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SETUP OF A HYDRODYNAMIC SEWER MODEL AND SCENARIO ANALYSES FOR AN URBAN SUBCATCHMENT IN SKOPJE

Master Thesis

by

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Wien, am ....
Laura Havinga

To my family

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Keywords: SWMM, storm water management, storm water modelling, waste water modelling, urban drainage, sewer database, sewer management system

Abstract

This thesis deals with a sewer system of an urban subcatchment (75 ha) in Skopje, the capital of the Former Yugoslav Republic of Macedonia. A hydrodynamic model and a sewer database were to be created. The sewer system discharges waste water from the industrial premises of OHIS (Organic Chemical Industry Skopje) as well the nearby settlement of Pintija and is connected to the waste water treatment plant of OHIS. Following storm events the two systems are surcharged and flooding occurs regularly. With the help of hydraulic modelling of the system with SWMM 5 (Storm Water Management Model) of the U.S. EPA bottlenecks were to be found and with further scenarios a possible solution for the problem was to be created. A sensitivity analysis was made to determine the responsiveness of the model on different input parameters. Before starting to model, data and information about the system had to be collected and verified in fieldtrips during a two month research stay. Further, the surface runoff had to be clarified. Evidence gathered during fieldtrips showed, that the roof runoff either discharges directly onto streets, into gardens or is connected to the sanitary sewer of Pintija. Formally a separate system was designed for Pintija but only the sanitary sewer exists. The only storm sewer line is full of sediments and not in use. Due to a large number of faulty connections the sanitary sewer is supposed to work like a combined system but the dimensions are not laid out accordingly. Further the sanitary sewer of Pintija is connected with bypasses to the storm sewer of the separate system in OHIS. Consequently, the untreated wastewater of Pintija is discharged directly into the receiving water. With respect to sustainable and modern water protection this situation is not acceptable and possibilities for change are given in this thesis with the help of a hydrodynamic model.

Abstract in German

In dieser Arbeit wird ein Kanalnetz eines Einzugsgebietes (75 ha) in Skopje, der Hauptstadt der Republik Mazedonien, modelliert und eine Datenbank dafür aufgebaut. Es handelt sich dabei um ein Kanalsystem einer Siedlung namens Pintija, das an das Kanalsystem des Industiegeländes von OHIS (Organic Chemical Industry Skopje) angeschlossen ist. Bei Starkregenereignissen sind beide überlastet und Überflutungen treten regelmäßig auf. Durch die hydrodynamische Modellierung sollten Engstellen im Kanalnetz gefunden und durch weitere Szenarien eine Problemlösung erarbeitet werden. Mit Hilfe einer Sensitivitätsanalyse wurde die Empfindlichkeit des Modells auf die Änderung verschiedener Einzugsgebietsparameter getestet. Um Grundlagen für die Modellierung des Kanalsystems in SWMM 5 (US EPA) zu erhalten, war es erforderlich, Untersuchungen im Einzugsgebiet durchzuführen. Dies erfolgte während eines zweimonatigen Aufenthaltes in Skopje. Dabei war der Ist-Zustand des Kanalsystems mit den zu Verfügung stehenden Unterlagen zu vergleichen und Widersprüche zu klären sowie weiter modellrelevante Daten zu sammeln. Auch die Frage des Oberflächenwasserabflusses musste geklärt werden. Durch die Besichtigungen in Pintija wurde klar, dass Dachflächen entweder direkt auf Straßen, in Garten oder in den Schmutzwasserkanal entwässert werden. Der Schmutzwasserkanal des einst geplanten Trennsystems fungiert derzeit aufgrund der hohen Anzahl an Fehlanschlüssen als Mischsystem, wobei dieser natürlich nicht dafür dimensioniert ist. Der einzige Strang des Regenwasserkanals ist voll mit Sedimenten. In OHIS ist ein Trennsystem vorhanden, jedoch gelangt das Schmutzwasser von Pintija durch zwei Bypasse in den Regenwasserkanal von OHIS und in weiterer Folge direkt in den Vorfluter. Diese Situation ist im Hinblick auf einen nachhaltigen und modernen Gewässerschutz nicht akzeptabel und Möglichkeiten zur Verbesserung mit der Hilfe eines hydrodynamischen Modells sollen in dieser Arbeit aufgezeigt werden.

1. Introduction

Globally, the use of water increased due to enhanced industrial production, intense agricultural activities and household consumption. Hence, the production of waste water and the pollution of nearby recipients through surface waters and waste waters have increased as well. In the international and regional legal instruments sustainable use of water resources and their protection, water quality and targets for achieving safe drinking water supply and basic sanitation have become more immediately addressed (ANALYTICA, 2009).

South East European countries have had a decade's long reputation of neglecting the few existing environmental laws. This has led to massive pressure on natural resources as living conditions improved. With no scarcity of water it was not dealt with carefully. Proper water management and waste water treatment were considered negligible (ANALYTICA, 2009).

The Former Yugoslav Republic of Macedonia (FYROM also referred to as Republic of Macedonia or only Macedonia) decided to become a member of EU as a part of its policy after becoming independent in 1991. The Candidate status was given in December 2005. Currently FYROM is participating in the Stabilisation and Association Process (EUROPEAN COMMISSION, 2012). The EU has provided wide support in the field of maintaining environment quality which is one of the required conditions for EU membership (JICA, 2009). Especially the fulfilment of the Water Framework Directive requires big efforts in the water resource management and therefore several laws with long-term goals have been issued (ANALYTICA, 2009).

Skopje is the capital and largest city of the Republic of Macedonia. The Japan International Cooperation Agency (JICA, 2009) states, that in Skopje the percentage of the population covered by sewerage service has reached 80 %. Nevertheless, no waste water treatment plant (WWTP) exists and the river Vardar, which passes through the city, is polluted due to discharge of untreated waste water from the entire city and suburbs along with untreated industrial waste water.

The master thesis is carried out within the scope of a bilateral research project based on a WTZ - Scientific and Technological Cooperation between Austria and FYROM. It is financed by the Federal Ministry of Science and Research of Austria as well as the Ministry of Education and Science of Macedonia and is an inter-governmental agreement regarding cooperation in the fields of science and technology (OEAD, 2013).

The cooperation between the Institute of Sanitary Engineering and Water Pollution Control of the University of Natural Resources and Life Sciences in Vienna with the Faculty of Technology and Metallurgy of the Ss. Cyril and Methodius University in Skopje began on May 1st 2011 with the title "A New Scientific Approach for Improvement and Appropriate Management of Wastewater Systems in the Republic of Macedonia". It determined at the end of April 2013. The total duration of the cooperation was 24 months and both theoretical aspects and practical examples were to be carried out. During a visit of Mr. Ertl and Macedonian colleagues at the premises of the Organic Chemical Industry Skopje (OHIS), where problems of the WWTP were discussed, the flooding of the parking lot in front of the office building due to a thunderstorm was observed. Afterwards the WWTP with its sewer system in OHIS and the sewer system of the nearby settlement of Pintija (about 2500 inhabitants) was selected for the practical examples of the research cooperation. This thesis deals with the sewer system and a Macedonian student has been working on the topic of the rehabilitation of the WWTP. It is a very good example for the interaction of sewerage system and WWTP and very interesting for the cooperation. During the cooperation four workshops were hold, two in Macedonia and two in Austria. The start of the thesis was the second workshop in Vienna in February 2012. Between the 2nd and 3rd workshop a two month research stay (16.4.2012 – 15.6.2012) was carried out and at the last workshop in Vienna in March 2013 results of the thesis were presented.

2. Objective and content of the thesis

The goal of this thesis is to obtain a data basis to model the sewer system of the study area with SWMM 5 from the US Environmental Protection Agency (US EPA). SWMM 5 is the renewed version of the US EPA's Stormwater Management Model (SWMM). It is used, because it is free ware and thus readily available. Consequently, the colleagues of the Republic of Macedonia can use the model as a basis for further investigations and projects. Besides, SWMM 5 is widely used and accepted. As a result of the modelling, the reason for flooding should be clarified and bottlenecks defined. Moreover, through modelling of different adaption scenarios suggestions for the unsatisfactory situation in Pintija and OHIS should be found. In addition, a sewer data base is to be created.

To conclude, the work considers the four main aspects:

- Collection of data
- Definition and setup of scenarios
- Hydrodynamic modelling
- Setup of a database

In the following the tasks of the main points are listed in more detail:

- Collection of data
    - Local investigations concerning the study area in Pintija and OHIS
    - Local investigations of the sewer system's current state and clarification of the contradictions between the provided sewer system data and the reality (data verification)
    - Collection of other model relevant data
- Definition of scenarios and setup of SWMM 5 model
    - Definition and setup of the basic scenario
    - Definition and setup of adaption scenarios
- Hydrodynamic modelling
    - Hydrodynamic modelling of the basic scenario with SWMM 5
    - Detection of bottlenecks and possible improvements for basic scenario
    - Validation of the model
    - Modelling of adaption scenarios with SWMM 5
    - Detection of bottlenecks and possible improvements for adaption scenarios
    - Sensitivity analysis of model parameters
- Setup of a sewer database
    - with the master data of the SWMM 5 model

In Chapter 3 "Basic principles" information to the waste and storm water management is given. Besides, the current state of sewers and the waste and storm water management in Austria and in the Republic of Macedonia is discussed including a review of the legal regulations. For Macedonia also a more detailed overview on waste water and sewer related issues is made. Another sub item deals with the basic principles of storm water modelling and in particular of the storm water management software SWMM 5 of US EPA. The material for the setup of the SWMM 5 model and the methods of the data collection is stated in Chapter 4. Furthermore, the development of the different scenarios is explained. The results of the data collection, the setup of the scenarios, the hydrodynamic modelling and the sewer database are shown in Chapter 5. This leads to the conclusion of the master thesis in Chapter 6 with remarks to the quality of the data obtained, the SWMM 5 model and the database.

3. Basic principles

3.1 Urban Hydrology

Urban hydrology is an applied science and a special case of hydrology employed for cities or areas with very high levels of human interference with natural processes. Facing the growth of urbanisation worldwide, with more than half of the world's population living in cities at present, urban hydrology will play an increasing role in human societies (FLETCHER et al., 2013) (NIEMCZYNOWICZ, 1999). Urbanisation has dramatic impact on catchment hydrology especially on infiltration resulting from impervious areas. Due to loss of infiltration the surface runoff increases and due to drainage networks the runoff response to rainfall occurs much faster [Figure 1]. Furthermore, urban surface run-off typically contains levels of pathogenic and organic substances. Failures in the urban infrastructure (sewer infiltration, leakage from landfills, direct connection of sanitary sewers to storm sewers) represent other sources of pollutions. The increase of impervious areas and the fast discharge of storm water result in high peak flow or flooding, lower base flow, erosion, sedimentation, increase in nutrients and toxicants as well as loss of sensitive species and organic matter. It is an alarming fact that when the total imperviousness of the catchment exceeds 10% a significant degradation of receiving water could already be expected (ZOPPOU, 2001) (FLETCHER et al., 2013). As pointed out by FLETCHER et al. (2013, p. 261) "*the science of urban hydrology has thus developed to improve the management of urban water systems for public health and sanitation, flood protection and more recently, the protection of the environment and of the liveability of cities.*"

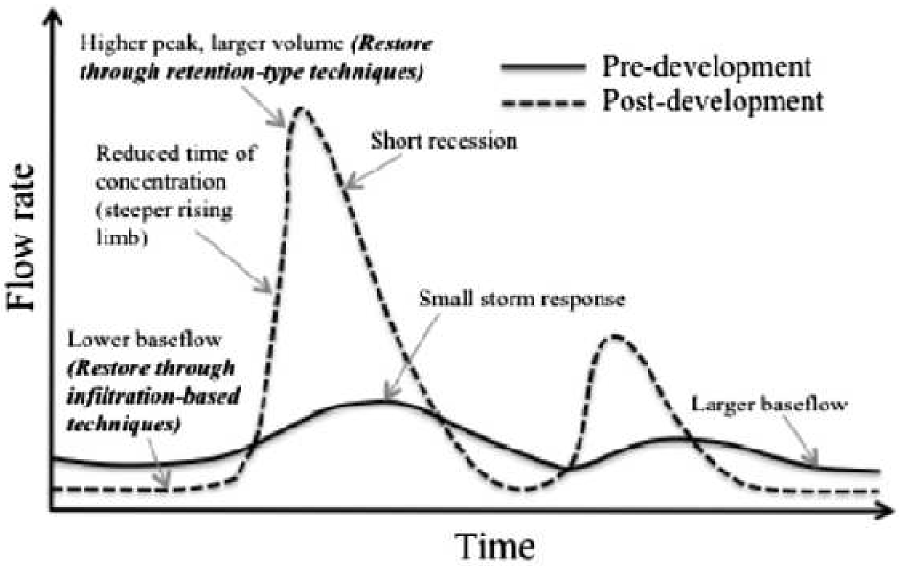


Figure 1: Schematic illustration of the pertinent impact of urbanisation on hydrology at the catchment scale (MARSELEK, 2007; as cited in (FLETCHER et al., 2013))

3.1.1 Storm water management

A storm is a rainfall event and rainfall is the amount of liquid precipitation (AKAN & HOUGHTALEN, 2003). "*Rainfall is a driving force of all hydrological processes and it constitutes the most important input to any runoff calculations and modelling procedures. Due to the lack of rainfall data representative for temporal and spatial variations of the natural rainfall process it is often a critical and weak point.*" (NIEMCZYNOWICZ, 1999, p. 2). Rainfall will fall either on pervious or impervious sub-areas of the watershed. As urban areas are characterised by extensive impervious areas and manmade watercourses, much more storm water is discharged into receiving waters as shown in Figure 2 and as already discussed above.

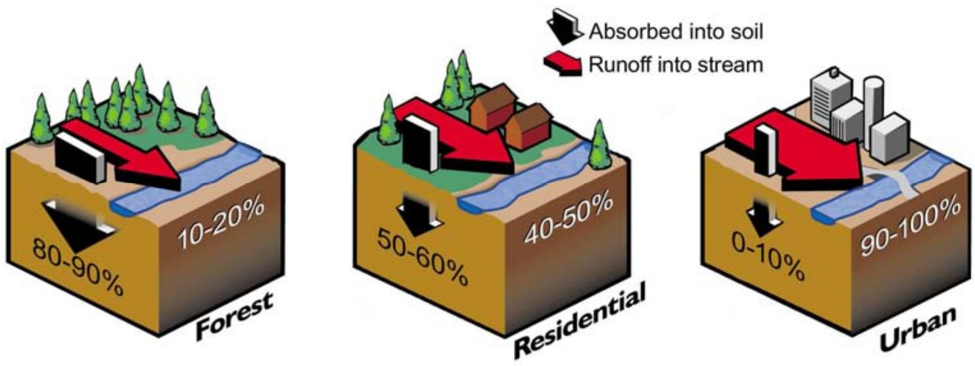


Figure 2: Changes in hydrology and runoff due to development (AMEC Earth and Environment et. al 2001; as cited in (ZILLER, 2010))

Storm water management can be divided into two main applications. One purpose is the aspect of mitigation of hydrologic change, and the other the treatment of water quality. To decrease the hydrologic change, storm water infiltration-based and retention-based technologies can be applied. The latter can be ponds, wetlands, vegetated roofs or rain water/storm water harvesting (tanks, storage basins). These methods operate by either attenuation of outflow or reduction through abstraction to retain storm water. The infiltration-based technologies aim to restore the base flow through recharging subsurface flow and groundwater as well as reducing the magnitude and frequency of peak flows. Swales, infiltration trenches and porous pavements are examples for this method. The risk to pollute the groundwater with this system is generally low for most contaminants. Nevertheless, uncertainties remain for pathogens, salt and thermal pollution (FLETCHER et al., 2013). Infiltration-based technologies also have the effect to improve the quality due to the filter effect of the soil. Systems which store runoff and release it slowly (attenuation), allow water to infiltrate into the soil, convey surface water slowly, filter out pollutions and allow sediments to settle out by controlling the flow of the water, are so-called sustainable urban drainage systems (SUDS). With these systems natural drainage should be simulated (SUSDRAIN, 2012a).

3.1.2 Sewer systems

Like waste water treatment plants (WWTP) and receiving waters, sewer systems are part of the integrated urban waste water system (DE TOFFOL, 2006). The aims of the system can be summarised according to the BS EN 752 in three points (BRITISH STANDARDS INSTITUTION, 2013):

- removal of wastewater from premises for public health and hygienic reasons
- prevention of flooding in urbanised areas
- protection of the environment

A sewerage system collects sewerage and storm water. It discharges it through pipes, which form complex branching sewer systems and usually have a continuous slope to transport the waste water by gravity (KAINZ et al., 2002).

Two main sewer systems can be classified; the combined and the separate sewer system. The combined sewer conveys storm water and sewerage together in the same pipe whereas the separate system consists of two pipes. In the big conduit the storm water is kept and in a much smaller one – located lower in the ground – the sewerage is conveyed [Figure 3].

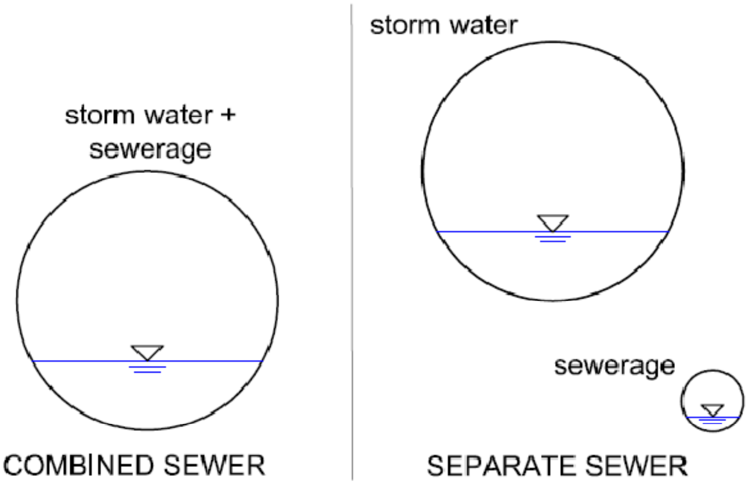


Figure 3: Sewerage systems (redrawn and translated from (KAINZ et al., 2002) by Havinga, 2013)

Additionally, hybrid systems exist. In Austria, so called “qualified/modified systems” discharge strongly polluted storm water from streets and parking areas through the sewer pipe to the WWTP. Basically unpolluted storm water from roofs are drained away on the premises or discharged through the storm water pipe when a separate system exists (HABERL, 2009). Regarding water protection, modified systems should be preferred whereas some considerations have to be made when the storm water should be drained. The soil has to be sufficiently drainable, the ground water should have an adequate depth regarding the water table and there could be the danger of soaked cellars (ÖWAV, 2008). The ÖWAV (Austrian Water and Waste Management Association) rule sheet 35 (2003) gives recommendations to treat storm water in separate systems (DE TOFFOL, 2006).

Combined systems discharge the storm water and the sewerage directly to the WWTP, unless a heavy storm event activates a combined sewer overflow (CSO) [Figure 4]. Even with light rainfall the storm water will overbalance and during heavy storm events the ratio waste water to storm water can easily be 1:50 or even 1:100 (BUTLER & DAVIES, 2011).

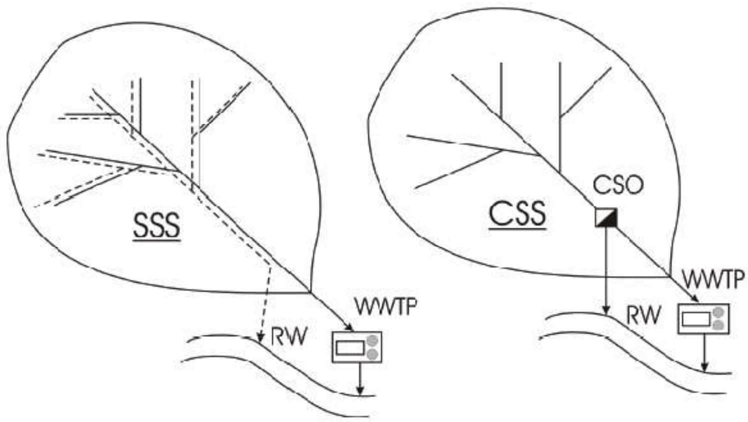


Figure 4: Schemes of separate sewer system (SSS) left and combined sewer system (CSS) right. RW = receiving water, WWTP = waste water treatment plant, CSO = combined sewer overflow

It is not economically feasible to provide the pipe capacity along the full length for the big amount during storm events. The WWTP can only treat a certain amount of storm water due to operational and economic reasons. The excess water has to be discharged into the receiving water via CSO whereas some flow remains in the sewer system and continues to the WWTP. The amount of this flow is an important characteristic of the CSO. To reduce the deposit-able solids in waste water, storm water tanks can be used. These store the mixed storm and waste water and discharge the water gradually to the WWTP after the rain event. Different designs can be applied: storm water tanks with overflow or storm water tanks retaining the first flush of storm water. The first flush is the most highly polluted amount of waste water in a storm event, when the increased flow has a “flushing” effect on the sewer system. Solids settled during dry periods are conveyed and should not be discharged into the receiving water. Consequently, storm tanks with over flow should only be used when no distinct first flush is expected but rather continuous pollution of the rain (flow time > 15min) (KAINZ et al., 2002) (BUTLER & DAVIES, 2011).

Due to the historical development of sewer systems, the old parts of cities are normally served by combined sewer systems and the new ones by separate systems (DE TOFFOL, 2006). BUTLER and DAVIS (2011) state that about 70% of central Europe’s sewer systems are combined sewers. The question which one of the two systems should be preferred is much discussed and the question is often “it depends”. Towards the end of last century many countries started to change from combined systems to separate systems. According to DE TOFFEL et al. (2007) the reason is on the one hand the easier optimisation possibility of the WWTP due to less diluted waste water and on the other hand the missing of combined sewer overflows – although displaced with direct storm water discharge. As discussed by BUTLER and DAVIS (2011) the advantages of the combined sewer are the lower pipe construction costs, less space is needed and house drainage is simpler and cheaper. Furthermore, the deposited waste water solids are flushed out in times of storm and some storm water is treated, which should include the first flush. The big disadvantage is the necessity of CSOs which may cause serious pollution of watercourses. Nevertheless, recent studies show that separate systems are not always the best solution for the receiving water quality (FENZ, 2002; PAOLETTI and SANFILIPPO, 2004; BROMBACH et al., 2005 as cited in (DE TOFFOL et al., 2007)). As found out by DE TOFFEL et al. (2007), combined systems with CSOs designed according to current design rules (ÖWAV RB 19 in Austria) discharge lower pollutant loads via their CSO structures than separate sewer systems when no storm water treatment is implemented. However, the ammonia concentration in the discharged water is higher in the combined sewer overflow leading to higher un-ionised ammonia concentrations in the receiving water. Certain types of rain can increase the impacts on the receiving water. The magnitude of the impact generated by the sewer overflows is controlled by characteristics of the rain. In the study, rains from among others Copenhagen and St. Marin (alpine rain) were examined. The rain of Copenhagen caused the lowest impact on the receiving water for all parameters (erosion frequency, nitrogen load, cupper load, un-ionised ammonia and critical oxygen deficit). The alpine rain produced the highest level of pollution in the receiving water. Furthermore, the pollution concentration is a contributory factor. If the pollution concentration is low, both systems have a comparable performance. With increasing pollution concentrations, the environmental impact caused by separate systems is higher. Summing up, the choice of the sewer system should therefore be made in terms of rain characteristics, pollution concentration in the catchment as well as the sensitivity of the receiving water.

DE TOFFEL et al. (2007) concluded that, in general, separate sewer systems are cheaper if the rainwater is not treated. Nevertheless, regulations to enforce the treatment of storm water have been implemented in many countries. Storm water treatment will increase costs and could thus result in lower costs for combined systems.

In Austria the ÖWAV Rule Sheet 9 (2008) “Guidelines for the application of drainage systems” (Richtlinien für die Anwendung der Entwässerungsverfahren) support the decision making process. It lists the advantages and disadvantages of the systems and analyses them with regard to effective water protection. Therefore technical and local surrounding conditions as well as operational aspects and costs are determined (ÖWAV, 2008). However, in Austria municipalities with a less than 500 PE have to construct separate sewer systems according to the Austrian standard ÖN B 2502-2 (2003) (HABERL, 2009).

3.1.3 Sustainable urban drainage systems

SUDS are named differently in various parts of the world. Since the 1970ies the term Best Management Practice (BMP) is used in some parts of North America. However, nowadays the designation, Low Impact Design (LID) is used more frequently. In Australia and New Zealand, the name Water Sensitive Urban Design (WSUD) and/or Low Impact (Urban) Design (LIUD) has become established (PURCKNER & MADRY, 2012).

Sustainable drainage attempts to solve the existing problems of flooding, pollution and damage to the environment due to urbanisation. The concept is to involve long term environmental and social factors in urban drainage and to balance the impact of urban drainage on water quantity and quality management as well as amenity and biodiversity [Figure 5] (SUSDRAIN, 2012b)

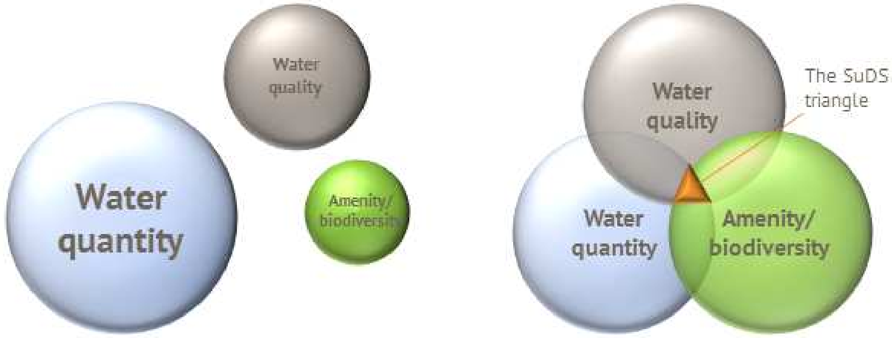


Figure 5: SUDS triangle (SUSDRAIN, 2012b)

A useful concept developing SUDS is the treatment train (also referred as management train) which modifies the flow and quality characteristics of runoff in different stages, just like in natural catchments. The surface runoff should always pass several varieties of applications and is conveyed between each stage by different techniques (e.g. swales, linear wetlands) before reaching the receiving water [Figure 6]. A first and very important step is prevention. This aims at an increase of impervious areas and good housekeeping measures for decreasing pollution. In general, the water should return to the natural drainage system as close to the source as possible. The next step is the site control from where water should only be conveyed slowly to the regional control if the surface water cannot be managed on the site. For example excess flow would need to be routed off site (SUSDRAIN, 2012c).

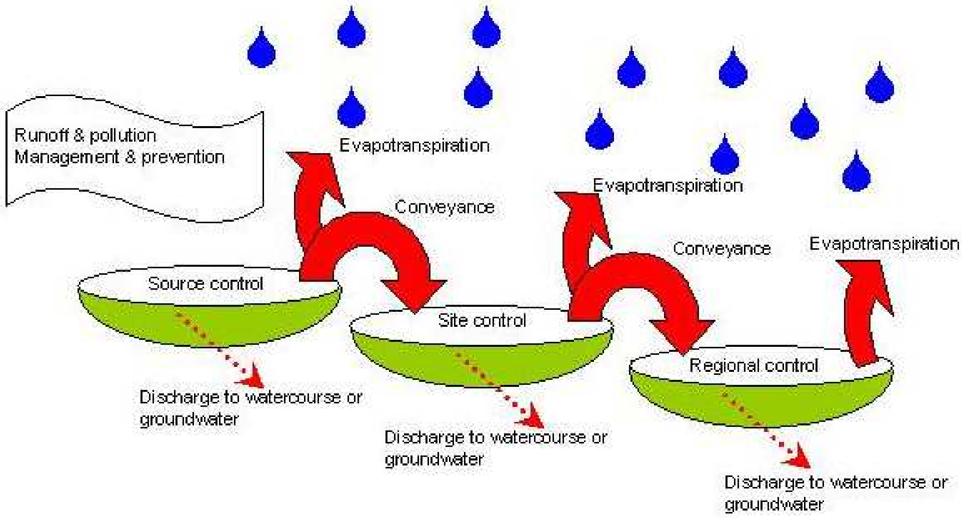


Figure 6: SUDS treatment/management train (SuDS Wales, 2013)

3.2 Current state and legal aspects related to sewer systems

Operation, maintenance, inspection, preservation and rehabilitation of sewer systems can be summarised as sewer management (HABERL, 2008). Sewer management goes hand in hand with environmental protection, sustainable development and health and safety. It is a significant challenge due the declining budgets of municipalities', the lack of available funds and the deficiency of consistency and completeness of data (HALFAWY et al., 2002) (PARK & KIM, 2013).

3.2.1 Austria

3.2.1.1 Overview on the current technical state of sewer systems

In Austria, in the last 50 years 44 billion Euros were spent on waste water issues. About 80 % thereof were deployed on sewer systems. The current connection rate is at an average of 92 % and the total public sewer length is approximately 90 000 km (ERTL, 2013). The distribution of combined and separate system in Austria varies in the federal states. The percentage distribution is illustrated in Figure 7.

Figure 7: Distribution combined system (light colour) and separate system (dark colour) in Austria (KRETSCHMER et al., 2013)

Due to this high connection rate, nowadays, the challenges are rather the optimisation and management of sewer systems than the design and construction, [Figure 8] (TELEGDY, 2012). According to BREINDL (2013) around 13 % of the sewers are older than 40 years.

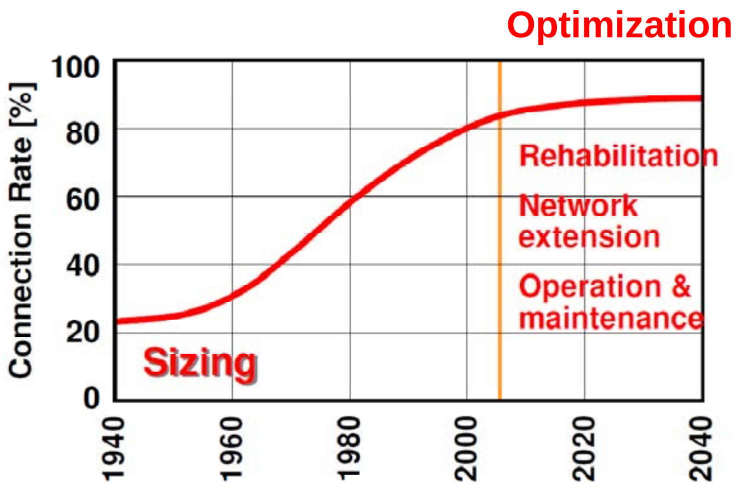


Figure 8: Sewer connection rate Austria (TELEGDY, 2012)

ERTL (2013) stated, that an alarming amount of 11 % (ca. 10 000 km) of the sewer system need urgent action (rehabilitation) and about 16 % require a middle-term action (at least frequent monitoring). In the last years funded rehabilitation of around 60 to 70 km was the rule in Austria, which is a rehabilitation rate of about 0.07 to 0.08 %. If a durability of 50 years is estimated, rehabilitation rates of 2 % would be required to keep the systems maintained. In other words, according to the current rehabilitation rate newly built sewer systems would have to have a life span of 1500 years (BREINDL, 2013).

3.2.1.2 Overview on waste water and sewer related legislation

EU Water Framework Directive 2000/60/EC

Since 2000 the Water Framework Directive (EU-WFD) has established a legal framework for the EU Member States, which aims to protect and restore clean water across Europe and should guarantee its long-term sustainable use. The directive constitutes an innovative guideline in water policy based on river basins, natural geographical and hydrological units and sets specific deadlines for Member States to protect aquatic ecosystems. It is designed for all kinds of surface water (inland, coastal, transitional) and groundwater with the aim to achieve the “good status” for all water bodies by 2015. This status is defined by combining ecological and chemical parameters (for surface water), which is also a new approach (DE TOFFOL, 2006) (EUROPEAN COMMISSION, 2008).

The holistic achievement of the EU-WFD (2000) is summarised below (EUROPEAN PARLIAMENT & COUNCIL, 2000):

- Water management based on river basins is to be achieved an ecological and chemical “good status” within the timescale
    - surface water: good ecological and chemical status
    - artificial and heavily modified water bodies: good ecological potential
    - groundwater: good chemical and quantitative status
- Extension of protection of all water bodies
- Promotion of sustainable water use
- Beginning to enhance the ecosystem and wetlands
- Prevention of the decline in the condition of water bodies
- “Combined approach” of emission limits and ambient water quality objectives (immission limits).
- Public participation to obtain the objectives of the river basin management plan and to involve citizens in decision making
- Waste water is to be treated according to state of the art
- In order to mitigate effects of floods and droughts the Member States have to undertake measures
- Cost-covering prices in water supply and waste water disposal

The implementation process is shown in Figure 9

Figure 9: Deadlines of implementation of the Water Framework Directive (DIS-WG2.3, 2003 redrawn by (DE TOFFOL, 2006))

The surface water classification, as previously mentioned, is based on ecological and chemical standards. To be able to classify the ecological standard every Member State has to set reference and calibration sites. The reference site is the standard for the high ecological status and the calibration site represents the lower limits or the good status. With these two sites the local authorities have to designate and evaluate the water bodies via the reference and calibration site. All water bodies should achieve the good status and the Member States have to guarantee that the status is retained. The reference system is a five class system including high, good, moderate, poor and bad quality. The indicators are hydro-morphological and chemical as well as physico-chemical quality elements. The chemical status is determined as "good" or "failing to achieve good" (DE TOFFOL, 2006).

The classification system is not assigned to artificial and heavily modified water bodies. An artificial water body is created by human activities while heavily modified bodies have undergone man-made adaptations that have substantially changed its character. About 15 % of EU's surface water bodies are heavily modified (EUROPEAN COMMISSION, 2008). They are used, for example, for navigation, hydropower generation or water supply or flood defence. At heavily modified water bodies the effort to reinstate the good ecological status in not cost-effective or the use will be effected (DE TOFFOL, 2006).

In Austria, lakes with a surface area larger than 50 ha and water courses with more than 100 km² catchment areas contain in the WFD implementation procedure. 78 % of the water courses achieved the good chemical status. Due to the high use of hydropower and flood protection measures 44 % of the Austrian rivers will probably not meet the goal of the EU-WFD (DE TOFFOL, 2006).

<u>EU Urban Waste Water Treatment Directive 91/271</u>

This directive has the biggest effects on the construction and standards of waste water treatment plants located inland. The aim is to reduce especially surface water pollution through nutrients from communal waste water. Further, it committed municipalities with more than 2000 population equivalents to supply sewerage systems by 31st of December, 2005. The collected waste water has to be treated biologically (secondary treatment) or with comparable methods (COUNCIL OF THE EUROPEAN COMMUNITIES, 1991).

<u>Austrian Water Rights Act 1959 (WRG 1959)</u>

The Water Rights Act is the legal basis for a variety of measures and therefore needed legal instruments, especially for the three following subjects:

- use of water bodies
- protection and water body pollution prevention
- protection of hazards from water

With the Water Rights Act Amendment 2003 the EU Water Framework Directive was transposed into national law (LEBENSMINISTERIUM, 2011). The following paragraphs and subparagraphs concern sewer management.

- § 50 deals with the general obligation of maintenance
- § 134 is devoted to designated supervision
    - (3) Inspection is to be carried out at least every 5 years, except when the Water Authority sets shorter intervals due to specific circumstances
    - (4) Inspections of pipes on the leak-tightness are to be carried out at least every 5 years, when hazardous water substances are conveyed, except when the Water Authority sets shorter intervals due to specific circumstances.

§ 134 (4) is a much discussed point and different interpretations in different federal states of Austria exist. However, the competent authority's interpretation of the law is that this is not applied for sewerage systems. For example it is valid for petrol stations (ERTL, 2013).

<u>Austrian General Regulation on Waste Water Emissions (AAEV 1996)</u>

It is based on the Water Rights Act 1959 and the water-related EU guidelines. It regulates general limits on waste water emission into flowing waters and public sewer systems. ERTL (2011) addresses the following subparagraphs of article 3 to sewer management:

- §3 (5) In regular intervals sewer systems should be inspected, maintained and the inventory checked for functionality. The results should be documented and faulty connections as well as infiltration water should be clarified and removed at regular intervals.
- §3 (13) Sewer systems and waste water treatment plants should be constructed according to state of the art and quality management. The trained personnel should operate and maintain these constructions to ensure that:
    - all predictable and extraordinary operational conditions can be controlled
    - the maintenance of all components are on time, so that no failure has to be apprehended
    - all official requirements are met to observe all predictable operational conditions

<u>European standard EN 752 (2008) “Drain and sewer systems outside buildings. Hydraulic design and environmental considerations”</u>

Standards are legally inconclusive to apply, but it is “strongly” recommended to do so. The Austrian Standard ÖNORM EN 752 (2008) is identical to the EU EN 752 (2008) and was implemented in Austria in 2008 (ERTL, 2011). It is the basis for dimensioning urban drainage systems. According to the BRITISH STANDARDS INSTIUTION (2013) it is “*applicable to drain and sewer systems, which operate essentially under gravity, from the point where wastewater leaves a building, roof drainage system, or paved area, to the point where it is discharged into a wastewater treatment plant or receiving water”*. The new approach is that the design criteria are return intervals of flooding instead of the precipitation. The key concept is the relation between the probabilities of damaged due to pluvial flooding as well as the protection of the catchment drained. Flooding is defined by the EN 752 (2008) as a condition where waste water and/or surface water escapes from or cannot enter a drain or sewer system and either remains on the surface or enters buildings. Flooding is connected with the occurrence of damage whereas the simulation of the probability of damage occurrence is a difficult task. Therefore a detailed knowledge of the local conditions is necessary (e.g. elevation of curb stones and cellar windows etc.) (DE TOFFOL, 2006). Another difficulty is the check of the frequency of occurrence. It does not make sense with today’s computer models and software. Further, instead of long term rains a selection of intense rainfalls should be used and afterwards the probabilities should be calculated (SCHMITT, 1998 as cited in (ERTL, 2012)). The suggested design frequencies in EN 752 are listed below at the sub-item “ÖWAV Rule Sheet 11”.

In the EN 752 (2008) the approach of an integrated sewer management is included. It provides a framework for the design, construction, rehabilitation, maintenance and operation of drain and sewer systems outside buildings. It also specifies the functional requirements for achieving these objectives and the principles for strategic and policy activities relating to the aforementioned tasks (BRITISH STANDARDS INSTITUTION, 2013). The general approach of the integrated sewer management includes four steps:

1. Investigation
2. Assessment
3. Plan development
4. Implementation

In other words, the investigation is the inventory of the sewer system. It includes a concept for the creation of a sewer management system as well as for the quality management and realisation of service performance. Additionally, the structural, operational, hydraulic and environmentally relevant condition has to be detected, an inventory created and a valuation made. The assessment should identify critical areas of the system and an order of priority should be implemented. Structural and operational condition detection should be carried out and proof of the hydraulic capacity should be given. The environmental relevance of surface and ground water bodies is to be evaluated. The development of the plan contains the planning of rehabilitation, maintenance, flushing and inspection. Economical aspects and the sustainability should be included and should lead to a maintenance strategy. In the end, these plans have to be implemented whereas all the plans and data should be checked continuously (ERTL, 2011).

An important standard with regards to the integrated sewer management is EN 13508 (2012) “Investigations and assessment of drain and sewer systems outside buildings”. The Austrian Standard ÖNORM EN 13508 (2012) is identical to the EN 13508 (2012).

Summing up, Figure 10 gives an overview of the applications of the EN 752 (2008) and lists other related standards for the operation of sewer systems.

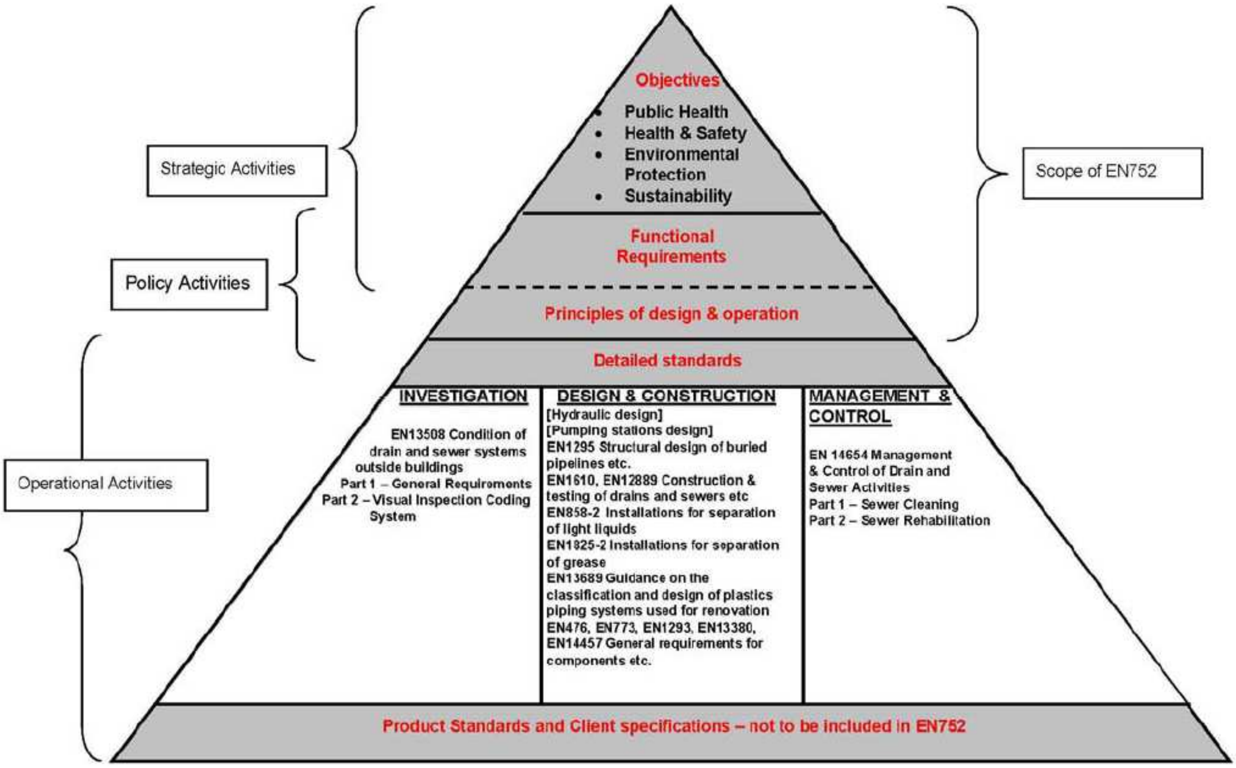


Figure 10: Application of EN 752 (2008 and related standards (ERTL, 2010))

<u>Austrian and German guidelines</u>

The Austrian Water and Waste Management Association (ÖWAV) is a non-profit organisation which develops technical regulations, practical guides and field manuals for water, waste water and waste management (ÖWAV, 2013b). The German Association for Water, Wastewater and Waste (DWA) is the counterpart of the ÖWAV in Germany.

- *ÖWAV Rule Sheet 11 (2009) on sewer design (ÖWAV Regelblatt 11 - Richtlinie für die abwassertechnische Berechnung und Dimensionierung von Abwasserkanälen 2009)*

In the ÖWAV Rule Sheet 11 (2009) the EN 752 is implemented and regulates the hydraulic calculation of sanitary water, storm water and combined waste water conveyed in open channel flow conditions. It includes content of the German guideline DWA-A 110 (2006) (Hydraulische Dimensionierung und Leistungsnachweis von Abwasserleitungen und –kanälen 2006) and DWA-A 118 (2006) (Hydraulische Bemessung und Nachweis von Entwässerungssystemen 1999), which are both guidelines for the design of sewers.

The innovative approach of this technical regulation is the separation between simple and complex systems. For simple systems it is sufficient to apply elementary calculation methods whereas for complex systems the simulation with hydrological or hydrodynamic based models is recommended. Furthermore, the rule sheet explains various types of rain input data for the calculations and suggest the field of application (DE TOFFOL, 2006).

In comparison to the EN 752 the guideline implies a surcharge frequency proof instead of flooding proof. Surcharge occurs when the level of the waste water is equal to the soil level, before flooding emerges. This brings advantages for modelling and is also applied in the German implementation of the EN 752 (DWA-A 118). Indeed, surcharge arise more often than flooding, consequently the allowed return periods are shorter as listed in Table 1 (DE TOFFOL, 2006).

Table 1: Suggested design frequency in EN 752, ÖWAV Rule Sheet 11 and ATV 118. For design storm no surcharge shall occur (DE TOFFOL, 2006)

Urbanisation categories	Design storm frequency EN 752 (1 in *n* years)	Design flooding frequency EN 752 (1 in *n* years)	Design surcharge frequency ÖWAV Rule Sheet 11 & DWA-A 118 (1 in *n* years)
Rural areas	1	10	2
Residential areas	2	20	3
City centres, industrial/commercial areas	5	30	5 (less than*)
Underground railway/underpass	10	50	10 (less than*)

* the ATV 118 presents return periods for the last two categories as less than 1 in 5 or in 10 respectively.´

The listed return period of the design storm is the one used for designing the sewer system with the time-area method (DE TOFFOL, 2006).

- *ÖWAV Rule Sheet 22 on sewer maintenance and preservation (in edition) (ÖWAV Regelblatt 22 Kanalwartung und Kanalerhaltung (in Überarbeitung))*

In Austria, the requirements on the operation of sewer systems are regulated by specific regulations of the federal states and the ÖWAV Rule Sheet 22, which is currently edited. It includes inspection and cleaning intervals for sewers and manholes as well as CSOs and storm tanks, if no demand oriented cleaning strategy is applied. A new approach is the distinction between sight and function checks and detailed structural and operational condition detection. Summing up, the degree of detail differs. At least every 10 years a detailed inspection is to be carried out and a functions check made twice as often. Cleaning intervals are also regulated in the German guideline DWA-A 147 of 2005 (ERTL, 2011) (SCHMIDT et al., 2013).

Other sewer management associated regulations are:

- ÖWAV Rule Sheet 28 (2007) Underground sewer rehabilitation (ÖWAV – Regelblatt 28 (2007) Unterirdische Kanalsanierung)
- ÖWAV Rule Sheet 34 (2003) High-pressure cleaning of sewers (ÖWAV – Regelblatt 34 (2003) Hochdruckreinigung von Kanälen)
- ÖWAV Rule sheet 43 (2013a) Visual sewer inspection (ÖWAV – Regelblatt 43 (2013) Optische Kanalinspektion)
- DWA-M 149 (2007) Condition detection and assessment of drainage systems (Arbeitsblatt DWA-M 149 Zustandserfassung und –beurteilung von Entwässuerngs-systemen 2007)

For designing a combined sewer, the ÖWAV Rule Sheet 19 (2007) “Guideline for the design of combined sewer overflows” (ÖWAV – Regelblatt 19 (2007) Richtlinie für die Bemessung von Mischwasserentlastungen) should be taken into account.

3.2.2 Republic of Macedonia

For the Republic of Macedonia the current problems and the institutions related to sewer systems is discussed in more detail. This should help to understand the unsatisfactory situation in the study area and should give background information on this situation.

3.2.2.1 Overview on waste water and sewer related issues

The Republic of Macedonia, as an EU candidate country, is faced with the need to fulfil high standards of water protection, demanded by the European Commission's Enlargement Directorate in the near future. ANALYTICA (2009, pp. 3-4) points out the main pressing issues in the water and waste water sector:

- "*small rate of in-dwelling connections to sewerage infrastructure, un-rational water use and poor to unsatisfactory water quality conditions of several surface waters, along with insufficient protection of the quality of waters;*
- *very low water-supply and sewerage service prices;*
- *insufficient investments in the sewerage infrastructure as well as not having adequate financing of the wastewater management;*
- *lack of substantial amount of implementing legislation which is in compliance with the EU aquis;*
- *lack of National Strategy on Water for the implementation steps of the Water Framework Directive and Water Master Plan that already should have replaced the Water Master Plan from 1976 (thus allowing proper institutionalized, territorial organization and planning progresse in the water sector);*
- *administrative capacity (human and financial resources) is still insufficient both at state and local levels and*
- *low level of monitoring system and available data."*

The waste water related institutional actors and legislation as well as its problems will be discussed in the next sub-item. The problems concerning the technical and environmental state in waste water issues will be discussed in more detail.

The Republic of Macedonia has four main hydrographical catchment areas. The river Vardar basin represents the largest with 20 535 km² and supplies 75 % of country's water recourses. The river Vardar flows through Skopje, the capital of the FYROM, and is polluted through agricultural and industrial activities – especially metallurgical, chemical and mining industries – as well as through communal waste water due to the lack of waste water treatment. The latter includes domestic waste water (households), waste water from commercial (e.g. car-washing services) and institutional facilities (e.g. hospitals) along with storm water runoff. As a result of this discharge from industries and agriculture the organic and toxic organic pollution increases. Heavy metal contents (Cd, Dr, Pb, Fe, Zn) in addition to high levels of toxic elements (Pb, Cr, Cd and Zn) have been noted in the river Vardar (ANALYTICA, 2009) (BASSI et al., 2008). In the Republic of Macedonia only eight WWTP exist [Figure 11]. Due to the lack of money and staff, the operation of the WWTP in Berovo, Sveti Nikole, Kumanovo, Star Dojran, Struga-Ohrid, Resen and Makedonski Brod cannot be carried out properly. The standards of these WWTP should be brought up to state-of-the-art in cooperation with an EC project. Within the framework of this project two new WWTPs were already built in Gevgelija and Prilep.

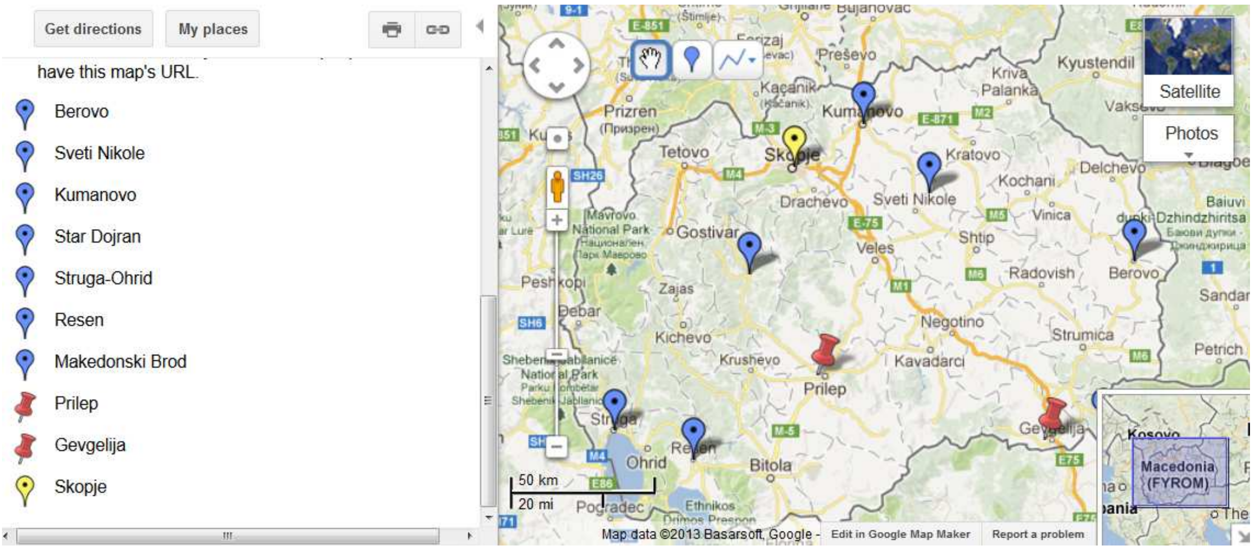


Figure 11: WWTPs in the Republic of Macedonia
Key: yellow = capital; blue = newly built WWTP; red = condition of WWTP is not state of the art

Figure 11 illustrates, that most major cities do not possess WWTPs, including the capital Skopje. Skopje has a coverage of sewer networks of nearly 80 % and generates 200 litres per capita and day, which are discharged directly into the river Vardar from nearly 60 outfalls. According to the WORLD BANK (as cited in (ANALYTICA, 2009)) the national average percentage of dwelling connected to the public sewer system is 74.8 % whereas in non-poor populated areas the connection rate is 77.8 % and in poorly populated areas 64 %. Not connected dwellings use septic tanks or the waste water is discharged directly into the receiving water. HIDROINZENIRING and RIKO (2010) noted that at the national level 280 km collector network and about 1240 km of sewerage network exist. This is not even 2 % of Austria's sewer network length. JICA (2009) stated that the sewer system in Skopje was developed as a separate system. The sanitary sewer was constructed after the huge earthquake in 1961. In the first half of the 1960ies the sanitary sewer system was developed and in the second half the storm sewer system. About 40 % of the drainage system of Skopje was built before 1966. Less than 5 % of the total sewer network was constructed between the years 2001-2006. HIDROINZENIRING and RIKO (2010) describe the current condition of the sewerage systems as old and in poor condition. The collecting networks are constructed of different materials, the pipes are cracked and consequently there is leakage of waste water into the ground. The storm sewer system is often incomplete. As a result, storm water pipes are connected into sanitary pipes and also rainwater from individual houses are faultily connected to the sanitary sewer (JICA, 2009).

