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Sustainable Water Management in the City of the Future

Integrated Project
Global Change and Ecosystems

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Final progress report PHD study on " Integrated Urban Wastewater Systems Modelling for Strategic Planning Purpose"

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SWITCH Document **Deliverable D1.2.7**
Audience The document was prepared for an audience both inside and outside the SWITCH consortium. For consortium members it summurises the progress made in urban drainage modelling under work package 1.1.2.
Purpose The purpose of the document is to report the final progress report of the research on urban drainage modelling under work package 1.1.2.
Background This document provides the final progress report of the PhD researches being undertaken in UNESCO-IHE Institute for Water Education Under the SWITCH project on urban drainage modelling.
Potential Impact
Issues Not applicable
Recommendations

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List of journal papers

1. Title: Effects of Model Schematization, Geometry and Parameter Values on Urban Flood Modelling
   Submitted to: Water Science and Technology
   Status: Accepted for publication
   Authors: Z. Vojinovic, S.D. Seyoum, J.M. Mwalwaka and R.K. Price

2. Title: A Coupled 1D and Non-inertia 2D Flood Inundation Model for Urban Pluvial flood Modelling
   Submitted to: ASCE Journal of Hydraulic Engineering
   Status: Under review
   Authors: S.D. Seyoum, Z. Vojinovic, and R.K. Price

3. Title: Generalization from fine to coarse grid for Urban Pluvial flood Modelling
   Submitted to: Yet to be submitted
   Status: Under preparation
   Authors: S.D. Seyoum, Z. Vojinovic, and R.K. Price

List of conference papers

1. Title: Urban Pluvial Flood Modeling: Development and Application
   Submitted to: 9^{th} International Conference on Hydroinformatics 2010, China
   Status: Published
   Authors: S.D. Seyoum, Z. Vojinovic, and R.K. Price

2. Title: Multi-object Optimization of Urban Drainage Rehabilitation Measures using Evolutionary Algorithms
   Submitted to: 9^{th} International Conference on Hydroinformatics 2010, China
   Status: Published
   Authors: Z. Vojinovic, H. Matingulu, A. Sanchez, S.D. Seyoum, and W. Barreto

3. Title: Modelling Urban Floodplain Inundation with Different Spatial Resolution and Model Parameterisation
   Submitted to: 9^{th} International Conference on Hydroinformatics 2010, China
   Status: Published
   Authors: Z. Vojinovic, S.D. Seyoum, M. Salum, J. Mwalwaka, R. Price and A.Fikri

4. Title: Integrated Modelling of Urban Wastewater Systems Conceptual simplified modelling for integrated urban water system simulation
   Submitted to: 8th International Conference on Urban Drainage Modelling, Tokyo, Japan, September 7-12
   Status: Published
   Authors: S.D. Seyoum, Z. Vojinovic, and R.K. Price

5. Title: Integrated Urban Water Systems Modelling with a Simplified Surrogate Modular Approach, 11th International Conference on Urban Drainage, Edinburgh,
   Submitted to: 11th International Conference on Urban Drainage, Edinburgh, Scotland, August 31-Septemeber 5.
   Status: Published
   Authors: S.D. Seyoum, Z. Vojinovic, and R.K. Price

Planning for finalisation of thesis

Remaining work to be done

Development of the modelling tool has been finalized and tests have been carried out. The remaining work includes undertake more case studies, analyse the results and draw conclusions. Two papers have been submitted to peer reviewed journals and the third one is under preparation. Thesis writing is underway and will be completed on end of the June 2011.

Deviations from the Research proposal

The overall purpose of the this research was to develop a modelling framework that enables conceptual modelling of integrated urban wastewater systems and urban flooding for providing decision support in strategic planning for integrated urban water management. However due to reasons mainly from the interest of the learning alliances, the inabilities of conceptual models to simulate surcharge flows and the unavailability of data anticipated during the proposal phase for estimating and regionalization of the conceptual model parameters, the focus of the research has been on development of physically based urban drainage and flood modelling tool (development of coupled one dimensional drainage network model and two dimensional overland flow model). The research also looked into reducing the computational time required to carry out the overland flow computation so that such models can be used for strategic planning purposes.

Likely source of funding for completing the research

The likely source of funding to cover the cost for completing the remaining research work is expected to be provided by UNESCO-IHE.

Time schedule for the remaining work

Activities	**2011**		
	1/4	**2/4**	**3/4**
Case studies			
Results discussion and conclusions			
Paper to a peer reviewed journal			
Dissertation and public defence	Thesis writing and defence		

Approval by supervisors

Comments:

Supervisor Approval:

Asso. Prof Zoran Voijnovic

ANNEX A- Research proposal

Integrated Urban Wastewater Systems Modelling for Strategic Planning Purpose

Ph. D Research Proposal

Promovendus	**:**	**Solomon Dagnachew Seyoum**
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Delft, the Netherlands

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Abstract

Increasing global pressures for change, escalating costs and other risks inherent to conventional urban water management are causing cities to face ever increasing difficulties in efficiently managing scarcer and less reliable water resources. Also the provision of effective water uses/services and responsible management of wastewater disposal without creating environmental, social or economic damage are an ever more difficult challenge. The nature of urban water management is changing as well as the number of parties involved. The changes call for a more integrated approach to urban water management. Integrated urban water management (IUWM) has emerged due to the growing recognition that an integrated approach to water management at the urban level could deliver more cost effective and optimal solutions than the traditional approach where different components of urban water cycle are managed with little consideration for each other.

Urban water management is a complex field, which includes provision of safe water supply and sanitation, sustainable use of water resources, pollution control, stormwater and wastewater network management and flood control and prevention. In a complex urban environment, modelling tools are needed to describe the complex water-related interactions, and to allow management strategies to be developed. Typically, two types of models are used: simplified (or strategic) and detailed ones. Simplified models are normally used for strategic planning purposes, whereas, detailed models are needed to describe the system's performance according to the specific local needs and objectives. Traditionally, the modelling practice would consider the analysis of a single component within the urban water cycle and there would be no adequate consideration of other components and their interactions. The challenge today is to move from such individual consideration of system performance to an integrated analysis of the entire urban water system.

It is the objective of this proposed work to develop a methodology and associated tool for integrated urban wastewater systems modelling in order to evaluate different strategies and scenarios for integrated urban water management at the planning level, focusing mainly on urban drainage and flooding. The research is primarily contributing to the Sustainable Water Management Improves Tomorrow's Cities Health (SWITCH) project theme one, with the main objective to develop a conceptual integrated urban wastewater system and urban flood modelling tool.

The proposed research work will develop a conceptual modelling approach for urban drainage, wastewater treatment plant and receiving

water modelling for strategic decision making. One of the main challenges will be to develop a conceptual urban drainage modelling tool for the estimation of stormwater flows in a reasonable accuracy. For gauged catchments the parameters of this conceptual model will be estimated from available catchment data and by calibration. To account for the requirements of extensive calibration, the model will be calibrated against physically based models which are themselves calibrated and verified for the catchments. Later on, correlation of the conceptual model parameters to measurable or easily obtainable catchment and rainfall characteristics will be established in order to make the conceptual model applicable for ungauged urban catchments too. The conceptual drainage model will simulate total flood volume for subcatchments, and therefore topographic feature analysis and interpretation techniques will be developed to produce flood risk maps. Finally this model will be integrated with simplified wastewater and receiving water models to make the integrated urban water systems modelling tool for strategic decision making, and the system will be tested and verified on two SWITCH demo cities, Belo Horizonte in Brazil and Birmingham in UK.

1 Introduction

1.1 Background

Increasing global change pressures, escalating costs and other risks inherent to conventional urban water management are causing cities to face ever increasing difficulties in efficiently managing scarcer and less reliable water resources. Besides, satisfying water uses/services and managing wastewater disposal without creating environmental, social or economic damage is an ever more difficult challenge. The public interest in urban drainage and water supply is very high, and each year large investments are made in urban water systems. However the functions of urban water are changing. The demands on the urban water system are rapidly increasing. The role and functions of urban water as well as the number of parties involved have increased. These changes call for a more integrated approach to urban water management.

