drainage problems and propose long-term improvements with a projected year of 2020 (DID, 2005).

Many studies have been made on the subject of urban flooding and there are several approaches to assess urban flooding. One method is one-dimensional modeling which consist of an artificial hydrological model and a hydraulic model. Another approach is to use two-dimensional surface modeling, where flooding can be simulated by overland flow. The studies show that one-dimensional modeling to simulate urban flooding is a conventional approach which can give promising simulation results (Mark *et al*., 1998). Increased precipitation and urbanization are two examples of common scenarios of the future. As the climate changes can have a large impact on the amount of urban runoff, projected climate models are useful in formulating scenarios of the future situation (Semadeni-Davies *et al*., 2008). A study made in Denmark suggests that compared to the past decades, extreme precipitation events that affect urban drainage and cause flooding will occur at least twice as often as a result of climate change (Grum *et al*., 2006).

There are two major objectives of this thesis. The first objective is to locate areas in the drainage system in Senai Town with high risk of flooding with today's situation in a created MIKE URBAN model. The second objective is to see how these sensitive parts of the system will stand the effects of future climate changes, as well as to look at the future effects on the total drainage system. In addition, proposed improvements by DMP and assumed expansion of the catchment area will be applied and analyzed in the model.

Method

A rainfall-runoff model was created in MIKE URBAN in order to forecast the future situation in the drainage system. The rainfall-runoff model consists of a hydrological and a hydraulic model. The hydrological model is a surface model that uses the "Time-Area Method", where the runoff contributing area varies in time. The hydraulic model mainly consists of an open drainage system.

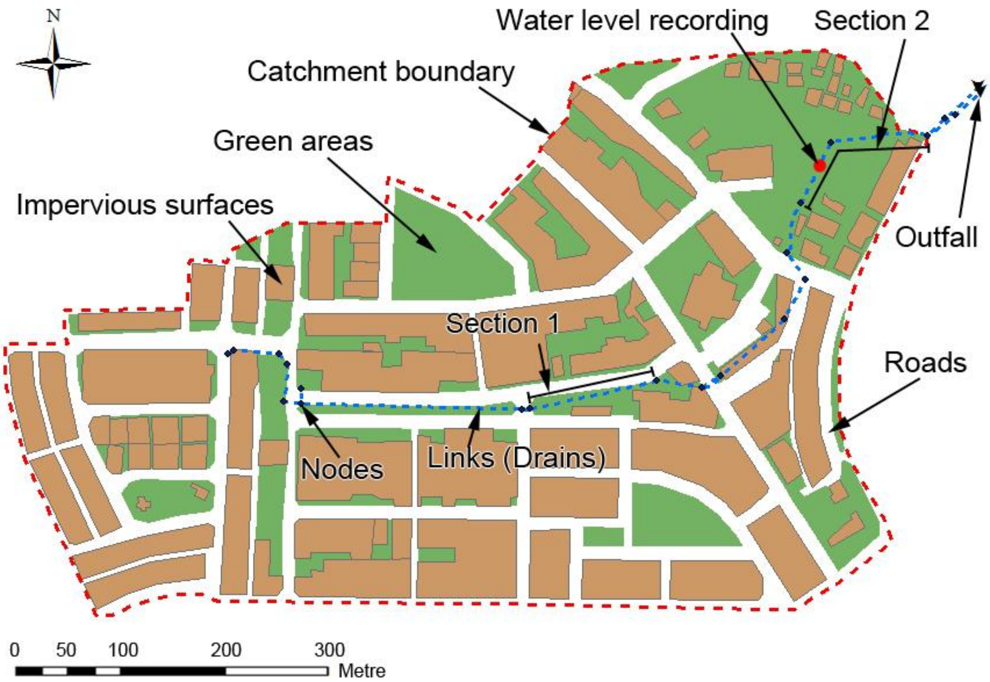

Figure 1. The figure shows an overview of the catchment area, presented in GIS-layers. Green areas and impervious surfaces such as roofs and roads are used for the hydrological calculations in MIKE URBAN. Manholes, drains and the outfall are parts of the hydraulic MIKE URBAN-model. Notice the definition of "Section 1" and "Section 2".

The necessary information to create the hydraulic model was taken from the DMP and from onsite observations. The DMP includes details about the drainage alignment, dimensions and slopes, which were directly used in MIKE URBAN to construct the hydraulic model. Useful information about land use was interpreted from an aerial photograph. This knowledge is important in order to define surfaces with different permeability. From onsite observations, information about the catchment area's boundaries was gathered. See Figure 1 for an overview of the catchment area. Data about rainfall and water level was collected in order to perform a calibration of the model. The measuring equipment for recording the rainfall data was a tipping bucket. In order to collect the water level data a water level recorder was installed in the main channel. In the calibration the constructed model was simulated with the recorded rainfall data. The curve of the simulated water level was compared to the recorded water level curve. In order to make the curve fit the recorded water level curve, some settings were adjusted.