The current desolate state of Macedonia's sewer systems is a result of the limited investment in sewer and treatment infrastructure in the past. The significant shortfall in sanitary coverage and waste water treatment has led to a growing surface water pollution issue. One big problem is the limited investment on sewer systems. This issue arises from the low cost- recovery due to the low price for water supply, waste water drainage and water treatment. Furthermore, the collection rates are poor. Estimates indicate rates slightly below 50 % and in the case of irrigation even as low as 25 %. In addition, many buildings have been built informally over the years and are not connected to the public sewer system or possibly connected informally to it. Consequently, municipalities miss out on the tax for the building site, which among others fund the construction and maintenance of the sewer system according to Article 13 of the Law on Communal Activities. In Macedonia the price for water includes charges for the waste water collection and the treatment. The average price on the national level stated by HIDROINZENIRING and RICO (2010) is 19.40 MKD/m³ (0.19 €/m³ based on a middle exchange rate on 1.1.2011) for households and 32.07 MKD/m³ (0.53 €/m³) for industries. In comparison the tariff in Vienna from January 1st 2009 till December 31st 2011 was 1.78 €/m³ (WIENER

WASSER - Magistratsabteilung 31, s.a.). Of course, low tariffs and collecting rates leads problems in the construction of new sewers as well as the operation, maintenance and rehabilitation of the networks. Especially small and rural municipalities which are, according to the Law on Self-Government, responsible for the construction, operation, maintenance and rehabilitation of water supply and sewer networks but do not have the financial means for all these tasks. The water companies of larger cities face the problems of poor management and huge administrative costs. (ANALYTICA, 2009) (HIDROINZENIRING & RIKO, 2010).

The Ministry of Transport and Communication has achieved to develop a basic database in the sector of water supply and sewage systems. However, the data is incomplete and the database does still not functioning as a valid source for reporting structured and efficient data of the systems. This is caused by the authorities, who feed the database, due to their lack of awareness on its importance which leads to its neglect (ANALYTICA, 2009).

As already mentioned above, in addition to the main pollution through urban waste water almost all industries and agricultural subjects release their discharge without any pre-treatment into the receiving waters. ANALYTICA (2009, pp. 11-12) points out the reasons for this source of pollutants:

- *“lack of will to invest in the costly technology and the lack of awareness amongst the managers of the enterprise on the need of pre-treatment of the effluents prior their discharge,*
- *limited or no monitoring of the discharge by the relevant authorities from the local self-government (appointed local environment inspector),* … and the State Inspectorates from different ministries,
- *relatively low prices (1400-3400 €) for non-compliance to the Article 23, paragraph 1 of the Law on drinking water supply and discharge of urban wastewaters.”*

According to the Law on Waters (Article 150) any waste water producer must install, operate and maintain measuring devices along with providing waste water quality analyses. However, in practice none of these requirements are carried out (HIDROINZENIRING & RIKO, 2010). Other parts of the Law on Waters are discussed below.

3.2.2.2 Overview on waste water and sewer related institutional actors

Many waste water responsibilities are split between different regulatory bodies. In addition, the shortage of investments and the lack of technical engineers make the fulfilment of demand in hydrogeological engineering and comprehensive water quality policy drafting a big challenge for the Republic of Macedonia. Table 2 shows the institutional actors and their responsibilities and functions in the waste water sector: The role of main cities is explained by the capital and its public enterprise Vodovod i Kanalizacija, which is the water and sewerage board of Skopje. It is responsible for the operation and maintenance of the sewer systems. The operating expenses including depreciation, which are met through the service charges, are collected by the board. However, in principle no subsidies from the City can be expected (JICA, 2009).

The City of Skopje consists of 10 municipalities, which are also eligible to plan, design and construct sewerage systems by themselves along with receiving external funds and grants according to the Law on Local Self-Government (2005). The Ministry of Finance which allocates the budget to each ministry, considers the financial fundaments of these municipalities not strong enough to borrow external loans (JICA, 2009).

Table 2: Institutional actors and their responsibilities / functions at the waste water sector (JICA, 2009)

Name of institutional actors	Responsibilities / Functions
Ministry of Transport and Communication (MTC)	o Regulation on sewerage o Assisting Cities in sewerage projects o Monitoring Water and Sewerage Board of Skopje o Laws on Water, collection and treatment of sewage o Sewerage tariff guidelines
Ministry of Environment and Physical Planning (MEPP)	o Law on Environment o Environmental Impact Assessment (EIA) regulations o Industrial waste water monitoring (Class A*) o Waste water monitoring o Proposed Law on Waters o Water management o Spatial planning
Ministry of Agriculture, Forestry and Water Economy (MAFWE)	o Law on Waters o Regulation on water quantity and quality o Monitoring river flow and quality
City of Skopje	o Planning, design and construction of sewerage facilities o Founder and controlling of the Water and Sewerage Board of Skopje o Approval of the revision of sewerage service tariffs o Industrial waste water monitoring (Class B**)
Water and Sewerage Board of Skopje “Vodovod i Kanalizacija – Skopje”	o Operation and maintenance of sewerage facilities o Water and sewerage tariff collection o Planning, design and construction of minor facilities

* Class A includes industries with large quantities of dangerous substances (e.g. waste water, noise, air pollutants)

** Class B includes similar industries but with smaller quantities of pollutants.

JICA (2009) lists the problems and weaknesses of the sewerage sector at Vodovod i Kanalizacija – Skopje as follows:

- Vodovod i Kanalizacija – Skopje does not participate in the actual planning and design process. It just gives the City of Skopje guidelines on planning and design sewerage networks and reviews the design network.
- Blockage of sewers and pollution of the rivers are results from throwing solid waste and garbage into the drainage system by the residents. Educational work is to be done.
- A number of privately constructed sewers are connected informally to the public sewer system
- Vodovod i Kanalizacija – Skopje is sometimes not informed when municipalities construct and connect new sewer lines to the existing networks.
- Shortage in mechanical equipment for sewer maintenance and monitoring such as small trucks, robot cameras etc.
- In general, the staff in this sector are inexperienced.

3.2.2.3 Overview on waste water and sewer related legislation

The following points list the waste water related legislation of the Republic of Macedonia and the capital Skopje (JICA, 2009).

- (Old) Law on Waters 1998 from the MAFWE
- Law on Waters 2008 from the MEPP
- Law on Water Supply, Drainage, Treatment and Discharge of Urban Wastewater 2006 from the MTC
- Law on Communal Services 2004 from the MTC
- Law on Local Self-Government 2002 from the Ministry of Local Self-Government
- Law on City of Skopje (2004) from the Ministry of Local Self-Government
- Law on Financing the Local Self-Government 2007 from the Ministry of Local Self-Government
- Law on Environment 2007 form the MEPP

The old Law on Waters from 1998 should have been the basis to deal with the increasing water pollution issue. Nevertheless, it did not provoke integrated policies and procedures for water protection and management of river basins. In fact, it was never fully implemented (ANALYTICA, 2009).

The new Law on Waters from 2008 implemented the EU Water Framework Directive as well as the Urban Wastewater Treatment Directive. It has been fully operating since 2010 and it has shown initial effort to provide water quality and solve water pollution problems within an integrated policy and legislative framework for the future management of water resources (ANALYTICA, 2009). As a result, water was to be managed by four river basins. Furthermore, standards, principles, duties and rights of the state, municipalities as well as individuals are defined. In addition, the Law on Waters determines rational and effective water use, sustainable water resource development and actions as well as processes for the protection of water pollution. The main implementation is made by the Ministry of Environment and Physical Planning. The MEPP is also given clear responsibilities for water management in the law (JICA, 2009).

According to Article 113, paragraph 3, of the Law on Waters (2012) municipalities, the municipalities in the city of Skopje and the City of Skopje shall be obliged to:

1) *"provide, improve and expand the sewage systems and to clean and maintain the drainage systems for the purpose of appropriate drainage of waste waters on their area;*
2) *take care for the septic tanks, in accordance with the needs;*
3) *allow discharging of industrial waste waters in the sewage systems in accordance with this Law and to provide conditions for their drainage, collection and purification*;"

According to Article 114, paragraph 1, of the Law on Waters (2012) the government in cooperation with the mayors of the municipalities in the City of Skopje shall ensure that:

1) *"presence of a system for collection of waste waters in every settlement with more than 2.000 p.e.;*
2) *appropriate purification of all waste waters that are discharged from waste water collection systems of settlements with less than 2.000 p.e.;*
3) *secondary (biological) or corresponding purification of waste waters from the waste water collection systems from settlements with more than 2.000 p.e.;"*

According to Article 115, paragraph 1 (Law on Waters, 2012) "*any discharge of industrial waste waters shall be made in the manner and under the conditions determined by the discharge permit, that is, the integrated environmental permit in accordance with the Law on Environment.*"

The effluent standard is, according to the EU Urban Waste Water Treatment Directive, 25 mg/l BOD_5, 125mg/l of COD and 35 mg/l of TSS when the waste water is not discharged to sensitive areas. In this case, more stringent treatment is required (JICA, 2009).

The EUROPEAN COMMISSION (2012) notes in its progress report that only limited improvement was made in the environmental legislation sector. However, further progress was made by adopting the legislation on strategic environmental assessment (SEA) and environmental impact assessment (EIA). Unfortunately only very little progress is reported in the area of water quality, because alignment with the *acquis* is still lagging behind. The EUROPEAN COMMISSION (2012, p. 61) complain that "*the national strategy for water has not been adopted yet. River basin management structures were established, but are not yet fully operational. The administrative capacity remains insufficient at central and local levels. The insufficient coordination between the competent authorities in the water sector continues to hamper implementation of the legislation. No progress was made on addressing the gaps in the water monitoring system. Planning and preparation of infrastructure investment are lagging behind and funding is low compared with the needs in the sector. No progress was made to apply the polluter-pays principle and establish an appropriate water pricing system. This continued to hamper operation of water treatment facilities. Preparations in this area are lagging behind.*"

3.3 Storm water management modelling

A variety of models for analysing problems in urban hydrology have been developed due to the fast urbanisation of river basins in and around metropolitan areas. Nevertheless, numerical techniques used to simulate the processes of urban hydrology can only approximate the actual response of real systems, because of the complexity of these natural processes. The mathematics must be simplified further to make the model efficient and economical (US ARMY CORPS OF ENGINEERS, 1993).

Since legislation has been introduced for the quality of storm water, computer software modelling the quality as well as the quantity of urban storm water has become increasingly popular. It was primarily the U.S. government agencies, such as the U.S. Environmental Protection Agency (EPA), that started to create these models in the early 1970s (ZOPPOU, 2001).

The primary purposes of storm water management models listed by AKAN & HOUGHTALEN (2003, pp. 327-328) are the following:

- "*characterize stormwater runoff in terms of peaks, volumes, and water quality,*
- *predict the effects of watershed changes (e.g., increases in runoff due to development),*
- *determine the results of control options (e.g., stormwater management ponds),*
- *perform hydraulic designs, like sizing ponds or outlet devices,*
- *generate data for frequency analysis using continuous simulations over years, and*
- *provide input to other models (e.g, water surface profiles and receiving water quality).*"

Computer models can be classified in different ways as discussed in ZOPPOU (2001):

1. stochastic models and deterministic models
    a. stochastic model: the variables of the model have a probability distribution
    b. deterministic model: the variables of the model have no probability distribution

In contrast to a deterministic model, a stochastic model will not always generate the same results for equal parameters, as a number of variables are selected randomly. A disadvantage of stochastic models is that their solutions for large problems are not practical, as the randomly selected variables are restricted to certain probability distributions. On the other hand, stochastic models implicate the uncertainty in a variable (ZOPPOU, 2001).

Both stochastic and deterministic models may be further classified into:

2. conceptual and empirical models
    a. conceptual model: is based on physical laws
    b. empirical model: is not based on physical laws

3. distributed and lumped models
    a. distributed model: includes spatial variability
    b. lumped model: does not include spatial variability

4. event and continuous models
    a. event model: short-term model for simulating a few or individual storm events
    b. continuous model: long-term model including monthly or seasonal predictions

Deterministic-distributed models are usually used for urban runoff modelling. In order to plan water resources and estimate the costs of different infrastructure configurations so-called planning models, which are based on continuous models, are applied. Event models are appropriate for designing storm water infrastructure and as operational models. For controlling, operating or allocating water resources in real time, operational models are used (ZOPPOU, 2001). HUBER (1986, as cited in (TSIHRINTZIS & HAMID, 1998)) states that single event simulations are used for relatively detailed catchment representation of the drainage system. Therefore, the simulation times are small (i.e. of a few hours) with short time steps (i.e. of a few minutes). When a lumped catchment area represented with a low detail in the drainage network should be simulated, then continuous simulation with long simulation time (e.g. a few years) and relatively long time steps (i.e. a few hours) are applied.

The basic components of an urban storm water model are:

1. rainfall-runoff modelling
2. transport modelling

The rainfall-runoff modelling involves converting rainfall into a runoff hydrograph for each subwatershed. This includes the generation of surface and sub-surface runoff from precipitation excess as well as the wash-off and build-up of pollutants from impervious areas. Model-specific procedures are used to perform this transformation using unit hydrograph techniques or physically based algorithms. Subsequently, the hydrographs and pollutants are routed through the transport system (such as pipe networks, open channels and storages) again with the model specific procedures (dynamic wave, kinematic wave, etc.). All the hydrographs from different downstream subwatersheds are collected along the way and are combined with upstream flow. The links between the rainfall-runoff modelling and the transport modelling are illustrated in Figure 12 (AKAN & HOUGHTALEN, 2003) (ZOPPOU, 2001).

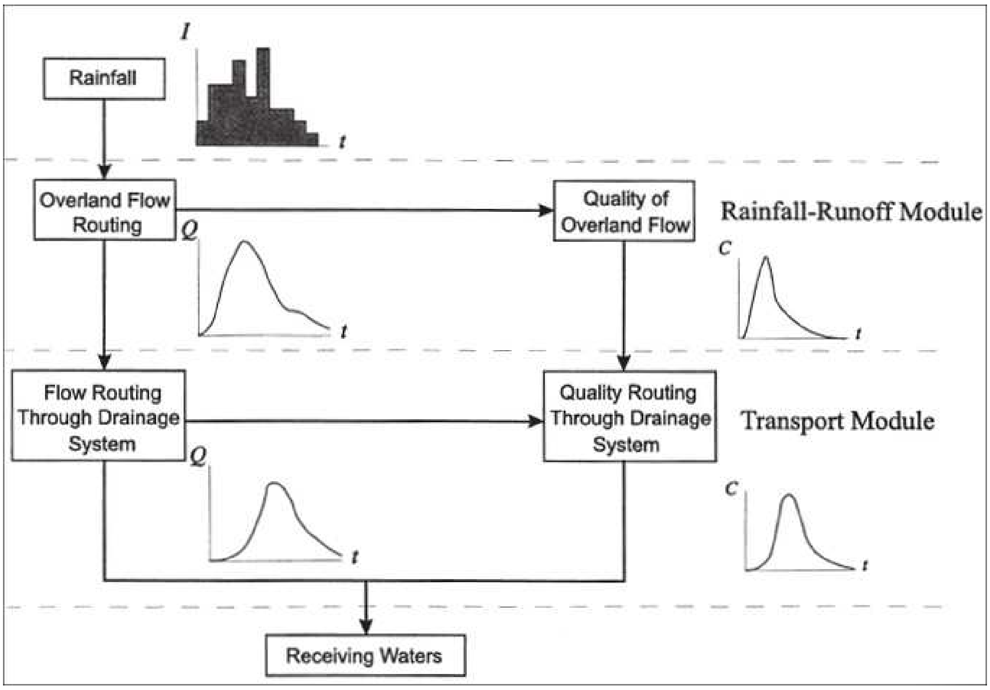


Figure 12: Overview of processes incorporated in a storm water model (ZOPPOU, 2001)

AKAN and HOUGHTALEN (2003, p.329) stated that "*the trend in hydrologic modelling is toward physically based models and away from unit hydrograph techniques for runoff transformation. Physically based models attempt to represent the actual rainfall/runoff process (infiltration, overland flow, etc.). This allows the user to change physical characteristics of the watershed (like percent imperviousness, soil moisture content and flow length) and examine the consequences. By contrast, unit hydrograph techniques generally allow for time-of-concentration changes, but significantly lump all other watershed characteristics into various empirical parameters.*"

3.3.1 U.S. EPA – SWMM 5

The EPA Storm Water Management Model (SWMM) is a dynamic rainfall-runoff simulations model of runoff quantity and quality from primarily urban areas (ROSSMANN, 2010). It is one of the most sophisticated storm water computer models currently available. It can be used for planning, analysis or design (of various hydraulic components) and for that, single events and long-term (continuous) simulations can be applied. Long term simulations over wet and dry periods can be performed. SWMM 5 is simulating four hydrologic/hydraulic processes starting with the precipitation, continuing with rainfall losses and runoff transportations and at the end flow routing. The collection of subwatershed, or so-called subcatchments in SWMM, receives precipitation and generates surface runoff and pollutant loads. This routing portion transports this runoff through the sewerage system which can include storage/treatment devices, pumps and regulators. The precipitation process can be entered as gauged (historical) storms from rainfall records or design (synthetic) storm developed externally. Regardless whether it is gauged or synthetic data the precipitation is entered as hyetograph. The rainfall loss produces rainfall excess or surface runoff from precipitation. These losses include evaporation, depression storage which includes interception and infiltration. Evaporation usually does not represent a great loss. However, it becomes more significant performing long-term simulations over wet and dry periods. At the process of runoff transformation the excess precipitation (runoff depth) is converted into a hydrograph leaving the subcatchment. The subcatchments are treated as reservoirs and combine the mass balance with Manning's equation to obtain outflow hydrographs. The parameters required for the subcatchments are Manning's roughness coefficients, the area, the width and the slope. Additionally, snowmelt can be enclosed in this process. Once runoff hydrographs are produced, flow routing conveys them downstream through the sewerage system (AKAN & HOUGHTALEN, 2003). Flow routing within a sewer system is governed by the conservation of mass and momentum equations for gradually varied and unsteady flow (the Saint Venant flow equations). The flow routing can be performed in three different ways due to different simplification level of the equation as explained by ROSSMANN (2010) and GIRONÁS et al. (2009).

- Steady Flow Routing
- Kinematic Wave Routing
- Dynamic Wave Routing

<u>Steady Flow Routing</u>

Steady Flow routing is actually no routing; it simply sums up the surface runoff from every subcatchment upstream of the chosen node through time. Consequently, a hydrograph is immediately translated from the upstream end of a conduit to a downstream end without any time delay and change in shape due to conduit storage. Steady flow routing does not take into account the back water effects, channel storage, entrance/exit losses, flow reversal or pressurized flow. This means that this type of routing is not sensitive to the time step applied and is basically only suitable for initial analysis using long- term continuous simulations.

Kinematic Wave Routing

This routing method again cannot consider the aforementioned effects. However, if these are not assumed to be considerable it can be an accurate and efficient alternative, especially for long-term solutions with moderately large time steps of about 5 to 15 minutes. The hydrographs, routed through the conduit, can be weakened and delayed at the outflow because flow and area can vary both spatially and temporally within a conduit. The kinematic wave routing uses a simplified form of the momentum equation in each conduit along with the continuity equation. The momentum equation requires that the slope of the hydraulic grade is the same as the conduit slope. The full normal value is the maximum flow that can be conveyed through a conduit. Any flow in excess entering the inlet node can either pond on the top of the inlet node and is re-entered as capacity becomes available, or is lost.

Dynamic Wave Routing

Dynamic wave routing is the most powerful method and generates the most theoretically accurate results. It solves the complete one-dimensional Saint Venant flow equations of flow for the entire conveyance system. These equations contain the continuity and momentum equations for conduits and a volume continuity equation at nodes. With this form of routing it is possible to simulate all gradually-varied flow conditions observed in urban drainage systems such as backwater, surcharged flow and flooding as well as pressurized flow. Flooding arises when the water depth at a node exceeds the maximum available depth. Again, any water in excess is lost or can pond atop the node and can be re-introduced into the node. Dynamic Wave routing can simulate bifurcated systems containing multiple downstream diversions and loops because it joins together the solution for both the water levels at nodes and the flow in conduits. This also offers the possibility to simulate pipes and gutters in parallel. In general, much smaller time steps of about one minute or less have to be used and therefore long-term simulations have limits. According to CAMBEZ et al. (2008) there could also be limits simulating long-term series with dynamic wave routing with SWMM 5 due to lack of computer memory.

SWMM 5 results can be easily exported and used by other software. The modeling results can also be seen and printed in form of tables, hydrographs, longitudinal profiles, reports and graphs for various variables from nodes or links. This includes for example the water depths, heads, volumes, velocity, flooding and pollutant loads. Furthermore, it provides statistics (mean, peak, etc.), histograms and frequency plots of parameters for annual, monthly, daily or event-dependent periods (CAMBEZ et al. 2008).

3.3.2 Model calibration, verification and sensitivity analysis

Model calibration, verification and sensitivity analysis are key issues in evaluating the accuracy and robustness of model results (FLETCHER et al., 2013). The results of modelling depend on the limitations of the algorithms of the model used, the assumed homogeneity of the subcatchments, the quality of the input data, the quality of assumed parameters and the skill of the modeller (AKAN & HOUGHTALEN, 2003). Parameter estimation is always a difficult task especially because input parameters can vary significantly depending on the characteristics of the catchment (TSIHRINTZIS & HAMID, 1998). The validity of the results can be improved through the process of verification and calibration. Both the verification and the calibration process require field measured storm event data. The goal of the verification is to determine if a model behaves as intended and if the calibration of the model was successful. Consequently, the calibration process precedes the verification. By using measured rainfall data as input data and adjusting certain parameters (Manning’s roughness values, infiltration parameters, etc.) until the modelled runoff closely matches the measured runoff, the model is calibrated. Afterwards different storm events are modelled; using these calibrated input data, and is checked again with the values measured. Consequently the calibration and verification process require the measurement of rainfall and runoff of a number of storms (at least six and preferably more). Certainly, the problem of the calibration and verification process is that it can be time intensive and consequently expensive. However, the processes should be performed for important hydrologic studies (AKAN & HOUGHTALEN, 2003).

For the calibration of a SWMM model the selection of parameters depends on the study objective and data available. For quantity calibration various parameters could be used, for instance, the percentage of imperviousness, slope, characteristic width, Manning's roughness coefficients, pervious and impervious depression storage and the infiltration parameters. JUWELL et al. (1978, as cited in (TSIHRINTZIS & HAMID, 1998)) found out, that the appropriate parameter for volume calibration is the impervious area. A significant effect on the total volume of runoff also has the depth of depression storage of impervious areas in particular for low volume rain events.

The sensitivity analysis examines the sensitivity of the model when different model parameters are changed. When it is not possible to measure data, a calibration of the model cannot be carried out. With the help of sensitivity analysis it can at least be checked to what extend the changing of parameters influence the model. For example, how the outfall loadings and surface runoff differ.

3.4 Geodata management

NEUMANN (2010a) defines geodata as every dataset that has a spatial component or aspect. The syllable “Geo” indicates the connection to the earth, which means that the dataset allows to georeference the described phenomena to a region or location on earth. In a narrow sense “geodata" refer only to data which are related to the planet earth. Synonyms used are “spatial data”, “geographic data”, or “GIS data”. Geodata can be linked to other data using spatial, temporal or thematic relation in geographic information systems (GIS). Geographic data therefore is often the most expensive but also most important component. Based on geodata simulations, spatial analysis and queries can be carried out (NEUMANN, 2010a).

Nowadays, a high quantity of geodata is for everybody available, especially in digital form, and consequently a large amount of data is accumulated. Nevertheless, geodata is regularly based on complex structures and can be expensive to acquire. Furthermore, data offer can be inconsistent and rarely extensive and up to date. Terms and rights of use can be very complicated. Users often expect high quality and complete data and are not able to identify deficits. This brings the drawbacks of using incorrect data, applying data inefficiently and uneconomically and even informally. Geodata present special challenges in information processing and geodata management should ensure the quality of geodata used. It should give reliable information as a basis for planning, measures and decision making processes in administration, economy and science. About 80 – 90 % of all decisions in the aforementioned fields as well as in politics and private domains are based on geodata. Geographical data get an administrative, operational and strategic added value due to well organised and functioning data management (FUCHS, 2013) (NEUMANN, 2010a).

The four main components in geodata management are shown in Figure 13.

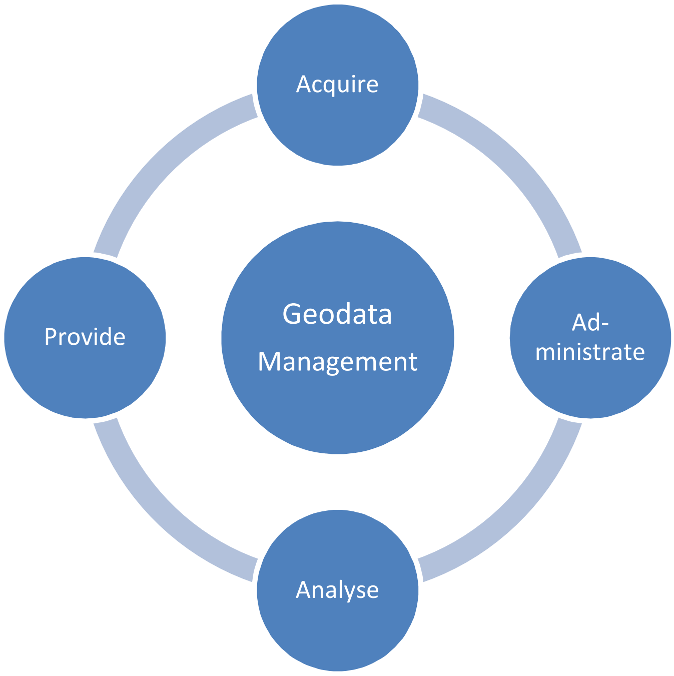


Figure 13: Components of geodata management (FUCHS, 2013; translated and redrawn by Havinga, 2013)

The first component of the geodata management is the most important one. It is the basis for all other processes and consequently, it has to be well planned and worked on accurately. All mistakes, made at this stage have various consequences in the following patches. However, delays have great impact on additional costs. The administration of geographical data deals among others with the creation and maintenance of metadata. Geodata would be useless without metadata, which give additional information on geographical data. A simple example is a map without key, which has no information value. A key is a typical instance for metadata. However, metadata are not only used to describe the content of the data, but also the quality and availability. With the help of metadata, a user should be able to determine if specific geodata is suitable. Geodata analysis contains data mining and knowledge discovery in databases (KDD). Data mining is a sub-process of knowledge discovery which searches for patterns. These can be dependences, cluster, links, sequences, variances and regularities. The complete process of KDD involves the selection, pre-processing, transformation, analysis and the interpretation of the data. Without the interpretation, the KDD gains no profit in knowledge (FUCHS, 2013).

As VAN DE LOOIJ & BROUWER (1999, as cited in (FENNER, 2000)) noted, standardisation of information is important if a system makes use of existing information. The storage of information in several kinds of databases presents a number of complex problems, if these are to be combined. For instance, issues relating to classifying objects, naming variables and distinguishing differences in dimensions of variables often require to be to be solved. For that reason, standardisation of the description of the information is very beneficial.

Geodata management and especially standardisation is also an issue of the EU. The Infrastructure for Spatial Information in the European Community directive (INSPIRE-directive) was established by the European Parliament and the Council. It came into force in May 2007 and should be fully implemented by 2019. INSPIRE aims at the sharing of environmental spatial information among public sector organisations and facilitates public access to spatial information across the Member States (EUROPEAN UNION, 2012).

INSPIRE is based on a number of common principles listed by the EUROPEAN UNION (2012):

- Data should be collected only once and kept where it can be maintained most effectively.
- It should be possible to combine seamless spatial information from different sources across Europe and share it with many users and applications.
- It should be possible for information collected at one level/scale to be shared with all levels/scales; detailed for thorough investigations, general for strategic purposes.
- Geographic information needed for good governance at all levels should be readily and transparently available.
- Easy to find what geographic information is available, how it can be used to meet a particular need, and under which conditions it can be acquired and used.

3.4.1 Sewer database

A sewer database is an organised collection of the comprehensive data referring to the sewer system and which are related to each other. In general, it is a module of a sewer information/management system, where technical and graphic data are administrated. State of the art is an object related database which can save a large amount of data efficiently, and produce consistent and lasting data. It provides adequate forms of expression for user and other application programs. The information is filed in a number of intertwined tables. The programming language SQL (Structural Query Language) is commonly used to create, edit and query databases (ÖWAV, 2010).

As mentioned before, sewer databases manage graphic and technical data. The graphic data normally include the X, Y and Z coordinates of the manhole cover and invert as well as coordinates from constructions and extraordinary constructions. The reach is generally a straight line between the manholes or constructions. Rules for acquiring technical data have to be defined. For example, it should be defined in which format and at which elevation the data should be gathered. Technical data are master, operational and conditional data. Further other data like cost data, hydraulic and static design data as well as surroundings relevant data can be included in the database. The conditional data are divided into structural-, hydraulic-, operational- and environmentally relevant data (ÖWAV, 2010).

One important task is the maintenance of the data, which includes the modification and continuation of already existing data as well as the sequential acquisition. If master data has to be changed and the former data are not stored but overridden with the current ones, then the process of change has to be documented and essential former master data is to be filed. Furthermore, operational and conditional data is to be filed in a historical way for comparison. All current data is to be checked for plausibility (ÖWAV, 2010).

3.4.2 Sewer management system

Beside the database sewer management systems include also other modules such as graphic models, analysis models, presentation modules, interface for in- and exporting data etcetera. In any case, it is recommended to operate a computerised sewer management system. These systems support a wide spectrum of functionality and systematic approaches that optimise the maintenance, operation, preservation and improvement of physical assets throughout their service lives at minimum costs (PARK & KIM, 2013). Planning of rehabilitation requires valid condition assessment and recording of data. Furthermore, a wide range of advanced algorithms for multi-objective optimisation and analytical techniques to accurately simulate and analyse system performance can be applied. These systems highly improve the efficiency, economy and maintainability of sewer systems. Especially the increasing number of aging systems combined with the declining maintenance budget and lack of funds present significant challenges to sewer system management. Therefore, efficient and cost-effective tools are to be used (HALFAWY et al., 2002). However, in many countries there is still a general lack of good information on the condition and well-recorded data is not available. This reflects the past philosophy of “build and forget”. Nevertheless, this data is the basis for implementing sewer management systems. Incomplete databases place considerable limits on the level and type of analysis achieved. One problem of using sewer management systems can be the focus on data presentation rather than effective analysis (FENNER, 2000).

Summing up, Table 3 lists the suggested data requirements by Anderson (1999 as cited in (FENNER, 2000)) for a valuable drainage management system.

Table 3: Data requirements for a data management system (Anderson, 1999; as cited in (FENNER, 2000, p. 352))

Requirements	*Description*
Accuracy	*All pipe and channel sizes and other physical attributes are known and the connectivity of the system is confirmed*
Completeness	*All constructed works are identified with no gaps in the pipe and channel networks unless confirmed by field study*
Spatially defined	*The location of the network should be referenced to the cadastral or property on road base to the nearest meter for presentation of the data in a GIS and for accurate development of hydraulic models*
Known system condition	*Moves to condition based depreciation rather than strait line depreciation on design life make condition assessment essential*
Data transfer	*Information must be easily transferred to the format required by modern hydraulic modelling products and GIS software*
Asset management	*Business decisions rules using asset condition (likelihood of failure) and asset criticality (consequences of failure) should be used to define proactive maintenance, inspection or rehabilitation programmes*
Maintenance management	*The drainage information system should link to a maintenance management system for recording incidents and for recording the nature of field operation work undertaken*
Quality Assurance	*The procedures for editing existing information of adding in more information need to be covered by sound QA and incorporate security on who can edit the data*

Constructing sewer information system the ÖWAV Rule Sheet 40 “Conduit information system – water and waste water” (ÖWAV – Regelblatt 40 (2010) Leitungsinformationssytem – Wasser und Abwasser) should be considered in Austria. It includes detailed information about the creation of conduit information systems as well as the acquisition, insertion, maintenance and processing of data. Some of the information has already been mentioned above. One point which should be stressed is the functional specification. The required functions of the functional specification are listed in the rule sheet 40. Currently, a lot of municipalities and agencies work with different programs and their own data formats. Consequently, other collected data and structures of databases vary by municipality and agency (PARK & KIM, 2013). PARK & KIM (2013) state, that the creation of sewer managements systems demands resources and extensive time. They point out, that a utility manager could considerably reduce the risk and costs of collection of unnecessary information for inventory.

4. Materials and methods

4.1 Collection of data

The aim of the two month research stay was to collect the data required in order to set up a model in SWMM 5. Local investigation regarding the study area and the verification of data were to be carried out in fieldtrips. Visits to different institutions were to be conducted and various people were to be interviewed in order to obtain as much data and information as possible.

To bear relation to the study area before starting the thesis, a new sewer system was designed for Pintija in the case study project "Sanitary Engineering" at the Institute of Sanitary Engineering and Water Pollution Control. Therefore, ahead of the research stay, the location and approximate boarders of the study area had been established. However, neither the general characteristics of the site nor the precise location or the state of the existing sewer system were known.

After the design of the new sewer system it was inserted in SWMM 5 to learn the software and to determine, which parameters and data have to be collected for the setup of the hydrodynamic sewer model in SWMM 5.

4.1.1 Study area

The study area is located about 7 km southeast of the city centre of Skopje and has a size of approximately one square kilometre [Figure 14]. The area is divided via the two lane road Prvomajska. In Google Maps this road is called Boris Trajkovski. Due to the fact, that in all data obtained the road name Prvomajska is used, this name is adopted in the thesis. In the southern part of the study area the settlement of Pintija is situated and in the northern side the Organic Chemical Industry Skopje (hereinafter referred as OHIS). In OHIS a WWTP exists at the north east side of the premises [Figure 14]. The receiving water is the river Vardar, which passes also through the city centre of Skopje [Figure 14].

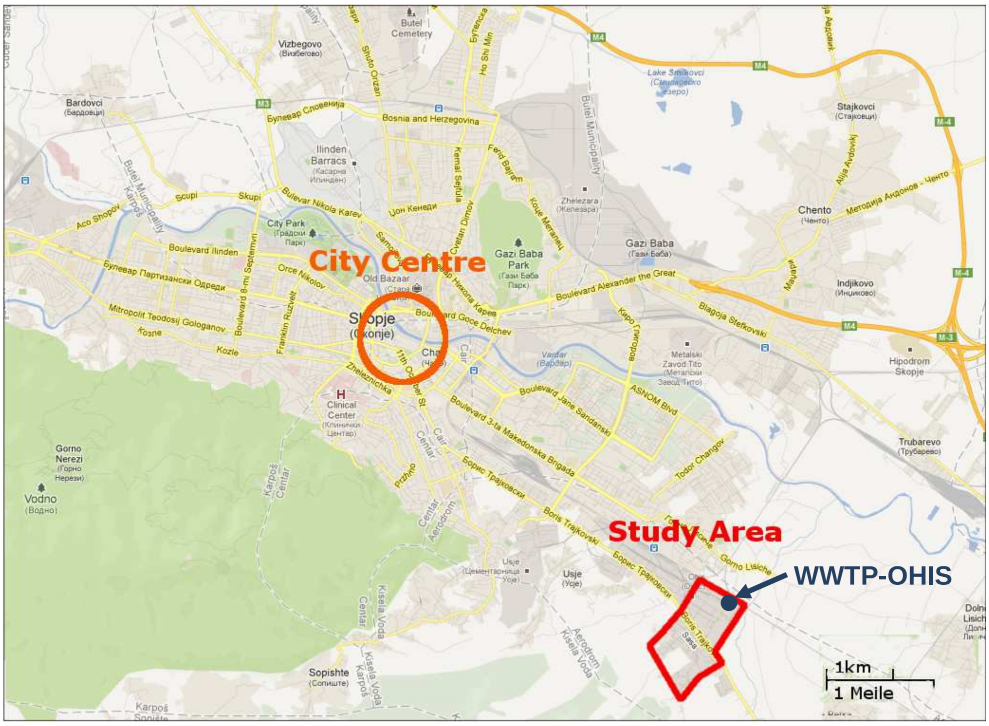


Figure 14: Location of the study area in Skopje (Google Maps; modified by Havinga, 2013)

4.1.2 Data required for SWMM 5 models

As discussed in chapter 3.3 “Storm water management modelling” the basic components of an urban storm water model are rainfall-runoff and transport modelling. The runoff is generated in the subwatersheds (in SWMM 5 referred as subcatchments) and data concerning this process for the subcatchment has to be gathered. The basis for the transport modelling is data from the sewerage system. Furthermore, additional data can be useful to substitute data missing or to get additional information necessary for the model. The master data for the setup of a hydrodynamic model are listed in Table 4.

This list was to be sent to the Macedonian colleagues some weeks ahead of the research stay to inform them about the master data needed and asking them to contact institutions which could possible provide data.

Table 4: Necessary and additional data for the model setup

<table>
<tr><th colspan="3">Necessary data</th></tr>
<tr><td colspan="2" rowspan="3">Precipitation</td><td>Intensity duration frequency (IDF) curves</td></tr>
<tr><td>Rain series</td></tr>
<tr><td>Characteristic rain events in Pintija</td></tr>
<tr><td colspan="2" rowspan="4">Subcatchments</td><td>Area</td></tr>
<tr><td>Slope</td></tr>
<tr><td>% impervious area</td></tr>
<tr><td>Connection to manholes</td></tr>
<tr><td rowspan="10">Sewer system</td><td rowspan="5">Manholes</td><td>ID</td></tr>
<tr><td>Coordinates</td></tr>
<tr><td>Invert elevation</td></tr>
<tr><td>Max depth (surface elevation)</td></tr>
<tr><td>Dry weather inflow (Inhabitants + PE)</td></tr>
<tr><td rowspan="5">Pipes</td><td>ID</td></tr>
<tr><td>Shape</td></tr>
<tr><td>Diameter</td></tr>
<tr><td>Length</td></tr>
<tr><td>Material + age</td></tr>
<tr><th colspan="3">Additional data</th></tr>
<tr><td colspan="3">Elevation model</td></tr>
<tr><td colspan="3">Orthophoto</td></tr>
<tr><td colspan="3">Fee system</td></tr>
</table>

Table 4 was developed using the detailed properties of the components found in chapter 5.2.2 Model-setup of basic scenario “Sanitary Sewer – Previous State” on page 61. The input masks from SWMM 5 are utilised to explain the model setup in detail and make it comprehensible for future users. For a clear explanation of the model setup, many results (parameters, information) of the data collection were required. Therefore, it was decided that the model-setup is rather a result of the data collection than strictly methodical information. Of course, there is some overlap between the methods and results. This was especially apparent with the numbering system for the manhole and pipe IDs. Consequently, a theoretical explanation of the numbering system would be redundant when in practice one may already exist. Ergo, the numbering system for the IDs of the subcatchments, manhole and pipes is defined in chapter “Results”. In addition, it should guarantee a better understanding of the setup of the model and should simplify creation of alternative scenarios of future users. The deliberate chapter arrangement and presentation of this thesis should eliminate the need for lengthy search periods reviewing the model setup.

As a result, the following sub items only give broad information in relation to the materials and methods of the acquisition of data required for the SWMM 5 models.

4.1.2.1 Precipitation

In Table 4 the necessary precipitation data to produce a good range of different precipitation scenarios are listed. Intensity duration frequency curves are especially needed for short time simulations. Long term simulations can only be carried out when rain series are available. The characteristic rain events in Pintija could be used for the model verification and to simulate the situation at storm events in Pintija.

First of all, it had to be determined, where the next rain gauge is located and who is responsible for the data obtained. It was to be checked, if a hydro-meteorological service exists in Macedonia and if precipitation data is also available online. In Austria, the internet platform eHYD provides hydrographical data as well as hydrographical yearbooks. The task was to find out, if similar data basis existed in Macedonia. If an Institute for Hydrology was located at the University of Skopje, it could also provide useful information.

4.1.2.2 Subcatchment

At the beginning of the setup of the SWMM 5 model, the study area had to be divided into subcatchments. Subcatchments and their subareas are defined as explained by ROSSMANN (2010, p. 34) as follows*: "Subcatchments are hydrologic units of land whose topography and drainage system elements direct surface runoff to a single discharge point. … Subcatchments can be divided into pervious and impervious subareas. Surface runoff can infiltrate into the upper soil zone of the pervious subarea, but not through the impervious subarea."*

For the division of the study area into subcatchments diverse plans are useful as well as orthophotos. The same applies to the estimation of the pervious and impervious subareas of the subcatchments. Cadastre, land development plans and sewer system plans were to be obtained to find out the accurate boarder of the study area and to carry out an adequate division of the study area in subcatchments. The sewer system plans are especially necessary to define the single discharge point of the subcatchment. In Austria, cadastres in GIS portals are available online and lists of roof areas can also be gathered online. Such lists are very beneficial for the assumption of the percentage of pervious and impervious areas. Otherwise, an orthophoto has to be used. The orthophoto can be easily obtained by Google Maps or Google Earth. For the slope of the study area an elevation model is essential. It had to be inquired which institution in Macedonia could provide it or if it is also available online like in Austria. If no elevation model could be provided, topographic maps had to be obtained.

4.1.2.3 Sewer system

It had to be determined which institutions are in charge of the sewer system in Skopje. Afterwards it had to identified, in which data format it can provide information of the sewer system. Maybe some kind of sewer management system, or was already in use or if only plans which may be georeferenced and/or lists as a database for the sewer system are relied on. If plans obtained were not georefereced, it had to be done with the help of Google Earth. For information of the sewer system in OHIS the operating company had to be contacted. The age of the pipe is more relevant for a sewer management than for the hydraulic modelling. Even in Austria it is sometimes difficult to get information related to the age of the pipes so in Macedonia it was probably the same.

4.1.2.4 Additional data

The necessity and the possible providing institutions for an elevation model and orthophotos have been already mentioned. The fee system can give good estimation about the amount of waste water and the number of inhabitants. Probably, the institution which is in charge of the water supply and the waste water service in Skopje can also provide data of the fee system and/or water use of Pintija. Furthermore, the operating company of OHIS had to be contacted in order to get information of the waste water discharge in OHIS.

4.1.3 Local investigations and verification of data

Local investigations in the form of fieldtrips were to be carried out to get acquainted with the study area. Fieldtrips should help to clarify the sewer system's current state and verify the contradictions between the sewer system data obtained and the reality. Consequently, fieldtrips cannot be carried out until sewer system plans of the area were provided.

Fieldtrips need good preparation. Orthophotos printed can help to orientate oneself in the study area. It can also be helpful to have an orthophoto as backdrop in the sewer system plan for orientation, if no coordinates exist. A good data basis has to be created ahead of the fieldtrip to be able to apply data obtained at local investigations afterwards. The locations of photos made in fieldtrips have to be stated in the plans (e.g. cadastre or orthophoto) to be able to retrace the location. The notification of the direction of the photo is also necessary. If photos from opened manholes are made, the ID of the manhole and the photo must be listed. Therefore, it is necessary that manhole IDs already exist before fieldtrips are carried out. Further useful utensils which are needed on the fieldtrips are a clipboard, a survey's measure, camera, GPS-device and a big umbrella for rainy days.

4.2 Development of scenarios

First of all, the actual situation in Pintija was to be simulated. Furthermore, scenarios were to be defined and were to be the basis for suggestions to improve the unsatisfactory situation in the study area. At the beginning, one basic scenario was to be setup and afterwards adaptions were to be made to get all the necessary results to be able to suggest improvements. Furthermore, future developments in Pintija like additional subcatchments and the change in impervious fraction (% of impervious areas) were to be considered. Summing up, the current state and the future state were to be simulated with the help of the different scenarios. As a result, suggestions for the improvement for the situation in the study area should be given with respect to sustainable and modern water protection.

4.3 Hydrodynamic modelling

For the hydrodynamic modelling SWMM 5 was to be used, because it is free ware and thus readily available. Therefore, it would be easy for the Macedonian colleagues to use the model as a basis for further investigations and projects. Besides, SWMM 5 is widely used and accepted for planning, analysis and design related to storm water runoff, combined sewers, sanitary sewers and other drainage systems in urban areas (ROSSMANN, 2010). Finally, a sensitivity analysis was to be used to determine which parameters are most sensitive and have to be estimated carefully.

4.4 Sewer database

The master data used for the SWMM 5 model components (manholes, reaches, subcatchments) were to be combined in a sewer database in the format of a excel list. The list was to be made available to the Macedonian colleagues in the annex and in digital form. It should be a basis to use the model for future projects and to setup a real database of the sewer system if currently none exists.

5. Results

5.1 Collection of data

5.1.1 Study area

Pintija lies at the bottom of a hill and the area has an average slope of 5 %. The complex of OHIS is located on level terrain. The maximum underground waters are 3 to 5 m and 5 to 10 m below ground level (DUP 2004 – 2009).

Pintija can be separated into a formal and an informal part. Consequently, the study area consists in total of the three following areas:

- Formal settlement of Pintija
- Informal settlement of Pintija
- Industrial area of OHIS

Pintija is part of the municipality Kisela Voda. Today, it is a mixed residential and industrial urban settlement, which was originally a small housing development where approximately 100 OHIS employees were accommodated. It has expanded over time to an extent that it now houses about 2500 people, which is soon to reach 5000 (N.N., 2012b). Within its boundaries several small commercial and industrial enterprises are located (ENVIRO ENGINEERING, 2001). Due to the Detailed Urban Plan (hereinafter referred to as DUP) of Kisela Voda, it became clear that a relatively big part of the settlement is informal. That means that these buildings do not have a building licence. Nevertheless, the municipality provides water supply services for the informal part of Pintija. It was finished at the end of summer 2012. The sanitary sewer system is connected only to the western informal part. Informally connected wastewater lines also exist and are included in the model. In Figure 15 the different parts of the study area are shown.

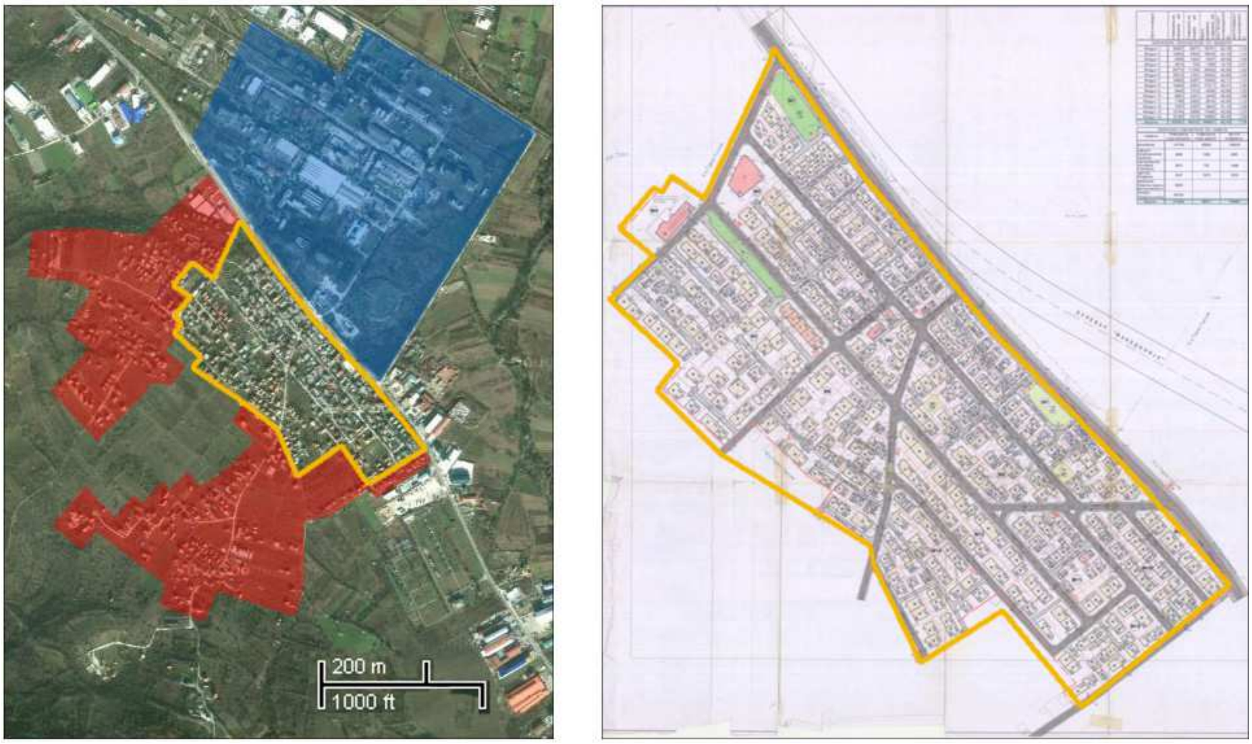


Figure 15: Different parts of the study area left (Google maps; modified by Havinga, 2013) and the plan of the DUP 2004-2009 right ((DUP, 2004); modified by Havinga, 2013)

The yellow bordered area is the formal part of Pintija which correspond with the DUP 2004 - 2009 on the right side of Figure 15. The red area on the left side illustrates the informal settlement. Hence, it appears that the DUP is only designed for the formal part. Consequently, the other areas are informal. According to oral reports from the municipality of Kisela Voda (N.N., 2012b), one half of all the houses are informal. There is an ongoing legalization process for which every informal household has applied. The following pictures should provide an overall impression of the study area. Figure 16 and Figure 17 show the format part of Pintija and Figure 18 and Figure 19 illustrate the informal part.

The blue area represents one part of the OHIS industrial area. OHIS is a huge manufacturing complex from the Yugoslavian era and encompasses about 14 manufacturing units (ENVIRO ENGINEERING, 2001) within a total area of about 1 km². Nowadays, some private factories use the infrastructure of the OHIS complex for production. Further OHIS includes a WWTP to which the waste water of the OHIS premises and Pintija discharge. In this thesis only the eastern part of OHIS is examined because the sewer system of Pintija connects to this part of the OHIS sewer system. In other words, only this area is discharging to the same sewer system as Pintija and has, therefore, an impact on the flooding and discharge processes and the hydrodynamic model. The western part of OHIS has its own sewer system which is not connected to the eastern one. The precise location of the WWTP is shown in Figure 22. In Figure 23 the road Prvomajska located between Pintija and OHIS is illustrated.

Figure 16: Pintija – formal settlement

Figure 17: Pintija – formal settlement

Figure 18: Pintija – informal settlement

Figure 19: Pintija – informal settlement

Figure 20: OHIS complex

Figure 21: OHIS complex

Figure 22: Location of the OHIS WWTP (Google Earth; modified by Havinga, 2013)

Figure 23: Road Prvomajska

5.1.2 Data obtained required for SWMM 5 models

The providing institutions and the type of the data obtained are summarised and presented in Table 5. The Detailed Urban Plan (DUP) for Pintija is made by the municipality of Kisela Voda and is based on the General Urban Plan of Skopje. In the GUP 2002 is defined, that Pintija should be a housing settlement with some additional contents (school, shop etc.).