Integrated urban water management has emerged as an important concept for several reasons. First, there is a growing need to manage the urban water cycle on a holistic basis. Second, a range of alternative technologies to process different aspects of the urban water cycle are becoming available. Third, advances in urban hydroinformatics enable different phases of the entire cycle to be modelled and such models can be used to optimise each phase locally and in the holistic context. In particular, the advances in urban hydroinformatics have made significant impacts on the development of new strategies for urban water management.

Urban water is a complex field, which includes provision of safe water supply and sanitation, sustainable use of water resources, pollution control, stormwater and wastewater network management and flood prevention. In a complex urban environment, modelling tools are needed to describe the complex water-related interactions, and to allow management strategies to be developed. Typically, two types of models are used: simplified (or strategic) and detailed ones. Simplified models are normally used for strategic planning purposes, whereas, detailed models are needed to describe the system's performance according to the specific local needs and objectives. Traditionally, the modelling practice would consider the analysis of a single component within the urban water cycle and there is no adequate consideration of other components and their interactions. The challenge today is to move from such individual consideration of system performance to an integrated analysis of the entire urban water system. Integrated modelling is defined here as modelling of the interaction between two or more physical systems having different characteristics. For example, a mathematical computer model, which contains representation of the sewer system, the wastewater treatment plant (WWTP) and the receiving waters would represent such modelling system.

Models can be employed to meet many different objectives during the planning, design and operation phase of urban water systems, and thus different types of models can be more appropriate depending on the specific situation. Mathematical models in general can range from simple equations to complex software codes including many equations and conditions over the time and spatial domain. It is useful to define mathematical models into different types in order to know what purposes the model can be used for. However, it is important to realise that models are usually a mix of different types. In terms of modelling mechanisms, models can be classified as physically-based, empirical or conceptual (Ahlman, 2006). Combinations of these categories are also possible.

There will be circumstances where a model can be used for planning, operations and design. The essential difference in the modelling approaches is the amount of data required, the information that can be obtained from the model, the sophistication of the analysis performed and the simulation period. For example, a planning model may involve an optimisation component. Due to the computational effort required in such a model, detailed hydraulic analysis of the infrastructure is not generally performed. In addition, if infrastructure life cycle costs are modelled, then the simulation period is of the order of years. Hydraulic modelling at this scale is prohibitive. Urban storm water models have been adapted for use as operational tools. However, they are more commonly used as either planning or design tools (Zoppou, 2001).

Simulation is used in many contexts, including the modelling of natural systems or human systems in order to gain insight to their functioning. Other contexts include simulation of technology for performance optimization, safety engineering, testing, training and education. Simulation can be used to show the eventual real effects of alternative conditions and courses of actions. Simulation models are used to simulate a sequence of time periods. For urban water system, these models must have a capability of simulating systems that operate under highly variable conditions. The simulation of water quantities and qualities in urban catchments serve three general purposes (UNESCO, 2005): (1) Planning/design to define system configurations, size or locate facilities and define long–term operating policies, (2) Operations to analyse scenarios that are expected to occur in the immediate future so as to inform immediate operational decisions. These are based on current system conditions and expected operating conditions. These analysis are often driven by regulations, and (3) Forensics to link presence of contaminants to the risk or actual occurrence of disease.

Integrated models can be classified into those with a compartment modeling approach and those with a holistic approach. Under the compartment approach there is a loose connection (loose coupling) between the models that is, only output data are usually transferred between the components. The various (sub) models can be very complex but the analysis is often difficult due to the loose connection between the components. . Under the holistic approach, there is one single unit with both components tightly connected (tight coupling) to a consistent model, and an integrated analytical framework is provided (Daene et al, 1999).

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

What is then therefore needed is the ability to undertake a holistic analysis of the urban water cycle by setting up relatively simple models with reasonable accuracy. Due to the limitations which make the use of detailed physically-based models, which are based on the conservation of mass and momentum, inefficient and impractical for integrated modeling for strategic planning purposes, such models need to be replaced by fast surrogate (an approximate substitute) models.

1.1 Research outline

This document is a proposal to undertake a research to develop a methodology and a tool towards integrated urban wastewater systems modelling for evaluating different strategies and scenarios of integrated urban water management at planning level focusing mainly on urban drainage and flooding. The research is primarily contributing to the Sustainable Water Management Improves Tomorrow's Cities Health (SWITCH) project theme one with the main objective to develop a conceptual integrated urban wastewater system and urban flood modelling tool. The aim is to develop a conceptual modelling approach for urban drainage, wastewater treatment plant and receiving water modelling for the purpose of strategic decision making. In most water quality models, pollutant concentrations and loads cannot be estimated without having estimated the flows and procedures to mitigate quantity and quality are often complementary, therefore it is important to have realistic estimation of the urban water flows. In this regard one of the main challenges will be to develop a conceptual urban drainage modelling tool for estimation of stormwater flows in a reasonable accuracy. It is also aimed to develop a methodology to estimate the parameters of the conceptual urban drainage model from the urban catchment and rainfall characteristics so that the model could also be applied to ungauged catchments. The modelling tool will be demonstrated and tested on two SWITCH demo cities, Belo Horizonte in Brazil and Birmingham in UK.

1.2 Reader

The proposal is presented in nine chapters including the introduction chapter. The first three chapters contain the main literature review covering the urban water cycle components and the need and challenges of integrated urban water management. Chapter four presents review of integrated urban water practices and modelling tools. Chapter five identifies the research problem and ways of approaching the problem. Chapter six outlines the research objectives and chapter seven explains the methodology and approaches used to undertake the study. Finally, Chapter 8 details of the organisation research, the funding and the schedule.

2 Urban Water Cycle

2.1 Introduction

Water is one of the most fundamental substances to the existence of life and also the most prevalent in the earth-atmosphere system.

Knowledge of the general laws governing the distribution and movement of water–the water cycle- is of practical importance for rational use and protection of water resources. On a global scale, the concept of water cycle is straightforward. The solar energy causes liquid water to evaporate from oceans, rivers, and lakes as water vapor, which then rises with warm air currents till it reaches the cooler layer of the atmosphere where it condenses. The condensed water droplets often adhere to dust particles and grow to a stage where the falling velocity exceeds the updraft. Depending on the air temperature and other climatic factors, the droplet will fall as rain, snow, sleet or hail. Precipitation that reaches the earth's surface can enter the ground via infiltration, contribute to surface streams and lakes as runoff, or return to the atmosphere as water vapor by evaporation. The surface runoff can either percolate in to the ground, or flow back to the sea and oceans, or evaporate to complete the hydrology cycle. Moving from the global to smaller spatial scales, e.g. Continental, regional and local scales, the complexity and variability of hydrologic processes grow enormously. Even for some climatic regime, we notice the notorious variability of rainfall in time (season) and in space that causes its occurrence very difficult to predict. On the land surface, the timing and amount of stream flow depends on the precipitation, with air, temperature, terrain features, vegetation cover, soil types and other factors. In addition, the land surface process also exerts a feedback on the atmospheric process. The feedback between the atmosphere and the land surface vary over a wide range of spatial and temporal scales.

With the progress of human civilization, this feedback mechanism is modified by human actions. Man intrudes the natural environment by building many huge hydraulic structures such as dams to store excess surface water as water supply for agricultural, residential, or industrial uses. Land uses changes, due to agricultural practices, aforestation, deforestation, building of mammoth reservoirs, drainage of wet lands, etc., usually result in soil erosion, excessive evaporation and, the decrease of runoff and soil moisture in some regions.

During urbanization process, many elements of the natural environment are placed by man-made structures, with concomitant changes to the hydrologic cycle.

The urban water cycle details the long journey of a drop of *water* from when it is collected for use in an urban *community* to when it is returned to the natural water cycle. Water is extracted from streams and aquifers and stored in reservoirs and processed to reach potable quality via various processes such as filtration and chlorination before it is delivered to residential, commercial and industrial developments through the pipe network system.

After used, the wastewater is collected by the sewer system and finds its way to the receiving water through the wastewater infrastructures. The stormwater also find its way to the receiving waters through stormwater collection and treatment systems.

