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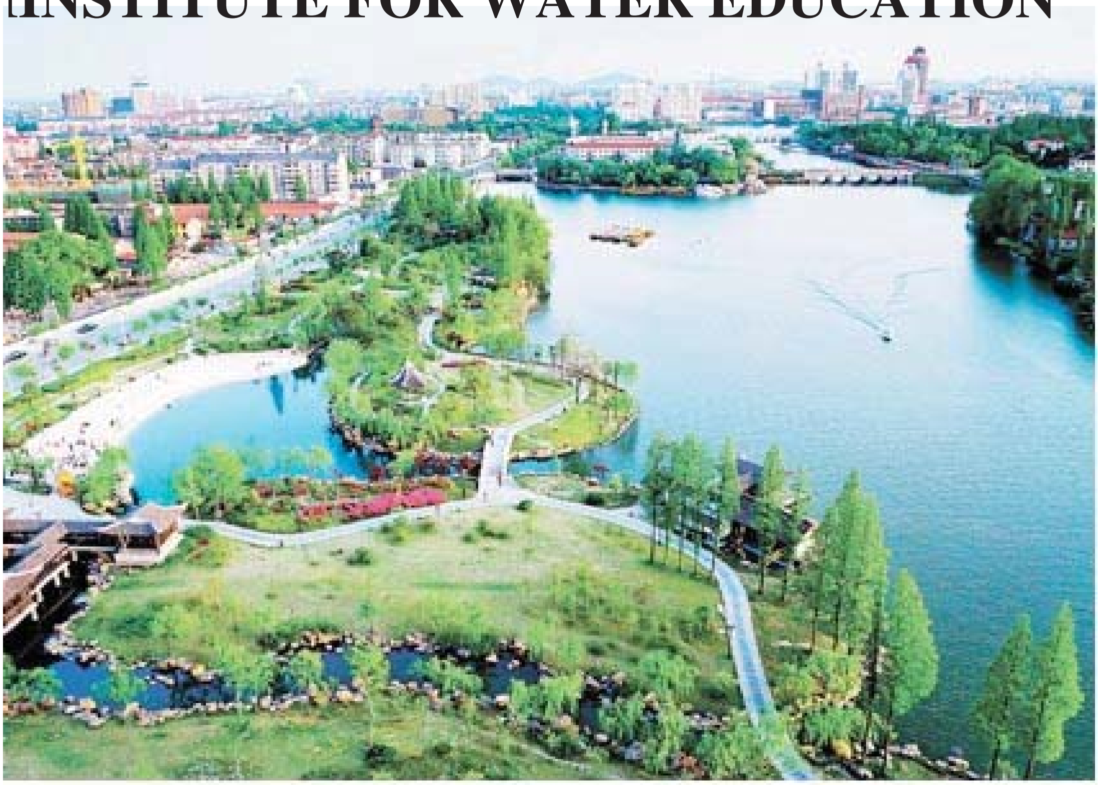

INTEGRATED URBAN WATER MANAGEMENT MODELLING AND STRATEGIC PLANNING

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MSc Thesis (WSE-HI.08-03)
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Institute for Water Education

SWITCH

Integrated Urban Water Management: Modelling and Strategic Planning

Master of Science Thesis
By

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Abstract

Historically the different parts of the urban water system were covered by different responsibilities and assessed separately. Recent years, urban environment became more complex than ever before Under this situation, urban areas are appropriate as units of management, as specific problems and needs faced by cities may transcend the physical and scientific boundary embodied by more traditional units of management of catchments and watersheds. Integrated Urban Water Management is emerged as the trend requires.

In such complex urban environment, modelling tools are expected to describe the complex water-related interactions and assist management to develop strategies. This MSc research work focuses on testing the potential usability of CITY DRAIN model for IUWM purposes as a simplified (conceptual) model.

The CITY DRAIN model for this research is developed on the basis of Ljubljana city, the capital of Slovenia, and four questions have been discussed around the case which are how good the sewer component of the CITY DDRAIN model's performance can be compared to a detailed model built in MOUSE, how the CITY DRAIN model represents flooding conditions, how CITY DRAIN model works on the strategic level and how CITY DRAIN model works as a integrated modelling. During the research period, a representative of detailed models, MOUSE (DHI), is invited to evaluate the CITY DRAIN model's performances especially for the sewer part.

Key words:

CITY DRAIN, MOUSE, simplified model, detailed model, conceptual model, Integrated Urban Water Management

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IUWM: Integrated Urban Water Management

IUWS: Integrated Urban Water System

IUWM: Integrated Urban Water Modelling

CD: CITY DRAIN

CSO: Combined Sewer Overflow

WWTP: Waste Water Treatment Plant

1. Introduction

1.1 Background information

Water is vital to this world for sustaining life and development of society, proper management and protection is a challenge for urban water management nowadays imposed by growing population and expansion of urbanization; especially in developing countries the situation is more serious. On the other hand, urban water is a complex field, which includes provision of safe water supply and sanitation, sustainable use of water resources, pollution control, storm water and wastewater network management and flood prevention. Working with complex systems such as urban water systems requires a wider knowledge than just knowledge of a particular component of the urban water cycle.

In this complex urban water environment, Integrated Urban Water Management (IUWM) as a new concept of management has emerged with the common recognition that an integrated approach to water management at the urban level offers a relevant framework for decision-making and concrete action. It refers to the practice of managing freshwater, wastewater, and storm water as links within the resource management structure, using an urban area as the unit of management (Figure 1). Urban areas are appropriate as units of management, as specific problems and needs faced by cities may transcend the physical and scientific boundary embodied by more traditional units of management of catchments and watersheds.

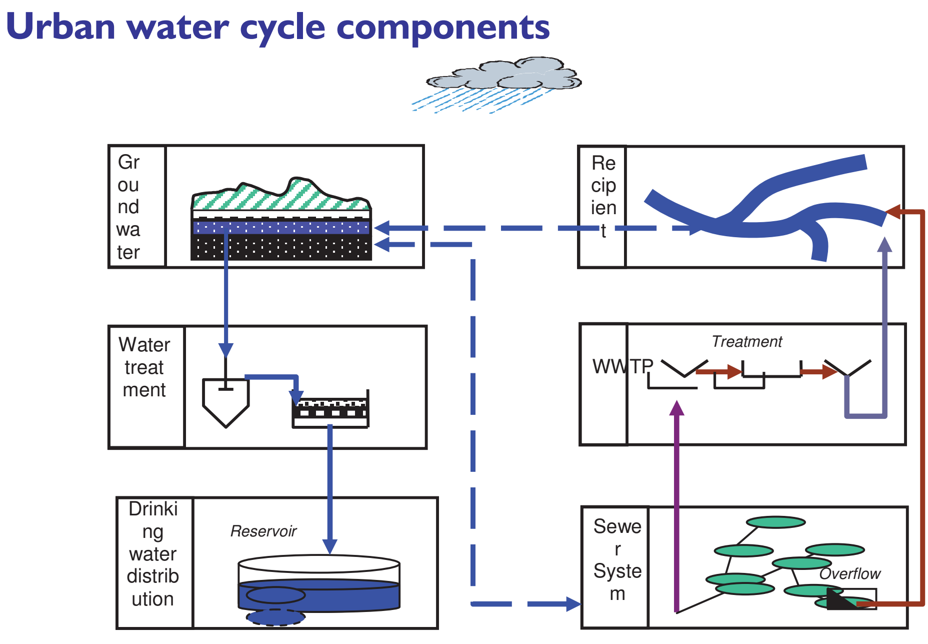


Figure 1 Schematisation of the urban water cycle and interactions between different components.

As a tool, the use of computer models pervades all aspects of water management. Traditionally, different part of the urban water cycle are replicated by using of models and assessed separately from each other, limitations are induced such as, inadequate understanding of interaction between different urban water parts. Along with the emergence of IUWM, integrated modelling is required. Integrated modelling is defined as modelling of the interaction between two or more physical systems having different characteristics. It can be used as a strategic level modelling tool for different scenario analysis and to describe the complex water-related interactions.

The shift towards the integrated modelling systems comes on one hand because of the need to manage urban water cycle on a holistic basis and on the other hand because of the advances in urban Hydroinformatics technologies which have enabled the modelling of different phases of the entire cycle and their optimisation them globally.

1.2 Problem definition

Typically, two types of models are used: *simplified* (or strategic) and *detailed* ones. Simplified models are normally used for strategic planning purposes, whereas, detailed models (e.g., sewers, treatment plants and receiving waters) are needed to describe the system's performance according to the specific local needs and objectives.

Although the basic principles are known, the development of integrated models still is a challenging task. The main bottleneck is the complexity of the total system that prevents a simple linkage of the existing physically based models of the individual subsystems to an entity (Rauch et al, 2001). Another problem encountered when creating an integrated model is that the existing models are quite complex and require sophisticated integration algorithms to solve them. This results in long calculation times, making these models impractical to use, especially within optimisation problems where a lot of simulations need to be performed.

Model integration can also in practice be difficult for many reasons related to data formats, compatibility of scales, ability to modify source codes, etc. To overcome such difficulties, there are attempts by commercial software companies to develop the links between different detailed physically-based models (Moore et al, 2004) to enable development of integrated modelling. However, efforts in instantiating such models and their linking and running, which usually takes a substantially long period of time, is far too impractical for strategic planning purposes where simulation of different scenarios in a short time and optimization are required.

Therefore what is needed is the ability to undertake a holistic analysis of the urban water cycle by setting up relatively simple models with reasonable accuracy. Implicit in this is a requirement both to understand and to be able to model not only the individual urban water processes but also their interactions in a relatively simplified modeling framework.

Several researchers have attempted to respond to the challenge of developing simplified integrate modelling. For example, the wastewater side of urban water cycle, which

involves interaction between the sewer system, treatment plant and recipients has been described by integrated urban wastewater modelling tools such as KOSIM-WEST (Solvi et al, 2005), SIMBA (Freni et al, 2003), Cosmos (Calabro, 2001) and CITY DRAIN (Achleitner et. al. 2007).

CITY DRAIN is a open source software for integrated urban drainage modelling, which developed in the Matlab/Simulink environment, enabling a block wise modelling of the different pasts of the urban drainage system (sewer system, WWTP, receiving water). Aim was to create a tool that provides simplicity in handling and a certain flexibility allowing coping with different situation and scenarios. It is avoid introducing unnecessary complexity in the implemented models, where the user is allowed to extend or modify models according to the specific needs.

✓ ***Can CITY DRAIN models perform for IUWM as simplified (conceptual) model instead of physically-based model?***

In urban drainage modelling area, for the description of flow conditions, two general approaches have been used, physical-mechanistic model or by a conceptual model.

Physical- mechanistic models are based on continuity (mass balance) equations as well as on the preservation of Energy or Momentum. Empirical relations are introduced for calculation of e.g. friction losses. Using physically based model enables to deal with back water effects. A disadvantage l is the high computational effort that limits its application for predominantly short simulation periods. MOUSE model is the typical physicall based model.

For a conceptual (hydrological) model continuity equation applies as well. Physical relations are described by conceptual relations mostly using simple descriptions of cause and effect relations. Therefore, conceptual models are significantly less demanding in computational effort. CITY DRAIN model is one of the representatives.

It is a fact that physically based models can describe the sewer component of urban drainge system individually more accurate than conceptual model. However, integrating physically based models is a challenge task, due to various types of data requirements, different formats of results file, connection ports differ from one to others, are unavoidable gaps. If conceptual model results could close to physically based model results, the use of such conceptual model would be beneficial for strategic planning. Some other advantages are less data requirement and short computational time.

In summary, the dominative problem is that results of conceptual models have relatively lower reliabilities when compared to physically-based models. The present research addresses the problem by comparing the performance of MOUSE (as a typical physically based model) and CITY DRAIN (as a typical conceptual model for modelling urban water processes).

1.3 Objective of the present study

The main objective of thesis work concerns the integrated conceptual modelling concept and its capabilities to replicate the functioning of a physically based model.

The research objectives can be divided into two parts.

Primary objectives

- Evaluate the use of a conceptual (i.e., CITY DRAIN) model (sewer component) for urban drainage modelling
- Research the potential use of conceptual models for strategic planning purposes
- Improve CD's ability to better represent flooding conditions.

Secondary objective

- Apply the CD model for integrated wastewater modelling on a case study

1.4 Methodology

The methodology applied in this MSc research work can be summarised to the following tasks:

- **Familiarisation the CD model**

To manipulate the software and understand the basic mechanism is vital to the whole research. The course consists with two parts; the first part is also the part of literature review, to review on Integrated Urban Water System components, the modelling process. After that, putting real hands on the software and build up model is the second part.

- **Develop MOUSE model for a case study**

In order to testify the potential usability of CITY DRAIN model, during the period of research, MOUSE model (physically based sewer modelling) is used to generate data for calibration and verification of the CITY DRIAN model(conceptual model), because MOUSE model is a qualified detail (physically-based) model specializing on the sewer system. The thing has to do is recalling all knowledge from past and build model according to the data collected from real system.

- **Calibrate CD model**

Conceptual models represent the hydrological processes that are important in the system using simplified conceptual representation. The hydrological properties are represented as parameters. These parameters have no direct physical meaning and are not directly measurable. These model parameters are usually estimated via calibration.

- **Development an integrated wastewater model in CITY DRAIN**

The model is verified will be connected with block of WWTP in CITY DRAIN model. The purpose of this development is to testify the potential usability of CITY DRAIN as an integrated modelling.

- **Re-calibrate a representative model for flooding condition**

One catchment will be selected out from the previous model, built up with retention basin and recalibrated, for the purpose of evaluat the sensibility of CITY DRAIN model for flooding condition.

- **Scenarios analysis for strategic planning**

Running the flooding condition modelling with different scenarios is the task of this stage, which are the potential challenges in the front of Integrated Urban Water Management.

  - ✓ Urbanizations (change of impervious area)
  - ✓ Increase of population
  - ✓ Climate change (rainfall event)

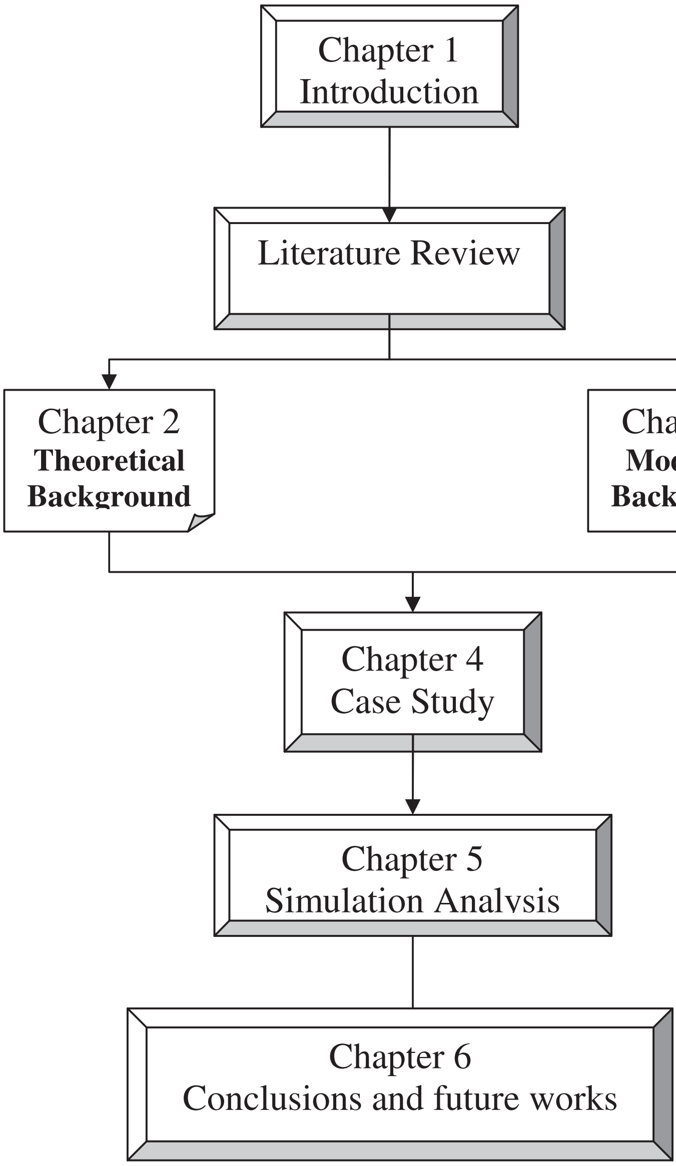
- **Discuss the results**

Analysis of the results and conclusion on how CITY DRAIN model performs

- **Write the thesis**

1.5 Outline of the thesis

The thesis has been divided into 6 chapters and the hearts of the thesis are chapter 2, 3 4 and 5.



Chapter 1	Introduction of Integrated Urban Water Modelling and research objectives
Chapter 2	The theoretical background of research area
Chapter 3	CITY DRAIN model introduction (modelling background)
Chapter 4	Case study
Chapter 5	Discussion of all simulation results
Chapter 6	conclusion and future works

2. Integrated Urban Water System

2.1 Components of urban water system

Collecting water: The entire area from which a stream or river receives its water is called a catchment. A catchment is a natural drainage area, bounded by sloping ground, hills or mountains, from which water flows to a low point. Virtually everybody lives in a catchment, which may include hundreds of sub-catchments. What happens in each of the smaller catchments will affect the main catchment. The water that comes out of a tap once flowed across a catchment - and that is why catchments are a crucial part of urban water systems. The quality of the catchment determines the quality of the water harvested from it. Few communities have pristine water sources and the quality of water from most sources is at risk from activities occurring in the catchment.

Storing water: In some urban water systems, the water supply is obtained directly from a river or another body of freshwater. In others, rivers are dammed and the water supply is distributed from artificial storages, such as reservoirs. Dams are built across rivers and streams to create reservoirs to collect water from catchments to ensure sufficient supply will be available when needed. Dams also have been built for a range of purposes besides water supply, such as agriculture and hydro-electricity generation. Water may also be released from a reservoir as an "environmental flow" to maintain the health of the ecosystem downstream of the reservoir. It is estimated that the significant reservoirs built around the world store five billion mega-litres of water.

Transporting water: Water is transported from catchments to communities by a variety of means including pipelines, aqueducts, and open channels or via natural waterways.

Treating water: Water that is to be used in an urban supply is treated to remove sediments and contaminants and is also disinfected to kill potentially harmful micro-organisms. The treatment process may use conventional technologies or apply newer, innovative approaches, to ensure the water is safe and pleasant to drink.

Supply the distribution system: The water mains and pipes beneath the streets of a community are described as the water supply distribution system or reticulation system. As part of this system, strategically located service reservoirs store and supply enough water to meet local peak demand at sufficient pressure. These service reservoirs are often large covered tanks in an elevated position. Pumps and valves also form an important part of the distribution system. The end points of the system are the consumers' taps.

Managing wastewater: Urban wastewater is known as sewage, and the pipes that transport sewage are called the sewerage system. No matter where you use water inside your home - the kitchen, bathroom, laundry or toilet - it is discharged to the sewer. From there, your wastewater begins a journey through a series of sewer pipes, pumps and mains to a sewage treatment plant. Wastewater from industry, schools, shops and other sources is also discharged to the sewerage system. At sewage treatment plants,

wastewater is treated in a way that mimics natural biodegradation processes. After intense treatment, the treated wastewater is discharged back into the environment. Wastewater is treated to protect public health and to minimize impacts on the ecosystems of receiving waters. Treated wastewater is increasingly being recycled or reused in agriculture, horticulture, golf courses and other businesses. A number of innovative housing developments are using dual water supply systems where recycled wastewater is supplied for some domestic purposes such as garden watering and toilet flushing, while conventional drinking water is supplied for other household uses.

Water recycling: Where homes and businesses are not connected to a sewage system, they will usually have some form of on-site treatment of sewage. Such on-site treatment needs to include provision for the safe discharge of the treated sewage into the local environment to protect both public health and local ecosystems. The septic tank is a common form of domestic on-site treatment.

Managing storm-water: Storm-water is the term used to describe the runoff from rain over an urban catchment. In cities and towns, storm-water washes across roads and streets, picking up oil, petrol, grease, sediment, industrial waste, leaf and other litter and dog droppings on roads, streets and paths. In rural areas, runoff may include agricultural and livestock waste, fertilisers and pesticides. Storm-water can also be contaminated by landfill leachate, septic tank effluent, sewer spills and by illegal dumping. It is estimated that contaminated storm-water causes up to half the pollution in surface and groundwater sources. In recent years, water authorities have begun to explore the use of urban wetlands to reduce the amount of sediments and soluble contaminants in urban runoff. (CRC, 2008)

2.2 Sewer system

The sewer system is responsible for the transportation of the wastewater from the households to the wastewater treatment plant. It is a part of the integrated urban wastewater system, which is also comprised of the wastewater treatment plant and the receiving waters. Artificial drainage systems are being developed since ancient times. Examples can be found in many ancient civilisations: the Mesopotamian, the Minoan (Crete), the Greeks (Athens) and the Romans. The ‘cloacae maxima’, the ancient drainage, built in the 6th century b.C., to drain the ‘Forum Romanum’ is still in use (Butler and Davies, 2000). The concept of modern sewer systems was born in the 19th century due to hygienic reasons. The cholera epidemic, directly connected to the inadequate sanitation in European cities, was the trigger for the construction and development of urban sewer systems (Ashley *et al.*, 1999; Harremoës, 1997). After the resolution of the hygienic issues, by means of the construction of underground pipes for the transport of the wastewater, the core issues of the urban drainage were the protection of the population from flooding and of the receiving waters from the anthropogenic impacts (Rauch *et al.*, 2002b).

