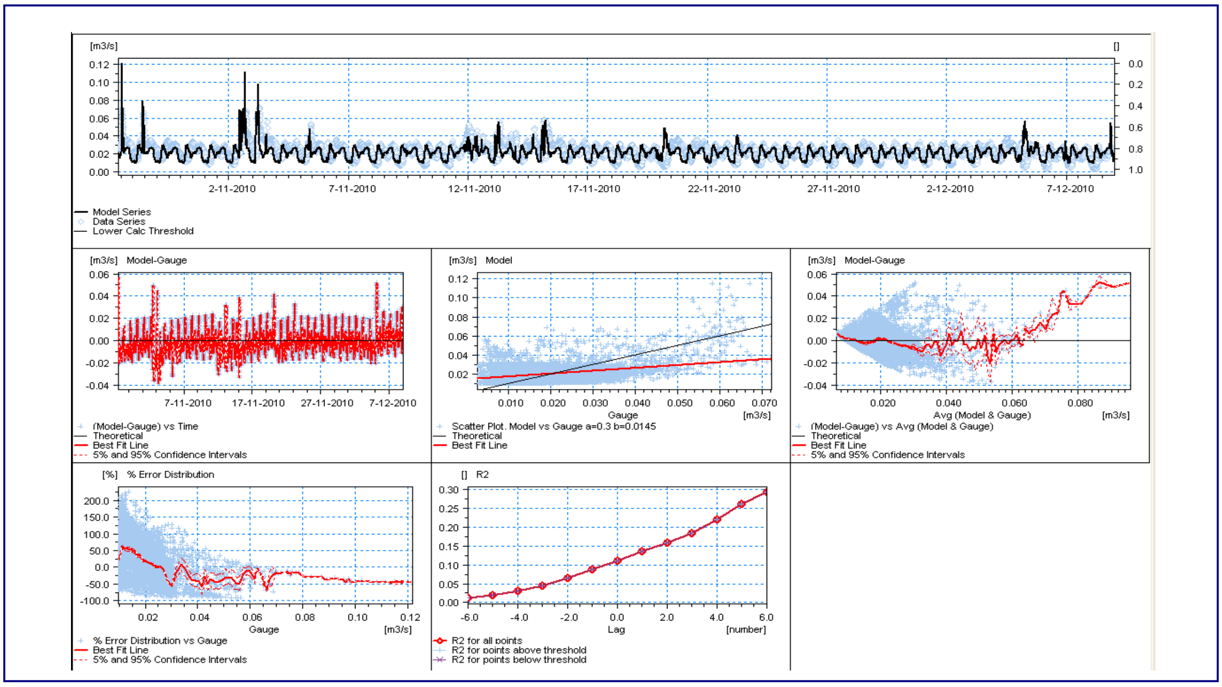

Hydraulic and Hydrological Simulations of Sewer System in Majorna Area, Gothenburg

Evaluation of system and suggestions for improvements

Master of Science Thesis in the Master's Programme Geo and Water Engineering

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Statistical analysis for calibration period (with permission of DHI)

Reproservice/ Department of Civil and Environmental Engineering Göteborg, Sweden 2011

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ABSTRACT

In the year 2010, Gothenburg Water utility has decided to study and improve the sewer network system of Majorna region located at Gothenburg city. Hydraulic and hydrological properties of sewer system were modeled and simulated by MOUSE, one of the tools provided in MIKE URBAN software, made by DHI (Danish Hydraulic Institute).

Most of the input data needed for simulation was provided by the Gothenburg Water utility databases and the GIS-based map of Gothenburg sewer systems, SolenX.

The calibration of the model has shown that although there is a good match between the model results and the measured values at one of the measuring nodes at the area, there is a difference in the other one which its reason should be studied and investigated in another study.

Finally the tests and comparisons between the sewer system at this area and the standard values have shown that the pipes leakages are the most problematic matter of system and solving this problem will improve the system considerably.

Key words: Sewer system, GIS MOUSE, hydraulic and hydrological simulation, leakage

To My Dear Mother and Father

Contents

Preface

In this study the sewer network system at Majorna area, Gothenburg Sweden has been simulated with MOUSE software and some methods for improvements of system have been suggested. This project was carried out at Gothenburg Water utility between December 2010 and May 2011.

The simulation and calibration parts of this project were done under supervision of Malin Suneson. She is highly appreciated for her help in these parts as it is always difficult when starting a new model needing lots of databases and assistance. The validation and improvement parts were done under supervision of Håkan Strandner and I would like to thank him also. I gratefully acknowledge my supervisor Annika Malm who always helps me with every aspect of the technical parts of project as well as the report. I would like to express my appreciation to Assistant Professor Thomas Pettersson for his support during the project. I would also like to thank all of the Gothenburg Water utility staff for their help.

And "Save the Best for Last" I would like to thank my lovely parents for their helps and supports during my study and my whole life.

Notations

A	Flow area
A_o	Area of the orifice
A_n	Area of sub-catchments
b	Width of weir
C_d	Orifice coefficient
C_d	Discharge coefficient
D	Hydraulic diameter
D_m	Diameter of manhole
f	Friction factor
g	Gravity acceleration
H	Difference of two levels
H_{bott}	Outlet bottom elevation
H_m	Water level in manhole
H_{out}	Water elevation at outlet
I_f	Friction slope
I_0	Bottom slope
L	Distance between two points
M	Inverse of Manning number
n	Manning coefficient
n	Number of cells
p	Pressure
Q	Flow discharge
q_{ldr}	Leakage and drainage flow
q_s	Sanitary water flow
q_{tot}	Total flow of wastewater

R_n	Hydraulic radius
S	Slope of water surface
T	Time
t_c	Concentration time
U	Average flow velocity
V	Average flow velocity
V_m	Velocity of flow
X	Distance
x_n	Distance between manholes
y	Flow depth
y_c	Critical depth
y_n	Normal depth.
y_n	Bottom levels of manholes
z_n	Levels of measurements
α	Coefficient of velocity distribution
$\triangle p$	Difference in fluid pressure between two points
Δt	Simulation time step
ρ	Fluid density
φ_n	Imperviousness coefficient

1 Introduction

Wastewater is defined as liquid or solid wastes "removed from residences, institutions, and commercial and industrial establishments, together with groundwater, surface water and stormwater" (Metcalf & Eddy 2004).

As long as cities and urban life have been developed during centuries the wastewater and sewage convey have became important issues for municipalities and other authorities. The problems caused by wastewater flows in terms of "public health, aquatic species or aquatic habitat" (EPA 1999), alongside "occasional fish kills, numerous beach closures and potential odors and solids deposits in the receiving water body" (EPA 1999) were all caused a considerable attention in this subject.

The goal of municipalities is to convey, treat and reuse the wastewater in a way that does not harm the public health and environment. They always try and test new methods to improve the sewage network system and wastewater treatment plants.

The aim of this thesis is to suggest methods to improve the sewer network at Majorna area located in Gothenburg city in a way that less stormwater flow be conveyed to the wastewater treatment plant Ryaverket and instead released into the receiving water, Göta Älv.

2 Theory

2.1 Wastewater generation and sewer systems

2.1.1 Wastewater generation

To gain the most efficiency form wastewater treatment, the amount and characteristics of flow in different times of the year should be known. This helps in building of both sewer networks and their properties and the wastewater treatment plants.

"The major wastewater producers are cities, industries and agricultural operations" (Viessman & Hammer 2005). There are some factors in estimating the wastewater generated by a society, but it is known that it is always depending on the number of inhabitants and also "the per capita discharge to the sewer" (Viessman & Hammer 2005). The geographical location of place has an important role in both drinking water consumption and hence the sewage production and according to this criterion an approximate value of 60-80 percent of water consumption is assumed as sewage volume. This value can be different at different municipalities, such as Gothenburg city which assumed it as 100 percent.

The surface runoff generated by rainfall or stormwater is the "second major urban flow of concern" (Butler & Davies 2004) in urban drainage flows. Its importance is mainly because of the risk of overflow on public places or basement flooding and also harmful effects on public health such as pesticides or suspended solids and hence predicting the long periods of rainfall and also return periods of floods have an important role in designing of urban drainage systems and wastewater treatment plants.

2.1.2 Sewer systems

Generally there are two kinds of sewer systems in each wastewater network. The one which "conveys both sanitary sewage and stormwater through a single pipe" (EPA 1999) is called combined system and the other one which conveys the sanitary and stormwater flow through two separate pipes referred to as separate system. Figure 1 shows a schematic view of these two systems.

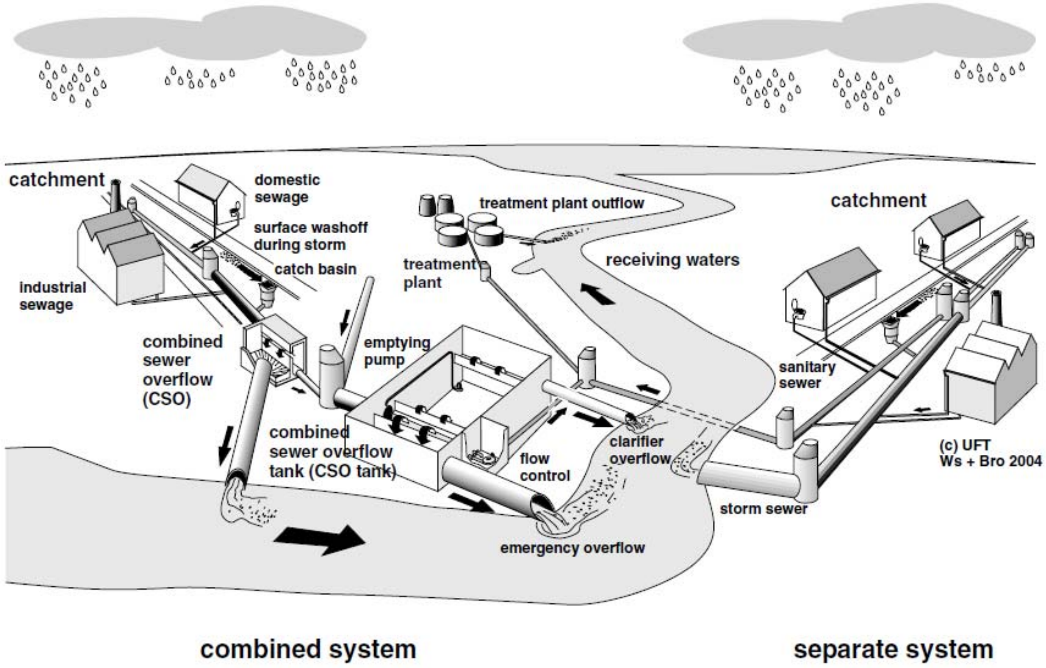

Figure 1 Two types of sewer systems (with permission of Stephan Fuchs).

Choosing each of these two systems has been a controversial discussion during some decades and most researches and companies has not given one straight answer (Welker 2008; Brombach *et al* 2005). However lots of research works have done about this subject during past years which most have a focus on the effects of these systems on environment.

One research example was done by A.Welker where the amounts of "two classical wastewater parameters (chemical oxygen demand (COD) and ammonium) supplemented by three pollutants (copper, carbamazepine and estradiol)" (Welker 2008) were studied in flows caused by the two sewer systems.

The main emissions caused by each of these two systems to the receiving and natural waters included wastewater treatment plant flow for both, as well as effluent of stormwater pipes for separate systems and CSO's flow for combined type. This is shown in the Figure 2.

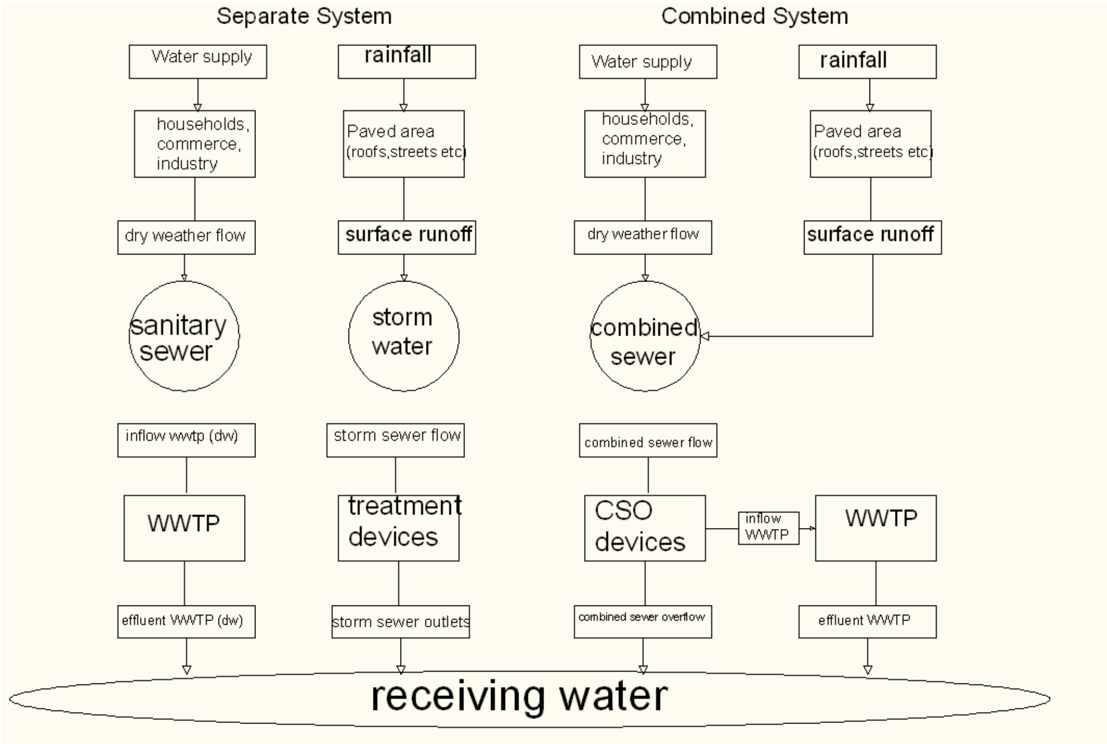

Figure 2 Effluents of combined and separate sewer systems to the receiving waters (According to Welker,2008).

The results of this study have shown that the emissions carried to the receiving waters by separate sewer systems such as copper and PAHs are more than those of combined systems. This is obviously because of the treatment process doing in the wastewater treatment plant before releasing to receiving water in combined type, while the separate system convey the stormwater and runoff directly to natural water bodies.

On the other hand the emissions caused by dry weather flow to the receiving water such as estradiol are higher in combined systems because of CSO effluents to natural waters.

The second research work which was done by H. Brombach *et al* to find the better choice between the two sewer systems, "measured concentration data for a range of pollutant parameters in the sewer" (Brombach *et al* 2005) and also for the effluent comes out of wastewater treatment plant were investigated.

The results of this work has shown that the combined system are in favor of releasing less pollutants such as COD and heavy metals while the separate system produce less nutrients such as phosphorus. Also it shows that in the case of improving the wastewater treatment plant the combined systems are more in favor.

2.2 Leakage in sewer systems

Leakages in urban sewer systems usually caused by a number of factors, including "aging, excessive demand, misuse, exposure, mismanagement and neglect" of the system (Wirahadikusumah *et al* 1998) that later lead to "deteriorated pipes, manholes, and pump stations" (EPA 2000) and finally leakages in wastewater networks.

In case of leakages in sewer systems and due to groundwater level two phenomena occur; Infiltration and exfiltration.

Infiltration occurs when the sewer system is located beneath the groundwater table and water enters the sewer systems through cracks and joints of pipes. This causes extra and unwanted flow entering the sewer system and wastewater treatment plants.

Exfiltration, on the other hand, occurs when the sewer system is located above the groundwater table and sewage leaks through the pipes and contaminates the groundwater, including "high levels of suspended solids, pathogenic microorganisms, toxic pollutants, floatables, nutrients, oxygen-demanding organic compounds, oil and grease" (EPA 2000).

To prevent infiltration and exfiltration in sewer networks some repairing or rehabilitation works are done. These are usually classified into two main methods; External methods and internal methods.

External rehabilitation usually is done "by excavating adjacent to the pipe, or the external region of the pipe is treated from inside the pipe through the wall" (EPA 2000). Some examples are external point repairing and different kinds of grouting.

Internal methods are the most in use by municipalities around the world and below some of their types are described.

- Chemical grouting: in this method the chemical grout are pushing through the pipes cracks and together with the soil around forming a "waterproof collar around leaking pipes" (EPA 2000).

- Sliplining: In this method after pushing a pipe in line with the sewer pipe the space between them are grouted and being sealed.

- Closed-fit lining: In this method after installation of a lining pipe into the existing pipe its diameter expands and matches with the sewer pipe to make a tight fitting.

Choosing each of these methods is due to number of customers and geographical, meteorological and monetary conditions. Gothenburg Water utility usually uses closed-fit lining method and rarely Sliplining method.

2.3 Solen X

Solen X is the GIS-based map of wastewater network in the city of Gothenburg. The map contains some important information such as the pipes and their properties, the CSOs, the border of the areas, the households connections to the main system, the kind of the sewer system, the manholes, the counter lines etc. The map provided in the Mike Urban for this project work has been imported from Solen X. Solen X was regarded as a reference map in this project work.

2.4 MOUSE

MOUSE is one of the tools provided in MIKE URBAN which is used widely in water engineering project works. It can be used in many aspects such as hydrology and hydraulic projects, modeling and simulating the wastewater systems (including both stormwater and sanitary sewage) and also water quality. Below the concepts of hydraulic and hydrological elements in wastewater engineering and the way they are modeled in MOUSE are described.

2.4.1 Modeling hydraulic elements with MOUSE

When modeling networks and their properties in MOUSE, the pipe flow (either in form of subcritical or super critical) has been simulated by MOUSE. The simulation has done on the basis of "an implicit, finite difference numerical solution of basic 1-D, free surface flow equations (Saint Venant)" (DHI 2009).

The Saint Venant equations including continuity and momentum equations read as:

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = 0 \qquad (1)$$

$$\frac{\partial Q}{\partial t} + \frac{\partial \left(\alpha \frac{Q^2}{A}\right)}{\partial x} + gA\frac{\partial y}{\partial x} = gA(I_0 - I_f) \qquad (2)$$

Where Q is the discharge, A is the flow area, y is the flow depth, g is the gravity acceleration, x is distance, t is time, α is the coefficient of velocity distribution and I_f and I_0 are friction and bottom slope respectively.

The elements being modeled by the MOUSE numerical modeling in this project work are listed below:

1. Links

-Pipes

2. Nodes

- Manholes

-Basins

-Outlets

3. Functions

-CSO's and their properties

2.4.1.1 Links

Links (pipes) are the connecting parts of each network, where flow passes through them. When modeling them in MOUSE, they have assumed as one-dimensional conduits which can be in form of either closed conduit or open channel.

Also the fluid is considered to be Newtonian, which means that the viscosity of the flow is independent of the fluid shear stress.

The fluid pressure loss in a straight and uniform pipe is calculated by Darcy-Weisbach formula:

$$\Delta p = \frac{\rho U^2}{2}\frac{fl}{D} \qquad (3)$$

Where Δp is fluid pressure between two points, f is the friction factor, D is hydraulic diameter, L is the distance between two points, U is the average flow velocity and ρ is the fluid density.

When deciding to choose each type of links, then they should be defined on the basis of their properties.

The following assumptions have been made when modeling the pipe flow:

1. The flow is incompressible.

2. The slope is small enough to regard it as horizontal.

3. The wavelength is much larger than water depth; hence the vertical acceleration is neglected.

4. The flow goes sub-critically most of way.

Also when modeling at MOUSE there will be a choice of selecting the flow description among these three options:

1. Dynamic wave approach:

This method is used when the full momentum equation (equation 2) is used. This method is used mostly in networks where the bed slopes of pipes are small and can be neglected.

2. Diffusive wave approach:

This method is applied when the only terms used in the momentum equation are; "bed friction, gravity force and hydrostatic gradient" (DHI 2009) and hence there is backwater flow in the network. In this case the bed friction can not be neglected.

3. Kinematic wave approach:

When using this method the backwater effects can not be calculated while the slope of network can be so steep.

As the only types used in this work are closed pipes, their most important properties that should be defined at MOUSE are pipe materials, basins and detention structures and outlets.

2.4.1.1.1 Pipes materials

When defining pipes in MOUSE, one of the required input data is their materials. This has a special importance because the formula used to calculate the flow pattern at pipes is the Manning Explicit formula and so Manning's number should be defined on the basis of pipes material.

$$V = \frac{1}{n} R_h^{\frac{2}{3}} . S^{\frac{1}{2}} \tag{4}$$

Where V is average velocity, n is Manning coefficient, R_n is the hydraulic radius and S is the slope of water surface.

There are eight types of default materials with their corresponding Manning's numbers in MOUSE. These materials and their Manning's number are presented in the table below:

Table 1 Pipes material and their corresponding Manning numbers.

Material	M (in MOUSE software)	N=1/M
Smooth Concrete	85	0.0118
Normal Concrete	75	0.0133
Rough Concrete	68	0.0147
Plastic	80	0.0125
Iron	70	0.0143
Ceramics	70	0.0143
Stone	80	0.0125
Other materials	50	0.0200

2.4.1.1.2 Pipes cross sections and their dimensions

Another important property of pipe that should be defined prior to modeling is their cross sections and the dimensions they have.

MOUSE provides 5 different types of standard piped including:

1. Circular pipe
2. Rectangular pipe
3. O-shaped pipe
4. Egg-shaped pipe
5. Quadratic pipe

Choosing each of these types depends on the pipe dimension. Egg-shaped pipes and O-shaped pipes are shown in Figure 3.

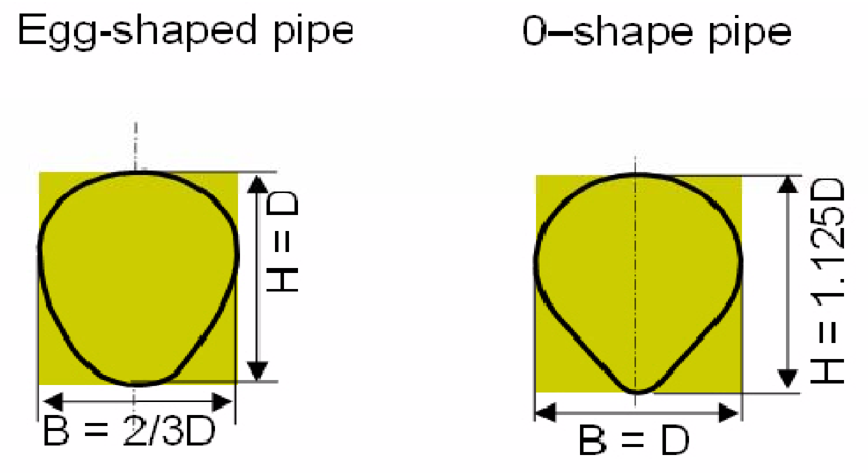

Figure 3 Egg-shape and O-shape pipes. (With permission of DHI)

2.4.1.2 Nodes

Nodes, defined as junction at most hydraulic articles, are the connection point of two or more pipes at each network.

Junctions are places where two streams with different velocity are meeting. This causes changes in velocity and pressures of both, which latter causes a difference in energy. The energy transfers form faster fluid stream to the slower one. The energy losses "through a junction are a function of flow areas, surface roughness and branch angle" (Blevins 1984).

In MOUSE nodes are defined by their X and Y co-ordinates and generally have these types: Manholes, basins and outlets.

2.4.1.2.1 Manholes

The main application of manholes in wastewater network system is providing "access to a sewer system" (Willi H. Hager & Corrado Gissoni Accessed April 2011) to provide;

1. Aeration of sewer,

2. Control the probability of clogging in sewer network

3. Changing any of the sewer elements such as discharge or diameter of pipes

Figure 4 shows a manhole, used for inspection purposes.

Figure 4 A manhole used for inspection. (Photo: Malin Suneson)

Generally there are three types of manholes used in each sewage network:

1. Through-Flow manholes

These manholes are used mostly for inspection and controlling of sewage network. These manholes are “connected to an equal upstream and downstream sewer of diameter D” (Willi H. Hager & Corrado Gissoni Accessed April 2011). There is one example at Figure 5.

Figure 5 Using a manhole for monitoring the sewage system. (Photo: Lars Lundborg)

2. Bend manholes

These kinds of manholes are actually the normal manholes at sewer network system where the shape of streets and hence wastewater network are making curves. Generally they have an angle of either 45 or 90 degrees.

3. Junction manholes

These kinds of manholes can be considered between the other two in manner of size and flow pattern, meaning that while they have equal upstream and downstream diameters they maybe somehow bended.

In Mike Urban program manholes are defined by their bottom levels (invert level), ground levels, diameter and shape. The following figure shows a manhole and its properties in MOUSE:

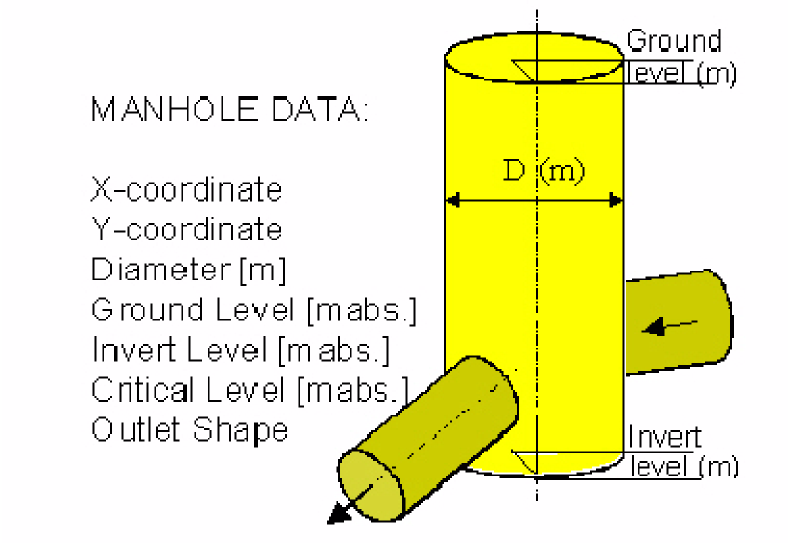

Figure 6 A manhole and its properties in MOUSE. (With permission of DHI)

The flow velocity at each manhole is calculated as:

$$v_m = \frac{Q}{(H_m - H_{bott}) \cdot D_m} \tag{5}$$

Where V_m is the velocity of flow at manhole, H_m is the water level in manhole, Q is flow and D_m is the diameter of manhole.

2.4.1.2.2 Basins and detention structures

One of the most in-use and efficient types of stormwater storage properties are concert basins. These facilities are widely used due to their flexibility and ability to build in most geometric shapes.

Basins can be applied both in-line and off-line to the sewer systems. This depends mostly on the strength of the system first flash, capacity of downstream pipes and the size and shape of the watersheds.

When using the in-line system an outlet and inlet are assumed for the basin, where the outlet has less hydraulic capacity. The flow is detained in the basin when the inflows discharge in exceeded than the outlet capacity.