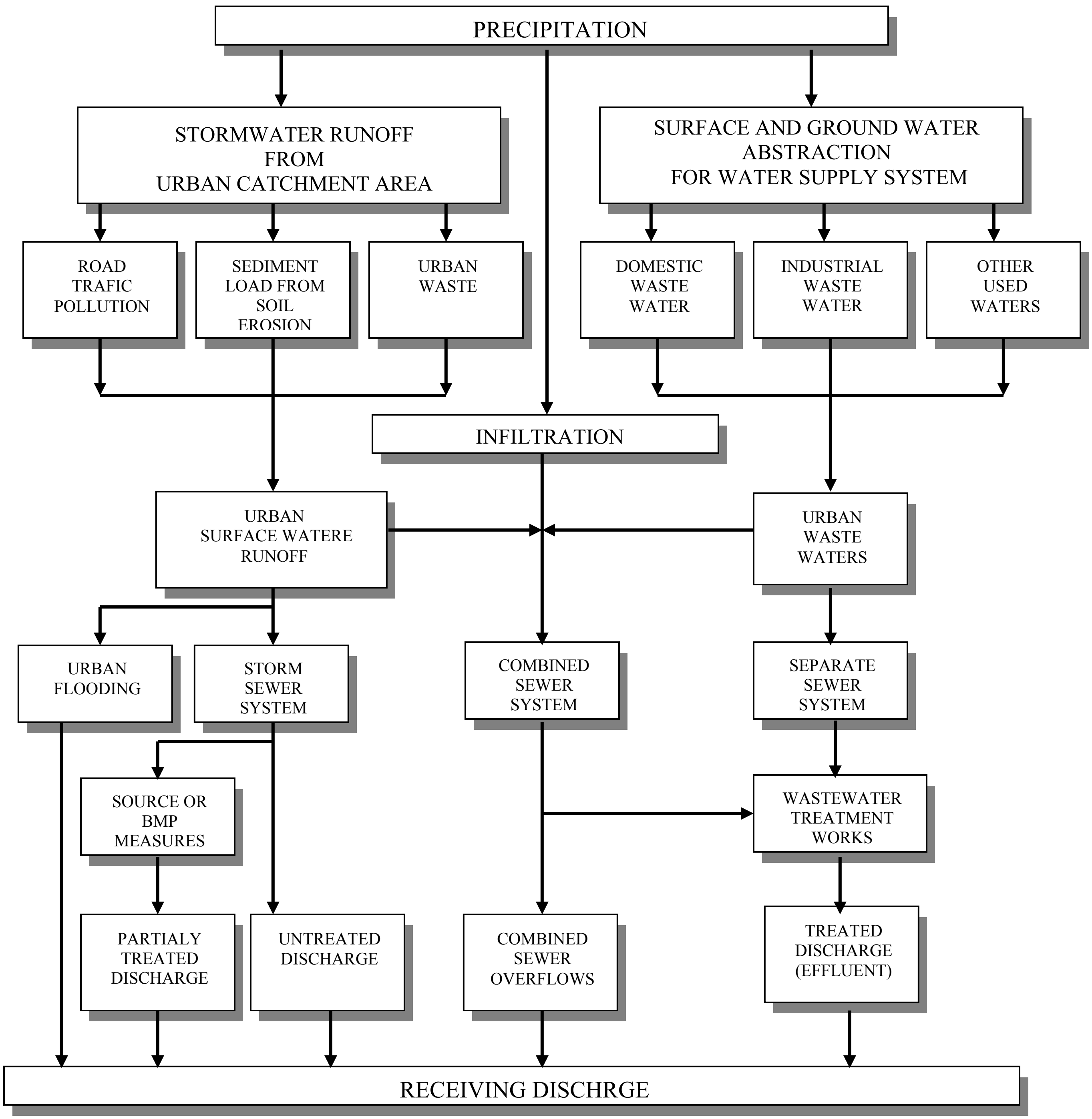

Figure 1. Movement of water in urban environment (Andjelkovic Ivan, 2001)

2.1 Components of Urban Water Cycle

Urban water cycle can be divided into several components, which can be defined as;

1. Rainfall
2. Stormwater
3. Water supply
4. Wastewater
5. Receiving environment

2.1.1 Rainfall

Cities tend to be 1-10 degrees Fahrenheit warmer than surrounding areas. The added heat destabilizes and changes air circulation around cities. During the warmer months, the added heat creates wind circulations and rising air that produces new clouds enhances existing ones. Under the right conditions, these clouds evolve into rain-producers or storms. Scientists suspect that converging air due to city surfaces of varying heights, like buildings, also promotes rising air needed to produce clouds and rainfall (Ramanujan, (2004).

Changnon et al (1976) studied the effect of urbanization and industrialization on rainfall and came up with the following conclusion. Examination of the rainfall yield of individual showers (cells), the spatial distribution of echo (rain) developments, and areal distribution of afternoon rain clearly point to the urban-industrial complex as the site for the favored initiation of the rain process under certain conditions. The greater frequency of rain initiations over the urban and industrial areas appear to be tied to three urban-related factors including thermodynamic effects leading to more clouds and greater incloud instability, mechanical and thermodynamic effects that produce confluence zones where clouds initiate, and enhancement of the coalescence process due to giant nuclei. Case studies reveal that once additional cells are produced, nature, coupled with the increased likelihood for merger with more storms per unit area, takes over and produces heavier rainfalls. Hence, the city is a focal point for both rain initiation and rain enhancement under conditions when rain is likely.

2.1.2 Stormwater

Stormwater is the flow of water that results from precipitation and which occurs immediately following rainfall or as a result of snowmelt. Stormwater discharges are generated by precipitation and runoff from land, pavements, building rooftops and other surfaces. The properties of stormwater, in terms of quantity and quality, are intrinsically linked to the nature and characteristics of both the rainfall and catchment.

The rapid expansion of urban areas has resulted in rapid growth in many population centers and settlements along coastal and low-lying areas that are prone to flooding. The frequency and severity of flooding have, as a consequence, increased at basin and local levels, particularly in the urban areas. Significant losses due to floods have been experienced in many major urban centers. Such losses are expected to increase with continuing urban expansion and escalation of land and property value and with climate change. In many of these major urban centers, flooding may be caused mainly by inadequate capacities of stormwater system and/or in conjunction with riverine flooding. While riverine flooding usually requires large scale measures, local flooding caused by inadequate stormwater system offers opportunities small-scale measures to be adopted and for local communities to play an active role in flood management.

It is commonly accepted that proper drainage of stormwater and protection against flood impacts are fundamental requirements for the growth of modern cities. Typically, both types of measures, structural and non structural are applied to manage urban flood problems. However, there are technical and economical constraints on the provision of structural measures to control urban flooding. Structural measures are usually expensive and their implementation requires time. In many cases, especially for urban flood management, non-structural measures are required to achieve optimal solution to the problems. For successful implementation of the measures, it is necessary to insure that all stakeholders fully understand the causes of urban flooding and recognize the financial and environmental implications on the basis of economic development and sound environmental management

The objectives of stormwater management have broadened over the last decade, from purely flood protection, to encompass pollution control, ecological regeneration, and enhancement of stormwater amenity value (Thomas et al., 1997). Water can provide other values in our urban landscape apart from a supply source. Water bodies such as ponds and wetlands as well as creeks, streams and rivers can add significantly to the aesthetic and recreational amenity of an urban area. This view is one of the concepts that underpins the water sensitive urban design movement.

In addition to this broader view of stormwater management, stormwater is increasingly being seen as a resource that we have undervalued thus far. Stormwater utilisation is likely to be of significant environmental benefit through the reduction of non-point source pollution and minimisation of the requirement to augment traditional water supply (Speers and Mitchell1, 2000). Options for stormwater use within an urban catchment include approaches that substitute stormwater for potable water supplies, such as on-site rainwater tanks, community collection and storage for irrigation, aquifer storage and recovery.

2.1.3 Wastewater

Wastewater is any water that has been adversely affected in quality by anthropogenic influence. It comprises liquid waste discharged by domestic residences, commercial properties, industry, and/or agriculture and can encompass a wide range of potential contaminants and concentrations. In the most common usage, it refers to the municipal wastewater that contains a broad spectrum of contaminants resulting from the mixing of wastewaters from different sources.