The DUP is separated into “planned development” and “document bases”. The “document bases” include important basic data for the current situation in Pintija and the setup of the model, although it is from 2004 and 2006. The “planned development” could be used for future scenarios because the development planned in the DUP did not occur until 2012. It seems that the planned development of the DUPs in Pintija could take another one or two decades to take place.

In the two DUPs for Pintija are some contradictions. In the DUP for Pintija 2006 – 2011 are calculation errors and it also says, that Pintija has no sanitary and storm sewer system. Due to these facts the DUP 2004 – 2009 is considered more reliable.

Vodovod i Kanalizacija – Skopje represent the water and sewerage board of Skopje.

Table 5: Providing institutions and obtained type of data

Necessary data		Providing institutions	Obtained type of data
Precipitation		National Hydrometeorological Service, Republic of Macedonia	Report of intensive rains in the Republic of Macedonia, Faculty of Civil Engineering, Institute of hydromechanics*
		Municipality Kisela Voda	DUP 2004 – 2009 of Pintija*
		Vodovod i Kanalizacija - Skopje	Intensity-duration-frequency curve in the area of Skopje from 1965
Subcatchments		OHIS	Surface areas of buildings
		Municipality of Kisela Voda	Plan from Detailed Urban Plan (DUP) of Pintija 2004 – 2009*
Sewer system	Manholes and Pipes	Vodovod i Kanalizacija - Skopje	Water supply and sewer system plan of Pintija
			Sewer system plan of OHIS
		Municipality Kisela Voda	DUPs*
			Oral reports
	Dry weather flow (Inhabitants and PE)	Municipality Kisela Voda	Detailed Urban Plan (DUP) for Pintija 2004 – 2009*
			Oral reports
		BOKU Students	Investigations for project Sanitary engineering
Additional data			
Elevation model		AREC organization	Digital cadastre (http://webgis.katastar.gov.mk/arec/)
Orthophoto		Google maps	Screen shots
Fee system		Vodovod i Kanalizacija - Skopje	Review of invoiced quantity (m^3) water for the settlement of Pintija by month for 2011 and 2012

**The data was in Macedonian and has been translated into English.*

The following sub items detail information about the data obtained.

5.1.2.1 Precipitation

Unfortunately, it was not possible to acquire rain series and characteristic rain events for the Pintija region. The nearest rain gauge is located at the National Hydrometeorological Service facility approximately 10km in the north west of Pintija. The model is run with precipitation date of an intensity-duration-frequency (IDF) curve from 1965 of Skopje that is also still used by "Vodovod i Kanalizacija – Skopje" for designing sewers [Figure 24] (N.N., 2012c).

In the DUPs is stated, that the rain intensity for calculating the storm sewer is 110l/s*ha. According to oral reports from employees of "Vodovod i Kanalizacija – Skopje" (N.N., 2012c) this refers to a 20 minute rain duration and a return period T_r of two years. The exceedence probability p is 0.5, as it is the inverse of the runoff period T_r. As explained by AKAN & HOUGHTALEN (2003, p. 9) "*the exceedence probability is defined as the probability that a rainfall event with specific duration and depth will be equalled or exceeded in any one year.*"

In Austria, a design storm of 15 minutes duration with a return period of one year is normally used. However, the recommended return period for design storms in residential areas as listed in the EN 752 – 4 (2008) is two years.

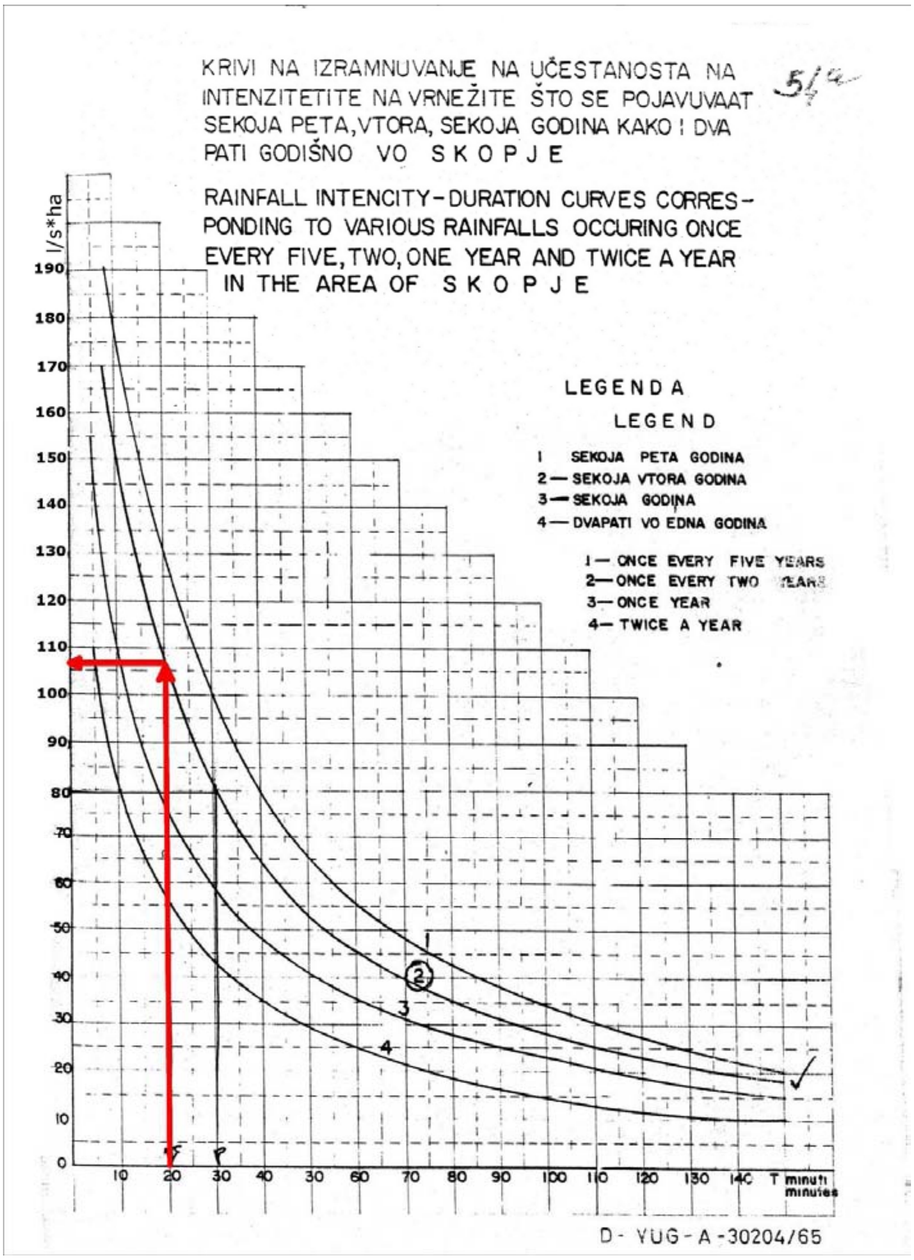


Figure 24: Rainfall intensity duration frequeny curve used by "Vodovod i Kanalizacija – Skopje" for sewer design ((VODOVOD I KANALIZACIJA - SKOPJE, 2012a); modified by Havinga, 2013)

Normally, the biggest runoff is produced if the rain duration is the same as the time of concentration. Therefore the time of concentration of the longest sewer line was calculated by dividing the length (2190m) by the mean velocity (1.2 m/s), which creates the time of concentration of approximately 30 minutes. To get the mean velocity by SWMM 5, the rain intensity of 107 l/s*ha ($r_{20,n=0.5}$) shown in Figure 24 was used. Referred to the IDF curve the intensity for a 30 minutes rain with return period of two years is 80 l/s ha ($r_{30,n=0.5}$). In the sub item 5.2.2.1 "Precipitation" on page 61 it is described, which intensity was applied for the basic scenario of the model.

The information obtained from the National Hydrometeorological Service, Republic of Macedonia, is not taken into consideration, because no applicable data could be gained.

5.1.2.2 Subcatchment

The division of the study area in subcatchments via the information of the DUP 2004 – 2009 for the formal part of Pintija is explained in chapter 5.2.2 Model-setup of basic scenario "Sanitary Sewer – Previous State". Also the estimations for the previous and impervious numbers are defined there.

For OHIS the sewer system plan of OHIS was used to create the subcatchments. By means of the plotted storm water pipes, it was easy to define them. For estimating the percentage of the impervious area OHIS provided the buildings' areas. Unfortunately there are contradictions between the provided area data and the measured areas in the OHIS plan. Consequently, it is not used and instead the estimations are made via AREC and the sewer system plan of OHIS.

5.1.2.3 Sewer system

Water supply and sewer system plan of Pintija

This plan provided by VODOVOD I KANALIZACIJA - SKOPJE (2012b) (hereinafter referred as sewer system plan of Pintija) can be found in Appendix B and an abstract is shown in Figure 25. The backdrop of the plan is the cadastre of Pintija and the following information is given by the plan:

- Blue line: water supply system
- Blue dotted line: planned water supply system
- Blue numbers: Diameters of water pipes (incomplete)
- Red line: sewer system
- Red numbers (at red lines): Diameters of sewer system pipes (incomplete)
- Red points: Location of the manholes
- Red numbers (at red points): Invert and surface elevation of manholes (incomplete)

The elevation description consists of three numbers. The number on the top is the elevation of the manhole cover on the surface. The second one is the invert elevation. When a third number is listed, the manhole is a drop manhole and the elevation of the second pipe intersection is listed as well. Due to safety restrictions, it was not possible to verify the pipe diameters during the fieldtrips.

Figure 25: Abstract of the water supply and sewer system plan of Pintija (VODOVOD I KANALIZACIJA - SKOPJE, 2012b)

<u>Water supply and sewer system plan of OHIS</u>

This plan can also be found in the Appendix B (MUNICIPALITY OF KISELA VODA, 2012). It includes the location of the sanitary and the storm sewer system as well as the location of the manholes. Furthermore, all diameters of the pipes are available but no information of the elevation of the system is given. Once again, due to safety restrictions, it was not possible to verify the diameters during the fieldtrips.

<u>Detailed urban plan (DUP 2004-2009)</u>

Planned development DUP 2004 - 2009:

For the prediction of the water supply, the maximum water use of 500 litres/person/day is estimated. The coefficient of the daily irregularity c_1 is 1.5 and the coefficient of the hourly irregularity c_2 is 1.3.

Q_{max}= Number of people * 500l/p d * c1 *c2 / 24*60*60 = 47.66 l/s

Necessary water supply for fire case: 10 l/s

Dimension of water supply pipes ≥ 100 mm

(Note of the author: the number of people is 4224, which are the predicted inhabitants in the DUP 2004 - 2009)

According to the basic urban plan for Skopje a separated sewer system is planned:

1. Waste sewer system: The conveyance of the waste water is done through to city sewer network; the waste water is transported to the pumping station Gorno Lisice. This pumping station is part of waste sewage network of the settlement of Gorno Lisice. According to the GUP for Skopje, it was planned to convey this waste water to a waste water treatment plant in the city of Skopje. The existing waste sewer system is not enough to meet the needs of the settlement. That's why it is planned to make additional extensions to cover the whole area. Pipe profiles will be DN ≥ 250 mm. The amount of sanitary waste water is calculated at 80% of the water supply increased by 25 % from the infiltration of underground water.

   Q_{waste}= 0.8* Number of residences * 500l/p d * c_1 *c_2*1.25 / (24*60*60) = 47.66 l/s

2. Storm sewer system: In the settlement no storm sewer system exists, the GUP includes a complete storm sewer network, which will be released to the receiving water of Markova River. The secondary network will be made with pipes DN ≥300mm, which will be modelled according to the amount of storm water. This amount will be calculated by empiric formulas that include the purpose, size and type of the effected areas and the intensity of the rain.

   $Q_{storm} = F_i * q_i * \Psi = 968.0$ l/s

   F_i= 22.00 catchment area

   q_i= rain intensity (110l/sec/ha)

   Ψ=0.4 run-off coefficient

Document bases DUP 2004 -2009:

The waste water is conveyed to the waste sewer system in the complex of OHIS. The existing sewer system is not enough to satisfy the needs, so it is necessary to make improvements and reconstruction. The storm water from streets, roofs and other areas goes by gravity.

<u>Inhabitants and population equivalents</u>

The inhabitants and the PE are rather secondary for the storm water model due to the big proportion of waste to storm water during a storm event (about 1:100). Nevertheless, it produces outfall and it should be considered. One scenario will deal only with the sanitary sewer. For the sanitary flow it is necessary to know the number of inhabitants and population equivalents. Like shown in Table 5, there are three different sources for the number of inhabitants and PE.

- *Detailed Urban Plan*

Planned development DUP 2004 - 2009: In Pintija 460 parcels for houses and 1150 apartments are to be situated. Of these apartments 450 are already built and 700 are planned. The average person – per - household value is 3.67 and the total predicted number of people is 4224. The average brutto density is 196 people/ha.

Document bases DUP 2004 -2009: In Pintija 409 buildings are located. Of these, 400 are family houses and the other nine are: one primary school, one administration object, three trading objects, two ware houses, one hairdresser and one post office. The actual density is 65 people/ha and the total population 1424 people.

- *Oral report*

At the meeting on the 12^{th} of June 2012 (N.N., 2012b) with one employee of Vodovod i Kanalizacija – Skopje and one worker from the municipality of Kisela Voda the following information was obtained.

Right now about 3500 people are living in Pintija. Every year 20 to 30 houses are newly built. Due to the new water supply system - which was recently built – this amount will increase. The plan is, that Pintija will have 10 000 residents in about 10 years.

450 buildings are formal, and of those that only about 250 pay the taxes (e.g. for building the houses) and 200 are in the cadastre. 450 houses are informal. All of these have already applied for the ongoing legalisation process; however, this will take some more years to finish. Then the water supply and waste water service will be available to all households in Pintija.

- *Information from the project Sanitary engineering*

In the project the houses in Pintija (formal and informal) were counted and 4 people per household assumed. Both the formal and the informal part house about 2800 people according to this investigation.

To conclude, about 2500 residents live in Pintija in the informal and formal part. If 25 houses are built every year (N.N., 2012b) then about 3500 people will live in Pintija in 10 years.

5.1.2.4 Additional Information

Elevation model

The Ministry of Environment and Physical Planning runs the Office of Spatial Information System. It developed a digital model of the terrain (DTM) for the territory of the Republic of Macedonia with a resolution of 20 metres (MEPP, s.a.). However, it was too expensive to obtain the DTM for the study area and in any case the 20 metre resolution may have lacked sufficient detail for the purposes of this thesis.

The only elevation model which was available for the thesis was the online AREC GIS portal (AREC, 2013). AREC is the Agency for Real Estate Cadastre of the Republic of Macedonia. It provides a GIS portal, which includes amongst other layers an orthophoto of 2009 and the cadastral map from 1978. Although this in not a real elevation model, the cadastral map includes contour lines of every meter and lent assistance to estimate the missing elevation.

In the model of the thesis it was used for obtaining the missing manhole elevation data and checking the elevation callouts of the sewer system plan of Pintija. Of course, streets do not always follow the surface elevations but the elevation model still gave evidence.

Figure 26: Orthophoto and cadastral map layer in the online cadastre (AREC, 2013)

Another useful layer for evaluating the missing elevation values was the cadastral layer, because also the manholes are distinguishable and some survey monuments from property lines are denoted. The location of the manholes is shown with red circles in Figure 27. In Figure 28 all the three layers are displayed.

Figure 27: Cadastral layer with manhole location in the online cadastre ((AREC, 2013); modified by Havinga, 2013)

Figure 28: Orthofoto, cadastral layer and cadastral map combined (AREC, 2013)

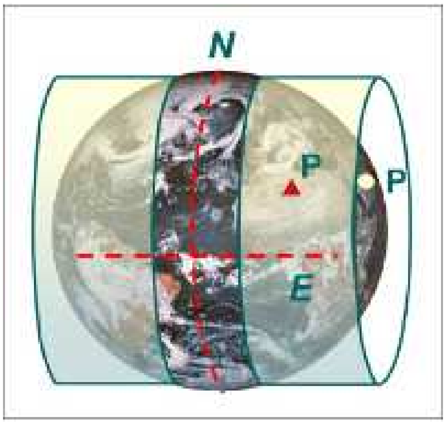
Unfortunately, the cadastral layer is only available for the formal part of Pintija. Another problem is that the elevation plan of the digital cadastre is not very useful for the OHIS premises. Due to the observation it is known that the OHIS premises are flat to a large extent but for instance a bank is illustrated in the cadastral map layer, as shown in Figure 29. Consequently, the estimation of the elevations is even more imprecise than in Pintija, where at least some elevation are known and can be compared with the information from AREC. In OHIS the elevation values of the main collector are estimated with the aid of AREC. For the other elevation it is assumed, that the slope of OHIS premises is 0.3 % in most cases.

Figure 29: Online cadastre with contour lines (AREC, 2013)

<u>Orthophoto</u>

One of the backdrops used for the SWMM model was a geo-referenced orthophoto from Google Earth. Before using a backdrop, the map dimensions have to be known. In SWMM 5 the X and Y coordinates of the lower left and the upper right corner of the picture have to be inserted. As a result the backdrop can be reloaded into SWMM 5 with the same position and will agree with other backdrops and the constructed sewer system of the model. Hence, the orthophoto backdrop will for example coincide with the constructed system based on the sewer system plan of Pintija.

In Google Earth the Universal Transverse Mercator (UTM) geographic coordinate system was chosen to display the coordinates. The UTM system of projections defines 60 different standard projections. Each of these 60 zones uses a different Transverse Mercator (cylinder) projection that is slightly rotated to use a different meridian for the central line of tangency. By rotating the cylinder in 60 steps (six degrees per step) the UTM assures that all spots on Earth will be within 3 degrees of the centreline [Figure 30] (MANIFOLD SOFTWARE LIMITED, s.a.). In each zone the scale factor of the central meridian reduces the diameter of the transverse cylinder to 0.9996 to produce a secant projection with two standard lines, or lines of true scale, about 180 km on each side(WIKIPEDIA, 2013).



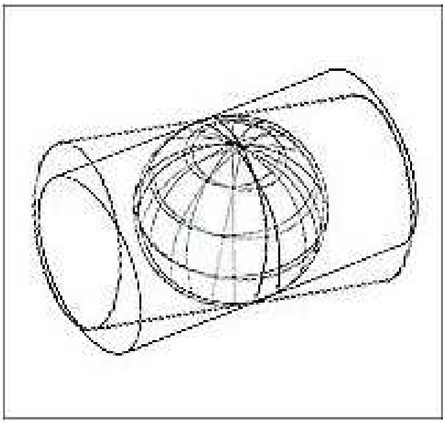


Figure 30: UTM projection (left: (FUCHS, 2010); right: (MANIFOLD SOFTWARE LIMITED, s.a.)

In front of the coordinates in Google Earth the grid zone of the UTM projection is stated. Skopje is located in T 34. The combination of a zone and a latitude band defines a grid zone. Each zone is segmented into 20 latitude bands; one has a height of eight degrees. The lettering is started form “C” at 80°S and increases up the alpha bet until “X” (WIKIPEDIA, 2013).

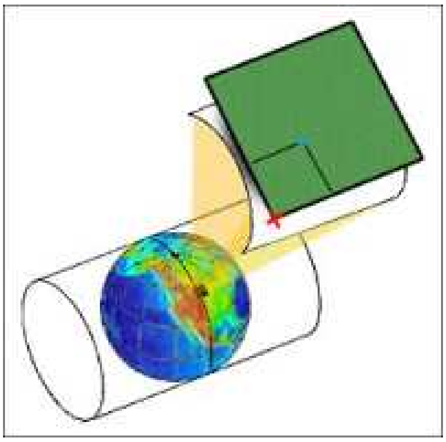



Figure 31: UTM grid zones (left: (MANIFOLD SOFTWARE LIMITED, s.a.); right: (WIKIPEDIA, 2013))

The UTM projection uses the WGS84 (World Geodetic System) as geodetic datum, which is the method, how the ellipsoid is adapted to the geoid of the earth. At the WGS84 the centre of the ellipsoid is in the geo centre of the geoid (FUCHS, 2010).

<u>Fee system</u>

The fee system can give a good estimation about the amount of the waste water and the number of inhabitants. The water supply and the wastewater service in Skopje are provided by Vodovod i Kanalizacija – Skopje. For Pintija OHIS performs the wastewater treatment but according to the final report of ENVIRO ENGINEERING (2001) OHIS doesn't charge anything for it.

From Vodovod i Kanalizacija – Skopje (2012c) the invoiced quantity (m^3) of water for the settlement of Pintija by month for 2011 was provided. The average fee for 1 m^3 water in Pintija in 2011 was about 34 Denar, which is about 0.55 € (calculated with the exchange rate of 14.05.2013 1€ = 61.49 Denar).

Table 6: Review of invoiced quantity (m^3) water for the settlement of Pintija by month for 2011 (VODOVOD I KANALIZACIJA - SKOPJE, 2012c)

	Small businesses			Households			Total		
Month	**water m³**	**Invoiced Denars**	**Customers**	**water m³**	**Invoiced Denars**	**Customers**	**water m³**	**Invoiced Denars**	**Customers**
1	1,430	86,128.00	21	14,267	417,078.50	467	15,697	503,206.50	488
2	703	40,705.00	22	9,656	272,314.50	446	10,359	313,019.50	468
3	800	49,222.50	16	10,489	291,205.50	349	11,289	340,428.00	365
4	262	16,547.00	17	9,513	273,602.00	431	9,775	290,149.00	448
5	377	24,540.00	22	9,133	259,919.00	455	9,510	284,459.00	477
6	407	26,646.50	21	10,172	294,409.50	454	10,579	321,056.00	475
7	332	21,380.50	23	9,419	266,863.50	476	9,751	288,244.00	499
8	331	20,639.50	22	9,951	275,882.00	473	10,282	296,521.50	495
9	404	25,927.50	22	8,861	260,448.00	473	9,265	286,375.50	495
10	266	15,588.00	17	16,530	499,719.50	403	16,796	515,307.50	420
11	12,688	887,120.00	28	9,580	281,681.00	436	22,268	1,168,801.00	464
12	385	25,387.00	21	8,294	237,324.00	443	8,679	262,711.00	464
Total:	**18,385**	**1,239,831.50**	**252**	**125,865**	**3,630,447.00**	**5,306**	**144,250**	**4,870,278.50**	**5,558**

The average household number for the year 2011 is 442. Some holiday houses might be located in Pintija, because in summer more households consumed water. This average number coincides with the oral report of N.N. (2012b), who specified 450 households in the formal part of Pintija. The average number of small businesses is 21. The total amount of invoiced water is used to calculate the average values in Table 7.

Table 7: Average invoiced water values

average values	
12021	m³/month
401	m³/day
463	households
865	l/day*household
3.67	resident/household (DUP 06-09)
236	l/resident*day

In the DUPs 500l/resident*day is used to calculate the amount of wastewater. This value is very high and not really comprehensible. Therefore, it is not going to be used for the calculation of the amount of waste water in chapter 5.2.2.

5.1.3 Local investigations and verification of data

Due to different information before the research stay, it was supposed that Pintija has a separate system what turned out not to be true. The data achieved from the fieldtrips were very fundamental to estimate the condition of the sewer system and find out the contributions between the provided sewer system plans and the reality. Another issue was to realise which areas generate runoff and where the surface water flows to as well as collect missing data of the sewer system. It is also very helpful to speak with neighbours, because they often know a lot about the sewer system.

During the research stay four fieldtrips were made. The first fieldtrip took place on May 15th 2012 after a day of heavy rain. On the day of the fieldtrip the rain was already lighter and stopped completely around noon. With the help of two workers, who work for the water supply system of Pintija for the municipality, manholes were opened and contradictions found [Figure 32]. On this day only the formal part of Pintija was visited. The second fieldtrip on May 22th 2012 was a meeting with Mr. Sreten Stojkovski, the manager of OHIS, and the responsible employee for the OHIS WWTP, Mrs. Tina Petkovska. The connections of the sewer systems between Pintija and OHIS were discussed and afterwards a site inspection of the informal western part of OHIS was made. On the third fieldtrip on the following day some manholes on the OHIS premises were opened and checked. On of June 12th 2012 one employee from the municipality of Kisela Voda and one from “Vodovod i Kanalizacija”, Mr. Radovan Ninovcki, were met in Pintija to discuss the system and informal connections.

Figure 32: Opening of manholes

5.1.3.1 Subcatchments

One of the basic information to build up a model is the surface runoff which is generated in the subcatchments. During the first fieldtrip after the heavy rain it was discovered, that a part of the roof runoff is discharged either directly onto the streets [Figure 33], into the gardens [Figure 34] or others are connected to the sewer system. According to the oral reports on the forth fieldtrip around 50 % of the houses in Pintija connect the rain drain to the sewer system and the other 50 % are discharged in gardens or the streets. More than 50 % apparently should be connected to the sewer system in the formal part and less than 50 % in the informal part, but all together it is 50 % to 50 % (N.N., 2012b). By checking one street in the formal part it was discovered that only about 15 % of the rain drains are connected to the waste system, about 40 % of the roofs runoff is directly conveyed to the streets and about 45 % into gardens. Admittedly, only the discharge facing the street could be inspected. Some surface water can also infiltrate at the manholes into the sewer system as shown on the right side of Figure 35. On the left side an example for a discharge into the waste sewer is pictured.

Figure 33: Storm water conveyed directly to the street

Figure 34: Storm water conveyed to the garden

Figure 35: Storm water discharged into the sewer system (left), broken manhole cover (right)

Due to this situation flooding often occurs. In Figure 36 the surface runoff and a street which was flooded the day before is shown.

Figure 36: Surface runoff right and flooding left

The woman in the back of the right picture explained that after two hours of heavy rain, the street was flooded and water even flooded her house. This picture is taken from the Prvomajska Road on which flooding also happens as shown in Figure 37. Figure 38 pictures the surface runoff from the Prvomajska Road to the OHIS premises.

Figure 37: Road Prvomajska

Figure 38: Surface runoff to OHIS premises

Further, additional subcatchments discharging to the OHIS storm sewer system were discovered on the first fieldtrip. This area located on the other side of the Prvomajska Street of the parking lot in OHIS is characterized by a very high level of imperviousness [Figure 39 and Figure 40].

Figure 39: Additional subcatchment with high percentage of imperviousness

Figure 40: Additional subcatchment with high percentage of imperviousness

Parts of these areas are discharged into a storage tank at the parking lot of the OHIS premises [Figure 41 and Figure 42] which is 4 m long, 3 m wide (measurements in the sewer system plan of OHIS) and has an estimated depth of 2.5 m.

Figure 41: Storage unit at parking lot in OHIS

Figure 42: Influent and effluent of the storage unit

The storage tank discharges into the storm sewer of the traffic area in front of the OHIS office building [Figure 43 and Figure 44].

Figure 43: Traffic areas in front of the office building

Figure 44: Street in front of the office building

5.1.3.2 Sewer system

As already mentioned, according to oral reports ahead of the research stay a separate system apparently provides the waste water discharge in Pintija. However, the storm sewer does not work, because it is full of sediments. In the sewer system Plan of Pintija only one sewer line is illustrated, which means that a combined system exists in Pintija. Moreover, in the feasibility study of ENVIRO ENGINEERING (2001) is stated, that Pintija has a combined system. Therefore, on the fieldtrip the attention was primarily turned to finding out which type of sewer system exists in Pintija and where the connections to OHIS are located. During the fieldtrip it was discovered, that only one storm sewer line is present. Nevertheless, it is blocked with sediments. For the rest of the sewer system only the sanitary sewer exists. Due to connections of roof runoff (faulty connections), it is misused as combined sewer, but of course, the dimensions are too small to operate like a combined sewer. The location of this storm sewer line is shown in Figure 45. The line is coloured green and the pictures point out the condition of the storm sewer. The two pictures at the bottom illustrate that in the eastern part the storm sewer and the sanitary sewer lie parallel on each side of the road. This can be also seen in Figure 46.

Figure 45: Location and blockage of the storm water reaches in Pintija (Plan: (VODOVOD I KANALIZACIJA - SKOPJE, 2012b))

Figure 46: Storm sewer manhole (left), sanitary sewer manhole (right)

Further contradictions between plan and reality were found. One contradiction is shown in Figure 47. It was found by opening the two manholes marked with green arrows.

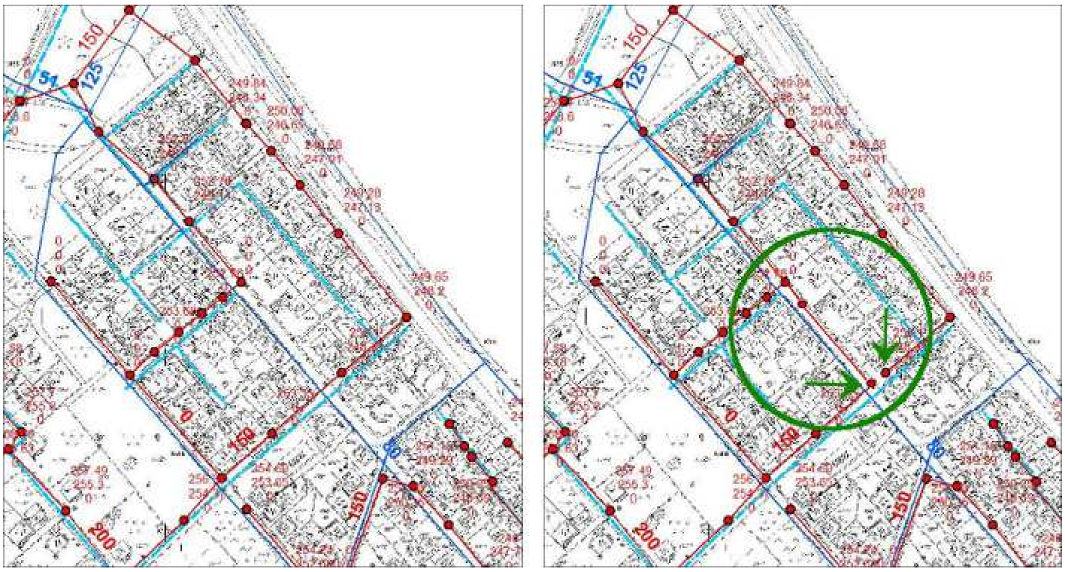


Figure 47: Contradiction between plan (left) and reality (right) ((VODOVOD I KANALIZACIJA - SKOPJE, 2012b); modified by Havinga, 2013)

The informal connections are pointed out by the red lines in Figure 48. The red points are the manholes, which are positioned due to estimations.

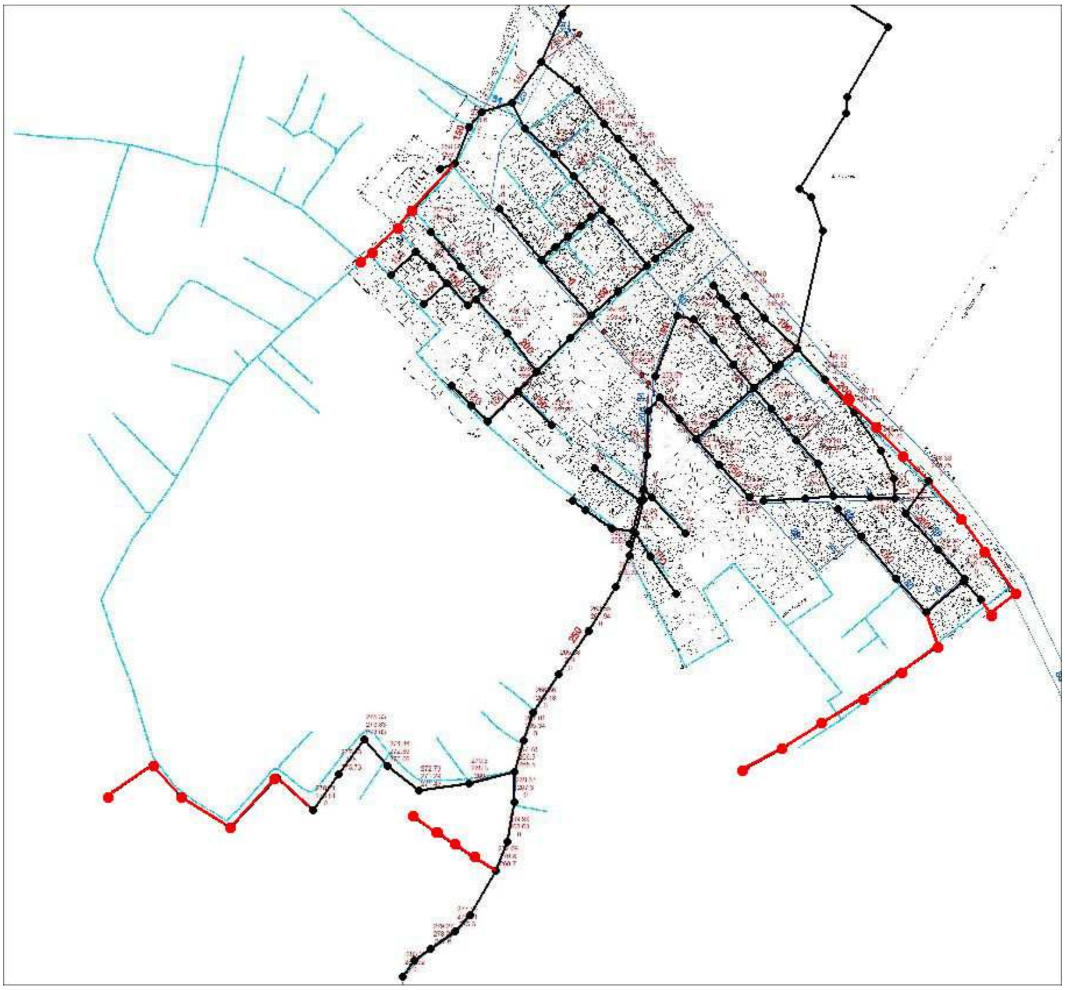


Figure 48: Informal connections to formal sewer system in Pintija

Another important point to be discovered was the connection to OHIS. According to the DUP 2004 – 2009 there were be three connections but in the sewer system plan of OHIS only two are illustrated. The sewer system plan of OHIS also shows two, whereas the one at the parking lot consists of a storm sewer and a waste sewer. By speaking with various people and opening the manholes, it was proved, that only two waste sewer connections exist and the first manhole of the sewer system plan of Pintija at the western connection is wrong. This can be seen in Figure 49 marked by the green circle. Figure 49 is a screenshot of the SWMM 5 model with the sewer system plan of OHIS as backdrop. The black line shows the conduit modelled in SWMM 5. Also the beginning of the storm sewer in the OHIS premises at this connection is visible in the green circle.

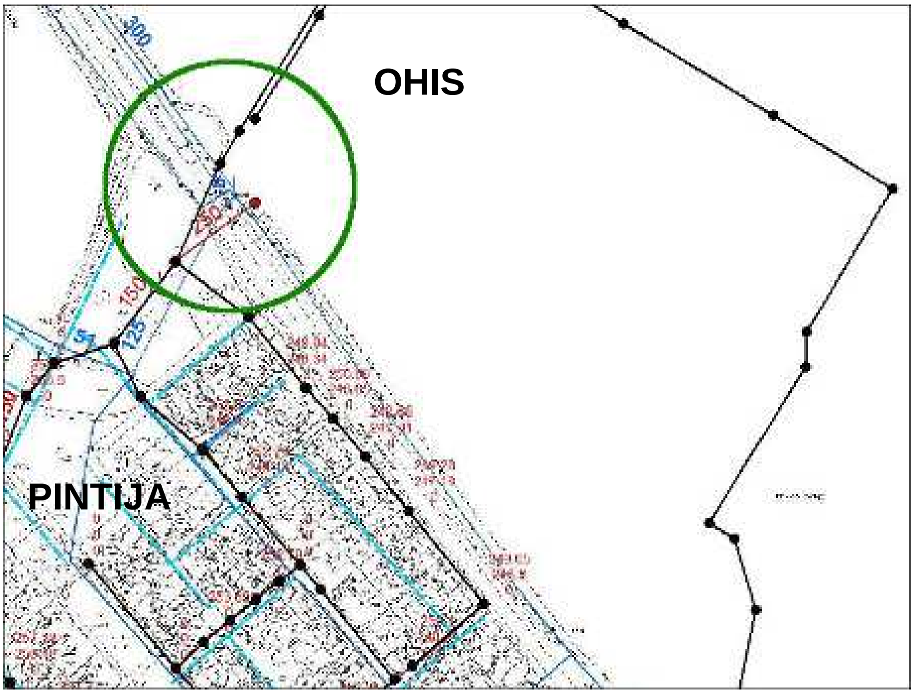


Figure 49: Connections Pintija – OHIS

The last but very important fact which was found during one fieldtrip are two bypasses in the OHIS sewer system. One of them is illustrated in the sewer system plan of OHIS. However, without opening the manholes it would not be possible to understand the actual meaning of this pipe in the plan. Through the bypasses the waste water is discharged into the storm sewer system of OHIS and consequently directly into the river Vardar. The location of the bypasses is highlighted with a red circle in Figure 50. The red arrow points out the location, from which the sanitary sewer system starts working again. Between the bypass and the red arrow it is not in use. At the other bypass it was not possible to investigate the condition of the sanitary sewer line after the bypass is, because it was not possible to open the manholes. In Figure 51 the bypass connected to the storm sewer of OHIS at the western connection is shown. Figure 52 illustrates a dry manhole of the waste sewer line, which does not work due to the bypass. The manhole in which the eastern bypass is discharges is demonstrated in Figure 53.

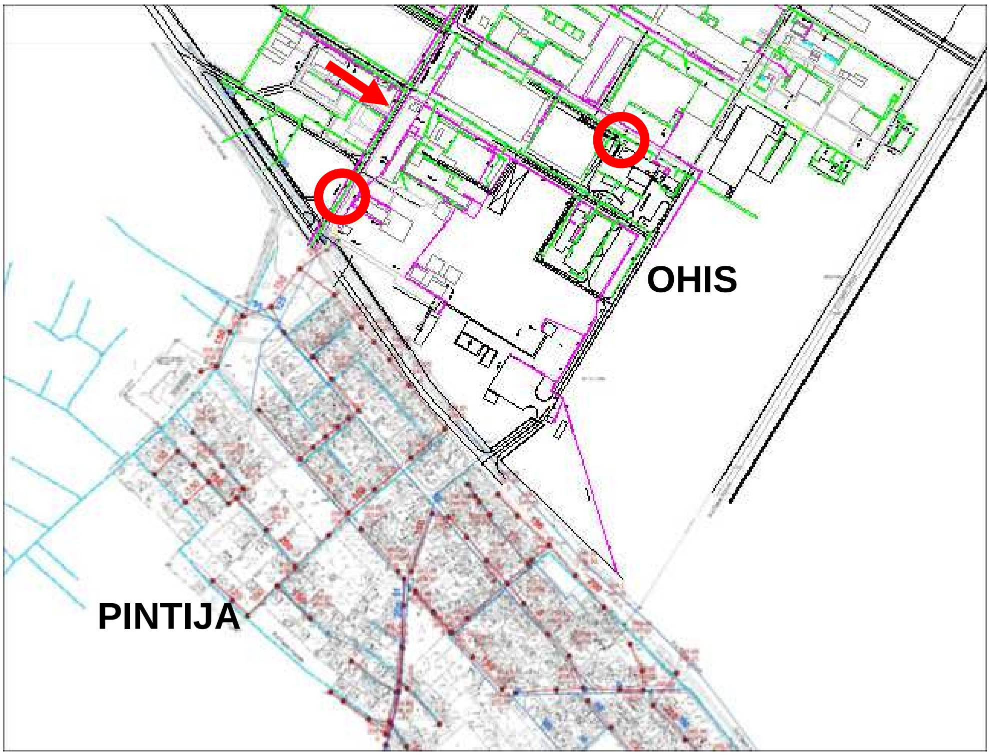


Figure 50: Location of the bypasses in OHIS

Figure 51: Manhole to which the western bypass discharges

Figure 52: Dry waste sewer system manhole

Figure 53: Manhole to which the eastern bypass discharges

It is assumed that the bypass on the western connection [Figure 51] has a diameter of 0.25 m and the other bypass [Figure 53] a diameter of 0.50 m.

5.1.4 Overall findings

Once the fieldtrips had concluded and meetings with relevant people involved had been undertaken, it was then possible to gain an understanding of the current state of the sewer system. These findings are presented in the scheme below [Figure 54]. In the illustration the informal parts of Pintija are marked. The eastern informal part is connected to the public sewer system. In Pintija and OHIS faulty connections exist. In Pintija rain drains are connected to the sanitary sewer and in OHIS sanitary connections from industrial buildings are linked to the storm sewer. As already mentioned, the sanitary sewer of Pintija is connected to the storm sewer of OHIS through two bypasses.

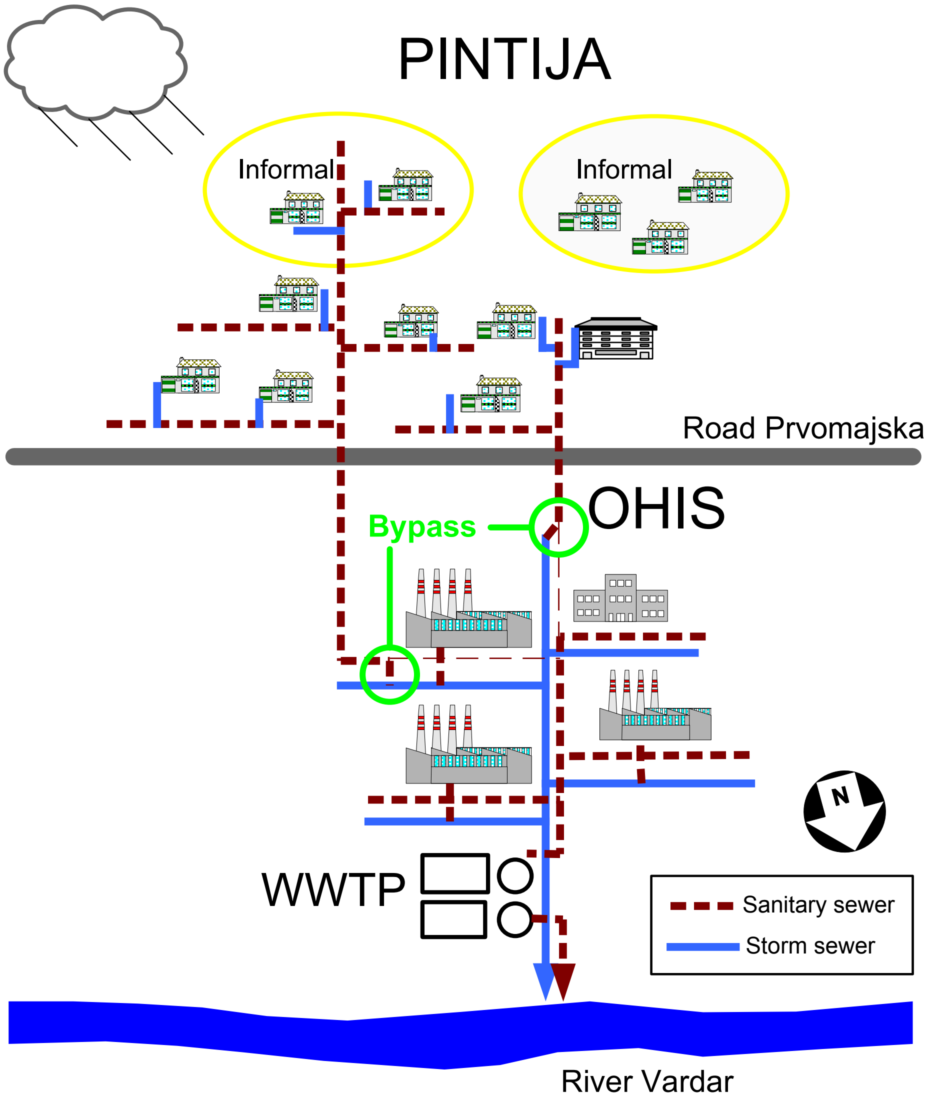


Figure 54: Current state of study area

This information provided the basis for the definition of the scenarios. It was decided that the basic scenario should exclude the bypasses in order to clarify the reason why they were constructed in the first place. It became clear that flooding at the manholes upstream of the bypasses provides the possibility for validation of the model since no data measured for a model calibration and verification exist.

Table 8 summarises the success of the data acquisition. It shows clearly that many data were incomplete or were not obtained. Of course, this has an impact on the quality of the results of the hydraulic modelling and makes accurate suggestions for improvements difficult. Nevertheless, it was determined that the data is sufficient to simulate the different scenarios to obtain basic information to identify potential bottlenecks. However, due to the basic nature of the available data, these simulations are certainly not suitable for use in detailed planning

Table 8: Success of the data acquisition

Necessary data			**Obtained**	**Approximate/ incomplete data**	**Not obtained**	**No need to be provided**
Precipita-tion		IDF curves	✓			
		Rain series			✓	
		Characteristic rain events in Pintija			✓	
Subcatch-ments		Area				✓
		Slope		✓		
		% impervious area			✓	
		Manholes connected			✓	
Sewer system	pipes	ID			✓	
		Shape	✓			
		Diameter		✓		
		Length		✓		
		Material + age			✓	
	manholes	ID			✓	
		Coordinates		✓		
		Invert elevation		✓		
		Max depth (surface elevation)		✓		
		Dry weather inflow (PE)	✓			
Additional data						
Elevation model				✓		
Orthophoto						✓
Fee system			✓			

The column on the left side “No need to be provided” is designated to data, which can be obtained in the internet, like the orthophoto with Google Maps or Google Earth. The area of the subcatchment did not have to be obtained, because the division of the study area in subcatchments can be done by the modeller. The shape of the pipes are not indicated in the data obtained, but were determined during the fieldtrips.

In the following section, the information gathered during the research stay is used for the definition of the scenarios and the setup of the SWMM 5 model.

5.2 Definition of scenarios and setup of SWMM 5 models

5.2.1 Definition of scenarios

Figure 55 illustrates the scheme of the definition and setup of the different scenarios. The first scenario modelled is the scenario “Sanitary Sewer - Previous State”. As it is the *Basic Scenario*, all other changes and adaptions for the other scenarios of the models are made on the basis of it. Consequently, the others are *Adaption Scenarios.* Both the scenario “Sanitary Sewer - Previous State” and “Sanitary Sewer - Current State” deal with the misuse of the separate system. In the basic scenario the sanitary sewer in Pintija is misused due to a high number of faulty connections. In the scenario “Sanitary Sewer - Current State” also the storm sewer in OHIS is rather a combined sewer than a storm sewer due to the connection of the sanitary sewer of Pintija by bypasses into it. Some faulty connections into a sanitary sewer can normally not be avoided. Nevertheless, the number of storm water discharged into the sanitary sewer in

Pintija highly exceeds the common number. The discharged water rather equals the situation of a combined sewer. The adaption scenarios deal either with the sanitary sewer or with the storm sewer. Furthermore, the scenario "Storm Sewer – Open Channel" is applied for modelling modifications of the subcatchments as well as carrying out the sensitivity analysis and . The modifications of the subcatchment are made in the model of the future scenario "Open Channel – Future Development".

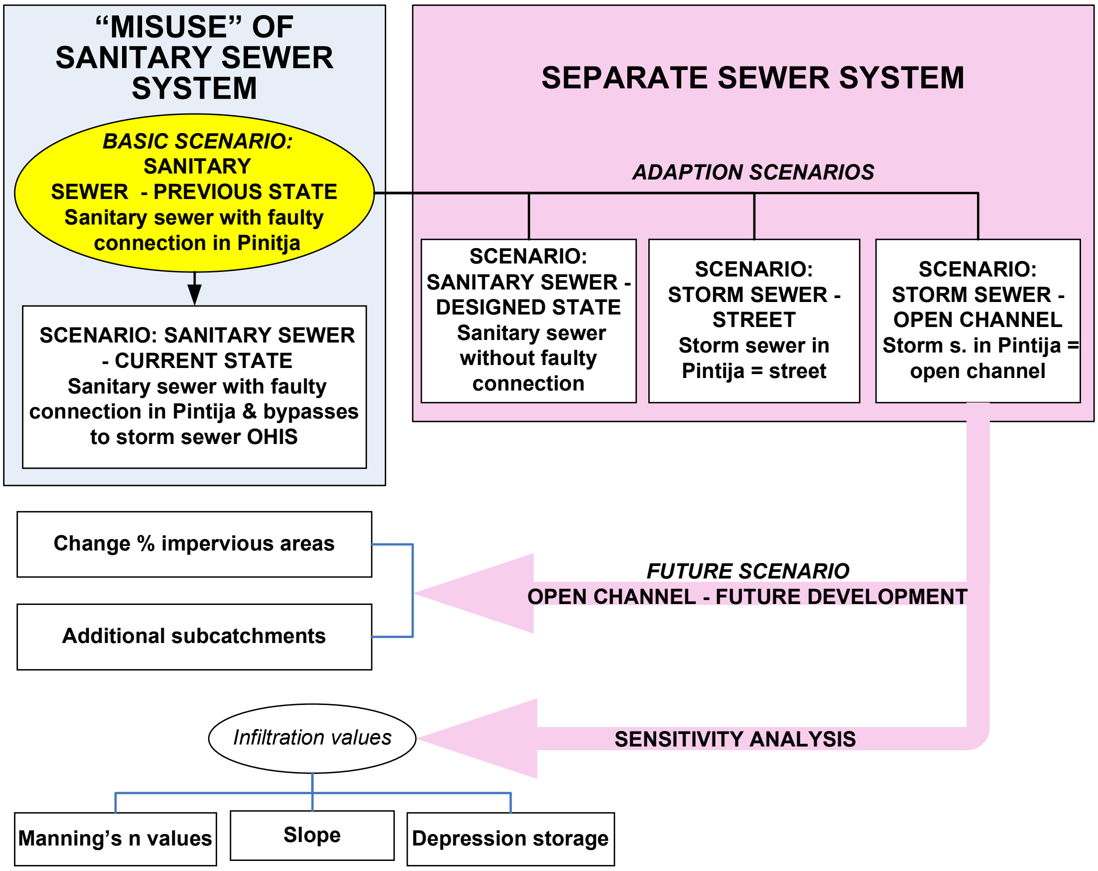


Figure 55: Scheme of the definition of the scenarios

The scenario "**Sanitary Sewer - Previous State"** examines the state of the system which does not include the connection of the sewer systems of OHIS and Pintija via bypasses. The bypasses are not taken into consideration, because in this scenario it is to be shown why the bypasses were constructed. As a result, the manholes in front of the bypasses should be flooded.

The scenario "**Sanitary Sewer - Current State"** simulates the current conditions of the sewer system in OHIS and Pintija. With this scenario the current flooding in Pintija should be clarified. In OHIS the focus is on the flooding of the parking lot. It should be queried, if due to the connection of the sanitary sewer (including storm water), the storm sewer of OHIS is surcharged and flooding at the traffic areas in front of the parking lot arises. As a matter of fact, the reason of the flooding is quite hard to figure out due to the lack of the elevation data of the OHIS sewer system. Furthermore, the model is not calibrated and the optimal state of a clean sewer is modelled.

The scenario **"Sanitary Sewer – Designed State"** deals only with the sanitary sewer and checks the capacity of it. It should be checked, if the existing system can handle the current amount of sanitary water in order that no storm water is discharged faultily into the sanitary sewer in Pintija. Due to the lack of information of the amount of waste water in OHIS, only a very rough estimation is used for the waste water discharge in OHIS.

The scenario “**Storm Sewer – Street”** models the streets of Pintija as storm sewer. Actually, it is the current state of the storm sewer of Pintija. OHIS is not included in this scenario. It should be verified, how much surface runoff is produced by the subcatchments and where flooding of the street arises (e.g. due to depression). Further, a focus is on the generation of surface runoff from pervious areas. The storm water is captured in two storage basins located at the road Prvomajska. Thus, the total amount of discharged surface runoff can be discovered easily and could be used for the design of retention basins or combined sewer overflows.