Off-line storage, on the other hand, which connects to the system parallel, stored the stormwater during an overflow situation.

These kinds of nodes in MOUSE are in each of these shapes: tanks, reservoirs and natural ponds and are defined with some properties as: elevation, the area of water surface and cross section and the outlet shapes.

The most uses of basins in this program are in the cases of overflow where the program makes the basin size bigger to avoid street flooding. Figure 7 shows this phenomenon:

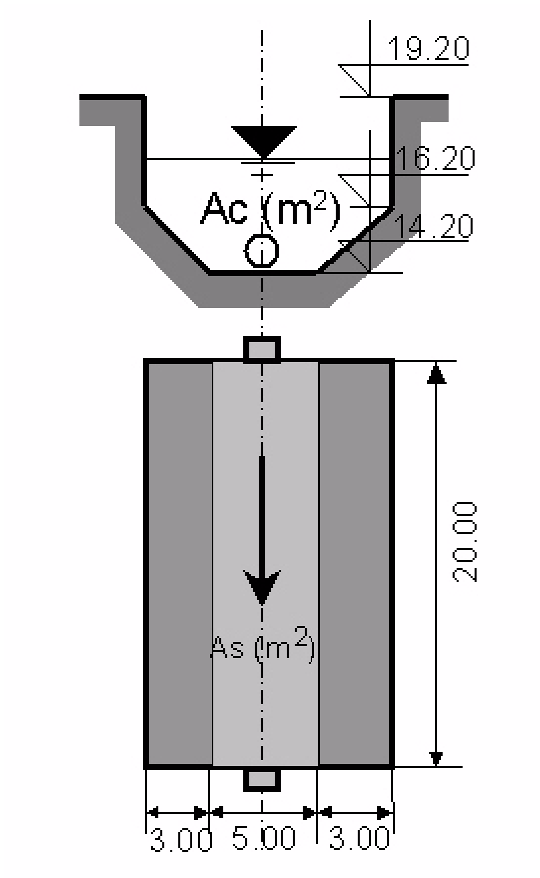

Figure 7 A basin in MOUSE. (With permission of DHI)

2.4.1.2.3 Outlets

The sewage outlets are defined as “outlet for sewage discharge” (Ministry of Water Resources 2004) through a canal or pipe, into the nearby receiving water such as river or lake for stormwater or through a tunnel for sanitary water flow.

In MOUSE software, outlets are defined with their bottom elevations and surface water elevation. When modeling nodes in MOUSE the program considers a water level in adjacent nodes as:

$$h = \begin{cases} H_{out} \text{ for } H_{out} \geq H_{bott} + \min(y_c \cdot y_n) \\ H_{bott} + \min(y_c \cdot y_n) \end{cases} \qquad (6)$$

Where H_{bott} is outlet bottom elevation, H_{out} is water elevation at outlet, y_c is the critical depth and y_n is the normal depth.

In the case which model does not apply the water elevation of outlet, the outlet is called a free outlet.

2.4.1.3 Functions

These kinds of hydraulic elements are used for calculation of flow in network's properties e.g. nodes and links.

-CSO's and their properties

Although wastewater systems are usually able to convey the flow to treatment plant, there is always the risk of overflow and flooding in cases of heavy rainfall or storms. In these cases the flow controls can be used to avoid the untreated sewage to reach the public places. Actually, flow controls restrict the flow at combined sewer overflows (CSO's) to "the intended setting and controlling water level in tanks" (Butler & Davies 2004) to store the maximum available volume.

1. Orifice plates

The easiest way of controlling the flow at a wastewater network system is by fixing an orifice plate at the inlet of a pipe since they shortened the area of flow pass.

The following figure shows an orifice plate:

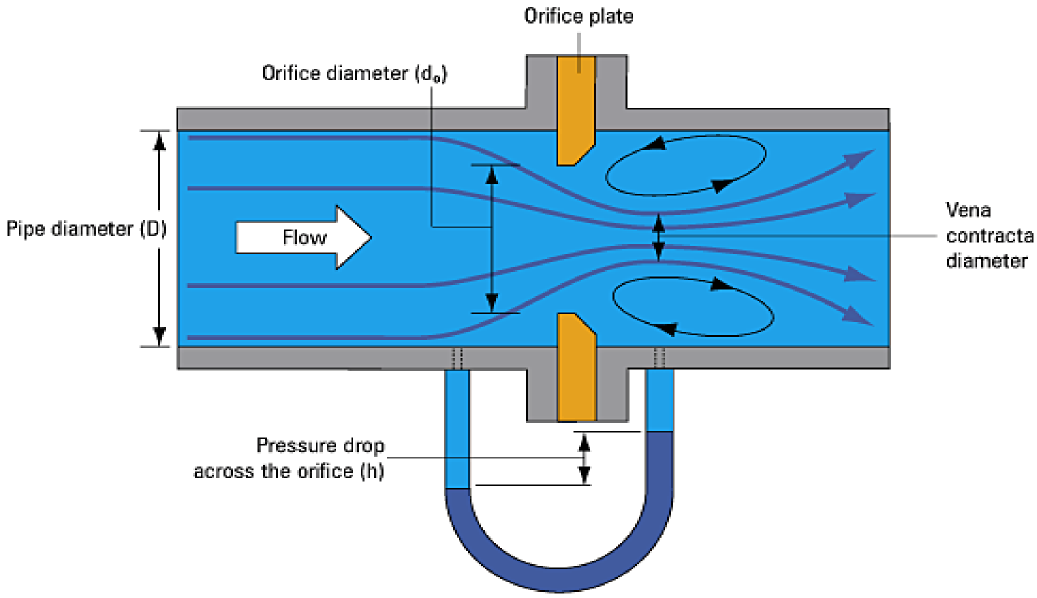

Figure 8. An orifice and its properties (with permission of Spirax Sarco).

Orifice plates can be fixed either in the form of normal or drowned. Using each one, their hydraulic analyses are calculated on the basis of Bernoulli equation (with assumption of neglecting the energy loss):

$$\frac{p_1}{\rho g}+\frac{v_1^2}{2g}+z_1=\frac{p_2}{\rho g}+\frac{v_2^2}{2g}+z_2 \qquad (7)$$

Where p_1 and p_2 are measured pressures at two levels, v_1 and v_2 are flow velocities at two levels and z_1 and z_2 are two levels where the measurements were done. When using this formula for orifice plates the pressures as well as velocity at the surface are assumed to be zero and the difference of two levels are assumed to be H.

1. Normal condition

This situation happens when the downstream flow level does not affect the discharge around the plate. In such a case the flow rate is calculated as:

$$Q = C_d A_o \sqrt{2gH} \tag{8}$$

Where Q is the orifice flow rate, C_d is the orifice coefficient which has a value between 0.57 and 0.6, A_o is the area of the orifice and H is the difference between pipe surface and the free water surface.

2. Drowned condition

This situation happens if downstream flow level affects the discharge around the plate or to be above the orifice opening.

The differences which are made in the orifice flow rate equation are that the H is assumed to be the difference in water levels and also the orifice coefficient is calculated as:

$$C_d = \frac{1}{1.7 - \left(\frac{A_o}{A}\right)} \tag{9}$$

Where C_d is the orifice coefficient, A_o is the area of the orifice and A is the flow area in pipe.

Orifices in MOUSE program are modeled at either manholes or other structures and are defined in between of two consecutive nodes known as upstream and downstream nodes.

The overflow crest height at the upstream node is calculated as the difference between orifice bottom level and the node bottom level and in the similar way for the downstream node.

2. Weirs

Generally weirs are “the body of the overfall structure” (Willi H. Hager 1999). Overfall structures have the ability to store the massive flow depths up to weir crest and also to reduce the hydraulic load in the sewer systems and hence are useful elements in urban drainage networks in the cases of heavy rainfall and storms.

In sewage network systems weirs are either free or submerged and have one of the three section forms; rectangular, triangular or circular.

When modeling weirs in Mike Urban, like orifices, either manholes or other structure, except than outlets, are used and they have been modeled between two nodes which are defined as upstream and downstream nodes.

MOUSE provides two ways of modeling the weirs; first one is based on the relation between the water level in the upstream node and the released discharge known as Q/H relation and the second one is based on the weir formula.

When using an overflow formula, actually a rectangular overflow weir is assumed and hence the below formula is applied for flow:

$$Q = C_d \frac{2}{3} b \sqrt{2g} H^{\frac{3}{2}} \tag{10}$$

Where Q is the flow rate, C_d is the discharge coefficient with a value between 0.6 and 0.7, b is the width of weir and H is the water elevation above weir crest.

2.4.2 Modeling hydrological elements by MOUSE

Hydrology plays an important role in wastewater engineering and project works. Calculating and simulating of rainfall, runoff, calculating of flood routing, catchment division and calculation of their properties, calculating the detention facilities volume with the usage of hydrographs and other methods are all among the important usage of hydrology in wastewater.

In this part, first a general description of how runoff calculation is done in MOUSE is presented, then one of the most important methods using for runoff computation , time area method is presented and finally simulation of runoff in MOUSE, using the time-area method is discussed.

2.4.2.1 Runoff modeling in MOUSE

There are four main methods of calculating the generated runoff in MOUSE program;

1. Time-area method

2. Kinematic wave method

3. Linear reservoir method

4. Unit hydrograph method

When doing the simulation with each of these methods some input data about the catchments or sub-catchments are needed. These include catchment size, their connection to wastewater network, and their geometry etc.

Using each of these methods depends of the available data and required simulation information. In each model simulation only one of this method can be used.

Since in this project work the time-area method has been used the concept and modeling of this method is presented below.

2.4.2.2 The time-area method

Indeed time-area method is one of the methods used for computation of detention facilities volumes. “It was developed to generate a more realistic runoff hydrograph” (Urbonas & Stahre, 1993). In this method the amount of runoff is calculated on the basis of initial loss, the effective area and the hydrological loss.

There are some assumptions when using this method, including;

1. The main catchment is divided to some sub-catchments which have “similar flow times to the outlet” (Urbonas & Stahre, 1993).

2. The rainfall intensity does not have any effect on the time of concentration.

3. The runoff velocity is independent of either it is raining or not

4. Each sub-catchment has a linear time-area curve

2.3.2.3 Runoff modeling in MOUSE, using time-area method

As mentioned before when modeling runoff in MOUSE some catchment input data is needed. For time-area method these include; Location of catchment, catchment co-ordinates, catchment area, the number of inhabitants in each catchment, a constant flow which shows the infiltration at each catchment and the catchment impervious coefficient.

Actually what MOUSE does when modeling on the basis of this method is that, it divides the catchment surface to a number of equal cells and then calculates the area of cells according to the corresponding time-area curve. The number of cells calculated for each catchment is calculated on the basis of the following equation.

$$n = \frac{t_c}{\Delta t} \tag{11}$$

Where n is the number of cells, t_c is the concentration time and Δt represents the simulation time step. The corresponding time-area curve of each sub-catchment defines the shape of that catchment. There are three defined curves in MOUSE. They are shown in the following figure.

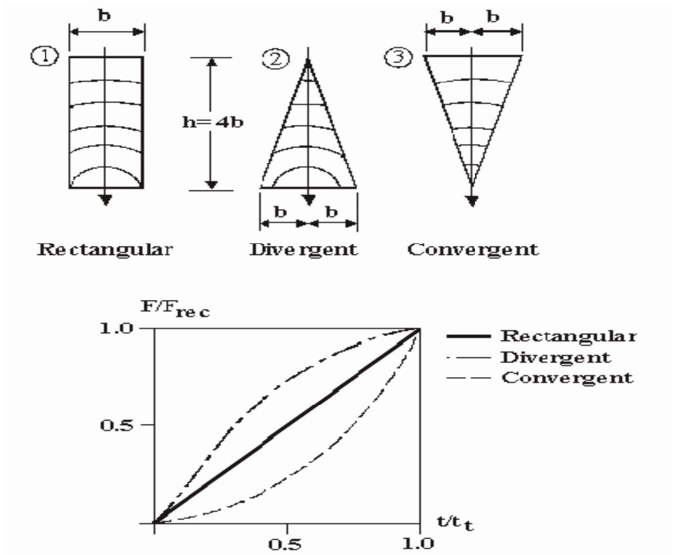

Figure 9 Pre-defined time-area curves in MOUSE program (with permission of DHI).

3 Material and Method

3.1 Case study: Gothenburg city and Majorna region

The city of Gothenburg located at the south west part of Sweden and is the second largest city of the country. Almost 500,000 people at the city are connected to the drinking water distribution system which uses the river Göta Älv as the main drinking water source. This river provides the drinking water treatment plants by two cubic meters of water per second.

In Gothenburg city there is a wastewater network system of about 2436 km. 871 km of this network are stormwater pipelines, 980 km are sanitary water pipelines, 401 km are combined pipe lines and also there is 182 km of sanitary water pressure line and about 1 km of stormwater pressure pipes. The wastewater network also includes a 124 km length tunnel to wastewater treatment plant Ryaverket.

The whole amount of wastewater which enters the wastewater treatment plant, Ryaverket, from the city of Gothenburg is 98.4 Mm^3 which from this amount 40Mm^3 is sanitary water. The total amount enters the wastewater treatment plant (including Gothenburg and the small municipalities around) is about 118Mm^3. It is expected that there is a value of 4Mm^3 of leakage in the tunnel network. (Gothenburg Water utility, accessed April 2011)

Majorna region located at the south west part of Gothenburg city. The total area of Majorna is about 130 hectare and it has a persons equivalence of about 17,000. The sanitary flow produced at this area is about 39.6 l/s. In the area there are both combined and separate sewer systems, some outlets to the river and a tunnel to Ryaverket. The pipelines of the area are shown in Figure 10.

Figure 10 Pipelines and sewer systems at Majorna area. Brown pipes represent combined system; green pipes show stormwater pipe and red ones the sanitary pipes (with permission of DHI and Gothenburg Water utility).

3.2 Hydraulic modeling

MOUSE provides the users the ability to define and model the hydraulic properties of a wastewater system. Hydrodynamic is one the most important aspect of each sewage network, as it defines the flow's movement and behavior in different parts of the system and also shows requirement of system to different hydraulic equipments.

The network input data in this project work has been mostly imported from Solen X. The pipes, CSO's and weirs, outlet nodes and manholes are examples of so, though some data of these elements were missed and were defined as will be described later. It should be noted that there is not any pump or pump station in this network as the flow moves in the direction of gravity all the time.

Below the hydraulic elements used in this project and the way they are defined in MOUSE are described.

3.2.1 Nodes and their structures

There are three types of nodes at this wastewater network which needs to be defined. They are manholes, network outlets and basins. In MOUSE each node is defined in the coordinates system using a unique X and Y coordinates.

In MOUSE software, nodes can be defined in three ways: open, sealed or spilling at the top. If choose open then there is the possibility of water overflow on the ground surface in the case of flooding and in this case the software will assume a basin on the top of the node so the excess water will be stored in that. The sealed type, on the other hand, does not let the water to spill on the ground and so there is not risk of overflowing anymore. In spilling type, if water overflows to the ground level, it will quit the network. Choosing each of these types depends on the condition of the area which the network is located at, the amount of rainfall and runoff and also the network. In this project due to these conditions the open type has been chosen.

Most of the bottom levels have been imported from the corresponding information at GIS map, Solen X, while the others have been interpolated manually. The calculation was done on the basis of linear interpolation for NULL points where they located between manholes with known bottom levels and with the assumption of a 0.5% slope for the others. Equation (12) represents the interpolation formula.

$$\frac{(y_1 - y_0)}{(x_1 - x_0)} = \frac{(y - y_0)}{(x - x_0)} \tag{12}$$

Where y_0 and y_1 are the known bottom levels of two manholes and x_1-x_0 is the distance between them and y is the unknown bottom level (which is calculated) and x-x_0 is its distance with one of the known manholes.

The ground levels are imported from a raster GIS file which was created by GIS department of Gothenburg Water utility based on the counter lines and ground levels at Solen X.

3.2.2 Pipes and links

After definition of different nodes and their types, the nodes should be connected to each other. This connection is done by links (pipes).

Links are always defined form upstream node to the downstream one; so the flow will be regarded as positive in the results. Generally pipes have two types in MOUSE; they are either from one of the standard form (Circular, rectangular, O shaped or so) or have other cross section types which are defined separately in CRS and Topography tool. The latter will be described later.

In this project the pipes are mostly defined with their diameters which are imported from Solen X. The pipe materials were also defined from data of Gothenburg Water utility and Solen X. As told before the nodes in MOUSE are defined in coordinates systems and so the lengths of links between the nodes are calculated by program automatically on the basis of each node coordinate.

3.2.3 CRS and topography

In Majorna area, there are some sewer pipes which cannot be classified as either the combined or separated systems and hence have to be modeled separately in the software. In these pipes, which are classified as irregular or symmetric cross sections in MOUSE, the sanitary pipe goes through the stormwater pipe and so their cross sections are not one of the general ones which are defined in MOUSE.

To model such pipes in MOUSE the CRS and Topography editors are used. The CRS editor is used for modeling the cross sections and the topography editor shows the topography of the conduits on the basis of their cross sections.

Under the CRS and Topography editor, there are some methods for modeling, which are based mainly on the type of conduit and the definition of the geometry. The geometry can be defined by either the coordinated pairs (for irregular cross sections) or the Height-Width pairs (for symmetric cross sections). For this case the Height-width and closed method where chosen. The pipes modeled using these method, are listed in Appendix A.

3.2.4 Weirs

A weir or CSO can be defined in MOUSE software to connect two manholes when one is overflowed to release the excess water into the other one. Each weir is defined in MOUSE with some characteristics such as weir type, crest width and its orientation degree.

At this project, databases of Gothenburg Water utility were used as input data of weirs. All the weirs types are assumed as rectangular and their orientation was defined as either 0 degree (excluded the flow energy) or 90 degrees (included the flow energy) on the basis of their real condition at the place. The weirs characteristics are listed in Appendix B.

3.3 Hydrological modeling

MOUSE software has the ability of modeling the rainfall-runoff models in urban areas. This job is done with in some steps:

1. Creating the main catchment and splitting it to some sub-catchments
2. Calculation of sub-catchments properties
3. Connection of sub-catchments to the wastewater network
4. Importing the rainfall input data
5. Runoff simulation

Figure 11 shows a schematic view of this process.

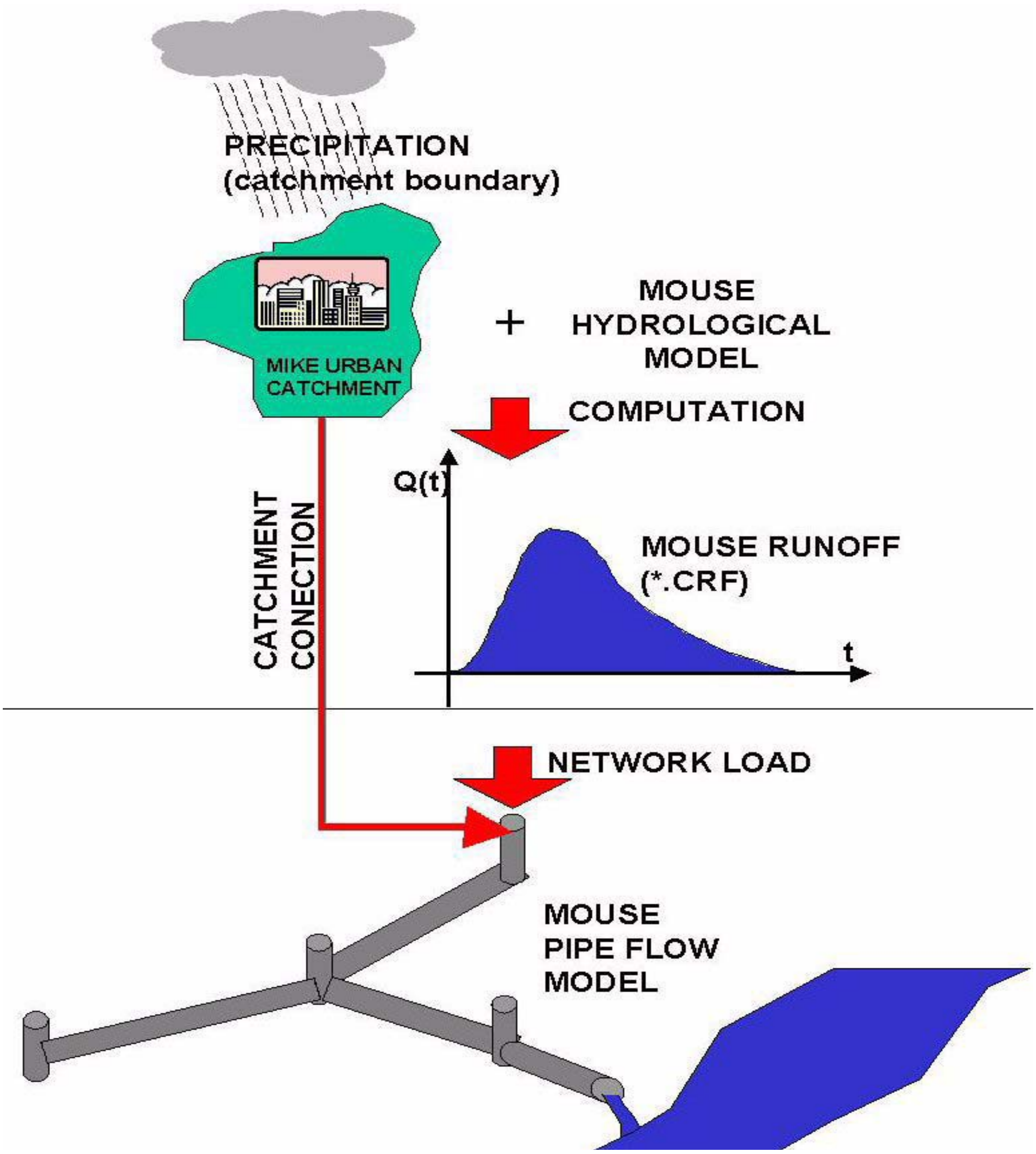

Figure 11 Hydrological modeling process (with permission of DHI).

3.3.1 Catchments and sub-catchments

In Mike Urban, catchments are defined as polygons which are made based on different criteria and will drain to a defined node. Then, the main catchment will be divided into smaller sub-catchments. In this project the whole region of Majorna was regarded as the main catchment and then it was divided to 24 sub-catchments. The division was done based on the different criteria such as: The topology of the land, the different types of sewage pipes (separated or combined) and also according to their drainage node. Generally it is done so that the stormwater of a certain region being released to one sub-catchment and that each sub-catchment contains the same network pipe and also a drainage node does not receive a high load of flow.

The main catchments and the sub-catchments are shown in the figure below:

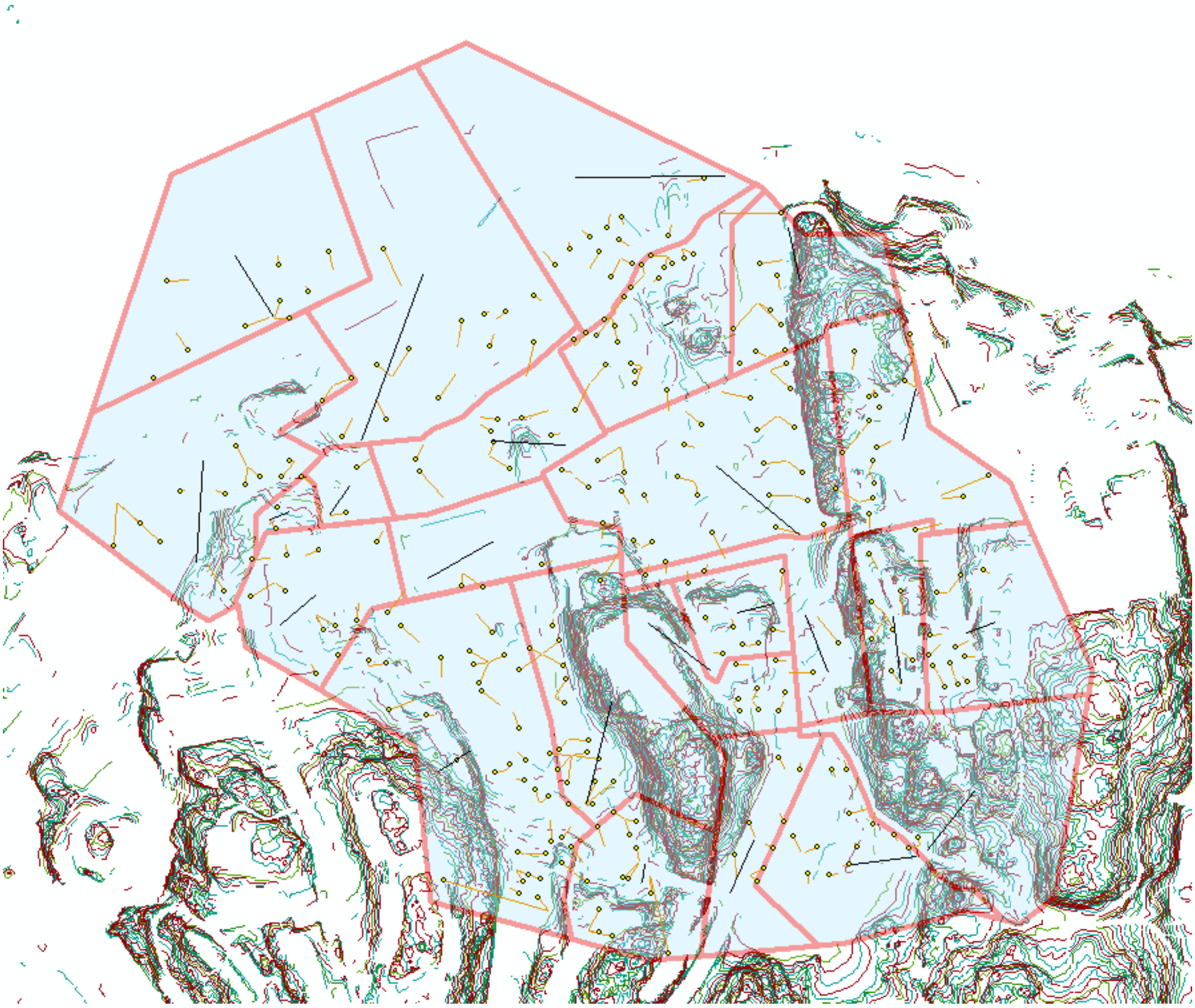

Figure 12 The main catchment and sub-catchments at Majorna (with permission of DHI and Gothenburg Water utility).

3.3.2 Calculation of sub-catchments properties

After definition of the sub-catchments their imperviousness coefficients were calculated according to equation (13).

$$\varphi = \frac{(A_1\varphi_1 + A_2\varphi_2 + \cdots + A_\tau\varphi_\tau + A_v\varphi_v)}{(A_1 + A_2 + \cdots + A_\tau + A_v)} \tag{13}$$

Where A_1, A_2… are areas of region of sub-catchments which have the same surface cover (such as roof, asphalt and …) and φ_1, φ_2… are their imperviousness coefficients (Svenskt Vatten 2004). The different parameters and results are listed in the table 2.