The sewer system, as described previously, is considered a part of the integrated urban drainage system (Figure 2). The concept of integrated urban drainage has gained increasing importance in the last years aiming at the optimisation of the drainage system. The integrated consideration of all parts of the system simultaneously allows better optimisation possibilities.

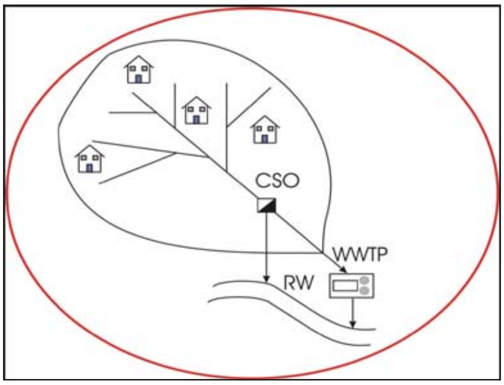


Figure 2: The integrated urban drainage system. RW = receiving water, WWTP =wastewater treatment plant, CSO = combined sewer system.

Generally, there are two main types of urban drainage system: the combined sewer system and the separate one. Very often there is a third one, which is a mixture between the two, in which the old part of the town, is served from the combined sewer system and the new one from the separate.

Two pipelines exist in the separate sewer system (Figure 3)**,** the storm sewer, which only carries, like its name says, the storm-water and discharges it (with or without treatment) to the receiving water, and the foul sewer, which carries only the sewage to the wastewater treatment plant. There, the wastewater is purified and discharged to the receiving water.

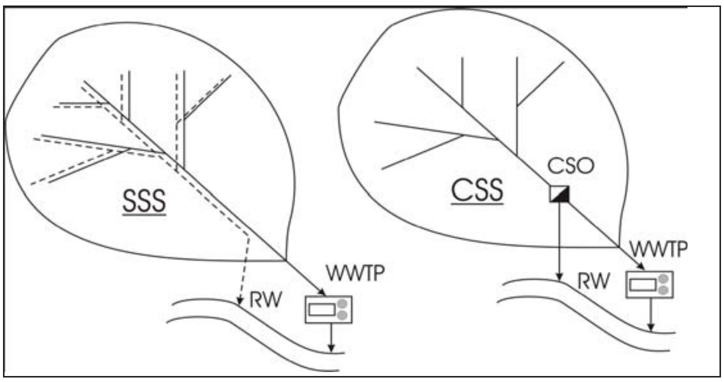


Figure 3: Schemes of the separate sewer system (SSS) (left) and combined sewer system (CSS) (right). RW = receiving water, WWTP = wastewater treatment plant, CSO = combined sewer system.

In the combined sewer system (Figure 3), the same pipeline carries both storm-water and sewage (also called dry weather flow) directly to the wastewater treatment plant. Due to economic reasons, it is difficult to treat a large amount of storm-water at the plant. The sewer system is therefore designed to transport only a part of the storm-water (normally 2-3 times the dry weather flow). In case of heavy rain, the storm-water in the sewer will exceed this amount; this excess water needs therefore to be discharged to a receiving water body. The structure responsible for this action is the combined sewer overflow (CSO).

The question 'which system is better?' has been vigorously discussed since decades. The answer is case specific. The first modern sewer systems were constructed in the middle of the 19th century in Europe and were combined systems. Main reasons for this choice were the fact that: 1) there were no European examples of successful separate systems, 2) there existed the belief that the combined systems were cheaper to build and 3) engineers were not convinced that agricultural use of separate sanitary wastewater was viable (Burian *et al.*, 1999). The first separate sewers were built in the USA at the end of the 19th century on the basis of the consideration that they can transport the sanitary wastes faster, preventing the formation of gases. In 1880 an American engineer, was sent to Europe in order to investigate the drainage systems. He suggested the use of combined systems in large or rapidly growing cities and separate systems for areas where rainwater did not need to be transported under the ground. This implies, that a large part of urban areas in the US, were served from combined systems. This philosophy dominated till the 1930s, when many more wastewater treatment plants were required, causing high costs. Due to this situation, American engineers started to suggest separate sewer systems (Burian *et al.*, 1999).

Starting in the 1950s, in Europe and in the USA, the increased environmental awareness led to considerations as regards the effect of the urban drainage on the receiving waters. The combined sewer overflows were considered the main cause of degradation of the receiving waters (Burian *et al.*, 1999; Butler and Davies, 2000). Due to this fact, in Europe the separate sewer started being suggested for the construction of new systems (Butler and Davies, 2000). In the USA a big CSO reducing campaign started, which suggested many different CSO reduction solutions. An example is the sewer separation, i.e. the adaptation of the old combined system into a separate one (US EPA, 1999), which is an expensive solution. In Europe the theory of sewer separation was adopted only in some regions due to the high costs related. Currently, there is a re-evaluation of the combined sewer system because it was demonstrated that the impacts on the receiving waters caused from the separate system can also be notable (Burian *et al.*, 1999; Sieker, 2003).

Based on the two main drainage types, there are numerous cases in which the different wastewater streams are further separated, e.g. urine separation and separate treatment of storm-water. Such methods, based on the separation of the streams, are called source control measures, or sustainable urban drainage. Their aim is to reduce the pollutants entering the sewer from the source. A classic example is the infiltration of storm-water. In this case, the sewer system is less hydraulically charged because of the fact that an

amount of storm-water is directly diverted to the groundwater. This method is often used in case of enlargement of the urban settlement; the old sewer cannot carry all the storm-water coming from the new impervious area added and consequently the uncontaminated surface water is infiltrated.

The enlargement of the urban settlement causes indeed an improvement of the rain runoff, i.e. the overland flow. In rural conditions, the rain can infiltrate easier, the trees can catch part of the rain, the overland flow resulting is smaller and the peak is reached later. In an urban catchment, the streets, parking lots, roofs do not catch the rain but also favour the flow, so that the peaks of runoff are higher and earlier. This fact causes more unexpected peaks in river flow and introduces pollutants in the receiving waters (Butler and Davies, 2000).

The pollutants, transported in the sewer system have two main sources: the human excrements (urine and faeces) and the anthropogenic environment (e.g. industry, traffic, atmospheric pollution etc.). Because of that, the pollution in the sewer system should also be divided in the two main streams, the storm-water and the foul water.

The pollutants in the storm-water are influenced by the rainfall and the catchment characteristics. Typical catchment sources are vehicle emissions, abrasion of tyres and brakes, animal faeces, street litter, de-icers (from the winter maintenance), fallen leaves, grass residues, and atmospheric pollutant wash-off, deposited on the streets. Further, a part of pollutant comes from the atmospheric wash-off, and enters the sewers directly with the rainfall. Main pollutants in the storm-water are heavy metals, but organic matter can also be found due to the street wash-off.

The main pollutant in the foul water is the organic matter, which can be quantified with the parameters BOD5, P, N. Further pathogens and micro-pollutants can be contained in the wastewater, but they are not considered in this work. Other pollutants are the gross solids, which are responsible for aesthetic problems caused by combined sewer overflow and can also favour the clogging.

The main impact from the urban drainage system on the receiving water is caused by the combined sewer overflow and the storm-water discharges (Sieker, 2003). Modern wastewater treatment plants have achieved a high standard, so that their impact on the receiving water is normally negligible compared to the impacts of direct discharges in wet weather conditions. Under these conditions the rain plays a major role due to its influence on the direct discharges.

The rain is the main input for the simulations of the sewer system. The rain causes pollution load not only from the combined sewer overflow (Sieker, 2003) but also from the outflow of the treatment plant, which can decrease among others the oxygen concentration in the receiving waters (Rauch and Harremoës, 1996a).

2.3 Integrated Urban Water Management

Integrated Urban Water Management is a hot topic was born in the end of last century and has been developed fast in the last years

The Integrated Urban Water Management (IUWM) refers to the practice of managing freshwater, wastewater, and storm water as links within the resource management structure, using an urban area as the unit of management. Activities under the IUWM umbrella are extensive and include the following:

- Improve water supply and consumption efficiency
- Ensure adequate water quality for drinking water as well as wastewater treatment
- Improve economic efficiency of services to sustain operations and investments for water, wastewater, and storm-water management
- Utilize alternative water sources, including rainwater, and reclaimed and treated water
- Engage communities to reflect their needs and knowledge for water management
- Establish and implement policies and strategies to facilitate the above activities
- Support capacity development of personnel and institutions that are engaged in IUWM

The IUWM approach has emerged from the growing recognition that an integrated approach to water management at the urban level offers a relevant framework for decision-making and concrete action. Urban areas are appropriate as units of management, as specific problems and needs faced by cities may transcend the physical and scientific boundary embodied by more traditional units of management of catchments and watersheds. The concept encompasses various aspects of water management, including environmental, economic, technical, political, as well as social impacts and implications.

The IUWM field focused on the integrated management of technical aspects of water services. This is a new field that has emerged as a direct result of conclusions drawn by international and local agencies that sanitation, waste disposal, urban storm-water and runoff, water reticulation, etc. can not be considered to be standalone issure as they have in the past.

In the IUWM approach consideration is given to the collective impact of all possible water-related urban processes (of which the management of human excreta or sewage is only one) on issues such as human health, environmental protection, quality of receiving waters and urban water demand. Individual processes are then planned and managed in a way that the collective impact, with due consideration of interaction among processes, is optimised as far as possible.

2.4 Modelling of Integrated Urban Water System

2.4.1 Need for Integrated Urban Water System modelling

First of all, challenges facing urban planners and governments continue to mount as populations in urban areas increase, pressure on the world's resources reaches critical levels and degradation of ecosystems around the world becomes increasingly apparent. The movement towards sustainable development has been met with enthusiasm by decision-makers, although exactly how to achieve this target, or even measure progress towards it, is not entirely evident.

On the other hand, the urban water cycle is currently managed as separate centralized water supply, wastewater and storm-water disposal processes that have endured for over 100 years. The infrastructure costs, water quality and environmental concerns associated with continuing with the current urban water cycle paradigm are increasing to unsustainable levels. It is argued that a systems approach is required to understand and hence find optimum solutions for urban water cycle management that includes decentralized approaches used to supplement to current centralized management methods.

Meanwhile, there is an increased attention on integrated analysis of sewer network, wastewater treatment plant (WWTP) and receiving waters. Its objective is to derive new strategies for an ecologically and economically optimised protection of receiving waters. Simultaneous numerical simulation of discharges from the sewer network and the WWTP is necessary if interactions between the subsystems are important and/or if integrated control is to be investigated.

2.4.2 Available tools for Integrated Urban Water Modelling

KOSIM-WEST

A combined model implemented the KOSIM hydrological catchment runoff and sewer transport model into WEST. WEST is a modular dynamic modelling tool for Waste water treatment engineers and other professionals who want to simulate processes in wastewater treatment plants or any places where physical, biological or chemical processes take place in water. The mathematical expressions inside KOSIM are recursive discrete time step equations (ITWH, 2000) which have been transformed into the underlying ordinary differential equations so that they can be numerically solved by the solvers contained in WEST. Modelled variables are water, soluble and particulate COD, ammonia and orthophosphates. The model blocks currently available are catchments (for runoff and dry weather generation), collectors (for transport) and basins (for retention). Pollutant loads are modelled as the sum of a daily concentration pattern for dry weather flow plus a constant load from surface runoff of rainwater. However, in order to take into account first flush concentrations, linear accumulation and exponential wash-off (Ashley *et al.*, 2004) of particulate COD were added as an option.

SIMBA - simulation of wastewater systems

The SIMBA simulation system allows the holistic consideration of sewer system, wastewater treatment plant, sludge treatment and rivers. All components necessary for a thorough analysis of the constituent subsystems, including their interactions, are now available within the same simulator. SIMBA can be applied for a large variety of tasks in engineering practice and in research and education. This range from plant and process design to analysis and operational optimisation of operation of urban wastewater systems. Also interactions of runoff, wastewater treatment and river water quality for scenarios with and without control can be analysed using SIMBA. SIMBA is shipped together with the Matlab/ Simulink software of MathWorks Inc.; it runs under the Windows 9x, NT 4.0, 2000 and XP operating systems.

2.4.3 Concerned tool for the research

MOUSE

MOUSE is an advanced, powerful, and comprehensive surface runoff, open channel flow, pipe flow, water quality and sediment transport modelling package for urban drainage systems, storm water sewers and sanitary sewers. MOUSE combines complex hydrology, hydraulics, water quality and sediment transport in a completely graphical, easy-to-use interface. MOUSE is a 32-bit Windows application specifically designed to operate within Microsoft Windows and Windows NT, and is optimized for fast simulations and graphics. Both metric (SI) and imperial (US customary) units are supported.

MOUSE owes its exceptional power to the advanced software implementation techniques, the efficient algorithmic formulations and the application versatility. And finally, it is the reliability of MOUSE, tested and proven in great many applications since the late 70s by more than one thousand users all around the world, which makes MOUSE the perfect choice.

Typical applications of MOUSE include studies of combined sewer overflows (CSO), sanitary sewer overflows (SSO), complex Real Time Control (RTC) schemes development and analysis, design of new site developments, regulatory consenting procedures and analysis & diagnosis of existing storm water and sanitary sewer systems.

The MOUSE system is organized in several modules, this report concerned are:

- MOUSE Runoff: surface runoff models for urban catchment applications;
- MOUSE HD: hydrodynamic network model with some limited options of flow regulation;
- MOUSE RDI: advanced hydrological model for continuous simulation;

MOUSE Surface Runoff Module

The MOUSE Surface Runoff Module includes five types of surface runoff computation and three hydrological levels for the description of the urban catchment surfaces. This means that the surface runoff computations can be adjusted according to the amount of

available information. The models run with well proven default hydrological parameters, which can be adjusted for better accuracy. The computed hydrographs are used as input to the MOUSE Pipe Flow model.

MOUSE Pipe Flow Module (HD)

MOUSE Hydrodynamic Pipe Flow Model (HD) solves the complete St. Venant (dynamic flow) equations throughout the drainage network (looped and dendritic), which allows for modelling of backwater effects, flow reversal, surcharging in manholes, free-surface and pressure flow, tidal outfalls and storage basins. The program has been designed to handle any type of pipe network system with alternating free surface and pressurized flows as well as open channel network.

The computational scheme uses an implicit, finite-difference numerical solution of the St. Venant flow equations. The numerical algorithm uses a self-adapting time-step, which provides efficient and accurate solutions in multiple connected branched and looped pipe networks. This computational scheme is applicable to unsteady flow conditions that occur in pipes ranging from small-profile collectors for detailed urban drainage, to low-lying, often pressurized, sewer mains affected by varying outlet water levels. Both sub-critical and supercritical flows are treated by means of the same

MOUSE Rainfall Dependent Infiltration Module

The Rainfall Dependent Infiltration (RDI) Module provides detailed, continuous modelling of the complete land phase of the hydrologic cycle, providing support for urban, rural and mixed catchments analyses. Precipitation is routed through four different types of storage: snow, surface, root zone and ground water, resulting in more accurate hydrographs. Instead of performing hydrological load analysis of the sewer system only for short periods of high intensity rainstorms, a continuous, long-term analysis can be used to look at periods of both wet and dry weather, as well as inflows and infiltration to the sewer network. This provides a more accurate picture of actual loads on treatment plants and combined sewer overflows.

3. CITY DRAIN

3.1 Dominant processes and complexity of models

3.1.1 Principals

Software for integrated modelling may incorporate a variety of models covering hydraulics, mass transport, processes for conversion of matter etc. within the subsystems. Main objective is the prediction of the system performance including the receiving water quality. For choosing the appropriate models it is therefore vital to characterise the impacts onto the receiving water with regard to their type (hydraulic, chemical, bio-chemical, etc.) and duration (e.g. acute, delayed, and accumulating).

Regarding the time scale for modelling not only the dynamics of the relevant processes in the drainage system itself are to be considered but also the duration of the impacts (and associated processes) in the receiving waters. E.g. acute pollution occurs instantly and requires short term modelling whereas accumulative effects in the receiving water can only be covered within a long term simulation effort. But also the stochastic nature of rainfall as the source of impacts in an urban catchment needs to be considered. Single rain events are often source for acute effects in the receiving water such as hydraulic stress or pollutants entering the receiving water. The assessment of those is based on an evaluation of frequency, magnitude and duration of the impact, and thus requires a statistical interpretation. This again is possible only within the framework of long term simulation studies.

Overall the computation in CITY DRAIN is based on an fixed discrete time steps approach where each subsystem uses the same time increments, usually being predetermined by the temporal resolution of the rain data used. Models implement for hydraulics and mass transport are formulated for discrete time stepsΔt.

3.1.2 Computational aspects for hydraulics

Flow of water in both sewers and rivers is described by the continuity and momentum equations. The latter is known as the Navier-Stokes or Reynolds equation. The actual form of a hydrodynamic model depends on assumptions made on characterizing turbulence but for water quality purposes mostly the well-known, cross-sectional integrated (one-dimension) Saint Venant equations or approximations to these equations are used. Different levels of simplifications of the momentum equation are known for describing unsteady flow. Most simple approximation is the kinematical wave model being valid where backwater effects are negligible. All hydrodynamic equations have in common that they are demanding from a computational point of view. Therefore a variety of simpler conceptual models where developed (frequently denoted as hydrological models). These as well respect conservation of mass but use conceptual relations instead of momentum equations. The rapid simulation with conceptual models puts them in favour to hydrodynamic models regarding computational effort. Effects such as

pressurized flow or backwater effects cannot be covered. For allowing long term simulations the blocks implemented in CITY DRAIN are based on purpose on simple conceptual models for hydraulics.

3.1.3 Computational aspects for transport and conversion of matter

For limiting the effort of simulation only relevant pollutants and processes need to be considered. Neglecting issues of secondary importance is required to avoid unnecessary complexity of models. Transport models describe in principle only the flow of soluble and conservative matter through the system. Effects such as physical or biological conversion processes (sedimentation, degradation, etc.) are considered by extension of the transport equations.

3.2 Implement models

Basic idea was to create an open source toolbox for integrated modelling of urban drainage systems. For the use in the daily engineering work such software tools are required to be simple in handling and to provide a certain flexibility to be adjustable for different scenarios. Different subsystems should be freely arrangable and connectible to each for describing an integrated urban drainage system and the fluxes of water and matter.

3.2.1 Software platform Simulink

The principle of block-wise modelling of integrated systems in CITY DRAIN has been developed in a Matlab/Simulink environment. The platform is widely used for all different kinds of dynamic simulations and was found suitable as hosting environment for the CITY DRAIN software. On the one hand the platform is tailored for dynamic and time dependent simulations, on the other hand a graphical user interface is already provided.

The user interface is block oriented for convenient usage and creation of coupled models. Blocks are connected to each other providing information flow between each other. Besides using pre-existing blocks provided by Simulink the creation of own blocks is supported. Creation of own routines is done by coding in either m-functions, or s-function or C++. For simulation either continuous or sampled (discrete) time may be used. Results can be visualized directly in Simulink. Alternatively results may be stored in the Matlab workspace for visualization or further analysis.

The codes underlying the CITY DRAIN blocks are realized either as s-functions or m-functions. With regard to time frame used for simulation a decision was taken for using fixed discrete time steps for the dynamic simulation. Sampling time used is defined in the global simulation parameters (Figure 4). All blocks utilize that globally defined timeframe. Since precipitation is the driving force in urban drainage models, global time steps are suggested to be chosen according to the sampling rate of the rain data used.

The modelling of fully integrated systems has shown that the amount of data being handled (and subsequently the time for calculation) is a restricting factor. Therefore the underlying models in CITY DRAIN are kept simple on purpose, applying only conceptual models for allowing quick calculation of hydraulics. Mass transport of pollutants is implemented for conservative matter/tracer substances. The number of substances to be routed is flexible and can be defied within each block separately.

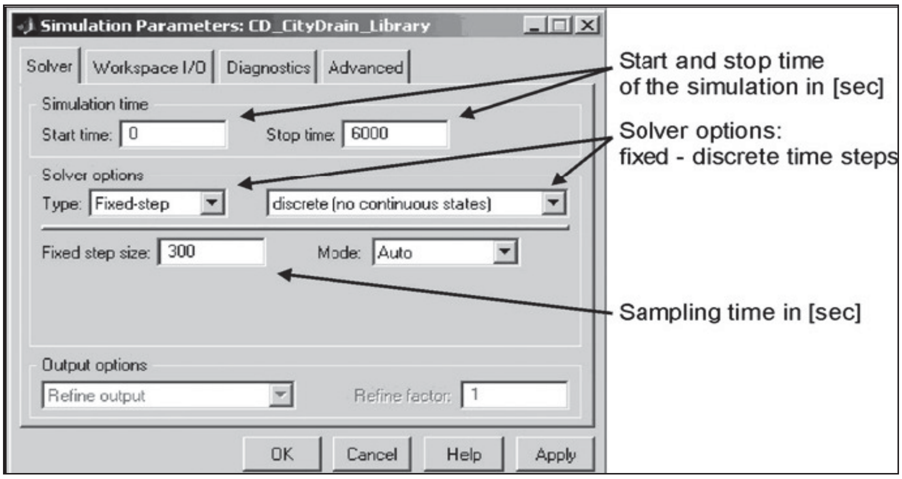


Figure 4: Simulink simulation parameters for CITY DRAIN.