The scenario **“Storm Sewer – Open Channel”** considers an open channel as storm sewer. It is, in a way, a future scenario of the storm sewer. Therefore, the elevations of the nodes in depressions are changed to avoid accumulated storm water. The locations of the flooding in scenario “Storm Sewer – Street” provides the position of these nodes. The big advantage of an open channel is the cost. Digging up and changing a big part of the system or building a complete new storm sewer system underground is much more expensive than constructing an open channel. Further the maintenance and cleaning of the open channel is easier, faster and cheaper. Disposals and waste can be spotted directly and the cleaning and maintenance could be easily done by the public waste collection service, so no specialists are needed. This is one of the big disadvantages of combined systems. As a consequence of bigger diameters the velocity in the sewer pipes is small in dry weather periods due to the little dry weather flow. This causes a higher amount of disposals in sewer pipes. As a result, the system has to be cleaned more often and the maintenance costs rise.

Afterwards, in the scenario **“Open Channel – Future Development”** the effect on the open channel considering the change of the percentage of impervious areas and the connection of additional subcatchment is checked. It should analyse the effect of future developments.

The scenario “Storm Sewer – Open Channel” is also used for the **Sensitivity Analysis**. Primarily, the sensitivity analysis focuses on the surface runoff of pervious areas and therefore the infiltration values are modified until surface runoff from pervious subareas is generated. Afterwards, the three subcatchment properties Manning’s roughness coefficient, slope and depression storage are changed. To check also the sensitivity from the parameters which effect surface runoff from pervious areas, it is important that surface runoff from pervious areas is generated.

5.2.2 Model-setup of basic scenario “Sanitary Sewer – Previous State”

5.2.2.1 Precipitation

As described in chapter 5.1.2.1 on page 37 two different intensities were taken into consideration. To find out which one is significant, the model was run with both $r_{30,n=0.5}$ and $r_{20,n=0.5}$. According to the total flooding of the nodes, the 20 minutes rain with an intensity of 107 l/s*ha and an return period of 2 years ($r_{20,n=0.5}$) has more impact on the runoff and is therefore relevant

In SWMM 5 it is possible to enter the precipitation in three different rain formats (ROSSMANN, 2010, p. 169):

- *“Intensity:* each rainfall value is an average rate in inches/hour (or mm/hour) over the recording interval,
- *Volume:* each rainfall value is the volume of rain that fell in the recording interval (in inches or millimeters),
- *Cumulative:* each rainfall value represents the cumulative rainfall that has occurred since the start of the last series of non-zero values (in inches or millimeters).”

The rain format “Intensity” is used for the models and inserted at the Time Series Editor in steps of five minutes. The unit is mm/h, which means the 107l/s*ha has to be converted (107 l/s*ha = 38.5 mm/h). Figure 56 shows the block rain from SWMM.

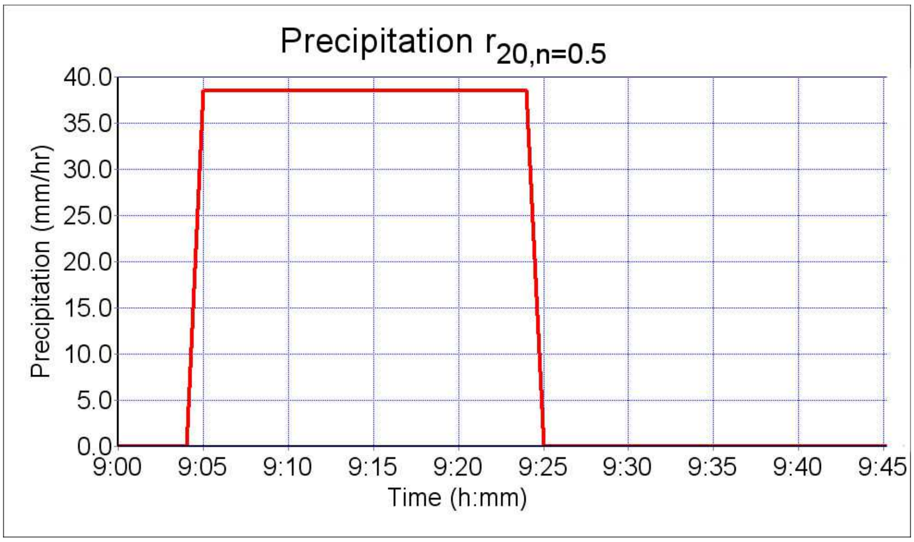


Figure 56: SWMM precipitation diagram for $r_{20,n=0.5}$

5.2.2.2 Subcatchments

In order to divide the catchment area into subcatchments, different geo referenced backdrops (plans, orthophotos) are used in SWMM 5. The big advantage of working with geo referenced backdrops is that the real areas of subcatchments as well as real lengths of conduits are calculated automatically. Therefore the “Auto-length” function in SWMM 5 has to be turned on. Additionally, it is possible to use different backdrops and to export the SWMM 5 data into a geographic information system (GIS). Georeferencing signifies the method of connecting a geodata set with the spatial information of coordinates (NEUMANN, 2010b). Consequently, for using georeferenced backdrops, it is necessary to know the map dimensions of the backdrop. In SWMM 5 the X- and Y-coordinates from the lower left corner and the X- and Y-coordinates of the upper right corner from the backdrop must be known. To define the sewer system in SWMM 5 the sewer system plans of Pintija and OHIS (Appendix B) were used as a backdrop. The sewer system plan of OHIS was imported into the AutoCad file of the sewer system plan of Pintija, to have the whole system in one backdrop. Both had to be georeferenced and spatially adjusted. The plan of Pintija was already oriented but had to be georeferenced and scaled. The coordinates of three different distinctive points (e.g. the corner of a roof) – so called ground control points - were looked up in Google Earth and marked in the AutoCAD file. The drawing of the sewer system of Pintija was scaled and translated until the coordinates of the three points in the plan matched the ground control points. The same was done with the sewer system plan of OHIS, but additionally it had to be rotated like illustrated in Figure 57. In this way the plans were transformed into a coordinated system. As it is not possible to use AutoCAD files as backdrops in SWMM 5, screenshots of sections with known corner coordinates had to be made.

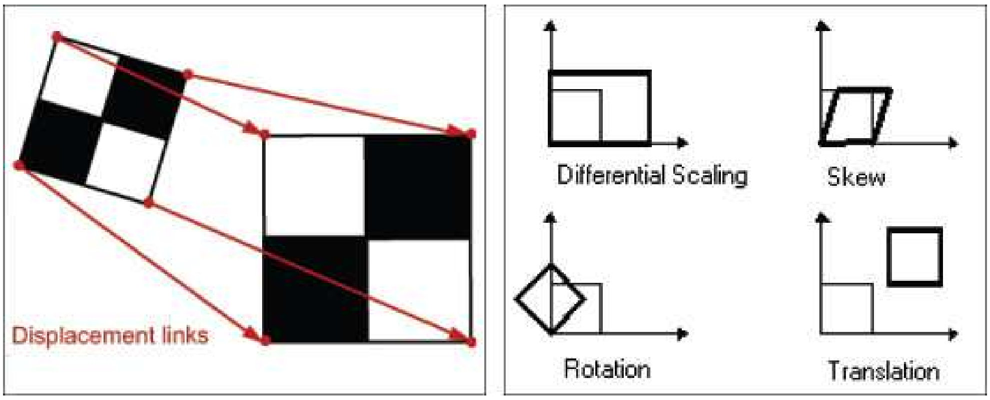


Figure 57: Displacement links connecting two datasets and transformation methods (NEUMANN, 2010b)

The process of transformation is quite easy if modern GIS software is used because an algorithm automatically calculates the transformation process. The user only has to select identical points in a correct dataset and one which needs to adjusted (NEUMANN, 2010b).

All the subcatchment's input parameters and properties needed for the SWMM 5 model are displayed in Figure 58. It is the input mask of the subcatchment properties in SWMM 5. Following the abbreviations, which are not self-explanatory, are explained.

- Width = width of overland flow path (m)
- "% Imperv" = percent of impervious area
- "N-Imperv"/ "N-Perv = Manning's roughness coefficient for impervious/ pervious areas
- "Dstore-Perv / "Dstore-Imperv" = depth of depression storage on impervious/pervious area (mm)
- "%Zero-Imperv" = percent of impervious area with no depression storage

More detailed information to the properties is given bellow.

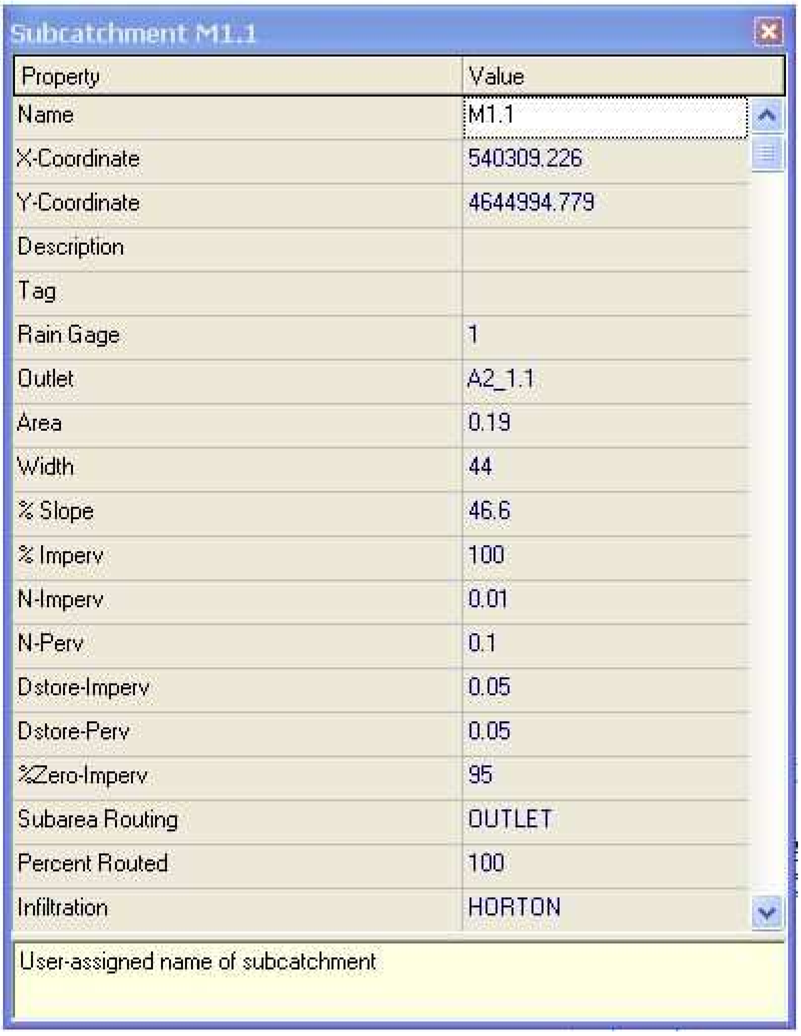


Figure 58: Properties of the subcatchments in SWMM 5

The first property of the input mask is the name of the subcatchment. According to the DUP 2004-2009 of Pintija, the formal settlement is divided into different modules. These modules were used for the creation of the subcatchments of the study area in SWMM 5. The DUP-modules are used, because there is a lot of information in the DUP for these modules for the future. If future scenarios are to be modelled, they have the same basis as scenarios of the current state and comparisons can be made easily. Besides, the models are usefully divided. In Figure 59 a section of the DUP 2004 – 2009 plan within the numbers of the modules is shown. In comparison subcatchments of the SWMM 5 models are pictured in Figure 60.

Figure 59: Modules in the DUP 2004 – 2009 (DUP, 2004)

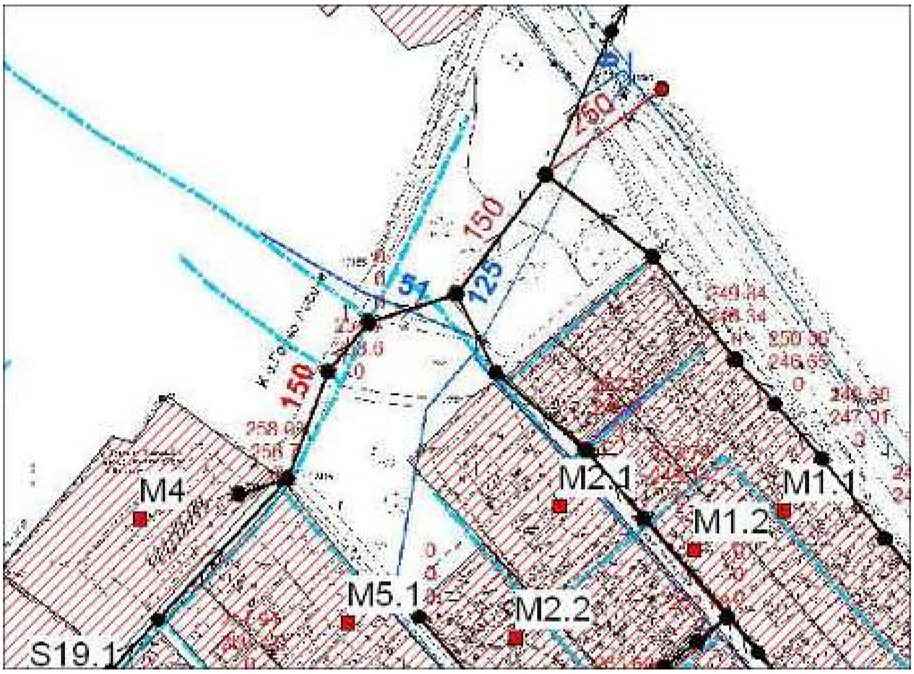


Figure 60: Subcatchments in SWMM 5

The subcatchments equal the modules, although they are divided again into smaller subcatchments. In addition, the labelling of the subcatchment is equal to the DUP plan, only if the modules are divided into smaller ones, they have an ascending second number (e.g. in Figure 60. M1.1 and M1.2.). The only information for defining the subcatchment boarders of the informal settlements was the oral report by N.N. (2012b). The subcatchments of the informal part are labelled with an "S" instead of "M".

The subcatchments can be divided into three different subareas, which affect the surface runoff differently. These subareas and the effects are explained in Figure 61.

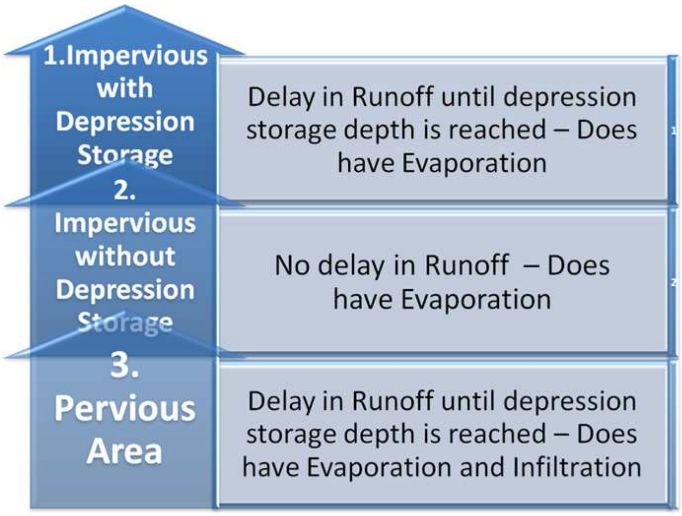


Figure 61: Subcatchment SubArea types (DICKINSON, 2011)

To simplify the model, it is estimated that 50 % of the subcatchments are roof areas and consequently impervious. From the roof area 50 % is discharged faultily into the sewer system. Accordingly, 25 % from the total area are impervious and 25 % of the precipitation is discharged into the sanitary sewer (if no additional surface runoff is generated from impervious areas). This assumption is illustrated in the diagram [Figure 62].

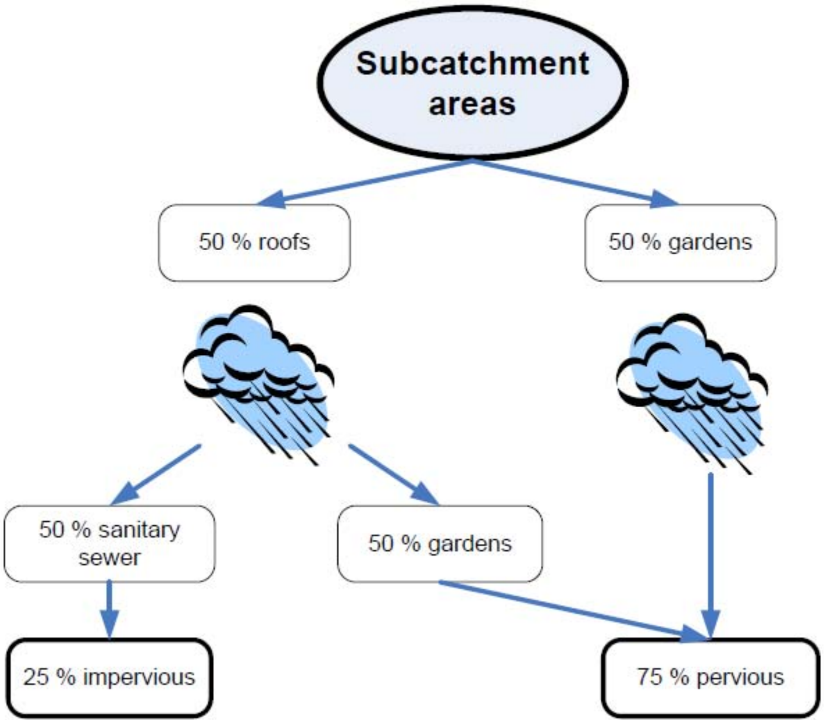


Figure 62: Subdivision of subcatchments and surface runoff in Pintija of the Basic Scenario

By quartering the subcatchment area and setting the value for the "percent of impervious area" to 100 % in SWMM 5 showed that only 25 % of the surface runoff is discharged in to the sanitary sewer system. Another option would be to insert such high infiltration values, that the whole rainfall would be infiltrated and no surface runoff would discharge into the sewer system. It is assumed that the width for the overland flow path is the root of the area. The slope of the impervious areas is 46.6 %, because it is estimated, that the roofs have an average slope of 25°.

For the OHIS premises the percentage of impervious areas is estimated by the ortho photo and the sewer plan of OHIS for every subcatchment. After reducing the subcatchment areas by this percentage, 100 % of the area is impervious. The industrial buildings have flat roofs and the slope is at evaluated 5.2 % (3°). Subcatchments in OHIS are labelled with an “O” at the beginning.

For the other parameters the default value is used, except for the “%Zero Imperv”. Due to the fact, that 100 % of the area is impervious, a high value of 95 % is selected. In the basic scenario the infiltration is not important since there are no pervious areas as a result of quartering the subcatchments areas to have only impervious areas, like explained before. Nevertheless, in other scenarios it has to be considered, and it is discussed in more detail in chapter 5.2.5.

In the Climatology Editor in SWMM, it is possible to insert temperature, evaporation, wind speed, snow melt and areal depletion data. Due to the fact, that no precipitation time series are available, it would be useless to insert time series for the climatology factors. For the master thesis only a constant value for the evaporation is entered. According to the National Hydrometeorological Service the average evaporation rate for the region of Skopje is 2 mm/day.

5.2.2.3 Sewer system

<u>Manholes</u>

In SWMM manholes are created with the drawing option “Junction” and sewer pipes with the option “Conduit”. The input mask of a junction is illustrated in Figure 63.

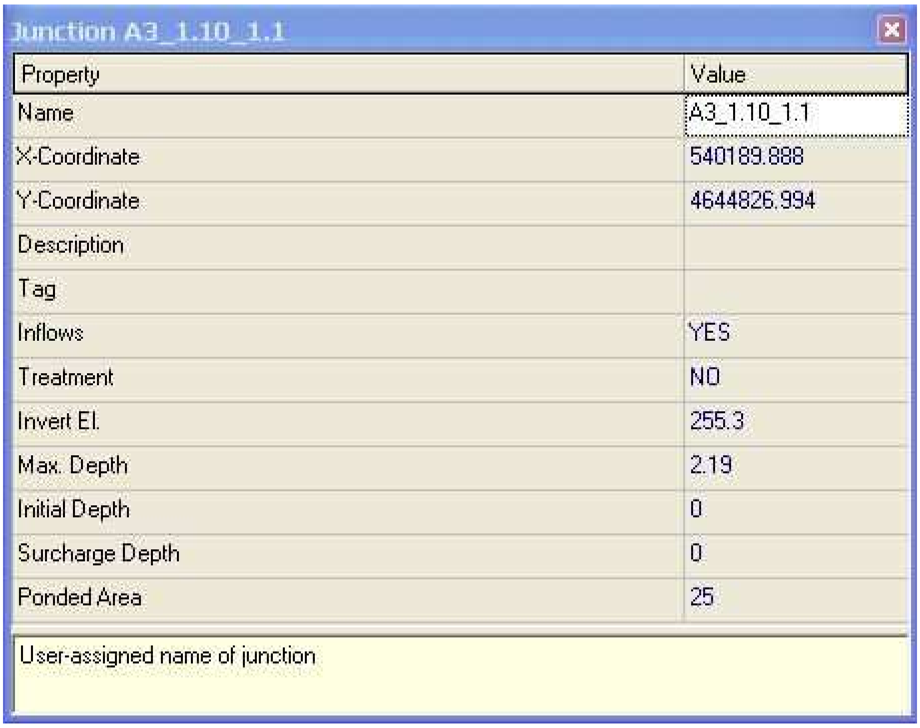


Figure 63: Junction input mask in SWMM 5

The first property is the name of the junction which is discussed in more detail later on. By using the geo-referenced sewer system plan of Pintija and OHIS as backdrop, the manholes could be easily positioned and the X- and Y- coordinate are registered automatically. In the property field “Inflows” the dry weather flow which is calculated later on can be inserted. The data for the invert elevation is taken from the sewer system plan of Pintija. Some elevations are missing and were estimated via the Macedonian online Cadastre (AREC). Also the manholes’ elevations in OHIS and of the informal sewer lines were gauged in this way. The missing maximum depths were estimated via fieldtrip data or assumed by the elevation of neighbouring manholes. All maximum depths of the manholes in OHIS had to be estimated. In Figure 64, the manholes’ surface elevations are shown to illustrate the difference in elevation in the study area. The southern part of the study area is not only high but also quite steep with values up to 9%.

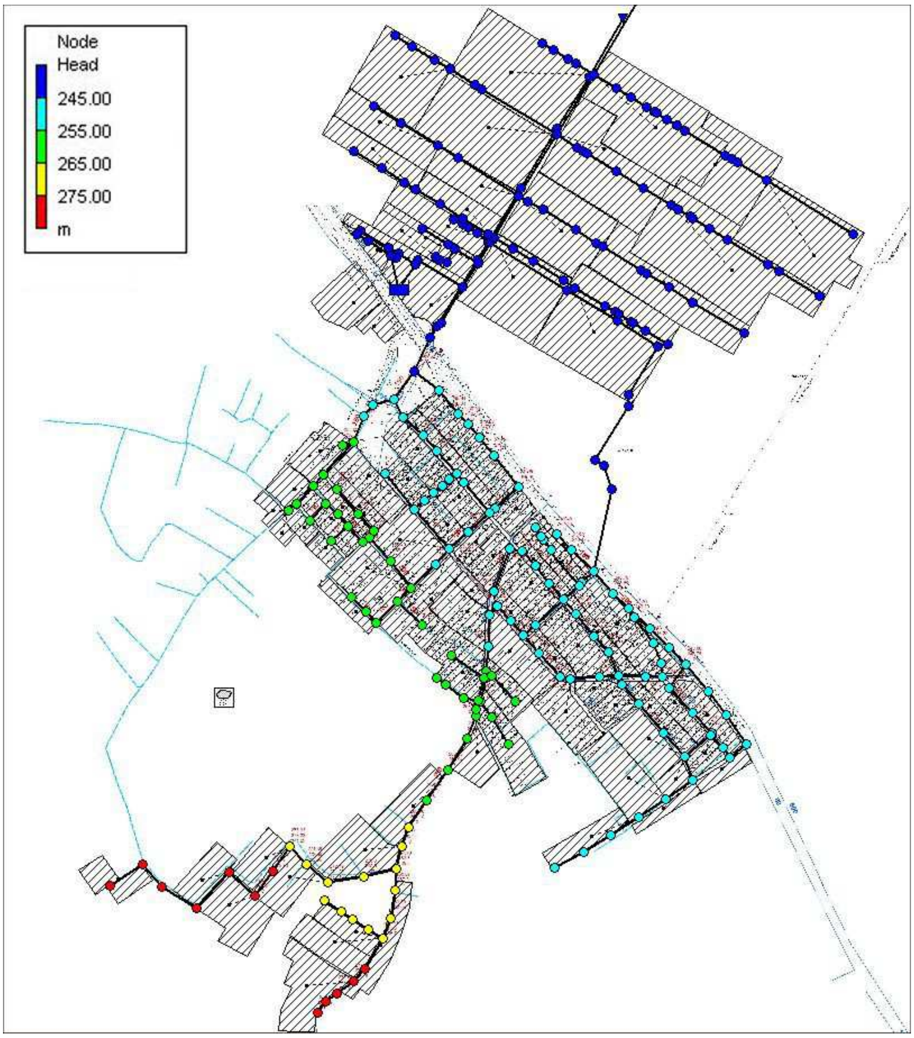


Figure 64: Surface elevation of the manholes in the study area

Another input property is the initial depth. *"It is the depth of water at the junction at the start of the simulation. The surcharge depth is the additional depth of water beyond the maximum depth that is allowed before the junction floods (feet or meters). This parameter can be used to simulate bolted manhole covers or force main connections."*(ROSSMANN, 2010, p. 172). The value for these two parameters is zero.

The last property on the input mask is the "pounded area". In SWMM 5 it can be distinguished between flooding and ponding. "Flooding is the default case where overflows are simply lost from the system and no temporary storage of excess flow appears at the node. Ponding is the case, when overflows are stored at the node until the time, as conditions allow the stored volume to be released. Under this option, overflows are never lost from the system. The size of the ponded area defines how quickly ponded water re-enters the sewer system. (ROSSMAN, 2007) ."*It is a rare situation where the water in real world "ponds" at a node and, unless the node is in a sump or the overflows physically leave the drainage system's watershed, the water leaving the node flows downhill via surface links (gutters, streets, channels, etc.) and connects back somewhere downstream to either reenter the underground conduits or to continue on the surface further downstream. In other words, whenever the underground conduit system's capacity is exceeded, a modeler needs to provide a surface link system that will account for the flows on the surface."* (URBONAS, 2007, p. 2)

Instead of providing a surface link system in the basic scenario, it was decided to look at the surface runoff on its own in the scenario "Storm Sewer – Street" hence a surface link system would not be possible to model in the extent of this thesis. Further, in the basic scenario ponding is only taken into consideration at manholes, which are located in a sump. For the property "Ponded Area" the value of 25 m² is assumed.

In the flooding section of the SWMM 5 status report also nodes which are surcharged are listed but as they are not flooded the "total flood volume" is zero in the list. The difference in flooding and surcharging is shown in Figure 65. A manhole is surcharged when the water level in the manhole is higher than the elevation of the highest connecting link crown.

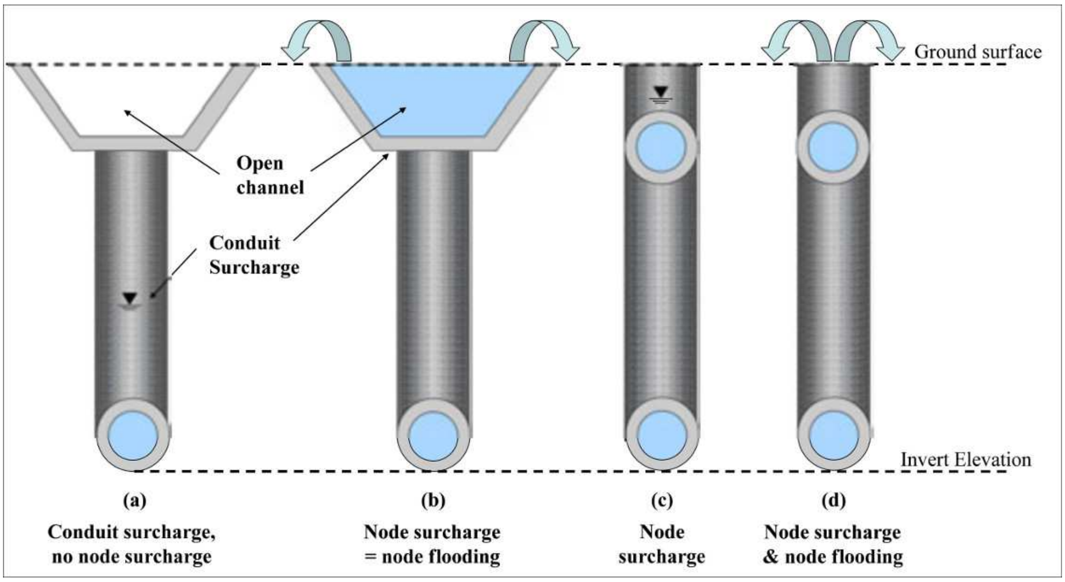


Figure 65: Examples of surcharge and flooding (GRIONÁS et al., 2009)

Dry weather inflow

In SWMM 5 the so-called dry weather inflow is the waste water flow and can be inserted at the manholes. Consequently, an average value for every manhole is calculated. As in sub item 5.1.2.4 on page 41 stated, 401 m³ water/day is supplied. It is assumed, that the amount of water supplied is the same as the amount of waste water discharged into the sanitary sewer. In the formal part of Pintija and in the informal part, which is also supplied with water, 119 manholes exist. To take the peak water flow into account the factor 1/12 is used, because Pintija is a suburb of Skopje and will not have such intense fluctuation like a small village far away from a big city.

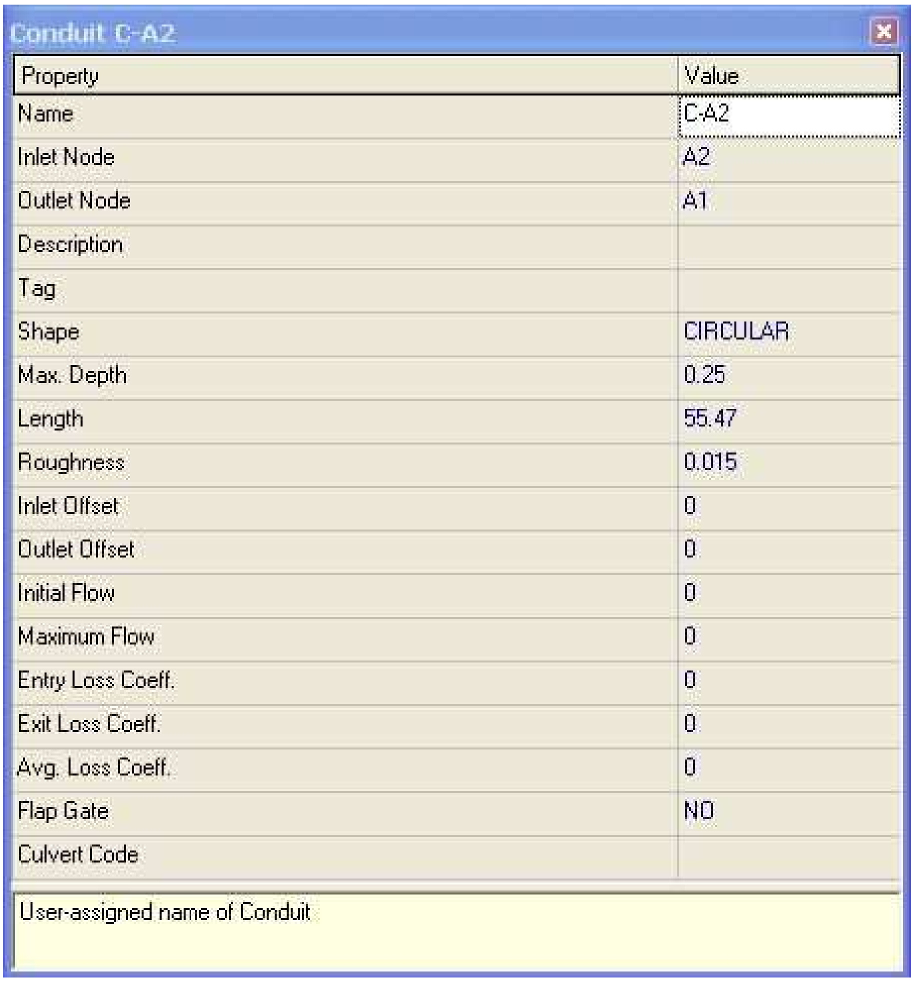
$$\frac{401\, m^3/day}{119\, manholes} = 3.37 \frac{m^3}{manhole\ \cdot day}$$

$$3.37\ \frac{m^3}{manhole \cdot\ day} = 3.37\ \frac{10^3\, l}{12 \cdot 3600\, s} = 0.08\ \frac{l}{manhole \cdot s}$$

The ÖWAV Rule Sheet 11 suggests a value of 4 l/s*1000 residents. Would the sanitary dry weather flow be calculated per resident (with estimated 1700 people living in the formal part of Pintija) instead of manhole, than 5.5 l/s*1000 residents would be the peak dry weather flow. This reflects the information from the JICA (2009) that due to the flat rate of the water tariff, costumers do not save water. The value of 0.08 l/manhole*s is also used for the manholes of the sanitary sewer system in OHIS since nothing is known about the amount of the water supplied in OHIS nor the number of people working there. In SWMM 5 the value is inserted at the dry weather flow of the external flow option of every node.

<u>Sewer pipes</u>

In Figure 66 the input mask of the conduits in SWMM is shown and the properties will to be explained in the following.



Conduit C-A2

Property	Value
Name	C-A2
Inlet Node	A2
Outlet Node	A1
Description	
Tag	
Shape	CIRCULAR
Max. Depth	0.25
Length	55.47
Roughness	0.015
Inlet Offset	0
Outlet Offset	0
Initial Flow	0
Maximum Flow	0
Entry Loss Coeff.	0
Exit Loss Coeff.	0
Avg. Loss Coeff.	0
Flap Gate	NO
Culvert Code	

User-assigned name of Conduit

Figure 66: Properties of the conduits in SWMM 5

The first three fields deal with the names of the pipe and the inlet and outlet node. The system of naming the conduits will also be explained in the follwing. The shape of every pipe in the basic scenario is circular. Some of the missing pipe diameters could be found in the plan of the DUP 2004-2009, because the existing sewer network is also illustrated in it. The other unavailable diameters were evaluated by the existing diameter information of the previous or following conduits. In Figure 67, the diameters of the system are demonstrated. Already at the setup of the model it become clear, that there are some bottlenecks due to the change from bigger to smaller diameters. By connecting the manholes with conduits using the “Auto-Length” function, the length is automatically calculated by SWMM 5.

“SWMM uses the Manning equation to express the relationship between flow rate (Q), cross-sectional area (A), hydraulic radius (R), and slope (S) in all conduits.” (ROSSMANN, 2010, p. 39)

$$Q = \frac{1.49}{n} \cdot A \cdot R^{\frac{2}{3}} \cdot S^{\frac{1}{2}} \qquad (1)$$

The parameter *n* is the Manning roughness coefficient and depends on the type of the conduits (opened or closed) and of the material. In Pintija, most pipes are concrete pipes, only the new pipes in the informal part are PVC. In OHIS, concrete pipes are used as well. Due to the fact that the sewer system includes manholes, inlets etc. the roughness is higher. The value of 0.015 is chosen for the whole study area. (N.N., 2006)

There is no need to consider the rest of the parameters and the default value of zero is used.

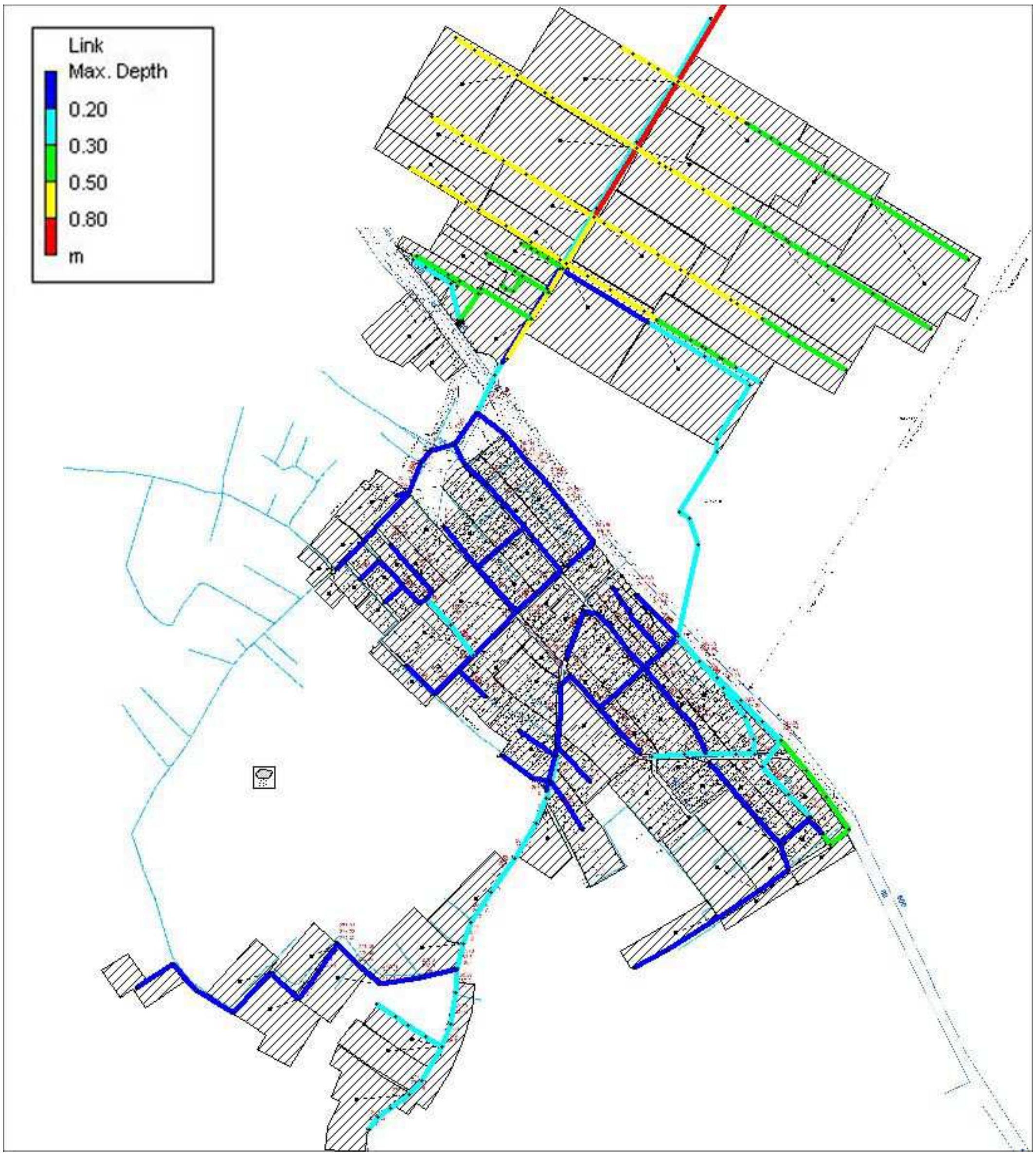


Figure 67: Diameter of the sewer pipes in the study area

Numbering System

As already mentioned, the numbering system is explained in this part of the thesis to simplify the understanding of the model setup for later users of the model and prevent long searching and browsing periods reading the thesis and working with the model.

No guidelines dealing with the labelling of manholes and sewer pipes exist in the EU. In general, a numbering system is the basis for a database. A systematic numbering will permanently affect the operation and maintenance of the sewer system. Pintija is divided into two different parts for the labelling, on the basis of the two different connections to OHIS. The west connection is called “Connection A” and the eastern one “Connection B”. Accordingly, all manholes and sewer pipes which convey the waste water to “Connection A” start with “A” and are marked red in Figure 68. In the same way, all connections discharging to “Connection B” start with a “B”, and are marked blue in Figure 68. By including the designations A and B in the ID, workers can quickly locate the general area where the manhole or the conduit is situated.

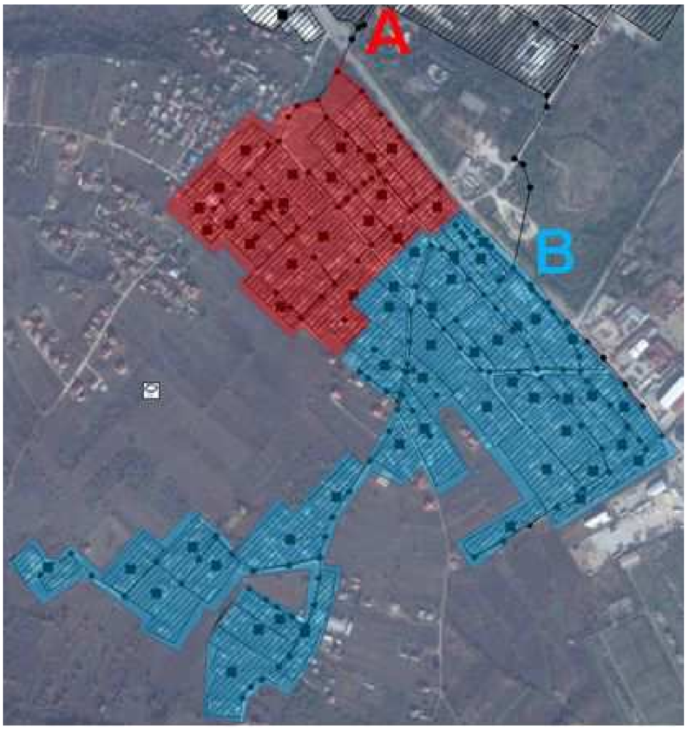


Figure 68: Connections to OHIS (Google Earth, modified by Havinga, 2012)

The numbering system is made according to a branching system. The main sewer line is the trunk and the lines connected to the manholes of the trunk are the branches. The manholes of the “trunk” get the letter of the connection (A or B) plus a number rising upwards. That means the higher the number, the farer away the manhole is located from the connection. Often the flow direction is important to know and accordingly which manhole is located downstream or upstream As the system gets further away from the outlet the increasing numbers can give workers immediate guidance on direction of flow and where to look for the manholes and pipes in the area (US EPA, 2012). Every manhole of a “branch” sewer line, which connects to a manhole of the”trunk” sewer line, starts with its number and additionally two numbers are added. The first one is the number of the “branch” sewer line and the other one the number of the manhole. Examples for the numbering system are stated below.

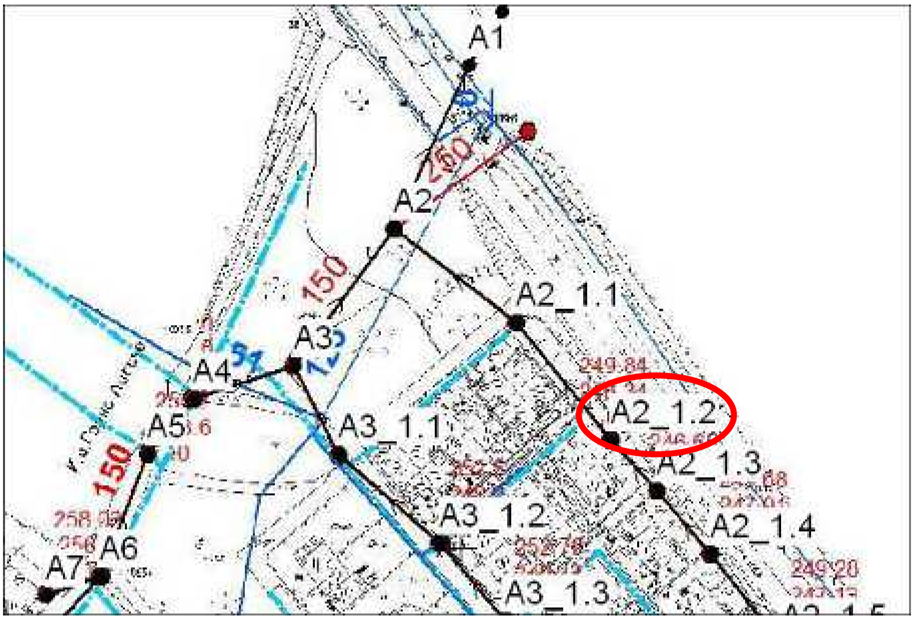


Figure 69: Labelling of the manholes

E.g.: The following ID is from the second manhole in the first sewer line (“branch”), which is connected to the main sewer line (“trunk”)

Manhole ID at the main sewer line

A2_1.2 → 2^{nd} manhole in the 1^{st} sewer line connected to the manhole A2

→ 1^{st} sewer line connected to manhole A2

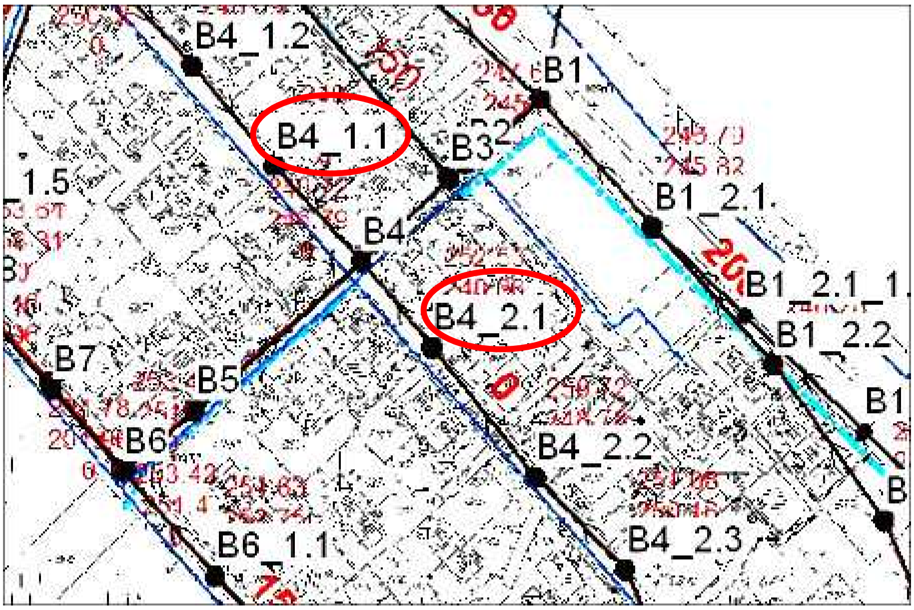


Figure 70: Labelling of manholes

B4_1.1 → 1^{st} manhole in the 1^{st} sewer line connected to manhole B4

B4_2.1 → 1^{st} manhole in the 2^{nd} sewer line, connected to manhole B4

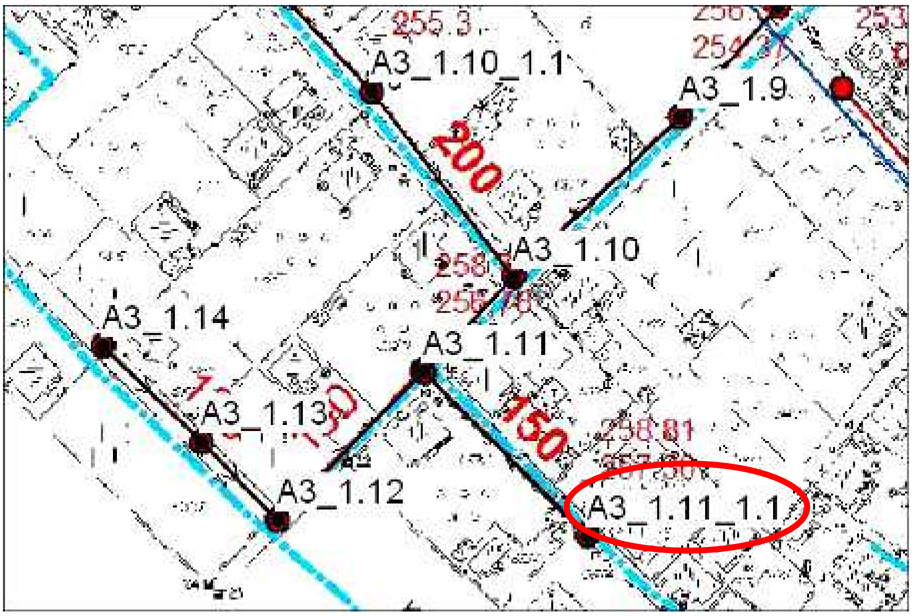


Figure 71: Labelling of manholes

A3_1.11_1.1 → 1^{st} manhole in the 1^{st} sewer line connected to manhole A3_1.1

This system allows adding new sewer lines and continuing the labelling without changing to existing numbers. Pintija is a quickly developing settlement and it is very important to have a labelling system which is easily expandable. Only if new manholes areto be constructed in existing lines, they have to be given for example lowercase letters or additional numbers to be able to keep the existing numeration. Further, this could also be necessary if manholes are being buried under easements or “missing” because of paving. Nevertheless, a change of using uppercase and lower case letters can increase the potential for errors particularly at data entry. In addition, no spaces between the characters should be used either and dashes or hyphens should be avoided (US EPA, 2012). For better clarity, the latter was not applied at numbering the sewer system of the thesis. As suggested by the US EPA (2012) the numbering could begin with 110 and continue by 10s (e.g. 120, 130 …). If a new manhole has to be labelled between 120 and 130 it can be assigned the number 121 and thus, be logically incorporated into the existing numbering system.

In OHIS, the manholes of the storm sewer are labelled “O_SS_number”. “O” stands for OHIS and “SS” for storm sewer. The manholes of the sanitary sewer have the abbreviation “FS” because sanitary sewers are also called foul sewers and otherwise the abbreviation would be again “SS”. The number rises from the connection from Pintija to the outlet. The outlet is called “out_SS”. In the manhole IDs of the sanitary sewer system again the name of the connection is included. The numbers rise from the connection (A or B) to the direction of the outfall as seen in the example bellow:

O_FS-A_2 ⟶ 2nd manhole of the sanitary sewer line from connection “A” to the outlet

O_FS-B_8 ⟶ 8th manhole of the sanitary sewer line from connection “B” to the outlet

For the IDs of the sewer conduits the IDs of the inlet manhole include a “C” for conduit at the beginning.

5.2.2.4 SWMM 5 model summary

Summing up, the SWMM 5 model contains 88 subcatchments with a total area of 72 ha. The subcatchments of Pintija have a total area of about 44 ha and the subcatchments of OHIS of about 28 ha. The model exists of 261 manholes and 266 conduits. The whole sewer system has a total length of 10.6 km.

5.2.3 Model-setup of scenario “Sanitary Sewer - Current State”

5.2.3.1 Changes to the basic scenario

Subcatchments

No changes are made.

Sewer System

The bypasses are constructed and some sanitary sewer reaches after the bypasses are deleted to prevent discharge into the sanitary sewer.

5.2.4 Model-setup of scenario “Sanitary Sewer – Designed State”

5.2.4.1 Changes to the basic scenario

<u>Subcatchments</u>

To avoid surface runoff discharging into the sanitary sewer system from the subcatchments, the precipitation inserted into the Time Series in SWMM 5 is deleted. This simulates the condition when no rain is falling and only waste water flow is conveyed in the sewer system. Another option would have been to delete all the subcatchments.

<u>Sewer System</u>

For the scenario “Sanitary Sewer – Designed State” the sewer system of the basic scenario is maintained whereas no storm water is discharged informally into it. Strictly speaking, a little amount of storm water is included, because extraneous water is contained in the model. The extraneous water includes the unwanted infiltration water from leaking sewer pipes and the storm water from unavoidable faulty connections. Therefore, the waste water discharge is doubled and instead of 0.08 l/s*manhole dry weather inflow, the amount of 0.16 l/s*manhole is inserted in the model. In OHIS, no information about the number of workers or the water demand is available. Due to this fact, it is very difficult to estimate the amount of waste water discharge there. Further, the sanitary sewer system is reduced to the main collector in the model. It is assumed that at every manhole four times more waste water is discharged into the system. Accordingly, 0.64l/manhole*s dry weather flow is inserted at the few manholes of the main sanitary collector in OHIS.