In order to test the drainage system's capacity and future function, four different scenarios were formulated and simulated in MIKE URBAN. The underlying information was taken from a literature study of the prospected future climate changes in the region, from the result of the Drainage Master Plan, from the Structure Plan for Johor Bahru 2002 to 2020 (Kulai Municipal Council, 2002) and from onsite observations.

- The first scenario simulates the effects of future climate changes in the region. An increase of precipitation with 3% is based on the study made on the southern region of Peninsula Malaysia in 2005 (NAHRIM, 2005). In addition, increases of 5% and 10% are also simulated based upon the projected changes over South-East Asia made by the IPCC in 2007 (IPCC, 2007).
- Backwater effects can have an effect on the water level recording. Therefore, the second scenario was put up with an increased external water level with +1, +1.5, +2 and +2.5 metres.
- According to the DMP some sections in the drainage network have limited water transporting capacity. The third scenario is based on suggested improvements in the DMP of these sections.
- An increased catchment area is put up as the fourth scenario, in order to simulate the growth of the town. The catchment area of 33 hectares will be increased with 5 and 10 hectares. The results were analyzed individually for each scenario in order to evaluate the possible different risk of future flooding in the area.

Results

The calibration shows that the water level is simulated too low, see Figure 2. Several attempts were made to increase the calibrated water level and at the same time to do realistic changes in the model. There seems to be other properties that affect the recorded water level in the drain. Figure 3 illustrates the profile view of the calibrated model. There are two sections in risk of flooding, section 1 and section 2.

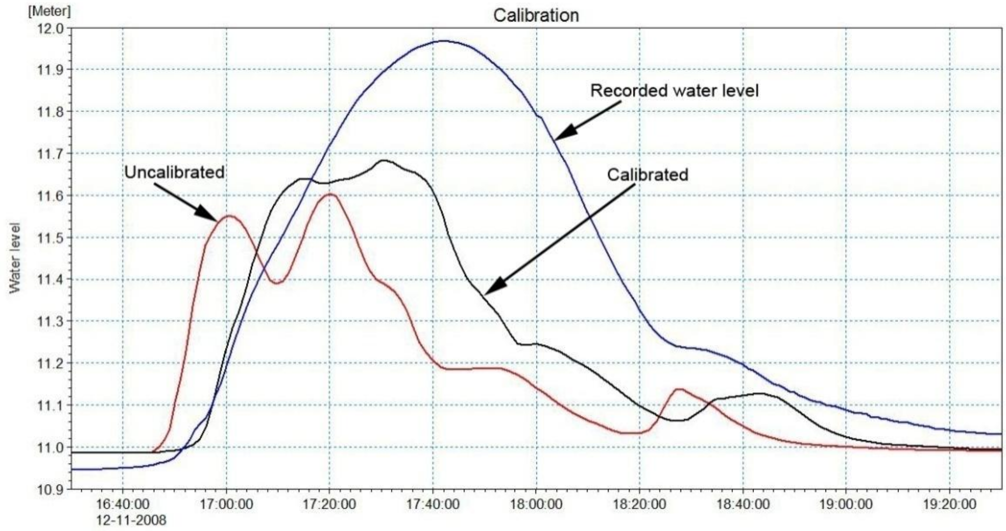

Figure 2. The graph illustrates the final calibrated, un-calibrated and recorded water level after the rainfall event on the 12th of November 2008. The calibrated water level is still simulated too low. Several attempts have been made to increase the water level and at the same time do realistic changes, but this did not improve the performance of the calibration. The location of the water level recorder can be seen in figure 1.