The numerical implementation requires for all models used in CITYDRAIN the re-formulation of equations from differential to difference equations. The decision which processes to be included or what type of hydraulic routing to implement is depending strongly on the problem to be solved. Hence we chose to provide a block library of commonly used models and keep the structure and codes open for access. Users may implement add and/or modify blocks with own routines for special needs. Figure 5 shows a screenshot of the CITY DRAIN library realized in Matlab/Simulink.

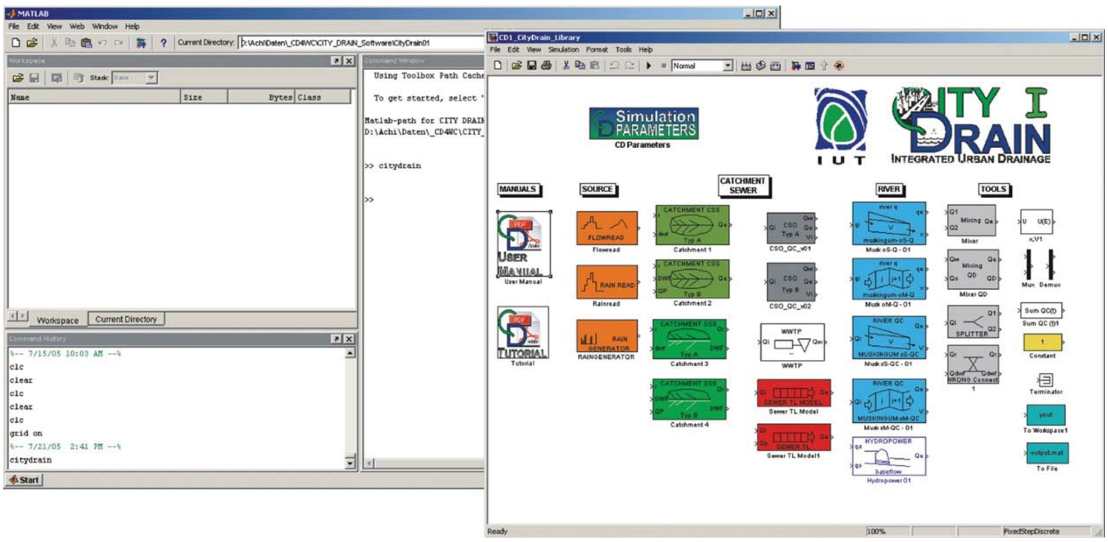


Figure 5. Screenshot, CITY DRAIN Library, (Rauch and Achleitner, 2004).

Current models include the fluid phase exclusively using tracer substances for pollutant routing. Due to CITY DRAIN being open source code, extension for describing processes in the soluble phase may be included. An example application for transport aside the soluble phase would be bed load transport. Sediment requires considering mass storage in compartments, with the sediment mass discharged downstream driven by hydraulics. The specific equations linking hydraulics and bed load quantities may vary, depending on the type of application and sediment particle sizes.

3.2.2 Implemented blocks

Source blocks

Different source blocks are provided for reading flows or rain data. The data is stored as ASCII files where different formats are supported. Most simple formats are for flow data containing either a time series of flow rates or flow rates and associated substance concentrations. For rain data, two formats, mse and ixx, are supported.

The syntax of both, using date and time formats, is shown in Table 1. The mse and ixx formats are used by the national weather service MeteoSwiss and the Austrian Hydrographic Service respectively. For both formats dates are read and transferred into consecutive numerical values in seconds. Output of rain data is cumulated volume in millimetres per time step (e.g. mm/5 min). Mse-format stores rain data only for rain events, neglecting dry periods. Missing gaps are therefore filled when data is read from the file. Where ixx format already provides rain data in [mm/Δt], data read from mse format is to be converted from units [10^{-3} mm/s].

Measured series for flow and/or associated concentrations may be read using the block ‘‘Flow Read’’. Table 2 provides an example input time series where the number of concentration is flexible.

Table 1: Syntax of supported rain formats; left: mse-format, right: ixx-format

mse-format	ixx-format
YY MM DD hh mm ss rR	DD.MM.YYYY.hh.mm.ss rR
[10_3 mm/s]	[mm/Dt]
81 1 1 22 40 0 0.0000	01.01.1991 00:00:00 0.1
81 1 1 22 50 0 0.0000	01.01.1991 00:05:00 0.1
81 1 1 23 0 0 0.1670	01.01.1991 00:10:00 0.1
81 1 2 4 30 0 0.1670	01.01.1991 00:15:00 0.1
81 1 2 4 40 0 0.0000	01.01.1991 00:20:00 0.1

Table 2: Syntax for flow and concentration series supported

t [s]	q [m3/s]	C1 [g/m3]	C2 [g/m3]	...Cx [g/m3]
0	0.40	0.16	0.06	
900	0.45	0.20	0.02	
1800	0.50	0.25	0.70	
2700	0.60	0.36	0.15	
3600	1.00	1.00	0.30	
4500	2.00	4.00	0.04	
5400	0.50	0.25	0.06	
6300	0.30	0.09	0.18	
7200	0.40	0.16	0.22	

Data read is differently treated as being either interpreted as grab samples or composite sample (Figure. 6). This differentiation is of special importance, since data may not necessarily be provided in the same temporal resolution as applied for modelling. For interpolated data points, the type of dataset (grab or composite samples) is of importance and would lead to wrong results if interpreted wrongly.

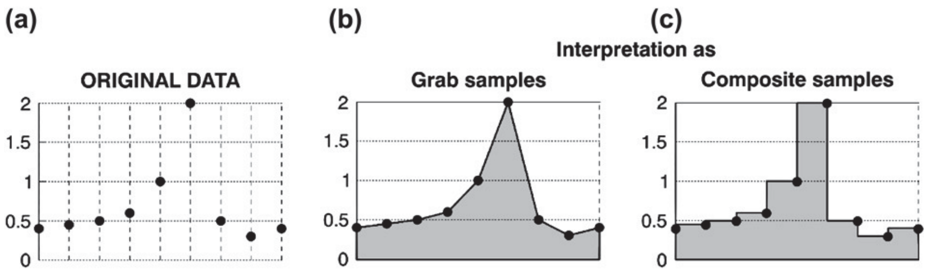


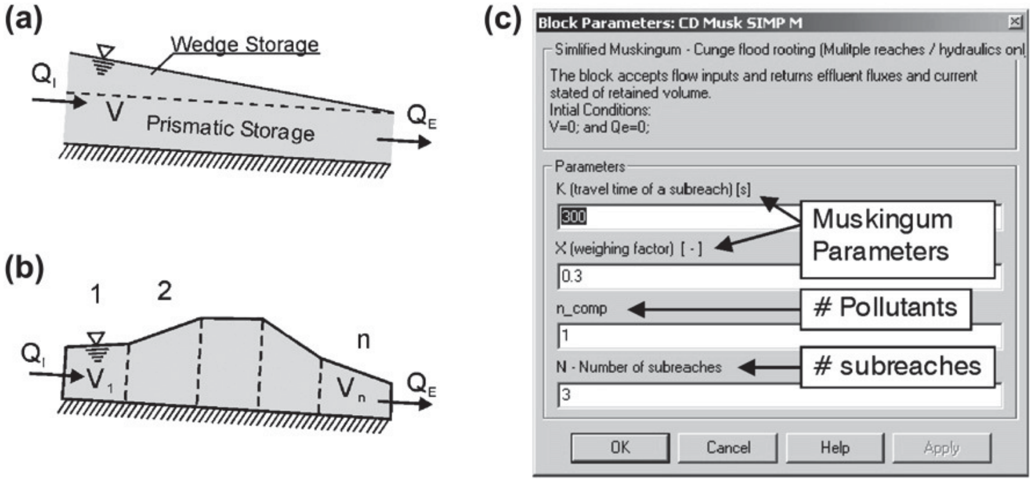
Figure 6. Interpretation of (a) stored data as either (b) grab samples or (c) composite samples.

River model

River hydraulics is described by means of the Muskingum method of flood routing (Roberson et al., 1995). For a wave passing a reach of a channel, the storage is described as a function of Inflow (Q_I) and Outflow (Q_E).

$$V = K \times Q_E(t) + K \times X(Q_I(t) - Q_E(t)) \qquad (1)$$

The method considers prismatic and wedge storage described by the Muskingum parameters K and X respectively (Figure 7a). Blocks for hydraulics and pollutant transport are offered for a single river stretches or subsequent arranged stretches (Figure 7b).



Figuer 7. Muskingum method for flood routing so (a) single or (b) multiple reaches; (c) User input mask of the block.

Instead of considering the discharge Q at instant times it is considered as mean discharge over the last discrete period of time. This is feasible when recalling that the measured precipitation represents mean/cumulated quantities of rainfall for discrete time periods. Continuity is therefore discretised as

$$\frac{V_i - V_{i-1}}{\Delta t} = Q_{I.i} - Q_{E,i} \qquad (2)$$

Such a simple implicit scheme has been used already previously by (Motiee et al., 1997) who described the scheme as being more stable than second-rate schemes. The Muskingum scheme derives finally to

$$Q_{E.i} = \frac{Q_{I,i} \times C_A + V_{i-1}}{C_B} \text{ with } C_A = \frac{\Delta t}{2} - K \times X \text{ and}$$

$$C_B = \frac{\Delta t}{2} + K \times (1 - X) \qquad (3)$$

Further the model is designed for use with a flexible number of sub reaches n. The total travelling time for a water wave therefore denotes a $\Delta T = K \times n$, where K is the flowtime of a single sub reach. Limitations for the choice of K and X are given with regard to numerical stability. A first requirement is stated as $\Delta t < K$ to properly reproduce a wave. Further, both parameters C_A and C_B are required to be greater than zero in order to have the inflow and stored volume contributing to the outflow. Comprehensive formulation of the limitations is given as:

$$1 \leq \frac{K}{\Delta t} \leq \frac{1}{2X} \quad (4)$$

Failing to meet this requirement leads to numerical unstable equations. The peak damping factor X is to be chosen between the numerical extremes 0.0 (linear reservoir storage) and 0.5 (translation).

Catchment model

Two catchments model are available for modelling either a combined or a separate sewer system (CSS or SSS). The dynamic inputs associated can be distinguished for inputs that: (a) origin from the catchment; and (b) inputs which originate from upstream and are to be routed through the catchment. For flow routing a modified Muskingum scheme is used (Figure 8) where the numeric used are essentially the same as for the River model.

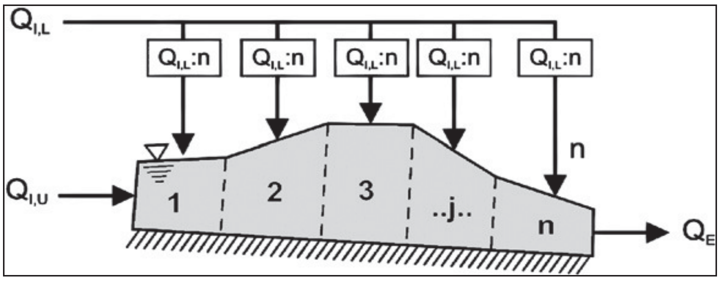


Figure 8. Modified Muskingum flow routing scheme as used in catchments.

The original Muskingum scheme allowed feeding of the uppermost block only. The modified scheme allows both, feeding of the uppermost block ($Q_{I,U}$) as well a distributed feeding of blocks ($Q_{I,L}$). Thus, inputs provided such as the rain intensities (rl) acting on the catchment, the dry weather flows generated in the catchment (DWFl) and parasite water infiltrating into the sewer system (Q_{pl}) are distributed homogeneously

Within the catchment, flows from upstream of the catchment are all the way routed trough, thus are fed to the uppermost sub-block. In case of the CSS block an upstream wastewater stream Qe may be provided as dynamic input. For the SSS block two ports allow the dynamic inputs to the storm and wastewater sewer. The blocks and their underlying sub-models are shown in Figure 9 and 10.

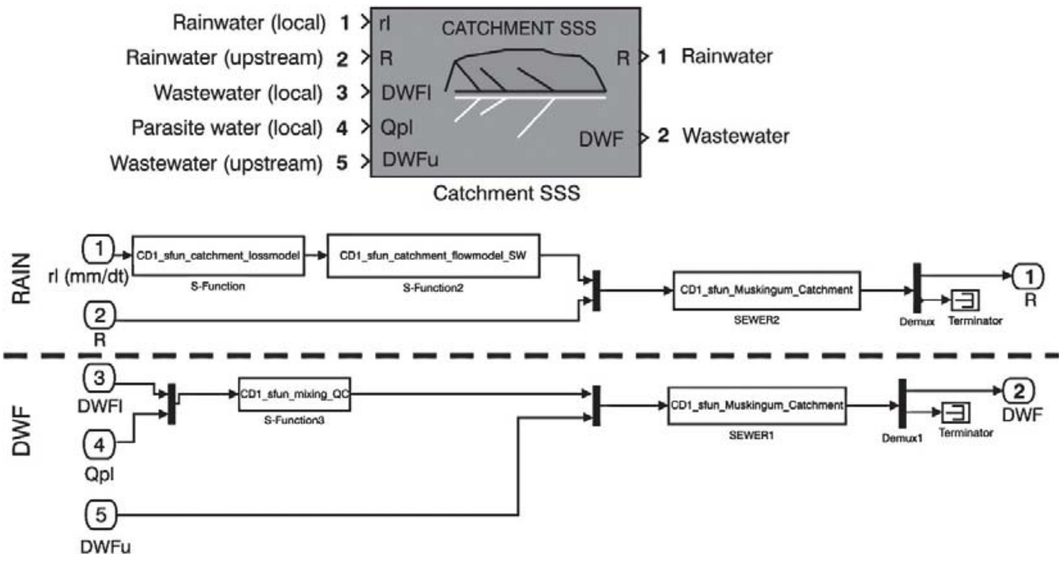


Figure 9: Screen shot: catchment block for SSS and underlying sub models.

When dealing with rainfall runoff generation both blocks are based on a loss model followed by flow model. The loss model accounts for an initial loss hi [mm] and a permanent losses hp [mm/Δt]. A simple storage basin methodology is used where the rain volume exceeding the basin volume is considered for the runoff, contributing to the catchment surface flow. Permanent losses such as evapo-transpiration are considered acting only during dry periods, such acting as ‘‘emptying process’’ for the virtual loss volume.

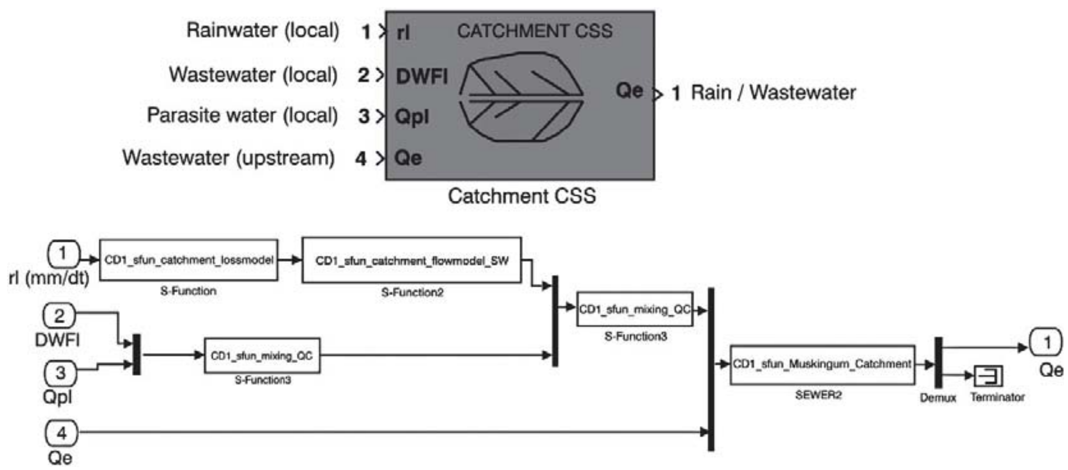


Figure 10: Screen shot: catchment block for CSS and underlying sub models.

The subsequent flow model transfers the effective rainfall heights he to flows using the total area (A_{TOT}) and the runoff coefficient 4. Substance concentrations associated to the rainfall runoff are defined as constant parameter and are to be prompted in the blocks mask.

Combined Sewer Overflow (CSO)
The model for the CSO can be again used for both, combined and separate system, and is based on the mass balance equation in discrete formulation.

$$\frac{V_i - V_{i-1}}{\Delta t} = Q_{I,i} - Q_{E,i} - Q_{W,i} \tag{5}$$

Therein the flows entering the CSO ($Q_{I,i}$) and leaving the CSO as excess flow ($Q_{E,i}$) and overflow ($Q_{W,i}$) are balanced against the volume change (Figure 11a).

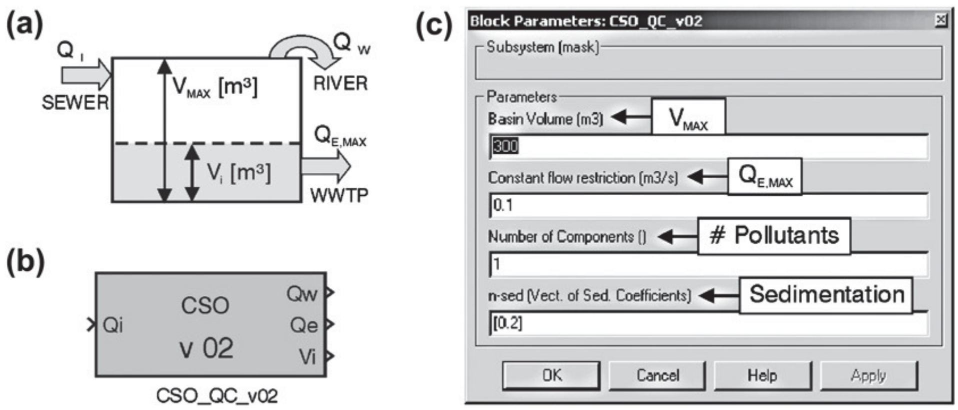


Figure 11. (a) CSO mass balance model; (b) CSO block; and (c) user input mask

All flows represent mean flows occurring during the current time step DT. Since the driving force of the system dynamics, the rain series, are as well cumulate (mean) values, this assumption was found feasible. An equivalent discrete scheme for mass balance is applied to pollutants. User input is required for the CSO volume (V_{MAX}) and the maximum excess flow $Q_{E,MAX}$ and the number of pollutants transported. Excess flow is either diverted to a wastewater treatment plant or a downstream sewer system. The number of pollutants transported can be freely chosen by the user. For settle-able matter the sedimentation process can be described by a linear sedimentation ratio. Sediments are thereby contained to a larger extend in the CSO structure and consequently in the lower effluent.

WWTP model
Finally the model for the WWTP currently implemented is abstracted as ''black box'' accounting for cleaning efficiencies and maximum effluent qualities. Thus neither flow nor quality delivered to the treatment plant influence the level of treatment. The user is required to define for the substances cleaning efficiencies h and the maximum effluent concentration C_{MAX}. For reasons of simplicity a ''perfect'' treatment plant in terms of emission standards is assumed.

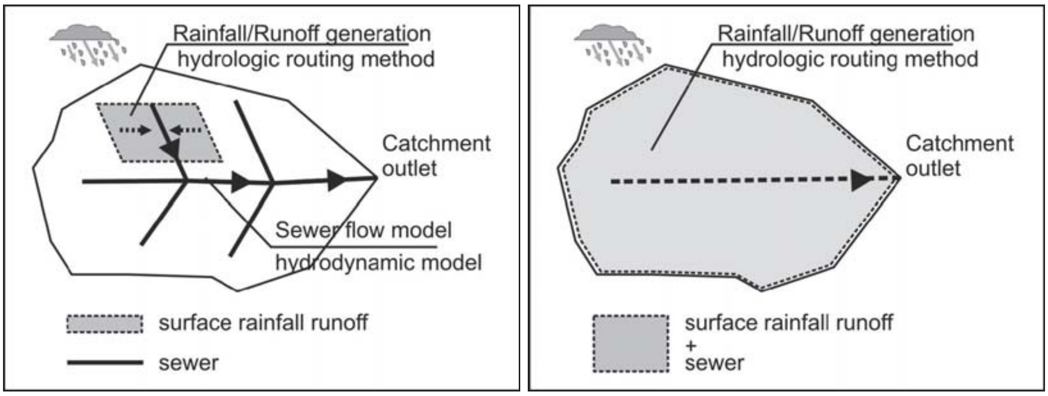
Tool blocks
Besides the presented blocks a number of frequently used tools from Simulink are added to the library. Next to these tool blocks additional useful tool block are provided. For

checks of mass balance blocks providing the cumulated block returning the sum of pollutant loads or flows. For combining flows from different sources (e.g. CSO overflow and river flow) a mixing block is implemented as well.

3.2.3 Flow Routing models

For the description of flow condition, two general approaches are used. Thereby flow can either be described (a) physical-mechanistic model or (b) a conceptual model. Physical models are based on continuity (mass balance) equations as well as on the preservation of Energy or Momentum. Empirical relations are introduced for calculation of e.g. friction or points loss

For conceptual (hydrological) model continuity applies as well. Physical relations are described by conceptual relations mostly using simple descriptions of cause effect relations.