Table 2 Sub-catchments and their properties.

MUID	A_1 (ha)	A_2 (ha)	A_3 (ha)	A_4 (ha)	φ_1 Roof	φ_2 Asphalt	φ_3 Park	φ_4 Forest	φ_5 Gravel Path	A_t(ha)	φ
10_2	6.61	0.83	0.83	0	0.9	0.8	0.1	0.1	0.2	8.26	0.25
11_1	1.45	0.72	0.72	0.72	0.9	0.8	0.1	0.1	0.2	3.62	0.38
13_2	2.51	0.84	0.84	0	0.9	0.8	0.1	0.1	0.2	4.19	0.40
16_2	3.64	5.46	0	0	0.9	0.8	0.1	0.1	0.2	9.10	0.84
17_2	4.52	4.52	0	0	0.9	0.8	0.1	0.1	0.2	9.05	0.85
19_2	0.11	0.45	0	0	0.9	0.8	0.1	0.1	0.2	0.57	0.26
20_1	0.86	1.73	1.73	0	0.9	0.8	0.1	0.1	0.2	4.32	0.70
20_2	0.11	1.00	0	0	0.9	0.8	0.1	0.1	0.2	1.11	0.89
21_1	1.83	0.91	0.91	0	0.9	0.8	0.1	0.1	0.2	3.66	0.48
21_2	1.24	1.44	1.44	0	0.9	0.8	0.1	0.1	0.2	4.12	0.63
22_1	1.05	0.35	0.70	1.40	0.9	0.8	0.1	0.1	0.2	3.50	0.55
22_2	1.89	3.79	3.79	0	0.9	0.8	0.1	0.1	0.2	9.46	0.70
23_1	1.17	0.29	0.88	0.88	0.9	0.8	0.1	0.1	0.2	2.93	0.57
23_2	0.75	0.75	0.65	0	0.9	0.8	0.1	0.1	0.2	2.15	0.63
24_1	0.83	0.83	2.48	0	0.9	0.8	0.1	0.1	0.2	4.14	0.40
24_2	1.25	1.25	2.50	0	0.9	0.8	0.1	0.1	0.2	5.01	0.48
25_1	1.43	1.43	4.28	0	0.9	0.8	0.1	0.1	0.2	7.13	0.40
25_2	3.48	3.48	4.64	0	0.9	0.8	0.1	0.1	0.2	11.6	0.55
26_1	3.68	3.68	3.15	0	0.9	0.8	0.1	0.1	0.2	10.5	0.63
26_2	6.74	6.74	0.00	0	0.9	0.8	0.1	0.1	0.2	13.5	0.85
6_1	1.52	1.77	1.77	0	0.9	0.8	0.1	0.1	0.2	5.07	0.63
7_1	1.66	1.94	1.94	0	0.9	0.8	0.1	0.1	0.2	5.54	0.63
8_2	0.52	1.03	1.03	0	0.9	0.8	0.1	0.1	0.2	2.58	0.70
9_1	0.54	2.41	2.41	0	0.9	0.8	0.1	0.1	0.2	5.36	0.78

3.3.3 Connection of sub-catchments to wastewater network

The generated runoff at each sub-catchment should be connected to one of the network manholes of a stormwater or a combined pipe at that sub-catchment. To do this a drainage node was assumed at each sub-catchment. The drainage node was chosen according to the topography of the ground (using Solen X) and also being a part of a stormwater pipe or combined one.

3.3.4 Importing the rainfall input data

The one-year rainfall data which is used for this project work is the Gothenburg annual rainfall measurements provided by Gothenburg Water utility. This is done in MOUSE under the tool boundary condition and boundary item when the type of file is rainfall. The annual rainfall measurement is presented in the figure below.

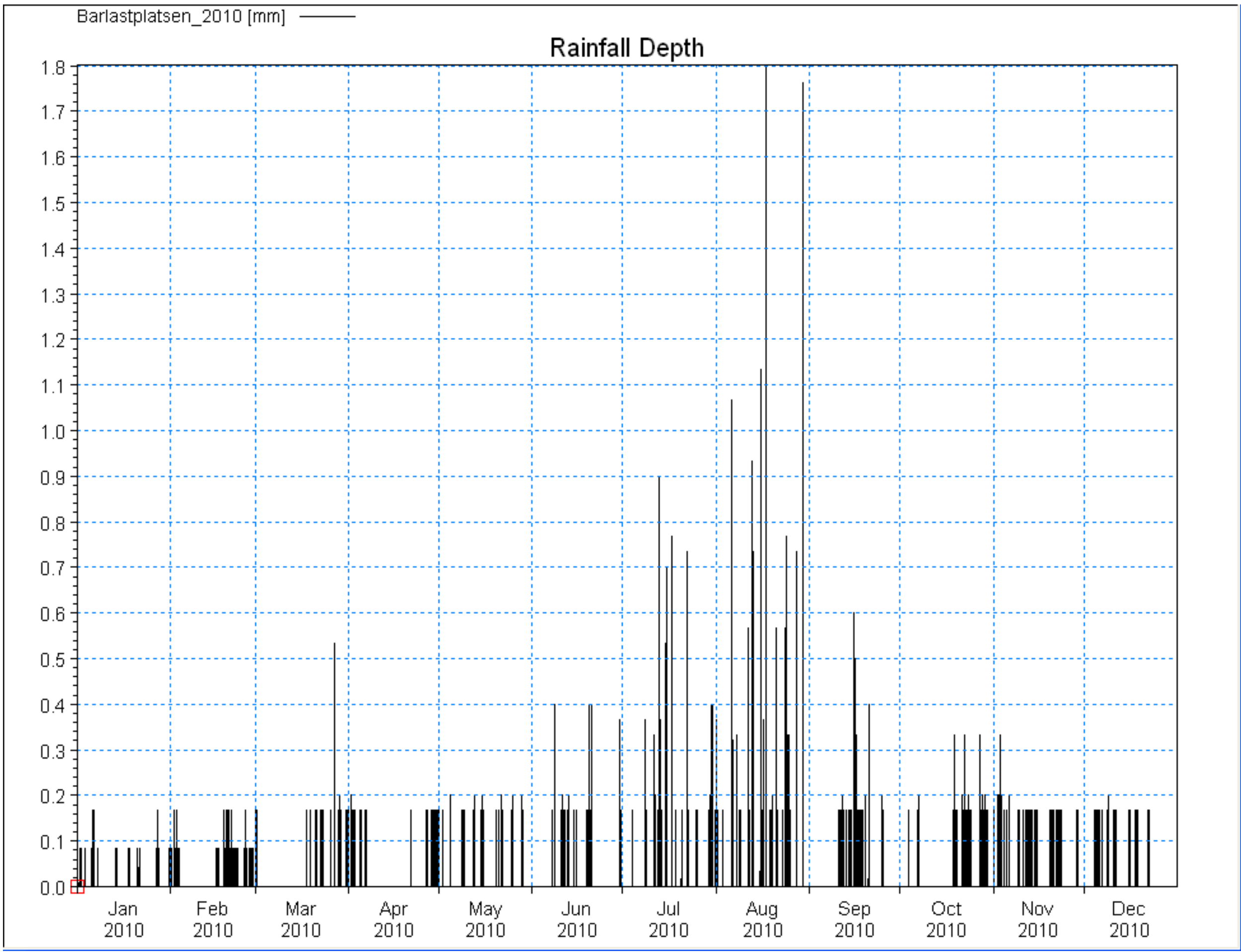

Figure 13 Annual measured rainfall at Gothenburg city.

Also the 24-hour water distribution pattern of Majorna region has been imported to the program to add the domestic wastewater flow, as the water and wastewater distribution patterns and curves are quite the same. The water distribution table and the corresponding graph are shown in Figure 14 and Figure 15.

From	To	Multiplier
12:00:00 AM	1:00:00 AM	0.51
1:00:00 AM	2:00:00 AM	0.43
2:00:00 AM	3:00:00 AM	0.29
3:00:00 AM	4:00:00 AM	0.41
4:00:00 AM	5:00:00 AM	0.95
5:00:00 AM	6:00:00 AM	1.72
6:00:00 AM	7:00:00 AM	1.73
7:00:00 AM	8:00:00 AM	1.41
8:00:00 AM	9:00:00 AM	1.23
9:00:00 AM	10:00:00 AM	1.09
10:00:00 AM	11:00:00 AM	0.66
11:00:00 AM	12:00:00 PM	0.92
12:00:00 PM	1:00:00 PM	1.15
1:00:00 PM	2:00:00 PM	1.18
2:00:00 PM	3:00:00 PM	1.04
3:00:00 PM	4:00:00 PM	1.18
4:00:00 PM	5:00:00 PM	1.37
5:00:00 PM	6:00:00 PM	1.54
6:00:00 PM	7:00:00 PM	1.47
7:00:00 PM	8:00:00 PM	1.46
8:00:00 PM	9:00:00 PM	1.37
9:00:00 PM	10:00:00 PM	0.69
10:00:00 PM	11:00:00 PM	0.51
11:00:00 PM	12:00:00 AM	0.36

Figure 14 Water distribution pattern in Majorna region during 24 hours.

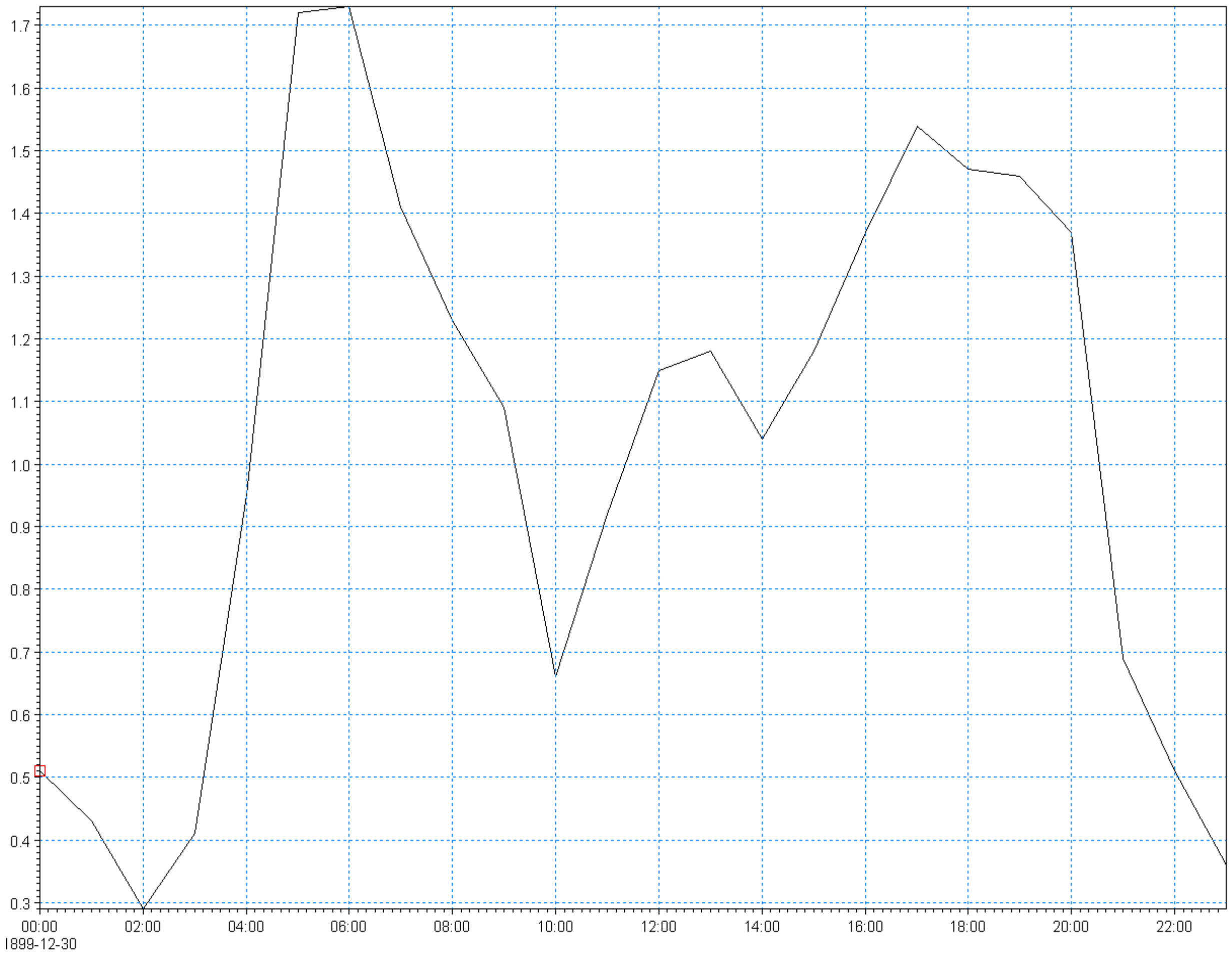

Figure 15   Water distribution graph in Majorna region during 24 hours.

3.4 Calibration

"Model calibration consists of changing values of model input parameters" (Department of Environmental quality 2011) to match them with a set of measured data which were measured with some standard devices.

The measurements at this region were done in sanitary pipes and in the period between October 28th and December 21st of 2010. It was decided to calibrate the model from the first day until December 9th and validate for the rest of period.

3.5 Validation

In computational modeling validation is done to ensures that "the model addresses the right problem, provides accurate information about the system being modeled" (Charles M. Macal 2005) and to make the model to apply in reality.

At this project work, as it said before, it was decided to validate the model for the period between December 9th and December 21st. The software used for calibration, validation and statistical analysis is MIKE VIEW.

4 Results

4.1 Calibration

There are two measurement nodes and one CSO at Majorna area named; ASN14276, ASN14294 and NU 4592. The nodes and their places around are shown in the below figure.

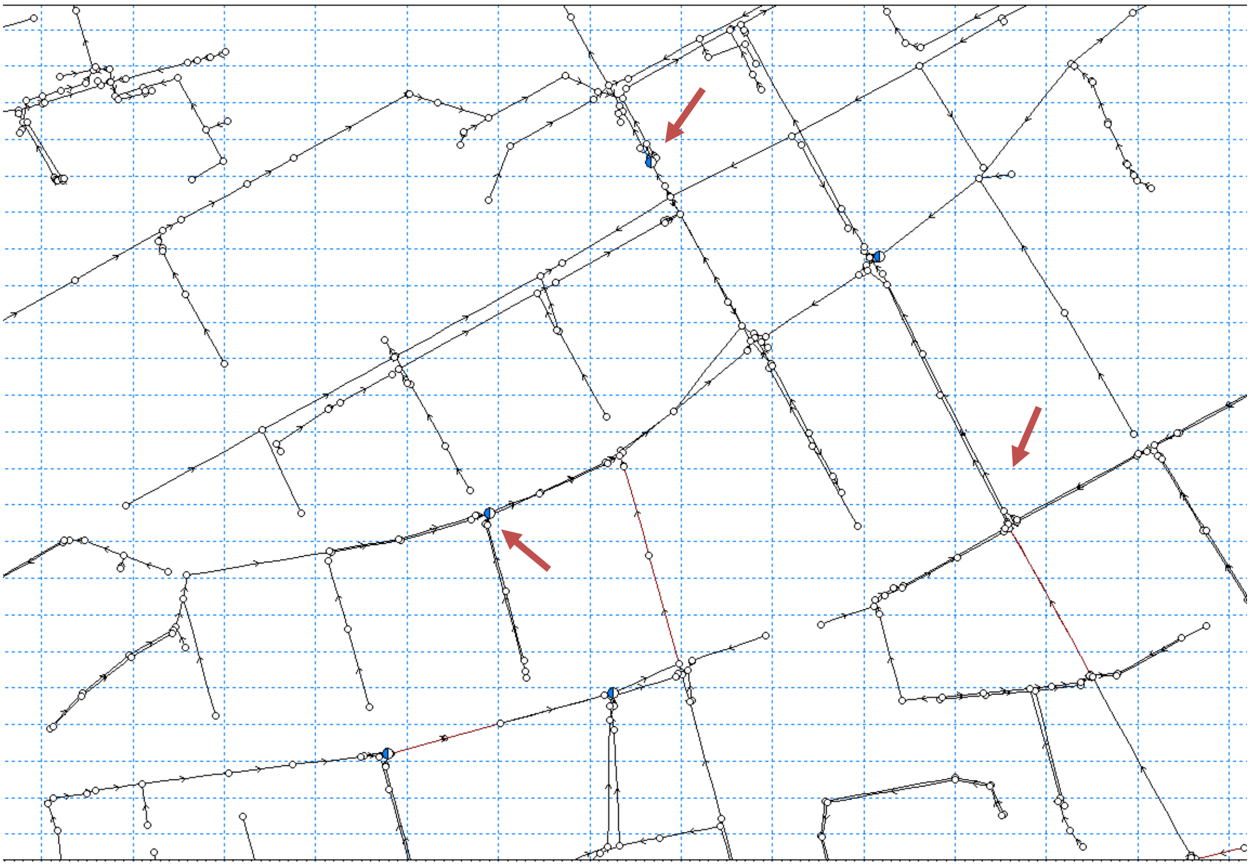

Figure 16 Measurement nodes and their locations.

When simulation of model has done; the results of simulation has been compared with the corresponding measured nodes.

The measured values for the CSO, NU 4592, show the period which it works and the period which it does not. This is shown in the below table, values of 1 shows working day and values of 0 shows the others.

Table 3 Working and non-working days of the CSO, NU4592.

YYYY MM DD	HH MM SE	Value
10/28/2010	09 38 05	0
10/28/2010	12 58 43	1
10/28/2010	13 40 17	0
10/29/2010	10 06 40	1
10/29/2010	10 47 31	0
10/29/2010	11 09 59	1
10/29/2010	11 20 48	0
11/2/2010	11 20 59	1
11/2/2010	11 32 49	0
11/2/2010	14 52 32	1
11/2/2010	15 23 28	0
11/2/2010	15 34 42	1
11/2/2010	15 54 04	0
11/2/2010	16 23 08	1
11/2/2010	16 50 00	0
11/3/2010	05 52 49	1
11/3/2010	06 25 37	0
11/11/2010	09 58 51	0
11/11/2010	11 01 53	0
12/21/2010	16 58 44	1
12/21/2010	16 58 45	0
12/21/2010	17 00 19	0

As it seen in Table 3 the CSO worked only once at the validation period, on 21st of December. This is because of a heavy snowfall happened at that time and caused the CSO to work.

The calibration of water discharge for the link upstream the CSO has shown that there is a good correlation between the calculated and the measured values. This is shown in the figure below.

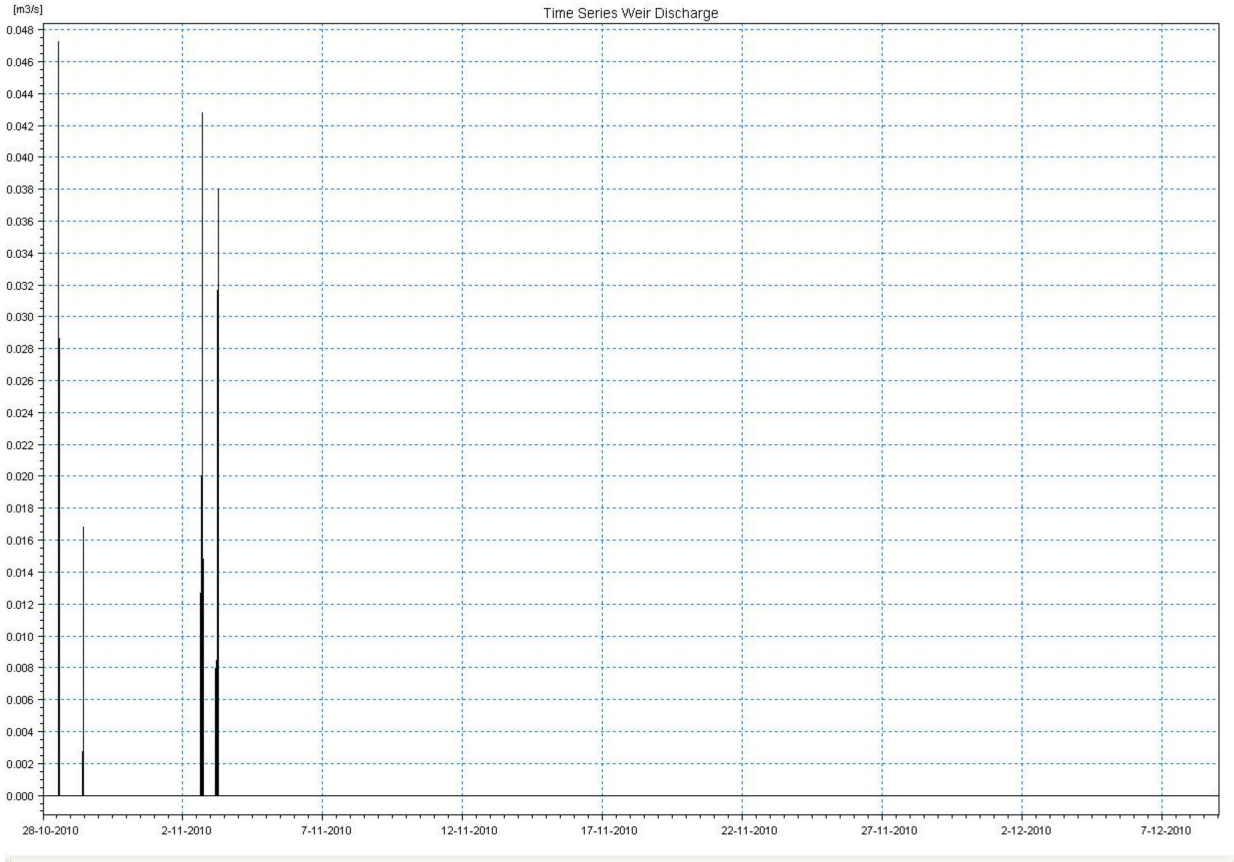

Figure 17 Water discharge for the CSo, NU4592.

For nodes ASN14276 and ASN14294 the water discharges at the upstream links have been compared for simulated and the corresponding measurement nodes:

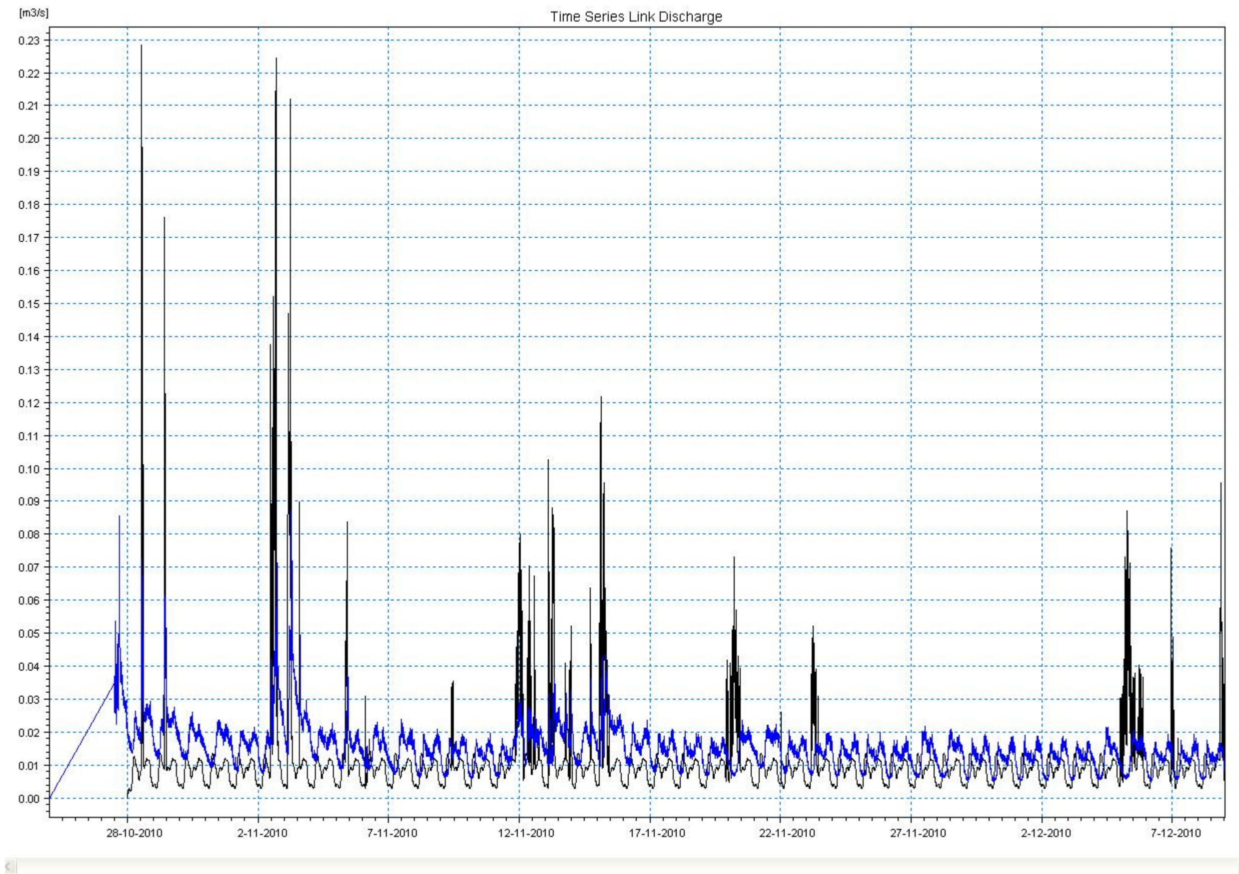

Figure 18 Comparison between computed (black) and measured (blue) values of water discharge for node ASN14276.