Every community produces both solid and liquid waste and the liquid portion is essentially the water supply after it has been fouled (contaminated) by the various uses to which it has been exposed. Wastewater may be classified into four categories:

1. Domestic – wastewater discharged from residences and commercial, institution and similar facilities;
2. Industrial - wastewater in which industrial waste predominates;
3. Infiltration/Inflow – extraneous water that enters the sewer system through indirect and direct means, such as through leaking joints, cracks, or porous walls. Inflow is storm water that enters the sewer system from storm drain connections, roof headers, foundation and basement drains or through manhole covers;
4. Storm water – runoff resulting from flooding due to rainfall;

Wastewater should be treated to reduce the level of contamination in the wastewater so that it can safely return to the environment. The wastewater needs to meet particular standards before it returns to the environment such that it does not cause harm to aquatic organisms present in the receiving water. It must also be safe for humans, who may use it or come in contact with it during recreational activities. Furthermore, one city's wastewater is often another city's water supply source.

There are various methods that wastewater can be treated depending on the degree to which the wastewater must be purified and the cost. For example, treatment methods such as anaerobic sludge bed bioreactors are usually classified as low cost treatment methods and membrane filtration is an example of high cost treatment method.

Today, modern and environmentally developed cities utilize vast sewage collection systems to collect and transport all types of wastewaters from homes, businesses and industries to wastewater treatment facilities. Once at the treatment plant, the wastewater is exposed to different processes which can remove most of the pollutants. The degree to which the wastewater must be purified depends on the ability of the recipient to accept, without harm, the effluent Modern wastewater treatment (WWT) techniques have been in use for over a century. Many different processes have been developed and many variations tested. The activated sludge process and processes using biofilms (i.e., biological treatment) are two of the most common processes used today. Practically all wastewater treatment systems also use sedimentation at some stage of the treatment process, to separate the solid matter from the liquid in a suspension (Jeppsson, 1996).

In order to improve wastewater management, separation of wastewater at the source has been researched. Such separation is used to improve the efficiency of the final process and to facilitate wastewater recycling for uses in other areas such as agriculture. When wastewater is separated at source, two level of treatment can be used where from toilet or garbage disposal can be treated by aerobic bioreactors while water from laundry, kitchen, bathroom faucets, and showers can be treated using simple and cost effective methods such as a wetland or sand filters. This method may allow a more efficient reuse of resources while increasing the sustainability of the system.

2.1.4 Water Supply

Water supply is the process of providing water for human consumption through water supply system. A water supply system includes all of the installations, services and actions used to produce and distribute water that complies with different water standards in force, from raw water sources.

Urban water supply systems are vitally required for day to day existence, commercial and industrial operations, and emergency fire fighting. The water in urban environment is used mainly for domestic, irrigation, industrial and commercial purposes. Many of these activities such as irrigation and flushing of toilets do not need water with high quality standards. The provision of a secondary water supply such as untreated or partially treated stormwater with recycled water may help to reduce the cost of treating and pumping more clean water. New technologies such as water saving toilet flushers, showerheads, washing machines and dishwashers can also be used to reduce domestic water usage.

Water recycling is reusing treated wastewater for beneficial purposes such as agricultural and landscape irrigation, industrial processes, toilet flushing, and replenishing a ground water basin (referred to as groundwater recharge).

Considerable efforts have been made towards the efficiency of the recycling process, and recycled water has been used by most industries to provide solution concerning water usage. Usually the recycled water is used as cooling water, and it covers a higher percentage of industrial water usage. This water, which is normally discharged as waste, can be again easily treated and reused in other aspects of the industrial process. Integration of water resources, water conservation measures, development of water saving technique, utilization of alternative water resources and public education are very important aspects and they should be considered holistically in order to efficiently manage the water supply of a city.

2.1.5 Receiving Environment

Typically within the urban water cycle, receiving environment refers to receiving water which can be a creek, stream, river, lake, or other water course that receives treated or untreated wastewater or stormwater. All receiving waters can assimilate waste to some extent, depending on their natural self-purification capacity. Problems arise when pollutant loads exceed this capacity, thus harming the aquatic ecology and restricting the potential use of the water such as water supply, recreation, fisheries and so on (Butler and Davis, 2004).

The protection of the receiving environment is a relatively new area for consideration with in the urban water management practice. Urban receiving waters may have different purposes including stormwater conveyance (flood protection), biological uses (warm water fishery, biological integrity, etc.), contact and non-contact recreation (swimming, linear parks, aesthetics, boating, etc.), water supply and irrigation. Each of theses water uses require different water quality standards. Stormwater conveyance and aesthetics are beneficial uses for all urban waters. (Hoffman and et al, 2002)

The effects of urban runoff on receiving water aquatic organisms or other beneficial uses are very site specific. Different land development practices create substantially different runoff flow characteristics. Different rain patterns cause different particulate washoff, transport and dilution conditions. Local attitudes also define specific beneficial uses and, therefore, current problems. There is also a wide variety of water types receiving urban runoff, and these waters all have watersheds that are urbanized to various degrees. Therefore, it is not surprising that urban runoff effects, though generally dramatic, are also quite variable and site specific.

Environmentalists concerned with the quality of urban receiving waters have been developing guidelines that reflect various water quality parameters in order to insure that the quality of waters meet safe standards for recreational purposes. Urban receiving waters are also valued for their environmental and ecological function providing an aquatic habitat and educational resource for urban residents.

2.2 Problems associated with Urban Water Cycle

The world's population is becoming increasingly urbanized. Between 1990 and 2000, the global population increased by 15% (from 5.27 to 6.06 billion), while the urban population grew by 24% (from 2.29 to 2.85 billion). The percentage of people living in cities thus went from 43.5% in 1990 to 47% by 2000. In developed countries, the percentage living in cities in 2000 reached 76%, while in less developed regions it was 40%, but growing rapidly. The latest projections show that by 2030 about 60% of the world's population will live in urban centers (United Nations, 2002)

Over half of the world's population will live in cities by year 2010, a large part in an increasing number of mega cities. Urban water problems are growing more complex and acute all over the globe. Widespread mismanagement of water resources, growing competition for the use of freshwater, degraded sources heighten the depth of these problems, which are likely to be increased under the looming effects of the climate change and variability.

2.2.1 Urban Flooding

Flooding is a localized hazard that is generally the result of excessive precipitation. Floods can be generally considered in two categories: flash floods, the product of heavy localized precipitation in a short time period over a given location; and general floods, caused by precipitation over a longer time period and over a given river basin.

Flash floods occur within a few minutes or hours of heavy amounts of rainfall, from a dam or levee failure, or from a sudden release of water held by an ice jam. Flash floods can destroy buildings and bridges, uproot trees, and scour out new drainage channels. Heavy rains that produce flash floods can also trigger mudslides. Most flash flooding is caused by slow-moving thunderstorms, repeated thunderstorms in a local area, or by heavy rains from hurricanes and tropical storms. Although flash flooding occurs often along mountain streams, it is also common in urban areas where much of the ground is covered by impervious surfaces. Roads and buildings generate greater amounts of runoff than typical forested land. Fixed drainage channels in urban areas may be unable to contain the runoff that is generated by relatively small, but intense, rainfall events.

While flash floods occur within hours of a rain event, general flooding is a longer-term event, and may last for several days. The primary types of flooding are riverine flooding, coastal flooding and urban flooding.

Periodic flooding of lands adjacent to non-tidal rivers and streams is a natural and inevitable occurrence. When stream flow exceeds the capacity of the normal water course, some of the above-normal stream flow spills over onto adjacent lands within the floodplain. Riverine flooding is a function of precipitation levels and water runoff volumes within the watershed of the stream or river. The recurrence interval of a flood is defined as the average time interval, in years, expected to take place between the occurrence of a flood of a particular magnitude and an equal or larger flood. Flood magnitude increases with increasing recurrence interval.