(a) (b)

Figure 12: Schematic on application of (a) hydrological in combination with hydrodynamic models and (b) hydrological models only.

Figure 10 above illustrates how hydrological and hydrodynamic models are used in urban drainage modelling. Common to both setups is that the transformation of distributed aerial rainfall to effective rainfall contributing to the runoff.

Runoff generation and routing in the catchment can be done either with a combination of hydrological and hydrodynamic model or with a hydrological model alone. (Figure 10b)

For case (a) the hydrological model is used to transform the effective precipitation to flow entering the sewer system, where flows are introduced to the connected sewer section via like the manholes. For calculation of the flow regime in the sewer itself, hydrodynamic models are used. Such concepts of linking hydrological and hydrodynamic models are used, for example, MOUSE. A benefit of using such an approach is that the flow regime in the sewer is assessable including backwater effects, overflows etc. A drawback is a larger computation time compared to the full conceptual approach. Still the correctness of results depends on the inputs from the connected conceptual surface flow

models.

Case (b) simplifies the situation, using only a hydrological model that describes the rainfall runoff relation down to the catchment outlet. In case the flow regime at the sewer level is of minor interest, this approach can provide satisfying output information. As a complete part of an urban catchment is approximated by a single model, a number of information is not required. Thus, a benefit of the model is a significant reduction of the amount of data required as input.

4. Case study

4.1 Project area

The city of Ljubljana- the capital of Slovenia- as an urbanized catchment area of approx. 4,000 ha with approx. 600 ha contributing from impervious surfaces. The length of the sewer system is approx. 700 km and the system has a daily load of approx. 240,000 person equivalents including industrial wastewater. 72 overflow structures are distributed over the whole city, most of them along the river. At present, Waste Water Treatment Plant located downstream of the City (Figure 13).

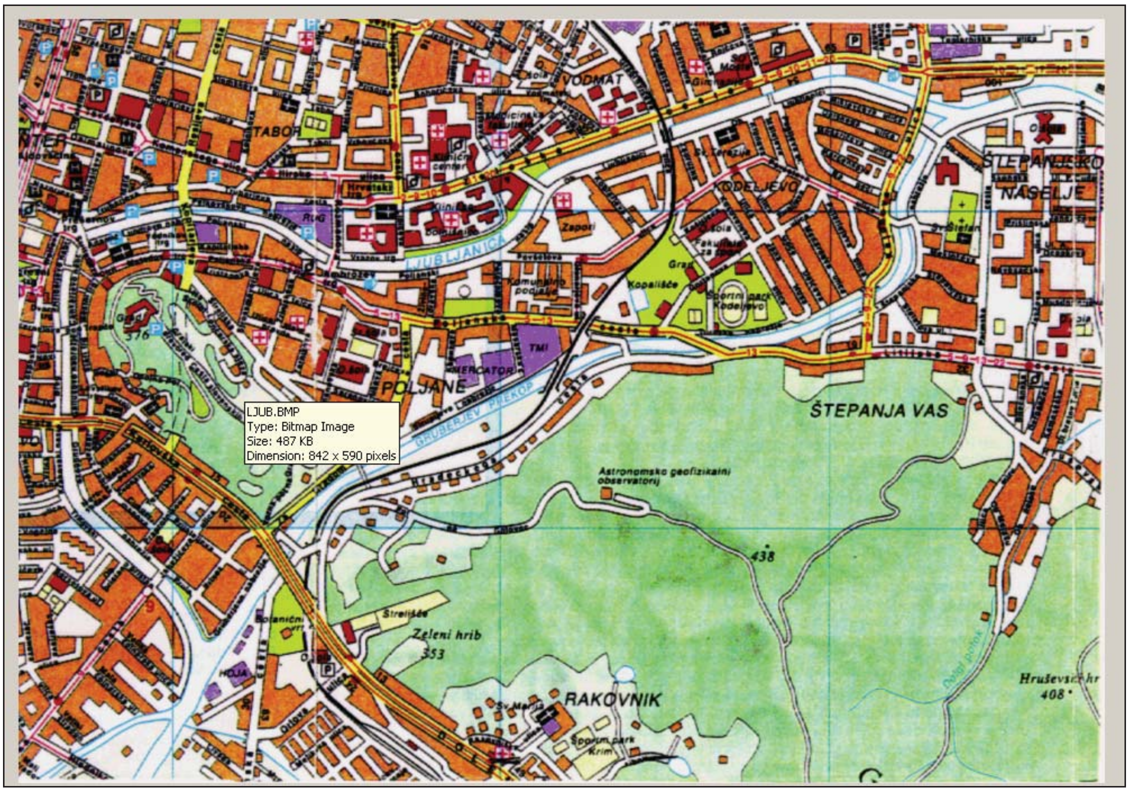


Figure 13: map of case study area

Today the sewer system does not perform satisfactory. During the heavy rain the sewers discharge too much water to the Ljubljanica River. Further, sediment deposit decrease the hydraulic capacity of the sewers and problem exist with infiltration of ground water and inflow from the river to the sewer system.

4.2 MOUSE model

MOUSE model is selected to carry out the modelling work since this package has been used in the Hydroinformatics course, and it is one of the popular packages for sewer system modelling. In the case study, MOUSE model (physically based sewer model) is used to generate data for the purpose of calibrating and verifying CITY DRIAN models.

Essentially, MOUSE divides an urban drainage system into two parts, urban catchment s and drainage network. The MOUSE data for each of these parts consist of the system data (physical properties) and the boundary data.

The data requirements for building a model of sewer system in MOUSE can be generally summarized in three parts.

- ✓ The layout of the drainage network and system data, such as nodes (manhole, storage node, outlet, etc), links, weir, pumps and orifices.
- ✓ Catchment data includes number of inhabitant, impervious area, total area, etc.
- ✓ Boundary data: rainfall, water level, inflow discharge, dry weather load discharge (diurnal variation)

The next step after the data analysis is that converting the available data into requited formats and importing them into model as input files. Urban network data (UND), Hydrological and catchment data (HGF), dry weather flow data (DWF) are the files needed for this model.

After the successfully converted data into MOUSE formats and imported prepared files into MOUSE, a MOUSE model incorporating both the rainfall-runoff and pipe-network was built. Later on, the construction of CITY DRAIN model is fully associated with this MOUSE model. (Figure 14)

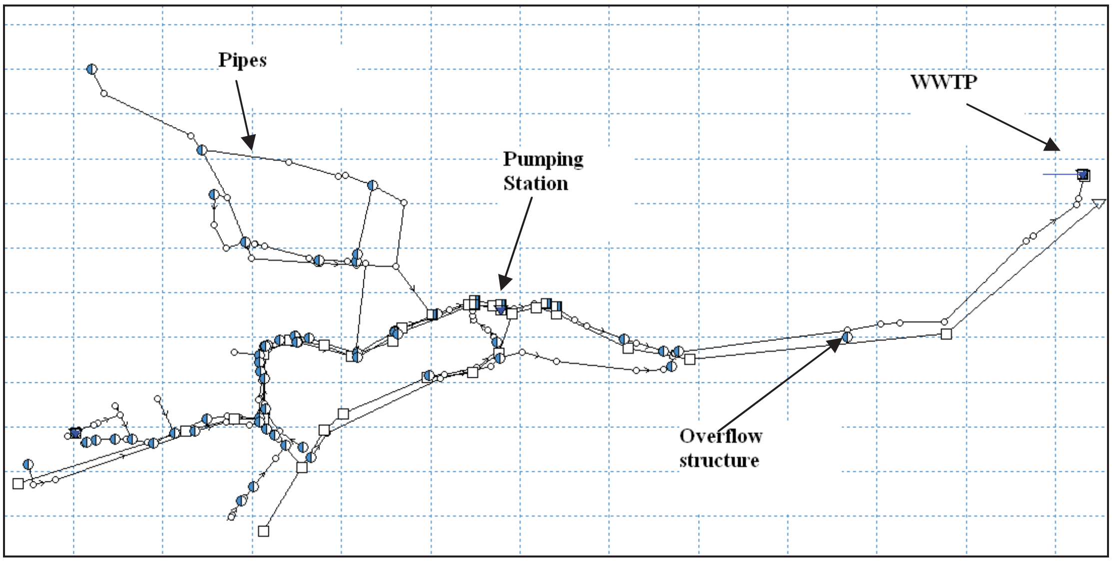


Figure 14: screen shot- drainage system outline in MOUSE model

4.3 CITY DRAIN model set up

4.3.1 Modelling of sewer component

Sewer system in fact can be seen as the initial component of the urban drainage system, since the effective rainfall water via manholes flow into the sewer system and bring the Dry Weather Flows to WWTP and receiving water bodies. Regarding to the idea of integrated urban drainage modelling, how sufficiently good works can be done by the sewer component modelling will directly affect the final results of the integrated system. Supposing, the performances of this modelling are not reliable, further connection with treatment plant and receiving water is meaningless. That is why the research starts with the sewer component modelling.

CITY DRAIN models are simplified models. They use only a hydrological model that describes the rainfall runoff relation down to the catchment outlet. In case the flow regime at the sewer level is of minor interest. According to this characteristic, the sewer system in CITY DRAIN model can be subdivided and catchment data are also lumped. In between each catchment, overflow structures are the nodes to connect them (see figure 15).

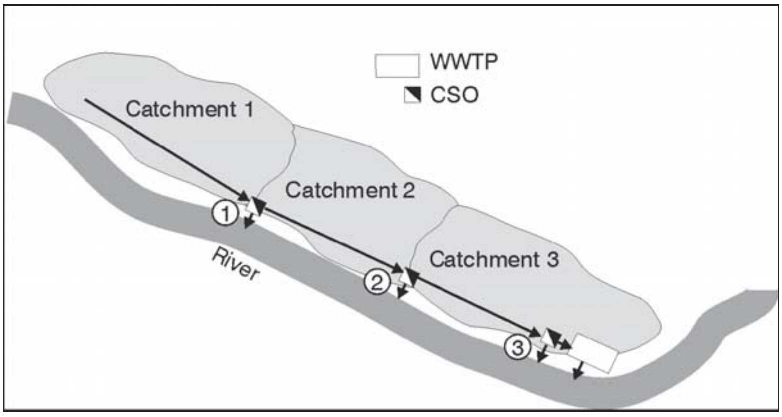


Figure 15: example of subdivided catchment

Figure 15 shows the urban catchment(s) to be simulated, thereby three sewer catchments in series, where CSO structures are located at the outlet of each of the catchments discharging in the river nearby.

The difficulty from the study area is that there are total 72 overflow structures placed in the whole area, to simulate them in normal way, 72 catchment and overflow structures are expected. To deal with the case in this way is impractical and inefficient. The solution adopted for the problem is that depending on the locations, catchments are grouped and overflow structures in the same grouped area is represented by only one. Figure 16 shows the final result of how the system is divided based on the analysis of city layout and distribution of sewer system.

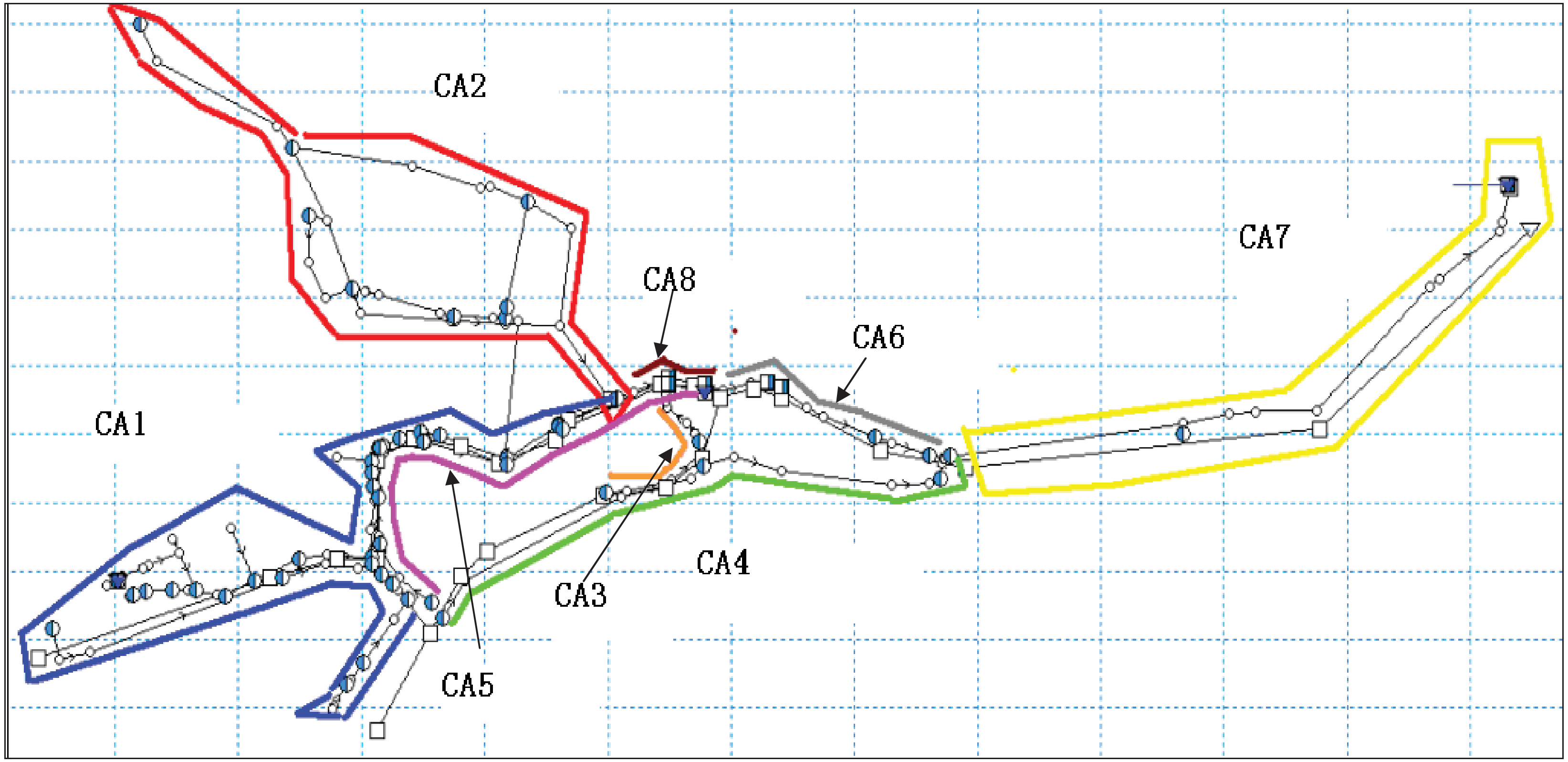


Figure 16: Final division of the case study area

The study area is divided into 8 districts and in CITY DRAIN model, one district is represented by one catchment. However, each district consists of a number of catchment in the MOUSE model.

Division is the first step to build up the model in CITY DRAIN, build up connections is the next step. Based on the final result of division, by transferring prepared modelling modules to the working area from CITY DRAIN library, the basic structure of CITY DRAIN model is completed.(Figure 17)

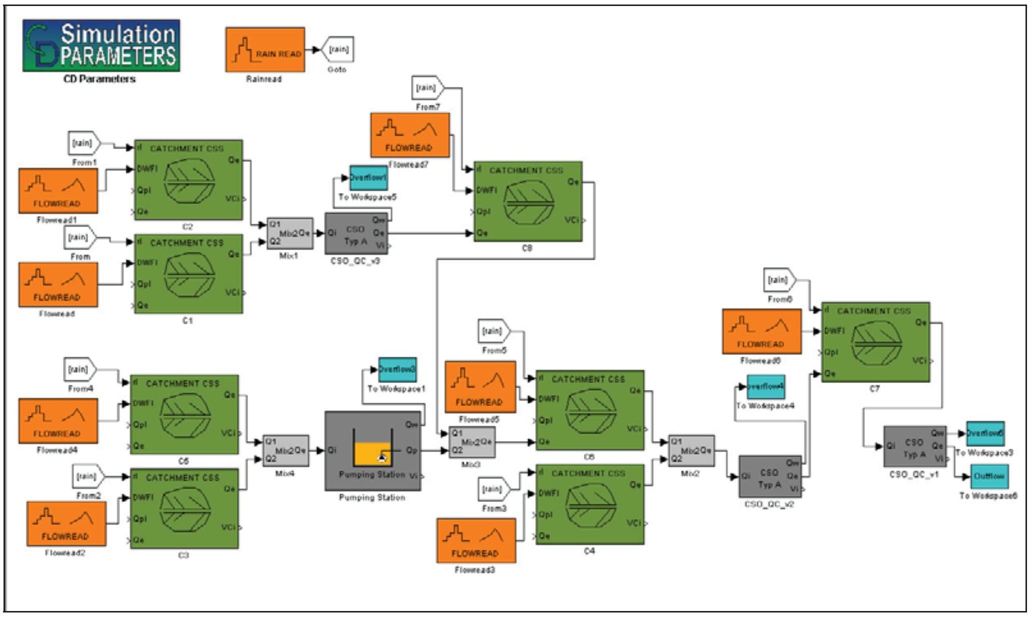
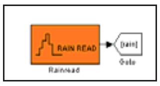
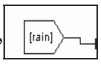
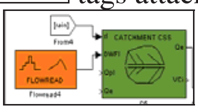
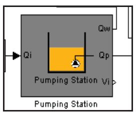
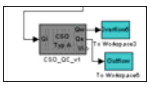


Figure17: Structure of the CITY DRAIN model

- ✓ "Rain Read"  is the module responsible for read rainfall data from files, by "Rain"  tags attached to each lumped- catchment, data is transferred.
- ✓ "Flowread"  is the module takes charge of reading of Dry Weather Flow.
- ✓ "Pumping station"  allocated as the same place as the MOUSE model.
- ✓ "Overflow"  is the workspace to gather overflow data follow the simulation time interval.

Those are the modules applied on the model associated with the detailed model built up

in MOUSE software. Again, the simplicity is displayed. By looking at the figure 17, overflow structure is not allocated after each catchment. Because from the observation of the MOUSE model results, overflow did not take place in some catchments, in this case, CSO(overflow structure) is not provided.

4.3.2 Modelling of flooding condition

In the real world, when water level exceeded the crest level of the weirs in sewer system, the excess water will be discharged to the receiving water via overflow structures, but sometimes the intensive rainfall comes in a very short time, even discharging to receiving water is not able leave enough space to convey stormwater smoothly to downstream, the surcharged water will spill out to the ground from manholes and cause flooding on the ground.

Physically based models, MOUSE, can simulate this situation due to the application of hydraulic model in sewer system. In contrast, CITY DRAIN models are not able to calculate this situation because of only hydrologic model is applied. In order to help conceptual model overcome the drawback, a retention basin is required. The idea is to store the excess water in the retention basin and release them back to system when water can flow freely in the pipes again.

The model set up in this part is used to evaluate the improvement of CITY DRAIN model's performance for flooding conditions by adding retention basin. Besides, the potential usability of CITY DRAIN model for the strategic planning is evaluated based on this model. The target area (figure18) will be simulated by both the CITY DRAIN model and the MOUSE model. The figure 19 shows the location of the target area in the MOUSE model.