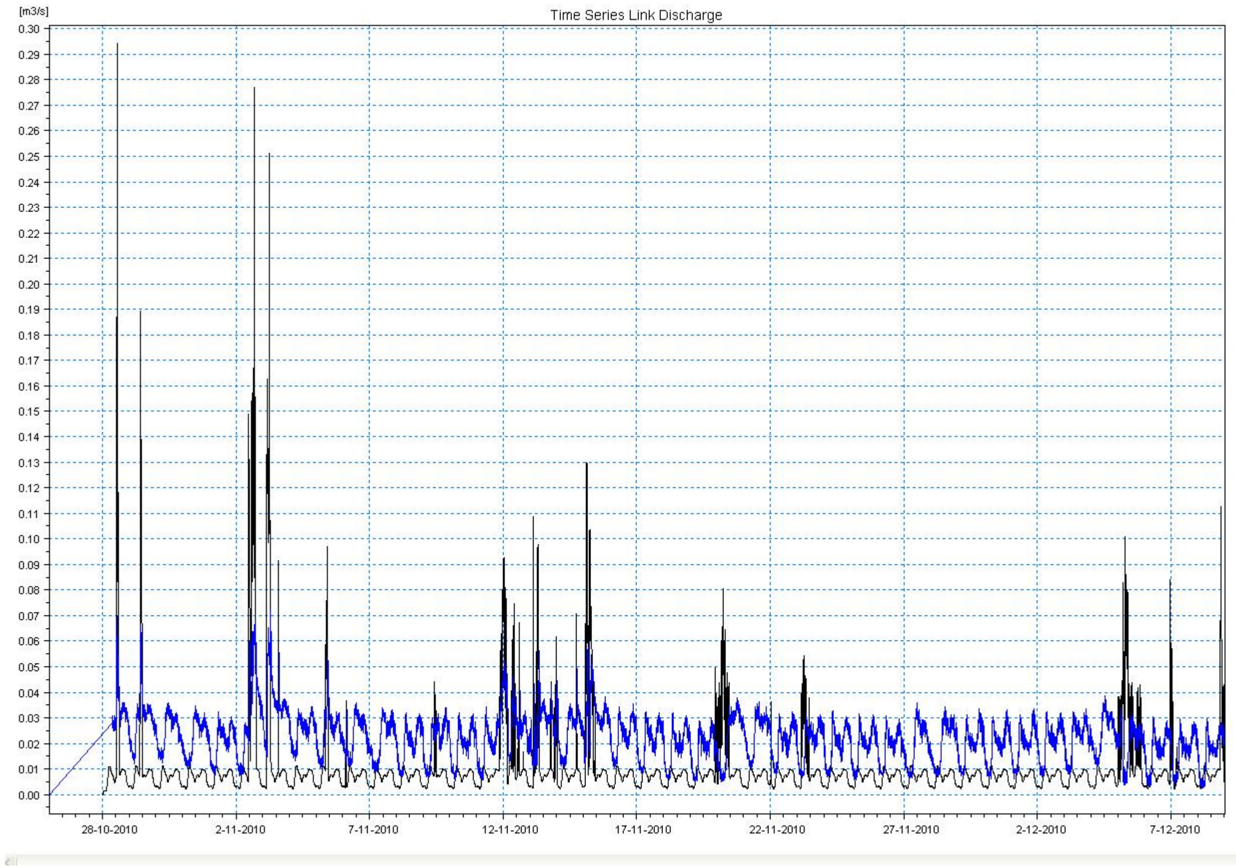

Figure 19 Comparison between computed (black) and measured (blue) values of water discharge for node ASN14294.

As seen in the figures, both the peeks of curves and their bases need to be matched to complete the calibration. The methods used to do this are described in the following parts.

4.1.1 Matching the peak values of curves

Peaks of curves show the rainfall events at the region. The comparison between computed and measured values for both nodes shows that the peaks are higher at simulation than what they are at the reality, hence it was decided to reduce the imperviousness coefficient of catchments since in reality some of the wastewater produced at each catchment, is not entering the sanitary pipes and instead infiltrates into the soil or entering the stormwater pipes.

Since the picks are higher in the node ASN14276 so it was decided to multiply the imperviousness coefficient of catchments which have effects on this node by 0.3 and the other one which has lower peak by 0.2. After Once calibrated with these changing, it was seen that the picks at the node ASN14276 are still a bit higher than the measured values and so the coefficients were reduced by 0.5%, and the same has happened for the point ASN14294 and hence the coefficients were multiplied by a factor of 0.6.

Results after these two calibrations are shown in the tables below.

Table 4 Catchment coefficients after first and second calibrations at the node ASN14276.

MUID	Old φ	1st Calibration	2nd Calibration
11_1	0.38	0.11	0.11
22_1	0.55	0.16	0.16
22_2	0.7	0.2	0.2
23_1	0.57	0.17	0.16
23_2	0.62	0.19	0.18
6_1	0.62	0.19	0.18
7_1	0.62	0.19	0.18
8_2	0.7	0.21	0.20
9_1	0.78	0.23	0.20

Table 5 Catchments coefficients after first and second calibrations at the node ASN14294.

MUID	Old φ	1st Calibration	2nd Calibration
13_2	0.4	0.08	0.048
19_2	0.26	0.052	0.0312
20_1	0.7	0.14	0.084
20_2	0.89	0.178	0.1068
21_1	0.475	0.095	0.057
21_2	0.625	0.125	0.075
25_1	0.4	0.08	0.048
25_2	0.55	0.11	0.066
26_1	0.625	0.125	0.075
26_2	0.85	0.17	0.102

4.1.2 Matching the base values of curves

Base parts of curves show the amount of sanitary water and there are differences between what was calculated and what was measured and so three methods were applied to correct this.

4.1.2.1 Adding new catchments

At Majorna region there are some small gullies around buildings which drain the stomwater and other surface water around them. These drainage facilities are supposed to release the stormwater into the stormwater pipes or into the combined pipes but in reality some of them are released into the sanitary pipes due to the oldness of wastewater network or leakages in the system and so the amount of their flow should be added to the base flow.

Hence some small catchments were made around some of buildings at each of the previous sub-catchments and being connected to the network and hence a more realistic result has been gained. These new catchments as well as the previous sub-catchments are shown in the figure below:

Figure 20 New catchments around the buildings. (With permission of DHI and Gothenburg Water utility)

4.1.2.2 Adding constant flows

To gain a proper correlation between bases, which is mostly affected by sanitary water, it was decided to add a constant flow to the nodes upstream each measurement nodes as there are natural leakages at each sewer system.

As the base flow of computed and measured curves were closer at the node ASN14276 it was decided to distribute a discharge value of 0.004 m^3/s among 10 nodes upstream. For the node ASN14294, a discharge value of 0.01 m^3/s was distributed. The discharge amount and the nodes they were added to, are listed in the table below.

Boundary ID	Apply	Connection	Item type	Node ID *	Node load type	Catchment load Check
14276_1	True	Individual	Node	ASN14282	1	False
14276_10	True	Individual	Node	ASN14230	1	False
14276_2	True	Individual	Node	ASN14233	1	False
14276_3	True	Individual	Node	ASN14248	1	False
14276_4	True	Individual	Node	ASN13550	1	False
14276_5	True	Individual	Node	ASN13561	1	False
14276_6	True	Individual	Node	ASN14237	1	False
14276_7	True	Individual	Node	ASN14264	1	False
14276_8	True	Individual	Node	ASN13582	1	False
14276_9	True	Individual	Node	ASN13591	1	False
14294_1	True	Individual	Node	ASIN24934	1	False
14294_10	True	Individual	Node	ASIN24929	1	False
14294_2	True	Individual	Node	ASN14293	1	False
14294_3	True	Individual	Node	AKN2348	1	False
14294_4	True	Individual	Node	1_34	1	False
14294_5	True	Individual	Node	ADN14811	1	False
14294_6	True	Individual	Node	AKN2295	1	False
14294_7	True	Individual	Node	AKN2289	1	False
14294_8	True	Individual	Node	1_25	1	False
14294_9	True	Individual	Node	ADN14789	1	False

Figure 21 Constant flows and their locations.

4.1.2.3 Adding persons equivalence upstream measuring node ASN14294

While after doing the described corrections there was a good correlation of curves at the node ASN14276, there was still a considerable difference between base parts of curves of the other measuring node, ASN14294. The reasons of this difference needs to be investigated in a different project work, but some probable answers may be the leakages of pipes or a doubled-measure flow after measuring once at the node ASN14276 as it is located downstream of this node.

Meanwhile, to gain a proper calibration at this project to be able to suggest improvements it was decided to add some new persons equivalence at some sub-catchments to increase the base flow.

Hence a 10 l/s, equal to 864 m^3/day, flow was added and since the average wastewater produced by each person at 24 hours is equal to 0.2 m^3/day, pe, hence a total number of 4320 people were distributed on 10 sub-catchments upstream the node ASN14294, means 432 people per each catchment. This value was increased to over 745 people per catchments after later tests.

After doing all of the mentioned steps, the final calibration was done. The figures for the two measuring nodes and the statistical analysis for some parameters are shown in the following figures and the simulation results are presented at appendix C.

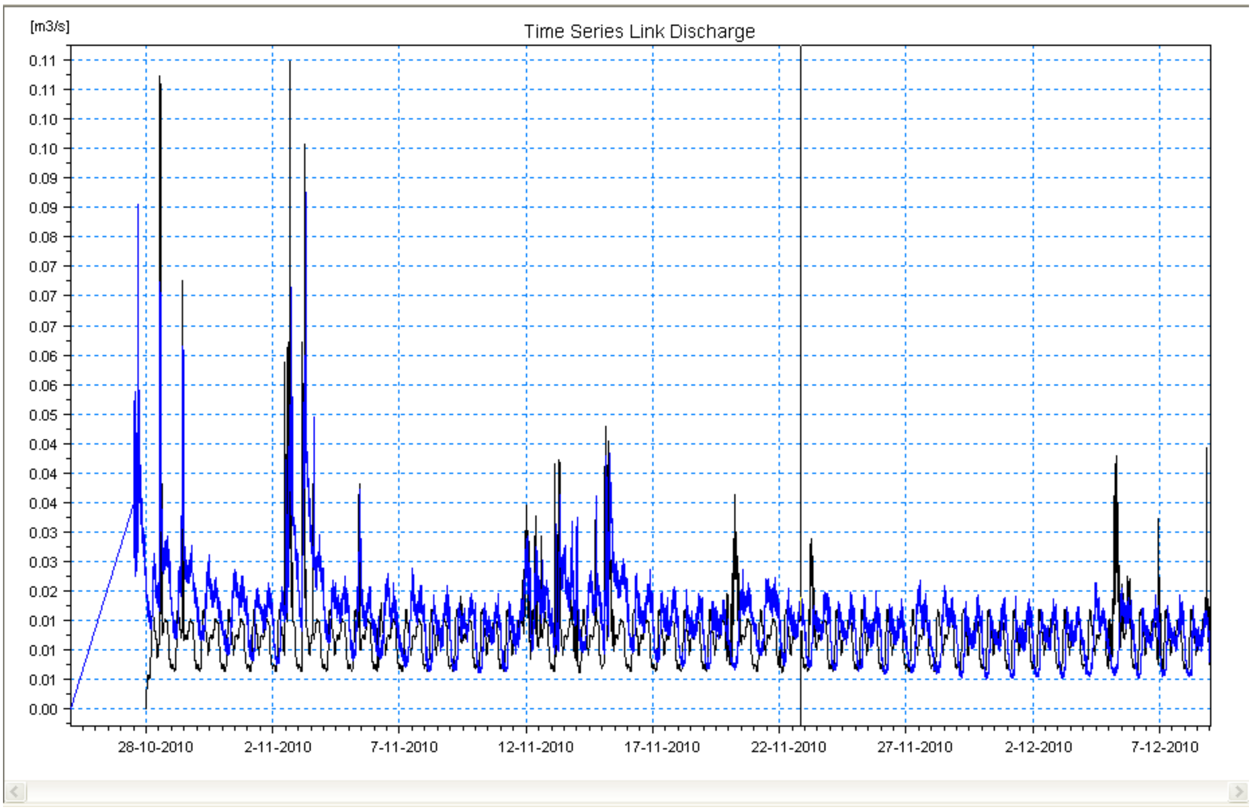

Figure 22 Comparison after final calibration between computed (black) and measured (blue) values of water discharge for node ASN14276.

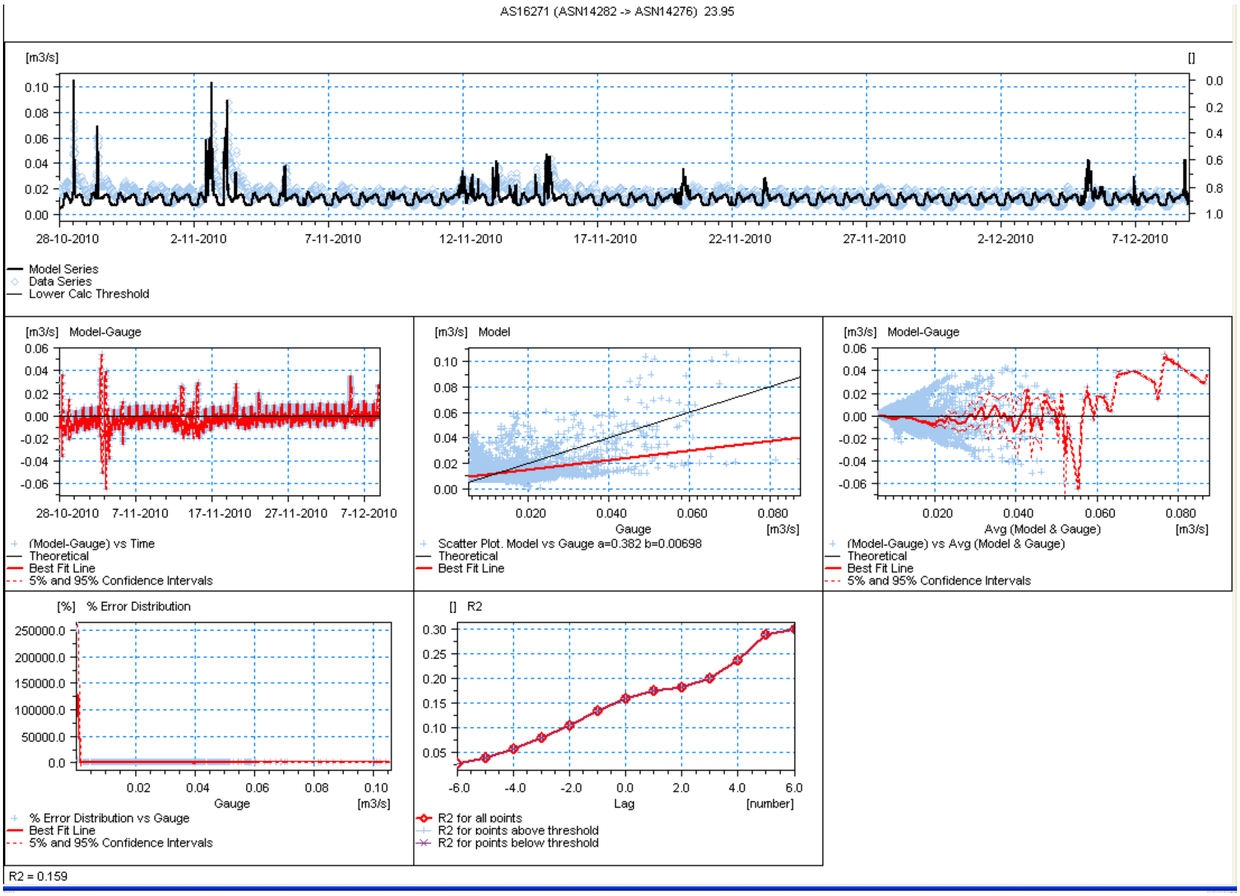

Figure 23 Statistical analysis for calibration period at the node ASN14276.

Statistical analysis for this node has shown that maximum positive difference between modeled and measured values is 0.055 m^3/s and the maximum negative difference is equal to -0.064 m^3/s. The total measured volume is 54406 m^3 and the total modeled volume is 46139 m^3 which means a volume error of -15.2% (minus mark shows deficiency in modeled value). Also the peak measured value is 0.087 m^3/s and the peak modeled value is equal to 0.106 m^3/s which means the peak error is equal to 21.2 %. The errors calculated for this node is a little high.

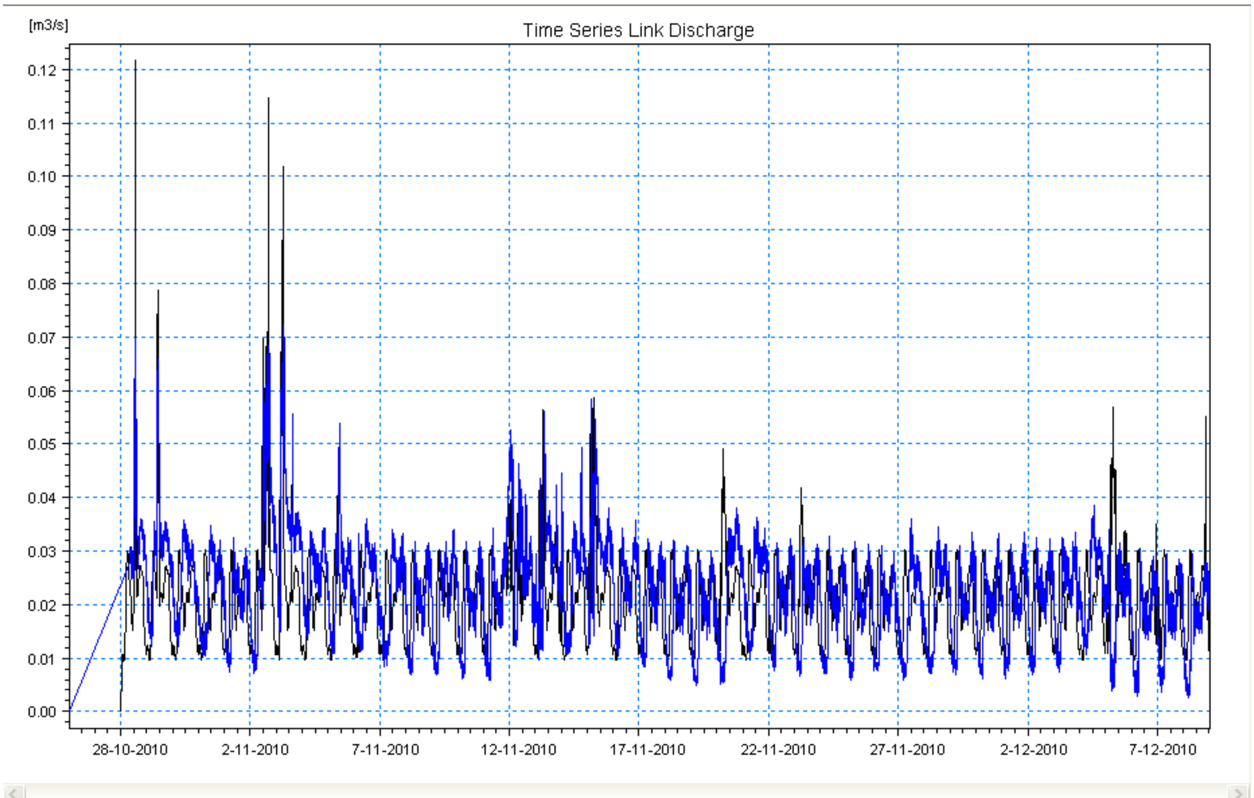

Figure 24 Comparison after final calibration between computed (black) and measured (blue) values of water discharge for node ASN14294.

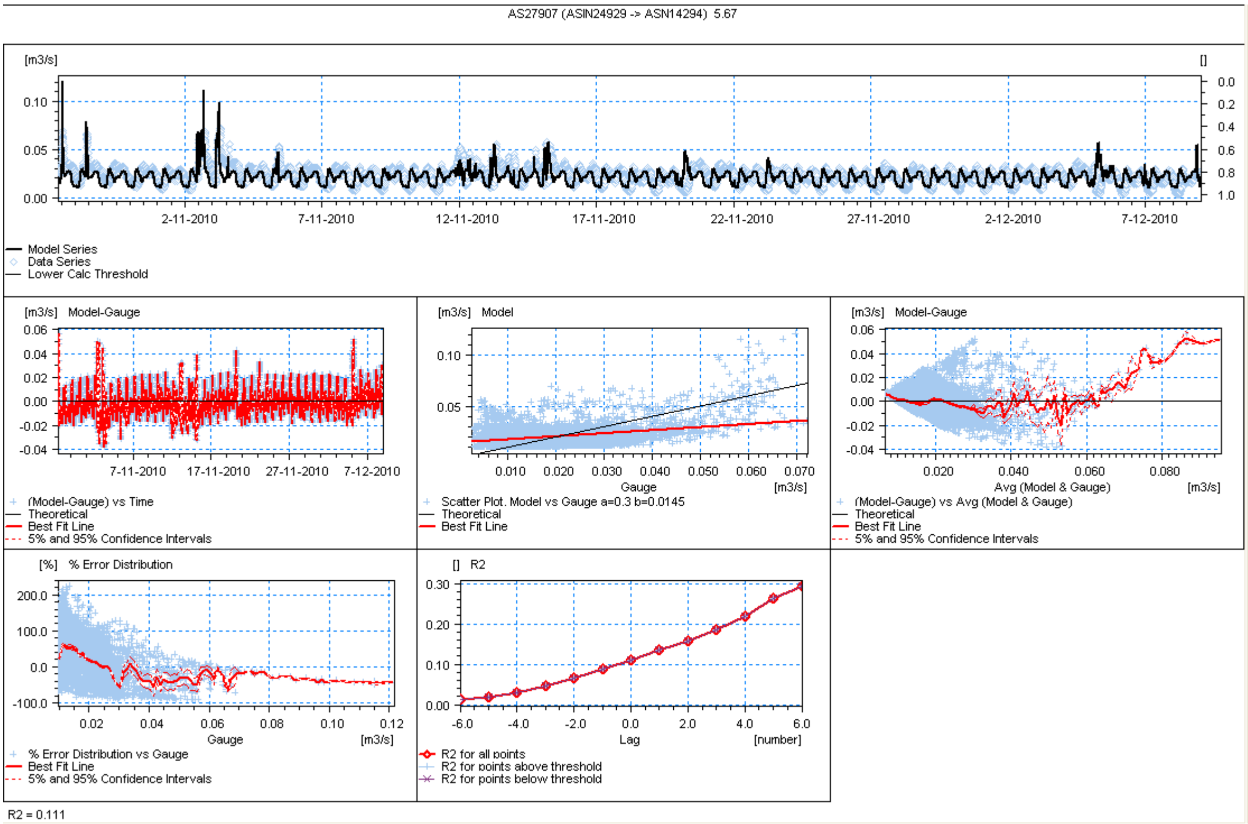

Figure 25   Statistical analysis for calibration period at the node ASN14294.

Statistical analysis for node ASN14294 has shown that maximum positive difference between modeled and measured values is 0.057m^3/s and the maximum negative difference is equal to -0.039 m^3/s. The total measured volume is 81173 m^3 and the total modeled volume is 76569.824 m^3 which means a volume error of -5. 7% (minus mark shows deficiency in modeled value). Also the peak measured value is 0.072 m^3/s and the peak modeled value is 0.122 m^3/s which means the peak error is equal to 68.4 %. Although the error calculated for total volume shows a good correlation between measured and modeled values the error between peaks are high.

4.2 Validation

The results for validation are shown in the following figures.

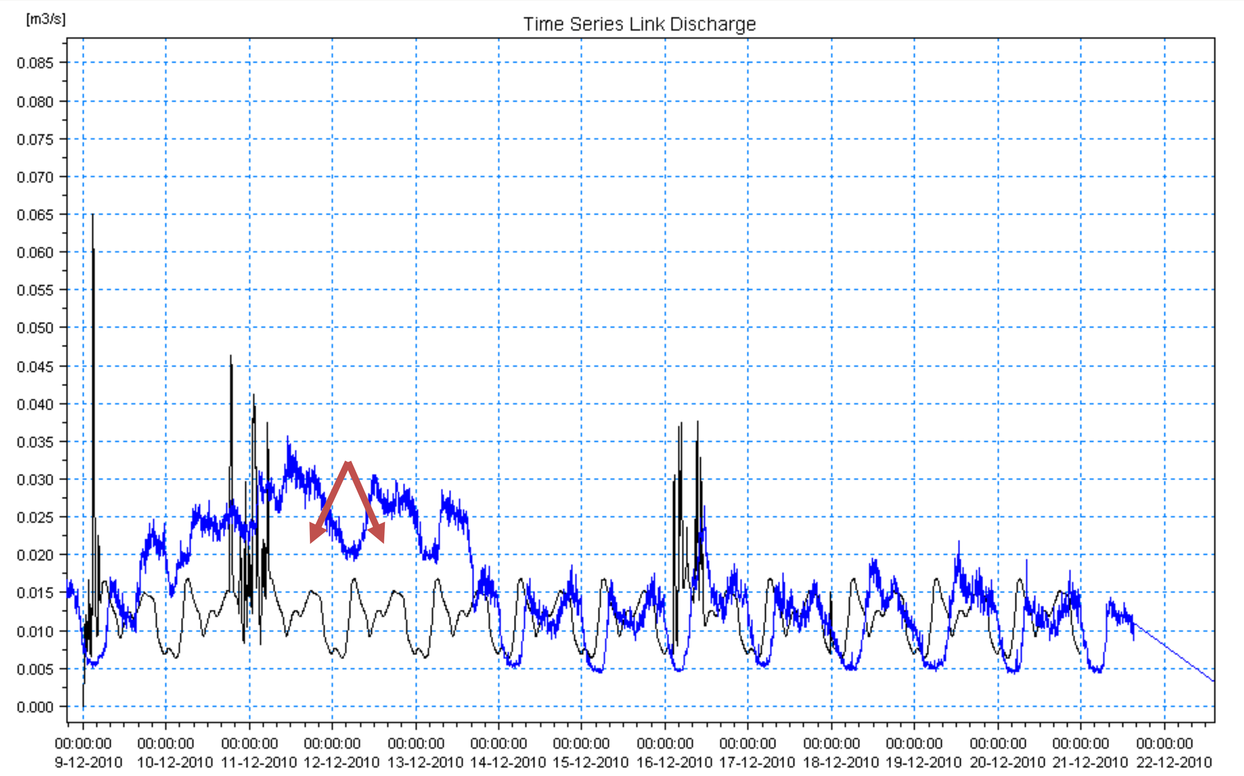

Figure 26 Validation between computed (black) and measured (blue) values at node ASN14276.

As it seen in the figure above there is a difference between computed and measured figures in the period between 11th until 14th of December. This phenomenon is described below.

"Flow peaks during rain events are often found to exceed the values that can be attributed to the contribution from participating impervious areas". (DHI 2009). What causes this event is the hydrological situation of the area and the way it responded to precipitation and infiltration, usually in slow rate named SRC. The SRC process is shown in the Figure 27.

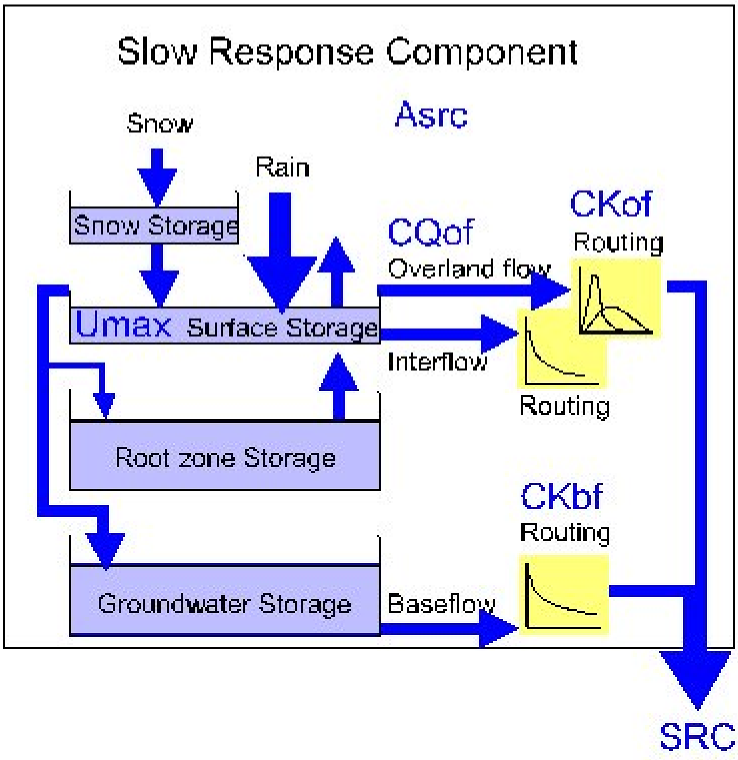

Figure 27 SRC process. (With permission of DHI)

The effects of rainfall, infiltration and storage can be simulated in MOUSE program using RDI model and hence calculate the effects of them on the sewer discharge. RDI model describes four types of storage.