Coastal flooding is typically a result of storm surge, wind-driven waves, and heavy rainfall. These conditions are produced by hurricanes during the summer and fall, and nor'easters and other large coastal storms during the winter and spring. Storm surges may overrun barrier islands and push sea water up coastal rivers and inlets, blocking the downstream flow of inland runoff. Thousands of acres of crops and forest lands may be inundated by both saltwater and freshwater. Escape routes, particularly from barrier islands, may be cut off quickly, stranding residents in flooded areas and hampering rescue efforts (NC Division of Emergency Management, Hazard Mitigation Section, 2004)

The primary cause of urban flooding is a severe thunderstorm or a rainstorm proceeded by a long-lasting moderate rainfall that saturates the soil. Floods in urban conditions are flashy in nature and occur both on urbanised surfaces (streets, parking lots, yards, parks) and in small urban creeks that deliver water to large water bodies (Andjelkovic Ivan, 2001).

Other causes of urban floods are:

a. inadequate land use and channelisation of natural waterways
b. failure of the city protection dikes
c. inflow from the river during high stages into urban drainage system
d. surcharge due to blockage of drains and street inlets
e. soil erosion generating material that clogs drainage system and inlets
f. inadequate street cleaning practice that clogs street inlets

Urban flooding occurs where there has been development within stream floodplains. Urbanization increases the magnitude and frequency of floods by increasing impermeable surfaces, increasing the speed of drainage collection, reducing the carrying capacity of the land and, occasionally, overwhelming sewer systems.

Flooding in urban drainage system may occur at different stages of hydraulic surcharge depending on the drainage system (separate or combined), general drainage characteristics as well as specific local constraints. Urbanization causes change of the land characteristics from pervious to imperviousness. Asphalt and concrete, and rooftops replace forest trees and soil. Storm-water sewers replace stream channels. All increase runoff, and the important flood peaks that cause stream channel erosion and destruction of channels, property, and lives. Impervious surfaces that cover most of the urban area decrease the ability of the land to absorb rainfall-runoff and causes rapid surface runoff. The runoff from the increased pavement goes into storm sewers, which then goes into streams. This runoff, which used to soak into the ground, now goes into streams, causing flooding. Blockage within a drainage system, inadequate capacity of drains and heavy precipitation can sometimes be the main causes or urban flooding. Such flooding may cause large damage to residential and commercial buildings and public and private infrastructure.

2.2.2 Environmental Impacts

Stormwater carries away a wide variety of contaminants as it runs across rooftops, roads, parking lots, and various urban surfaces in cities. The problem of polluted stormwater runoff has two main components: 1) the increased volume and rate of runoff from impervious surfaces; and 2) the concentration of pollutants in the runoff. Both components are highly related to development in urban and urbanising areas. Everyday activities, including driving and maintaining vehicles, maintaining lawns and parks, disposing of waste and even walking pets, often cover these impervious surfaces with a coating of various harmful materials. Construction sites, power plants, failed septic systems, illegal discharges and improper sewer connections also contribute substantial amounts of pollutants to runoff. Sediments, toxic metal particles, pesticides and fertilizers, oil and grease, pathogens, excess nutrients and trash are common stormwater pollutants. Many of these constituents end up on roads and parking lots during dry weather only to be washed into water bodies when it rains or when snow melts. Together, these pollutants and the increased velocity and volume of runoff cause dramatic changes in hydrology and water quality that result in a variety of problems (Barrios, 2000).

Hydrologic impact due to urbanization is reported to cause water quality problems such as sedimentation, increased temperatures, habitat change and loss of fish population. There is widespread recognition that these problems are caused by increased runoff volumes and velocities from urbanization and associated increases in watershed imperviousness. Increased imperviousness leads to increases in volume of water, increased peak flow and duration and changes in sediment load. All these effects can result in flooding, habitat loss, erosion, channel widening and streambed alteration. Habitat loss can also result from increased stream temperature and decreased base flow, which are also effects of increased imperviousness.

Urban runoff pollutants are many and varied depending on the land uses and pollutant sources present in an urban area. Land use is one of the most important factors for determining pollutants in urban stormwater runoff. Typically loadings of urban pollutants are greatest from industrial and commercial areas, roads and freeways, and higher density residential areas. Major categories of urban pollutants include sediments, nutrients, microbes, and toxic metals and organics.

Sediment concentrations in urban runoff are particularly problematic because of their ubiquitous nature, and the fact that many other pollutants occur in a solid state associated with sediment particles. Sediment loadings occur primarily from soil erosion and runoff from construction sites in urban areas. Road sanding can also be a major source of sediments. Increased sediment in urban runoff may cause significant biological, chemical, and physical changes in receiving waters including loss of water clarity, clogging of gills and filters of aquatic organisms, and aquatic habitat degradation including the smothering of spawning beds and benthic communities.

Nitrogen, in the forms of nitrate, nitrite, or ammonium, is a nutrient needed for plant growth. About 78% of the air that we breathe is composed of nitrogen gas; certain forms of nitrogen are commonly deposited in acid rain. Two of the major problems with excess levels of nitrogen in the environment are: Excess nitrogen can cause over stimulation of growth of aquatic plants and algae. Excessive growth of these organisms, in turn, can clog water intakes, use up dissolved oxygen as they decompose, and block light to deeper waters. This seriously affects the respiration of fish and aquatic invertebrates, leads to a decrease in animal and plant diversity, and affects our use of the water for fishing, swimming, and boating. Too much nitrate in drinking water can be harmful to young infants or young livestock.

Phosphorus is an essential element for plant life, but when there is too much of it in water, it can speed up eutrophication (a reduction in dissolved oxygen in water bodies caused by an increase of mineral and organic nutrients) of rivers and lakes.

Microbes include hundreds of different kinds of bacteria, protozoa, and viruses that are ubiquitous in the natural environment. Many are beneficial, while others can cause diseases in aquatic biota, and illness or even death in humans. Some types of microbes are pathogenic (e.g., Giardia spp.), while others indicate a potential risk for water contamination (e.g., fecal coliform bacteria) and may limit swimming, boating, and consumption of fish and shellfish in receiving waters. Microbes are almost always found in high concentrations in urban stormwater, but are highly variable in nature and very difficult to eliminate. Primary sources of microbes include failed septic systems, and waste products from pets, birds, and wild mammals commonly found in urban areas.

Many sewer lines are constructed next to streams to take advantage of the continuous, gradual slopes of stream valleys. Blockages, inadequate carrying capacity, leaking pipes, and power outages at pumping stations often lead to sewage overflows into nearby streams (Pouraghniaei, 2002).

Studies indicate that streams in urban areas have increased levels of phosphorus, nitrogen, total suspended solids, biochemical oxygen demand, heavy metals, oil and grease, fecal coliform bacteria when compared to streams in non- urban areas. Even though specific sources are difficult to identify, it is well known that potential pollutants in urban environment such as street liter, end products from fossil fuel combustion, rubber and metal eroded from vehicles, corrosion of galvanized roofing materials, pet wastes, fertilizers and pesticides contribute to this situation (Carle et al, 2005)

2.2.3 Sewer systems

The function of a sewerage network is to convey household and industrial wastewater and surface water runoff from impermeable surfaces, to an appropriate location for treatment and disposal. Sewer systems may carry combined flows of household and industrial wastewater together with surface water runoff in a single pipe system for treatment at the sewage treatment works. Alternatively, separate piped systems may be provided for each type of flow, with surface water runoff being discharged to the nearest receiving water and only household and industrial wastewaters being taken to the treatment works.

The combined volume of household & industrial wastewater and surface water runoff generated from an urban area during a significant rainfall event is such that it is generally not economically feasible or environmentally cost effective either to transport the total flow for large distances via a combined sewer system or to treat it at the sewage treatment works when delivered. For these reasons, and also to minimise the risk of sewer flooding, it has been customary to provide combined sewer overflows (CSOs) that serve as "safety valves" for the pipe system by limiting the quantities of flow passed forward to treatment to a level that the downstream sewer and sewage treatment system can practically and economically accommodate. Historically, the quantity of flow passed forward at CSOs has been based on a multiple of the base (or dry weather) flow carried in the sewer. The rationale behind this approach was that the heavily polluted base flow would be sufficiently diluted by relatively clean surface water runoff. Hence, it would be environmentally acceptable to discharge excess flows into a local watercourse which, it was assumed, would also have increased inflow from the same rainfall event.