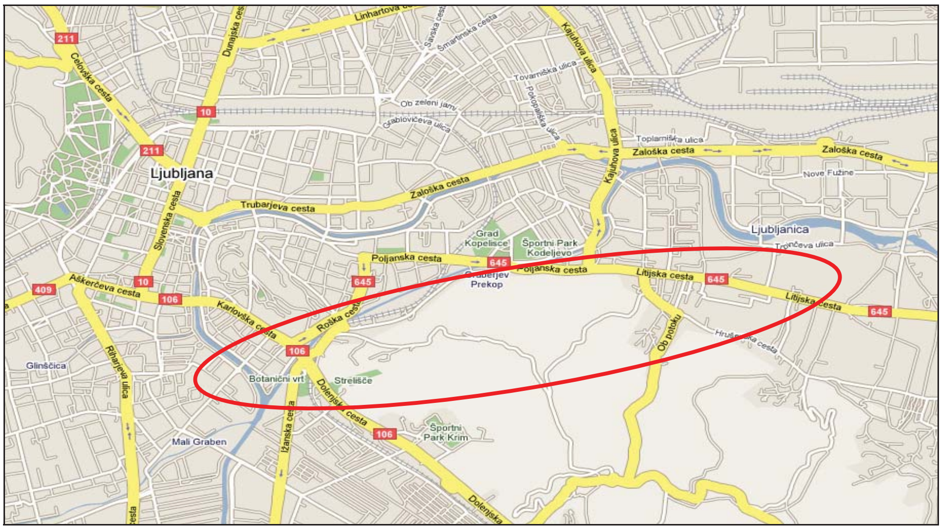


Figure18: Study area of flooding condition modelling

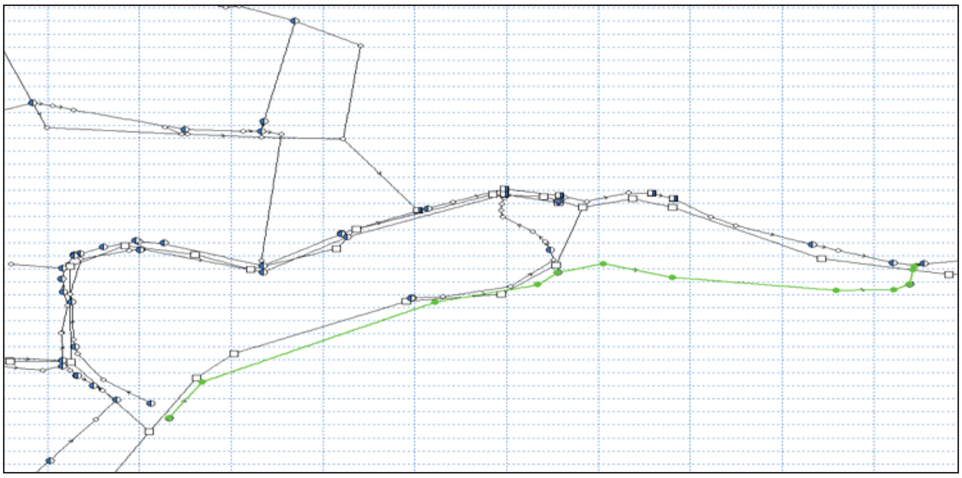


Figure19: Study area (green) in the MOUSE model

Compare with the previous model, the CITY DRAIN model assembled in this part is simpler. It composed of 2 catchments and two overflow structures as usual. The obvious difference is the red block between catchment and CSO, which is the retention basin. (Figure 20)

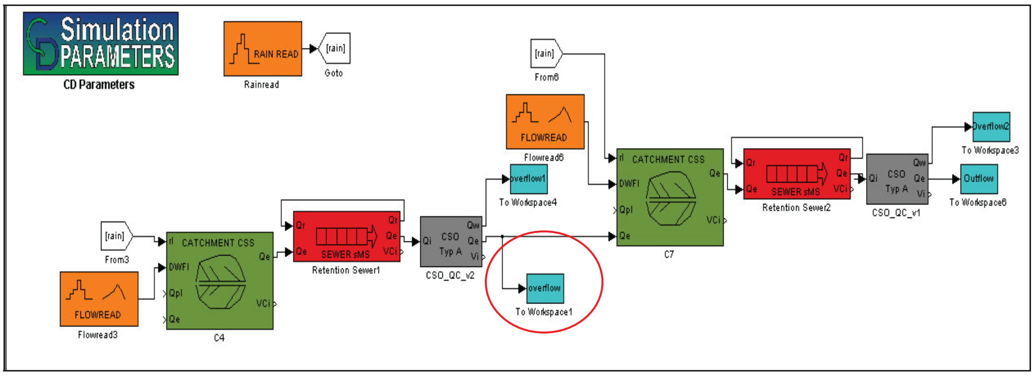


Figure20: Outline of the CITY DRAIN model for flooding condition modelling

4.3.3 Modelling of sewer component with WWTP

The construction of this model aims to evaluate the potential usability of CITY DRAIN software for the integrated modelling purpose. Unfortunately, MOUSE does not include WWTP model, to simulate the sewer system combine with WWTP, other software is needed, e.g.WEST. Therefore, the results of this model are not fully reliable. Despite, the reliability, to test and demonstrate the special function is the idea of this modelling.

Due to the lack of "observed" results, here the simple WWTP module is applied. It requires only to define for the substances cleaning efficiencies h and the maximum effluent concentration C_{MAX}.(Figure 21) For reasons of simplicity a ''perfect'' treatment

plant in terms of emission standards is assumed.

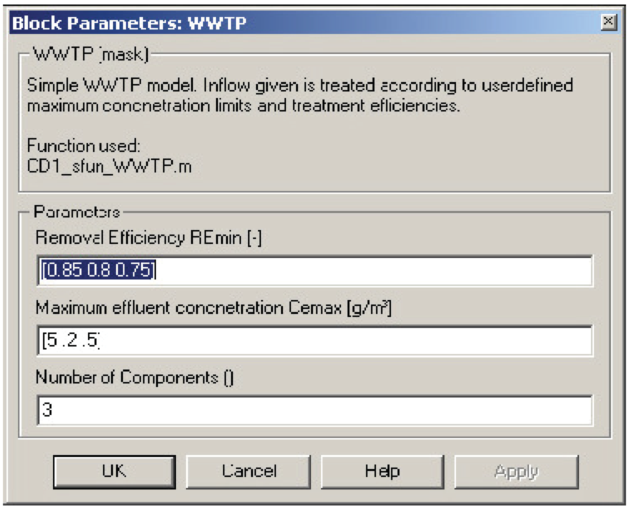


Figure 21: Illustration of concerned parameters in the simple WWTP module

In the CITY DRAIN software, another type of WWTP module is also assembled. It much more complex then the simple one and is designed to consider biological treatment as well as primary and secondary clarification. In contrast to other blocks, specific substances are required. The completed model shows in the figure 22. It consists of sewer component modelling and treatment plant (red circle).

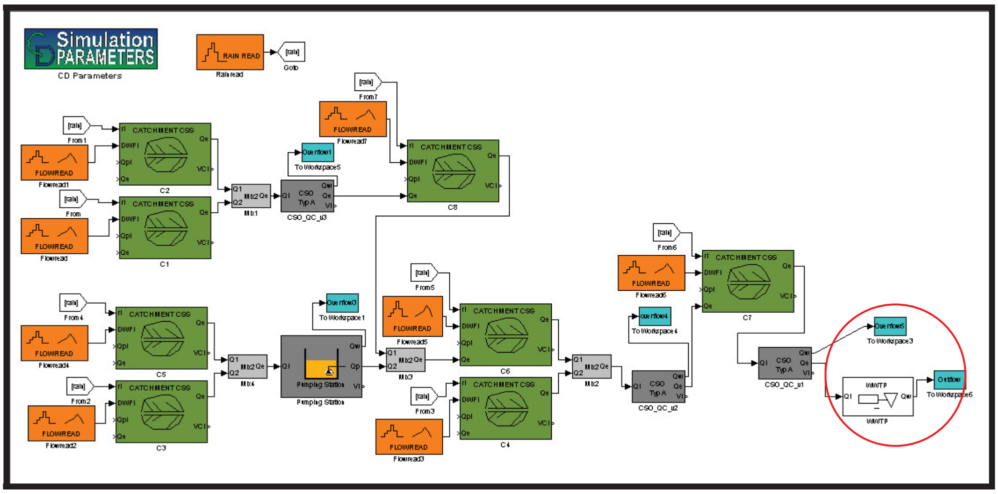


Figure 22: Integrated model consists of completed sewer model and simple WWTP

4.3.4 Data preparation

Compare with MOUSE model, the required data for CITY DRAIN models are more in general. Depending on different modules applied on the three CITY DRAIN models, data requirements are varied. CITY DRAIN does not offer a graphical user interface; therefore, all input data have to be prepared in CITY DRAIN format manually.

Rainfall data: the rainfall data format is MSE (see table1). This rain data only stores rain events, neglecting dry periods. When reading the data timely gaps are filled by zero values for dry the periods. The format uses a line per data entry having either 5 or 10 minute intervals.

Dry Weather Flow data: Dry Weather Flow data is produced depending on the number of inhabitant included in the catchment and the number is not same in different catchment, thus, how many catchments are included in the CITY DRAIN models, the same number of input files have to be prepared. Below is the equation for preparing input files. (A program has been used to produce files, refer to appendix 1)

$$\frac{\text{Average value m3/PE/day}}{\text{Total seconds of a day}} \times \text{Population} \times \text{Diurnal hourly factor} = \text{CD value}$$

In addition, catchments data and CSO (Combine Sewer Overflow) data is the summation of data derived from MOUSE model, e.g. inhabitant. Because the same size of area covered by catchments defined in CITY DRAIN models include a number of catchments from MOUSE models.

Basically, other required data are the same data from MOUSE model or the observed in the real life.

5. Simulation and results discussion

In this chapter, simulations will be carried out around the three completed CITY DRAIN models. In addition, all results obtained during the simulations will be discussed at the end of the chapter; results of model calibration and verification are also included.

The use of visual tools, e.g. graph, is the most direct way to judge the goodness of a result, but it is subject to personal judgement. Statistical methods are usually used to evaluate the performance of models, such as coefficient of determination R^2, Nash-Sutcliffe model efficiency coefficient (E), etc.

The Nash-Sutcliffe model efficiency coefficient
The Nash-Sutcliffe model efficiency coefficient is used to assess the predictive power of hydrological models. It is defined as:

$$E=1-\frac{\sum_{t=1}^{T}(Q_0^t - Q_m^t)^2}{\sum_{t=1}^{T}(Q_0^t - \overline{Q_0})^2}$$

where Qo is observed discharge, and Qm is modelled discharge. Q_o^t is observed discharge at time t.

Nash-Sutcliffe efficiencies can range from $-\infty$ to 1. An efficiency of 1 (E=1) corresponds to a perfect match of modelled discharge to the observed data. An efficiency of 0 (E=0) indicates that the model predictions are as accurate as the mean of the observed data, whereas an efficiency less than zero ($-\infty<E<0$) occurs when the observed mean is a better predictor than the model.

Essentially, the closer the model efficiency is to 1, the more accurate the model is.

It should be noted that Nash-Sutcliffe efficiencies can also be used to quantitatively describe the accuracy of model outputs other than discharge. This method can be used to describe the predicative accuracy of other models as long as there is observed data to compare the model results to. In other applications, the measure may be known as the Coefficient of determination, or R2. Nash-Sutcliffe efficiencies have been reported in scientific literature for model simulations of discharge, and water quality constituents such as sediment, nitrogen, and phosphorus loadings.

Water balance
In the urban area, effective rainfall and dry weather flow can be seen as input water of the modelling system. One the other hand, overflow together with the discharge at the outlet is the output water, of course, infiltration, evapor-transpiration also existing in the system, but only hold a small proportion, because of impervious area. Another criterion to judge

the model performance could be the continuity balance. The volume input to the system should be equal to the output volume and the volume stored in the system, if there is any.

5.1 Simulation and results

5.1.1 Modelling of the sewer component

Simulation of calibration

Conceptual models represent the hydrological processes that are important in the system using simplified conceptual representation. The hydrological properties are represented as parameters. These parameters have no direct physical meaning and are not directly measurable. These model parameters are usually estimated via calibration.

Basically, manually calibrate model is process of modifying the input parameters to minimize the difference between the observed data and model result. Here, as mentioned at the beginning, the MOUSE model results will be used to calibrate the CITY DRAIN model.

Calibration parameters include:.

Catchment

- ✓ Runoff coefficient: In the range of 0...1.
- ✓ No of timesteps: Number of sub- areas/sub- reaches
- ✓ K: Muskingum parameter describing the time required for a discharge wave traveling through the reach. K applies to one lumped- reach and does not cover travelling time for all sub- reaches.
- ✓ X: Dimensionless weighting factor that relates to the amount of wedge storage [-] in the range of 0 (linear reservoir storage) and 0.5. (Typical value = 0,2).

CSO

- ✓ Bain volume: Basin volume (storage volume) [m³]
- ✓ Maximum effluence: Maximum Effluent flow [m³/s]

On the other hand, for calibration of the CITY DRAIN model, a good understanding of what happened in side of the model is necessary. Once the water coming into system (DWF and rainfall), the water flows from upstream to downstream, and because the existing of overflow structure, the excess water above the crest level will be discharged to the river, thus the discharge value at the outlet of the whole catchment and the overflow discharged at each CSO should be observed, certainly, calibration is carried out around them.

Generally, two points is where the attention of calibration should lay on:

- ✓ *Volume of output water in total (in general)*: how much water has produced by the model in total, including outflow at the outlet and overflow.
- ✓ *Discharge value varied related to time (in detail)*: how much water discharged in

each time interval to the receiving water and to the outlet.

There are total 3 overflow structures and one outlet is (Figure17) provided in the CITY DRAIN model, from them CITY DRAIN results can be recorded.

Below are the calibration results graphs, meanwhile, analysis of E and water balance are also provided.

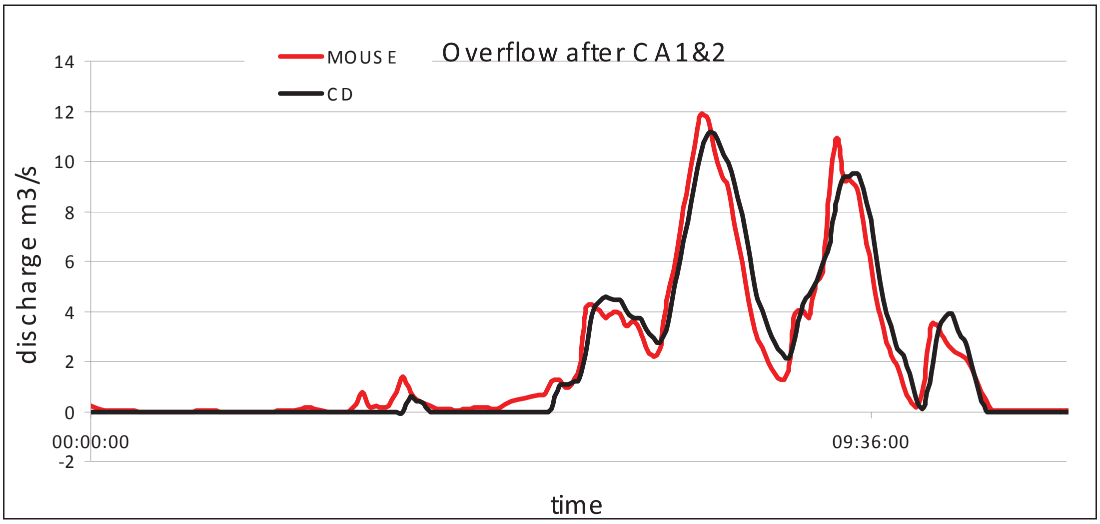


Figure 23: Calibration result of sewer component modelling-"overflow 1"

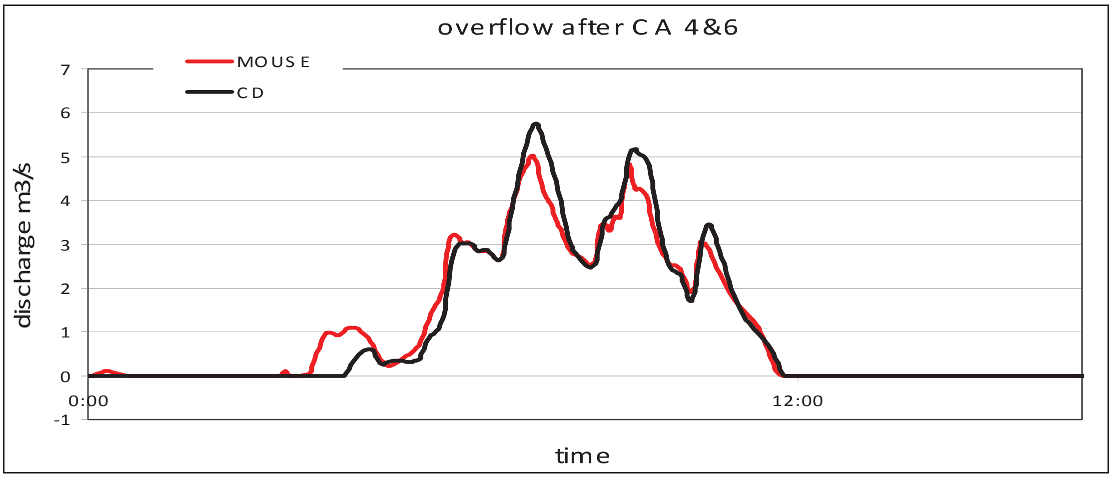


Figure 24: Calibration result of sewer component modelling-"overflow 2"

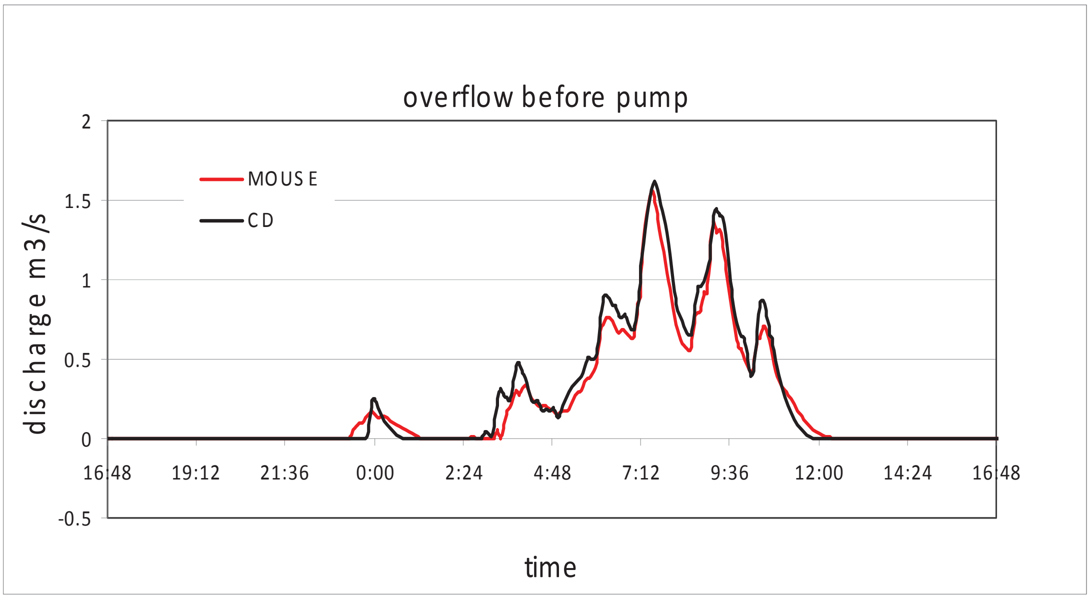


Figure 25: Calibration result of sewer component modelling-"overflow 3"

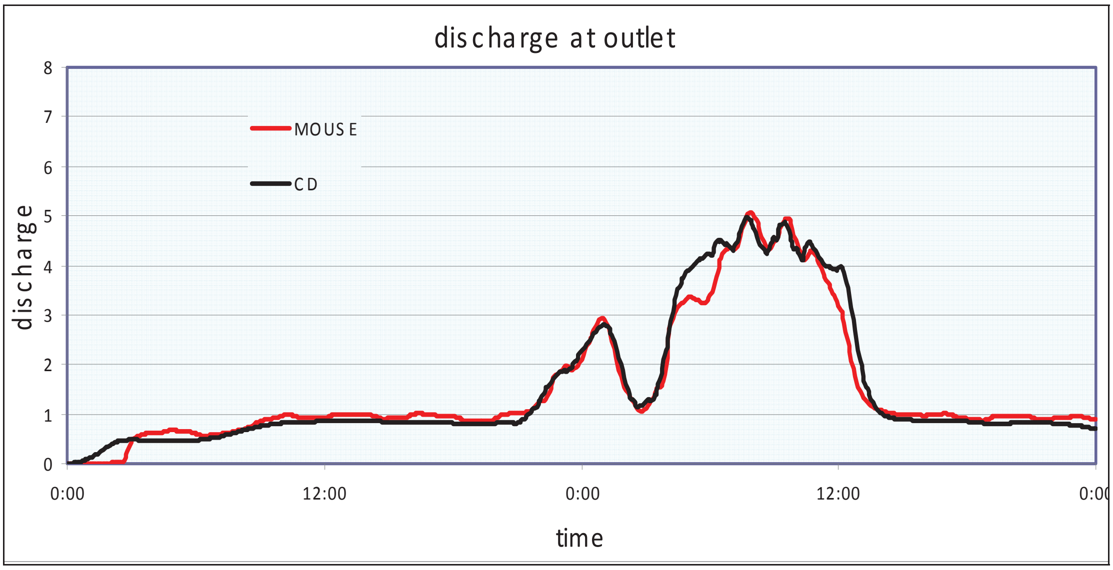


Figure 26: Calibration result of sewer component modelling-"outlet"

By looking at the comparison of two results profiles for each overflow and outlet (Figure 23,24,25,26), it can be said that results are quite close to the results from the MOUSE model. Besides, the peak values are nearly matched, especially the result of "overflow 3"(Figure25), before the pumping station. The goodness can be known also by the E number, "overflow 2" has the highest mark (Table 3). Moreover, almost no obvious time lag or ahead for all results is observed.

Table 3: Statistical comparison of calibration result sewer component modelling

R-square		**Water Balance**				**Volume Comparison**		
						MOUSE	**CD**	**Difference**
Overflow 1	0.952265		**MOUSE**	**CD**	**Overflow 1**	90584.4	90465.81	118.5876
Overflow 2	0.967644	**Input**	481276.4952		**Overflow 2**	18366.3	20351.84	-1985.53674
Overflow 3	0.962792	**output**	436665.9	441037.6166	**Overflow 3**	66226.5	66122.28	104.2239
Outlet	0.960492	**Difference %**	0.908358627		**Outlet**	261488.7	264097.7	-2608.991322

In general, performances of the CITY DRAIN model can be regarded as sufficiently good, as this can be confirmed by E. All results are above 0.95. But the difference showing for the water balance is big, and the CITY DRAIN model "produced" more water.

Simulation of verification

The calibrated model will run simulation again with different set of rainfall, in order to evaluate on the performances of the CITY DRAIN model performance objectively, especially for the sewer component.