1. Snow storage
2. Root zone storage
3. Surface storage
4. Groundwater storage

This model is described in Figure 28.

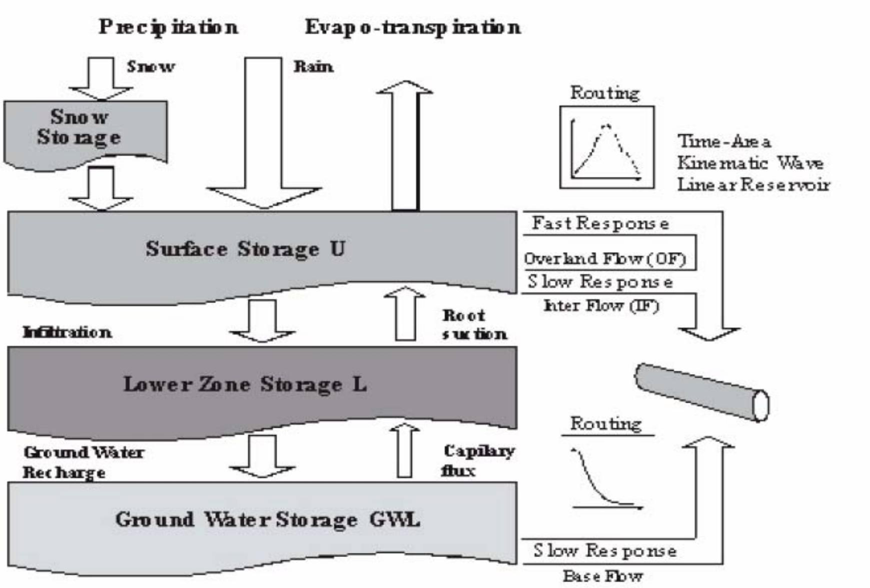

Figure 28 RDI model structure. (With permission of DHI)

What has happened in this period is that a heavy snowfall occured a few days ago which was recorded as rainfall by the gauge and being melted during the period which caused that amount of storage. It should be noted that "the snow storage is controlled by the temperature conditions and the current amount of snow on the catchment surface" (DHI 2009). The temperature variation at Gothenburg city is shown in the Figure 29.

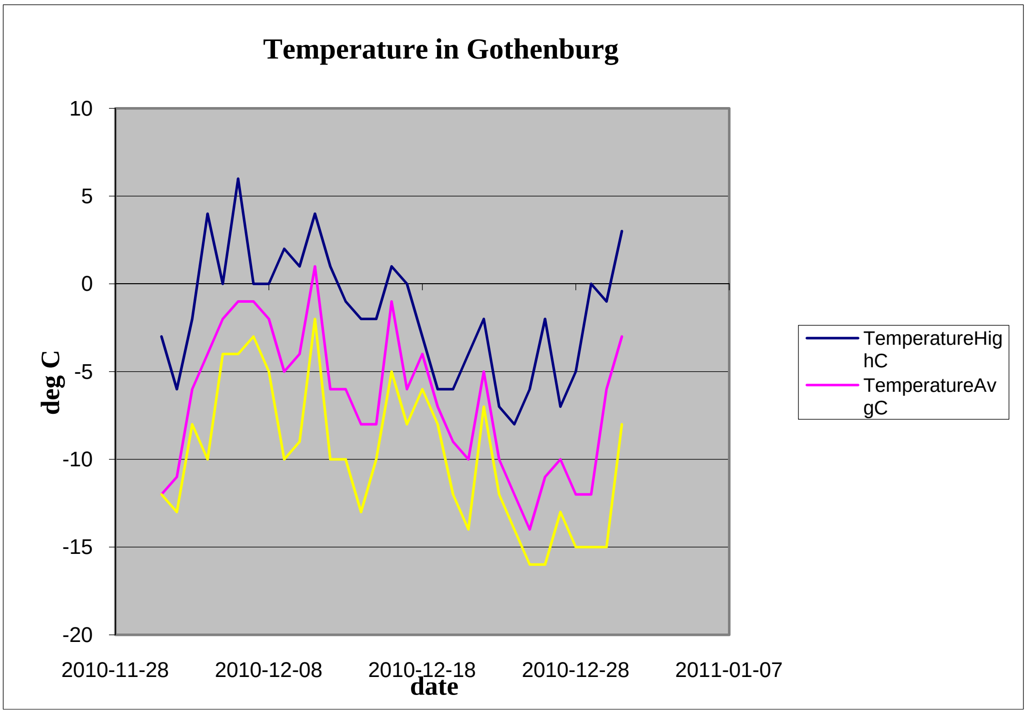

Figure 29 Temperature variation at Gothenburg city.

The statistical analysis at this node is shown in Figure 30.

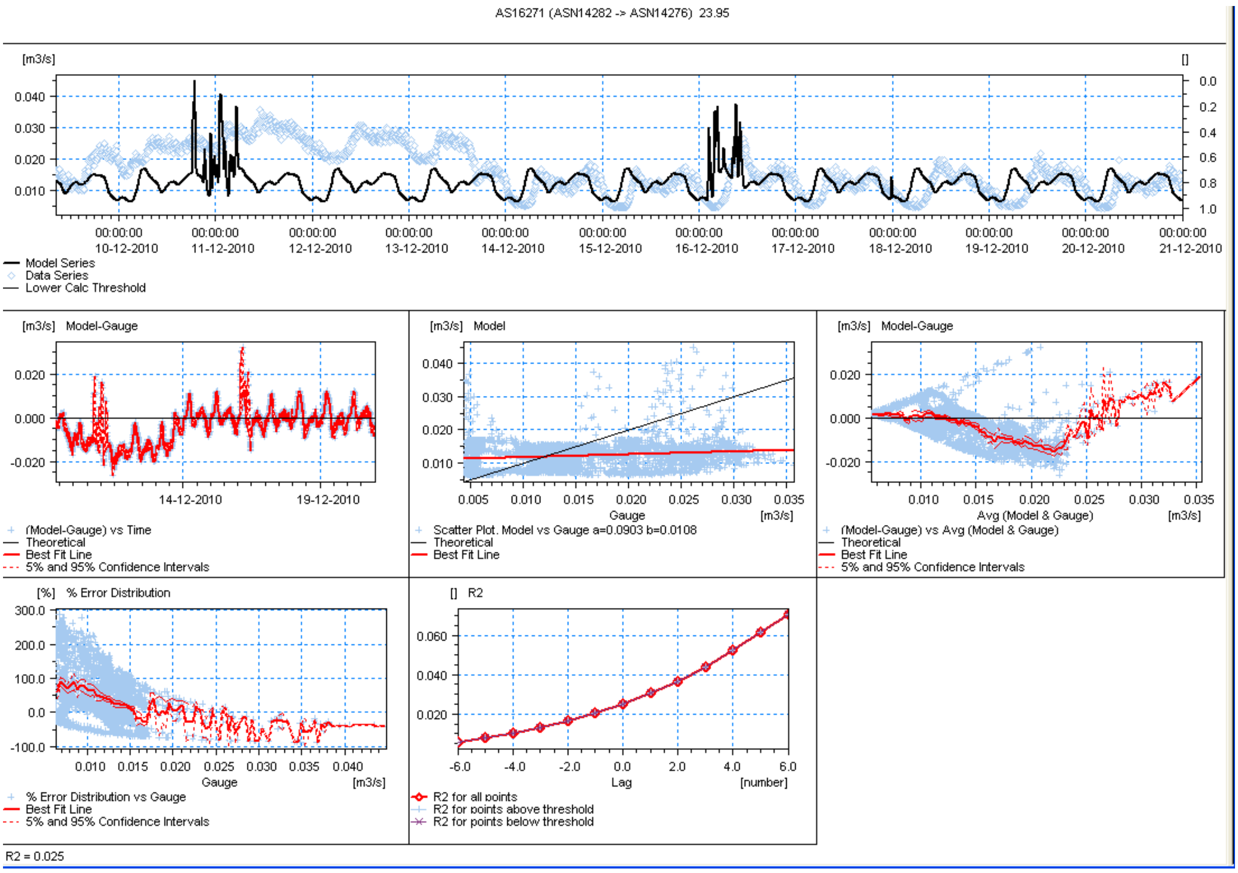

Figure 30 Statistical analysis for validation period at the node ASN14276.

Statistical analysis for node ASN14276 has shown that maximum positive difference between modeled and measured values is 0.032 m^3/s and the maximum negative difference is equal to -0.026 m^3/s. The total measured volume is 16535 m^3 and the total modeled volume is 12661 m^3 which means a volume error of -23.4% (minus mark shows deficiency in modeled value). Also the peak measured value is 0.036 m^3/s and the peak modeled value 0.045 m^3/s which means the peak error is equal to 25.5 %. The errors calculated for peak values is a little high which its reason has explained before.

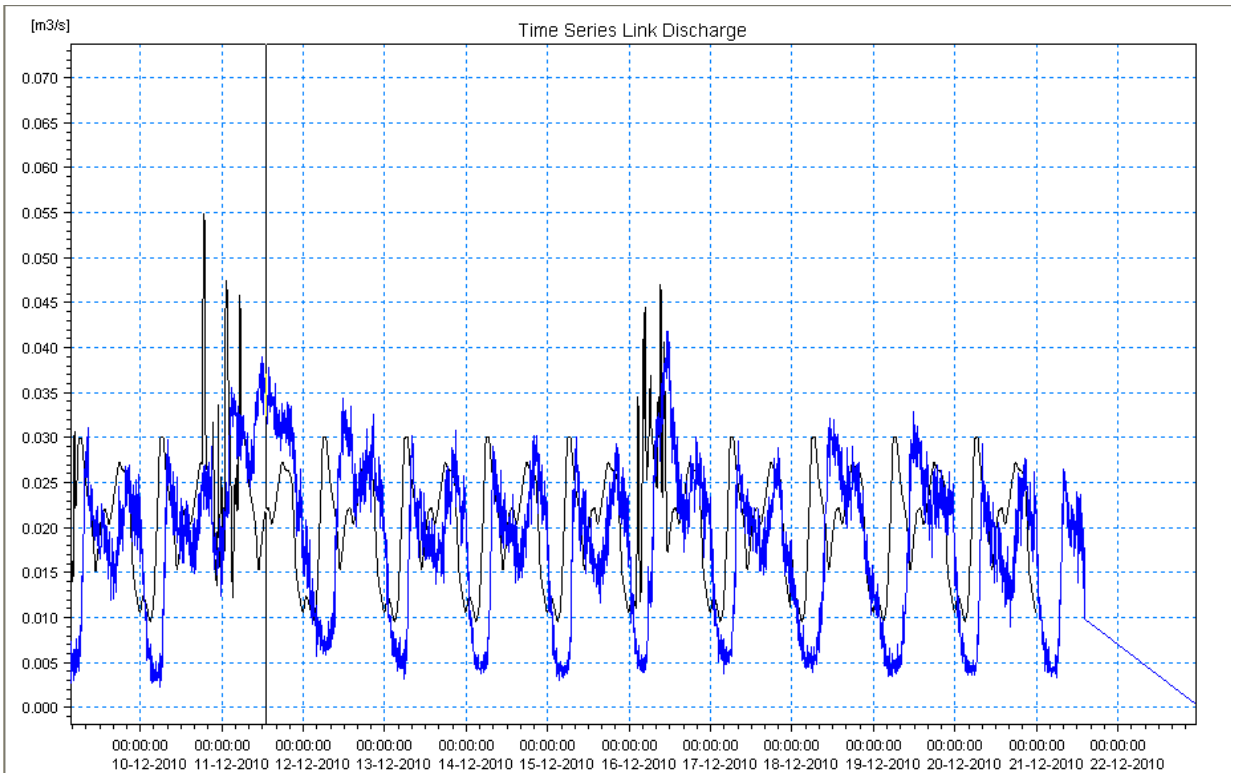

Figure 31 Validation between computed (black) and measured (blue) values at node ASN14294.

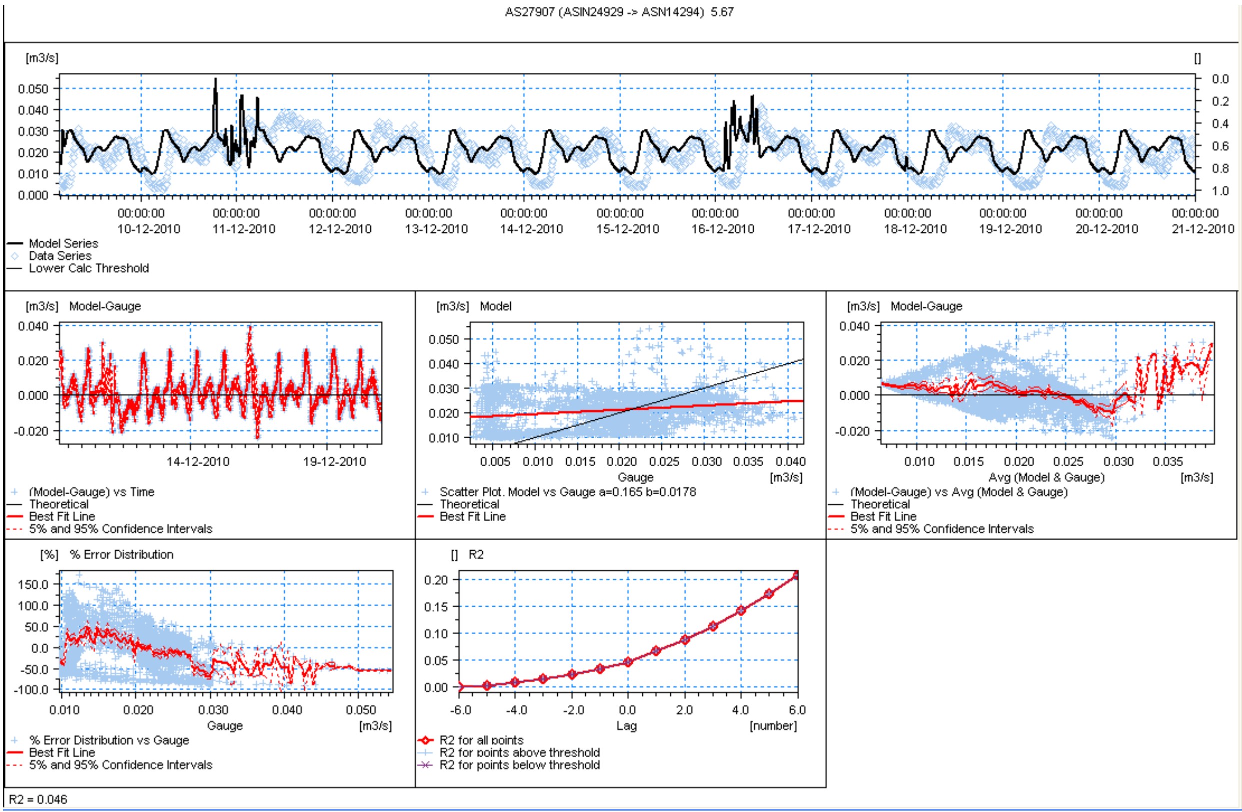

Figure 32 Statistical analysis for validation period at the node ASN14294.

Statistical analysis for this node has shown that maximum positive difference between modeled and measured values is 0.039 m^3/s and the maximum negative difference is equal to -0.024 m^3/s (minus mark shows deficiency in modeled value). The total measured volume is 19710 m^3 and the total modeled volume is 22000 m^3 which means a volume error of 11.6%. Also the peak measured value is 0.042 m^3/s and the peak modeled value 0.055 m^3/s which means the peak error is equal to 30.7 %. The errors calculated for total volume is quite good but is a little high for peak value.

5 Discussion

5.1 Evaluation of wastewater network system at Majorna

The aim of this project, as mentioned before, is to suggest some methods to improve the wastewater network system at Majorna region and then reduce the stormwater volume to the downstream wastewater treatment plant, Ryaverket, and instead releasing more to the receiving water, Göta Älv.

Hence some important key numbers which show the operation efficiency of network system have been calculated and used for suggestion of improvements. These parameters have been taken from annual average values of Gothenburg city to Ryaverket wastewater treatment plant (Naturvårdsverket 1996).

The first key number used; is the leakage and drainage value which shows the amount of leakage in system and has the standard value of 0.8-1 l/s.km. It was calculated based on the following equation.

$$\mathrm{LDM} = \frac{q_{ldr}}{\text{sanitary pipes length} + \text{combined pipes length}} \quad (14)$$

Where q_{ldr} is the summation of total leakage and drainage flow. Total leakage was assumed to be equal to the constant flows added to sub-catchments upstream each measuring point.

This parameter has been calculated for sub-catchments upstream the two measuring nodes and for the whole period of simulation, October 28th to December 21st. The results are presented in the tables below.

Table 6 Input data for sub-catchments upstream the node ASN14276.

Catchments	Total leakage (m^3/s)	Drainage volume (m^3)	Sanitary and combined pipes length (m)
22_2		1826.77	934
8_2		498.34	292
10_2		1997.72	265
22_1		529.93	386
6_1	0.004	873.82	647
11_1		379.25	502
23_1		459.97	338
23_2		370.88	379
7_1		954.91	399
Sum	**0.004**	**7891.59**	**4142**

The value of 7891.59 m^3 at 54 days is equal to 0.002 m^3/s or 2 l/s and the pipes length is equal to 4.142 km. The total leakage is also equal to 0.004 m^3/s or 4 l/s and hence according to the equation above the leakage and drainage value for this measuring node is equal to 1.5 l/s,km.

Table 7 Input data for sub-catchments upstream the node ASN 14294.

Catchments	Total leakage (m^3/s)	Drainage volume (m^3)	Sanitary and combined pipes length (m)
19_2	0.01	17.05	87
20_2		113.57	276
20_1		351.08	402
21_1		201.735	564
21_2		298.93	759
25_1		331	524
25_2		740.09	1363
26_1		762.56	1079
26_2		1330.73	697
13_2		194.36	272
Sum	0.01	4341.105	6023

The value of 4341.1 m^3 at 54 days is equal to 0.00093 m^3/s or 0.93 l/s and the pipes length is equal to 6.023 km. The total leakage is also equal to 0.01 m^3/s or 10 l/s and hence according to the equation above the value of leakage and drainage for this measuring node is equal to 1.8 l/s.km.

As it has seen both calculated leakage values are more than the standard value which is 0.8 l/s.km. This means that the pipelines in the whole sewer system at Majorna are old or not fixed properly and hence leaking a lot.

The second key number used is the degree of delineation, which represents the amount of stormwater in the system and its standard value is equal to 1.8. This parameter has been calculated on the basis of following equation.

$$\mathbf{USG} = \frac{q_{tot}}{q_s} \tag{15}$$

Where q_{tot} is the total flow of wastewater and q_s is the sanitary flow. These results for this value are presented in the tables below.

Table 8 Delineation factor for the node ASN14276.

Total flow(m^3)	Sanitary flow(m^3)	USG
58849.23	50957.64	1.82

Table 9 Delineation factor for the node ASN14294.

Total flow(m^3)	Sanitary flow(m^3)	USG
98484.65	47487.55	2.07

As it is seen the USG values for the two nodes are also higher than standard value which means the stormwater transported to the wastewater treatment plant form this region is more than standard.

Another criterion used to assess the model was the data about the daily average flow to wastewater treatment plant Ryaverket. Through the simulated model, the daily average flow of the two measuring node, ASN14276 and ASN14294, was calculated and then plotted against the flow to wastewater treatment plant. The data are presented in the appendix D and the results are plotted in the following figures.

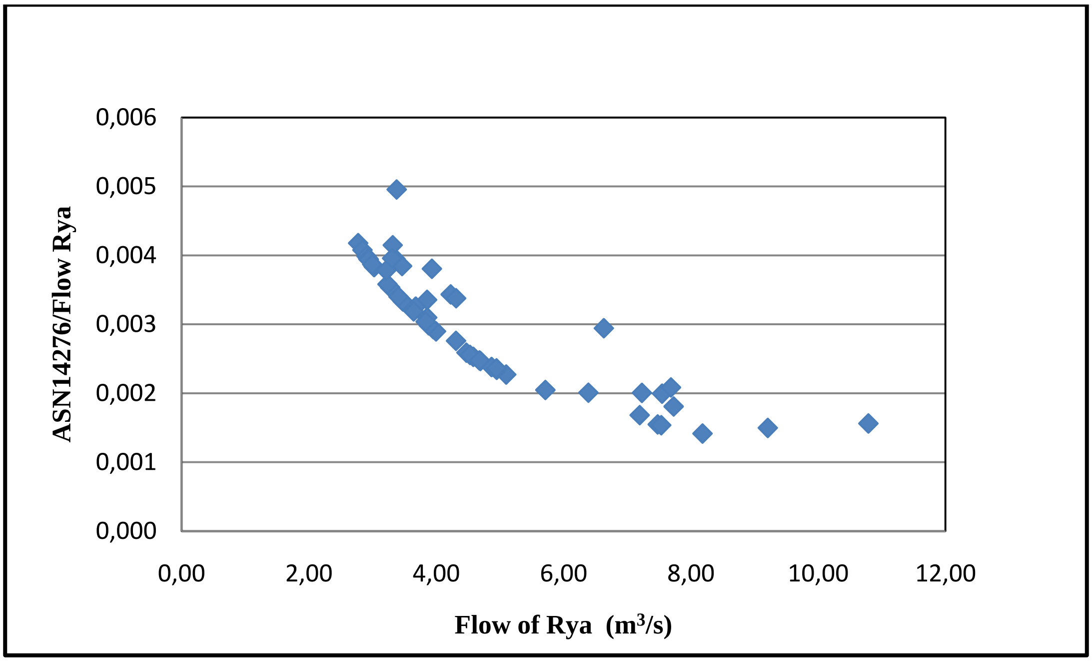

Figure 33 Comparison of flows at the node ASN14276.

Figure 33 has shown that when the flow to Ryaverket is high the ratio of Majorna area flow to the wastewater treatment plant is low and vice versa. The reason is the high amount of leakages at pipes which on the cases of high flow increase and so the flow conveyed at pipes are reduced which cause less portion to Ryaverket flow. In cases of low flow the leakages reduced as well and so the ration increases. This phenomenon occurs at both measuring nodes.

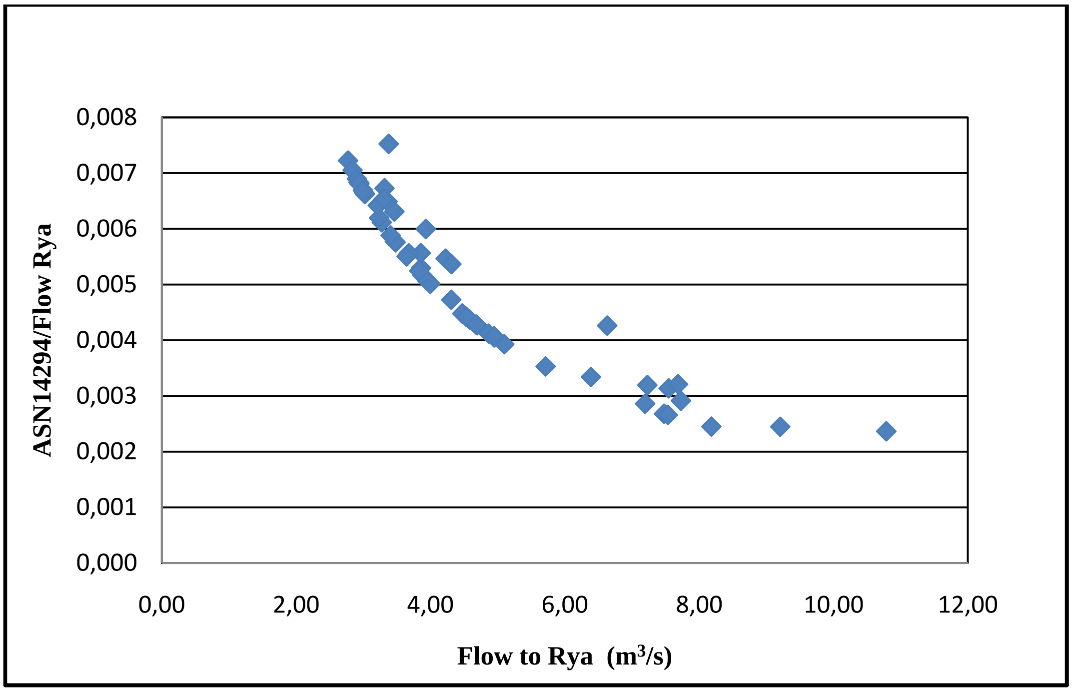

Figure 34 Comparison of the flows at the node ASN14294.

5.2 Improvements

The first suggestion has been made for improving the system, was to reduce the contributing area of the sub-catchments upstream the node ASN14294 by 30%, to reduce the delineation factor and find out its sensitivity to this criterion. In reality this means to connect flows form hard roofs to the stormwater system if they have been connected to sanitary pipes before. The results are presented in the tables below.

Table 10 Reduction of contributing area and the corresponding drainage volume for sub-catchments upstream the node ASN14294.

Catchments	Area(ha)	New area(ha)	Drainage volume(m^3)
19_2	0.57	0.40	11.94
20_2	1.11	0.77	79.78
20_1	4.32	3.02	245.78
21_1	3.66	2.56	141.23
21_2	4.12	2.88	209.24
25_1	7.13	4.99	231.70
25_2	11.59	8.11	518.06
26_1	10.51	7.36	533.80
26_2	13.48	9.44	931.50
13_2	4.19	2.93	136.06
Sum	60.66	42.46	3039.08

Table 11 New delineation factor for the node ASN14294.

Total flow	Sanitary flow	USG
97907.94	48212.86	2.03

As it is seen the USG factor did not show a considerable sensitivity for reducing the contributing area as it reduced from the value of 2.07 to 2.03.

The reason that this method did not work well is that, reduction of contributing area affects the storwater flow and not the base flow or sanitary water in a considerable manner. Another criterion which exists in this sewer system is the high amount of leakages which again have not been affected by this method. In a case of high stormwater the CSO upstream will release the excess runoff to the river downstream and hence in fact it does not affect the flow to the wastewater treatment plant Ryaverket.

As the second suggestion, it was decided to reduce the base flow, the constant flows added in calibration part, by 30% and find out the sensitivity of system to this criterion. The results are presented in the tables below.

Table 12 Old and new values of factors after reducing the base flow by 30% at the node ASN14276.