Despite the considerable dilution of household and industrial wastewater base flows by surface water runoff, storm sewage discharges from CSOs may contain significant loads of a wide variety of pollutants, including bacteria and viruses, oxygen demanding and toxic pollutants, as well as persistent materials such as heavy metals, Polycyclic Aromatic Hydrocarbons (PAHs), etc. The presence of gross solids of obvious sewage origin is also a frequent problem. Although only discharged over short periods of time on an infrequent basis, these pollutants can seriously compromise many beneficial uses of receiving waters such as fisheries, shellfisheries, bathing and recreational water use, as well as the perceived amenity value of the waters. In extreme cases, CSO discharges can result in fish mortalities, shellfish unfit for human consumption, public health hazards and visual and odor problems.

Typically, the performance of a combined sewer system is reflected by the frequency and volume of its overflows. CSOs differ from other point source discharges in that they occur only intermittently. The impact of CSO discharge depend on such divers factors as catchment characteristics; nature of the pollutants; variability of the stormwater flow reaching the sewer; condition, volume and flow rate of the receiving water during the storm; location of the overflow; and use of the receiving water body. Each storm event may have a different impact on water quality than the previous storm event.

2.2.4 Wastewater treatment plant

Sewage treatment is a multi-stage process to renovate wastewater before it reenters a body of water, is applied to the land, or is reused. The goal is to reduce or remove organic matter, solids, nutrients, disease-causing organisms, and other pollutants from wastewater.

Wastewater treatment plant effluent composition can be variable depending on the source of the wastewater. The wastewater received at the site of wastewater treatment plant will contain suspended solids, biodegradable organic matter, pathogens and nutrients. In addition dissolved inorganic solids, refractory organics and heavy metals may also be present.

A wastewater treatment system provides a combination of selected unit operations to produce an acceptable effluent. The operations may be grouped into 'Primary Treatment' or 'Secondary Treatment' or 'Tertiary Treatment'.

Primary treatment involves: screening- to remove large objects, such as stones or sticks, that could plug lines or block tank inlets, grit chamber to slows down the flow to allow grit to fall out and sedimentation tank (settling tank or clarifier) where settleable solids settle out and are pumped away, while oils float to the top and are skimmed off. Secondary treatment typically utilizes biological treatment processes, in which microorganisms convert nonsettleable solids to settleable solids. Sedimentation typically follows, allowing the settleable solids to settle out.

After primary and secondary treatment, municipal wastewater is usually disinfected using chlorine (or other disinfecting compounds, or occasionally ozone or ultraviolet light). An increasing number of wastewater facilities also employ tertiary treatment, often using advanced treatment methods. Tertiary treatment may include processes to remove nutrients such as nitrogen and phosphorus, and carbon adsorption to remove chemicals. These processes can be physical, biological, or chemical. Settled solids (sludge) from primary treatment and secondary treatment settling tanks are given further treatment and undergo several options for disposal.

Problems associated with wastewater treatment plants include the release of toxic substances such as unionized ammonia and total residual chlorine to the receiving environment. These toxic substances together with other chemicals can have adverse impacts on human health as well as negative biological effects such as adverse impact on the food web, biodiversity, critical species, genetic diversity, dispersal and migration and ecosystem development. Having not enough capacity to adequately treat the wastewater coming to them and inability to maintain highly technical wastewater treatment systems are also problems associated with wastewater treatment plants.

2.2.5 Water Supply

Population growth and urbanisation are enforcing rapid changes leading to a dramatic increase in high-quality water consumption. Frequently, this demand for water cannot be satisfied by the locally available water resources, while the discharge of insufficiently treated wastewater increases costs for downstream users and has detrimental effects on the aquatic systems. Water supply is a critical element in the urban water management practice. Recently in many countries, water conservation by demand management and distribution loss management has been adopted in order to provide relatively reliable and inexispensive services to residents.

Water demand management is defined as any socially beneficial measure that reduces or re-schedules average or peak withdrawals from surface- or ground-water sources while maintaining or mitigating the extent to which return flows are degraded. The demand management approach differs from traditional supply-oriented approaches in placing its emphasis on social and economic policies to influence the uses to which water is put.

Pipe burst and leakage are among the main issues in water supply management. Economic and social costs associate with pipe bursts and leakage problem are rapidly rising to unacceptably high levels. Pipe burst risks depend on a number of factors which are extremely difficult to characterise. Apart of the problem is that water supply assets are mainly situated underground, and therefore not visible and under influence of various highly unpredictable forces. The maintenance and rehabilitation has to be carried out regardless of such incomplete and inaccurate knowledge about the asset. It is not financially feasible to monitor the evolution of the state of an asset on a regular basis. Information is fully available only when the pipe is laid. The knowledge about the state of the pipe is only updated when a burst occurs and the pipe is partially unearthed. Moreover the management of a pipe network must deal with administrative, environmental, and social constraints upon the action of the water company. A poor condition of water supply asset typically implies high pipe burst rates, which in turn results in high water leakage rates. Reports of leakage typically amounting between 35% and 65% of total supplied volume water are not at all uncommon (Babovic et al, 2002)

2.2.6 Asset Management

Asset management (AM) is a thoughtful process of self evaluation, the development of strategy, objectives and an action plan and a phased implementation plan that coordinates the knowledge and functions of the entire organization. AM is a way to think about an organization’s management and stewardship of its asset to understanding what assets are and prioritizing maintenance and management activities. It is also used to manage the life cycle cost, use and reliability of utility’s asset and tailoring each organization’s needs using a systematic, proactive, scalable approach.

Asset management—the stretching of scarce financial resources through more efficient operations and appropriate investments—is an important component of bringing about better efficiencies in the delivery of water supply and sanitation services. A comprehensive approach to asset management focuses on minimizing the total cost of acquiring; operating, maintaining, replacing and disposing of a utility's assets and doing it in a way that achieves the level of service that customer's desire.

There are many prospective how people define AM depending on who they are and what sector they are in. For example, to the accountant and finance staff, AM means to ensure the assets are booked on the organization's books when placed in service. When the assets retired, they are properly depreciated and removed from the books. As for the engineering department, AM centers around the planning for and designing of the replacement and major rehabilitation of system assets. To the IT engineers, AM concerns tracking and monitoring the asset maintenance and replacement activities. The goals of AM are to reduce risk, increase asset life & minimize asset life cycle costs, optimize maintenance and capital improvement programs, reliable plan expenditures, maximize organization's knowledge of its assets and finally understand financial implications of expenditures (scares resources assigned to proper investments). In order to achieve theses goals, managers should and need to understand the consequences of making and not making difficult decisions. There are two levels in AM which are the big picture and the detailed look. In the big picture level, there are five major categories, which are knowledge base, information technology, people, infrastructure and customers.

3 Integrated Urban Water Management

3.1 Introduction

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

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

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

Traditionally, components of urban water cycle such as water supply, wastewater and stormwater were considered as separate entities. The planning, delivering and operating process is done independently with limited reference to each other. Thus water management represents an area of conflict between economic, ecological and social issues (Simon et al, 2004).

The urban water cycle begins with water extracted from streams and aquifers, usually stored in reservoirs and then processed to potable quality via filtration and chlorination processes before delivery through an extensive pipe system to residential, commercial and industrial developments. The treated water is also used for recreational purposes including irrigation of parks and gardens. Some of this water is then used to transport wastes through a network of sewers to treatment plants which discharge effluent into receiving waters such as rivers, lakes and oceans. Rainfall falling on the consumer's allotment contributes to the urban catchment's stormwater that is collected by an extensive drainage system for disposal into receiving waters (Coombes and Kuczera, 2002).

In Integrated Urban Water Management, issues ranging from the region wide to the site scale need to be considered. This is important due to the complexities of urban water systems and inter-relations between different components. Any decision or change to the system may have impact on the downstream or upstream areas. This will then affect the costs, sustainability and opportunities.

The primary aim of Integrated Urban Water Management is to facilitate the multi-functional nature of urban water services in order to optimize the outcomes achieved by the system. The dimensions of this multi-functionality include community satisfaction, ecosystem protection, energy usage and greenhouse gas emissions, maintenance of biodiversity, water minimization, pollution prevention and control, public health protection and sanitation, sharing of water resources, stormwater management, and flood protection, stormwater quality management and last but not least, enough and good quality of water supply.