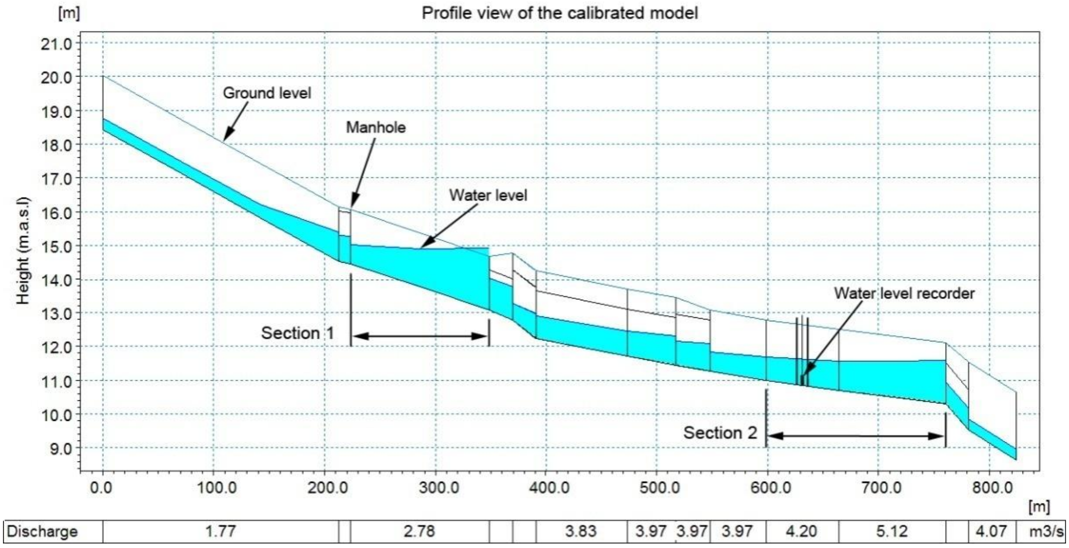

Figure 3. The figure shows a profile-view of the main channel in the drainage network. The profile shows the maximum water level after the rainfall on the 12th of November 2008.

The results in scenario 1 show a small impact of increased precipitation on the drainage system. Even with an increase of 10% precipitation the system has the capacity to hold the water, with the exception of section 1 where the water level is above ground level. However, this section is sensitive in all scenarios. Roughly, the percentage of increase in precipitation is equivalent to the percentage of water level increase of the peak.

In scenario 2, when increasing the external water level, there is an increase in section 2 and it is limited to the low-lying parts of the drainage network. If there is flooding in this section the water will most likely be transported by overland flow to the river Sungai Senai. Section 1 is still subject to flooding, of the same magnitude as the calibrated simulation.

The suggested changes in scenario 3 result in a lowering of the water level. The increased dimensions lead to lower water levels in both section 1 and 2, making flooding no longer a problem. The changes are not intended to take place in the near future. Other solutions such as detention reservoirs are planned to be constructed. This detention can lower the water level in river Sungai Senai and keep the external water level in the study catchment low.

In scenario 4 the catchment area is increased in the western part of the catchment. This results in severe flooding in section 1. The water is likely to be transported overland towards downstream drainage sections due to the topography around section 1. However, if there is an exploitation of Senai Town to the west of the original catchment area, the runoff will most likely be discharged outside the catchment in a South-West direction due to the topography.

Discussion

The amount of impervious surfaces has a big impact on the result in the model and having access to such accurate data makes the model more reliable. However, such information was not available and an interpretation from an aerial photo was made which results in a less accurate determination of the amount of impervious surfaces.

It is possible to simulate sediment transport, however in this model it is difficult to take into consideration. In addition, the impact of sediment, garbage and litter in the drains are assumed to have a small effect of the out coming result and were therefore neglected in the model.

Evaporation was neglected in the model because it is assumed to have a small effect on the result as the runoff is generated from impervious surfaces where the evaporation is smaller than the soil evaporation.

The rain gauge was placed close to the catchment area. Our own observation during the time in Malaysia is that local rainfalls are very common during this time of year, which could have given incorrect rainfall measurements. This could be one of the reasons why the calibration could not be performed with better match between the simulated and recorded water level.

Two water level recorders were placed in the drain in section 1 and section 2, see the sections in Figure 3. Unfortunately the recorder in section 1 was stolen and no recordings were retrieved from this recorder. Access to data from the stolen recorder could have improved the results of the calibration. Recordings of the water level in the river Sungai Senai would have made it easier to estimate the backwater effects in section 2. This could also have been added in the model as a varying external water level. If the recording time of rainfall and water level had been longer, more rainfall events could have been obtained. This could have resulted in a larger number of useful rainfall events for calibration and possibly also a validation of the model.

Conclusion

Two sections are risk of flooding with today's situation. The problem is associated with open drains with big dimensions that are connected to downstream underground drains with too small dimensions, creating backwater effects. This problem occurs especially in section 1 and 2, where large amounts of water are built up.

- Climate changes in form of increased rainfall intensity have small effects on the water level in the sensitive parts, sections 1 and 2. Neither does it have a considerable effect on the overall drainage system. The water level increased roughly with the corresponding percentage increase of rainfall intensity in section 2.

- Increased external water level of +2 m has a large effect on the water level in section 2. The backwater effect due to this external water level increase is not transferred up to section 1.
- The suggested changes by the consultant in the Drainage Master Plan improved the system's capacity. The water level decreased significantly in sections 1 and 2.
- An increase of the catchment area will raise the water level significantly in section 1, which can cause flooding in the nearby houses. The risk of the flooding to spread is limited by the topographical situation that will lead the water to downstream drainage with larger water transporting capacity.

None of the scenarios indicate any additional areas in risk of flooding in the future. The flooding problems are limited to sections 1 and 2.

Acknowledgements

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