Factor	Old value	New value	Percentage of reduction
LDM	1.5	0.77	48.67
USG	1.82	1.39	23.63

Table 13 Old and new values of factors after reducing the base flow by 30% at the node ASN14294.

Factor	Old value	New value	Percentage of reduction
LDM	1.8	0.65	63.89
USG	2.07	1.28	38.16

So this method seems effective as the values of both leakage and delineation key factors have reduced and being appropriate according to standard values of each.

Also, like the previous part, the daily average flows of improved model for the two measuring nodes are plotted against daily average flow to wastewater treatment plant to evaluate the efficiency of this improvement method. The data are presented in appendix D.

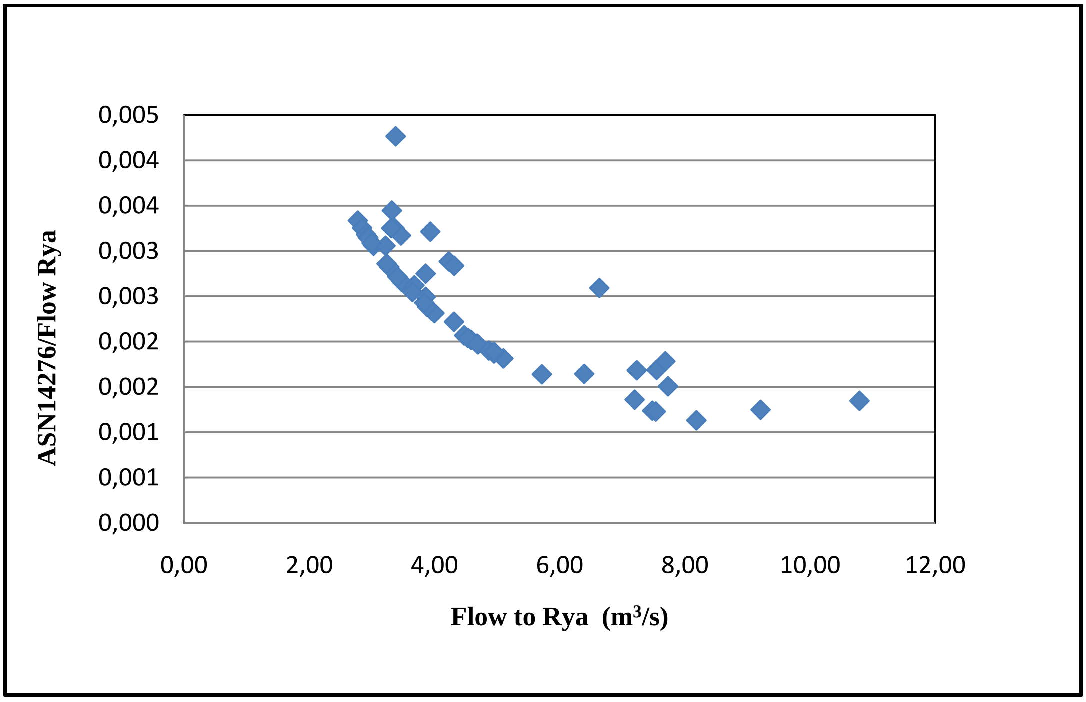

Figure 35 Comparison of the flows at the node ASN14276 after improvement of the system.

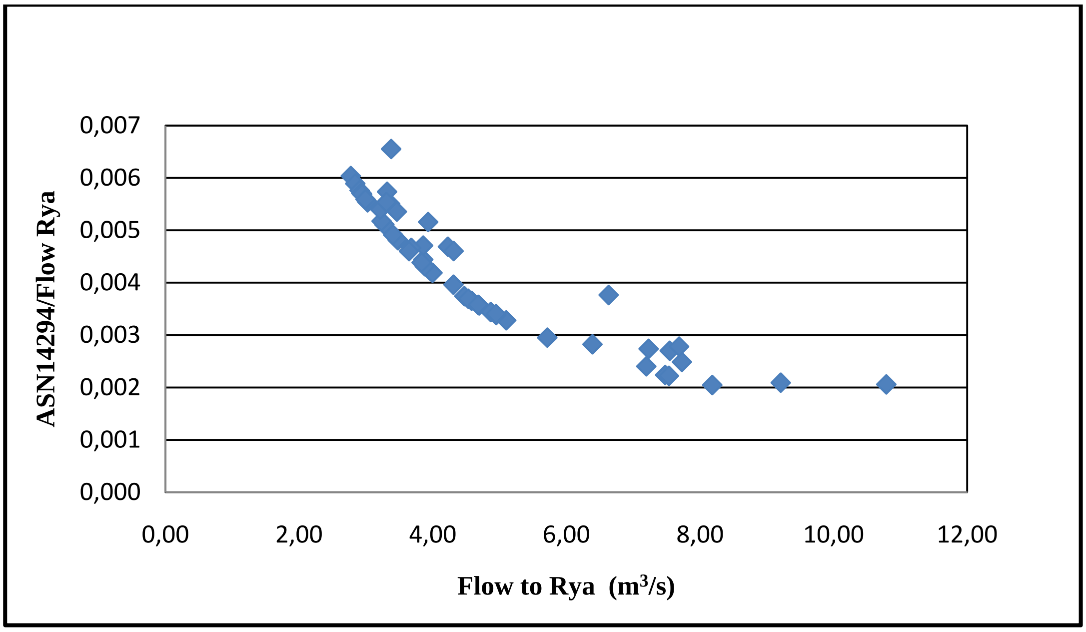

Figure 36 Comparison of the flows at the node ASN14294 after improvement of the system.

As it seen the ratio of the both measuring nodes flows to the wastewater flow has decreased comparing to the simulated values, which again shows that this improvement method is effective. The simulation results for this improvement method are presented at appendix D.

5.3 Conclusions and recommendations

Simulation of sewer system network at Majorna region has shown that there is a problem at one of the node which the measurements are done, ASN 14294. As discussed at the calibration part this mis-function may be caused by the leakages at the system or be an error of double discharge measuring. However it is recommended that a field study to be done for this node and also the measuring devices been calibrated again.

Comparison of the leakages at the system with the standard value has shown that there is a high leakage at the whole system. As a further study it is recommended that the exact places of leakages at system being investigated and reported. The rehabilitation which should be done can also be a subject of another investigation and methods and their motivations to use being discussed and finally the best one regarding technical as well as cost-benefit criteria being introduced.

It has shown that reduction of contributing area does not affect the USG factor considerably. The reason is, that reduction of contributing area only affects the peak flow, mostly stormwater that already nowadays is released to the river via the CSO located upstream node ASN14294.

It has shown that a reduction of 30% in the constant flows, which describes the leakages in the system, will lead to a leakage reduction of 49% for the sub-catchments upstream ASN14276 and 64% for the sub-catchments ASN14294.

Reduction of base flow by 30% also affected the USG factor which is a representative of the amount of stormwater at the system. According to this improvement method the amount of stormwater to the wastewater treatment plant for sub-catchments upstream the node ASN14276 has reduced 24% and for the ones upstream the node ASN14294 reduced 38%.

Majorna area located at a low altitude and hence the groundwater table plays an important role in sewer systems. In places where groundwater locates above the sewer systems it can enter the sewage pipes due to leakages at pipes and junctions and where sewer systems located above groundwater table the sewer may cause pollution.

As a general recommendation, it can be said that as simulations has shown that the Majorna wastewater system has lots of leakages. Repair of pipes junction and other properties will lead to a better system function, a lower risk of groundwater pollution and also less stormwater flow to Ryaverket.

6 References

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7 Appendix A: CRS and Topography

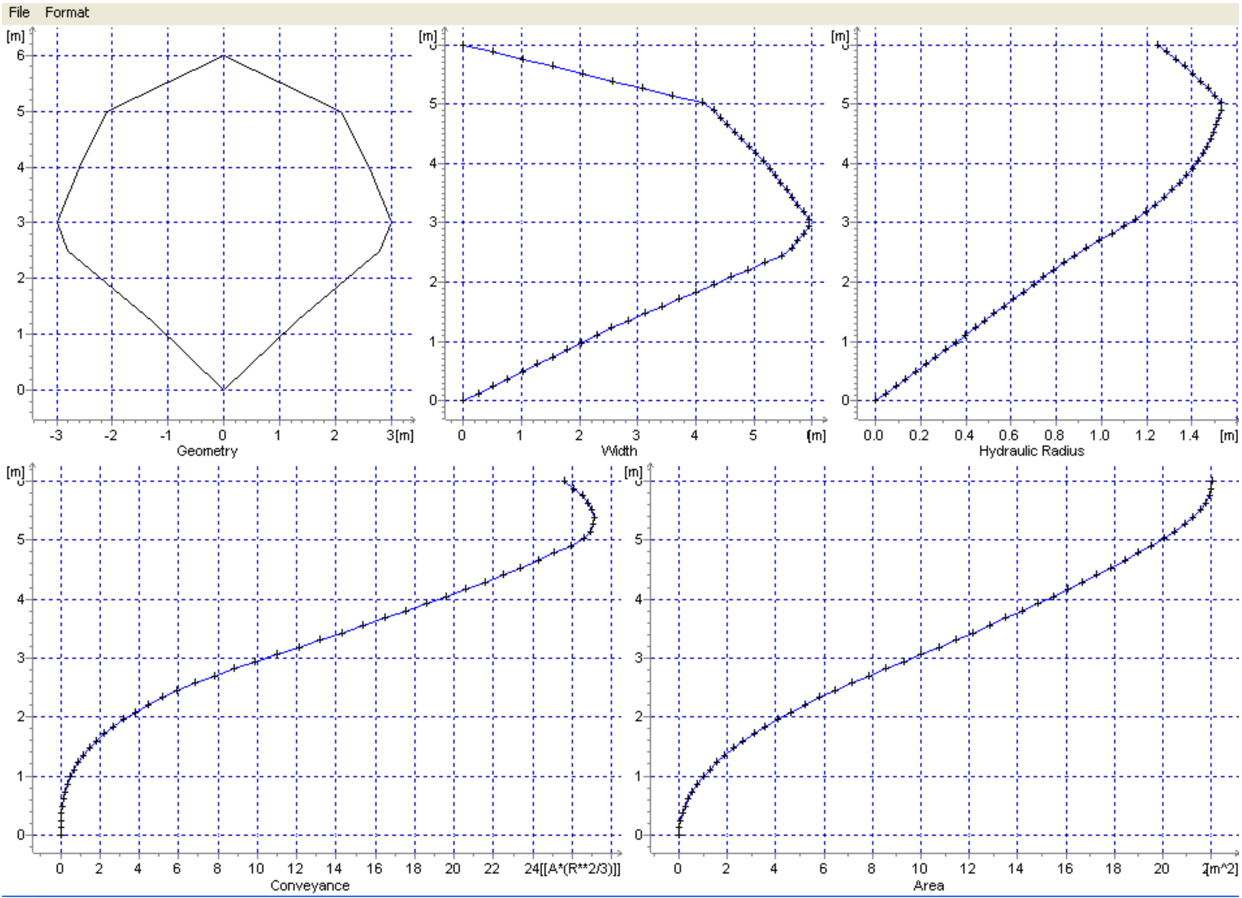

Figure 37 Pipes AD29859, AD9492 and AD9492_2 with inner diameter of 250 mm and outer diameter of 600 mm.

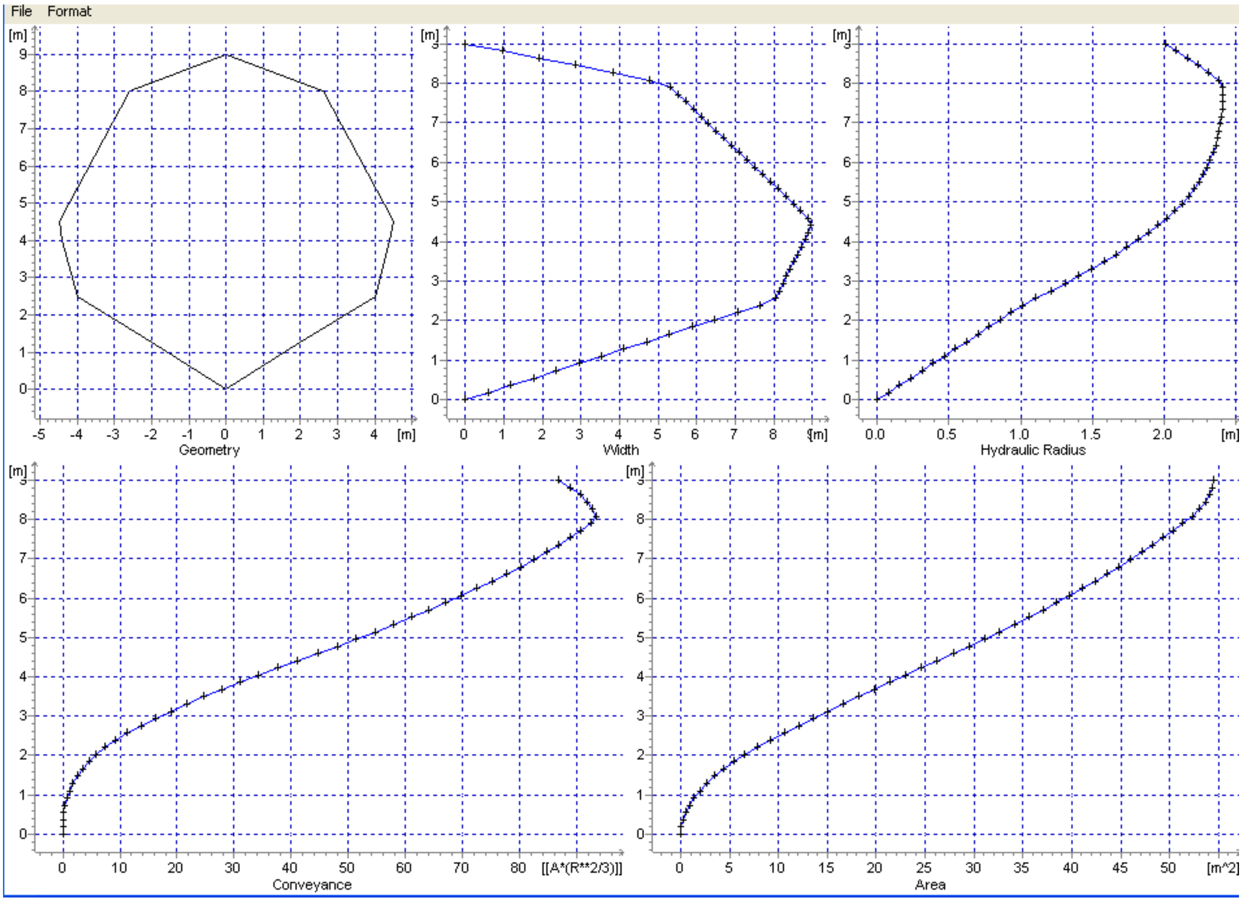

Figure 38 *Pipe AS40742 with inner diameter of 250 mm and outer diameter of 900 mm.*

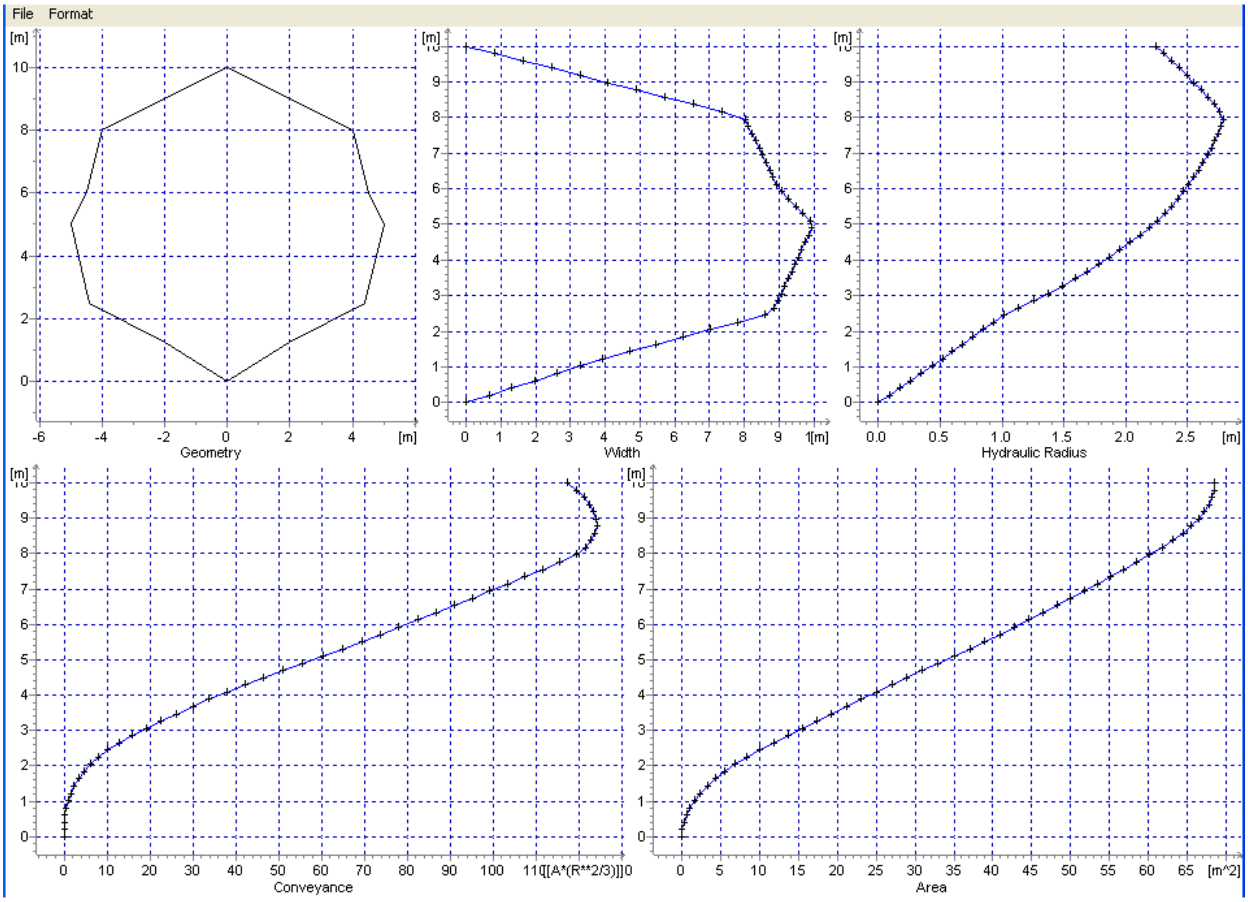

Figure 39 Pipes AD18146 and AD29858 with inner diameter of 250 mm and outer diameter of 1000 mm.

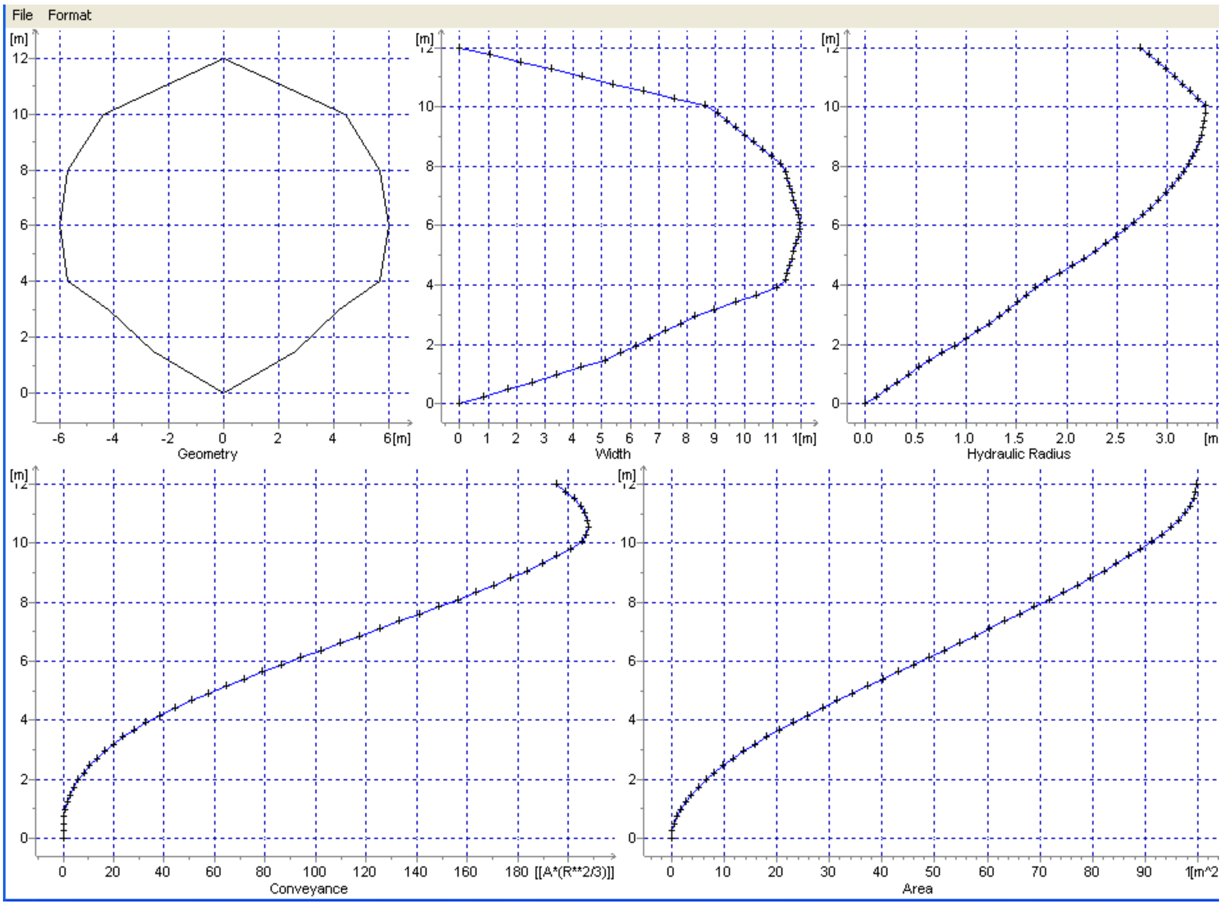

Figure 40 Pipes AD31051 and AS27822 with inner diameter of 300 mm and outer diameter of 1200 mm.

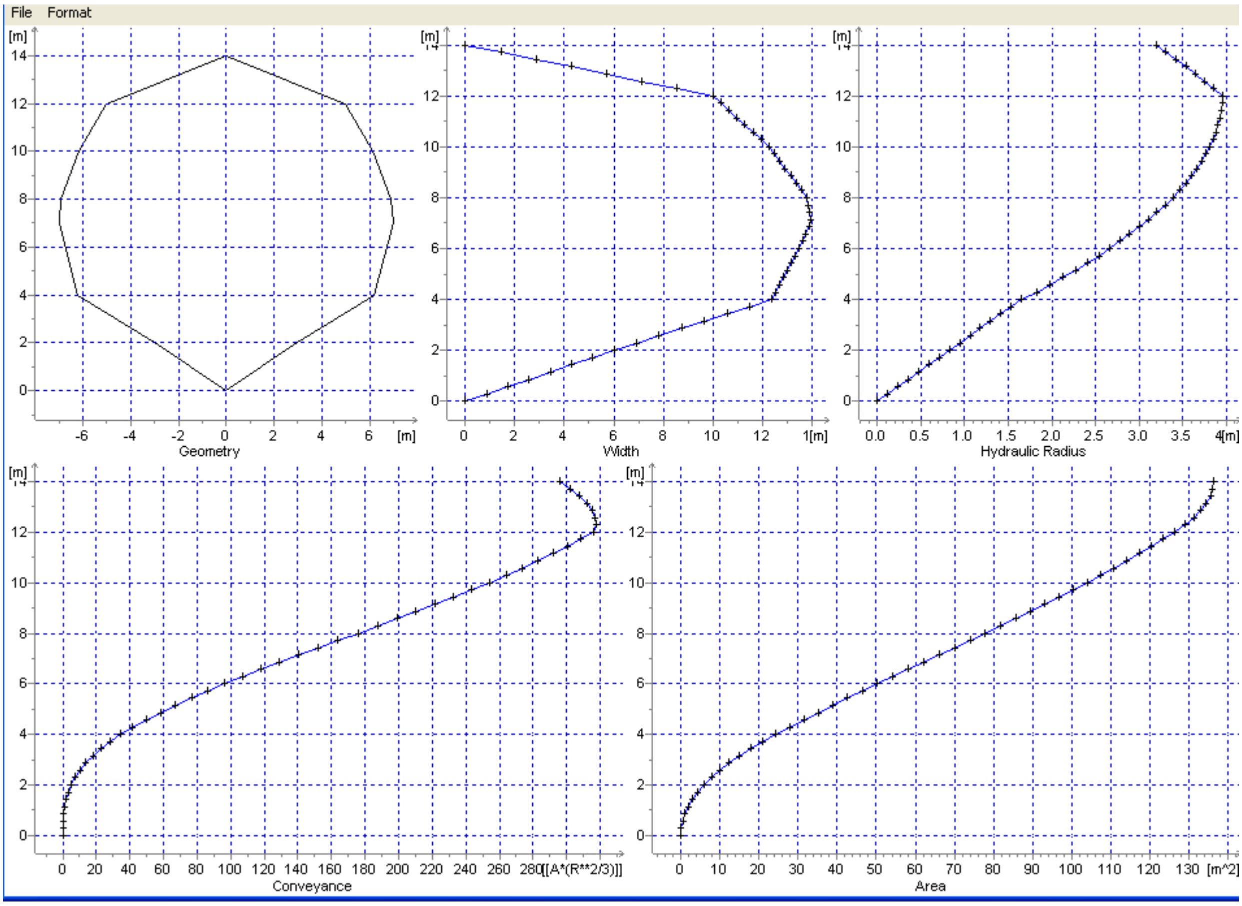

Figure 41 Pipe AD16614 with inner diameter of 400 mm and outer diameter of 1380 mm.

8 Appendix B: Weirs and their characteristics

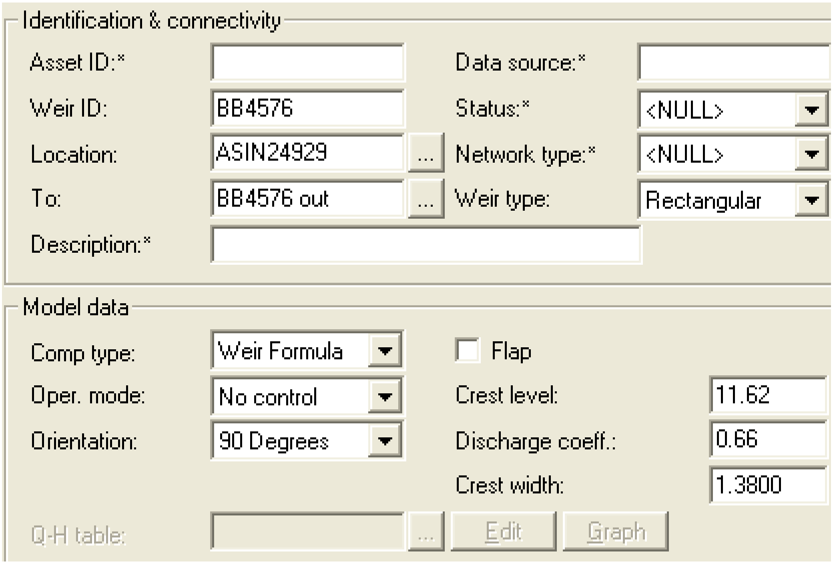

Figure 42 BB4576.