Principles of integrated urban water management

Integrated urban water management is based on several principles and the main principles can be summarized to the following.

i. Consider all parts of the water cycle, natural and constructed, sub-surface as an integrated system,
ii. Consider all requirements for water, both anthropogenic and ecological,
iii. Consider the local context, accounting for environment, social, cultural and economic perspectives,
iv. Involve all stakeholders in the process,
v. Strive for sustainability and balancing of technical, environmental, social and economic needs for the evaluations of short, medium, and long term system improvement measures.

IUWM means that in the planning and operation of urban water management, consideration should be given to the interaction and collective impact of all water-related urban processes on issues such as human health; environmental protection; quality of receiving waters; water demand; affordability; land and water-based recreation; and stakeholder satisfaction.

3.2 Need for Integrated Urban Water Management

The public interest in urban drainage and water supply is very high, and each year large investments are made in urban water systems. However the functions of urban water are changing. The demands on the urban water system are rapidly increasing. The role and functions of urban water as well as the number of parties involved have increased. Techniques to make an area suitable for building have changed, new types of water infrastructure have been developed, the role of water in urban design and spatial development has changed, etc. The change in all of these interests calls for a more integrated approach to urban water management.

Population and economic growth in urban areas raise concerns over the adequacy of water supplies. Traditionally, water authorities give effort to developing new water resources to meet the growth in demand. This situation is being changed recently. The effort to outsource the water from outside an urban area in order to fulfill the water demand is now facing increasing environmental constraints associated with climate changes and the potential for decreased yield from existing water supply catchments. As a result, the conflict between society needs and water resources is ever increasing with this traditional means of supply.

The past 20 to 30 years in particular are characterized by significant changes in planning, design and management of urban water resources all over the planet. Mounting concerns about the environmental impacts of human activities, potential climatic shift, expanding population and the use of mega cities as well as new knowledge are part of the pressing need to develop alternative institutional schemes for managing in an integrated manner scares natural resources (Makismovic and Tejada-Guibert, 2001).

In integrated urban water management, optimal utilization of the available water sources and that includes measures to control abstractions, artificially recharge groundwater aquifer or encouraging the conjunctive use of multiple resources has been applied. The joint use of two or more sources with the well planed rule can lead to a less expensive supply than when use independently. Besides this, the integrated approach of demand management and distribution loss management with good regulation, metering and asset management can lead to the reduction in water requirement in the future. There are many examples of adverse economic, social and environmental impacts associated with traditional approach to water service provision. These includes changes of aquatic habitats; modifications to natural systems, increased waste disposal, inadequate handling of contaminants and nutrients, increased energy and chemical usage, high economic cost of rehabilitation and replacement of ageing water infrastructure in highly developed urbanized areas. Besides that, wastewater discharge standards are also increasing due to environmental and public health protection requirements. Stormwater management has also changed from its sole considerations as flood protection issue to a more holistic issue which encompasses both quantity and quality management.

Awareness of the consequences of a traditional water servicing approach has led to a paradigm shift in urban water industry. In the new paradigm, demand side management is treated as being as important as supply side management. Utilization of non-traditional water resources, together with the concept of fit-for-purpose and decentralization is applied widely in order to improve urban water management and sustainability. Table 3.1 shows the difference between the traditional approach and the emerging paradigm of urban water systems (UWS).

In order to accomplish this new paradigm, the philosophy of urban water management has been developed. This is very important aspect needed for the sustainability of water services in urban areas to serves societies.

Table 3-1 Characteristics of 'old' and 'emerging' paradigms UWS (Pinkham, 1999)

The Old Paradigm	The Emerging Paradigm
Human waste is a nuisance. It is to be disposed of after the minimum required treatment to reduce its harmful properties.	*Human waste is a resource.* It should be captured and processed effectively, and put to use nourishing land and crops.
Stormwater is a nuisance. Convey stormwater away from urban areas as rapidly as possible	*Stormwater is a resource.* Harvest stormwater as a water supply, and infiltrate or retain it to support urban aquifers, waterways, and vegetation.
Build to demand. It is necessary to build more capacity as demand increases	*Manage demand.* Demand management opportunities are real and increasing. Take advantage of all cost-effective options before increasing infrastructure capacity.
Demand is a matter of quantity. The amount of water required or produced by water end-users is the only end-use parameter relevant to infrastructure choices. Treat all supply-side water to potable standards, and collect all wastewater for treatment in one system	*Demand is multi-faceted.* Infrastructure choices should match the varying characteristics of water required or produced by different end-users: quantity, quality (biological, chemical, physical), level of reliability, etc.
One use (throughput). Water follows a one-way path from supply, to a single use, to treatment and disposal to the environment.	*Reuse and reclamation.* Water can be used multiple times, by cascading it from higher to lower-quality needs (e.g. using household graywater for irrigation), and by reclamation treatment for return to the supply side of the infrastructure.
Gray infrastructure. The only things we call infrastructure are made of concrete, metal and plastic.	*Green infrastructure.* Besides pipes and treatment plants, infrastructure includes the natural capacities of soil and vegetation to absorb and treat water.
Bigger/centralized is better. Larger systems, especially treatment plants, attain economies of scale.	*Small/decentralized is possible, often desirable.* Small scale systems are effective and can be economic, especially when diseconomies of scale in conventional distribution/collection networks are considered.
Limit complexity: employ standard solutions. A small number of technologies, well-known by urban water professionals, defines the range of responsible infrastructure choices.	*Allow diverse solutions.* A multiplicity of situation tuned solutions is required in increasingly complex and resource-limited urban environments, and enabled by new management technologies and strategies.
Integration by accident. Water supply, stormwater, and wastewater systems may be managed by the same agency as a matter of local historic happenstance. Physically, however, the systems should be separated.	*Physical and institutional integration by design.* Important linkages can and should be made between physical infrastructures for water supply, stormwater, and wastewater management. Realizing the benefits of integration requires highly coordinated management.
Collaboration = public relations. Approach other agencies and the public when approval of pre-chosen solutions is required.	*Collaboration = engagement.* Enlist other agencies and the public in the search for effective, multi-benefit solutions

3.3 The Challenges of Integrated Urban Water Management

In order to move towards integrated urban water management, there are several challenges that need to be confronted (e.g., technical, institutional, etc.). With respect to the present practice of urban water management, most of the current guidelines, standards and regulations have been developed to suit conventional urban water management based on individual components with very little consideration of wider issues. As a result, the guidelines, standards and regulations are often not suitable to reflect a new integrated approach. By their nature, standards, guidelines and regulations tend to be rigid. More flexibility is required to foster innovation whilst protecting public health and the environment. It will take some time before the comprehensive set of guidelines, standards and regulations that cover all aspects of integrated urban water management are formulated.

Skills and knowledge also can be barriers to implementation of integrated urban water management. Due to the relatively short history of integrated urban water management, many people involved in such projects are so for the first time. As a result they do not always have the required skill themselves or access to others who do have the appropriate skill and knowledge. They also lack of appropriate tools and analysis techniques required to move through the process of reaching a preferred integrated urban water management approach for a given site. With current work practice it is also difficult to choose the best combination of available system improvement measures.

In the current situation, not only guidelines, standards and regulations have been made for conventional water systems, but structures of water authorities, government departments, local authorities and private industry have also been shaped in order to deliver conventional water services. They are often fragmented, complex and work independently from region to region. Despite the current effort, it will still take some time for the appropriateness of structures and the associated roles and responsibilities to be reconstructed because the current structures have been known to constrain integration and innovation.

The appropriate understanding and management of risk has also been a barrier to current work practices. New systems create new risk profiles that do not easily fit within the current organization and operational structures. There has been a lack of strong incentives for the adoption of integrated urban water management approaches due to unclear guidelines, regulations and complexity of approval processes. There are counteracting forces for the development of water and wastewater industry. The inclusion of mandatory requirements for adoption of integrated urban water management approaches within the regulatory frame works of planning codes as well as local municipalities, state environmental protection agencies and water authorities could provide strong incentive to private industry that is often requested (Mitchell et al, 2003).

Water-related research effort is an important means for addressing knowledge gaps and raising industry and community understanding of integrated urban water management, but there is much more work required before we gain a comprehensive knowledge about the advantage and disadvantage of the many tools and systems which fall under the banner of integrated urban water management.