5.2.5 Model-setup of scenario “Storm Sewer - Street”

5.2.5.1 Changes to the basic scenario

<u>Subcatchments</u>

As already mentioned, the study area of Pintija has an average slope of 5 %. Compared to the basic scenario, were the roof slope is representative, in the two “Storm Sewer” scenarios also the slope of the pervious areas are taken into consideration. In SWMM 5 it is unfortunately not possible to insert different slopes for pervious and impervious areas. As a result of the estimation, that 50% are houses and 50% are gardens, the mean of the two corresponding slopes are used for the subcatchment. The slope used for both “Storm Sewer” scenarios is 25.8 %.

The basic estimation, that 50 % of the subcatchments are houses and the other 50 % are gardens is maintained. However, the surface runoff is discharged onto the street and not into the sanitary sewer [Figure 72]. Furthermore, the percentage of impervious area with no depression storage is set back to the default value of 25 %. In SWMM 5 the areas are not reduced by the percentage of the imperviousness like in the basic scenario, since in this scenario it is important to know if the pervious areas also generate surface runoff.

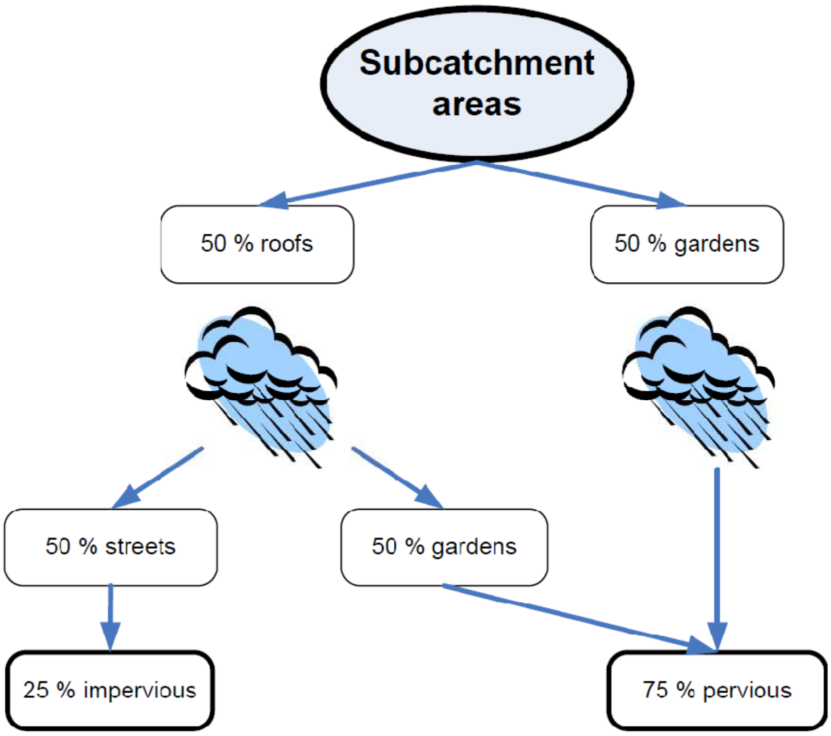


Figure 72: Subdivision of subcatchments and surface runoff in Pintija of scenario “Storm Sewer –Street”

Infiltration:

The process of infiltration provides the largest portion of rainfall losses in pervious areas. Depending on the rainfall intensity and the moist value of the soil the infiltration capacity allows the total infiltration of the rainfall, or surface runoff is generated. Infiltration arises until the soil is saturated or if the underlying soil is much more compact than the top layer and therefore cannot discharge the water infiltrated from the surface layer. On the contrary, it might happen that surface runoff is generated because the infiltration capacity of the surface layer is surpassed though the underlying soil might still be able to infiltrate water even if it is dry (PITT & LANTRIP, 1999). AKAN & HOUGHTALEN (2003) also state that the infiltration rates depend on the surface as well as the subsurface conditions. They suggest that a credible infiltration capacity model should take into account the initial moisture conditions of the soil and the amount of water that has already infiltrated into the soil after rainfall has begun. According to PITT & LANTRIP (1999) also many other factors affect the entry rate of the water such as texture and structure of the soil, root development, soil insects and animal bore holes as well as presence of organic matter. The presence of thin layers of silt and clay particles at the surface can cause a surface seal that would decrease the infiltration rate. In addition, the effect on sandy soils due to compaction is very high, reducing the rates by between 5 and 10 times. *“The classical assumption is that the infiltration capacity of a soil is highest at the very beginning of a storm and decreases with time.”* (WILLEKE, 1966 as cited in (PITT & LANTRIP, 1999, p. 3))

In SWMM three different models can be used to describe the infiltration of rainfall from the previous area of a subcatchment into the unsaturated upper soil zone (ROSSMANN, 2010):

- Horton infiltration
- Green-Ampt infiltration
- Curve Number infiltration.

According to PITT and LANTRIP (1999) the Horton Method is one of the oldest and most widely used infiltration equations used. It is selected for the SWMM 5 model of the thesis. This approach works with an exponential decay function which is based on experimental data as

$$f_p = f_f + (f_0 - f_f)e^{-kt} \quad (2)$$

where

$$f_p = infiltration\ capacity$$

$$f_f = final\ infiltration\ capacity$$

$$f_0 = initial\ infiltration\ capacity$$

$$k = exponitnial\ decay\ constant$$

$$t = time\ from\ beginning\ of\ rainfall.$$

(AKAN & HOUGHTALEN, 2003)

“This equation assumes that the rainfall intensity is greater than the infiltration capacity at all times and that the infiltration rate decreases with time. … The Horton equation’s major drawback is that it does not consider the soil storage availability after varying amounts of infiltration have occurred, but only considers infiltration as a function of time.” (BEDIENT and HUBER, 1992; AKAN, 1993) as cited in (PITT & LANTRIP, 1999, p. 3))

Normally the three parameters f_0, f_f and k should be determined by fitting the Horton equation to measured infiltration data (AKAN & HOUGHTALEN, 2003). This cannot be done as it was not possible to make infiltration rate measurements in Pintija. Nevertheless, a soil sample was taken (the texture is displayed in Figure 73) and examined in Austria. The grain size distribution (Figure 74) and the coefficient of permeability were determined in the geotechnical laboratory of the Engineering College (HTL) Saalfelden, Austria. In conformity with the Austrian standard ÖNORM B4422-1 (1992) it is medium permeable, slight silty sandy gravel with a permeability factor of $5*10^{-5}$ m/s. This factor could represent the initial infiltration capacity of the Horton equation.

Figure 73: Texture of the soil in the study area

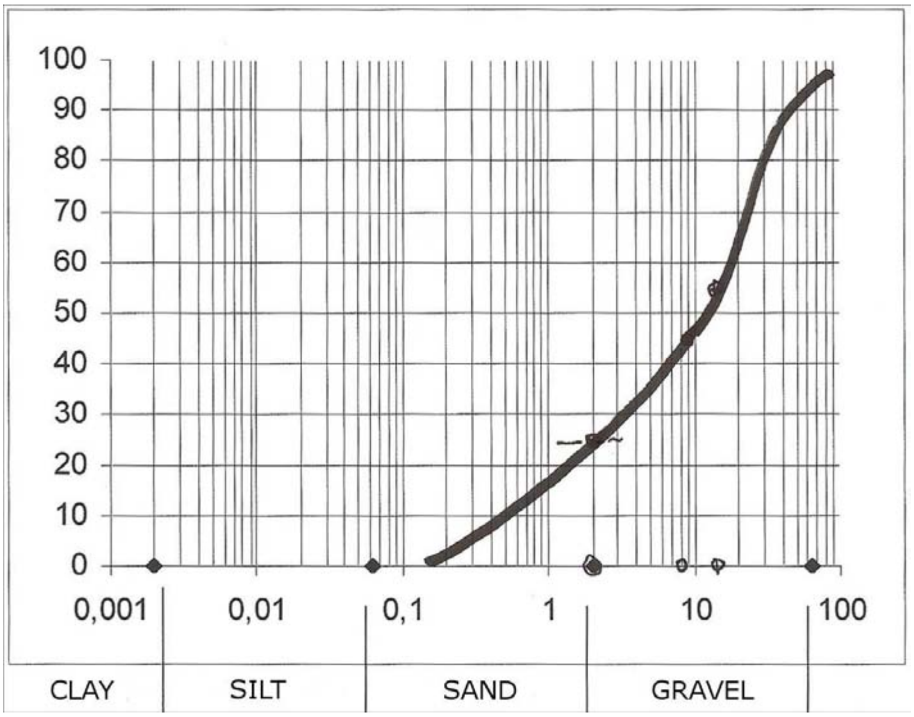


Figure 74: Grain size distribution curve according to ÖNORM B 4400 (1987)

In Table 9 values for the Horton parameter are listed. The highlighted values are used for the models of Scenario 2.

Table 9: Horton parameters Scenario "Storm Sewer – Street"

Source	**Soil description**	**f_0 [mm/h]**	**f_f [mm/h]**	**k [1/h]**
Soil sample/ permeability test	slight silty sandy gravel	180		
AKAN & HOUGHTALEN (2003)	Sand, loamy sand, sandy loam, bluegrass turf vegetation	254	25,4	2

For the two scenarios dealing with the storm sewer an initial infiltration capacity f_0 of 180 mm/h is used. According to the information above, sand soils are affected mostly by compaction. Consequently, the 180 mm/h is used and not 254 mm/h. For the final infiltration capacity f_f and the decay factor k values from literature are taken since it was not possible to detect them from the soil sample. In Figure 75, the Horton infiltration curve for the chosen Horton parameters is illustrated.

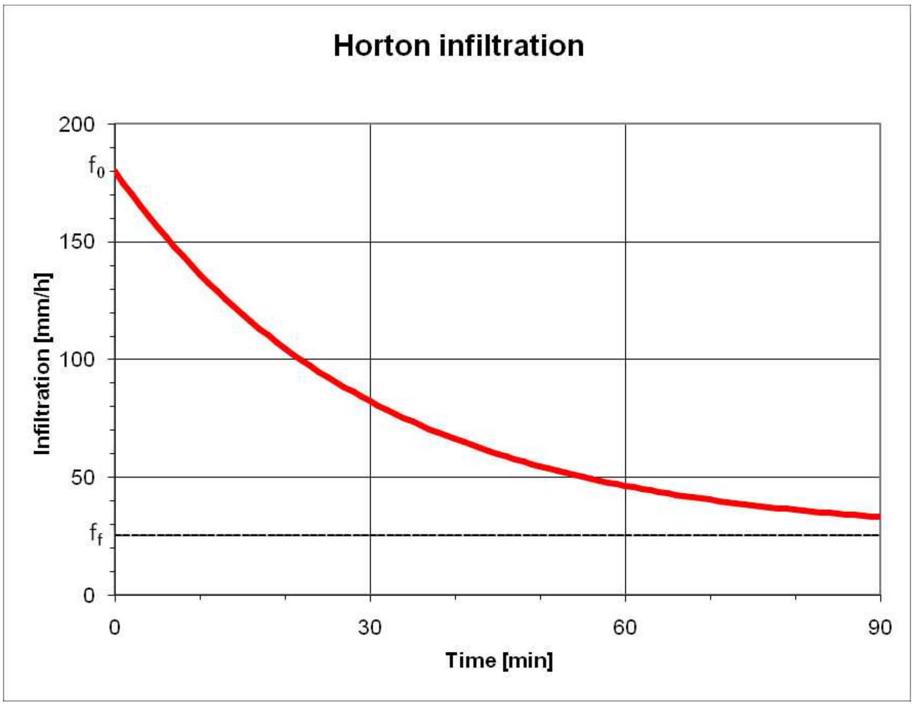


Figure 75: Horton infiltration “Storm Sewer Scenarios”

<u>Sewer System</u>

In this scenario only Pintija is part of the SWMM model, because the focus is turned to the surface runoff on the streets of Pintija. Therefore, the pipes are modified to open channels in the shape of the street cross section. To keep the model simple, it is estimated, that all streets have a width of 5.00 m and the curb a height of 0.15 m. Furthermore, the invert elevations of the manholes have to be changed to the ground level. Instead of the connection to OHIS, two storage units are created. Due to the ground levels at connection B, a basin is located at the road Prvomajska connected to manhole B1_2.1, since it is the lowest point of the depression positioned in this area. With the shape of the storage unit this basin is simulated on the street. In SWMM 5 the shape is generated by a storage curve, where the input date is the depth and the area belonging to the depth. For the storage units a depth of 1.0 m and an area of 1000 m² are inserted. The basin on the road Prvomajska is assumed to be 10 m wide and 100 m long. For the Manning’s roughness coefficient the value 0.020 is selected. The value for constructed channels with rough asphalt is 0.016 and for gravel bottom with sides of cornet 0.020 (CHOW, 1959 as cited in (N.N., 2006)). Due to the fact, that the streets have a lot of imperfections and no asphalt covers in some parts the higher value is chosen. In Scenario “Storm Sewer – Street” no “Ponded Area” is used in SWMM 5. Further, some additional conduits are constructed to adapt the water flow on the streets more to reality. Hence, the manholes A2_1.7 and A3_1.6 as well as B1_2.1_1.9_1.1 and B1_2.1_1.4_1.4 are connected.

5.2.6 Model-setup of scenario “Storm Sewer – Open Channel”

5.2.6.1 Changes to scenario “Storm Sewer – Street”

Subcatchments

The same subdivision of the impervious and pervious areas as shown in Figure 72 on page 75 is applied for this scenario. In comparison, the surface runoff is not discharged onto the street but into the open channel. In comparison to the Scenario “Storm Sewer – Street” in this scenario OHIS is part of the model.

Sewer System

In this scenario the surface runoff in Pintija is discharged into an open channel. To estimate the necessary dimensions of the open channel the cross section was calculated roughly from the maximal inflow at junction A2 (132 l/s) and the maximal velocity (0.7 l/s). The required cross section should be about 0.19 m³.Of course, in upper parts of the study area smaller cross sections would be sufficient but due to all the rough estimations of variables in the model only one cross section is selected. A precast sewer lining (60x40x45 cm) with a cross section area of 0.23 m³ from Rohloff, a German concrete factory, is selected [Figure 76]. The Manning’s roughness coefficient 0.017 is chosen. It is the value for finished concrete constructed channels with gravel on the bottom (CHOW, 1959 as cited in (N.N., 2006)), to take disposals into account. Exceptions are the conduits between the junctions A1 and A4, where the storm water is conveyed in circular pipes with a diameter of 0.5 m underground. Between junction A1 and A2 the open channel would have to cross the road Prvomajska underground anyway and between the junctions A2 and A4 there is steep terrain. The diameters of the sanitary sewer system are assumed.

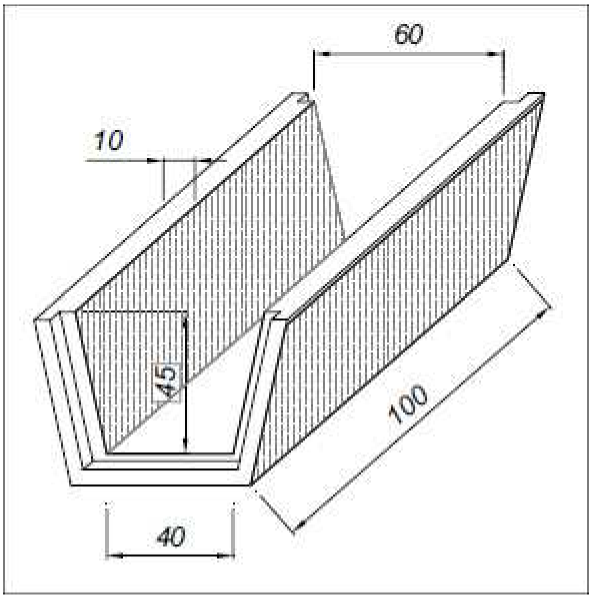


Figure 76: Shape of the open channel (ROHLOFF BETONSTEINWERK GmbH, 2011)

In addition, the connection to OHIS is changed. Only the western part will still be connected to OHIS (connection A) and the storm water is conveyed to the outfall in OHIS. For the eastern part, two new outfalls are constructed. To guarantee the conveyance of the storm water to these outfalls and to the connection to OHIS the system in Pintija is slightly changed to avoid depression storage in the open channel. The location of these modifications of the sewer system as well as the subdivision of Pintija’s subcatchments is shown in Figure 77. The yellow lines display the sewer lines, where the elevation of the junctions had to be corrected. The storm water from the turquoise colored catchment area is discharged to the storm sewer system of OHIS. Therefore, the sewer line at the Prvomajska Road was adjusted in this area. The storm water from the red and green catchment area is to be conveyed to the receiving water, which is displayed in blue. It is a small brook, which discharges into the river Vardar. Two outfalls are necessary, because at the border between the red and the green area on the road Prvomajska an up-station is located. At this point, the sewer line was disconnected. The outfall of the red catchment area (red arrow, outfall west) is connected to the junction at the depression of the road Pvromajska. At the eastern border of the green catchment area the road Prvomajska is declining and the outfall (green arrow, outfall east) is connected to the last and therefore lowest junction. The yellow line on the eastern side of the green catchment area pictures one of the newly made connections.

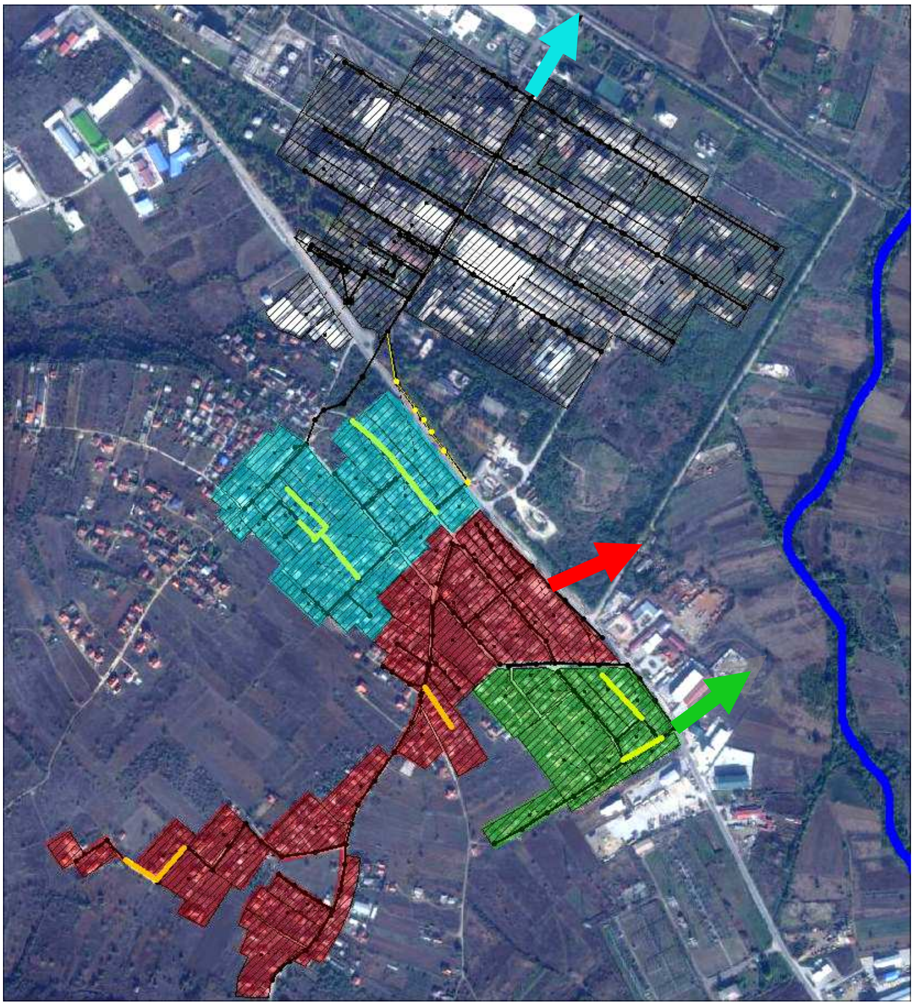


Figure 77: Subdivision of the catchment Pintija, changes of the sewer system (yellow lines) and catchment outfalls (arrows)

5.2.7 Model-setup of scenario “Open Channel – Future Development”

5.2.7.1 Change of percentage of impervious area

Additional surface runoff into the open channel due to sealed areas in the gardens [Figure 78] is considered. It is assumed that 20 % of the garden area is impervious. In total, 35 % of the subcatchments are impervious.

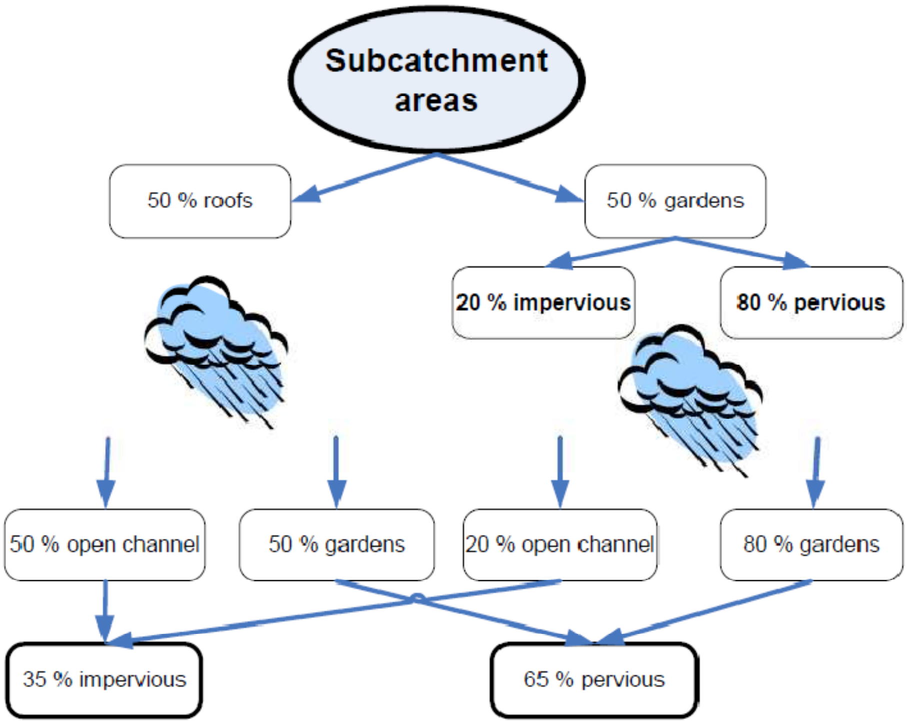


Figure 78: Subdivision of subcatchments and surface runoff in Pintija of scenario “Storm Sewer – Open Channel” with changed percentage of pervious areas

5.2.7.2 Additional subcatchments

Since there is the plan of the municipality to connect the informal part of Pintija to the sewer system as soon as it is affordable, the capacity of the open channel is checked. Pintija is a fast growing settlement especially in the informal part as shown in Figure 79. The red lines point out the area in which most building activity took place in the last decade. Comparing aerial photos from 2002 and 2011 it became clear, that roughly 100 houses were built in the last 9 years. Consequently, about 400 more people will settle in Pintija every 10 years. According to the oral information of N.N. (2012b) even more people will build their houses in the informal part due to the newly constructed water supply system.

Figure 79: Comparison of the orthophoto from Pintija from 2002 (left) and 2011 (right) (Google Earth, modified by Havinga, 2013)

The basic assumption that the subcatchments consists of 50 % houses and 50 % gardens is relatively high for the informal part, which is already connected to the sewer system. Therefore, only slight expansions of subcatchments for future developments are made in this part. The informal part on the western side of Pintija is not connected to the sanitary sewer system. New subcatchments are created for this area and connected to the open channel of the modified scenario “Storm Sewer – Open Channel”. These new subcatchments include parts, where houses have already been built or will be build in near future due to the planned water supply system, which is part of the sewer system plan of Pintija. The locations of the additional subcatchments are illustrated in red in Figure 80.

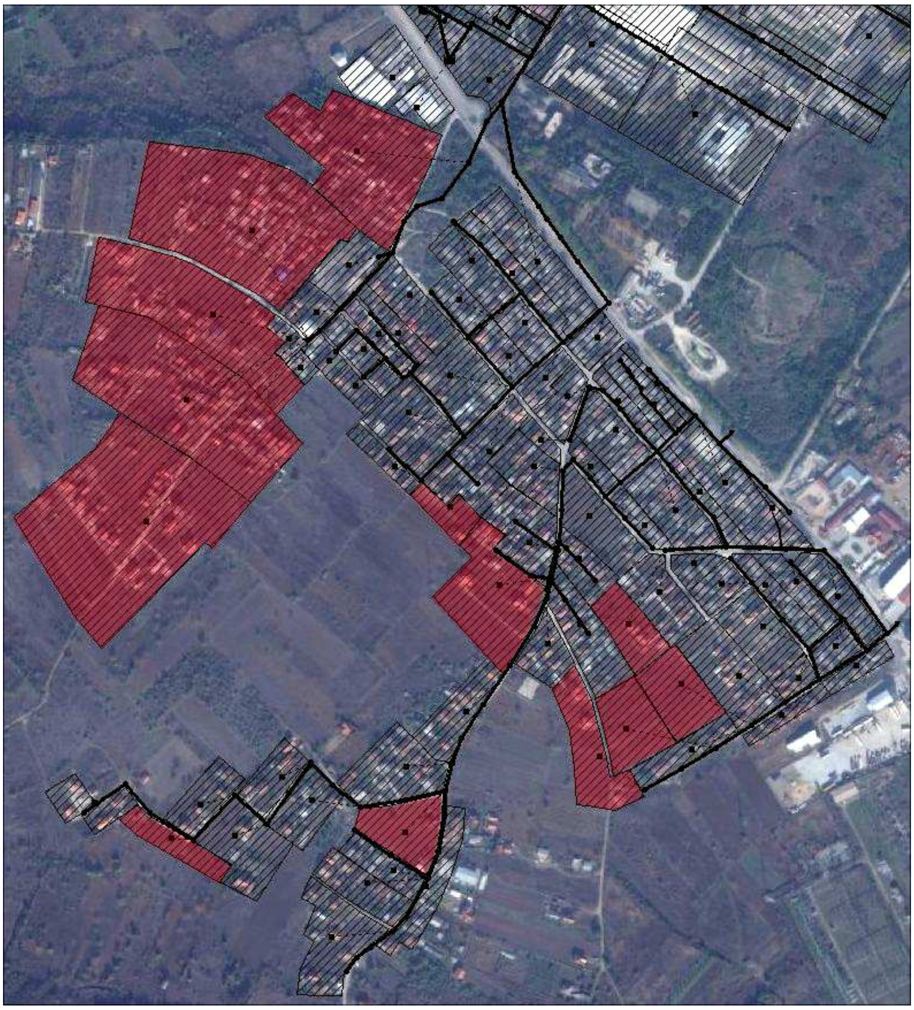


Figure 80: Additional subcatchments modified Scenario “Storm Sewer – Open Channel”

5.2.8 Sensitivity analysis

Primarily, the sensitivity analysis focuses on the surface runoff. Afterwards, subcatchment properties such as the Horton infiltration values, the Manning roughness coefficient, the slope and the depression storage are changed. As already mentioned and showed in Figure 61 on page 65, subcatchments have three different subareas. One is the pervious subarea and the other the impervious area which is itself divided into two subareas – one that includes depression storage and another that does not. Both of them have losses due to evaporation, the pervious areas, in addition, lose surface water through infiltration. The depression storage works like a reservoir, which includes ponding, surface wetting and interception. Surface runoff is only generated if the depth of the water from precipitation exceeds the maximum storage depth d_p as illustrated in Figure 81. When surface runoff occurs, the outflow of this “reservoir” is calculated by Manning’s equation and the depth d is continuously updated with time (in seconds) by numerically solving a water balance equation over the subcatchment. (ROSSMANN, 2010).

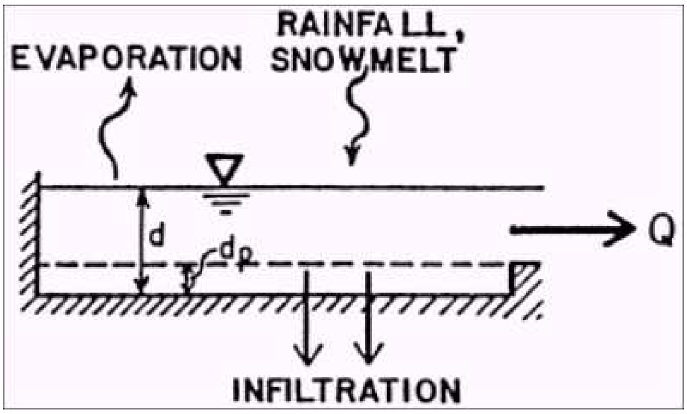


Figure 81: Conceptual view of surface runoff (ROSSMANN, 2010)

Horton Infiltration Values

For the sensitivity analysis, the Horton infiltration values are changed until significant changes in the surface runoff from pervious areas can be distinguished. In the first step, values from the moist sandy soil are applied. In Table 10, also the default values of the "Storm Sewer Scenarios" are listed again (to first lines) for the purpose of a better comparison.

Table 10: Horton parameters Scenarios "Storm sewers" and Sensitivity Analysis

Source	Soil description	f_0 [mm/h]	f_f [mm/h]	k [1/h]
Soil sample/ permeability test	slight silty sandy gravel	180		
AKAN & HOUGHTALEN (2003)	Sand, loamy sand, sandy loam, bluegrass turf vegetation	254	25,4	2
AKAN (1993a); AKAN (1993b)	Moist sandy soils with dense vegetation	84	7,6 – 11,4*	4.14**

* The mean value of 9.5 mm/h is used in the model

** If no field data is available an estimate of 4.14/h could be used (AKAN, 1993c)

In Figure 82, the Horton infiltration curve for a moist sandy soil with dense vegetation is illustrated. Comparing the Horton infiltration curve of the previous values in Figure 75 on page 78 it can be seen, that the decay factor shapes the curve. If it decreases, the infiltration values decrease more slowly and the curve is smoother. Consequently, the final infiltration capacity f_f is reached in Figure 82 after about 80 minutes and in Figure 75 not even after 90 minutes.

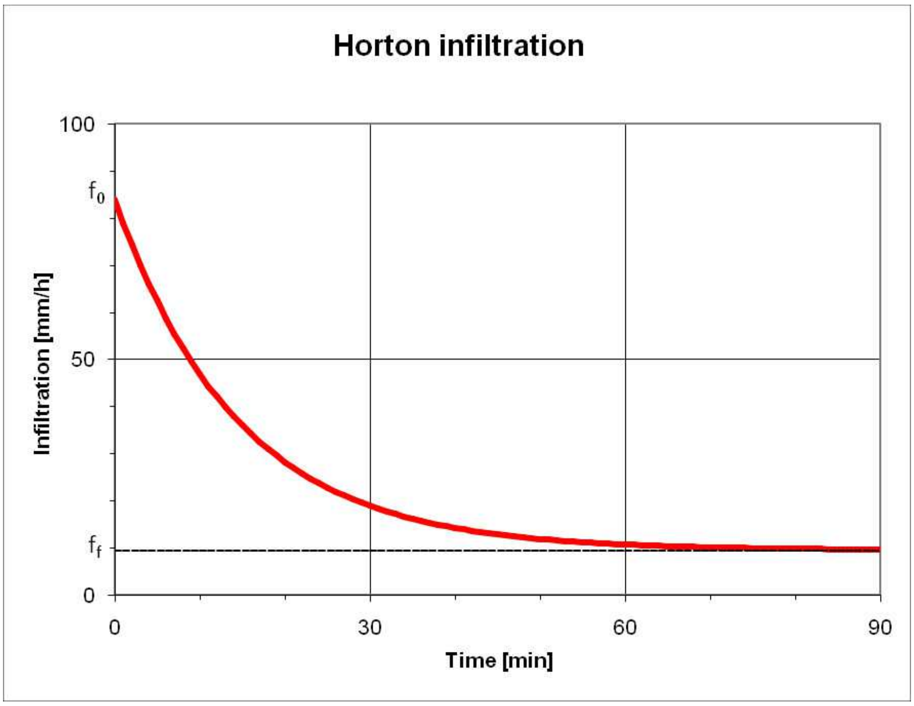


Figure 82: Horton infiltration Sensitivity Analysis

Further variations of the Horton infiltration values can be made after obtaining the results of this first step. These are discussed with the results of the sensitivity analysis in chapter 5.3.7. As mentioned before, many factors affect the infiltration capacity. Especially soils which are still saturated from previous rain events and compacted soils generate a considerable quantity of surface runoff. Furthermore, is it possible that thin layers of silt particles at the surface are present and cause a surface seal thus decreasing the infiltration rate like compaction of the sandy soils also do. Hence, the infiltration values are changed until a reasonable quantity of surface water is generated because it is not considered accurate that no surface runoff at all is generated at a storm event of this intensity. With SWMM 5 it would be possible to run continuous models which consider the saturation of the soil. Due to the lack of precipitation data obtained this effect cannot be modelled. Infiltration capacities for moist soils should be applied to take this into account. After gathering infiltration values which generate an adequate amount of surface runoff, the sensitivity of the model on different subcatchment properties such as Manning's roughness coefficient for impervious and pervious areas, slope of the subcatchments and depression storage can be determined. This would be useless when no surface runoff arises.

Manning's roughness coefficient for pervious areas

The default value in SWMM 5 for impervious areas is 0.01 and for pervious 0.1. According to McCuen et al. (1996 as cited in ROSSMANN, 2010) dense grass has a value of 0.24 and Bermuda grass 0.41. The Manning's roughness coefficient for asphalt and concrete are only slightly different to the default value, therefore only the value for impervious areas is changed. The default value and the values for dense grass and Bermuda grass are used for the sensitivity analysis.

Slopes

In the "Storm Sewer" scenarios the slope of the subcatchments in Pintija is 25.8 % and in OHIS 5.2 %. For the sensitivity analysis the slope of the OHIS subcatchments are changed to 25.8 % to be able to determine better the effect of the slope. The slope also affects the surface runoff from impervious areas. The subcatchments of OHIS have the highest percentage of impervious areas and therefore the subcatchments are changed to the 25.8 %. For the sensitivity analysis the default value of 0.5 % and the average slope of the study area, which is 5 %, should be used for Pintija and OHIS.

Depression storage

In SWMM 5 the default value of 0.05 inches (1.3 mm) is used for impervious and pervious subareas and is applied for the “Storm Sewer Scenarios”. Due to the change of the measurement units from US units to SI metric units the default values are quite small because SWMM 5 does not convert them automatically in SI values. With smaller values more surface runoff is generated and the results are on the safe side. Nevertheless, other values should be tested in the sensitivity analysis. ASCE (1992, as cited in ROSSMANN 2010) suggests for impervious surfaces 0.05–0.10 inches (1.3–2.5 mm) and for lawns 0.10–0.20 inches (2.5–5.1 mm). For the sensitivity analysis the model is run once with the Manning’s n value of 1.5 mm for impervious and 2.5 mm pervious surface and another time with 3 mm for impervious and 5 mm for pervious areas. Further it is possible to choose the percent of impervious area with no depression storage. The default value is 25% and was used in the “Storm Sewer Scenarios” which is also recommended unless special circumstances are known to exist (GIRONÁS et al., 2009).

5.3 Hydrodynamic modelling

First of all it has to be mentioned, that the ideal condition of the sewer system is modelled. This means, that no damages, no deposits, no root ingrowth etc. and no inflow of extraneous water is considered. Without doubt, these factors would worsen the conditition and change the results of the scenarios. Further the model is not calibrated and only very rough assumptions of missing data were made.

In the status report of the SWMM 5 model detailed information and results of the model are listed. Due to the complexity of the report it cannot be itemised in the Annex for all the different scenarios. In the following sub terms excerpted information from the status report is listed. Generally the status report includes the following sections:

- Analysis Options
- Continuity Errors
- Stability Results
- Runoff Results
- Node Depths
- Node Inflows
- Node Surcharge
- Node Flooding
- Storage Volumes
- Outfall Loadings
- Link Flows
- Flow Classification
- Conduit Surcharging

For every scenario the mass balance of the model is discussed. The information therefore can be found in the section Continuity Error of the status report. Further the Outfall Loadings, from the same named section in the report are listed. For the sub item “Flooding” information from the section Node Flooding is used, as well as for the clarification of the system’s bottlenecks. If results from other parts of the status report are applied, it is going to be stated in the work.

5.3.1 Basic scenario “Sanitary Sewer – Previous State”

5.3.1.1 Mass balance

Two different mass balances are listed in the status report, one for the Runoff in mm and the other for the Flow in m³ [Table 11].

Table 11: Mass balance Scenario “Sanitary Sewer – Previous State”

Runoff	mm	Flow	m³
Total Precipitation	12.840	Dry Weather Inflow	213
Evaporation Loss	0.117	Wet Weather Inflow	2574
Infiltration Loss	0.000	External Outflow	2005
Surface Runoff	12.761	Internal Outflow	759
Final Surface Storage	0.000	Final Stored Volume	28

The Total Precipitation of the runoff mass balance is the same in all scenarios. Compared to the block rain inserted and explained in 5.2.2.1 on page 61 12.84 mm is the amount of rainfall in 20 minutes and listed in the runoff mass balance. The Infiltration Loss is zero, because as aforementioned only the impervious areas are taken into account in the basic scenario. Hence, only the Evaporation Loss is the difference between Total Precipitation and Surface Runoff.

The Internal Outflow of the flow mass balance is the amount of water lost through flooding. If a value is set for Ponded Area at all manholes, no Internal Outflow would occur and any remaining ponded volume at the end of the simulation would show up in the Final Stored Volume (ROSSMAN, 2007). The Final Stored Volume includes also water remaining in the hydraulic components (JAMES, 2008). In this case the 28 m³ are the result of the continuous dry weather flow. The mass balance is not completely right. For that reason, a Runoff Continuity Error and a Flow Routing Continuity Error are stated in the status report. These errors are explained below according to DICKINSON (2010).

*Percent Error = 100.0 * (1.0 – Total Outflow / Total Inflow)*

Runoff Quantity Continuity Error:

Total Inflow = Rainfall

Total Outflow = Evaporation + Infiltration + Runoff + Final Stored Volume

Flow Continuity Error:

Total Inflow = Dry Weather Inflow + Wet Weather Inflow

Total Outflow = External Outflow + Internal Outflow + Final Stored Volume

The Runoff Quantity Continuity Error of the basic scenario = - 0.295 % and the Flow Routing Continuity Error = -0.171 %. The validity of the model results must be reviewed, if the errors exceed some reasonable level, such as 10 % (ROSSMANN, 2010).

Table 12 lists the outfall loadings from the storm sewer and the sanitary sewer in OHIS. The sum of the total Outfall Loadings (2005 m³) in Table 12 equals the External Outflow in Table 11.

Table 12: System outfall loading Scenario "Sanitary Sewer – Previous State"

Outfall Loadings	Average Flow l/s	Max. Flow l/s	Total Volume m³
Out_SS = outfall storm sewer	204.94	1174.42	1728
Out_FS = outfall sanitary sewer	21.50	36.99	277
System	226.44	1211.38	2005

The outfall loading of the storm sewer Out_SS only includes storm water of the connected OHIS premises in this basic scenario. Due to the high amount of Internal Outflow [Table 11] the outfall loading of Out_FS is quite low, assuming that the flooding largely appears in Pintija.

5.3.1.2 Flooding

Table 13 is an analysis of the node flooding section of the status report. The nodes which are flooded are separated into manholes with a total flood volume less than 10 m³ and greater than 10 m³, because flooding less than 10 m³ ones every two years is considered tolerable.

Table 13: Number of surcharged and flooded manholes Scenario "Sanitary Sewer – Previous State"

	Number of manholes						
		surcharged		flooded		flooded > 10 m³	
	total	absolute	relative	absolute	relative	absolute	relative
Pintija	152	74	49 %	35	23 %	15	11 %
OHIS	109	47	43 %	10	9 %	4	4 %

On the basis of Table 13 it is obvious, that the system in Pintija is not capable of conveying such an amount of storm water discharged by faulty connections into the sanitary sewer. Nearly half of the manholes are surcharged, a quarter flooded and 11 % flooded with a total volume exceeding 10 m³. In OHIS fewer manholes are surcharged and flooded, but the real situation can look different because of the lack of the elevation data from the OHIS sewer system.

Table 14 is an abstract of the node flooding section of the status report. The locations of the most significant manholes are discussed in the following sub-item "Bottlenecks". Manhole B11 is flooded most with a total volume of 140 m³ followed by two manholes in OHIS, which grey marked grey. These two manholes are the ones where the bypasses were constructed.

Table 14: Flooded manholes Scenario "Sanitary Sewer – Previous State"

Node	Hours Flooded	Maximum Flooding Rate l/s	Time of Max Occurence hr:min	Total Flood Volumen m³
A3_1.4	0.55	29.91	00:38	11
A3_1.5	0.49	25.21	00:55	31
A3_1.6	0.59	16.95	00:53	27
A3_1.7	0.35	20.81	00:36	8
A3_1.8	0.31	37.83	00:54	38
A3_1.10	0.11	16.85	00:37	2
A3_1.4_1.1	0.25	14.76	00:37	4
A3_1.4_1.3	0.27	5.58	00:37	5
A3_1.10_1.1	0.39	29.93	00:38	8
A3_1.10_1.2	0.12	29.20	00:38	2
A3_1.10_1.2_1.1	0.28	27.39	00:38	12
A3_1.10_1.2_1.2	0.43	16.12	00:39	3
B2	0.28	10.18	00:48	8
B4	0.63	62.51	00:40	76
B5	0.31	8.37	00:37	3
B6	0.28	10.56	00:37	8
B8	0.37	9.65	00:55	11
B9	0.31	9.52	00:54	10
B11	0.48	112.89	00:50	140
B13	0.23	1.63	00:40	1
B14	0.23	14.29	00:40	2
B15	0.23	17.85	00:40	5
B19	0.24	15.32	00:54	13
B20	0.22	13.03	00:39	6
B1_2.1	0.89	46.57	00:41	8
B1_2.2	0.28	34.06	00:40	9
B13_1.2	0.25	15.21	00:40	5
B20_1.2	0.25	7.62	00:50	6
B20_1.4	0.26	12.09	00:54	11
B20_1.6	0.29	23.86	00:54	23
B1_2.1_1.9	0.25	23.02	00:54	14
B1_2.1_1.9_1.1	0.67	33.92	00:37	19
B1_2.1_1.9_1.2	0.32	18.71	00:54	17
B1_2.1_1.4_1.3	0.07	23.37	00:52	4
B1_2.1_1.1	0.64	53.39	00:55	57
O_FS-A_1	0.62	59.59	00:54	70
O_FS-B_6	0.96	18.11	00:45	5
O_FS-B_7	0.99	22.11	00:45	1
O_FS-B_8	1.14	20.46	00:52	76
O_SS-A_5	0.03	77.97	00:55	6
O_SS-A_7	0.03	60.98	00:54	4
O_SS-A_7_2.6	0.11	65.83	00:54	14
O_SS-A_8_2.8	0.13	15.54	00:54	3
O_SS-A_8_2.9	0.14	4.40	00:44	1
O_SS-A_8_2.11	0.18	23.92	00:41	14

In Figure 83 the flooding in litre per second over time of these two manholes is shown. The total amount is nearly the same, but the shape of the curves is totally different. The subcatchments connected to manhole O_FS-A_1 are closer and consequently the flow time shorter until the highest amount of surface runoff reaches the manhole. On the other hand, the flow time of the surface water discharged from subcatchments connected to manhole O_FS-B_8 is longer. Accordingly the flooding occurs later and the curve is smoother.

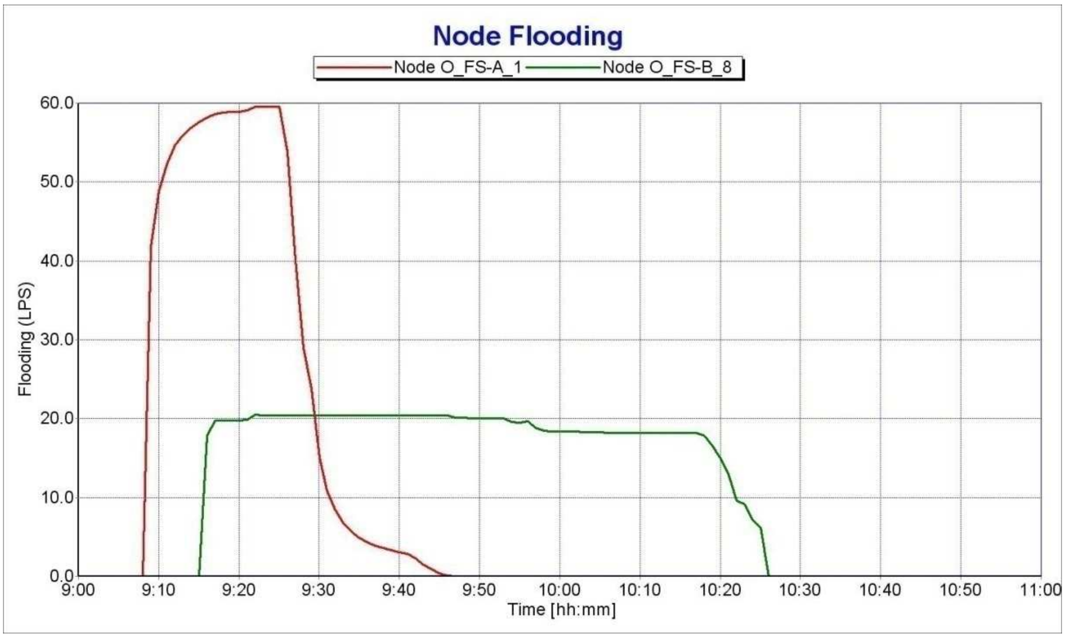


Figure 83: Flooding of the manholes, where the bypasses were constructed

5.3.1.3 Bottlenecks

First it has to be stated again, that the sewer system was very likely dimensioned as a separate system, but the storm sewer – except for one line - was never finished. Without doubt, a combined sewer system cannot operate with the dimensions of a sanitary sewer system and the flooding will arise as a result of overloading. Nevertheless, the bottlenecks determined in this scenario could also be significant for a sheer sanitary sewer system. Therefore, it should be clarified why flooding occurs at these specific manholes, especially the ones with a total amount greater than 10 m³. Particularly, the diameters of the sewer pipes should be considered. In Figure 84 as well as in Figure 67 on page 70 the diameters are illustrated by the colour of the conduits. In SWMM 5 the diameter of conduits is called “Link Max. Depth”. In the figures five changes from a bigger to a smaller diameter can be spotted, which are marked with red arrows and numbers in Figure 84. The change from a bigger to smaller diameter indeed provokes a bottleneck and it is obvious that this results in flooding. Unfortunately in SWMM 5 it is not possible to display the total amount of water flooded. Hence, some manholes in Figure 84 are highlighted, because they have a high amount of node flooding in l/s but in total, the flooding is not significant and vice versa.

“Arrow 1” points out manhole O_FS-A_1 and number 2 manhole O_FS-B_8. At both nodes the pipe diameter changes from 250 mm to 150 mm. At manhole O_FS-A_1 a total amount of 70 m³ and at O_FS-B_8 76 m³ of water overflows the manhole. As a result the bypasses were probably constructed at these locations. The reason why manhole B1_2.1_1.4 (arrow number 3) in not listed in Table 14 and consequently not flooded is the relative high depth of 2.13 m. Nevertheless, other nodes nearby with smaller maximal depths, like B1_2.1_1.1 and B1_2.1_1.4_1.3, are flooded. At manhole B11 (arrow number 4) the pipe diameter also changes from 150 mm to 250 mm and it has by far the greatest total flood volume with 140 m³ followed by manhole B4 with 76 m. The manhole B4 is the second manhole located in Pintija, which is marked red in Figure 84. Three sewer lines and two subcatchments are directly connected into manhole B4. Of course without this simplification of the directly connected subcatchments the flooding could be less, but it is definitely a bottleneck and can become one in the sanitary sewer system. The slope changes at manhole B4 from 5.5 % to 2.2 % and as a result the velocity decreases. Consequently, a bigger diameter would be needed to convey the same flow. Further disposals are more frequent and hence blockage can be caused. In Table 14 nearly every manhole between B4 and B11 is listed and is flooded. The whole system in this section is surcharged and backwater effects even manhole B11. Manhole A3_1.10, pointed out with arrow number 5, is not highlighted in Figure 84 due to its low node flooding in l/s. Nevertheless, flooding of 12 m³ occurs.

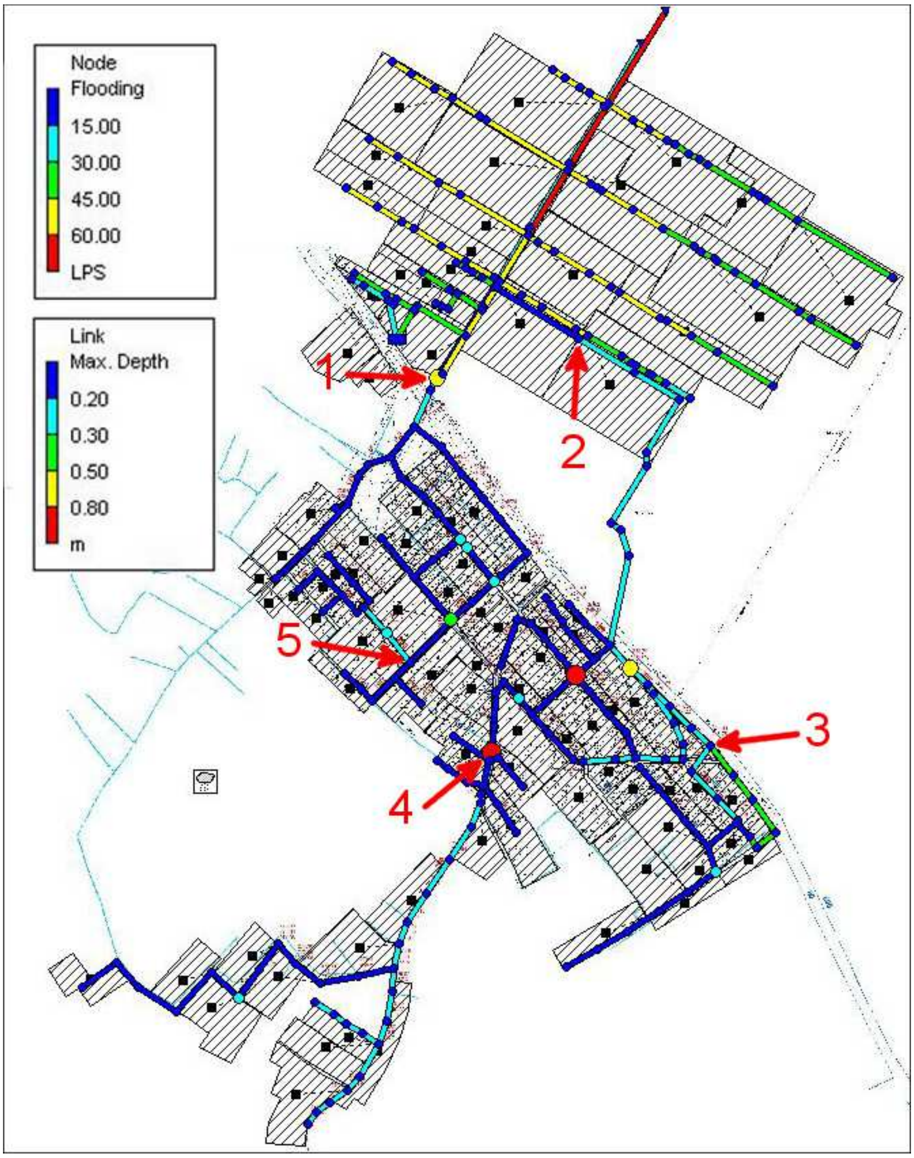


Figure 84: Diameters and flooding after 13 min of Scenario "Sanitary Sewer – Previous State"

The fact that the manholes, where the bypasses were constructed, have the highest total flood volume presents a "light" validation of the model. Furthermore, where manhole B4 is located disposals on the street were spotted during the fieldtrip after the heavy storm event. Neighbours also affirmed the flooding in this section as already mentioned in Figure 36 on page 48. The model cannot be calibrated because no data measured are available. Hence, the flooding of these specific manholes is the verification that the model can be used to simulate conditions of the real system for first basic investigations.