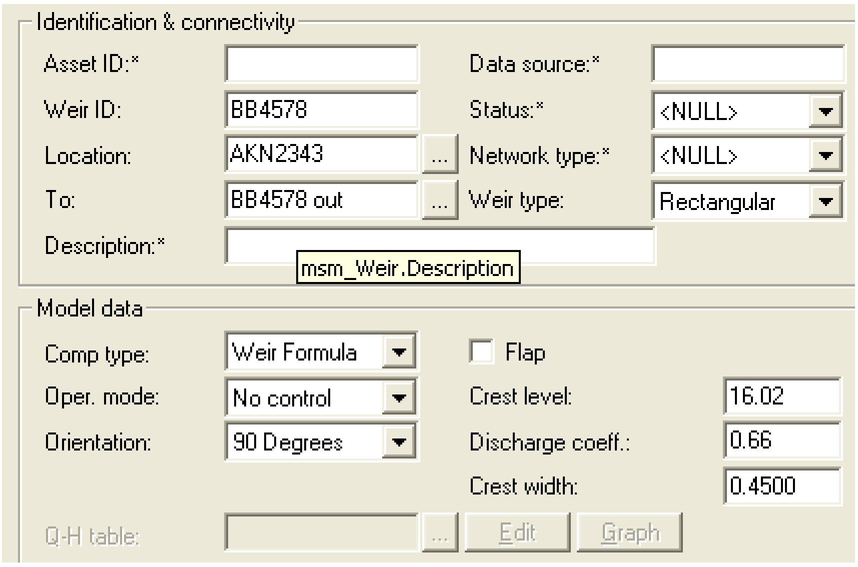

Figure 43 BB4578.

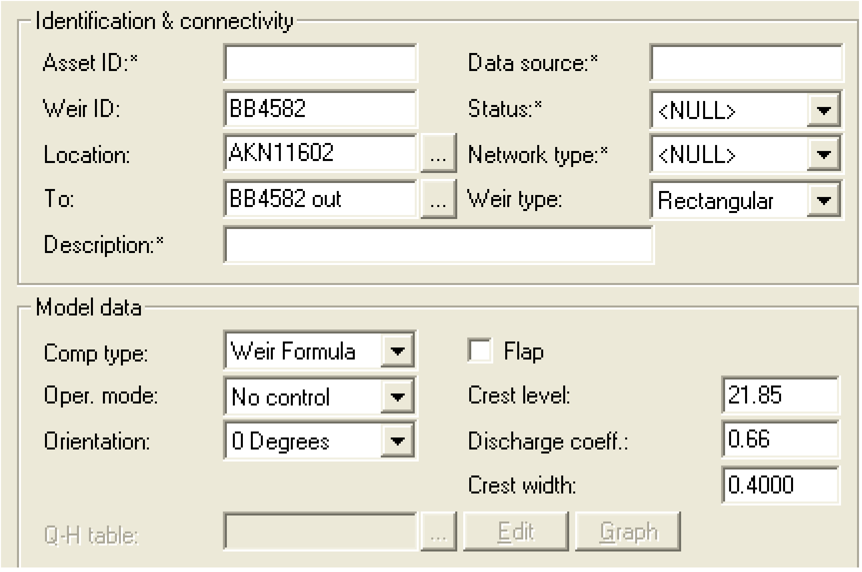

Figure 44 BB4582.

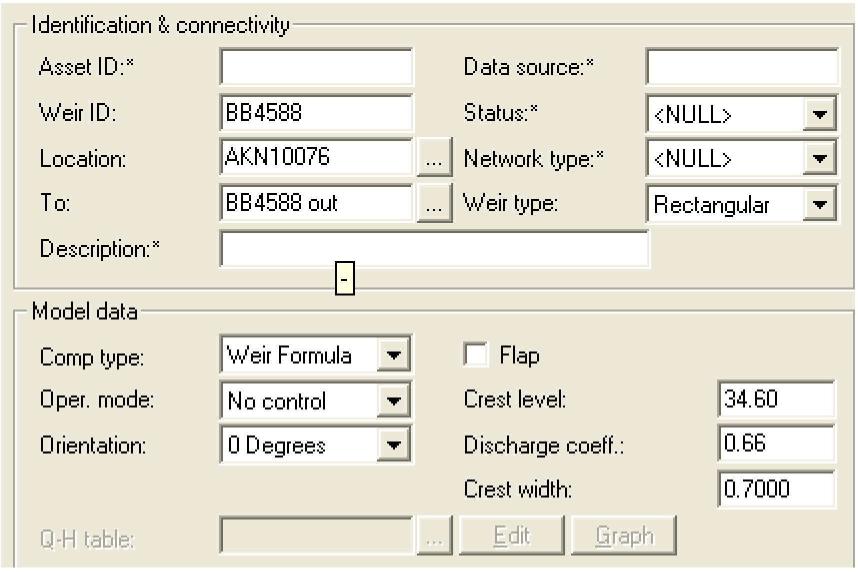

Figure 45 BB4588.

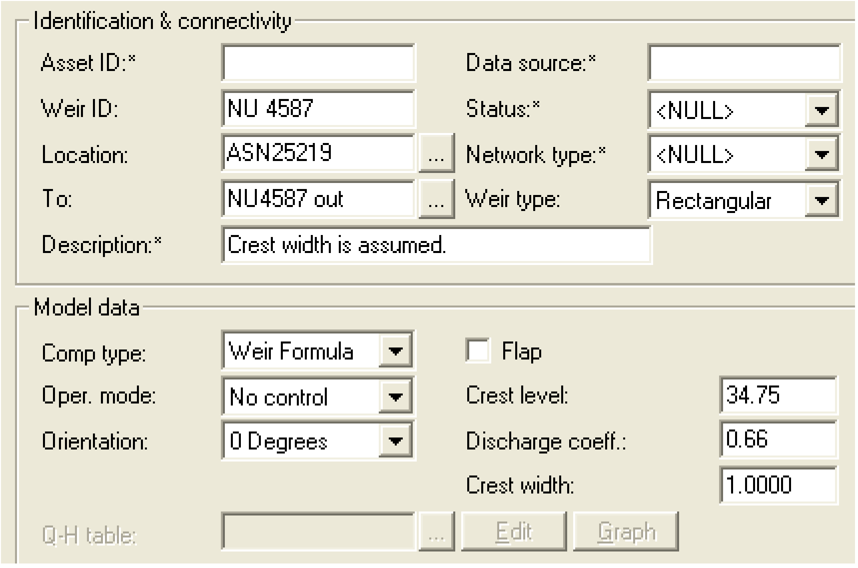

Figure 46   NU4587.

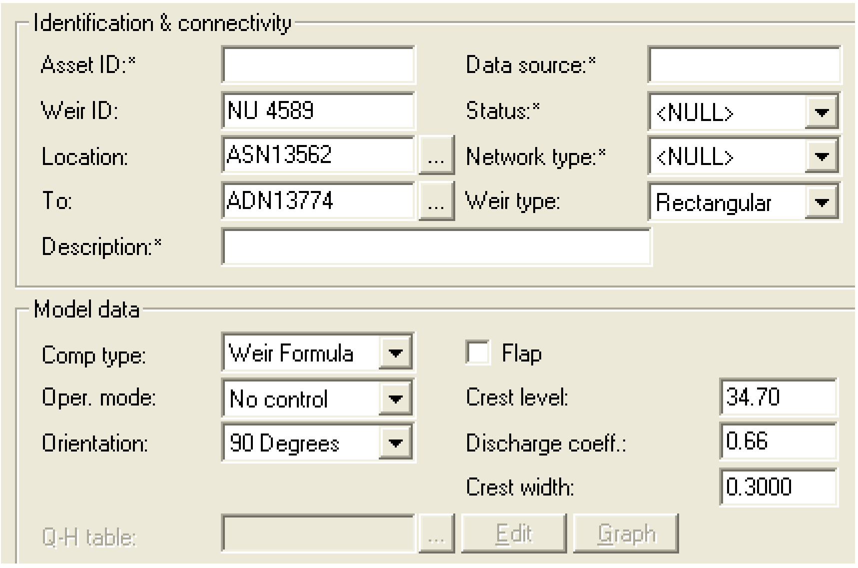

Figure 47   NU4589.

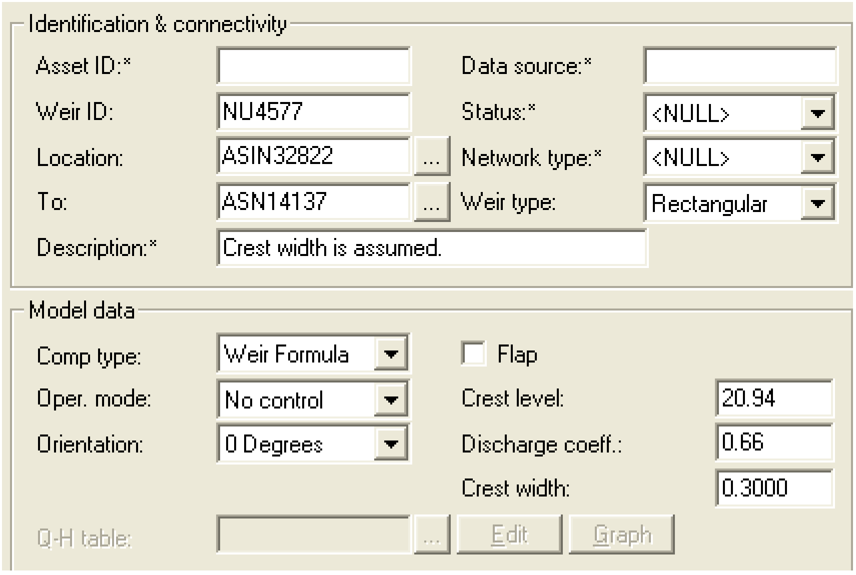

Figure 48 NU4577.

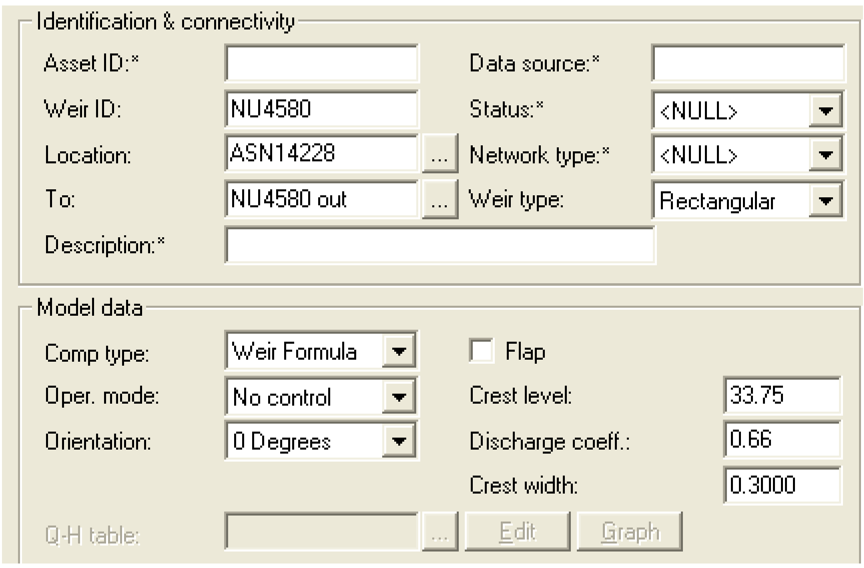

Figure 49 NU4580.

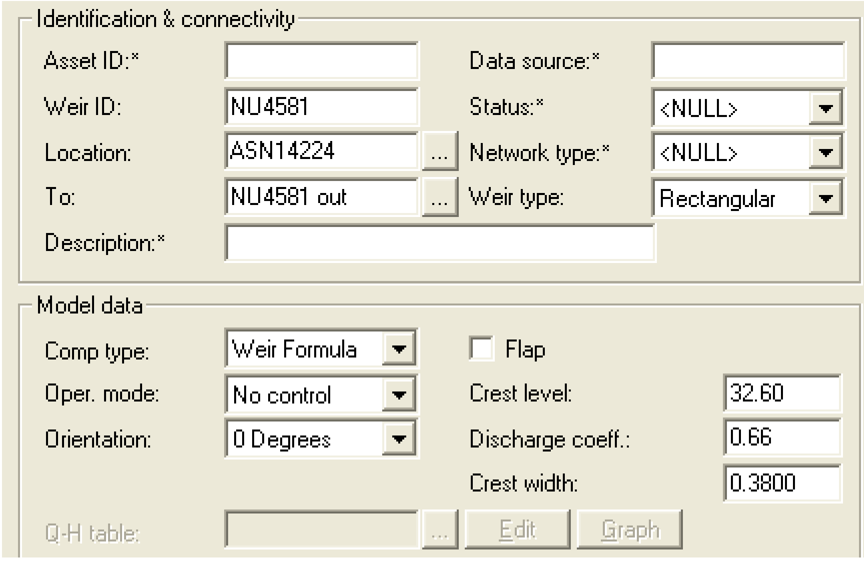

Figure 50 NU4581.

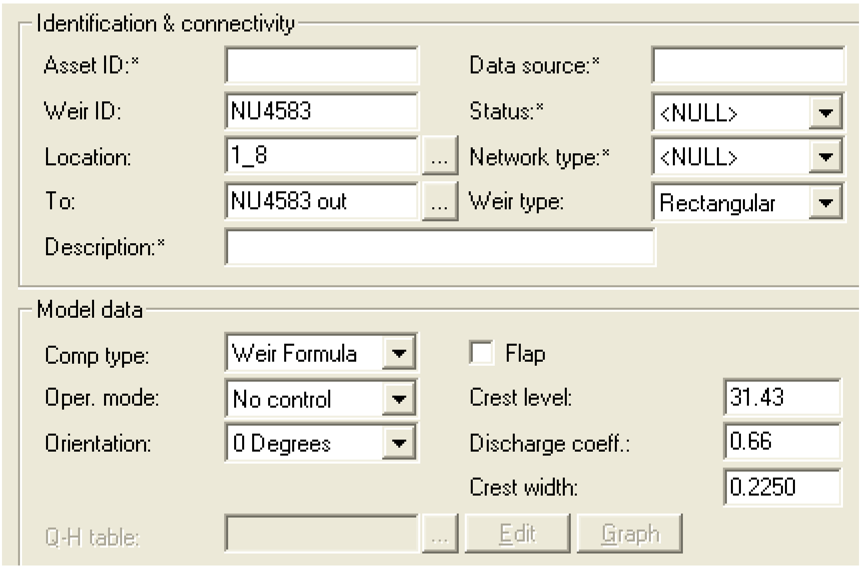

Figure 51 NU4583.

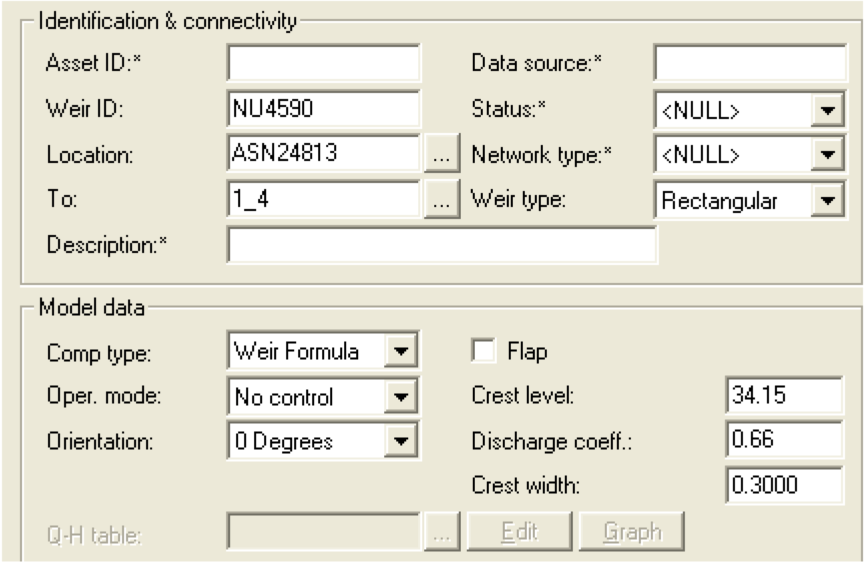

Figure 52 NU4590.

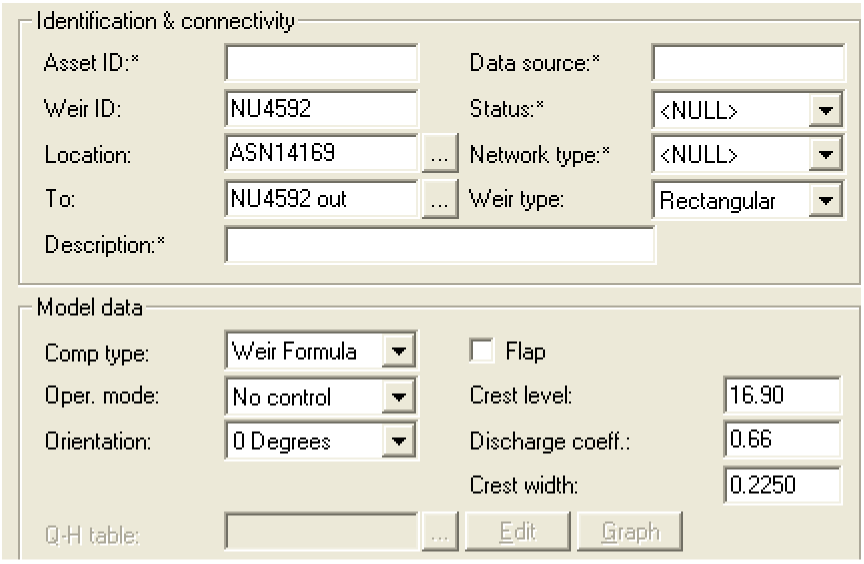

Figure 53 NU4592.

9 Appendix C: Simulation results

9.1 Calibration

MOUSE HD Computation Engine v2009 Release Version (0.0.0.3073)

MOUSE Pipe Flow Simulation --- Status Report ---Dynamic Wave

Input Summary

Number of Manholes:	994
Number of Basins:	0
Number of Outlets:	6
Number of Storage Nodes:	0
Number of Circular Pipes:	993
Number of Rectangular pipes:	0
Number of CRS defined pipes:	10
Number of Pumps:	0
Number of Controlled Pumps:	0
Number of Weirs/Orifices:	12
Number of Controlled Weirs/Gates:	0
Number of Valves:	0
Number of Controlled Valves:	0

Nodes

Min Invert Level	ADN14690	8.02 m

Max Invert Level	AKN1741	71.95 m
Min Ground Level	ADN14710	11.24 m
Max Ground Level	AKN1856	73.59 m
Min X Coordinate	ASN14026	1.4518E05 m
Max X Coordinate	AKN1847	1.4648E05 m
Min Y Coordinate	ADN25385	6.3967E06 m
Max Y Coordinate	ADN14709	6.3979E06 m
Total Manhole Volume		2478.1 m^3
Total Basin Volume		0.0 m^3

Links

Total Circular Volume	3398.3 m^3
Total CRS Volume	43744.7 m^3
Total Length	28276.00 m

Time Step parameters loaded from the DHIAPP.INI file

INI file :	C:\PROGRA~1\DHI\2009\bin\DHIAPP.INI
Relative change criteria for inflow time series :	0.100
Low flow limit for inflow time series :	0.010
Maximum relative water level change :	0.100
Maximum variation in Cross Section parameters :	0.100

Cross check low depth limit (relative) :	0.040
Cross check level :	1.000
Maximum Courant Number :	20.000

Simulation Result Summary

Continuity Balance

1:	**Start volume in Pipes, Manholes and Structures**			**4.8 m^3**
2:	**End volume in Pipes, Manholes and Structures**			**10342.0 m^3**
3:	**Total inflow volume**			
	Specified inflows			
	Runoff :	27740.6 m^3		
	DWF :	224872.8 m^3		
	Non-specified inflows			
	Outlets (inflow) :	105.0 m^3		
		252718.3 m^3	**-->**	**252718.3 m^3**
4:	**Total diverted volume**			
	Operational, non-specified outflows			
	Outlets :	253582.8 m^3		

	253582.8 m^3	**-->**	**253582.8 m^3**
5:	**Water generated in empty parts of the system :**		**2675.9 m^3**
6:	**Continuity Balance = (2-1) - (3-4+5) :**		**8525.8 m^3**
	Continuity Balance max value :	8525.8 m^3	
	Continuity Balance min value :	0.0 m^3	

Boundary Connections

Network loads (discharges)

Boundary Condition ID	Type	Connection Type	Location	Temporal variation	Value /pattern/TS name	Validity	Validity Start	Validity End	Minimum Value	Maximum Value	Accumulated Value
									m^3/s	m^3/s	m^3
14276_1	Discharge	Individual	ASN14282	Constant	0.0004	Unlimited	-	-	0.000	0.000	1451.5
14276_10	Discharge	Individual	ASN14230	Constant	0.0004	Unlimited	-	-	0.000	0.000	1451.5
14276_2	Discharge	Individual	ASN14233	Constant	0.0004	Unlimited	-	-	0.000	0.000	1451.5
14276_3	Discharge	Individual	ASN14248	Constant	0.0004	Unlimited	-	-	0.000	0.000	1451.5
14276_4	Disch	Indivi	ASN1	Constant	0.000	Unli	-	-	0.000	0.000	1451.5

	arge	dual	3550		4	mited					
14276_5	Disch arge	Indivi dual	ASN1 3561	Constant	0.000 4	Unli mited	-	-	0.000	0.000	1451.5
14276_6	Disch arge	Indivi dual	ASN1 4237	Constant	0.000 4	Unli mited	-	-	0.000	0.000	1451.5
14276_7	Disch arge	Indivi dual	ASN1 4264	Constant	0.000 4	Unli mited	-	-	0.000	0.000	1451.5
14276_8	Disch arge	Indivi dual	ASN1 3582	Constant	0.000 4	Unli mited	-	-	0.000	0.000	1451.5
14276_9	Disch arge	Indivi dual	ASN1 3591	Constant	0.000 4	Unli mited	-	-	0.000	0.000	1451.5
14294_1	Disch arge	Indivi dual	ASIN2 4934	Constant	0.001	Unli mited	-	-	0.001	0.001	3628.8
14294_10	Disch arge	Indivi dual	ASIN2 4929	Constant	0.001	Unli mited	-	-	0.001	0.001	3628.8
14294_2	Disch arge	Indivi dual	ASN1 4293	Constant	0.001	Unli mited	-	-	0.001	0.001	3628.8
14294_3	Disch arge	Indivi dual	AKN2 348	Constant	0.001	Unli mited	-	-	0.001	0.001	3628.8
14294_4	Disch arge	Indivi dual	1_34	Constant	0.001	Unli mited	-	-	0.001	0.001	3628.8
14294_5	Disch arge	Indivi dual	ADN1 4811	Constant	0.001	Unli mited	-	-	0.001	0.001	3628.8
14294_6	Disch arge	Indivi dual	AKN2 295	Constant	0.001	Unli mited	-	-	0.001	0.001	3628.8
14294_7	Disch arge	Indivi dual	AKN2 289	Constant	0.001	Unli mited	-	-	0.001	0.001	3628.8
14294_8	Disch arge	Indivi dual	1_25	Constant	0.001	Unli mited	-	-	0.001	0.001	3628.8
14294_9	Disch arge	Indivi dual	ADN1 4789	Constant	0.001	Unli mited	-	-	0.001	0.001	3628.8
Domestic Wastewater	Disch arge	Geoco ded		Cyclic	Profil e_1	Unli mited	-	-	0.009	0.052	111490. 6
PE-basedDWF	Disch arge	All		Cyclic	Profil e_1	Unli mited	-	-	0.005	0.029	62580.0

9.2 Validation

MOUSE HD Computation Engine v2009 Release Version (0.0.0.3073)

MOUSE Pipe Flow Simulation --- Status Report ---Dynamic Wave

Input Summary

Number of Manholes:	994
Number of Basins:	0
Number of Outlets:	6
Number of Storage Nodes:	0
Number of Circular Pipes:	993
Number of Rectangular pipes:	0
Number of CRS defined pipes:	10
Number of Pumps:	0
Number of Controlled Pumps:	0
Number of Weirs/Orifices:	12
Number of Controlled Weirs/Gates:	0
Number of Valves:	0
Number of Controlled Valves:	0

Nodes

Min Invert Level	ADN14690	8.02 m
Max Invert Level	AKN1741	71.95 m

Min Ground Level	ADN14710	11.24 m
Max Ground Level	AKN1856	73.59 m
Min X Coordinate	ASN14026	1.4518E05 m
Max X Coordinate	AKN1847	1.4648E05 m
Min Y Coordinate	ADN25385	6.3967E06 m
Max Y Coordinate	ADN14709	6.3979E06 m
Total Manhole Volume		2478.1 m^3
Total Basin Volume		0.0 m^3

Links

Total Circular Volume	3398.3 m^3
Total CRS Volume	43744.7 m^3
Total Length	28276.00 m

Time Step parameters loaded from the DHIAPP.INI file

INI file :	C:\PROGRA~1\DHI\2009\bin\DHIAPP.INI
Relative change criteria for inflow time series :	0.100
Low flow limit for inflow time series :	0.010
Maximum relative water level change :	0.100
Maximum variation in Cross Section parameters :	0.100
Cross check low depth limit (relative) :	0.040

Cross check level :	1.000
Maximum Courant Number :	20.000

Simulation Result Summary

Continuity Balance

1 :	**Start volume in Pipes, Manholes and Structures**			**4.8 m^3**
2 :	**End volume in Pipes, Manholes and Structures**			**3030.1 m^3**
3 :	**Total inflow volume**			
	Specified inflows			
	Runoff :	5735.9 m^3		
	DWF :	64248.5 m^3		
	Non-specified inflows			
	Outlets (inflow) :	23.4 m^3		
		70007.8 m^3	**-->**	**70007.8 m^3**
4 :	**Total diverted volume**			
	Operational, non-specified outflows			
	Outlets :	69524.3 m^3		
		69524.3 m^3	**-->**	**69524.3 m^3**
5	**Water generated in empty parts of the**			**713.7 m^3**

: system :

6 : **Continuity Balance = (2-1) - (3-4+5) :** **1828.1 m^3**

Continuity Balance max value : 1828.1 m^3

Continuity Balance min value : 0.0 m^3

Boundary Connections

Network loads (discharges)