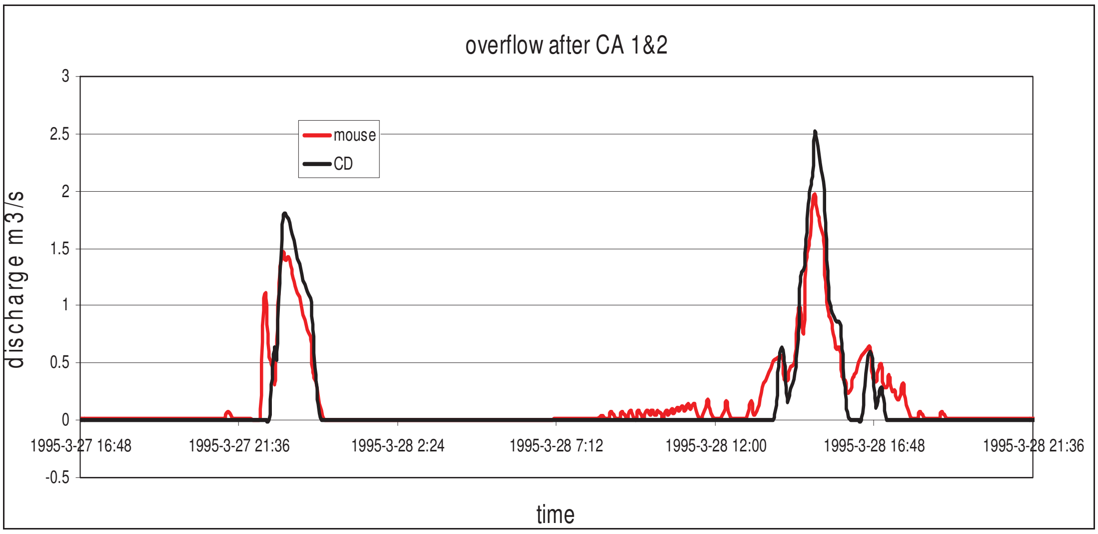


Figure 27: Verification result of sewer component modelling – "overflow 1"

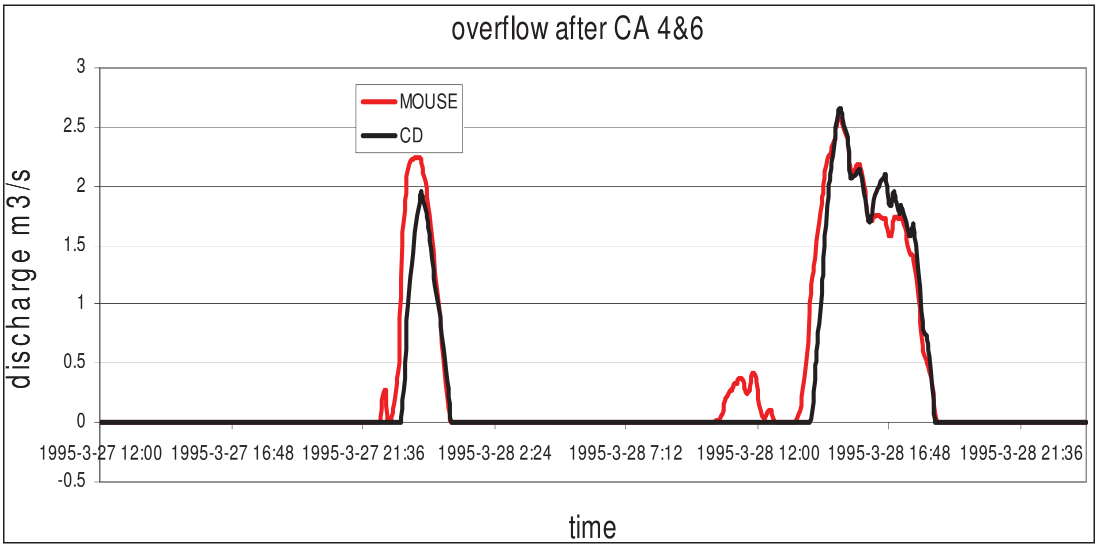


Figure 28: Verification result of sewer component modelling – "overflow 2"

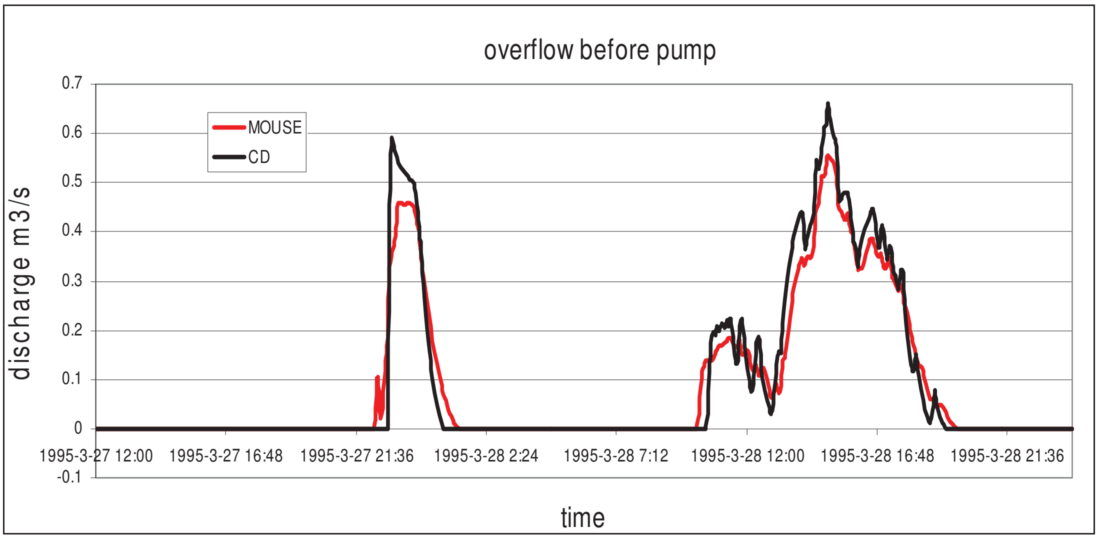


Figure 29: Verification result of sewer component modelling – "overflow 3"

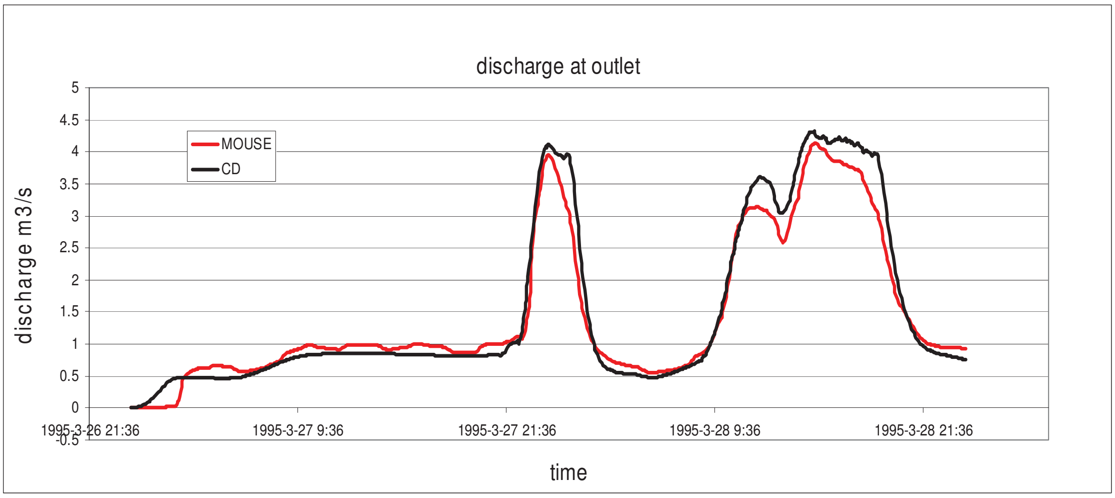


Figure 30: Verification result of sewer component modelling – “outlet”

Table 4: Statistical comparison of verification result sewer component modelling

E		**Water Balance**				**Volume Comparison**		
						MOUSE	**CD**	**Difference**
Overflow 1	0.790		**MOUSE**	**CD**	**Overflow 1**	18151.2	15400.21	2750.987
Overflow 2	0.932	**Input**	357923.43		**Overflow 2**	10701.6	11335.68	-634.081
Overflow 3	0.907	**output**	320117.40	322964.29	**Overflow 3**	40785.6	34645.08	6140.522
Outlet	0.944	**Difference %**	0.80		**Outlet**	250479	261583.3	-11104.3

Simulations of the calibrated model for different set of rainfall, results are displayed above (Figure 27,28,29,30). The CITY DRAIN model results are quite close to the MOUSE results. But the peak values are tending to be higher. An obvious time lag situation happened on “overflow 3” (Figure 29). For the “overflow 1” (Figure 27) except the main events, other smaller peaks are produced, from the volume comparison table(Table 4), MOUSE produced 2750 m^3 water more than CITY DRAIN. Thus, E for “overflow 1” stays lowest level. But in total CITY DRAIN model produced more water than MOUSE model at the outlet.

To sum up the performance of the CITY DRAIN model for verification case, results are reasonable good and acceptable.

5.1.2 Modelling of sewer component and WWTP

Construction of this model aims on checking the potential usability of CITY DRAIN software as a simplified conceptual model for an integrated purpose. Unfortunately, the model will not be calibrated, because to simulate the sewer system combine with WWTP, other software is needed, for example WEST. Therefore, the results of this model are not fully reliable. Despite, the reliability, to test and demonstrate the special function is the idea of this modeling. A random selected rainfall event from history is used to run the simulation. Furthermore, a given concentration of a substance will be part of input data together with the Dry Weather Flow files.

In order to understand how CITY DRAIN model deals with water quality problem, 3 observation points are placed in the model, one after the representative catchment, one right before the WWTP and one after WWTP

Below are the results

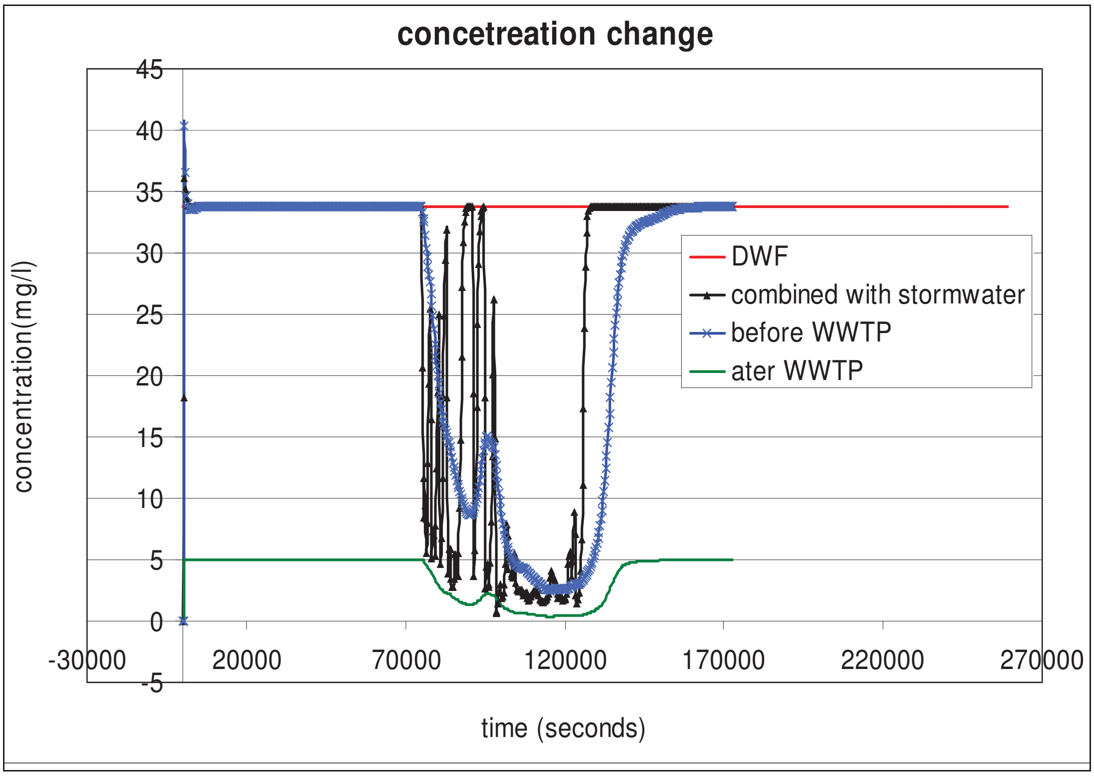


Figure 31: Concentration of substance at different observation points

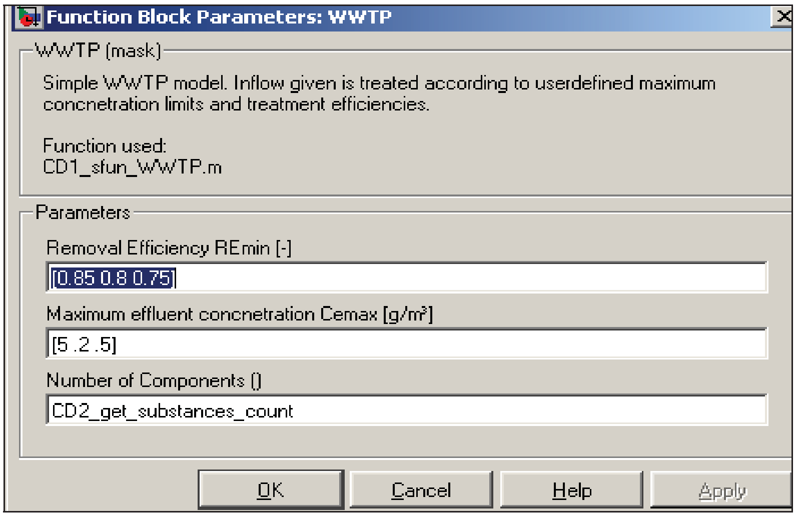


Figure 32: Parameters of WWTP applied for simulation

Compare the results of four observation points from the figure 31, the changing of concentration in the sewage is highly depending on the rainfall water, before the rainfall event, concentration in the sewage did not change. On the other hand, compare the differences of concentration before and after the WWTP, the change is based on the working efficiency value determined by user before the simulation.(Figure 32).

5.1.3 Modelling of flooding condition

Simulation of calibration

When a heavy rainfall event came, flooding situation can be simulated in MOUSE model and the water flooded to the ground is assumed will come back to system after the peak period. In contrast, the conceptual model assumes water coming into the catchment together without the limitation on pipe capacity and flowing out so.

Through the calibration process, how big improvement can be brought by adding of retention basin will be evaluated. The model is consists of two catchments (Figure 20), and one retention base for each. For better understanding the model performance, the discharge value after each catchments will be recorded.

Figure 33 shows the MOUSE model results during the heavy rainfall event, the red circles mark the places where flooding happened. In figure34, the places where the maximum water level is higher than ground level are flooding.

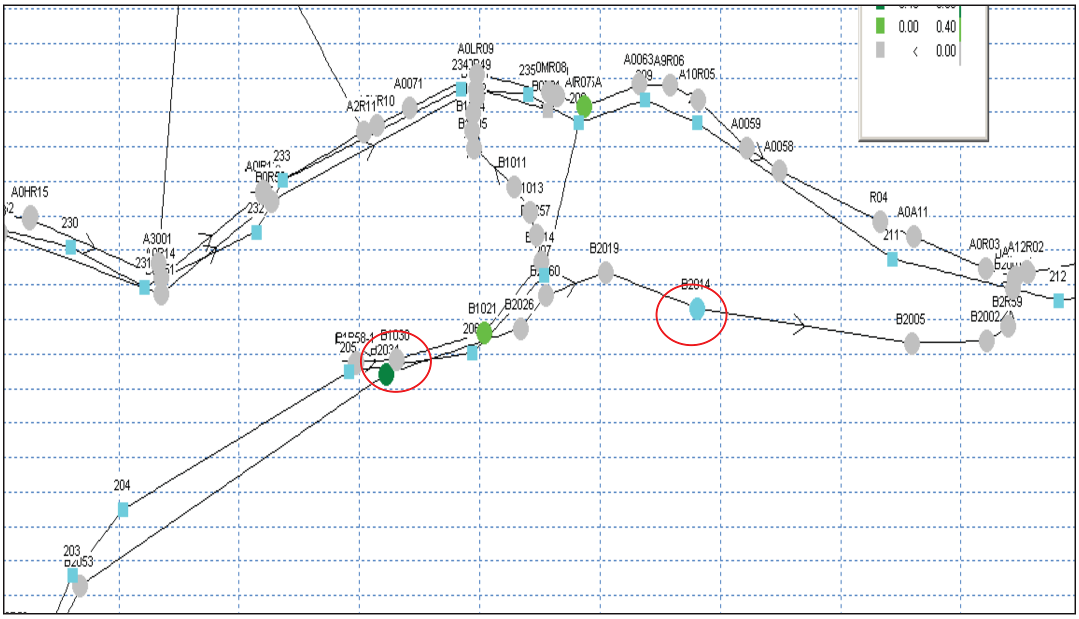


Figure 33: Flooding map of the MOUSE model result (red circles mark the flooding area)

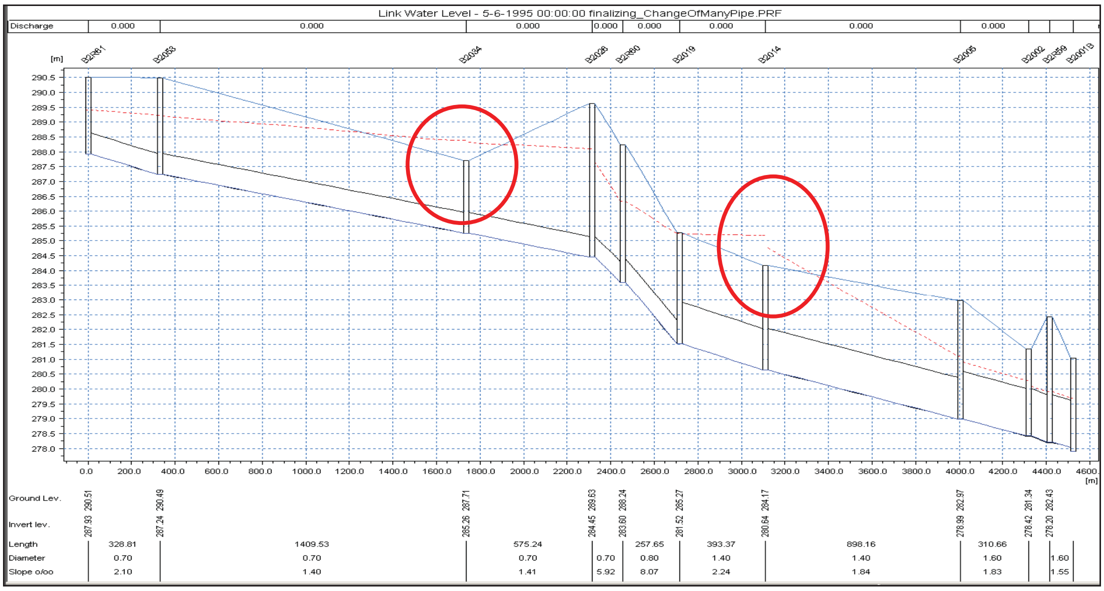


Figure 34: Maximum water level (red line) during the heavy rainfall in sewer system

Normally when the flooding conditions displayed in MOUSE results (Figure 33), the excess water is spilling out from manholes to ground (Figure 34) in compare with CITY DRAIN results (Figure 35,36), the discharge value goes rapidly up in the CITY DRAIN model, and drops sharply. That is the reflection of the drawback defined before.

It is important to know that the peak values from MOUSE model shows in the following graphs are the actual maximum outflow can be carried by pipes. Follow the logical

thinking, in the CITY DRAIN model, the maximum outflow values of retention basin should be the same. In addition, parameters of the retention basin are basically same as parameters of catchment, thus the same consideration can be applied on it as well.