5.3.1.4 Possible improvements

One approach could be the increase of the pipe dimensions. In fact, this would produce a combined system which is not considered useful in this situation where a sanitary sewer system already exists. One suggestion is to use an open channel as storm sewer. It is going to be examined in the scenario “Storm sewer – Open Channel”. The capability of the sanitary sewer without faulty connections is checked in the scenario “Sanitary sewer – designed state”.

5.3.2 Scenario “Sanitary Sewer – Current State”

5.3.2.1 Mass balance

The runoff mass balance [Table 15] equals the one from scenario “Sanitary sewer – previous state” [Table 11] because no changes in precipitation or evaporation were made. Consequently, there are also no changes of the Dry Weather Inflow and Outflow. In the flow mass balance only slight changes occur. The Internal Outflow (flooding) is about 80m³ less than in the previous scenario.

Table 15: Mass balance Scenario “Sanitary Sewer – Current State”

Runoff	mm	Flow	m³
Total Precipitation	12.840	Dry Weather Inflow	213
Evaporation Loss	0.117	Wet Weather Inflow	2574
Infiltration Loss	0.000	External Outflow	2077
Surface Runoff	12.761	Internal Outflow	677
Final Surface Storage	0.000	Final Stored Volume	35

Due to the discharge of the waste water of Pintija into the storm sewer through the bypasses it is obvious that there is only very little sanitary sewer outfall listed in Table 16. This is only the amount from the OHIS premises which was not disconnected from the sanitary sewer due to the bypasses. The outfall loading from outfall Out_SS increases from 1728 m³ in the previous scenario without bypass to 2070 m³ with bypass. This is a gain of about 20 %.

Table 16: System outfall loading Scenario “Sanitary Sewer – Current State”

Outfall Loadings	Average Flow l/s	Max. Flow l/s	Total Volume m³
Out_SS = outfall storm sewer	238.40	1170.35	2070
Out_FS = outfall sanitary sewer	0.46	0.48	7
System	248.00	1170.81	2077

5.3.2.2 Flooding

In the scenario “Sanitary Sewer – Current State” the focus is on the OHIS premises, because in Pintija the situation is not changed due to the bypasses. Consequently Pintija is not Part of Table 17 and Table 18. Instead the numbers of the scenario “Sanitary Sewer – Previous State” are shown again for better comparison.

Table 17: Number of surcharged and flooded manholes in OHIS of the Scenarios “Sanitary Sewer – Previous and Current State”

	Number of manholes						
		surcharged		flooded		flooded > 10 m³	
	total	absolute	relative	absolute	relative	absolute	relative
OHIS - Previous State	109	47	43 %	10	9 %	4	4 %
OHIS - Current State	109	43	39 %	8	7 %	3	3 %

By means of Table 17 a statement cannot really be made. There are only light differences in the numbers and percentages. Hence, Table 18 lists all flooded nodes of OHIS of the two scenarios and compares the time and the total flood volume.

Table 18: Flooded manholes in OHIS Scenario “Sanitary Sewer – Previous and Current State”

Node	Scenario Previous State		Scenario Current State	
	Hours Flooded	**Total Flood Volume m³**	**Hours Flooded**	**Total Flood Volume m³**
O_FS-A_1	0.62	70	0.00	0
O_FS-B_6	1.00	6	0.00	0
O_FS-B_7	1.03	2	0.00	0
O_FS-B_8	1.17	78	0.00	0
O_SS-A_5	0.03	5	0.10	64
O_SS-A_7	0.03	4	0.07	10
O_SS-A_6_1.4	0.00	0	0.01	1
O_SS-A_6_2.9	0.00	0	0.01	1
O_SS-A_7_2.6	0.11	14	0.12	22
O_SS-A_8_2.8	0.12	3	0.14	5
O_SS-A_8_2.9	0.14	1	0.15	1
O_SS-A_8_2.11	0.18	14	0.18	14

Again O_FS-A_1 and O_FS-B_8 are marked grey. The numbers show that the bypasses work and no flooding in the sanitary sewer system occurs any more. However, manhole O_SS-A_5 of the OHIS storm sewer system gets flooded significantly despite the fact that the flooding lasts only six minutes. Another increase of flooding takes place at manhole O_SS-A_7_2.6, where the amount of overflowing water increases nearly 60 % due to backwater effects.

The storm sewer at the traffic areas in front of the office building is also surcharged more than in scenario “Sanitary Sewer – Previous State”. The discharged storm water and the backwater effect is too small that flooding arises in this section with this specific rain intensity. The minimum depth of surcharge below the node’s top rim can be seen in Table 19, where the values from both scenarios are compared. The values of Table 19 can be found in the section Node Surcharging of the status report. For all the listed manholes the maximum depth of 1.20 m is assumed, because no data could be obtained. At a storm event with an intensity of the design storm at least about 30 cm of the manhole are not surcharged in the current state. The reported flooding of this particular area of the study area could be a result of disposals and blockage in the storm sewer or storm events with a higher intensity. Without doubt, the only estimated elevations of the sewer system in OHIS are a big issue to be able to simulate the real situation of the system in OHIS and to get informative results.

Table 19: Minimal depth below the rim from the manholes at the parking lot

Node	Scenario "Previous State" Min. Depth Below Rim Meters	Scenario "Current State" Min. Depth Below Rim Meters
O_SS-A_2_1.1	0.52	0.33
O_SS-A_2_1.2	0.59	0.35
O_SS-A_2_1.3	0.75	0.51
O_SS-A_2_1.4	0.74	0.51
O_SS-A_2_1.5	0.85	0.65
O_SS-A_2_1.8	----	0.40
O_SS-A_2_1.9	----	0.52

Similarly, the storage tank O_SS-P at the parking lot has a higher Maximal Outflow and the Maximum Percentage Full is 27 % in Scenario "Sanitary Sewer – Current State", contrary to 16 % in Scenario "Sanitary Sewer – Previous State". The Maximum Percentage Full does of course not include the sediments in the tank and the blockage of the effluent which can be seen in Figure 42 on page 51. Furthermore, the influent on the left hand side located near the bottom of the tank causes backwater effects and surcharges the storm sewer system.

5.3.2.3 Bottlenecks

In Pintija the bottlenecks of Scenario "Sanitary Sewer – Previous State" remain the same in this current scenario because the system was not changed there. With the bypasses at the OHIS premises the two bottleneck manholes O_FS-A_1 and O_FS-B_8 are eliminated but as a result a new one, manhole O_SS-A_5, is created.

5.3.2.4 Possible improvements

Undeniably, the bypasses are neither a solution for Scenario "Sanitary Sewer – Previous State" nor for Scenario "Sanitary Sewer – Current State". Not only because flooding still occurs in OHIS with the bypass, but because it is also not acceptable ecologically that any waste water is discharged into the Vardar Rive without treatment. Therefore, the same approach is suggested as in the previous scenario. A storm sewerage system – economically viable in the form of an open channel – could be constructed and no storm water must be discharged faultily into the sanitary sewer system.

For the separate system in OHIS one suggestion is regular cleaning to prevent flooding. During the fieldtrip in OHIS it emerged, that regular cleaning as a matter of fact is not common practice. The sewerage system is only cleaned if it is blocked. Cultural aspects are also an issue. According to oral reports the rest of the Ajvar (a type of relish made from red peppers) production and pickled vegetables in spring are littered into the sanitary sewer system and consequently blockage arises. The public has to be briefed to changes this behaviour. For example this change could be promoted in local newspapers and with leaflets sent to the households in Pintija.

5.3.3 Scenario "Sanitary Sewer – Designed State"

5.3.3.1 Mass balance

The mass balance for Scenario "Sanitary Sewer – Designed State" has to be treated with caution, because the dry weather inflow is discharged continuously into the system. Therefore, the so-called Dry Weather Inflow (waste water flow) in SWMM 5 and External and Internal Outflow increase with time. Whereas the Final Stored Volume stays the same. The listed flow values in Table 20 are the results of the flow routing over one hour on the left side and four hours on the right side. Besides, the Continuity Error decreases with time. With a routing duration of one hour, the Continuity Error is 4.44 %, with four hours 1.52 % and with six hours 1.05 %. According to the mass balance, no flooding appears in the sanitary sewer system if about 5.5 l/s*1000 residents are discharged.

Table 20: Mass balance Scenario "Sanitary Sewer – Designed State" with a routing time of 1 hour (left) and 4 hours (right)

Flow	m³	Flow	m³
Dry Weather Inflow	152	Dry Weather Inflow	456
Wet Weather Inflow	0	Wet Weather Inflow	0
External Outflow	97	External Outflow	400
Internal Outflow	0	Internal Outflow	0
Final Stored Volume	49	Final Stored Volume	49

More informative character than the mass balance has the Average Flow and the Maximal Flow of Outfall Loadings in Table 21. There is only little change of the values attributed to the change of the routing time. The values of Table 21 are the results of a three hours routing time.

Table 21: System outfall loading Scenario "Sanitary Sewer – Designed State" with a routing time of 4 hours

Outfall Loadings	Average Flow l/s	Max. Flow l/s	Total Volume m³
Out_FS = outfall sanitary sewer	27.39	28.16	400
System	27.39	28.16	400

These values are important information for the waste water treatment plant in OHIS or for designing a new WWTP. Unfortunately no information about the sanitary inflow from OHIS is available. Consequently, only very rough estimations can be used for the sanitary waste water discharge in OHIS. The average sanitary flow from Pintija only is about 25 l/s. With the current estimations the main source of the sanitary waste water (25 l/s) is Pintija.

5.3.3.2 Flooding

No flooding arises in Scenario "Sanitary Sewer – designed state".

5.3.3.3 Bottlenecks

Although no flooding appears, bottlenecks can still be spotted in Figure 85. As discovered in Scenario "Sanitary Sewer – Previous State" [Figure 84, page 90] at five locations the pipe diameter decreases. The worst bottleneck in this scenario is obviously the conduit between the manholes O-FS-B_8 (red arrow) and O-FS-A_3 (green arrow) [Figure 85]. It has a diameter of only 150 mm and the previous pipe 250 mm. The colours in Figure 85 represent the link capacity. Manhole O_FS-B_7 (blue arrow) and O_FS-B_8 are surcharged and the maximal height above the crown at manhole O_FS-B_8 is already 0.91 m. The minimal depth below the rim is only 0.40 m. The backwater effects also conduit C-FS-B_7. The problem at this sanitary sewer bottleneck is that sanitary water remains in the two manholes when the sewer is surcharged due to the continuous flow. After 6 minutes the manhole O_FS-B_8 already starts to surcharge and after 1 hour and 10 minutes the surcharge reaches the level that does not decrease any more. So the inflow equals the outflow. At the other locations, where the pipe diameters are decreased, obviously the link capacity gets higher. However, they are not surcharged and not under pressure. Link capacities over 80 % occur only in OHIS and in Pintija the highest with 68 % is at conduit C-B2 (pink arrow). This increase of the link capacity is a result of the decrease in slope as well as the rather little pipe diameter of 0.15 m. The other two green coloured conduits in the western part of Pintija have a link capacity of 52 % and 62 %, which is also a result of a decrease in slope from 2.32 % to 0.77 %.

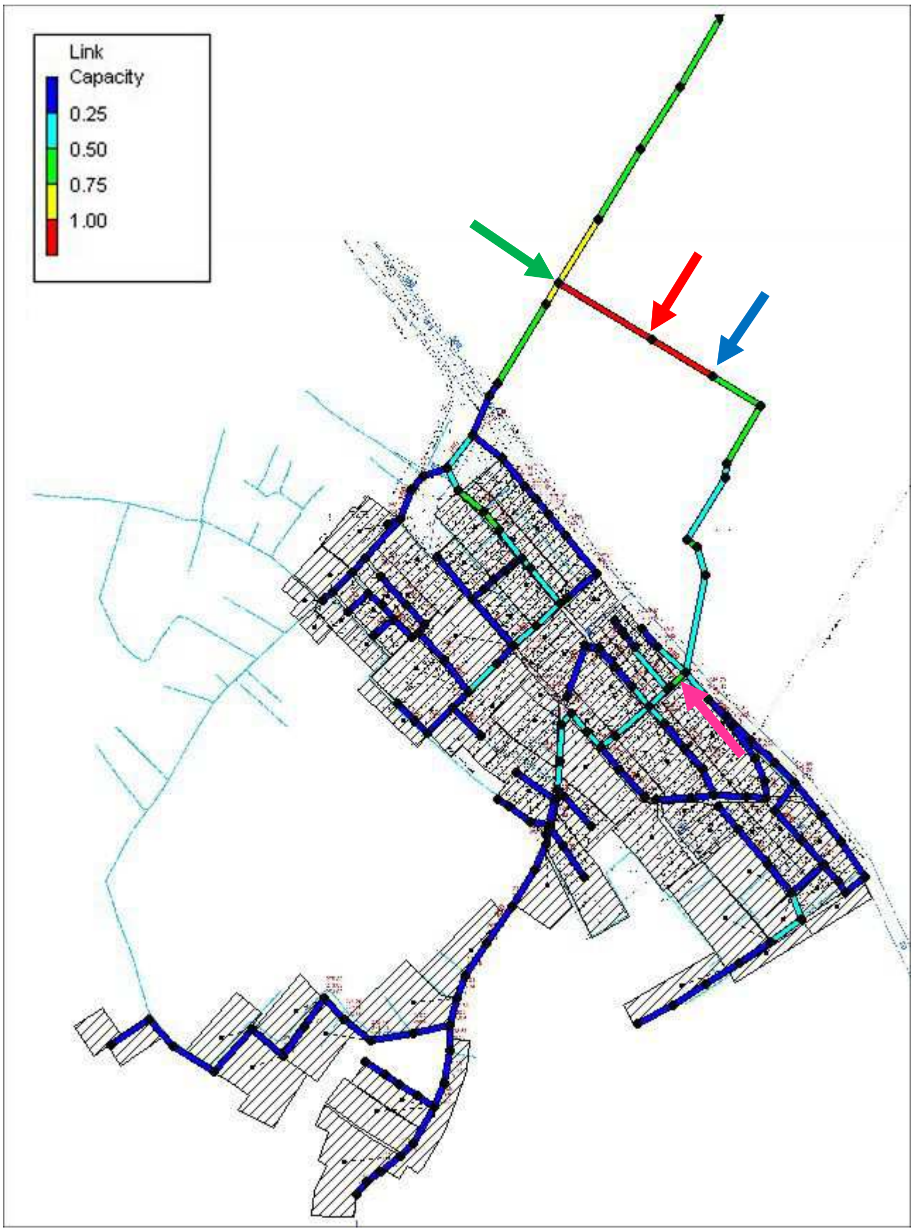


Figure 85: Link Capacity of Scenario "Sanitary Sewer – Designed state" after 1 hour and 5 minutes

5.3.3.4 Possible improvements

Conduit C-FS-B_8 should be replaced by a pipe with a bigger diameter because it is not appropriate that sanitary waste water surcharges manholes and does not discharge. If replaced by a pipe DN 250, the link capacity of C-FS-B8_8 would be 67 % and from C-FS-B8_7 only 40 %. The outfall loading for this modified system is shown in Table 22. There are only slight changes of the outfall loadings.

Table 22: System outfall loading modified Scenario "Sanitary Sewer – Designed State" with a routing time of 4 hours

Outfall Loadings	Average Flow l/s	Max. Flow l/s	Total Volume m³
Out_WW = outfall waste water	27.64	28.16	403
System	27.64	28.16	403

The sanitary sewer system would work with the assumed sanitary flow and if no faulty connections exist. In future the rather small diameters between B1 and B14 (150 mm) could cause problems. The whole system should be cleaned regularly. The best cleaning strategy would be demand oriented where pipes with high link capacity are cleaned in shorter intervals.

5.3.4 Scenario “Storm Sewer – Street”

5.3.4.1 Mass balance

In Table 23: Mass balance Scenario it can be seen, that no Dry Weather Inflow is computed in Scenario “Storm Sewer – Street”, because of course only the storm water discharge is modelled on the street. This means that the Dry Weather Inflow in SWMM had to be removed at the manhole properties. No External Outflow is generated, because all the storm water is stored in the storage units located at the road Prvomajska. The Final Stored Volume is 735 m³.

Table 23: Mass balance Scenario “Storm Sewer – Street”

Runoff	mm	Flow	m³
Total Precipitation	12.840	Dry Weather Inflow	0
Evaporation Loss	0.023	Wet Weather Inflow	803
Infiltration Loss	9.630	External Outflow	0
Surface Runoff	3.209	Internal Outflow	71
Final Surface Storage	0.000	Final Stored Volume	735

Due to the fact that the subcatchments of Scenario “Storm sewer – Street” have pervious areas, Infiltration Loss is a part of the mass balance. In the section Runoff Results of the status report the Runoff Coefficient for the subcatchments is listed. It is 25 %for all subcatchment, like the percentage for impervious areas. Consequently, the chosen infiltration values explained in 5.2.5 on page 74 allow that the whole precipitation infiltrates into the soil. This can also be clarified with in the values of the runoff mass balance in Table 23. The Surface Runoff is a quarter of the Total Precipitation. Figure 86 shows the connection between the precipitation and the surface runoff. Due to the precipitation surface runoff is generated within only one minute. Unfortunately 5 it is not possible in SWMM to list the surface runoff also in mm/h, but due to the shape of the runoff curve it is obvious, that saturation of the soil is not relevant and no surface runoff is generated from pervious areas. Accordingly, the runoff curve does no increase at a partial time. Subcatchment M1.1 is only an example, the surface runoff of the other subcatchments also behave like this due to the equal infiltration values.

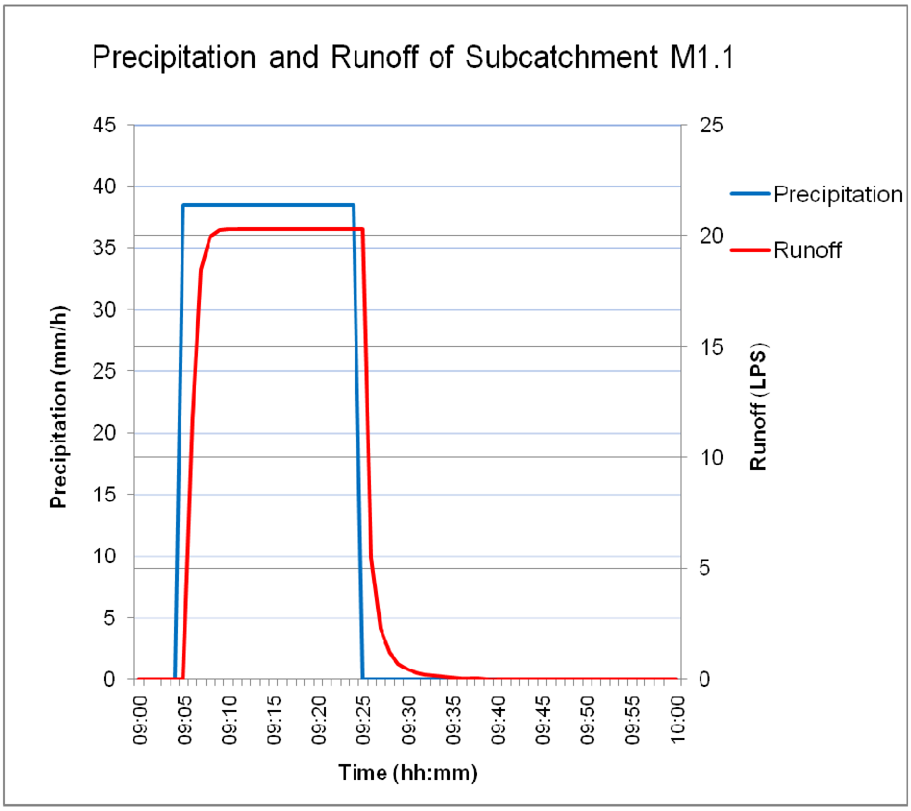


Figure 86: Precipitation and Runoff of Subcatchment M1.1

Due to the fact, that no ponding is used in Scenario "Storm Sewer – Street", there is also an Internal Outflow of 71 m³ in Table 23, which is the system's total flooding. The Final Stored Volume includes the Volume in the storage tanks. The maximum volume of the storage unit SU-A is 160 m³ and for SU-B it is 384 m³ [Figure 87]. Figure 87 shows, that after about 1.5 hours the whole surface runoff of the two catchment areas is conveyed onto the Prvomajska Road.

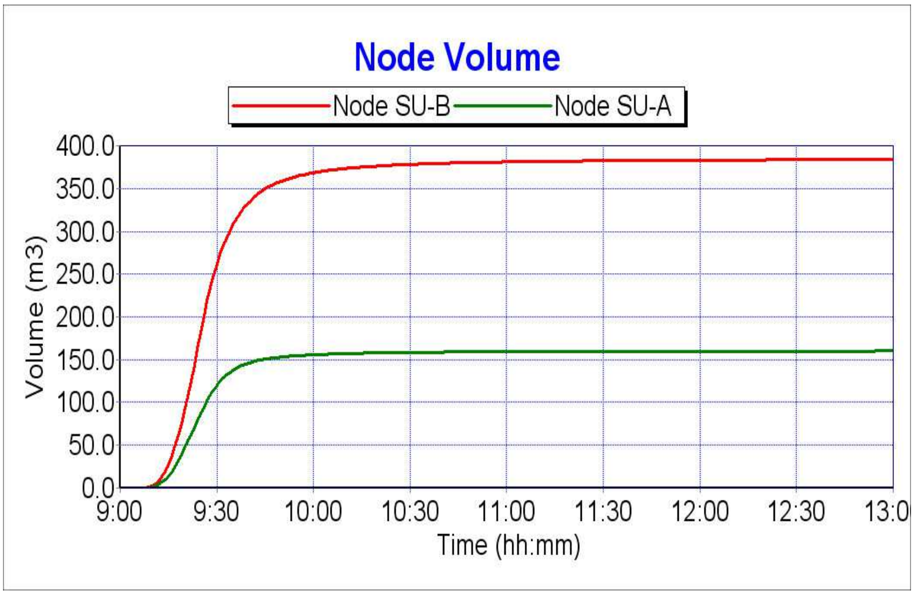


Figure 87: Storage volumes of Scenario "Storm Sewer – Street"

The Maximum Percentage Full of storage unit SU-A is 16 % and of storage unit SU-B 38 %. It can be imagined that the street is - at the dimensions of 10 m*100 m – 16 cm at the location of node SU-B and 38 cm at the location of node SU-A flooded. Of course, this implements that the water cannot discharge. Even though all the precipitation fallen on pervious ground is infiltrated;

the stored amounts in the storage units are quite high. If these values are used for more than getting a survey over surface runoff it definitely would have to be verified.

5.3.4.2 Flooding

In this scenario and all scenario which deal with the storm sewer the nodes of the model in Pintija are not manholes like in this scenarios of the sanitary sewer; instead, they are elevation spots of the storm sewer system with a maximal depth of the currently used profile. Consequently, flooding arises if the water overflows the rim of the profile [Table 24]. In Scenario “Storm sewer – Street” the street profile is 0.15 m high.

Table 24: Flooded nodes Scenario “Storm Sewer – Street”

Node	Hours Flooded	Maximum Flooding Rate l/s	Time of Max Occurence hr:min	Total Flood Volume m³
B13_1.2	2.78	15.89	01:04	5
B1_2.1_1.4_1.3	3.69	87.28	00:55	66

The flooding in this scenario naturally arises only where depressions are located or where the slope is towards the main sewer. The last named is the case at B13_1.2. Manhole B1_2.1_1.4_1.3 is situated at the Prvomajska Road, where the water is conveyed downhill to the east and not to the storage unit as a result of the declining road.

5.3.4.3 Bottlenecks

In Scenario “Storm Sewer – Street” the bottlenecks are depressions and of course the locations, where the storm water is discharged onto the Prvomajska Road. The latter must definitely be prevented.

5.3.4.4 Possible improvements

Of course, a storm sewer system would be an improvement. However, the amount of surface runoff could also be reduced regardless if the estimations of the node elevations are incorrect or a storm sewer is available. The easiest way would be to stop discharging water directly onto the streets in Pintija. Instead, rainwater can be infiltrated on site and rainwater tanks could be used. The latter have the second positive effect of having irrigation water for the garden in summer. Generally speaking, the generation of surface runoff should be minimized. This could also be achieved through Sustainable Urban Drainage Systems.

5.3.5 Scenario “Storm Sewer – Open Channel”

5.3.5.1 Mass balance

The mass balance of this scenario is not similar to Scenario “Storm Sewer – Street” because in the last-named scenario only Pintija is part of the model.

Table 25: Mass balance Scenario “Storm Sewer – Open Channel”

Runoff	mm	Flow	m³
Total Precipitation	12.840	Dry Weather Inflow	0
Evaporation Loss	0.052	Wet Weather Inflow	2568
Infiltration Loss	7.940	External Outflow	2396
Surface Runoff	4.866	Internal Outflow	177
Final Surface Storage	0.000	Final Stored Volume	1

Scenario “Storm Sewer – Open Channel” is the first scenario with practical no Final Stored Volume. The 1 m³ is stored in the storage unit at the OHIS parking lot, because in the status report it is stated that the average volume in the storage tank is 1 m³. Further the Surface Runoff is not a quarter of the Total Precipitation, because the subcatchments of OHIS do have different assumption for the percentage of impervious areas and may also generate surface runoff from pervious areas. Therefore, in Table 26 a look at the Runoff Results of OHIS is taken. These values (except the subcatchment areas and the percent of the impervious area) can be found in the chapter Subcatchment Runoff Summery in the status report. Lastly, the subcatchment M1.1 of Pintija is listed for the purpose of comparison in Table 26.

Table 26: Runoff Results and Area of the OHIS subcatchments Scenario “Storm Sewer – Open Channel”

Sub-catchment	Area ha	Total Precip. mm	Total Evap mm	Total Inflilt. mm	Total Runoff mm	Total Runoff m³	Peak Runoff l/s	Runoff Coeff. %	Percent Imperv. Area
O_1-1	0.64	12.84	0.02	10.27	2.56	20	13.66	19.9	20.0
O_1-2	0.38	12.84	0.02	10.27	2.56	10	8.11	20.0	20.0
O_1-3	0.15	12.84	0.02	10.27	2.57	0	3.20	20.0	20.0
O_2-1	0.59	12.84	0.04	8.35	4.47	30	22.05	34.8	35.0
O_2-2	0.36	12.84	0.04	8.35	4.47	20	13.45	34.8	35.0
O_2-3	0.30	12.84	0.04	8.35	4.48	10	11.21	34.9	35.0
O_3-1	1.53	12.84	0.08	6.42	6.36	100	81.67	49.5	50.0
O_3-2	2.50	12.84	0.07	7.06	5.72	140	120.09	44.5	45.0
O_4-1	0.49	12.84	0.10	3.85	8.91	40	36.62	69.4	70.0
O_4-2	0.56	12.84	0.10	3.85	8.91	50	41.85	69.4	70.0
O_5-1	0.61	12.84	0.10	3.85	8.91	50	45.58	69.4	70.0
O_5-2	0.72	12.84	0.11	3.85	8.90	60	53.80	69.3	70.0
O_6-1	1.52	12.84	0.14	3.21	9.51	140	121.66	74.1	75.0
O_6-2	1.44	12.84	0.13	3.21	9.51	140	115.26	74.1	75.0
O_7-1	1.86	12.84	0.04	8.99	3.82	70	59.57	29.8	30.0
O_7-2	1.29	12.84	0.07	7.06	5.73	70	61.97	44.6	45.0
O_8-1	1.84	12.84	0.12	4.49	8.25	150	127.65	64.2	65.0
O_8-2	2.65	12.84	0.12	4.49	8.24	220	183.75	64.1	65.0
O_9	2.10	12.84	0.06	7.70	5.09	110	89.67	39.6	40.0
O_10-1	2.32	12.84	0.05	8.35	4.45	100	86.69	34.7	35.0
O_10-2	1.18	12.84	0.05	8.35	4.46	50	44.09	34.7	35.0
O_10-3	1.89	12.84	0.04	8.99	3.82	70	60.53	29.8	30.0
O_11	0.60	12.84	0.11	1.28	11.48	70	57.65	89.4	90.0
O_12	0.23	12.84	0.10	1.28	11.51	30	22.10	89.6	90.0
M1.1	0.77	12.84	0.02	9.63	3.21	20	20.28	25.0	25.0

The runoff coefficient is the total runoff divided by the total precipitation. For M1.1 and all other subcatchments in Pintija it equals the percent of the impervious areas, as already mentioned in Scenario “Storm Sewer – Street”. Accordingly only impervious areas generate runoff. The runoff coefficients of the subcatchments in OHIS are also quite similar to the percentage of impervious areas, but still, they are slightly under the value of the percentage of impervious area. Hence, the percent of impervious area of the subcatchments in OHIS are big enough that the evaporation loss becomes relevant. Consequently, the runoff coefficient does not equal the percentage of impervious area. Table 26 displays that the bigger the percentage of impervious area, the bigger the evaporation loss. In M1.1 evaporation loss is also shown, but it is too small to see an effect on the runoff coefficient. If surface runoff from previous areas is also generated, the runoff coefficient would be greater than the percentage of impervious area.

The system's total outfall volume in Table 27 is correctly the External Outflow of Table 25. Further, the outfall loadings of the two new outfalls are listed.

Table 27: System outfall loading Scenario "Storm Sewer – Open Channel"

Outfall Loadings	Average Flow l/s	Max. Flow l/s	Total Volume m³
Out_SS = outfall OHIS	532.25	1170.46	1838
Out_west_receiving-w.	136.78	350.07	420
Out_east_receiving-w.	53.37	111.79	134
System	722.40	1632.09	2393

Of course the storm water outfall of OHIS (Out_SS) has the highest total volume, because the OHIS premises and a part of Pintija are connected. In reality, the two other outfalls should be located at the receiving water, and the catchment areas connected to it via an open channel or closed channel. This would need further investigations of the elevation situation of the area between the receiving water and Pintija. According to the contour lines in AREC it should be possible to convey the storm water by gravity to the receiving water. For now, the assumption of the amount of the outfall loading and the maximal flow discharged into the receiving water is sufficient. With these values it would have to be checked, if the laws and/or guidelines of the Republic of Macedonia allow this discharge into the receiving water and if the receiving water has the capacity to discharge these outfall loadings.

5.3.5.2 Flooding

In Table 28 only OHIS manholes are listed, because the open channel is dimensioned big enough and no flooding occurs in Pintija. The flooding in OHIS is a result of backwater effects of the system's surcharge.

Table 28: Flooded nodes Scenario "Storm Sewer – Open Channel"

Node	Hours Flooded	Maximum Flooding Rate l/s	Time of Max Occurrence hr:min	Total Flood Volume m³
O_SS-A_2	0.10	36.56	00:55	8
O_SS-A_3	0.10	13.59	00:53	4
O_SS-A_5	0.12	290.17	00:54	99
O_SS-A_7	0.09	51.13	00:51	12
O_SS-A_5_1.6	0.01	46.66	00:48	1
O_SS-A_6_1.4	0.01	119.01	00:49	1
O_SS-A_6_2.9	0.01	118.90	00:50	1
O_SS-A_6_2.10	0.01	56.72	00:51	1
O_SS-A_7_2.6	0.13	66.10	00:54	25
O_SS-A_8_2.8	0.15	13.99	00:54	5
O_SS-A_8_2.9	0.16	2.79	00:55	1
O_SS-A_8_2.11	0.20	29.22	00:40	15

Generally speaking, the specified manholes are the same as in Scenario "Sanitary Sewer – Current State". Surprisingly the total flooded volume of O_SS-A_5 in the last-named scenario (64 m³), where the whole catchment of Pintija is connected to OHIS, is less than in Scenario "Storm sewer – Open Channel" like shown in Figure 88.

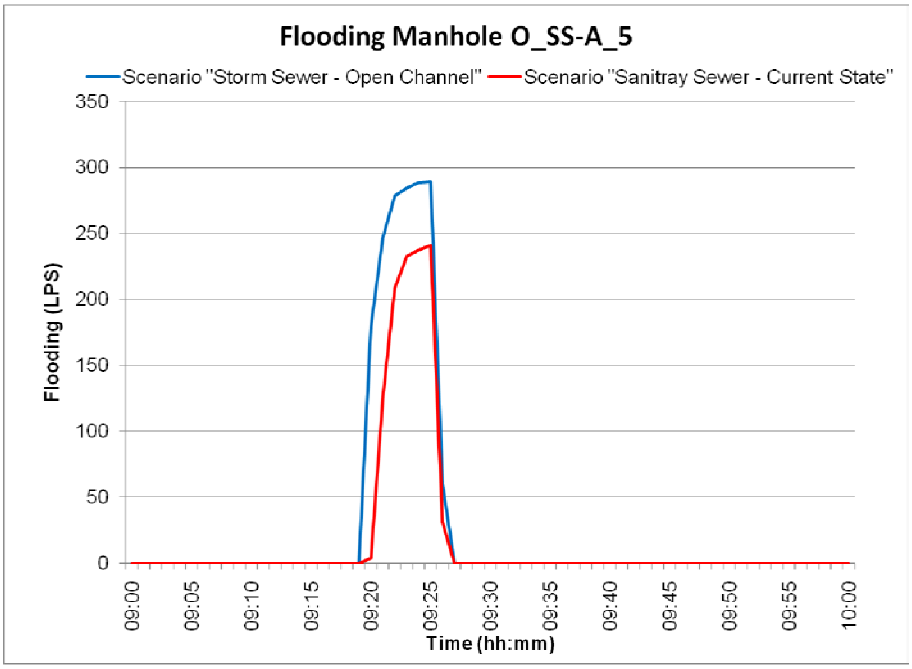


Figure 88: Flooding of manhole O_SS-A_5 in Scenario "Storm Sewer – Open Channel" and "Sanitary Sewer – Current State"

The big rate of flooding in Pintija in Scenario "Sanitary Sewer – Current State" could be a reason for this. For example the peak inflow at the connection A to OHIS in Scenario "Storm Sewer – Open Channel" is more than 200 litres per second and in Scenario "Sanitary Sewer – Current State" about 80 litres per second. This information can be generated by the Statistics Report in SWMM 5. The peak inflow to the connection B in Scenario "Sanitary Sewer – Current State" is also only 45 l/s, obviously because of the high flood amounts at the manholes ahead of the connection B. In fact this can also be seen by comparing the internal outflow in the mass balance of Scenario "Sanitary Sewer – Current State" in Table 15 and "Storm Sewer – Open Channel" in Table 25.

In Figure 89 the location of the flooded manholes in OHIS are shown after 26 minutes, as well as the capacity of the links. The storm sewer system in Pintija with a cross area of 0.23 m^2 is definitely not working at full capacity in the upper parts of the catchment at a storm event with the design intensity. The main collectors in Pintija are utilised less than 50 %, except for the two conduits between the manholes B1 (blue arrow) and B3 (pink arrow). Conduit C-B2 is 84 % full and conduit C-B3 82 % after 26 minutes of rain. On the other hand, nearly every link in OHIS is surcharged and flooding arises.

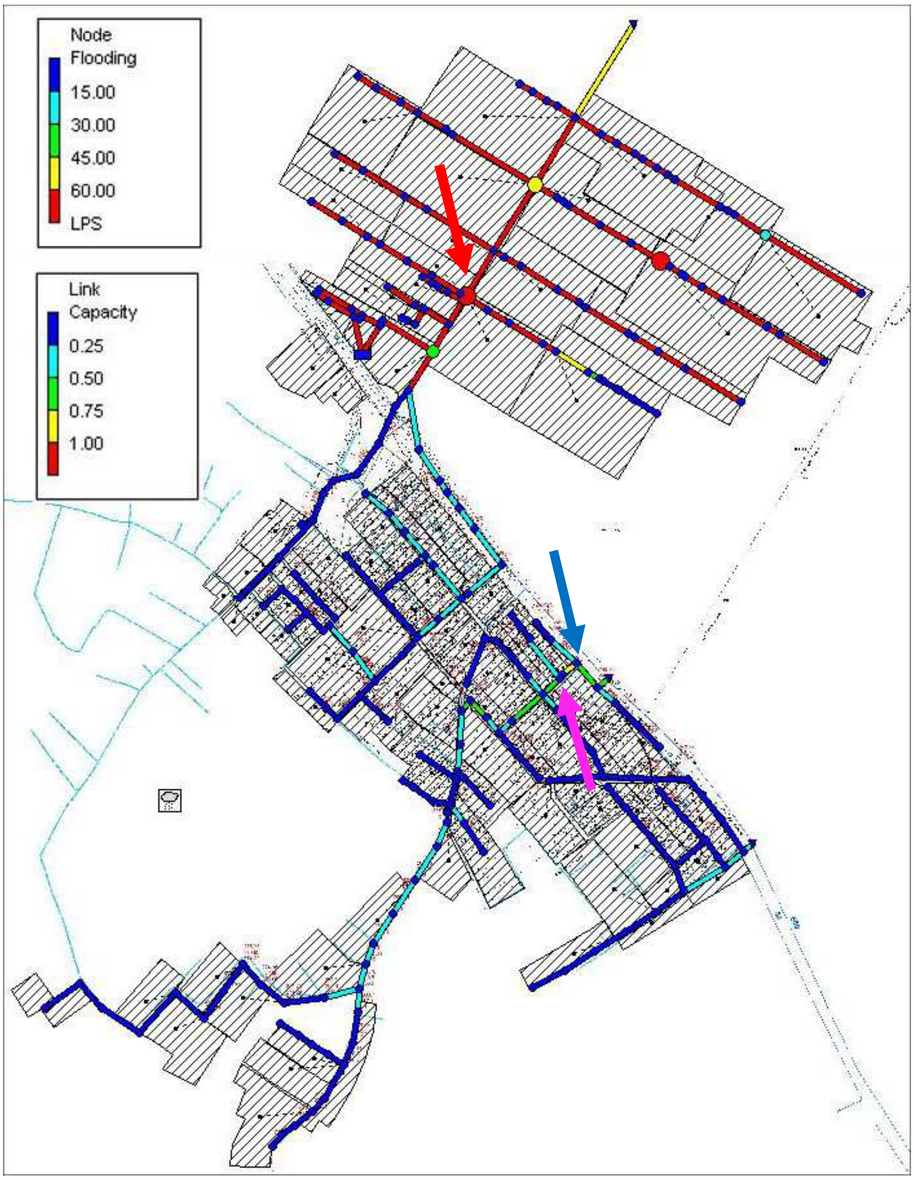


Figure 89: Node Flooding and Link Capacity of Scenario "Storm sewer – Open Channel" after 26min

5.3.5.3 Bottlenecks

The bottleneck of Scenario "Storm Sewer – Open Channel" is in particular manhole O_SS-A_5, indicated with the red arrow in Figure 89, and the dimension of the main collector of the storm sewer system in OHIS. In Pintija, the only bottlenecks which can be spotted are two conduits between the manholes B1 and B3 (blue and pink arrow in Figure 89) with Link Capacity of 84 % and 82 %, as already mentioned. The upstream and downstream conduits have a link capacity between 50 % and 75 % which may cause problems if waste and disposals are in the channel and in heavier storms.

5.3.5.4 Possible improvements

The possible improvements can be divided into two groups. One group which avoids and minimises storm water runoff in Pintija and OHIS and another which adapts the storm sewer system to the extent that no flooding develops at the event of a design storm.

Of course the former approaches would be more reasonable ecological and economic. The adaption of the storm sewer system in OHIS could also be done in two different ways. The first would be to build an open channel through OHIS for the storm water discharged from Pintija. The space for an open channel would be available on the OHIS premises. This can be seen in Figure 20 on page 34. The other possibility would be to rebuild the main storm water collector in OHIS with bigger dimensions. For the thesis this last-mentioned approach is chosen to avoid another sewer line without any proper information of elevations.

<u>Modification</u>

In SWMM the diameter of the storm water pipes in OHIS are modified until no flooding occurs. To reach this condition of this theoretical approach the changes listed in Table 29 would have to be carried out. In Figure 90 between the pink arrows the conduits C-SS-A_2 to C-SS-A_8 are located and between the blue arrows are the conduits C-SS-A_8_2.5 to C-SS-A_8_2.11.

Table 29: Comparison original and modified nominal diameter of the main collector pipes in OHIS

Conduit	DN original	DN modified	Conduit	DN original	DN modified
C-SS-A_2	500	600	C-SS-A_8_2.5	300	400
C-SS-A_3	500	600	C-SS-A_8_2.6	300	400
C-SS-A_4	500	600	C-SS-A_8_2.7	300	400
C-SS-A_5	600	800	C-SS-A_8_2.8	300	400
C-SS-A_6	600	1000	C-SS-A_8_2.9	300	400
C-SS-A_7	800	1000	C-SS-A_8_2.10	300	400
C-SS-A_8	800	1000	C-SS-A_8_2.11	300	400

Figure 90 displays node flooding and the link capacity of the modified sewer system of Scenario “Storm Sewer – Open Channel” after 26 min. In OHIS the storm sewer system still gets surcharged but this is tolerable. If the storm sewer system in OHIS really is to be rehabilitated, investigations on the elevations of the system are to be carried out by all means.

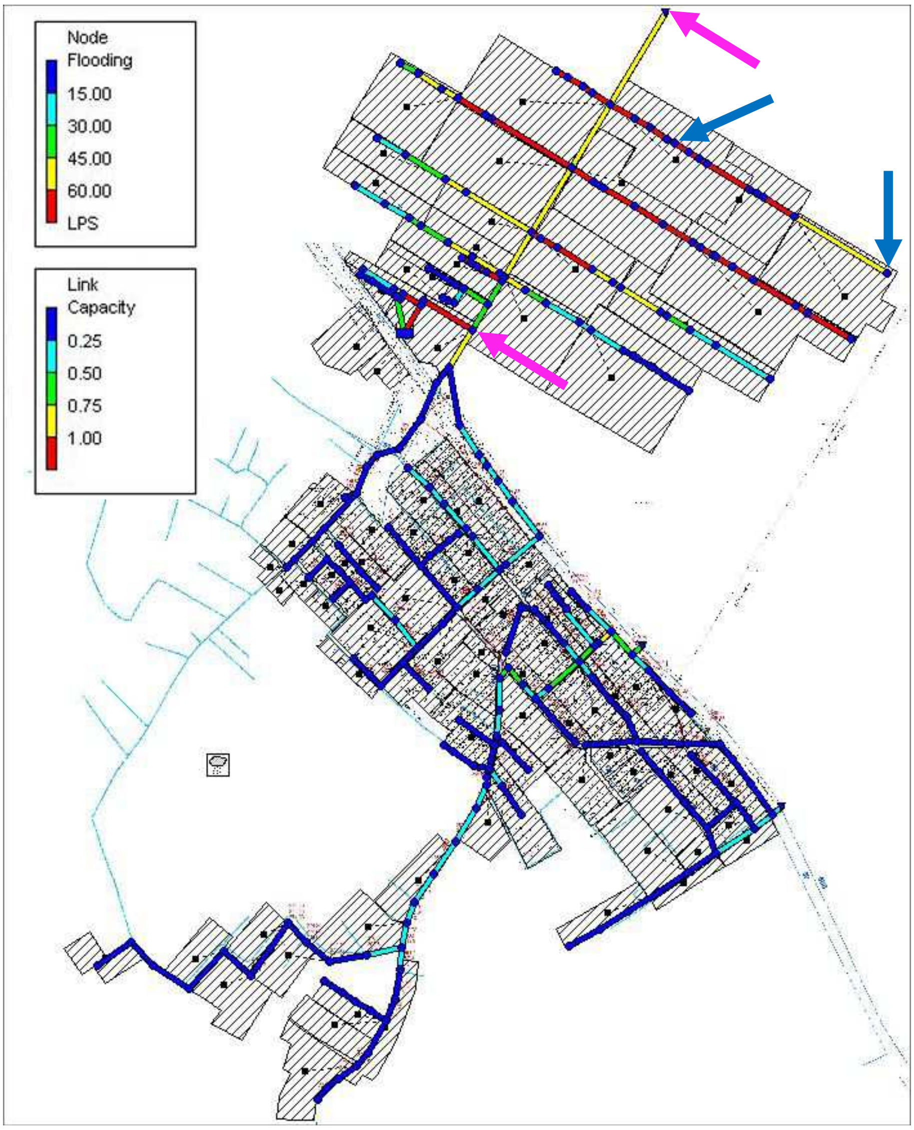


Figure 90: Node flooding and Link Capacity of the modified sewer system of Scenario “Storm Sewer – Street” after 26 min

The mass balance and the outfall loadings of the modified Scenario “Storm Sewer – Open Channel” is listed in Table 30 below.

Table 30: Mass balance modified Scenario “Storm Sewer – Open Channel”

Runoff	mm	Flow	m³
Total Precipitation	12.840	Dry Weather Inflow	0
Evaporation Loss	0.052	Wet Weather Inflow	2568
Infiltration Loss	7.940	External Outflow	2568
Surface Runoff	4.866	Internal Outflow	0
Final Surface Storage	0.000	Final Stored Volume	1

The Wet Weather Inflow equals the External Outflow and the Internal Outflow is zero. This shows that no flooding arises. Again the Final Stored Volume is practical zero. Of course, there are no changes in the runoff mass balance.

Of course, the Outfall Loadings from the outfalls in Pintija in Table 31 do not change. The modification only increases the outfall loadings at the OHIS outfall. The increase of the Total Volume equals the Internal Outflow of Scenario “Storm Sewer – Open Channel” in Table 25.

Table 31: Outfall loadings of the modified Scenario “Storm Sewer – Open Channel”

Outfall Loadings	Average Flow l/s	Max. Flow l/s	Total Volume m³
Out_SS = outfall OHIS	640.09	1588.00	2014
Out_west_receiving-w.	146.50	350.07	420
Out_east_receiving-w.	58.21	111.79	134
System	844.80	2049.16	2568

5.3.6 Scenario “Open Channel – Future Development”

The modification of the subcatchments are based on this modified sewer system of Scenario “Storm Sewer – Open Channel”. It should be clarified, if the modified system could also handle future developments or if even bigger diameters would have to be used for this theoretical approach.

5.3.6.1 Change percentage of impervious area

<u>Mass balance</u>

Accordingly, the increase of the percentage of impervious areas from 25 % to 35 % the Surface Runoff in Table 32 is naturally higher compared to the Scenario “Storm Sewer – Street”, although it is not exactly 10 % but 12.5 %. Furthermore, it is obvious that the Infiltration Loss is decreased, because less pervious area for infiltration exists. The Evaporation Loss is slightly higher in comparison to Scenario “Storm Sewer – Street”, which means the assertion that Evaporation Loss increases with the rise of the percentage of impervious area in 5.3.5.1 is correct. In the same way the Wet Weather Inflow is higher and flooding with a volume of 70 m³ appears.

Table 32: Mass balance scenario “Open Channel – Future Development” - change % impervious area

Runoff	mm	Flow	m³
Total Precipitation	12.840	Dry Weather Inflow	0
Evaporation Loss	0.058	Wet Weather Inflow	2888
Infiltration Loss	7.331	External Outflow	2819
Surface Runoff	5.472	Internal Outflow	70
Final Surface Storage	0.000	Final Stored Volume	1

The system’s total Outfall Loading increases by 10 % to 2819 m³ [Table 33] in comparison to the modified Scenario “Storm Sewer – Street” if the Internal Outflow (70 m³) is not included. If it is reckoned in, the increase is 12.5 % like the increase of the Surface Runoff. The Total Volume of the outfall Out_west rises from 420 m³ to 518 m³ 23 % and of the outfall Out_east even more. It increases form 134 m³ to 188 m³, which is a rise of 40 %. Likewise, the Maximal Flow increases at the same percentage. If the receiving water is small, this would have significant effects on it.

Table 33: Outfall loadings scenario “Open Channel – Future Development” - change % impervious area

Outfall Loadings	Average Flow l/s	Max. Flow l/s	Total Volume m³
Out_SS = outfall OHIS	708.13	1650.52	2113
Out_west_receiving-w.	189.77	396.58	518
Out_east_receiving-w.	84.86	156.67	188
System	982.76	2196.32	2819

Flooding

As already mentioned, the Total Flood Volume is 70 m³. As listed in Table 34 only one node is flooded.

Table 34: Flooded manholes scenario "Open Channel – Future Development"- change % impervious area

Node	Hours Flooded	Maximum Flooding Rate l/s	Time of Max Occurence hr:min	Total Flood Volume m³
B2	0.23	100.46	00:52	70

Manhole B2 is located between the previously stated links with link capacities higher than 80% in scenario "Storm Sewer – Open Channel and indicated with the red arrow in Figure 91. The link capacity of the storm sewer system and the flooded node are also illustrated in Figure 91. The surcharge of the storm sewer system in OHIS is tolerable and due to the rough assumptions of the impervious areas and the lack of elevation information of the sewer system need not be considered.

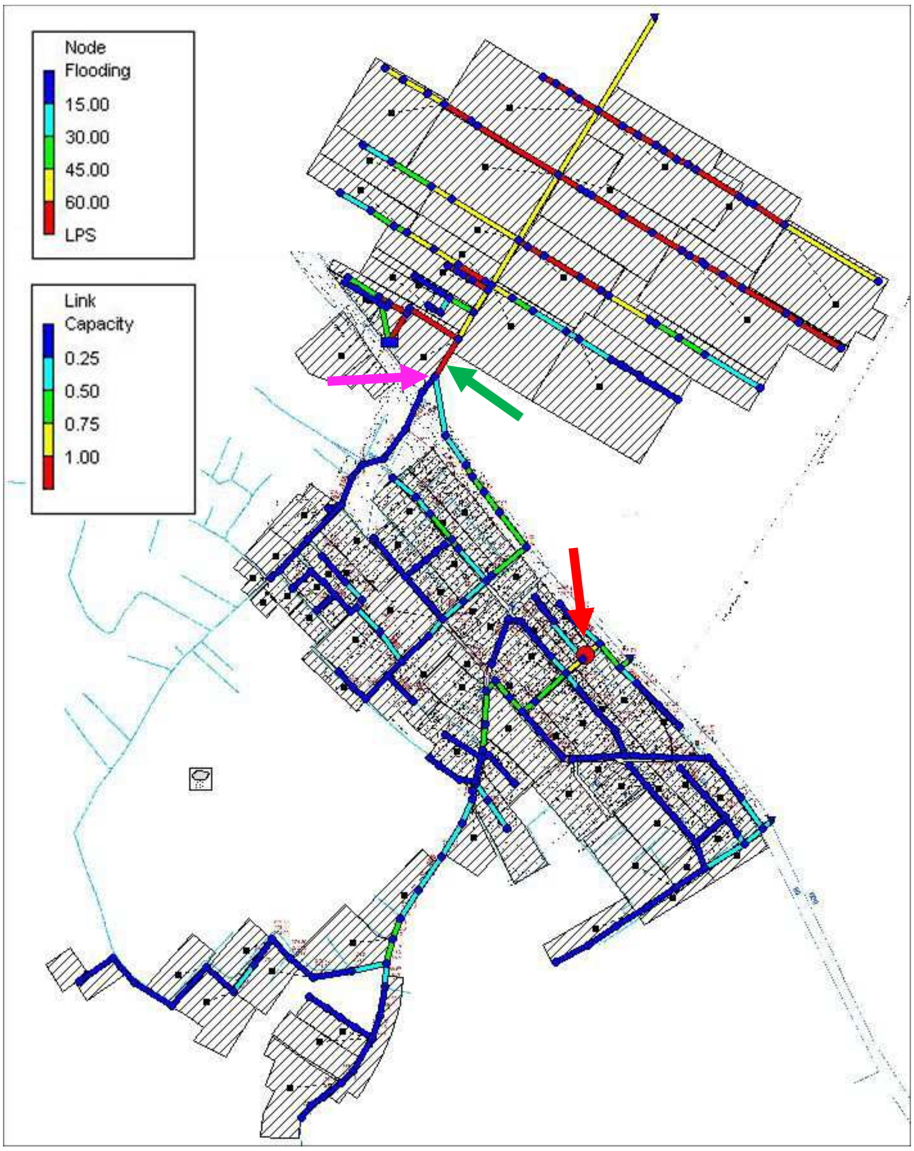


Figure 91: Node Flooding and Link Capacity of scenario "Open Channel – Future Development" - change % impervious area after 25 min

Bottlenecks

In Pintija the bottleneck is the node B2 (red arrow in Figure 91). The capacities of the links connected to B2 are 90 % and 89 %. As shown in Figure 92, flooding occurs at B2 only because of a terrain drop. Since the elevation is missing in the sewer system plan of Pintija it could easily be, that in reality no terrain drop exists and no flooding would arise. However, due to the decrease in slope, disposals are bound to occur and it can definitely become a bottleneck.