Boundary Condition ID	Type	Connection Type	Location	Temporal variation	Value /pattern/TS name	Validity	Validity Start	Validity End	Minimum Value	Maximum Value	Accumulated Value
									m3/s	m3/s	m3
14276_1	Discharge	Individual	ASN14282	Constant	0.0004	Unlimited	-	-	0.000	0.000	414.7
14276_10	Discharge	Individual	ASN14230	Constant	0.0004	Unlimited	-	-	0.000	0.000	414.7
14276_2	Discharge	Individual	ASN14233	Constant	0.0004	Unlimited	-	-	0.000	0.000	414.7
14276_3	Discharge	Individual	ASN14248	Constant	0.0004	Unlimited	-	-	0.000	0.000	414.7
14276_4	Discharge	Individual	ASN13550	Constant	0.0004	Unlimited	-	-	0.000	0.000	414.7
14276_5	Discharge	Individual	ASN13561	Constant	0.0004	Unlimited	-	-	0.000	0.000	414.7
14276_6	Discharge	Individual	ASN14237	Constant	0.0004	Unlimited	-	-	0.000	0.000	414.7
14276_7	Discharge	Individual	ASN14264	Constant	0.0004	Unlimited	-	-	0.000	0.000	414.7
14276_8	Discharge	Individual	ASN13582	Constant	0.0004	Unlimited	-	-	0.000	0.000	414.7

14276_9	Discharge	Individual	ASN13591	Constant	0.0004	Unlimited	-	-	0.000	0.000	414.7
14294_1	Discharge	Individual	ASIN24934	Constant	0.001	Unlimited	-	-	0.001	0.001	1036.8
14294_10	Discharge	Individual	ASIN24929	Constant	0.001	Unlimited	-	-	0.001	0.001	1036.8
14294_2	Discharge	Individual	ASN14293	Constant	0.001	Unlimited	-	-	0.001	0.001	1036.8
14294_3	Discharge	Individual	AKN2348	Constant	0.001	Unlimited	-	-	0.001	0.001	1036.8
14294_4	Discharge	Individual	1_34	Constant	0.001	Unlimited	-	-	0.001	0.001	1036.8
14294_5	Discharge	Individual	ADN14811	Constant	0.001	Unlimited	-	-	0.001	0.001	1036.8
14294_6	Discharge	Individual	AKN2295	Constant	0.001	Unlimited	-	-	0.001	0.001	1036.8
14294_7	Discharge	Individual	AKN2289	Constant	0.001	Unlimited	-	-	0.001	0.001	1036.8
14294_8	Discharge	Individual	1_25	Constant	0.001	Unlimited	-	-	0.001	0.001	1036.8
14294_9	Discharge	Individual	ADN14789	Constant	0.001	Unlimited	-	-	0.001	0.001	1036.8
Domestic Wastewater	Discharge	Geocoded		Cyclic	Profile_1	Unlimited	-	-	0.009	0.052	31854.4
PE-basedDWF	Discharge	All		Cyclic	Profile_1	Unlimited	-	-	0.005	0.029	17880.0

9.3 Improvement

9.3.1 Runoff simulation

MOUSE Runoff Computation Engine v2009 Release Version (0.0.0.3073)

MOUSE Runoff Model A Status Report

Dry Weather Periods

Initial loss recovery rate [m/hour] : 0.0000500

Simulation Result Summary

Catchment Result Summary

Catchment runoff hydrograph summary

	Rain Event	Minimum	Maximum	Flow - Accumulated	Time - Minimum	Time - Maximum
		[m^3/s]	[m^3/s]	m^3		
Catchment_10_2	Gothenburg Rainfall	0.000	0.050	1997.725	2010-10-28 00:00:00	2010-10-28 13:11:00
Catchment_11	Gothenburg Rainfall	0.000	0.000	0.000	2010-10-28 00:00:00	2010-10-28 00:00:00
Catchment_11_1	Gothenburg Rainfall	0.000	0.009	379.250	2010-10-28 00:00:00	2010-10-28 13:11:00
Catchment_12	Gothenburg Rainfall	0.000	0.000	0.000	2010-10-28 00:00:00	2010-10-28 00:00:00
Catchment_13	Gothenburg	0.000	0.000	0.000	2010-10-28	2010-10-28

	Rainfall				00:00:00	00:00:00
Catchment_13_2	Gothenburg Rainfall	0.000	0.005	194.358	2010-10-28 00:00:00	2010-10-28 13:11:00
Catchment_14	Gothenburg Rainfall	0.000	0.000	0.000	2010-10-28 00:00:00	2010-10-28 00:00:00
Catchment_15	Gothenburg Rainfall	0.000	0.000	0.000	2010-10-28 00:00:00	2010-10-28 00:00:00
Catchment_16	Gothenburg Rainfall	0.000	0.000	0.000	2010-10-28 00:00:00	2010-10-28 00:00:00
Catchment_16_2	Gothenburg Rainfall	0.000	0.184	7395.548	2010-10-28 00:00:00	2010-10-28 13:11:00
Catchment_17	Gothenburg Rainfall	0.000	0.000	0.000	2010-10-28 00:00:00	2010-10-28 00:00:00
Catchment_17_2	Gothenburg Rainfall	0.000	0.185	7438.789	2010-10-28 00:00:00	2010-10-28 13:11:00
Catchment_18	Gothenburg Rainfall	0.000	0.000	0.000	2010-10-28 00:00:00	2010-10-28 00:00:00
Catchment_19	Gothenburg Rainfall	0.000	0.000	0.000	2010-10-28 00:00:00	2010-10-28 00:00:00
Catchment_19_2	Gothenburg Rainfall	0.000	0.000	17.046	2010-10-28 00:00:00	2010-10-28 13:11:00
Catchment_20	Gothenburg Rainfall	0.000	0.000	0.000	2010-10-28 00:00:00	2010-10-28 00:00:00
Catchment_20_1	Gothenburg Rainfall	0.000	0.009	351.088	2010-10-28 00:00:00	2010-10-28 13:11:00
Catchment_20_2	Gothenburg Rainfall	0.000	0.003	113.573	2010-10-28 00:00:00	2010-10-28 13:11:00
Catchment_21	Gothenburg Rainfall	0.000	0.000	0.000	2010-10-28 00:00:00	2010-10-28 00:00:00
Catchment_21_1	Gothenburg Rainfall	0.000	0.005	201.735	2010-10-28 00:00:00	2010-10-28 13:11:00
Catchment_21_2	Gothenburg Rainfall	0.000	0.007	298.927	2010-10-28 00:00:00	2010-10-28 13:11:00
Catchment_22	Gothenburg Rainfall	0.000	0.000	0.000	2010-10-28 00:00:00	2010-10-28 00:00:00

Catchment_22_1	Gothenburg Rainfall	0.000	0.013	529.931	2010-10-28 00:00:00	2010-10-28 13:11:00
Catchment_22_2	Gothenburg Rainfall	0.000	0.045	1826.773	2010-10-28 00:00:00	2010-10-28 13:11:00
Catchment_23	Gothenburg Rainfall	0.000	0.000	0.000	2010-10-28 00:00:00	2010-10-28 00:00:00
Catchment_23_1	Gothenburg Rainfall	0.000	0.011	459.979	2010-10-28 00:00:00	2010-10-28 13:11:00
Catchment_23_2	Gothenburg Rainfall	0.000	0.009	370.882	2010-10-28 00:00:00	2010-10-28 13:11:00
Catchment_24	Gothenburg Rainfall	0.000	0.000	0.000	2010-10-28 00:00:00	2010-10-28 00:00:00
Catchment_24_1	Gothenburg Rainfall	0.000	0.040	1601.466	2010-10-28 00:00:00	2010-10-28 13:11:00
Catchment_24_2	Gothenburg Rainfall	0.000	0.057	2300.584	2010-10-28 00:00:00	2010-10-28 13:11:00
Catchment_25	Gothenburg Rainfall	0.000	0.000	0.000	2010-10-28 00:00:00	2010-10-28 00:00:00
Catchment_25_1	Gothenburg Rainfall	0.000	0.008	331.001	2010-10-28 00:00:00	2010-10-28 13:11:00
Catchment_25_2	Gothenburg Rainfall	0.000	0.018	740.093	2010-10-28 00:00:00	2010-10-28 13:11:00
Catchment_26	Gothenburg Rainfall	0.000	0.000	0.000	2010-10-28 00:00:00	2010-10-28 00:00:00
Catchment_26_1	Gothenburg Rainfall	0.000	0.019	762.565	2010-10-28 00:00:00	2010-10-28 13:11:00
Catchment_26_2	Gothenburg Rainfall	0.000	0.033	1330.737	2010-10-28 00:00:00	2010-10-28 13:11:00
Catchment_27	Gothenburg Rainfall	0.000	0.000	0.000	2010-10-28 00:00:00	2010-10-28 00:00:00
Catchment_28	Gothenburg Rainfall	0.000	0.000	0.000	2010-10-28 00:00:00	2010-10-28 00:00:00
Catchment_29	Gothenburg Rainfall	0.000	0.000	0.000	2010-10-28 00:00:00	2010-10-28 00:00:00

Catchment_30	Gothenburg Rainfall	0.000	0.000	0.000	2010-10-28 00:00:00	2010-10-28 00:00:00
Catchment_31	Gothenburg Rainfall	0.000	0.000	0.000	2010-10-28 00:00:00	2010-10-28 00:00:00
Catchment_32	Gothenburg Rainfall	0.000	0.000	0.000	2010-10-28 00:00:00	2010-10-28 00:00:00
Catchment_33	Gothenburg Rainfall	0.000	0.000	0.000	2010-10-28 00:00:00	2010-10-28 00:00:00
Catchment_34	Gothenburg Rainfall	0.000	0.000	0.000	2010-10-28 00:00:00	2010-10-28 00:00:00
Catchment_35	Gothenburg Rainfall	0.000	0.000	0.000	2010-10-28 00:00:00	2010-10-28 00:00:00
Catchment_36	Gothenburg Rainfall	0.000	0.000	0.000	2010-10-28 00:00:00	2010-10-28 00:00:00
Catchment_37	Gothenburg Rainfall	0.000	0.000	0.000	2010-10-28 00:00:00	2010-10-28 00:00:00
Catchment_38	Gothenburg Rainfall	0.000	0.000	0.000	2010-10-28 00:00:00	2010-10-28 00:00:00
Catchment_39	Gothenburg Rainfall	0.000	0.000	0.000	2010-10-28 00:00:00	2010-10-28 00:00:00
Catchment_40	Gothenburg Rainfall	0.000	0.000	0.000	2010-10-28 00:00:00	2010-10-28 00:00:00
Catchment_41	Gothenburg Rainfall	0.000	0.000	0.000	2010-10-28 00:00:00	2010-10-28 00:00:00
Catchment_42	Gothenburg Rainfall	0.000	0.000	0.000	2010-10-28 00:00:00	2010-10-28 00:00:00
Catchment_44	Gothenburg Rainfall	0.000	0.000	0.000	2010-10-28 00:00:00	2010-10-28 00:00:00
Catchment_45	Gothenburg Rainfall	0.000	0.000	0.000	2010-10-28 00:00:00	2010-10-28 00:00:00
Catchment_46	Gothenburg Rainfall	0.000	0.000	0.000	2010-10-28 00:00:00	2010-10-28 00:00:00
Catchment_47	Gothenburg Rainfall	0.000	0.000	0.000	2010-10-28 00:00:00	2010-10-28 00:00:00

Catchment_48	Gothenburg Rainfall	0.000	0.000	0.000	2010-10-28 00:00:00	2010-10-28 00:00:00
Catchment_6_1	Gothenburg Rainfall	0.000	0.022	873.822	2010-10-28 00:00:00	2010-10-28 13:11:00
Catchment_7	Gothenburg Rainfall	0.000	0.000	0.000	2010-10-28 00:00:00	2010-10-28 00:00:00
Catchment_7_1	Gothenburg Rainfall	0.000	0.024	954.911	2010-10-28 00:00:00	2010-10-28 13:11:00
Catchment_8	Gothenburg Rainfall	0.000	0.000	0.000	2010-10-28 00:00:00	2010-10-28 00:00:00
Catchment_8_2	Gothenburg Rainfall	0.000	0.012	498.343	2010-10-28 00:00:00	2010-10-28 13:11:00
Catchment_9	Gothenburg Rainfall	0.000	0.000	0.000	2010-10-28 00:00:00	2010-10-28 00:00:00
Catchment_9_1	Gothenburg Rainfall	0.000	0.028	1145.022	2010-10-28 00:00:00	2010-10-28 13:11:00
Total :				32114.149		

Boundary Connections

Rainfall and Meteo Boundaries

Boundary Condition ID	Type	Connection Type	Location	Temporal variation	Value/pattern/TS name	Validity	Validity Start	Validity End	Minimum Value	Maximum Value	Accumulated Value
									mym/s	mym/s	mm
Gothenburg Rainfall	Rainfall	All catchments		Time Series	Gbg_regn_2010.dfs0	Unlimited	-	-	0.00000	5.56100	124.76

9.3.2 Network simulation

MOUSE HD Computation Engine v2009 Release Version (0.0.0.3073)

MOUSE Pipe Flow Simulation --- Status Report ---Dynamic Wave

Input Summary

Number of Manholes:	994
Number of Basins:	0
Number of Outlets:	6
Number of Storage Nodes:	0
Number of Circular Pipes:	993
Number of Rectangular pipes:	0
Number of CRS defined pipes:	10
Number of Pumps:	0
Number of Controlled Pumps:	0
Number of Weirs/Orifices:	12
Number of Controlled Weirs/Gates:	0
Number of Valves:	0
Number of Controlled Valves:	0

Nodes

Min Invert Level	ADN14690	8.02 m
Max Invert Level	AKN1741	71.95 m

Min Ground Level	ADN14710	11.24 m
Max Ground Level	AKN1856	73.59 m
Min X Coordinate	ASN14026	1.4518E05 m
Max X Coordinate	AKN1847	1.4648E05 m
Min Y Coordinate	ADN25385	6.3967E06 m
Max Y Coordinate	ADN14709	6.3979E06 m
Total Manhole Volume		2478.1 m3
Total Basin Volume		0.0 m3

Links

Total Circular Volume	3398.3 m3
Total CRS Volume	43744.7 m3
Total Length	28276.00 m

Time Step parameters loaded from the DHIAPP.INI file

INI file :	C:\PROGRA~1\DHI\2009\bin\DHIAPP.INI83
Relative change criteria for inflow time series :	0.100
Low flow limit for inflow time series :	0.010
Maximum relative water level change :	0.100
Maximum variation in Cross Section parameters :	0.100
Cross check low depth limit (relative) :	0.040

Cross check level : 1.000

Maximum Courant Number : 20.000

Simulation Result Summary

Continuity Balance

1:	**Start volume in Pipes, Manholes and Structures**			**4.8 m^3**
2:	**End volume in Pipes, Manholes and Structures**			**12432.6 m^3**
3:	**Total inflow volume**			
	Specified inflows			
	Runoff :	32113.4 m^3		
	DWF :	243399.7 m^3		
	Non-specified inflows			
	Outlets (inflow) :	137.7 m^3		
		275650.8 m^3	-->	**275650.8 m^3**
4:	**Total diverted volume**			
	Operational, non-specified outflows			
	Outlets :	275135.3 m^3		
		275135.3 m^3	-->	**275135.3 m^3**
5:	**Water generated in empty parts of the system :**			**3234.9 m^3**

6: Continuity Balance = (2-1) - (3-4+5) : 8677.5 m^3

Continuity Balance max value : 8677.5 m^3

Continuity Balance min value : 0.0 m^3

Boundary Connections

Network loads (discharges)

Boundary Condition ID	Type	Connection Type	Location	Temporal variation	Value /pattern/TS name	Validity	Validity Start	Validity End	Minimum Value	Maximum Value	Accumulated Value
									m^3/s	m^3/s	m^3
14276_1	Discharge	Individual	ASN14282	Constant	0.00012	Unlimited	-	-	0.000	0.000	559.9
14276_10	Discharge	Individual	ASN14230	Constant	0.00012	Unlimited	-	-	0.000	0.000	559.9
14276_2	Discharge	Individual	ASN14233	Constant	0.00012	Unlimited	-	-	0.000	0.000	559.9
14276_3	Discharge	Individual	ASN14248	Constant	0.00012	Unlimited	-	-	0.000	0.000	559.9
14276_4	Discharge	Individual	ASN13550	Constant	0.00012	Unlimited	-	-	0.000	0.000	559.9
14276_5	Discharge	Individual	ASN13561	Constant	0.00012	Unlimited	-	-	0.000	0.000	559.9
14276_6	Discharge	Individual	ASN14237	Constant	0.00012	Unlimited	-	-	0.000	0.000	559.9
14276_7	Discharge	Individual	ASN14264	Constant	0.00012	Unlimited	-	-	0.000	0.000	559.9
14276_8	Discharge	Individual	ASN13582	Constant	0.00012	Unlimited	-	-	0.000	0.000	559.9
14276_9	Discharge	Individual	ASN13591	Constant	0.00012	Unlimited	-	-	0.000	0.000	559.9

14294_1	Disch arge	Indivi dual	ASIN2 4934	Constant	0.000 3	Unli mited	-	-	0.000	0.000	1399.7
14294_10	Disch arge	Indivi dual	ASIN2 4929	Constant	0.000 3	Unli mited	-	-	0.000	0.000	1399.7
14294_2	Disch arge	Indivi dual	ASN1 4293	Constant	0.000 3	Unli mited	-	-	0.000	0.000	1399.7
14294_3	Disch arge	Indivi dual	AKN2 348	Constant	0.000 3	Unli mited	-	-	0.000	0.000	1399.7
14294_4	Disch arge	Indivi dual	1_34	Constant	0.000 3	Unli mited	-	-	0.000	0.000	1399.7
14294_5	Disch arge	Indivi dual	ADN1 4811	Constant	0.000 3	Unli mited	-	-	0.000	0.000	1399.7
14294_6	Disch arge	Indivi dual	AKN2 295	Constant	0.000 3	Unli mited	-	-	0.000	0.000	1399.7
14294_7	Disch arge	Indivi dual	AKN2 289	Constant	0.000 3	Unli mited	-	-	0.000	0.000	1399.7
14294_8	Disch arge	Indivi dual	1_25	Constant	0.000 3	Unli mited	-	-	0.000	0.000	1399.7
14294_9	Disch arge	Indivi dual	ADN1 4789	Constant	0.000 3	Unli mited	-	-	0.000	0.000	1399.7
Domestic Wastewater	Disch arge	Geoco ded		Cyclic	Profil e_1	Unli mited	-	-	0.009	0.052	143345. 0
PE- basedDWF	Disch arge	All		Cyclic	Profil e_1	Unli mited	-	-	0.005	0.029	80460.0

10 Appendix D: Data about daily average flow of wastewater treatment plant Ryaverket and the measuring nodes at Majorna

Table 14 Data of daily average flow of Ryaverket and measuring nodes for simulated model.

Date	Daily average flow to Wastewater treatment plant Ryaverket m^3/s	ASN14276 (m^3/s)	ASN14294 (m^3/s)	ASN14276/ Flow Rya	ASN14294 /Flow Rya
10/10/28 00:00	9.21	0.014	0.023	0.001	0.002
10/10/29 00:00	7.73	0.014	0.023	0.002	0.003
10/10/30 00:00	7.48	0.012	0.020	0.002	0.003
10/10/31 00:00	5.10	0.012	0.020	0.002	0.004
10/11/01 00:00	4.58	0.012	0.020	0.003	0.004
10/11/02 00:00	6.63	0.020	0.028	0.003	0.004
10/11/03 00:00	10.79	0.017	0.026	0.002	0.002
10/11/04 00:00	8.18	0.012	0.020	0.001	0.002
10/11/05 00:00	6.39	0.013	0.021	0.002	0.003
10/11/06 00:00	5.71	0.012	0.020	0.002	0.004
10/11/07 00:00	4.70	0.012	0.020	0.002	0.004
10/11/08 00:00	4.47	0.012	0.020	0.003	0.004

10/11/09 00:00	4.31	0.012	0.020	0.003	0.005
10/11/10 00:00	3.95	0.012	0.020	0.003	0.005
10/11/11 00:00	3.36	0.013	0.022	0.004	0.006
10/11/12 00:00	7.55	0.015	0.024	0.002	0.003
10/11/13 00:00	7.23	0.015	0.023	0.002	0.003
10/11/14 00:00	7.20	0.012	0.021	0.002	0.003
10/11/15 00:00	7.69	0.016	0.025	0.002	0.003
10/11/16 00:00	7.54	0.012	0.020	0.002	0.003
10/11/17 00:00	4.95	0.012	0.020	0.002	0.004
10/11/18 00:00	4.53	0.012	0.020	0.003	0.004
10/11/19 00:00	3.86	0.012	0.020	0.003	0.005
10/11/20 00:00	3.93	0.015	0.024	0.004	0.006
10/11/21 00:00	4.87	0.012	0.020	0.002	0.004
10/11/22 00:00	4.95	0.012	0.020	0.002	0.004
10/11/23 00:00	3.86	0.013	0.021	0.003	0.006
10/11/24 00:00	3.48	0.012	0.020	0.003	0.006
10/11/25 00:00	4.00	0.012	0.020	0.003	0.005

10/11/26 00:00	3.28	0.012	0.020	0.004	0.006
10/11/27 00:00	3.03	0.012	0.020	0.004	0.007
10/11/28 00:00	3.23	0.012	0.020	0.004	0.006
10/11/29 00:00	3.01	0.012	0.020	0.004	0.007
10/11/30 00:00	3.47	0.012	0.020	0.003	0.006
10/12/01 00:00	3.41	0.012	0.020	0.003	0.006
10/12/02 00:00	2.77	0.012	0.020	0.004	0.007
10/12/03 00:00	2.84	0.012	0.020	0.004	0.007
10/12/04 00:00	2.93	0.012	0.020	0.004	0.007
10/12/05 00:00	3.38	0.017	0.025	0.005	0.008
10/12/06 00:00	3.68	0.012	0.020	0.003	0.006
10/12/07 00:00	3.22	0.012	0.021	0.004	0.006
10/12/08 00:00	3.46	0.013	0.022	0.004	0.006
10/12/09 00:00	3.32	0.014	0.022	0.004	0.007
10/12/10 00:00	3.31	0.013	0.022	0.004	0.007
10/12/11 00:00	4.23	0.015	0.023	0.003	0.005
10/12/12 00:00	4.68	0.012	0.020	0.002	0.004

10/12/13 00:00	3.88	0.012	0.020	0.003	0.005
10/12/14 00:00	2.91	0.012	0.020	0.004	0.007
10/12/15 00:00	2.93	0.012	0.020	0.004	0.007
10/12/16 00:00	4.31	0.015	0.023	0.003	0.005
10/12/17 00:00	3.83	0.012	0.020	0.003	0.005
10/12/18 00:00	3.65	0.012	0.020	0.003	0.006
10/12/19 00:00	2.94	0.012	0.020	0.004	0.007
10/12/20 00:00	2.99	0.012	0.020	0.004	0.007

Table 15 Data of daily average flow of Ryaverket and measuring nodes for improved model.

Date	Daily average flow to Wastewater treatment plant Ryaverket m^3/s	ASN14276 (m^3/s)	ASN14294 (m^3/s)	ASN14276/ Flow Rya	ASN14294/ Flow Rya
10/10/28 00:00	9.21	0.011	0.019	0.001	0.002
10/10/29 00:00	7.73	0.012	0.019	0.002	0.002
10/10/30 00:00	7.48	0.009	0.017	0.001	0.002
10/10/31 00:00	5.10	0.009	0.017	0.002	0.003
10/11/01 00:00	4.58	0.009	0.017	0.002	0.004

10/11/02 00:00	6.63	0.017	0.025	0.003	0.004
10/11/03 00:00	10.79	0.015	0.022	0.001	0.002
10/11/04 00:00	8.18	0.009	0.017	0.001	0.002
10/11/05 00:00	6.39	0.011	0.018	0.002	0.003
10/11/06 00:00	5.71	0.009	0.017	0.002	0.003
10/11/07 00:00	4.70	0.009	0.017	0.002	0.004
10/11/08 00:00	4.47	0.009	0.017	0.002	0.004
10/11/09 00:00	4.31	0.010	0.017	0.002	0.004
10/11/10 00:00	3.95	0.009	0.017	0.002	0.004
10/11/11 00:00	3.36	0.011	0.019	0.003	0.006
10/11/12 00:00	7.55	0.013	0.020	0.002	0.003
10/11/13 00:00	7.23	0.012	0.020	0.002	0.003
10/11/14 00:00	7.20	0.010	0.017	0.001	0.002
10/11/15 00:00	7.69	0.014	0.021	0.002	0.003
10/11/16 00:00	7.54	0.009	0.017	0.001	0.002
10/11/17 00:00	4.95	0.009	0.017	0.002	0.003
10/11/18 00:00	4.53	0.009	0.017	0.002	0.004

10/11/19 00:00	3.86	0.010	0.017	0.002	0.004
10/11/20 00:00	3.93	0.013	0.020	0.003	0.005
10/11/21 00:00	4.87	0.009	0.017	0.002	0.003
10/11/22 00:00	4.95	0.009	0.017	0.002	0.003
10/11/23 00:00	3.86	0.011	0.018	0.003	0.005
10/11/24 00:00	3.48	0.009	0.017	0.003	0.005
10/11/25 00:00	4.00	0.009	0.017	0.002	0.004
10/11/26 00:00	3.28	0.009	0.017	0.003	0.005
10/11/27 00:00	3.03	0.009	0.017	0.003	0.006
10/11/28 00:00	3.23	0.009	0.017	0.003	0.005
10/11/29 00:00	3.01	0.009	0.017	0.003	0.006
10/11/30 00:00	3.47	0.009	0.017	0.003	0.005
10/12/01 00:00	3.41	0.009	0.017	0.003	0.005
10/12/02 00:00	2.77	0.009	0.017	0.003	0.006
10/12/03 00:00	2.84	0.009	0.017	0.003	0.006
10/12/04 00:00	2.93	0.009	0.017	0.003	0.006
10/12/05 00:00	3.38	0.014	0.022	0.004	0.007

10/12/06 00:00	3.68	0.010	0.017	0.003	0.005
10/12/07 00:00	3.22	0.010	0.017	0.003	0.005
10/12/08 00:00	3.46	0.011	0.019	0.003	0.005
10/12/09 00:00	3.32	0.011	0.019	0.003	0.006
10/12/10 00:00	3.31	0.011	0.018	0.003	0.006
10/12/11 00:00	4.23	0.012	0.020	0.003	0.005
10/12/12 00:00	4.68	0.009	0.017	0.002	0.004
10/12/13 00:00	3.88	0.009	0.017	0.002	0.004
10/12/14 00:00	2.91	0.009	0.017	0.003	0.006
10/12/15 00:00	2.93	0.009	0.017	0.003	0.006
10/12/16 00:00	4.31	0.012	0.020	0.003	0.005
10/12/17 00:00	3.83	0.009	0.017	0.002	0.004
10/12/18 00:00	3.65	0.009	0.017	0.003	0.005
10/12/19 00:00	2.94	0.009	0.017	0.003	0.006
10/12/20 00:00	2.99	0.009	0.017	0.003	0.006