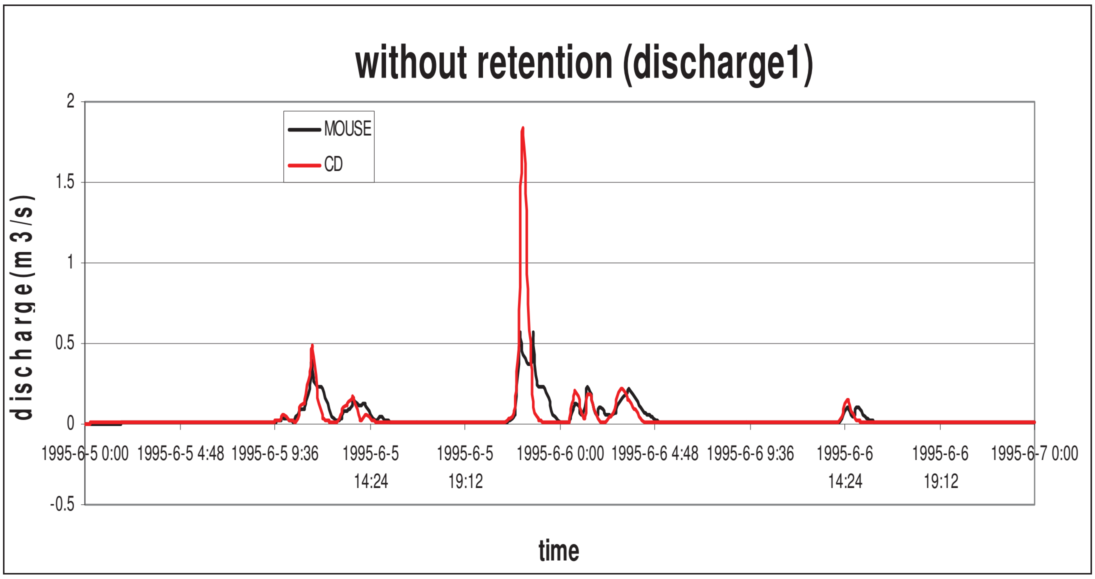


Figure 35: Simulation result of flooding condition modelling <u>without</u> retention basins – discharge from catchement 1

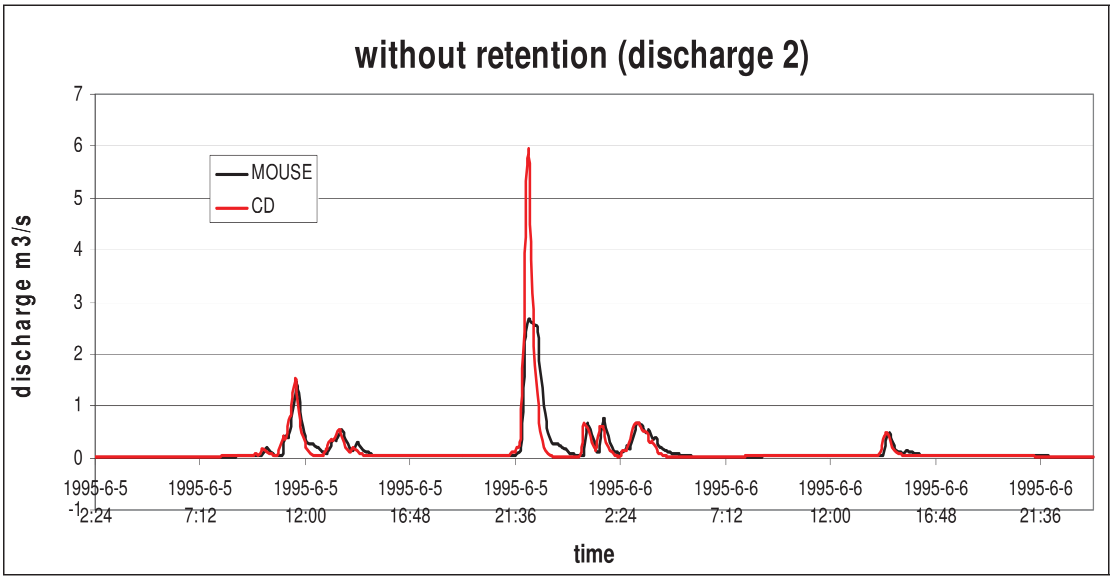


Figure 37: Simulation result of flooding condition modelling <u>without</u> retention basins – discharge from catchement 2

Calibration Results

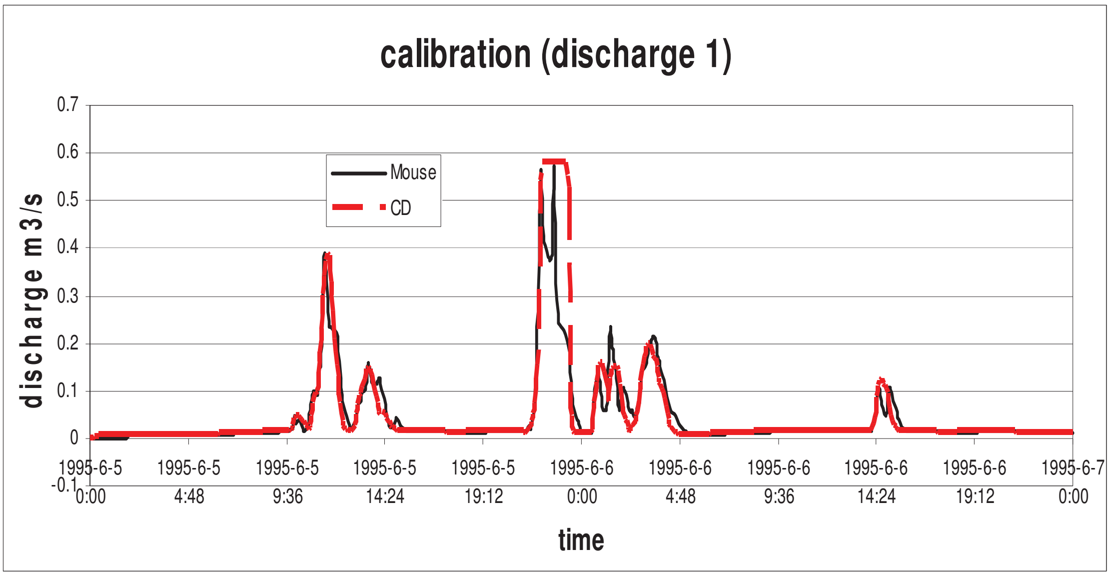


Figure 37: Calibration result of flooding condition modelling – catchment 1

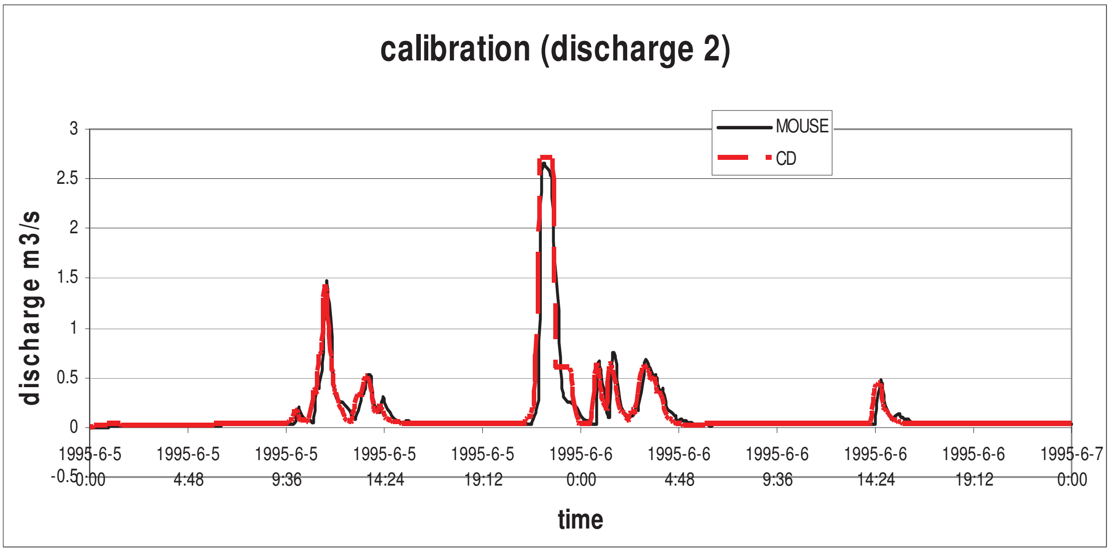


Figure 38: Calibration result of flooding condition modelling – catchment 2

Compare the result of calibrated model after added retention basin, the peak values in CITY DRAIN results that above the peak values of the MOUSE model are removed(Figure 37,38)), in other words, this part of water has been stored in the retention basin, and compensated by the longer recessional period. After calculation, the total areas covered in the graphs are same, which means the water volume should be same.

Table 5: Statistical comparison of calibration result (flooding condition modelling)

E		Water Balance		
Dischage 1	0.596685		**MOUSE**	**CD**
		Input	25329.43125	
		output	24866.59725	24957.6
Dischage 2	0.895857	**Difference %**	0.359276721	

Due the adding of retention basin, model results have a big change on the peak values. The differences can be observed by comparing figure 35 with figure 37, and figure 36 with figure 38. Thus, E results are not good as before, especially for the first catchment (Table 5), it is understandable, even so, that results are still acceptable. The difference for water balance is quite small, only 0.3% more water produced by CITY DRAIN.

Besides the reasonable imperfect point on the peak values, a small peak is mismatched in the result of the first catchment, rest of the results are quite good,

Verification results

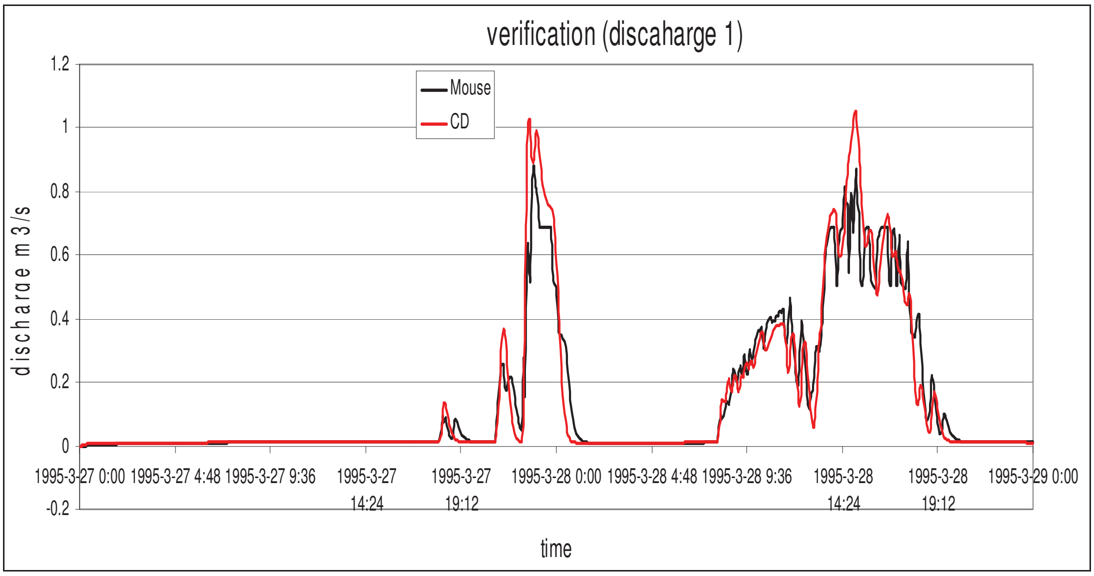


Figure 39: Verification result of flooding condition modelling – catchment 1

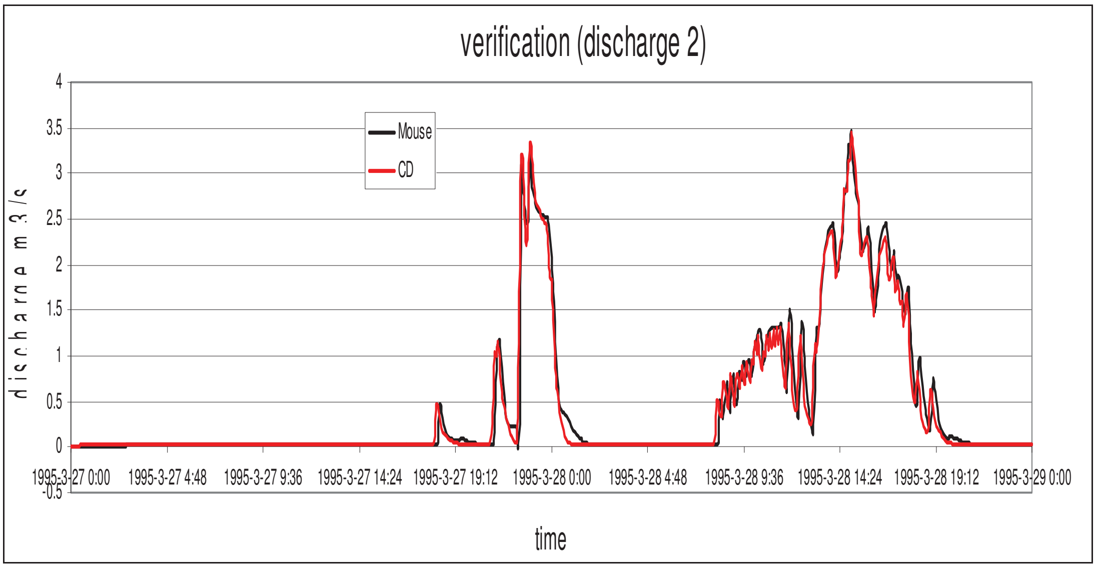


Figure 40: Verification result of flooding condition modelling – catchment 2

Table 6: Statistical comparison of verification result (flooding condition modelling)

E		**Water Balance**		
Dischage 1	0.893662		**MOUSE**	**CD**
		Input	80044.63125	
		output	76655.77143	79672.8
Dischage 2	0.957923	**Difference %**	3.769182921	

Figure model 2 result of verification R^2 and water balance

It is can be concluded that the CITY DRAIN result is quite close to the MOUSE result, including the peak values. Besides, it is good that the E result for "catchment 1" (Table 6) is increased, around 0.9. But, the difference of water balance more significant.

According to the "maximum effluence flows" parameter set for calibrated model was 0.57m3/s for the first retention basin and 2.7 m3/s for the second, for this rainfall event both of them did not reached, whereas, the results are still very close to "observe result" even with retention basins.

5.1.4 Modelling of strategic planning

Using the same calibrated and verified model with retention basins to discuss the potential usability of CITY DRAIN models for strategic planning is the basic concept of this part of the report. There are three scenarios are chosen to do the analysis,

- ✓ Urbanization (increase of percentage of impervious area)
- ✓ Population (increase of amount of inhabitant)
- ✓ Climate change (increase of intensity of rainfall)

The scenarios have been selected are present challenges in the front of the urban water management and simulation results obtained from these scenarios are quite important for them in developing strategic planning.

To analyze the results, the attention will be concentrated on the discharge of the outlet

Urbanization
Along with expansion of urban area, more building will stand up and pavement will be constructed around buildings. Apparently, impervious area will increase. In this scenario, the increase percentage is 30%.

Population increase
More inhabitants lead to more water consuming and more wastewater producing. Therefore the input file of DWF is the object will be changed during the simulation. The increase percentage is 50%

Climate change
It is a sensitive topic has been mentioned frequently during last years. For the Integrated Urban Water Management, the most important effect is the increase of rainfall intensity. Heavy intensive rainfall is the dangerous signal to urban area, especially the area with low capacity in drainage system is vulnerable by flooding. By increase 20% of rainfall volume, the model performance will be examined.

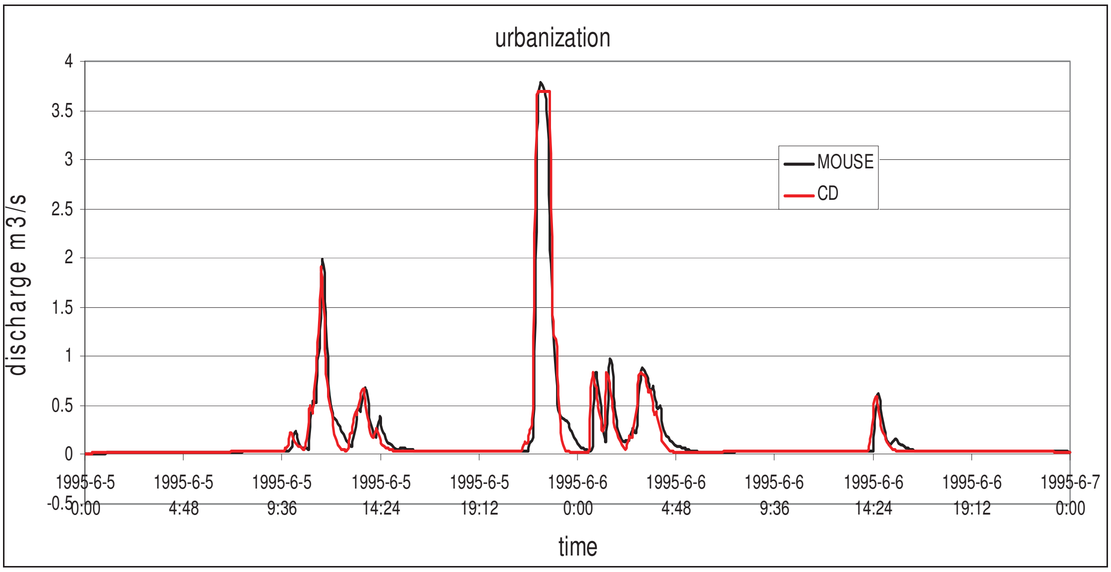


Figure 41: Simulation results of strategic planning – urbanization

Table 7: Statistical comparison of "urbanization" simulation

E		Water Balance		
			MOUSE	**CD**
Dischage	0.916267	**Input**	31145.62802	
		output	30697.08243	30737.1
		Difference %	0.128485353	

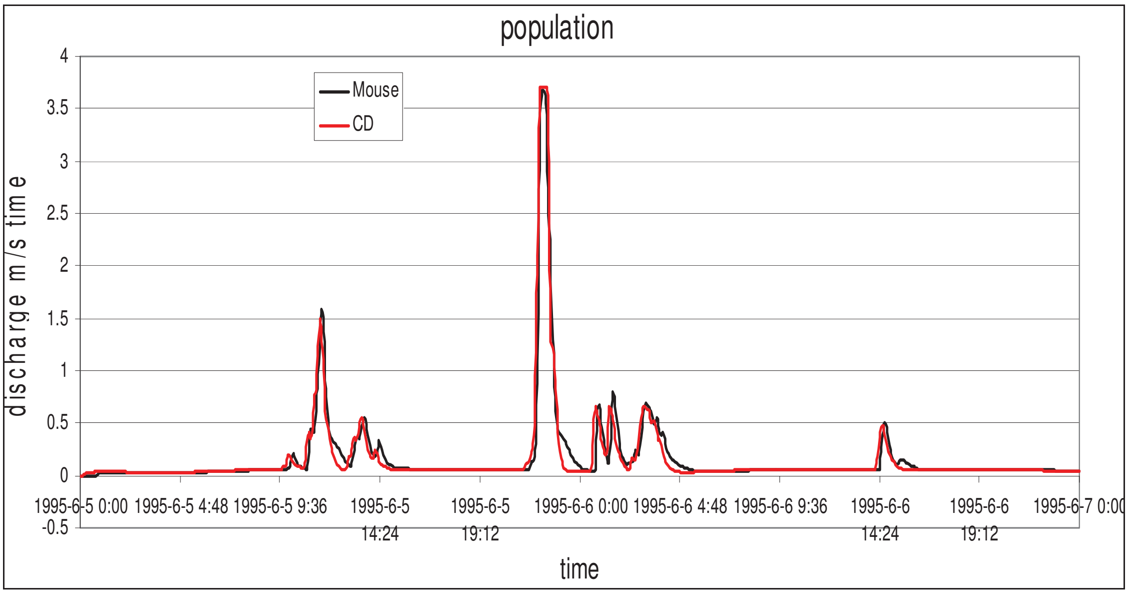


Figure 42: Simulation results of strategic planning – population increase

Table 8: Statistical comparison of "population increase" simulation

E		Water Balance		
			MOUSE	CD
Dischage	0.918246	Input	28033.1911	
		output	27592.42731	27998.4
		Difference %	1.44818579	

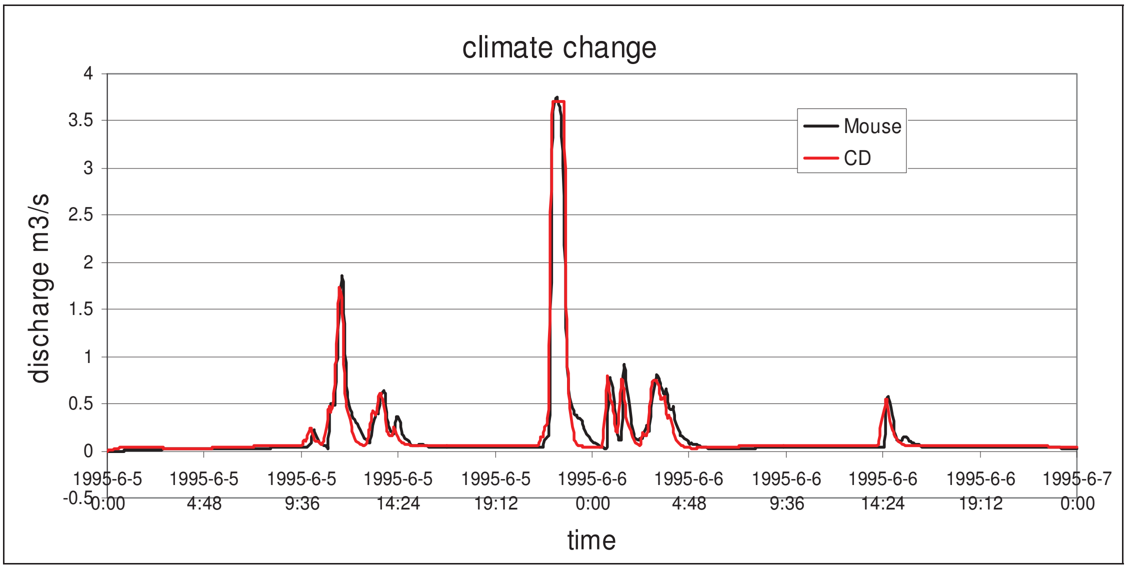


Figure 43: Simulation results of strategic planning – climate change

Table 9: Statistical comparison of "climate change" simulation

E		Water Balance		
			MOUSE	CD
Dischage	0.924148	Input	36280.06002	
		output	28706.4	30042.43
		Difference %	3.682537485	

By looking at the result profiles, CITY DRAIN model performs well, E numbers are the best evidence, and the average result for E is 0.918. Only several small peak values are not produced, the highest peak values of "climate change" scenario (Figure 42) and "urbanization" scenario (Figure 41) from MOUSE are a little higher. The explanation regarding to the phenomenon is that MOUSE model is physically-based detail model, everything happened in reality are included. In the flooding conditions, sewer system is filled up by water, meanwhile, water spilled out on the ground tends to flow back to the sewer, therefore more water flooded on the ground will definitely produce more pressure

to the downstream pipes, and the pressure will push more water pass the pipes in the same time interval. The situation reflected in the simulation results is slightly higher maximum discharge value than expected, if much higher, the model is failed and recalibration is needed.