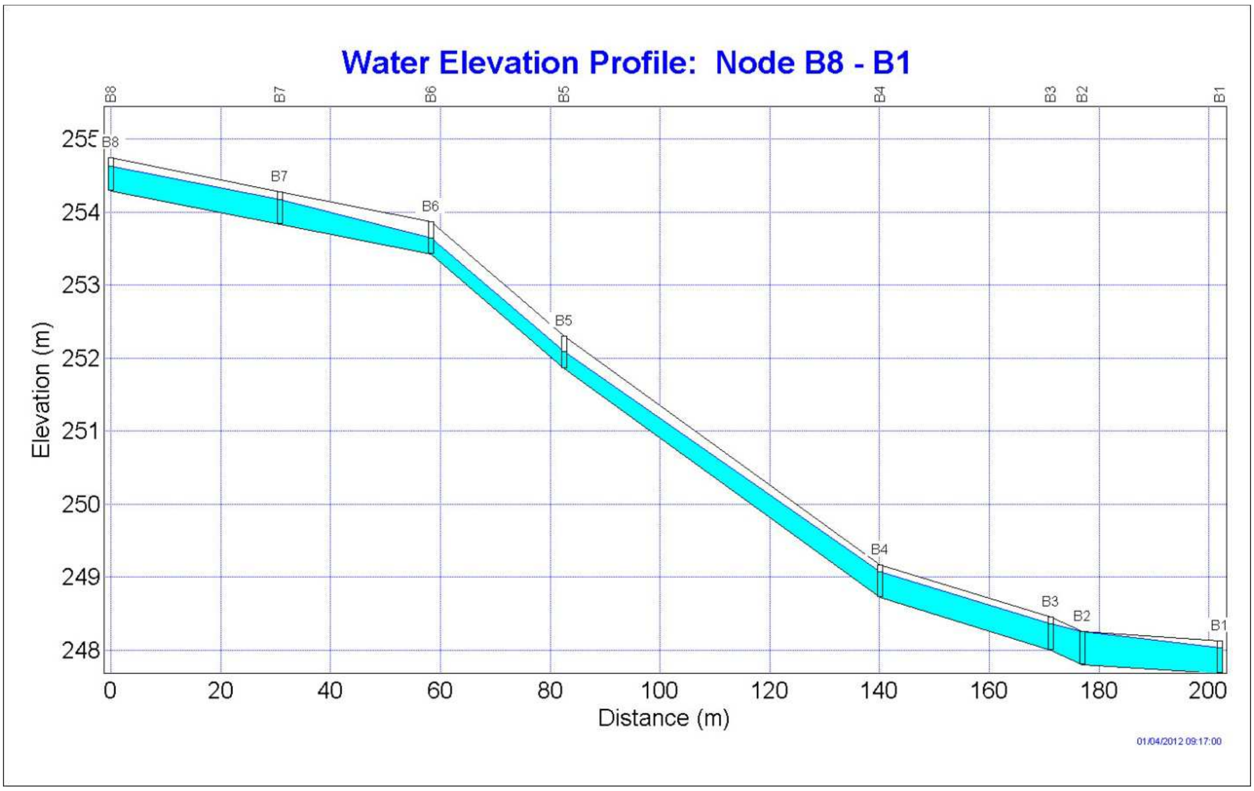


Figure 92: Water elevation profile node B8 – B1 with elevation drop scenario "Open Channel – Future Development" - change % impervious area after 25 min

As already mentioned the surcharge of the storm sewer system in OHIS is tolerable and need not be considered. However, the first link C-SS-A_1 (green arrow in Figure 91) after the connection to OHIS should be noted. It is part of the main collector and is primarily affected by the discharge of the subcatchments of Pintija. In this scenario it is already surcharged as well as manhole O_SS-A_1 (pink arrow in Figure 91). It could easily become to a significant bottleneck if disposals are part of the system or more discharge arises due to higher storm intensities.

Possible improvements

Due to the fact, that node B2 probably does not get flooded in reality because of the estimation of the elevation, but would probably become a bottleneck a approach should be found. First of all, the elevation of B2 would has be verified. If there is an elevation drop of the street, an attempt to decrease or remove it should be made. Nevertheless, it is recommended to construct the open channel from B4 [Figure 92] downwards with the next bigger precast sewer lining profile produced by the concrete factory. In the case of the concrete factory ROHLOFF (2011) this would be a 96x50x40 cm profile with a cross section area of 0.29 m². The cross section of this profile is only 0.08 m² bigger because of the decreased height in comparison with the previous one (45 cm). Unfortunately, no other more appropriate profiles are available. Profiles from other factories or purpose-built profiles could be used. The best possibility may be self made profiles for this small part of the storm sewer system.

In general, a solution would of course be a minimisation of the impervious areas, on site infiltration and the implementation of SUD.

5.3.6.2 Additional subcatchments

Mass balance

The Internal Outflow in Table 35 indicates that due to the expansion of subcatchments flooding of 98 m³ in the system arises.

Table 35: Mass balance "Open Channel – Future Development" - additional subcatchments

Runoff	mm	Flow	m³
Total Precipitation	12.840	Dry Weather Inflow	0
Evaporation Loss	0.046	Wet Weather Inflow	3188
Infiltration Loss	8.394	External Outflow	3088
Surface Runoff	4.418	Internal Outflow	98
Final Surface Storage	0.000	Final Stored Volume	1

The outfall loadings will be analysed after the elimination of the bottlenecks and flooding. After this, the results can be compared with the modified Scenario "Storm Sewer – Open Channel".

Flooding

As a result of the additional subcatchment in Pintija manholes in OHIS get flooded [Table 36]. Affected are the two first manholes after the connection to Pintija, whereas the flooding of manhole O_SS-A_2 is not significant with 2 m³. The other two manholes in OHIS also get only flooded by 2 m³ in total. On the contrary, manhole O_SS-A_1 1 (pink arrow in Figure 91) has a high Total Flood Volume. At node B2 flooding appears. It nearly equals the amount when changing the percentage of impervious area (70 m³).

Table 36: Flooded manholes "Open Channel – Future Development" - additional subcatchments

Node	Hours Flooded	Maximum Flooding Rate l/s	Time of Max Occurence hr:min	Total Flood Volume m³
B2	0.13	30.91	00:53	45
O_SS-A_1	0.19	132.92	00:55	73
O_SS-A_2	0.06	23.44	00:55	2
O_SS-A_2_1.1	0.06	9.26	00:54	2
O_SS-A_2_1.2	0.05	16.28	00:54	2

Bottlenecks

In addition to node B2 (red arrow in Figure 91) also manhole O_SS-A_1 1 (pink arrow in Figure 91) with its connections is a bottleneck when connecting additional subcatchments, as already forecast previously. If the flooding at O_SS-A_1 is eliminated, the following manholes should not be flooded any more.

Possible improvements

The same approach for possible problem solutions as previously mentioned can be applied. Following the problem of the terrain drop at node B2 is alleviated and the capacity of the open channel at this bottleneck section checked. For the manhole O_SS-A_1 the diameter of the following link is modified until no flooding occurs any more.

Modification:

The new node elevation of B2 is 248.10 m and of B3 248.20 m [Figure 93]. After this change the node B2 is not flooded any more [Figure 93]. The link capacity of the links C-B2, C-B3 and C-B4 is 81%. Again, due to the rather high link capacity it seems reasonable to use a bigger profile at this part of the storm sewer system.

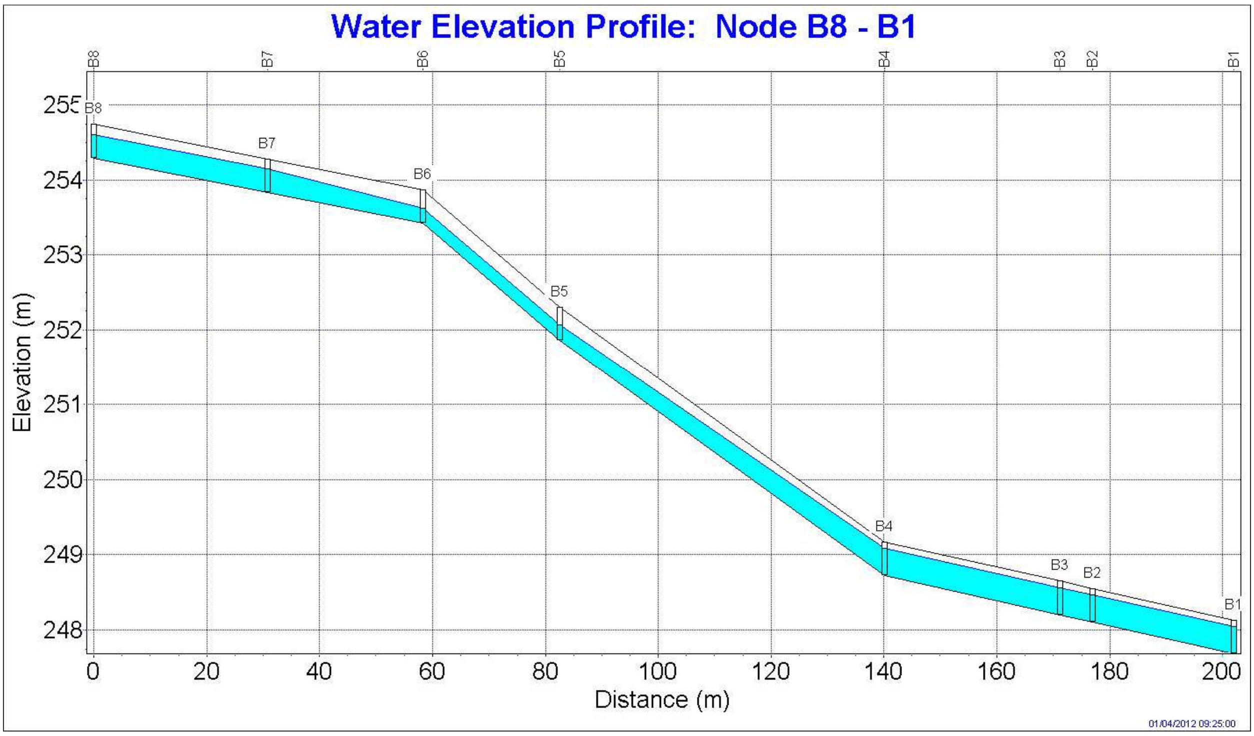


Figure 93: Water Elevation Profile Node B8 – B1without elevation drop "Open Channel – Future Development" - additional subcatchments

The theoretical approach of modifying the pipe diameters of the main collector in OHIS to avoid flooding are listed in Table 37 in comparison with the original diameters of Scenario "Storm sewer – Open Channel", the modified diameters of Scenario "Storm sewer – Open Channel" and the new modified ones of this future scenario with the additional subcatchments. The modified conduits are located between the pink arrows in Figure 90 on page 104.

Table 37: Comparison original and modified nominal diameter of Scenario "Storm Sewer – Open Channel" and "Open Channel – Future Development" - additional subcatchments

Conduit	DN original	DN modified	DN additional subcatchments
C-SS-A_2	500	600	800
C-SS-A_3	500	600	800
C-SS-A_4	500	600	800
C-SS-A_5	600	800	1000
C-SS-A_6	600	1000	1000
C-SS-A_7	800	1000	1100
C-SS-A_8	800	1000	1100

Again, this is only a very rough estimation of the dimensions. Accurate system data must be used for more precise results.

In Table 38 the Outfall Loadings with the modified main collector in OHIS are listed.

Table 38: Outfall loadings of the modified "Open Channel – Future Development" - additional subcatchments

Outfall Loadings	Average Flow l/s	Max. Flow l/s	Total Volume m³
Out_SS = outfall OHIS	829.47	2004.39	2482
Out_west_receiving-w.	180.79	414.08	497
Out_east_receiving-w.	92.21	174.10	209
System	1102.48	2591.78	3188

The Total Volume of the system increases by 24 % in comparison with the modified scenario "Storm sewer – Open Channel". The receiving water would have to receive 152 m³ more, and the Maximal Flow increases at outfall Out_west 18 % and at Out_east 56 % due to a large number of future developments discharging to Out_east. The Maximal Flow at outfall Out_SS is about a quarter higher than in the modified Scenario "Storm Sewer – Open Channel" and the Average Flow about a third. The Average Outflow increases by 23 %at Out_west and by 58 % at Out_east As stated previously, the receiving water has to be checked beforehand.

5.3.7 Sensitivity analysis

The sensitivity analysis is also based on this modified sewer system of Scenario "Storm Sewer – Open Channel". As mentioned before, the infiltration values are changed until a reasonable quantity of surface runoff is generated from pervious areas and afterwards Manning's roughness coefficient for the pervious subareas, the slope of the subcatchments and the depth for the depression storage for impervious and pervious subareas are modified. Without surface runoff from pervious areas it would not be possible to see an effect of a changing quantity due to the modification of Manning's roughness coefficient for pervious areas and the depth of depression storage for impervious areas.

First of all, the model is run with an initial infiltration capacity of 84 mm/h, a final infiltration capacity of 9.5 mm/h and a decay value of 4.14 for moist sandy soils with dense vegetation. Table 39 shows the mass balance.

Table 39: Mass balance Sensitivity analysis f_0=84 mm/h, f_f=9.5 mm/h and k=4.14

Runoff	mm	Flow	m³
Total Precipitation	12.840	Dry Weather Inflow	0
Evaporation Loss	0.052	Wet Weather Inflow	2568
Infiltration Loss	7.940	External Outflow	2568
Surface Runoff	4.866	Internal Outflow	0
Final Surface Storage	0.000	Final Stored Volume	1

According to the mass balance the change of the Horton infiltration values does not have an effect on the infiltration and still no surface runoff from previous areas is generated. The mass balance equals the mass balance of the Scenario "Storm Sewer – Open Channel". Consequently, lower infiltration capacities have to be applied [Table 40].

Table 40: Horton parameters Sensitivity analysis

Source	Soil description	f_0 mm/h	f_f mm/h	k 1/h
AKAN (1993a); AKAN (1993b)	Moist sandy soils with dense vegetation	84	9.5	4.14
	Moist sand soils with vegetation*	64**	7.6***	4.14
AKAN (1993a); AKAN (1993b)	Moist sandy soils with little or vegetation	43	7,6***	4.14

* Soil description by the author.

** The initial infiltration capacity f_0 of 64 mm/h is the mean from moist sandy soils with dense vegetation (84 mm/h) and little or no vegetation (43 mm/h).

*** According to AKAN (1993b) sand, loamy sand and sandy loam has a final infiltrations capacity of 7.6 – 11.4 mm/h. 7.6 mm/h is used because it is the worst infiltration capacity and therefore more surface runoff is generated.

Of course, Pintija is a residential area with a lot of gardens. However, with the values of little vegetation the effects of the soil compaction and the thin silt layers, which can seal the ground, should be taken into account. Furthermore, as already aforementioned, the effects on changing subcatchment parameters on the surface runoff from pervious areas should be detected and therefore surface runoff has to be generated.

Table 41 shows differences in the mass balance in comparison to the previous one. The second run with the initial infiltration capacity f_0 of 64 mm/h and a final infiltration capacity f_f of 7.6 mm/h eventually generates surface runoff from previous subareas. As mentioned in 5.3.5.1, the runoff coefficient in the status report would also show the existence of surface runoff.

Table 41: Mass balance Sensitivity analysis with f_0=64 mm/h, f_f=7.6 mm/h and k=4.14

Runoff	mm	Flow	m³
Total Precipitation	12.840	Dry Weather Inflow	0
Evaporation Loss	0.062	Wet Weather Inflow	2610
Infiltration Loss	7.855	External Outflow	2610
Surface Runoff	4.944	Internal Outflow	0
Final Surface Storage	0.000	Final Stored Volume	1

The surface runoff and consequently the Wet Weather Inflow as well as the External Outflow are slightly higher. No flooding arises, the internal outflow is cero. The Wet Weather Inflow increases to 2610 m³, which is only a very slight increase of less than 2 %. This cannot be applied to the third run [Table 42].

Table 42: Mass balance Sensitivity analysis with f_0=43 mm/h, f_f=7.6 mm/h and k=4.14

Runoff	mm	Flow	m³
Total Precipitation	12.840	Dry Weather Inflow	0
Evaporation Loss	0.077	Wet Weather Inflow	3130
Infiltration Loss	6.856	External Outflow	3036
Surface Runoff	5.930	Internal Outflow	96
Final Surface Storage	0.000	Final Stored Volume	1

The External Outflow rises by 18 % in comparison to the first run and flooding of 96 m³ appears. Consequently, it has more effect on the outfall loadings than the 10 % increase of the impervious areas. When the runoff results in the status report of both simulations are checked, this also becomes obvious. Due to the change of the initial infiltration capacity all subcatchments in Pintija have higher runoff coefficients than 35 %. The flooding of 96 m³ arises at the node B2.

This simulation with an initial infiltration capacity of 43 mm/h is now adapted with the different parameters for the sensitivity analysis of the model. The following diagrams are the compilation of the results of the sensitivity analysis [Figure 94 and Figure 95]. Figure 94 illustrates the changing in the surface runoff of subcatchment M.17.1. (0.76 ha) and Figure 95 the maximal outflow loading of the different outfalls when the parameters for Manning's roughness coefficient, the subcatchments' slope as well as the depth of the depression storage for pervious and impervious areas are modified.

The surface runoff curve with the initial infiltration capacity of 84 mm/h has the same shape as already illustrated in Figure 86 on page 97. No surface runoff from pervious areas arises. With an initial infiltration capacity of 63 mm/h only at the end of the rain event surface runoff from pervious subareas are generated. Pervious subareas with an initial surface runoff capacity of 43 mm/h develop surface runoff already shortly after the impervious areas. The initial infiltration capacity of 43 mm/h was used as initial infiltration capacity when changing other parameters as already mentioned. Consequently, the blue curve is the same in all four diagrams. The first parameters shown in the keys are the ones used for the simulations of all the scenarios. In comparison to the diagrams of the initial infiltration capacity and Manning's roughness coefficient the slope also changes the surface runoff of the impervious subareas. Certainly the steeper the subcatchment, the faster surface runoff is developed. Without doubt, the diagram of the depression storage is not in line with the others. Although the red curve is shaped similarly to the red one from the initial infiltration capacity but the surface runoff with the depression storage depth of 3.0 mm at pervious and 5.0 mm at impervious subareas has a completely different shape.

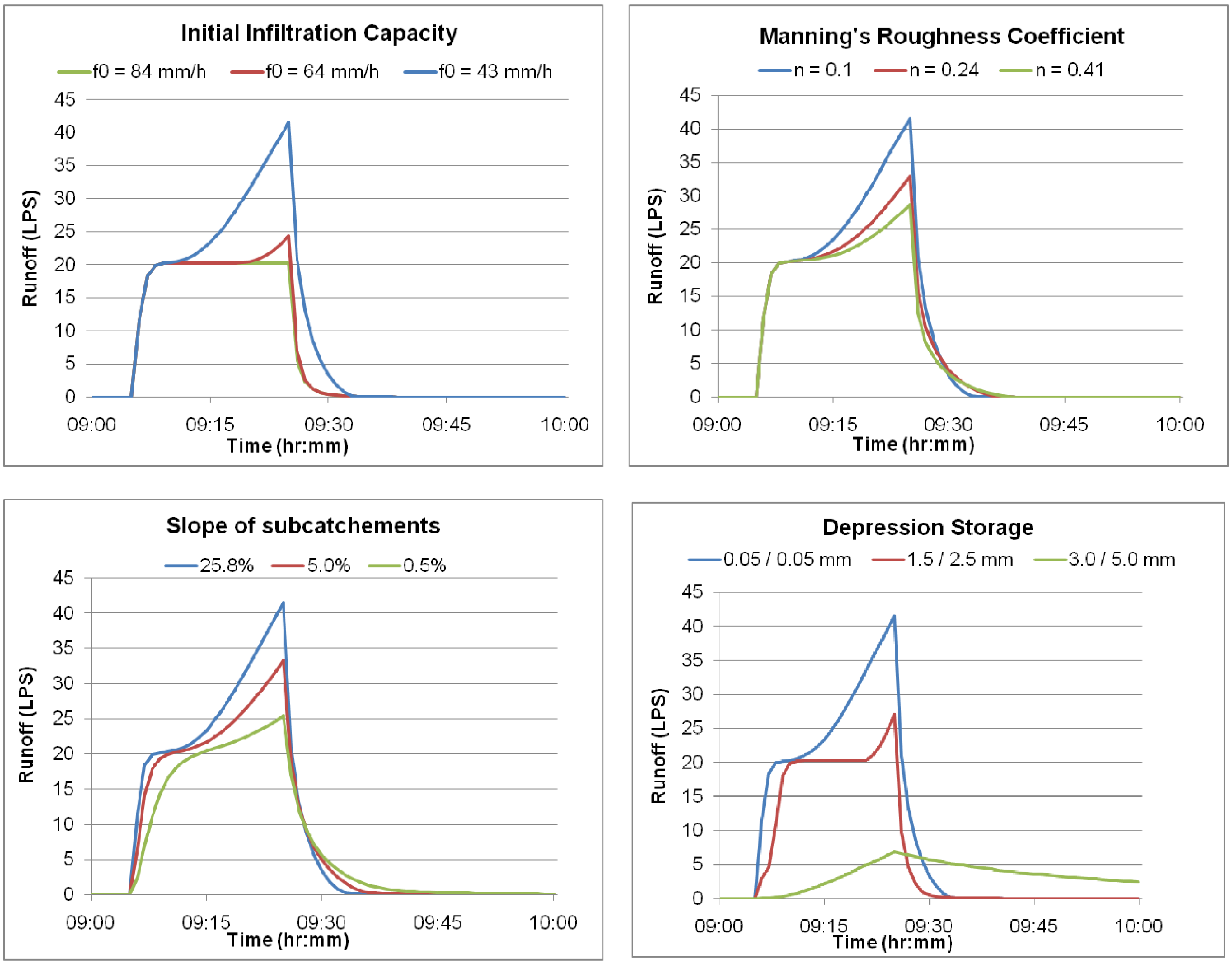


Figure 94: Change of the surface runoff (l/s) due to the sensitivity analysis of subcatchment S17.1

Looking at the first diagram of Figure 94, the biggest impact of modifying the initial infiltration capacity can be spotted on the outfall “Pintija east”. The maximum outfall loading increases by about 80 % when the capacity is 63 mm/h and not 43 mm/h. The outfall loadings of the other two outfalls raise considerably less. At outfall “Pintija west”, it increases only by about 6 % and at the outfall of OHIS 11 %. The reason for these differences is hard to define; maybe it is due to the difference in flow times and/or the percentage as well as the size of the catchment’s impervious and pervious areas. The catchment with the longest flow time discharges to the western outfall of Pintija. In all runoff diagrams the outflow at the western outfall of Pintija has the smallest variation. By modifying Manning’s roughness coefficient and the slope of the subcatchment nearly no change in the outfall loading occurs. The variation of slope of the subcatchments has more impact at lower levels than at higher ones. Again, the biggest effect can be seen at the eastern outfall of Pintija, to which the smallest catchment is connected and which has the shortest flow time. As already seen in Figure 94, the modification of the depth of the depression storage has the most significant effect. Especially the outfall of OHIS shows a considerable decline of the outfall loading. The subcatchments of OHIS have big impervious areas. This could mean that particularly the depth of the depression storage of impervious areas has the biggest impact on the surface runoff.

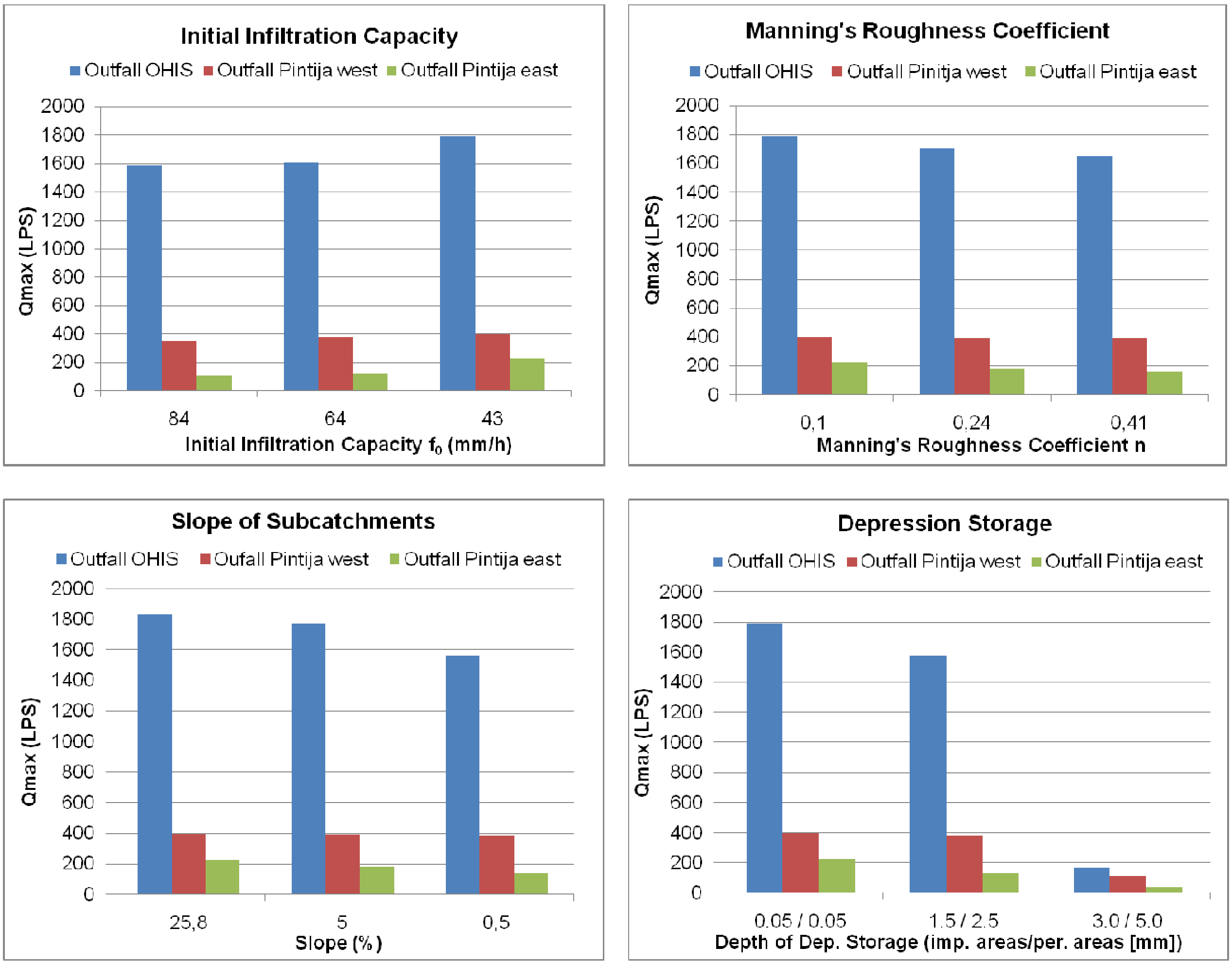


Figure 95: Change of the maximal outflow (l/s) due to the sensitivity analysis

With the results of the sensitivity analysis the depth of the depression storage of impervious areas is the most sensitive parameter of the ones used for this analysis. In second place is the slope of the subcatchment, followed by the initial infiltration capacity and Manning's roughness coefficient of pervious areas. Thus, the change of the slope affects both the impervious and pervious areas. The impact on the depth of depression storage from impervious areas is hard to define in the simulation. It would be advantageous to make separate analyses for both depths. Other parameters which could also be checked are Manning's roughness coefficient for conduits and the width of the subcatchments.

These results point out that the sensitivity of the parameters also depends on the characteristics of the catchments. Especially the percentage of impervious areas is significant and parameters which affect the surface runoff of impervious areas should be focused on.

5.4 Sewer database

The sewer database can be found in Appendix A. The master data used in the SWMM 5 model are listed. The basis is the Project Details of the model in SWMM 5. The database contains three different lists. The first one includes the master data of the manhole. It lists the ID of the manholes and two invert elevations, when the manhole is a drop manhole and a second conduit is connected with a higher invert elevation. Furthermore, the depth of the manholes is stated. The second list contains the master data of the reaches. It notes the ID of the conduits as well as the inlet and outlet manhole, the length, the shape, the diameter and the material of the conduits. The third list comprises the master data of the subcatchments. It includes the ID and the outlet of the subcatchments as well as the area.

The fields of the lists for the manholes and the reaches are coloured differently. White fields state, that the values were obtained, light grey fields indicate that the values had to be estimated and dark grey fields include master data from informal manholes and reaches. Therefore, also the location and the number of manholes of informal sewer lines had to be estimated. The ID of the manholes and reaches are assigned by the author and the fields are also white.

6. Discussion

6.1 Remarks

6.1.1 Collection of data

Data collection is the first step for the setup of a hydrodynamic model. It is the basis and therefore has to be well planned and carried out accurately. All mistakes made at this stage have consequences for the model results. Delays in the setup due to troubleshooting can lead to additional costs. Unnoticed errors can have further consequence on increasing project costs. Consequently, it is important to schedule enough time for the acquisition of data. Naturally this is very time-consuming. In the case of this master thesis the fact of not knowing the language of the data obtained was an additional challenging and prolonging circumstance. A lot of the data had to be translated, which is a time-consuming process. Furthermore, it is also very helpful to speak the language to talk with the inhabitants because they have often good knowledge of the sewer system. Without the need of a translator the locals are probably more sociable and more information can be gained.

The two months research stay was an accurate time framework for the collection of data needed for the setup of the model. The fieldtrips were essential to find out the current state of the sewer system and to determine contributions between plan and reality. It also showed that cultural aspects lead to problems, like the Ajvar protection explained before. The public has to be briefed and sewer cleaning should be common practice instead of emergency cleaning. However, a lot of data is missing and the data obtained has a lot of gaps and is often not up to date.

6.1.2 Hydrodynamic modelling

Apart from the advantage that SWMM 5 is a non-proprietary government model, easily available for free from the internet as well as the extensive manuals, SWMM 5 additionally has advantages in learning this particular computer model. It is widely used and accepted and for this reason many proprietary models are based on these government models. They are used either in a direct manner (through the use of preprocessors and postprocessors) or indirectly (by using the same methods and algorithms) (AKAN & HOUGHTALEN, 2003).

The quality of a model and simulation always depends on the quality of the input data. Large numbers of estimations had to be made for missing data and gaps in the data which make the results weak. Many of the data must be reviewed, updated and gathered, before the model can be used for further investigations on the basis of this model. As CARDOSA et al. (1999, as cited in (FENNER, 2000)) point out, the accuracy of any methodology cannot be greater than that of the original information about the networks state variables. Models which perform largely on default values and assumed values can produce misleading results. Furthermore, the design or record drawing information may often be inaccurate when checked against field data and so should not be relied upon when creating models as this may not be a true representation of the system in reality (FENNER, 2000).

A certain weak and critical point of the model is the precipitation. It is the driving impact for all hydrological processes and the most important input parameter for the runoff calculation and modelling of hydrodynamic models (NIEMCZYNOWICZ, 1999). The precipitation data obtained are not satisfactory. The intensity-duration-frequency (IDF) curve used for the simulations dates from 1965 and the intensity is converted into a block rain. DE TOFFEL (2006) states, that the precipitation format of block rains is only useful for quick first checks of the drainage system and not appropriate for investigations of the system’s behaviour. However, no rain series and characteristic rain events for Pintija could be gathered. In general, single event simulations are first used for the model calibration and verification. The selected events are based on the study objective. If the aim of the study is flood control design then for example relatively large single events are selected. After the model's calibration with single events, continuous simulation of several years can be applied to derive the frequency statistically. However, because continuous events are normally only used for a rough representation of the drainage system, final design may need single event simulation (HUBER, 1986, as cited in (TSIHRINTZIS & HAMID, 1998)). Another factor of the precipitation is the climate change. The IDF curve obtained is nearly 50 years old and naturally the intensity could have increased and it will also increase in the future. Updated precipitation data are of great importance if the model is to be used for more accurate studies.

One of the roughest estimations made for the setup of the model was the basic assumption that Pintija's subcatchments consist of 50 % houses and 50 % gardens. Definitely, this estimation has a significant impact on the total volume of runoff. The impervious fractions of land use suggested by ZAMAN and BALL (1994, as cited in (CHOI & BALL, 2002)) are shown in Table 43. With these assumptions they achieved reliable results in their study. The basic estimation for the thesis of 50 % impervious seems a bit high in comparison to the values of ZAMAN and BALL, especially for the informal parts of Pintija, where the settlement is of low density. However, due to the assumption that 25 % of the roof runoff is discharged into gardens and the street areas are not included in the subcatchments of the model, the impervious fraction is probably too low in the model. It must definitely be clarified, from which impervious areas surface runoff is discharged into the sewer system. In OHIS the percentage of imperviousness was estimated for each subcatchment on its own and due to the information of the sewer system plan of OHIS it is clear, that all the roof runoff is discharged into the storm sewer system. The average value for all subcatchments of OHIS is 50 %, but again no streets are included. When also counting in the latter, the value could be surprisingly close to the value of Table 43.

Table 43: Imperviousness of land use after ZAMAN and BALL (1994, as cited in (CHOI & BALL, 2002))

Land use	Impervious fraction	Land use	Impervious fraction
Low density residential	37 %	Commercial	55 %
Medium density residential	45 %	Industrial	55 %
High density residential	55 %	Special use	55 %

Without doubt the investigation of accurate values would be one of the most important ones, if the model is to be used for further projects.

The model's sewer system is also developed with a lot of estimations due to data missing. In OHIS no elevation data of the sewer system was available at all and the ones from Pintija have gaps. Furthermore, informal sewer lines are part of the model, for also all input parameters had to be assumed. The location of the manholes had to be estimated as well. The pipe diameter could be gathered in OHIS, in Pintija somewhere lacking. However, contradictions between plan and reality are common and the elevations and pipe diameters have to be checked too. When checking the pipe diameter the condition of the manholes and pipes as well as the material of the pipes should also be inspected. Additionally, the connection situation of the sewer line on the eastern part of Pintija at the road Prvomajska (between manhole B1 and B1_2.1_1.4) is open and has to be clarified.

Another important fact is that the model assumes perfect operational conditions. It does not take into account any disposals, ingrowth of roots or damages. Furthermore, the model is not calibrated and no presentable verification is done for the simulations. Consequently, the validity of the result cannot be guaranteed. However, the model reflected the flooding at the manholes where the bypasses where constructed and at another manhole in Pintija, which was pointed out by an inhabitant. This shows that the model could be used for the basis of other investigations, if the input data are improved.

Sensitivity Analysis

Parameter estimation is always a difficult task especially because input parameters can vary significantly depending on the characteristics of the catchment (TSIHRINTZIS & HAMID, 1998). The sensitivity analysis examines the sensitivity of the model when different model parameters are changed. Since it is not possible to measure data, a calibration of the model cannot be carried out. With the help of a sensitivity analysis it can at least be checked to what extent the changing of parameters influence the model and its results. In this work the change in the outfall loadings and surface runoff was analysed. The result was that the depth of the depression storage of the impervious area is the most sensitive one. This corresponds to the results of the research from TSIHRINTZIS and HAMID (1998). They also found out that the impervious depression storage is the most sensitive parameter followed by the Manning's roughness coefficient of conduits and pervious subareas, the infiltration coefficients and, finally, the pervious depression storage. Of course, the percentage of impervious areas would also have great impact on the total volume of runoff, but as this is obvious it was not inlcuded in this sensitivity analysis.

The default values of SWMM 5 for the infiltration parameter are the following: 3 inch/h (76 mm/h) for the initial infiltration capacity, 0.5 inch/h (13 mm/h) for the minimum infiltration capacity and the decay factor is 4. These values are quite plausible despite SI metric units are used and the modeller converted them from US customary to SI metric units on his/herself. At SWMM 5 the default units are the U.S. customary and not the SI metric ones. Changing the units does not mean that the default values are converted automatically. The best approach indeed would be to make some in situ infiltration tests to achieve some accurate values. The default value for the Manning's roughness coefficient is 0.1. With this value the model is on the save side because with smaller values more surface runoff is generated from pervious areas. The default value of the slope (0.5 %) should be changed, despite the fact that the catchment is really flat. However, there is no need for very accurate values. The sensitivity analysis showed that there is not a lot difference in the maximal outfall and surface runoff between the values of 5 % and 25.8 %. On the other hand the analysis made clear that the impervious depression storage should be considered carefully. The default values are for both impervious and pervious subareas 0.05 inches (1.3 mm). According to Huber and Dickson (1988 as cited in (AKAN & HOUGHTALEN, 2003) an initial loss estimated of 0.1 inch (2.5 mm) for impervious areas and 0.2 inch (5.1 mm) for pervious areas is a reasonable estimate for this value. Due to the fact that SWMM 5 does not convert the default values into SI metric units when changing the unit type at the icon on the bottom of the SWMM 5 interface, all the simulations made with the small value of 0.05 mm impervious and pervious depression storage by mistake. However, with these values the results are on the safe side because more surface runoff from the subcatchments is discharged. Without doubt this is not a big issue since the percentage of impervious areas is only estimated very roughly and the results of the model are only first reference points for further investigations and simulations.

If a calibration of the model is not possible, the modeller should – to be on the safe side – choose values for the infiltration parameters and other parameter with influence on the surface runoff of pervious areas in a range that at least some surface runoff is generated.

6.1.3 Sewer database

The database created in connection with this thesis was to be only a collection of data obtained as a basis for a reliable and consistent database which is, without doubt, a basic requirement for sewer management. Considerable efforts need to be made by all institutional actors in standardising data records. This is very important when sewer information systems should be used in a widespread manner. A number of complex issues relating to naming variables, classifying objects as well as distinguishing differences in dimensions of variables often need to be solved. However, the lack of information and standardisation on which to implement meaningful analyses of the system performance is common to many (though not all) cities in Europe, Australia and North America (FENNER, 2000).

6.2 Conclusion

The situation in Pintija and OHIS is not state of the art and should be improved as soon as possible. The implementation to connect Pintija to a main WWTP of Skopje will probably take at least one more decade. To guarantee the protection of the river Vardar and the environment of Pintija and OHIS a rehabilitation of the OHIS WWTP is to be carried out as fast as possible and it must be assured, that all waste water from OHIS and Pintija is treated before discharged into the river Vardar.

At present the flooding in Pintija is a result of the lack of a storm sewer. The storm water from roofs are discharged either informally into the sanitary sewer, directly onto the streets or into gardens. During storm events the sanitary sewer system is surcharged and flooding occurs. Additionally, a lot of surface runoff is conveyed onto the street to the road Prvomajska. As a result of the terrain level the surface water of the western part from Pintija is conveyed onto the road Prvomajska in the direction of the OHIS premises where the parking lot is located. The flooding of this part of the premises – the reason for this work – is the result of surface water from Pintija additionally to the storm sewer surcharge in OHIS in heavy storms. The surcharge of the storm sewer of OHIS is also a result of the connection of the sanitary sewer of Pintija to the storm sewer of OHIS via bypasses. Another reason is blockage through waste disposal into the sewer system by the inhabitants of Pintija. This leads to flooding also in dry weather periods (N.N., 2012a).

To change this unsatisfactory situation a storm sewer has to be constructed in Pintija. Furthermore, the inhabitants have to be instructed by the authorities to alter their behaviour to make the development a functioning sanitary sewer system possible. In Pintija the existing sanitary sewer should have sufficient dimensions to discharge the current sanitary water load. Probably can also handle future development assuming the removal of faulty connections and bottlenecks as well as a functioning and preferably demand oriented sewer management is established. The basis for these measures is condition detection and assessment and the creation of a sewer information system. The thesis conveys that a relatively small open channel (60x45x40) would be adequate to convey 25 % of the storm water via three outfalls to the receiving water. The streets of Pintija are definitely wide enough to place this open channel. The authorities have to counteract the well-known problem, that the open channel could be used for waste disposals. Again the residents have to be briefed and instructed. If this does not work, a possibility would be to cover the channel with perforated steel. On the one hand, the channel could then be driven on, but on the other hand, waste is not seen and the big advantage of the open channel is lost. The outfalls of the eastern part of the storm sewer could be placed at a nearby brook. Of course, if this is the case, the hydraulic and environmental conditions of it have to be checked and the legal regulations have to be met. Another option would be to convey the storm water of the eastern part via open channels to the WWTP of OHIS, like it should be done for the western part of Pintija. The WWTP has two huge primary settling tanks. One of them (~ 5000m^3) could be used as a storm water tank with the advantage that also the storm water is treated before being discharged into the river Vardar. In a storm event with an intensity of 107 l/s*ha in the study area with the assumed subcatchments and its parameters as well as the estimated land use a total surface runoff of about 2600 m^3 is generated. For OHIS it is suggested that the storm sewer should be used as a combined sewer. Therefore, a storm water tank is also necessary. The big benefit of a combined sewer system in OHIS is that the faulty connections need not to be removed. Additionally, the sanitary sewer can be kept in operation. Again, a condition detection and assessment are the basis for this and the legal framework has to be met for the use of a storm water tank. As already mentioned, this solution brings the big advantage of also treating the storm water which is according to LEE and JONES-LEE (1994, as cited in (TSIHRINTZIS & HAMID, 1998)) the third largest source of pollution of rivers.

In order to construct and especially maintain the sewer system the fees for the public waste water service have to be increased considerably.

7. Summary

The background of this work is a bilateral research project based on a WTZ - Scientific and Technological Cooperation between Austria and the Republic of Macedonia. Within this framework collaboration between the Institute of Sanitary Engineering and Water Pollution Control of the University of Natural Resources and Life Sciences in Vienna with the Faculty of Technology and Metallurgy of the Ss. Cyril and Methodius University in Skopje was developed. The cooperation began in May 2011 with the title “A New Scientific Approach for Improvement and Appropriate Management of Wastewater Systems in the Republic of Macedonia“. The collaboration included both theoretical aspects as well as practical examples and four workshops were held. The start of the thesis was the second workshop in Vienna in February 2012. Between the second and third workshop a two month research stay (16.4.2012 – 15.6.2012) was carried out and at the last workshop in Vienna in March 2013 results of the thesis were presented. The cooperation ended at the end of April 2013.

For the practical examples of the research project the waste water treatment plant of OHIS (Organic Chemical Industry Skopje) in the suburbs of Skopje with its sewer system and the connected sewer system of the nearby settlement of Pintija (about 2500 inhabitants) was selected. The reason for this choice is the issue of frequent flooding at the OHIS premises, especially at the traffic area in front of the office building, and in the settlement of Pintija. Furthermore, the WWTP is not operating. This thesis dealt with the sewer system and a Macedonian student has been working on the topic of the rehabilitation of the WWTP.

The goal of this thesis was to obtain a data basis to model the sewer system of the study area with SWMM 5 (US EPA). SWMM 5 is the renewed version of the US Environmental Protection Agency’s Stormwater Management Model. It was used, because it is open source and thus readily available. Consequently, the colleagues of the Republic of Macedonia can use the model as a basis for further investigations and projects. Besides, SWMM 5 is widely used and accepted. As a result of the modelling, the reason for flooding should be clarified and bottlenecks defined. Moreover, by modelling different adaption scenarios a solution for the unsatisfactory situation in Pintija and OHIS can be found. In addition, a sewer data base is to be created.

The aim of the research stay in Skopje was to collect data in order to set up a model in SWMM 5. However, a lot of data is missing and the data obtained have a lot of gaps and are often not up to date. During the stay, four fieldtrips were carried out with the focus on detecting the type and the current state of the sewer system. Due to information before the research stay, it was supposed, that Pintija has a separate system which turned not out to be true. Another issue was to realize which areas generate runoff and where the surface water is discharged to. The fieldtrips were essential to verify the existing type of sewer system, to determine contradictions between the plans of the sewer systems obtained and reality as well as to detect the discharge of surface runoff.

Pintija is a residential settlement about 7 km away from the city centre of Skopje. It consists of a formal part and two informal parts. The eastern one is connected to the public water supply and sewer system. In the formal and the eastern informal part of Pintija a sanitary sewer exists. However, there is only one line of storm sewer, which it is also blocked by sediments. Due to a large number of faulty connections the sanitary sewer is supposed to work as a combined system but the dimensions are not laid out accordingly. Evidence gathered during fieldtrips showed, that the roof runoff either discharges directly onto streets, into gardens or, as aforementioned, is connected to the sanitary sewer of Pintija. In OHIS, the separate system consists of a sanitary sewer and a storm sewer. Nevertheless, faulty sanitary house connections of the industrial buildings into the storm sewer exist. In addition, the sanitary sewer of Pintija is connected through two bypasses to the storm sewer of OHIS. Consequently, the untreated wastewater of Pintija is discharged directly into the receiving water.

To verify the bottlenecks of the sewer system and obtain suggestions for the improvement of the unsatisfactory situation in the study area a hydrodynamic model in SWMM 5 was set up and five different scenarios were modelled. Primarily, a basic scenario was created. For the other four adaption scenarios modifications on the sewer system were carried out. The different scenarios are explained as follows:

1. The basic scenario describes the previous state of the sewer system. It is called *“Sanitary Sewer – Previous State”* and examines the state of the sewer system which does not include the connection of the sewer systems of OHIS and Pintija through bypasses. The bypasses are not taken into consideration, because in this scenario it should be figured out why the bypasses were constructed. As a result, the manholes in front of the bypasses should be flooded to achieve a “light” validation of the model. Due to the lack of data measured the model cannot be calibrated.
2. The scenario “*Sanitary Sewer - Current State”* simulates the current conditions of the sewer system in OHIS and Pintija. With this scenario the current flooding in Pintija can be clarified. In OHIS, the focus is on the flooding of the parking lot. It should be queried, if due to the connection of the sanitary sewer (including storm water), the storm sewer of OHIS is surcharged this flooding the traffic areas in front of the parking lot.
3. The scenario “Sanitary Sewer – Designed State” deals only with the sanitary sewer of the study area and checks the capacity of it. It should be verified, if the existing system can handle the current amount of sanitary water without the high number of faulty connections to the sanitary sewer in Pintija.
4. The scenario *“Storm Sewer – Street*” models the streets of Pintija as storm sewer and simulates the current state of the storm water conveyance in Pintija. OHIS is not included in this scenario. The quantity of surface runoff generated by the subcatchments should be verified and where flooding of the street arises (e.g. due to depression). Further, a focus is on the generation of surface runoff from pervious areas. The total volume of surface water can be used for the design of retentions basins, combined sewer overflow or storm water tanks.
5. The scenario *“Storm Sewer – Open Channel”* is devoted to the design of an open channel for the currently missing storm sewer in Pintija. It is, in a way, a future scenario of the storm sewer.

Afterwards, the effect on the open channel considering the change of the assumed percentage of impervious areas and the connection of additional subcatchment was determined in two future scenarios. Following, the scenario “Storm Sewer – Open Channel” was also used for the sensitivity analysis.

According to the results of the flooding in scenario “Sanitary Sewer – Previous State” the system in Pintija is not capable of conveying the amount of storm water discharged by faulty connections into the sanitary sewer. Following a 20 minutes lasting design storm with a return period of 2 years and the intensity of 107 l/s*ha, 11 % of the manholes located in Pintija and 4 % of the manholes in OHIS are flooded with a total volume of more than 10 m³. Five bottlenecks were determined as a result of decreasing pipe diameters. These bottlenecks are also valid for the scenarios “Sanitary Sewer - Current State” and “Sanitary Sewer – Designed State”. Two of the bottlenecks are located at the manholes, where the bypasses where constructed. At both, a total flood volume of more than 70 m³ occurs at a design storm event. The highest total flood volume of the system is 140 m³ arising at a manhole in Pintija due to the decrease of the pipe diameter from 200 mm to 150 mm and backwater effects from downstream.

The results of scenario “Sanitary Sewer – Current State” show, that in fact the manholes, where the bypasses were constructed, are no longer flooded but instead another manhole from the storm sewer becomes a bottleneck and is flooded by 64 m³ in total. No flooding at the traffic area in front of the OHIS office building occurs when the specific and assumed parameters are used for the model.

The results of scenario “Sanitary Sewer – Designed State” point out that the sanitary sewer would have enough capacity to convey the current waste water load. The waste water load from the residents of 5.5 l/s*1000 residents was doubled to take also extraneous water (infiltration and faulty connections) into account. In total 11 l/s*1000 residents was reckoned in.

Scenario “Storm Sewer - Street” compute that a volume of about 800 m^3 surface runoff is generated from the subcatchments in Pintija and is conveyed to the main road Prvomajska, where flooding arises. Surface runoff starts to occur with an initial infiltration capacity of 64 mm/h.

In Scenario “Storm Sewer – Open Channel” it is determined that an open channel with the dimensions of 60x40x45 cm would be sufficient to discharge the storm water of Pintija with the assumed conditions and parameters of the study area. However, flooding develops at the storm sewer of OHIS.

With the help of the sensitivity analysis it was found out, that the depth of the impervious depression storage is the most sensitive parameter and the depth of depression storage of the pervious areas the less sensitive parameter. Manning’s roughness coefficients and the slope of the subcatchment are in between.

Unfortunately, the results are weak due inaccurate and out-of-date or lack of input data of the hydrodynamic model. Further developments of this model are only justified by the increase in accuracy and update of input data as well as the availability of missing data.

The situation in Pintija and OHIS is not state of the art and should be improved as soon as possible. One possible way would be to construct an open channel as storm sewer and remove the faulty connections of the sanitary sewer. An open channel has especially economical and operational advantages in comparison to a buried storm sewer. Of course, sustainable urban drainage systems would be an even better measure to reduce the flooding in Pintija. In OHIS, the storm sewer could be operated as a combined sewer. The WWTP of OHIS contains two huge primary settling tanks and one (~5000 m^3) could be used as a storm sewer tank. At a storm event with an intensity of 107 l/s*ha in the study area with the assumed subcatchments and its parameters as well as the estimated land use a total surface runoff of about 2600 m^3 is generated. The benefit of this solution would be that the faulty connections do not have to be removed and the storm water would also be treated. With respect to sustainable and modern water and environmental protection it would be an efficient way to improve the bad condition of the receiving water, River Vardar, and the environment of Pintija and OHIS.

As the model is not calibrated and no verification could be carried out, the results and the possible improvements can only be the basis for further investigations. For detailed planning information accuracy must be increased considerably, the input data updated and the missing data made available.

8. Outlook

The river Vardar is classified as quality class II in the upstream of the city of Skopje and as class III – a moderately eutrophic water - in its downstream due to the discharge of untreated urban and industrial waste water. In the upstream part the BOD level ranges from 2 -3 mg/l and in the downstream 2 – 7 mg/l. It is expected that the level for BOD will reach 15 mg/l (class IV) in near future (JICA, 2009). In comparison the highest values of BOD at some gauges along the river Danube in Austria are 2.8 mg/l (RODINGER & KRÄMER, 2010). Nevertheless, it should be mentioned that the Republic of Macedonia has a huge potential to avoid the mistakes Austria and other European countries made. There are still a large number of unaffected brooks. Austria has problems in this sector to meet the good status required by the EU Water Framework Directive until 2015. Therefore, the federal state of Lower Austria for instance has cooperated with the Ministry of Environment of the Republic of Macedonia to get reference sites for the high ecological status for the significantly chemically contaminated small brooks in Lower Austria (NÖ-LReg. & aquaCC, 2008). Furthermore, in Austria 80 % of the cost of the waste water sector are used for the sewer systems. This demonstrates that the construction of new drainage systems has to go hand in hand with the planning of an efficient sewer management. Without doubt, a proper sewer management requires the operation of a sewer information system.

Storm water should be considered as a valuable resource and a sustainable management would be beneficial and innovative. This implies that agencies responsible for the urban waste water management must work closely with land use policy, city and landscape planning, development control, building construction, economy, legislation, education and social acceptance issues and local community involvement. It could take decades to organize this cross-sectorial cooperation between several actors and introduce innovative water technologies, management systems and institutional arrangements. However, formulations of goals for a change are necessary in order to guide the direction of future actions (NIEMCZYNOWICZ, 1999).

The City of Skopje plans to build a central WWTP for Skopje as soon as grants are available. In Pintija a new separate sewer should be constructed and connected to the central WWTP via a main collector under the road Prvomajska. The design of the sewer system is already part of the DUP 2006-09 and the Japan International Cooperation Agency made a study on waste water management in Skopje in 2009 to plan the WWTP. However, the unsatisfactory current state and the uncertainty when the central WWTP will actually be constructed and how soon it will be in operation require immediate measures with regard to the river Vardar and the surrounding environment.

The residential settlement of Pintija and the industrial premises of OHIS are an excellent combination for case studies and research. It has a number of different components which have to be considered and dealt with. It is a good example that the whole integrated urban waste water system has to be taken into consideration and it is useless to improve only one part of the system.

Using the hydrodynamic SWMM 5 model of this thesis for further investigations, projects and simulations it has to be clear that a lot of input data are weak and further developments of this model are only justified by the increase in accuracy and update of input data as well as the availability of missing data.

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12. Appendix

Appendix A: Sewer database

Master data of the SWMM 5 model

Manholes

Master data obtained *(excluding ID)* | Master data estimated | Master data estimated *(informal manhole)*

ID	Invert elevation 1	Invert elevation 2	Depth [m]
A1	240.30		1.50
A2	242.50		4.50
A3	247.10		4.50
A4	250.80		2.00
A5	253.60		0.87
A6	255.41		1.10
A7	256.70		1.32
A2_1.1	246.10		3.50
A2_1.2	246.34		3.50
A2_1.3	246.65		3.41
A2_1.4	247.01		2.67
A2_1.5	247.13		2.15
A2_1.6	248.20		1.45
A2_1.7	248.31		1.79
A3_1.1	248.80		4.00
A3_1.2	248.90		3.60
A3_1.3	249.14		3.62
A3_1.4	250.20		2.00
A3_1.5	250.30		2.00
A3_1.6	250.50		2.00
A3_1.7	251.56		1.79
A3_1.8	252.94		1.87
A3_1.9	254.37		1.94
A3_1.10	255.00		2.75
A3_1.11	256.76		1.96
A3_1.12	258.24		1.96
A3_1.13	258.44		1.96
A3_1.14	258.54		1.96
A3_1.4_1.1	250.78		2.00
A3_1.4_1.2	251.45		2.00
A3_1.4_1.3	251.68		2.00
A3_1.4_1.4	252.15		2.00
A3_1.4_1.5	253.20		1.80
A3_1.4_1.6	253.40		2.00
A3_1.10_1.1	255.30		2.19
A3_1.10_1.2	255.70		2.10
A3_1.10_1.3	256.63		1.83
A3_1.10_1.4	256.95		1.45
A3_1.10_1.5	257.29		1.08
A3_1.10_1.6	257.52		1.08
A3_1.10_1.2_1.1	255.80		1.90
A3_1.10_1.2_1.2	256.18		1.40
A3_1.10_1.2_1.3	256.72		1.19
A3_1.10_1.4_1.1	258.15		1.45
A3_1.10_1.6_1.1	258.62		1.08
A3_1.11_1.1	257.36		1.45
A6_1.1	257.00		2.00
A6_1.2	257.70		2.00
A6_1.3	258.30		2.00
A6_1.4	259.00		2.00
B1	245.60		2.08
B2	245.90		1.90
B3	246.10		1.90
B4	246.79		1.93
B5	249.88		1.97
B6	251.40		2.02
B7	251.81		2.02
B8	252.27		2.02
B9	253.04		1.96
B10	254.50		1.90
B11	255.60		1.90
B12	256.15		1.85
B13	257.81		1.85
B14	258.75		1.75

ID	Invert elevation 1	Invert elevation 2	Depth [m]
B15	259.96		1.64
B16	261.94		1.61
B17	264.00		1.38
B18	265.18		1.48
B19	265.34		1.67
B20	265.50	266.5	2.28
B21	267.30		1.37
B22	268.03		1.95
B23	268.70	270.8	3.39
B24	275.60	276.01	1.59
B25	277.60	278.06	1.67
B26	280.33		1.67
B27	281.52		1.68
B28	283.32		1.68
B1_1.1	246.42		1.78
B1_1.2	247.49		1.99
B1_2.1	245.82		0.97
B1_2.2	246.28		0.82
B1_2.3	247.22		0.93
B1_2.4	248.28		1.36
B1_2.5	248.32		1.48
B1_2.6	248.84		1.61
B1_2.7	250.06		1.55
B1_2.8	251.07		1.48
B1_2.9	252.64		1.26
B3_1.1	247.84		1.66
B3_1.2	248.44		1.66
B3_1.3	248.59		1.66
B3_1.4	248.94		1.66
B4_1.1	247.75		1.55
B4_1.2	248.80		1.71
B4_1.3	249.29		1.86
B4_1.4	250.35		2.28
B4_1.5	251.92		2.28
B4_2.1	248.66		1.06
B4_2.2	248.78		1.94
B4_2.3	250.16		0.92
B6_1.1	252.75		1.88
B6_1.2	253.25		1.09
B11_1.1	256.47		1.53
B11_1.2	258.07		1.53
B11_1.3	258.69		1.53
B11_1.1_1.1	257.27		1.53
B11_1.2_1.1	258.57		1.53
B11_1.2_1.2	258.92		1.53
B11_1.2_1.3	259.22		1.53
B11_2.1	255.80		1.90
B11_2.2	255.90		1.90
B13_1.1	257.90		1.70
B13_1.2	258.00		1.50
B20_1.1	268.80	269.00	1.50
B20_1.2	271.29	271.49	1.50
B20_1.3	272.86	273.06	1.50
B20_1.4	273.83	274.03	1.50
B20_1.5	275.00	275.73	2.03
B20_1.6	276.81		1.50
B20_1.7	278.00		1.50
B20_1.8	281.30		1.50
B20_1.9	283.90		1.50
B20_1.10	284.80		1.50
B20_1.11	286.90		1.50
B23_1.1	270.40	270.20	2.10
B23_1.2	270.60		2.40
B23_1.3	270.80		2.00
B23_1.4	271.00		1.50
B1_2.1_1.1	246.05		0.95
B1_2.1_1.2	246.28		1.22
B1_2.1_1.3	246.50		1.30
B1_2.1_1.4	246.75		2.13
B1_2.1_1.5	247.05		2.80
B1_2.1_1.6	247.33		2.01
B1_2.1_1.7	248.05		1.20
B1_2.1_1.8	248.13		1.15
B1_2.1_1.9	248.65		1.50
B1_2.1_1.10	249.30		1.50
B1_2.1_1.11	250.10		1.50
B1_2.1_1.12	250.20		1.50

ID	Invert elevation 1	Invert elevation 2	Depth [m]
B1_2.1_1.9_1.1	248.70		1.10
B1_2.1_1.9_1.2	249.00		2.00
B1_2.1_1.9_1.3	251.00		2.00
B1_2.1_1.9_1.4	252.20		2.00
B1_2.1_1.9_1.5	253.50		2.00
B1_2.1_1.9_1.6	254.80		2.00
B1_2.1_1.4_1.1	246.85		1.65
B1_2.1_1.4_1.2	246.90		1.10
B1_2.1_1.4_1.3	247.00		0.50
B1_2.1_1.4_1.4	247.10		0.75
B1_2.1_1.4_1.5	248.20		0.50
O_FS-A_1	239.50		1.50
O_FS-A_2	236.80		2.00
O_FS-A_3	236.50		2.00
O_FS-A_4	236.30		1.60
O_FS-A_5	235.90		1.60
O_FS-A_6	235.50		1.60
O_FS-B_1	244.00		2.00
O_FS-B_2	242.30		3.50
O_FS-B_3	242.20		3.50
O_FS-B_4	240.50		2.50
O_FS-B_5	240.10		2.50
O_FS-B_6	238.89		1.20
O_FS-B_7	238.53		1.20
O_FS-B_8	237.73		1.56
O_SS-A_1	237.60	239.20	2.60
O_SS-A_2	237.50		1.45
O_SS-A_3	237.40		1.30
O_SS-A_4	237.07		1.40
O_SS-A_5	237.00		1.40
O_SS-A_6	236.70		1.60
O_SS-A_7	236.30		1.60
O_SS-A_8	235.90		1.60
O_SS-A_2_1.1	238.25		1.20
O_SS-A_2_1.2	238.30		1.20
O_SS-A_2_1.3	238.55		1.20
O_SS-A_2_1.4	238.58		1.20
O_SS-A_2_1.5	238.68		1.20
O_SS-A_2_1.6	239.09		1.20
O_SS-A_2_1.7	239.11		1.20
O_SS-A_2_1.8	238.95		1.20
O_SS-A_2_1.9	238.87		1.20
O_SS-A_3_1.1	237.80		1.20
O_SS-A_3_1.2	237.87		1.20
O_SS-A_3_1.3	238.10		1.20
O_SS-A_3_1.1_1.1	237.94		1.20
O_SS-A_3_1.1_1.2	238.00		1.20
O_SS-A_3_1.1_1.3	238.04		1.20
O_SS-A_4_1.1	237.12		1.40
O_SS-A_4_1.2	237.15		1.40
O_SS-A_4_1.3	237.17		1.40
O_SS-A_4_1.4	237.20		1.40
O_SS-A_5_1.1	237.02		1.40
O_SS-A_5_1.2	237.11		1.40
O_SS-A_5_1.3	237.19		1.40
O_SS-A_5_1.4	237.28		1.40
O_SS-A_5_1.5	237.32		1.40
O_SS-A_5_1.6	237.40		1.40
O_SS-A_5_1.7	237.50		1.40
O_SS-A_5_2.1	237.23		1.54
O_SS-A_5_2.2	237.47		1.47
O_SS-A_5_2.3	237.85		1.38
O_SS-A_5_2.4	237.98		1.34
O_SS-A_5_2.5	238.35		1.24
O_SS-A_5_2.6	238.46		1.21
O_SS-A_5_2.7	238.51		1.20
O_SS-A_5_2.8	238.62		1.20
O_SS-A_5_2.9	238.64		1.20
O_SS-A_5_2.10	238.75		1.20
O_SS-A_5_2.11	238.94		1.20
O_SS-A_6_1.1	236.92		1.60
O_SS-A_6_1.2	236.99		1.60
O_SS-A_6_1.3	237.12		1.60
O_SS-A_6_1.4	237.21		1.60
O_SS-A_6_2.1	236.73		1.60
O_SS-A_6_2.2	236.79		1.60
O_SS-A_6_2.3	236.90		1.60

ID	Invert elevation 1	Invert elevation 2	Depth [m]
O_SS-A_6_2.4	236.97		1.60
O_SS-A_6_2.5	237.00		1.60
O_SS-A_6_2.6	237.13		1.60
O_SS-A_6_2.7	237.15		1.60
O_SS-A_6_2.8	237.23		1.60
O_SS-A_6_2.9	237.32		1.60
O_SS-A_6_2.10	237.50		1.60
O_SS-A_7_1.1	236.56		1.60
O_SS-A_7_1.2	236.59		1.60
O_SS-A_7_1.3	236.68		1.60
O_SS-A_7_1.4	236.73		1.60
O_SS-A_7_1.5	236.81		1.60
O_SS-A_7_1.6	236.87		1.60
O_SS-A_7_2.1	236.37		1.60
O_SS-A_7_2.2	236.39		1.60
O_SS-A_7_2.3	236.41		1.60
O_SS-A_7_2.4	236.51		1.60
O_SS-A_7_2.5	236.61		1.60
O_SS-A_7_2.6	236.71		1.60
O_SS-A_7_2.7	236.73		1.60
O_SS-A_7_2.8	236.77		1.60
O_SS-A_7_2.9	236.78		1.60
O_SS-A_7_2.10	236.84		1.60
O_SS-A_7_2.11	236.91		1.60
O_SS-A_7_2.12	237.05		1.60
O_SS-A_7_2.13	237.09		1.60
O_SS-A_7_2.14	237.23		1.60
O_SS-A_8_1.1	235.96		1.60
O_SS-A_8_1.2	235.99		1.60
O_SS-A_8_1.3	236.04		1.60
O_SS-A_8_1.4	236.08		1.60
O_SS-A_8_2.1	235.98		1.60
O_SS-A_8_2.2	236.03		1.60
O_SS-A_8_2.3	236.09		1.60
O_SS-A_8_2.4	236.12		1.60
O_SS-A_8_2.5	236.16		1.60
O_SS-A_8_2.6	236.19		1.60
O_SS-A_8_2.7	236.22		1.60
O_SS-A_8_2.8	236.37		1.60
O_SS-A_8_2.9	236.39		1.60
O_SS-A_8_2.10	236.41		1.60
O_SS-A_8_2.11	236.51		1.60
O_SS-A_8_2.12	236.82		1.60

Sewer pipes

Master data obtained *(excluding ID)* Master data estimated Master data estimated *(informal sewer pipe)*

ID	Inlet manole	Outlet manhole	Length [m]	Shape	Diameter [mm]	Material
C-A1	A1	O_FS-A_1	19.61	CIRCULAR	0.25	concrete
C-A2	A2	A1	55.47	CIRCULAR	0.25	concrete
C-A3	A3	A2	52.20	CIRCULAR	0.15	concrete
C-A4	A4	A3	32.47	CIRCULAR	0.15	concrete
C-A5	A5	A4	22.05	CIRCULAR	0.15	concrete
C-A6	A6	A5	40.50	CIRCULAR	0.15	concrete
C-A7	A7	A6	17.69	CIRCULAR	0.15	concrete
C-A2_1.1	A2_1.1	A2	47.40	CIRCULAR	0.15	concrete
C-A2_1.2	A2_1.2	A2_1.1	46.29	CIRCULAR	0.15	concrete
C-A2_1.3	A2_1.3	A2_1.2	21.10	CIRCULAR	0.15	concrete
C-A2_1.4	A2_1.4	A2_1.3	25.45	CIRCULAR	0.15	concrete
C-A2_1.5	A2_1.5	A2_1.4	35.46	CIRCULAR	0.15	concrete
C-A2_1.6	A2_1.6	A2_1.5	61.25	CIRCULAR	0.15	concrete
C-A2_1.7	A2_1.7	A2_1.6	48.53	CIRCULAR	0.15	concrete
C-A3_1.1	A3_1.1	A3	30.61	CIRCULAR	0.15	concrete
C-A3_1.2	A3_1.2	A3_1.1	41.72	CIRCULAR	0.15	concrete
C-A3_1.3	A3_1.3	A3_1.2	31.20	CIRCULAR	0.15	concrete
C-A3_1.4	A3_1.4	A3_1.3	45.70	CIRCULAR	0.15	concrete
C-A3_1.5	A3_1.5	A3_1.4	16.23	CIRCULAR	0.15	concrete
C-A3_1.6	A3_1.6	A3_1.5	60.24	CIRCULAR	0.15	concrete
C-A3_1.7	A3_1.7	A3_1.6	41.58	CIRCULAR	0.15	concrete
C-A3_1.8	A3_1.8	A3_1.7	38.45	CIRCULAR	0.15	concrete
C-A3_1.9	A3_1.9	A3_1.8	32.20	CIRCULAR	0.15	concrete
C-A3_1.10	A3_1.10	A3_1.9	50.50	CIRCULAR	0.15	concrete
C-A3_1.11	A3_1.11	A3_1.10	28.56	CIRCULAR	0.16	concrete
C-A3_1.12	A3_1.12	A3_1.11	45.40	CIRCULAR	0.16	concrete
C-A3_1.13	A3_1.13	A3_1.12	23.62	CIRCULAR	0.12	concrete
C-A3_1.14	A3_1.14	A3_1.13	30.13	CIRCULAR	0.12	concrete
C-A3_1.4_1.1	A3_1.4_1.1	A3_1.4	13.71	CIRCULAR	0.15	concrete
C-A3_1.4_1.2	A3_1.4_1.2	A3_1.4_1.1	14.86	CIRCULAR	0.15	concrete
C-A3_1.4_1.3	A3_1.4_1.3	A3_1.4_1.2	17.18	CIRCULAR	0.15	concrete
C-A3_1.4_1.4	A3_1.4_1.4	A3_1.4_1.3	17.86	CIRCULAR	0.15	concrete
C-A3_1.4_1.5	A3_1.4_1.5	A3_1.4_1.4	19.21	CIRCULAR	0.15	concrete
C-A3_1.4_1.5/2	A3_1.4_1.5	A3_1.8	78.64	CIRCULAR	0.15	concrete
C-A3_1.4_1.6	A3_1.4_1.6	A3_1.4_1.5	69.78	CIRCULAR	0.15	concrete
C-A3_1.10_1.1	A3_1.10_1.1	A3_1.10	50.87	CIRCULAR	0.20	concrete
C-A3_1.10_1.2	A3_1.10_1.2	A3_1.10_1.1	47.85	CIRCULAR	0.20	concrete
C-A3_1.10_1.3	A3_1.10_1.3	A3_1.10_1.2	10.93	CIRCULAR	0.15	concrete
C-A3_1.10_1.4	A3_1.10_1.4	A3_1.10_1.3	32.16	CIRCULAR	0.15	concrete
C-A3_1.10_1.5	A3_1.10_1.5	A3_1.10_1.4	23.64	CIRCULAR	0.15	concrete
C-A3_1.10_1.6	A3_1.10_1.6	A3_1.10_1.5	23.50	CIRCULAR	0.15	concrete
C-A3_1.10_1.2_1.1	A3_1.10_1.2_1.1	A3_1.10_1.2	12.23	CIRCULAR	0.15	concrete
C-A3_1.10_1.2_1.2	A3_1.10_1.2_1.2	A3_1.10_1.2_1.1	34.06	CIRCULAR	0.15	concrete
C-A3_1.10_1.2_1.3	A3_1.10_1.2_1.3	A3_1.10_1.2_1.2	49.12	CIRCULAR	0.15	concrete
C-A3_1.10_1.4_1.1	A3_1.10_1.4_1.1	A3_1.10_1.4	33.70	CIRCULAR	0.15	concrete
C-A3_1.10_1.6_1.1	A3_1.10_1.6_1.1	A3_1.10_1.6	35.14	CIRCULAR	0.15	concrete
C-A3_1.11_1.1	A3_1.11_1.1	A3_1.11	50.49	CIRCULAR	0.15	concrete
C-A6_1.1	A6_1.1	A6	67.63	CIRCULAR	0.15	concrete
C-A6_1.2	A6_1.2	A6_1.1	23.73	CIRCULAR	0.15	concrete
C-A6_1.3	A6_1.3	A6_1.2	35.79	CIRCULAR	0.15	concrete
C-A6_1.4	A6_1.4	A6_1.3	16.84	CIRCULAR	0.15	concrete
C-B1	B1	O_FS-B_1	126.76	CIRCULAR	0.20	concrete
C-B2	B2	B1	25.00	CIRCULAR	0.15	concrete
C-B3	B3	B2	5.77	CIRCULAR	0.15	concrete
C-B4	B4	B3	31.04	CIRCULAR	0.15	concrete
C-B5	B5	B4	57.60	CIRCULAR	0.15	concrete
C-B6	B6	B5	24.17	CIRCULAR	0.15	concrete
C-B7	B7	B6	27.53	CIRCULAR	0.15	concrete
C-B8	B8	B7	30.85	CIRCULAR	0.15	concrete
C-B9	B9	B8	18.79	CIRCULAR	0.15	concrete
C-B10	B10	B9	46.83	CIRCULAR	0.15	concrete
C-B11	B11	B10	36.64	CIRCULAR	0.15	concrete
C-B12	B12	B11	10.96	CIRCULAR	0.25	concrete
C-B13	B13	B12	36.95	CIRCULAR	0.25	concrete
C-B14	B14	B13	23.25	CIRCULAR	0.25	concrete
C-B15	B15	B14	35.95	CIRCULAR	0.25	concrete
C-B16	B16	B15	55.12	CIRCULAR	0.25	concrete
C-B17	B17	B16	56.38	CIRCULAR	0.25	concrete
C-B18	B18	B17	47.71	CIRCULAR	0.25	concrete
C-B19	B19	B18	31.67	CIRCULAR	0.25	concrete
C-B20	B20	B19	34.22	CIRCULAR	0.25	concrete
C-B21	B21	B20	32.52	CIRCULAR	0.25	concrete
C-B22	B22	B21	42.02	CIRCULAR	0.25	concrete

ID	Inlet manole	Outlet manhole	Length [m]	Shape	Diameter [mm]	Material
C-B23	B23	B22	33.12	CIRCULAR	0.25	concrete
C-B24	B24	B23	53.59	CIRCULAR	0.25	concrete
C-B25	B25	B24	23.91	CIRCULAR	0.25	concrete
C-B26	B26	B25	31.50	CIRCULAR	0.25	concrete
C-B27	B27	B26	21.41	CIRCULAR	0.25	concrete
C-B28	B28	B27	20.67	CIRCULAR	0.25	concrete
C-B1_1.1	B1_1.1	B1	47.61	CIRCULAR	0.15	concrete
C-B1_1.2	B1_1.2	B1_1.1	31.41	CIRCULAR	0.15	concrete
C-B1_3.1	B1_2.1	B1	43.65	CIRCULAR	0.20	concrete
C-B1_3.2	B1_2.2	B1_2.1	47.01	CIRCULAR	0.20	concrete
C-B1_3.3	B1_2.3	B1_2.2	49.39	CIRCULAR	0.20	concrete
C-B1_3.4	B1_2.4	B1_2.3	31.73	CIRCULAR	0.20	concrete
C-B1_3.5	B1_2.5	B1_2.4	21.29	CIRCULAR	0.20	concrete
C-B1_3.6	B1_2.6	B1_2.5	25.42	CIRCULAR	0.20	concrete
C-B1_3.7	B1_2.7	B1_2.6	40.02	CIRCULAR	0.20	concrete
C-B1_3.7/2	B1_2.7	B4_2.3	38.29	CIRCULAR	0.15	concrete
C-B1_3.8	B1_2.8	B1_2.7	29.23	CIRCULAR	0.20	concrete
C-B1_3.9	B1_2.9	B1_2.8	44.44	CIRCULAR	0.20	concrete
C-B3_1.1	B3_1.1	B3	68.88	CIRCULAR	0.15	concrete
C-B3_1.2	B3_1.2	B3_1.1	18.49	CIRCULAR	0.15	concrete
C-B3_1.3	B3_1.3	B3_1.2	7.39	CIRCULAR	0.15	concrete
C-B3_1.4	B3_1.4	B3_1.3	15.12	CIRCULAR	0.15	concrete
C-B4_1.1	B4_1.1	B4	33.17	CIRCULAR	0.15	concrete
C-B4_1.2	B4_1.2	B4_1.1	33.38	CIRCULAR	0.15	concrete
C-B4_1.3	B4_1.3	B4_1.2	29.85	CIRCULAR	0.15	concrete
C-B4_1.4	B4_1.4	B4_1.3	17.89	CIRCULAR	0.15	concrete
C-B4_1.5	B4_1.5	B4_1.4	67.77	CIRCULAR	0.15	concrete
C-B4_2.1	B4_2.1	B4	28.69	CIRCULAR	0.15	concrete
C-B4_2.2	B4_2.2	B4_2.1	42.39	CIRCULAR	0.15	concrete
C-B4_2.3	B4_2.3	B4_2.2	33.40	CIRCULAR	0.15	concrete
C-B6_1.1	B6_1.1	B6	36.33	CIRCULAR	0.15	concrete
C-B6_1.2	B6_1.2	B6_1.1	47.85	CIRCULAR	0.15	concrete
C-B11_1.1	B11_1.1	B11	11.85	CIRCULAR	0.15	concrete
C-B11_1.2	B11_1.2	B11_1.1	33.73	CIRCULAR	0.15	concrete
C-B11_1.3	B11_1.3	B11_1.2	13.95	CIRCULAR	0.15	concrete
C-B11_1.1_1.1	B11_1.1_1.1	B11_1.1	59.39	CIRCULAR	0.15	concrete
C-B11_1.2_1.1	B11_1.2_1.1	B11_1.2	22.09	CIRCULAR	0.15	concrete
C-B11_1.2_1.2	B11_1.2_1.2	B11_1.2_1.1	33.91	CIRCULAR	0.15	concrete
C-B11_1.2_1.3	B11_1.2_1.3	B11_1.2_1.2	17.14	CIRCULAR	0.15	concrete
C-B11_2.1	B11_2.1	B11	11.61	CIRCULAR	0.15	concrete
C-B11_2.2	B11_2.2	B11_2.1	52.38	CIRCULAR	0.15	concrete
C-B13_1.1	B13_1.1	B13	29.08	CIRCULAR	0.15	concrete
C-B13_1.2	B13_1.2	B13_1.1	47.30	CIRCULAR	0.15	concrete
C-B20_1.1	B20_1.1	B20	49.67	CIRCULAR	0.15	concrete
C-B20_1.2	B20_1.2	B20_1.1	54.38	CIRCULAR	0.15	concrete
C-B20_1.3	B20_1.3	B20_1.2	42.11	CIRCULAR	0.15	concrete
C-B20_1.4	B20_1.4	B20_1.3	37.33	CIRCULAR	0.15	concrete
C-B20_1.5	B20_1.5	B20_1.4	45.04	CIRCULAR	0.15	concrete
C-B20_1.6	B20_1.6	B20_1.5	46.79	CIRCULAR	0.15	concrete
C-B20_1.7	B20_1.7	B20_1.6	51.96	CIRCULAR	0.15	concrete
C-B20_1.8	B20_1.8	B20_1.7	73.04	CIRCULAR	0.15	concrete
C-B20_1.9	B20_1.9	B20_1.8	60.67	CIRCULAR	0.15	concrete
C-B20_1.10	B20_1.10	B20_1.9	45.73	CIRCULAR	0.15	concrete
C-B20_1.11	B20_1.11	B20_1.10	58.87	CIRCULAR	0.15	concrete
C-B23_1.1	B23_1.1	B23	26.22	CIRCULAR	0.25	concrete
C-B23_1.2	B23_1.2	B23_1.1	26.70	CIRCULAR	0.25	concrete
C-B23_1.3	B23_1.3	B23_1.2	21.90	CIRCULAR	0.25	concrete
C-B23_1.4	B23_1.4	B23_1.3	30.02	CIRCULAR	0.25	concrete
C-B1_2.1_1.1	B1_2.1_1.1	B1_2.1	32.74	CIRCULAR	0.25	concrete
C-B1_2.1_1.2	B1_2.1_1.2	B1_2.1_1.1	42.73	CIRCULAR	0.25	concrete
C-B1_2.1_1.3	B1_2.1_1.3	B1_2.1_1.2	42.04	CIRCULAR	0.25	concrete
C-B1_2.1_1.4	B1_2.1_1.4	B1_2.1_1.3	35.76	CIRCULAR	0.25	concrete
C-B1_2.1_1.5	B1_2.1_1.5	B1_2.1_1.4	43.43	CIRCULAR	0.20	concrete
C-B1_2.1_1.6	B1_2.1_1.6	B1_2.1_1.5	51.23	CIRCULAR	0.20	concrete
C-B1_2.1_1.7	B1_2.1_1.7	B1_2.1_1.6	41.40	CIRCULAR	0.20	concrete
C-B1_2.1_1.8	B1_2.1_1.8	B1_2.1_1.7	3.20	CIRCULAR	0.15	concrete
C-B1_2.1_1.9	B1_2.1_1.9	B1_2.1_1.8	51.60	CIRCULAR	0.15	concrete
C-B1_2.1_1.10	B1_2.1_1.10	B1_2.1_1.9	47.72	CIRCULAR	0.15	concrete
C-B1_2.1_1.11	B1_2.1_1.11	B1_2.1_1.10	57.23	CIRCULAR	0.15	concrete
C-B1_2.1_1.12	B1_2.1_1.12	B1_2.1_1.11	57.23	CIRCULAR	0.15	concrete
C-B1_2.1_1.9_1.1	B1_2.1_1.9_1.1	B1_2.1_1.9	37.43	CIRCULAR	0.15	concrete
C-B1_2.1_1.9_1.2	B1_2.1_1.9_1.2	B1_2.1_1.9_1.1	49.08	CIRCULAR	0.15	concrete
C-B1_2.1_1.9_1.3	B1_2.1_1.9_1.3	B1_2.1_1.9_1.2	48.19	CIRCULAR	0.15	concrete
C-B1_2.1_1.9_1.4	B1_2.1_1.9_1.4	B1_2.1_1.9_1.3	50.60	CIRCULAR	0.15	concrete
C-B1_2.1_1.9_1.5	B1_2.1_1.9_1.5	B1_2.1_1.9_1.4	48.55	CIRCULAR	0.15	concrete
C-B1_2.1_1.9_1.6	B1_2.1_1.9_1.6	B1_2.1_1.9_1.5	50.12	CIRCULAR	0.15	concrete

ID	Inlet manole	Outlet manhole	Length [m]	Shape	Diameter [mm]	Material
C-B1_2.1_1.4_1.1	B1_2.1_1.4_1.1	B1_2.1_1.4	52.66	CIRCULAR	0.40	concrete
C-B1_2.1_1.4_1.2	B1_2.1_1.4_1.2	B1_2.1_1.4_1.1	43.60	CIRCULAR	0.40	concrete
C-B1_2.1_1.4_1.3	B1_2.1_1.4_1.3	B1_2.1_1.4_1.2	54.01	CIRCULAR	0.40	concrete
C-B1_2.1_1.4_1.4	B1_2.1_1.4_1.4	B1_2.1_1.4_1.3	31.88	CIRCULAR	0.40	concrete
C-B1_2.1_1.4_1.5	B1_2.1_1.4_1.5	B1_2.1_1.8	27.20	CIRCULAR	0.15	concrete
C-B1_2.1_1.4_1.5/2	B1_2.1_1.4_1.5	B1_2.1_1.4_1.4	17.44	CIRCULAR	0.40	concrete
C-FS-A_2	O_FS-A_2	O_FS-A_3	32.05	CIRCULAR	0.15	concrete
C-FS-A_3	O_FS-A_3	O_FS-A_4	95.25	CIRCULAR	0.25	concrete
C-FS-A_4	O_FS-A_4	O_FS-A_5	104.02	CIRCULAR	0.25	concrete
C-FS-A_5	O_FS-A_5	O_FS-A_6	93.14	CIRCULAR	0.25	concrete
C-FS-A_6	O_FS-A_6	Out_WS	101.29	CIRCULAR	0.25	concrete
C-FS-B_1	O_FS-B_1	O_FS-B_2	37.94	CIRCULAR	0.20	concrete
C-FS-B_2	O_FS-B_2	O_FS-B_3	15.63	CIRCULAR	0.20	concrete
C-FS-B_3	O_FS-B_3	O_FS-B_4	93.95	CIRCULAR	0.20	concrete
C-FS-B_4	O_FS-B_4	O_FS-B_5	17.63	CIRCULAR	0.20	concrete
C-FS-B_5	O_FS-B_5	O_FS-B_6	85.49	CIRCULAR	0.20	concrete
C-FS-B_6	O_FS-B_6	O_FS-B_7	72.09	CIRCULAR	0.25	concrete
C-FS-B_8	O_FS-B_8	O_FS-A_3	138.75	CIRCULAR	0.15	concrete
C-SS-A_1	O_SS-A_1	O_SS-A_2	62.20	CIRCULAR	0.50	concrete
C-SS-A_2	O_SS-A_2	O_SS-A_3	43.00	CIRCULAR	0.50	concrete
C-SS-A_3	O_SS-A_3	O_SS-A_4	37.45	CIRCULAR	0.50	concrete
C-SS-A_4	O_SS-A_4	O_SS-A_5	8.35	CIRCULAR	0.50	concrete
C-SS-A_5	O_SS-A_5	O_SS-A_6	73.52	CIRCULAR	0.60	concrete
C-SS-A_6	O_SS-A_6	O_SS-A_7	107.35	CIRCULAR	0.80	concrete
C-SS-A_7	O_SS-A_7	O_SS-A_8	106.55	CIRCULAR	0.80	concrete
C-SS-A_8	O_SS-A_8	Out_SS	151.31	CIRCULAR	0.80	concrete
C-SS-A_2_1.1	O_SS-A_2_1.1	O_SS-A_2	80.00	CIRCULAR	0.30	concrete
C-SS-A_2_1.2	O_SS-A_2_1.2	O_SS-A_2_1.1	7.73	CIRCULAR	0.30	concrete
C-SS-A_2_1.3	O_SS-A_2_1.3	O_SS-A_2_1.2	29.30	CIRCULAR	0.30	concrete
O_SS-A_2_1.4	O_SS-A_2_1.4	O_SS-A_2_1.3	7.67	CIRCULAR	0.30	concrete
C-SS-A_2_1.5	O_SS-A_2_1.5	O_SS-A_2_1.3	16.70	CIRCULAR	0.30	concrete
C-SS-A_2_1.6	O_SS-A_2_1.6	O_SS-A_2_1.5	51.07	CIRCULAR	0.30	concrete
C-SS-A_2_1.7-1	O_SS-A_2_1.7	O_SS-A_2_1.6	7.67	CIRCULAR	0.30	concrete
C-SS-A_2_1.7-2	O_SS-A_2_1.7	O_SS-A_2_1.8	19.45	CIRCULAR	0.20	concrete
C-SS-A_2_1.8	O_SS-A_2_1.8	O_SS-A_2_1.9	40.28	CIRCULAR	0.20	concrete
C-SS-A_2_1.9	O_SS-A_2_1.9	O_SS-P	52.79	CIRCULAR	0.20	concrete
C-SS-P	O_SS-P	O_SS-A_2_1.2	45.58	CIRCULAR	0.30	concrete
C-SS-A_3_1.1	O_SS-A_3_1.1	O_SS-A_3	40.70	CIRCULAR	0.30	concrete
C-SS-A_3_1.2	O_SS-A_3_1.2	O_SS-A_3_1.1	13.00	CIRCULAR	0.30	concrete
C-SS-A_3_1.3	O_SS-A_3_1.3	O_SS-A_3_1.2	45.00	CIRCULAR	0.30	concrete
C-SS-A_3_1.1_1.1	O_SS-A_3_1.1_1.1	O_SS-A_3_1.1	23.68	CIRCULAR	0.30	concrete
C-SS-A_3_1.1_1.2	O_SS-A_3_1.1_1.2	O_SS-A_3_1.1_1.1	11.12	CIRCULAR	0.30	concrete
C-SS-A_3_1.1_1.3	O_SS-A_3_1.1_1.3	O_SS-A_3_1.1_1.2	7.83	CIRCULAR	0.30	concrete
C-SS-A_4_1.1	O_SS-A_4_1.1	O_SS-A_4	25.00	CIRCULAR	0.30	concrete
C-SS-A_4_1.2	O_SS-A_4_1.2	O_SS-A_4_1.1	15.00	CIRCULAR	0.30	concrete
C-SS-A_4_1.3	O_SS-A_4_1.3	O_SS-A_4_1.2	10.00	CIRCULAR	0.30	concrete
C-SS-A_4_1.4	O_SS-A_4_1.4	O_SS-A_4_1.3	15.00	CIRCULAR	0.30	concrete
C-SS-A_5_1.1	O_SS-A_5_1.1	O_SS-A_5	9.56	CIRCULAR	0.50	concrete
C-SS-A_5_1.2	O_SS-A_5_1.2	O_SS-A_5_1.1	45.00	CIRCULAR	0.50	concrete
C-SS-A_5_1.3	O_SS-A_5_1.3	O_SS-A_5_1.2	40.00	CIRCULAR	0.50	concrete
C-SS-A_5_1.4	O_SS-A_5_1.4	O_SS-A_5_1.3	43.94	CIRCULAR	0.50	concrete
C-SS-A_5_1.5	O_SS-A_5_1.5	O_SS-A_5_1.4	20.20	CIRCULAR	0.50	concrete
C-SS-A_5_1.6	O_SS-A_5_1.6	O_SS-A_5_1.5	39.80	CIRCULAR	0.50	concrete
C-SS-A_5_1.7	O_SS-A_5_1.7	O_SS-A_5_1.6	50.00	CIRCULAR	0.50	concrete
C-SS-A_5_2.1	O_SS-A_5_2.1	O_SS-A_5	34.30	CIRCULAR	0.50	concrete
C-SS-A_5_2.2	O_SS-A_5_2.2	O_SS-A_5_2.1	35.00	CIRCULAR	0.50	concrete
C-SS-A_5_2.3	O_SS-A_5_2.3	O_SS-A_5_2.2	55.00	CIRCULAR	0.50	concrete
C-SS-A_5_2.4	O_SS-A_5_2.4	O_SS-A_5_2.3	20.20	CIRCULAR	0.50	concrete
C-SS-A_5_2.5	O_SS-A_5_2.5	O_SS-A_5_2.4	53.67	CIRCULAR	0.30	concrete
C-SS-A_5_2.6	O_SS-A_5_2.6	O_SS-A_5_2.5	16.73	CIRCULAR	0.30	concrete
C-SS-A_5_2.7	O_SS-A_5_2.7	O_SS-A_5_2.6	6.52	CIRCULAR	0.30	concrete
C-SS-A_5_2.8	O_SS-A_5_2.8	O_SS-A_5_2.7	22.00	CIRCULAR	0.30	concrete
C-SS-A_5_2.9	O_SS-A_5_2.9	O_SS-A_5_2.8	3.98	CIRCULAR	0.30	concrete
C-SS-A_5_2.10	O_SS-A_5_2.10	O_SS-A_5_2.9	22.00	CIRCULAR	0.30	concrete
C-SS-A_5_2.11	O_SS-A_5_2.11	O_SS-A_5_2.10	38.51	CIRCULAR	0.20	concrete
C-SS-A_6_1.1	O_SS-A_6_1.1	O_SS-A_6	108.57	CIRCULAR	0.50	concrete
CSS-A_6_1.2	O_SS-A_6_1.2	O_SS-A_6_1.1	35.38	CIRCULAR	0.50	concrete
C-SS-A_6_1.3	O_SS-A_6_1.3	O_SS-A_6_1.2	66.04	CIRCULAR	0.50	concrete
C-SS-A_6_1.4	O_SS-A_6_1.4	O_SS-A_6_1.3	46.39	CIRCULAR	0.50	concrete
C-SS-A_6_2.1	O_SS-A_6_2.1	O_SS-A_6	15.71	CIRCULAR	0.50	concrete
C-SS-A_6_2.2	O_SS-A_6_2.2	O_SS-A_6_2.1	27.00	CIRCULAR	0.50	concrete
C-SS-A_6_2.3	O_SS-A_6_2.3	O_SS-A_6_2.2	58.02	CIRCULAR	0.50	concrete
C-SS-A_6_2.4	O_SS-A_6_2.4	O_SS-A_6_2.3	35.50	CIRCULAR	0.50	concrete
C-SS-A_6_2.5	O_SS-A_6_2.5	O_SS-A_6_2.4	11.55	CIRCULAR	0.50	concrete
C-SS-A_6_2.6	O_SS-A_6_2.6	O_SS-A_6_2.5	67.89	CIRCULAR	0.50	concrete
C-SS-A_6_2.7	O_SS-A_6_2.7	O_SS-A_6_2.6	10.03	CIRCULAR	0.50	concrete

ID	Inlet manole	Outlet manhole	Length [m]	Shape	Diameter [mm]	Material
C-SS-A_6_2.8	O_SS-A_6_2.8	O_SS-A_6_2.7	38.85	CIRCULAR	0.50	concrete
C-SS-A_6_2.9	O_SS-A_6_2.9	O_SS-A_6_2.8	43.22	CIRCULAR	0.40	concrete
C-SS-A_6_2.10	O_SS-A_6_2.10	O_SS-A_6_2.9	89.99	CIRCULAR	0.30	concrete
C-SS-A_7_1.1	O_SS-A_7_1.1	O_SS-A_7	132.32	CIRCULAR	0.50	concrete
C-SS-A_7_1.2	O_SS-A_7_1.2	O_SS-A_7_1.1	11.55	CIRCULAR	0.50	concrete
C-SS-A_7_1.3	O_SS-A_7_1.3	O_SS-A_7_1.2	44.83	CIRCULAR	0.50	concrete
C-SS-A_7_1.4	O_SS-A_7_1.4	O_SS-A_7_1.3	27.31	CIRCULAR	0.50	concrete
C-SS-A_7_1.5	O_SS-A_7_1.5	O_SS-A_7_1.4	38.89	CIRCULAR	0.50	concrete
C-SS-A_7_1.6	O_SS-A_7_1.6	O_SS-A_7_1.5	30.45	CIRCULAR	0.50	concrete
C-SS-A_7_2.1	O_SS-A_7_2.1	O_SS-A_7	36.37	CIRCULAR	0.50	concrete
C-SS-A_7_2.2	O_SS-A_7_2.2	O_SS-A_7_2.1	10.59	CIRCULAR	0.50	concrete
C-SS-A_7_2.3	O_SS-A_7_2.3	O_SS-A_7_2.2	7.98	CIRCULAR	0.50	concrete
C-SS-A_7_2.4	O_SS-A_7_2.4	O_SS-A_7_2.3	50.37	CIRCULAR	0.50	concrete
C-SS-A_7_2.5	O_SS-A_7_2.5	O_SS-A_7_2.4	48.52	CIRCULAR	0.50	concrete
C-SS-A_7_2.6	O_SS-A_7_2.6	O_SS-A_7_2.5	49.30	CIRCULAR	0.40	concrete
C-SS-A_7_2.7	O_SS-A_7_2.7	O_SS-A_7_2.6	12.94	CIRCULAR	0.40	concrete
C-SS-A_7_2.8	O_SS-A_7_2.8	O_SS-A_7_2.7	20.37	CIRCULAR	0.40	concrete
C-SS-A_7_2.9	O_SS-A_7_2.9	O_SS-A_7_2.8	5.23	CIRCULAR	0.40	concrete
C-SS-A_7_2.10	O_SS-A_7_2.10	O_SS-A_7_2.9	28.08	CIRCULAR	0.40	concrete
C-SS-A_7_2.11	O_SS-A_7_2.11	O_SS-A_7_2.10	33.38	CIRCULAR	0.30	concrete
C-SS-A_7_2.12	O_SS-A_7_2.12	O_SS-A_7_2.11	70.76	CIRCULAR	0.30	concrete
C-SS-A_7_2.13	O_SS-A_7_2.13	O_SS-A_7_2.12	20.76	CIRCULAR	0.30	concrete
C-SS-A_7_2.14	O_SS-A_7_2.14	O_SS-A_7_2.13	71.24	CIRCULAR	0.30	concrete
C-SS-A_8_1.1	O_SS-A_8_1.1	O_SS-A_8	30.57	CIRCULAR	0.50	concrete
C-SS-A_8_1.2	O_SS-A_8_1.2	O_SS-A_8_1.1	14.99	CIRCULAR	0.50	concrete
C-SS-A_8_1.3	O_SS-A_8_1.3	O_SS-A_8_1.2	24.68	CIRCULAR	0.50	concrete
C-SS-A_8_1.4	O_SS-A_8_1.4	O_SS-A_8_1.3	19.73	CIRCULAR	0.50	concrete
C-SS-A_8_2.1	O_SS-A_8_2.1	O_SS-A_8	40.72	CIRCULAR	0.50	concrete
C-SS-A_8_2.2	O_SS-A_8_2.2	O_SS-A_8_2.1	25.45	CIRCULAR	0.50	concrete
C-SS-A_8_2.3	O_SS-A_8_2.3	O_SS-A_8_2.2	28.30	CIRCULAR	0.50	concrete
C-SS-A_8_2.4	O_SS-A_8_2.4	O_SS-A_8_2.3	13.18	CIRCULAR	0.50	concrete
C-SS-A_8_2.5	O_SS-A_8_2.5	O_SS-A_8_2.4	22.57	CIRCULAR	0.30	concrete
C-SS-A_8_2.6	O_SS-A_8_2.6	O_SS-A_8_2.5	17.01	CIRCULAR	0.30	concrete
C-SS-A_8_2.7	O_SS-A_8_2.7	O_SS-A_8_2.6	13.87	CIRCULAR	0.30	concrete
C-SS-A_8_2.8	O_SS-A_8_2.8	O_SS-A_8_2.7	71.45	CIRCULAR	0.30	concrete
C-SS-A_8_2.9	O_SS-A_8_2.9	O_SS-A_8_2.8	12.27	CIRCULAR	0.30	concrete
C-SS-A_8_2.10	O_SS-A_8_2.10	O_SS-A_8_2.9	10.47	CIRCULAR	0.30	concrete
C-SS-A_8_2.11	O_SS-A_8_2.11	O_SS-A_8_2.10	50.79	CIRCULAR	0.30	concrete
C-SS-A_8_2.12	O_SS-A_8_2.12	O_SS-A_8_2.11	154.06	CIRCULAR	0.30	concrete
BYPASS_A	O_FS-A_1	O_SS-A_1	9.55	CIRCULAR	0.25	concrete
BYPASS_B	O_FS-B_7	O_SS-A_5_2.7	10.74	CIRCULAR	0.50	concrete

Subcatchments

ID	Outlet	Area [ha]
O_1-1	O_SS-A_2	0.64
O_1-2	O_SS-A_2_1.1	0.38
O_1-3	O_SS-A_2_1.9	0.15
O_2-1	O_SS-A_4	0.59
O_2-2	O_SS-A_3	0.36
O_2-3	O_SS-A_3_1.1_1.3	0.30
O_3-1	O_SS-A_5	1.53
O_3-2	O_SS-A_5_2.4	2.50
O_4-1	O_SS-A_5	0.49
O_4-2	O_SS-A_5_1.4	0.56
O_5-1	O_SS-A_6	0.61
O_5-2	O_SS-A_6_1.2	0.72
O_6-1	O_SS-A_6	1.52
O_6-2	O_SS-A_6_2.5	1.44
O_7-1	O_SS-A_7	1.86
O_7-2	O_SS-A_7_1.3	1.29
O_8-1	O_SS-A_7	1.84
O_8-2	O_SS-A_7_2.6	2.65
O_9	O_SS-A_8	2.10
O_10-1	O_SS-A_8	2.32
O_10-2	O_SS-A_8_2.8	1.18
O_10-3	O_SS-A_8_2.11	1.89
O_11	O_SS-A_2_1.4	0.60
O_12	O_SS-P	0.23
M1.1	A2_1.1	0.76
M1.2	A3_1.1	0.40
M1.3	A2_1.6	0.24
M2.1	A3_1.1	0.47
M2.2	A3_1.4_1.3	0.25
M2.3	A3_1.4	0.30
M2.4	A3_1.8	0.27
M3.1	A3_1.6	0.21
M3.2	B4_1.4	0.30
M4	A6	0.47
M5.1	A3_1.4_1.5	0.48
M5.2	A3_1.10_1.2_1.1	0.21
M5.3	A3_1.10_1.2	0.21
M5.4	A3_1.10_1.3	0.33
M5.5	A3_1.10_1.6_1.1	0.15
M5.6	A3_1.10_1.4_1.1	0.15
M5.7	A3_1.8	0.70
M5.8	A3_1.10	0.75
M5.9	A3_1.12	0.20
M6.1	A3_1.8	0.75
M6.2	B4_1.5	0.11
M6.3	B9	0.46
M6.4	B11_1.1	0.60
M7.1	B1	0.10
M7.2	B2	0.39
M7.3	B4	0.20
M7.4	B1_2.1_1.3	0.13
M7.5	B1	0.78
M7.6	B4	0.23
M8.1	B4	0.49
M8.2	B6	0.16
M8.3	B4	0.60
M8.4	B6	0.19
M9	B1_2.1_1.4	0.40
M10.1	B1_2.1_1.5	0.29
M10.2	B1_2.1_1.9	0.33
M11.1	B1_2.7	0.17
M11.2	B1_2.1_1.11	0.22
M11.3	B1_2.1_1.9	0.58
M12.1	B1_2.1_1.8	0.20
M12.2	B1_2.1_1.9	0.15
M13.1	B6	0.63
M13.2	B1_2.9	0.57
M13.3	B1_2.1_1.9_1.2	0.80
M14.1	B11	0.35
M14.2	B13	0.68
S16.1	B14	0.36
S16.2	B16	0.52
S17.1	B19	0.76
S17.2	B20_1.2	0.48

ID	Outlet	Area [ha]
S17.3	B20_1.4	0.44
S17.4	B20_1.6	1.12
S17.5	B20_1.7	0.29
S17.6	B20_1.10	0.36
S18.1	B21	0.48
S18.2	B23	0.32
S18.3	B23	0.48
S18.4	B25	0.80
S15.3	B1_2.1_1.9_1.3	0.40
S15.2	B1_2.1_1.9_1.1	0.20
S15.1	B1_2.1_1.4_1.3	0.18
S19.1	A6_1.2	0.25
S19.2	A6_1.4	0.11
S19.3	A6_1.4	0.08

Appendix B: Maps

Sewer system plan Pintija M 1:400

Manhole sewer system
Sewer system
Water supply system
Waster supply system planned

Sewer system plan OHIS M 1:400

13. Curriculum Vitae

LAURA HAVINGA Bakk.techn.

E-Mail: laura_havinga@gmx.at

Date of birth: 01.04.1987

Place of birth: Zell/See, Austria

Nationality: Austrian and USA

EDUCATION & QUALIFICATIONS

Since Nov. 2010 — **University of Natural Resources and Life Sciences, Vienna**
- Master Environmental Engineering
- Master thesis: Setup of a hydrodynamic sewer model and scenario analysis for an urban subcatchment in Skopje

Apr. 2012 – Jun. 2012 — **University Cyril &Methodius Skopje, FYROM**
- Research stay for my master thesis

Feb. 2010 – Jul. 2010 — **Technical University Valencia, Spain**
- Exchange semester

Oct. 2008 – Jun. 2009 — **University of Natural Resources and Life Sciences, Vienna**
- Tutor at the Institute for Transport Studies

2006-2010 — **University of Natural Resources and Life Sciences, Vienna**
- Bachelor Environmental Engineering

2001-2006 — **Engineering College (HTL) Saalfelden, Austria**
- A-levels
- Civil Engineering
- Final project: Planning of an underground car park

1999-2001 — **St. George’s Austrian High School, Istanbul, Turkey**

WORK EXPERIENCE

Mar. 2013 – Jul. 2013 — **University of Natural Resources and Life Sciences, Vienna**
- Tutor at the Institute of Sanitary Engineering and Water Pollution Control

Summer 2012 — **Sewerage Board of Limassol – Amathus, Limassol, Cypurs**
- Assistant in the Technical Department of SBLA

Oct. 2011 – Jul. 2012 — **University of Natural Resources and Life Sciences, Vienna**
- Tutor at the Institute of Sanitary Engineering and Water Pollution Control

Summer 2010 — **Civil engineering office STE.P, Vienna, Austria**
- Focus: Traffic engineering and underground construction planning

Summer 2008 & 2009	**Austrian Service for Torrent and Avalanche Control, Zell/See, Austria** • Focus: Mountain risk plans, work with ArcGIS
Summer 2007	**Civil engineering office ALPINFRA, Vienna, Austria** • Focus: Mountain risk plans, work with ArcGIS, surveying
Summer 2006	**Work in a hotel in Guernsey/Channel Islands (GB)** • Improving my English language skills
Summer 2004 & 2005	**Civil Engineering office BAUCON, Zell/See, Austria** • Trainee as a draftsperson for reinforcement plans
Summer 2002	**Construction company SPILLUTINI&DORER, Bruck/Glstr., Austria** • Work placement at building sites

SKILLS & COMPETENCE

Languages:	German: native language English: upper-intermediate level Spanish: pre-intermediate level Turkish: beginner level
Computer:	AutoCAD, SWMM (Storm Water Management Model), ArcGIS, SibaCAD, Microsoft Office

Vienna, 7th June 2013