For the urbanization scenario, with respect to the water balance part, the difference is quite small, only 0.4%, compared to MOUSE outflows. But the climate change scenario has the biggest different.

There are two possible explanations can help us to understand what happened, and why CITY DRAIN models tend to produce more water than MOUSE models. The same idea has to be picked up again. MOUSE contains physical detailed data which means pipes and manholes are treated explicitly, undynamic water can stay in, if there is. The second possible explanation concerning to the simulation period. From the water entering the sewer system to it flows out to the WWTP, the process consumes time, the bigger catchments require more time, and this factor has been accounted by MOUSE model. Supposing, at the end of simulation period, parts of water was still flowing but did not reach the outlet, this part of water will be not recorded by result files. In contrast, CITY DRAIN models calculate the discharge water at the outlet only depending on the input of parameters.

To justify the changes of results are reasonable from the CITY DRAIN model, an additional comparison is carried out, which is to compare the result of changed model with the result from the original model.(see appendix)

5.2 Discussion of simulations results

Conclusion of sewer component modeling

To conclude the model performances that built up in CITY DRAIN software, specific on sewer component, first of all is about calibration and verification results. In general, they all are acceptable based on the E results, except one “overflow” result is 0.7, the rest are above 0.9. Simulation results matched “observed” data very well.

The difference in outflow volume is around 0.85% compared to MOUSE results and the differences are likely unavoidable, because of different mechanisms, physically detailed model considered the whole system in detailed ways, but CITY DRAIN simulates the system from a general level.

The entire report is discussing about the potential usability of conceptual model for IUWM. The globe optimization is the ultimate goal referring to this management. Therefore, results from detailed aspects are not highly concerned. The outflow results at the outlet are sufficiently good in this specific case, but in other cases, with other types of conditions, wheather model performances can be good as same will be answered by comprehensive researches.

Conclusion of flooding condition modelling

To sum up the performance of the model with retention basin, three phases could be followed. The first phase is the model without retention basin. It is hard to simulate the flooding situation by CITY DRAIN, because of the different mechanism applied for conceptual model. Water is assumed flowing in and out without any limitation, e.g. maximum effluent flows. Despite the peak values, the simulation result is still reasonable good and fully acceptable.

Second phase is the model added with the retention basin for to mimic flooding conditions. The problem happened on the peak values are removed, and the results became closer to “observed” data. Although R2 value for “discharge 1” is a little low, mainly because of the remediation made on the peak value, the results are also quite good.

The last phase is verification. Using the calibrated retention model to run another event. Overall speaking, the result of verification is good, and the model performances can be improved by adding retention basin to represent the flooding conditions better.

Conclusion of model performance for three scenarios

Urbanization, population increase and climate change is the three present challenges in the front of IUWM. They are treated as globe problems, not only for specific area.

Although the simulations are carried out only depending on some conceptual relations, the results are quite close to the physically detailed MOUSE model results. However, drawbacks still need to be admitted, such as the surcharge, backwater effects. The function of retention basins has presented again with the scenarios.

The modelling does not show any preference to certain changes and sensitivity for each of scenarios is equal. Supposing the drawbacks can be eliminated, the potential usability of this model is high.

Conclusion of WWTP module

To build up this model the key point is only to demonstrate the potential usability of this software for IUWM. For testify the real usability, a set of observed results must be ready, and in other words, some reliable data can be used to compare the results of the CITY DRAIN model. Unfortunately, MOUSE does provide treatment plant model, the other specific software must be invited, e.g. WEST. Moreover, WWTP software is rather complex referring to the basic concepts of treatment plant; to manipulate it need a lot of time.

MOUSE software provides the TRAP module, which can calculate wastewater concentration with different conditions. For example, sediment transport and water quality for both urban catchments surfaces and sewer systems. Since pollutants are carried by sediment, sediment transport processes and water quality in sewer systems are

closely interconnected. However, the concept applied on the same part of the CITY DRAIN model is simple, concentration of pollutants are inputted to the model together with DWF data, and concentration is diluted by the rainfall water, or in other words, other conditions, e.g. transportation of sediment, are not considered. The result from CITY DRAIN has low comparability.

6. Conclusions and future works

6.1 Conclusions

The potential use of simplified conceptual integrated model for strategic planning purpose for IUWM has been discussed. City Drain model is designed as an integrated modelling tool for integrated analysis of the urban wastewater system, which uses simple conceptual relations to describe the complex connections between several components of urban water cycle. The performances of three models built up in City Drain compared to results of MOUSE models are quite good and acceptable. Even though it cannot reasonably predict the flow during surface flooding, surcharge and significant back water effects, with extensive calibration for different flow conditions, CITY DRAIN model has good potential to be used as a strategic planning purpose..

Meanwhile, several advantages and disadvantage were discovered during the research, mainly based on the comparison to physically based models, namely, MOUSE.

Advantages

- City Drain is modular software, where all modules are prepared in provided in a "library". Simply selecting from the library and according to the flow of water in the system is the way to structure models.
- The model construction enables to display a catchment in a visualized way.
- Its data requirements computational time is significantly lower than the requirements of the physically based model.

Disadvantages

- It has many calibration parameters, for example, the calibration parameters of the sewer component include the runoff coefficient, the initial loss (mm), the permanent loss (mm/day), the number of time steps and the Muskingum parameters K(s) and X. And the number of calibration parameters increase as other structures are included, like overflows and pumping stations. This makes the calibrate process difficult and even more difficult to calibrate the model manually.
- Effect of some parameters overlap, which disturbs the calibration process, for example, the parameters K and the number of time steps, has been observed during calibration process.
- City Drain model performs quite well for free flow condition (no surface flooding and surcharge).For surface flooding and surcharge conditions is not expected to produce reliable results owing to its conceptual nature. The retention block provided to mimic such flow conditions improves its performance.
- The adaptability of City Drain model is low. If changes made in the system, for example if the outfall pipe diameter is upgraded, re-calibration is needed.
- Retention basin, exceed maximum effluence flows, model filed

6.2 Future works

The time for an MSc research is limited, only certan areas have been researched by and presented here. Therefore, the following points can be used as a guide for future research steps:

- CITY DRAIN model has the potential to be used as a strategic planning tool for integrated urban wastewater modelling tool. In this report, the simple WWTP module was included. However, it can not be used as a real representation of WWTP. The development of another WWTP block which includes the process in wastewater treatment plant such as ASTM1 model is recommended.
- During the research, a lot of time has been spent on the manually calibrating the model. Despite the time consumption, the results are still subject to personal judgment. Therefore, development of automatic calibration process is highly recommended to be added into the system.
- Improvements can also be made on the graphical user interface to make the process friendlier and ease data input output system.
- Provision of methodology for estimation of model parameters from measurable catchment characteristics.
- For the strategic planning, management needs more visualized answers. Numbers, graphs are good, but hardly related with real life. Visualization is the best way to connect the simulation result with real life and help management make decision easily.

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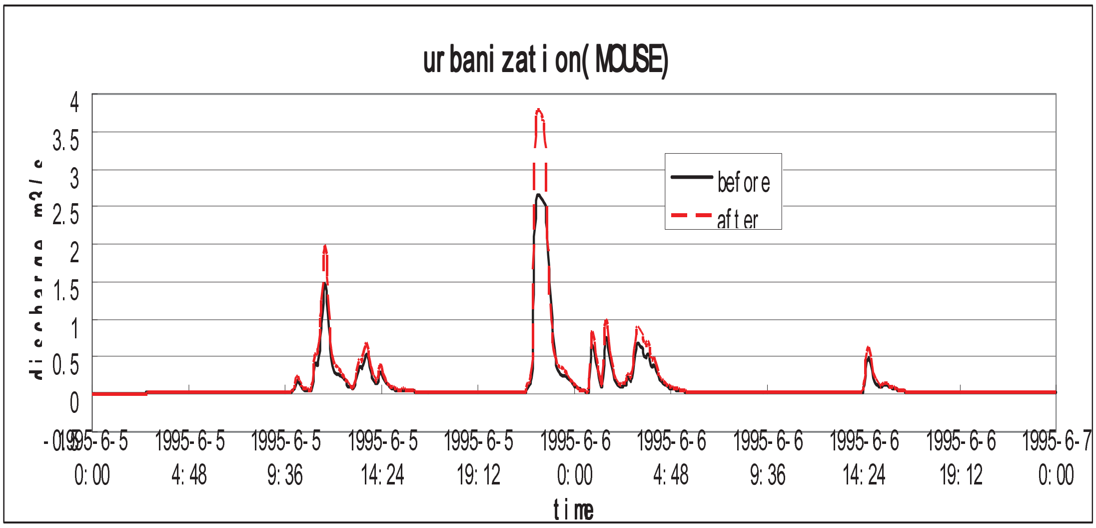
Appendixes

DWF program:

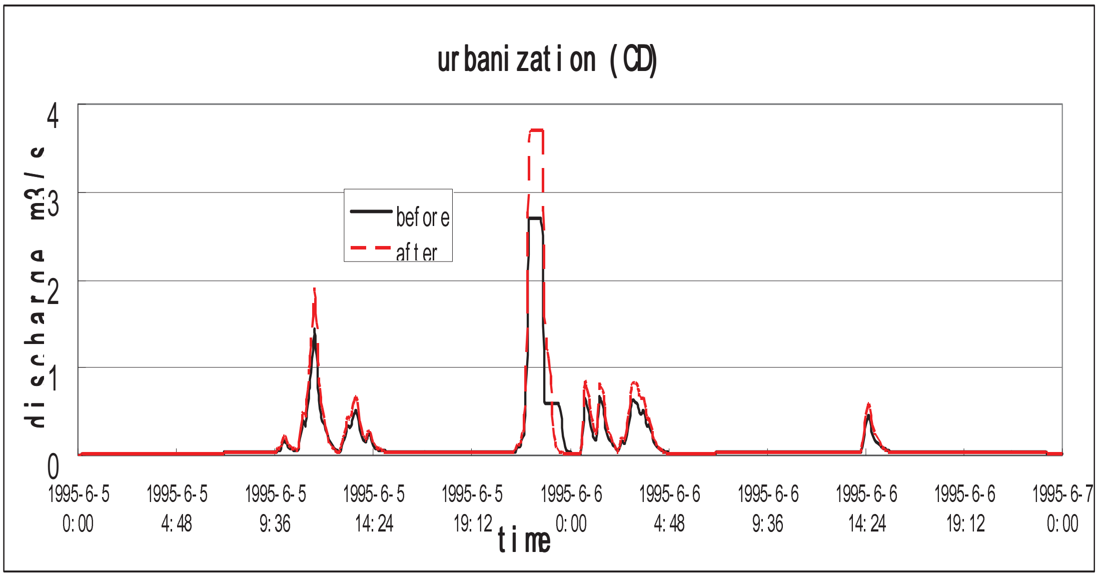
```
  Input #12, TimeAmount(I)
Next I
Close #12
    Open OutputFile For Output As #11
    HourAttime = stHour
    For I = 1 To CalStep
        If HourAttime > 24 Then
           HourAttime = 1
        End If
       totalAmount = uCapital * TimeAmount(HourAttime)
        Print #11, totalAmount
        HourAttime = HourAttime + 1
    Next I
    Close #11

    MsgBox ("Calculation is finished")


End Sub

Private Sub CmdOpen_Click()
    CommonDia.CancelError = True
    CommonDia.Flags = cdlOFNHideReadOnly
    ' 设置过滤器
    CommonDia.Filter = "All Files (*.*)|*.*|Text Files" & _
    "(*.txt)|*.txt|Batch Files (*.bat)|*.bat"
    ' 指定缺省的过滤器
    CommonDia.FilterIndex = 2
    ' 显示“打开”对话框
    CommonDia.ShowOpen
    ' 显示选定文件的名字
    txtInput.Text = CommonDia.FileName
    InputFile = CommonDia.FileName
End Sub

Private Sub CmdOpeno_Click()
    CommonDia.CancelError = True
    CommonDia.Flags = cdlOFNHideReadOnly
```

```
    ' 设置过滤器
    CommonDia.Filter = "All Files (*.*)|*.*|Text Files" & _
    "(*.txt)|*.txt|Batch Files (*.bat)|*.bat"
    ' 指定缺省的过滤器
    CommonDia.FilterIndex = 2
    ' 显示“打开”对话框
    CommonDia.ShowSave
    ' 显示选定文件的名字
    txtOutput.Text = CommonDia.FileName
    OutputFile = CommonDia.FileName
End Sub

Private Sub Command1_Click()
    End
End Sub
```

Additional comparison of "strategic planning" modelling results



Comparison of changes before and after "urbanization" scenario (MOUSE)



Comparison of changes before and after "urbanization" scenario (CD)

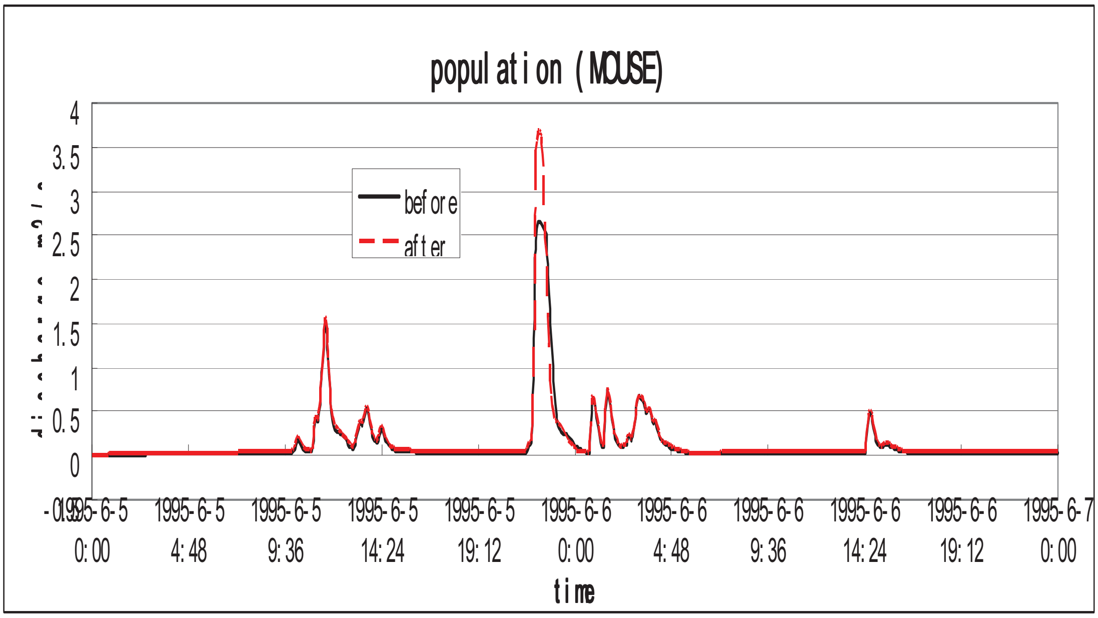
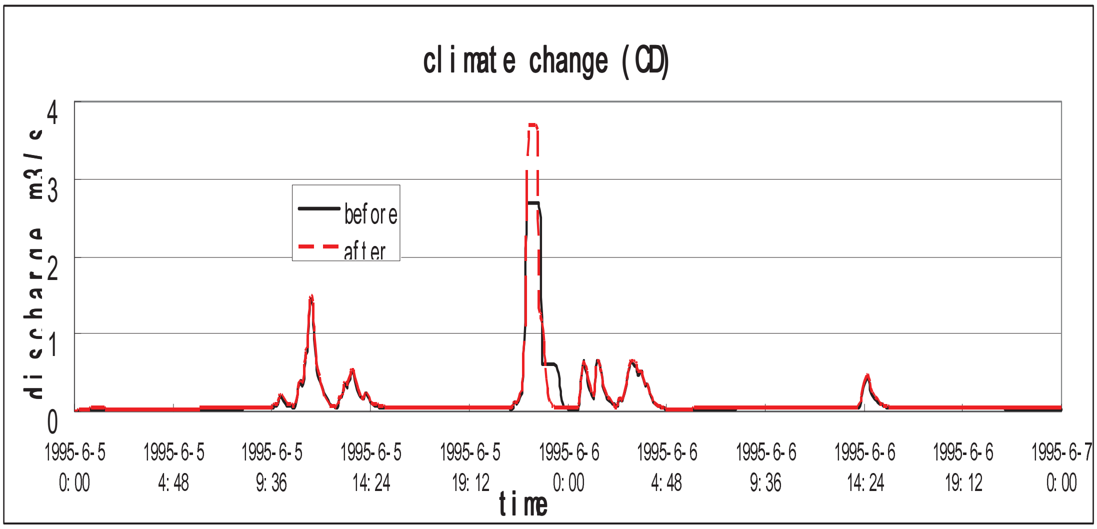
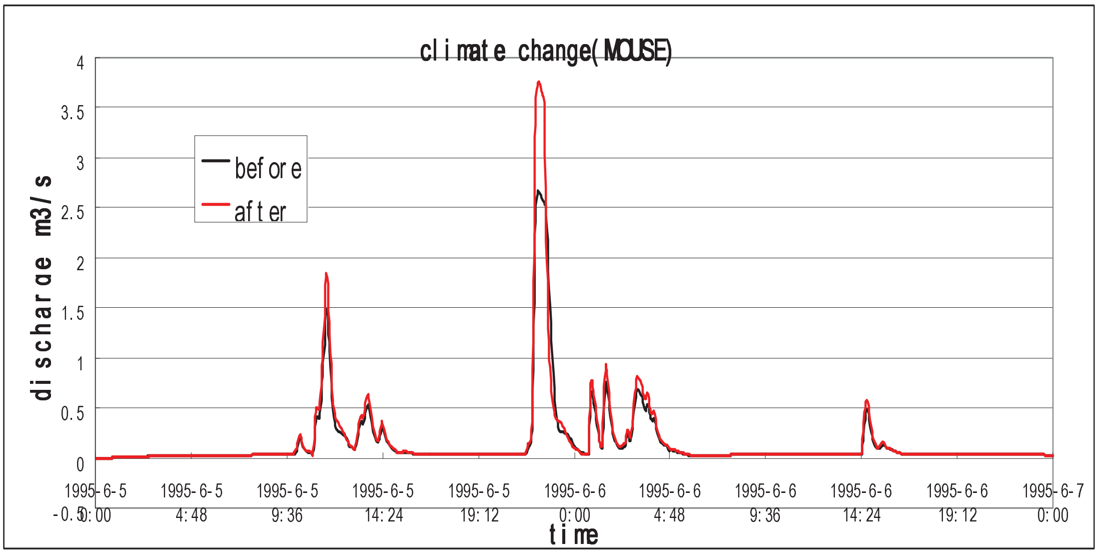


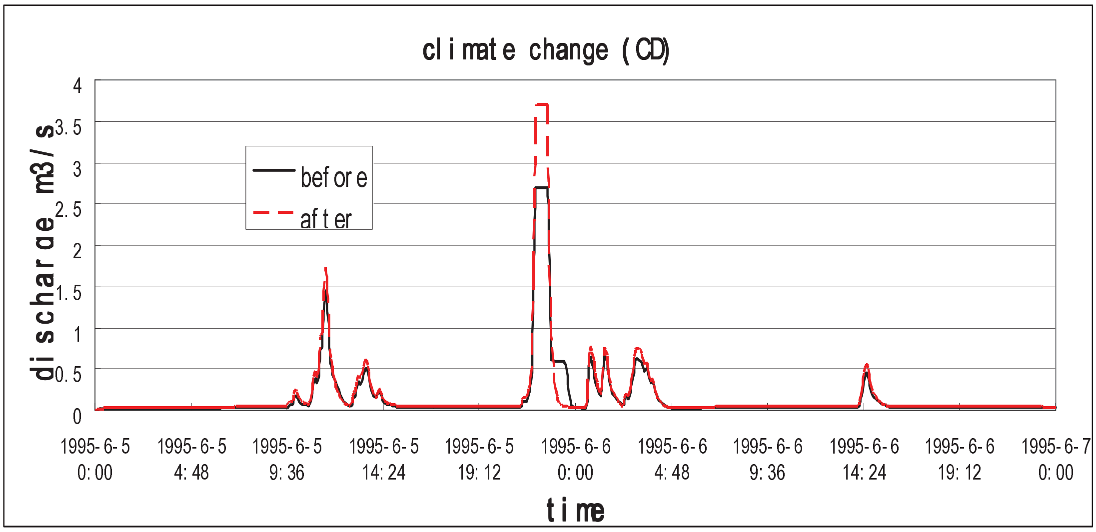
Figure 45: Comparison of changes before and after "population increase" scenario (MOUSE)



Comparison of changes before and after "population increase" scenario (CD)



Comparison of changes before and after “climate change” scenario (MOUSE)



Comparison of changes before and after “climate change” scenario (CD)