Nowadays, water authorities do not have enough confidence about the end result of long-term changes including system performance, operation and maintenance costs with respect to the adoption of the new integrated approach. As a consequence, they are unwilling to deviate very far from traditional infrastructure planning practice. Furthermore, research in to the change in system behavior, and therefore, the change in design, operation and maintenance requirements, is required to alter this situation. This will require a greater activity in systems performance monitoring and analysis as well as tracking, reporting on operational and maintenance regimes including costs, and broad dissemination of the findings. There is also the need for research into the acceptability of source control and prevention-at- source measures. This kind of research is important especially to those environments that require behavioral change of individuals. This is because this area is poorly understood, but may be required for certain integrated urban water management options to be successfully implemented, particularly within existing urban areas. Further research into the risk is also needed to cover different dimensions such as public health, financial, political, environmental and technical. Such research should take a balanced view of the risks in the existing conventional systems and the potential benefit of alternating these systems.

4 Integrated Urban Water Systems Modelling

As discussed earlier the nature of urban water systems are very complex and difficult phenomenon. They include not only the resources water supply needed to meet the varied demands, but also the water treatment plants and the water distribution systems that transport water to where the demands are located. In order to maintain public health as well as to control the quality of the waters discharging to receiving environment, well designed and operated urban drainage systems are equally important. Regulations and standards such as adequate pressures for fire protection, adequate water quality to protect public health and adequate standard of urban waste and stormwater drainage are needed to control the water quality. Besides that, the overall system also requires monitoring as well as the use of various models for detecting leaks and for predicting the impacts of alternative urban water treatment, distribution, and collection system designs operating, maintenance and repair policies.

Modelling the water and wastewater flows, pressure heads and quality in urban water conveyance, treatment, and distribution and collection systems is a challenging exercise, not only because of its hydraulic complexity, but also because of the stochastic inputs and unknown sub-processes. Simulation and optimization models play an important role in analyzing a variety of design and operational problems. Simulation is used in many contexts, including the modelling of natural systems or human systems in order to gain insight to their functioning. Other contexts include simulation of technology for performance optimization, safety engineering, testing, training and education. Simulation can be used to show the eventual real effects of alternative conditions and courses of actions. Simulation models are used to simulate a sequence of time periods. For urban water system, these models must have a capability of simulating systems that operate under highly variable conditions. The simulation of water quantities and qualities in urban catchments serve three general purposes (Loucks and Bee, 2005):

1. Planning/design to define system configurations, size or locate facilities and define long–term operating policies,
2. Operations to analyse scenarios that are expected to occur in the immediate future so as to inform immediate operational decisions. These are based on current system conditions and expected operating conditions. These analysis are often driven by regulations,
3. Forensics to link presence of contaminants to the risk or actual occurrence of disease

4.1 Modelling Approach

Models can be employed to meet many different objectives during the planning, design and operation phase of urban water systems, and thus different types of models can be more appropriate depending on the specific situation. Mathematical models in general can range from simple equations to complex software codes including many equations and conditions over the time and spatial domain. It is useful to define mathematical models into different types in order to know what purposes the model can be used for.

However, it is important to realise that models are usually a mix of different types. In terms of modelling mechanisms, models can be classified as physically-based, empirical or conceptual (Ahlman, 2006). Combinations of these categories are also possible.

Physically or process based models should be derived from established physical principles and ideally produce results that are consistent with observations. Physically-based models use fundamental equations with model parameters that have direct physical meaning. This type of model has a high explanatory capacity, i.e. it is possible to find out in process terms why an outcome is as it is.

Empirical models describe the observed behavior between variables using the observations alone and do not include any processes. Because of the direct link between input and output these models are also referred to as black box models. Empirical models have high predictive power but low explanatory depth. In terms of stormwater modelling, an empirical approach would be a model that relates runoff quantity or quality to a number of factors, such as rainfall or other characteristics of the catchment.

Conceptual models explain the behavior of a system based on ideas of how the system works. The processes are explained by simplified conceptual formulations and described by equations using parameters that do not have a direct physical meaning. These parameters must usually be determined in a procedure of calibration and validation. Conceptual models have higher explanatory depth than empirical models.

Mathematical models can be further subdivided depending on how the equations are formulated and solved in the time domain, either **discrete** or **continuous**. Further subdivision can be made in terms of the mathematical type of the model. This explains the characteristics of the equations, whether the equations are **deterministic** or **stochastic**. In the deterministic approach, a single set of inputs will always produce the same output. In the stochastic approach, a single set of inputs will produce output that is not identical each time. This is achieved by introducing random processes in the governing equations of the model. Models are also of different spatial types and can be divided into **lumped** or **distributed** models. Lumped models simulate a spatially heterogeneous area or structure as a single value, while distributed models break the area or structure into discrete units. The spatial type of a model can be one-dimensional (1D), two-dimensional (2D) or three dimensional (3D). The 2D scale is usually used in the context of a geographical information system (GIS). Mathematical models can be further classified accordingly on their temporal scale. Static models have no time dependence while **dynamic** models include a time variation.

Finally, one additional classification is especially applicable to urban stormwater models. A stormwater model can be **event based** or **continuous** in terms of how it handles the input rainfall data. Event models are short-term models used for simulating a few or individual storm events. An event based model can also be a single event model that uses a design storm with a given frequency and duration. Continuous models simulate a catchment's overall water balance over a long period of time, involving monthly or seasonal predictions, and form the basis of a planning model for water resources.

Planning models are usually used to estimate the costs associated with different infrastructure configurations over the life of the infrastructure. Event driven models are suitable for the design of storm water infrastructure and as operational models. Models that are required to control, operate or allocate water resources in real time are known as operational models. Flood forecasting models, models used to control weirs and locks in an irrigation channel and models used to establish what level water is extracted from a reservoir to meet certain water quality requirements are examples of operational models. Design models refer to models that can be used to model in detail the flow through the storm water infrastructure.

There will be circumstances where a model can be used for planning, operations and design. The essential difference in the modelling approaches is the amount of data required, the information that can be obtained from the model, the sophistication of the analysis performed and the simulation period. For example, a planning model may involve an optimisation component. Due to the computational effort required in such a model, detailed hydraulic analysis of the infrastructure is not generally performed. In addition, if infrastructure life cycle costs are modelled, then the simulation period is of the order of years. Hydraulic modelling at this scale is prohibitive. Urban storm water models have been adapted for use as operational tools. However, they are more commonly used as either planning or design tools (Zoppou, 2001).

4.2 A Review of Urban Water Systems Modelling

4.2.1 Total urban water cycle modellilng

In the past various types of urban water cycle modelling tools have been developed. Many authors have reported results of water and contaminant balance analysis of the urban water system, primarily based on relatively simple average monthly or annual desktop or spreadsheet calculations, while few utilise more detailed analysis tools such as simulation modelling software (Mitchell et al, 2003).

A brief review of urban water cycle modelling tools was made by (Mitchell et al, 2003).
The reviewed models include a simple generic total urban water balance computer model based on empirical equations that has a variable time step, ranging from a daily to annual and models developed in Australia with the primary purpose of providing preliminary screening tools for alternative water servicing options which are quasi-distributed daily time step models. These models divide a study area into water system components (nodes) that are interconnected by drainage or supply links, or into clusters that comprise allotments, road corridors and open space. Sub-daily time step models called PURRS which was developed to model the impact of local stormwater management devices on stormwater and water supply infrastructure was also included in the review. (Mitchell et al, 2003) concluded that urban water cycle modelling activity spans several decades, although since the mid 1990's there has been a rapid increase in activity, as is the case with many types of environmental software. Only recently have the models broadened their scope to include water quality aspects as well as water quantity and sizing of infrastructure.

(Mitchell et al, 2003) developed a total urban water cycle modelling tool called UVQ which is reviewed as follows.

UVQ is a daily time step, conceptual model, which represents an urban area in a quasi-distributed manner. (Mitchell et al, 2003) stated that the objectives of the modelling methodology employed during development of UVQ are climate, landuse and existing infrastructure representation as these are the primary factors determining the water and contaminant balance of an urban area and the representation of the multitude of alternative methods for water supply, stormwater and wastewater service provisions, enabling the assessment of the impact of alternative water servicing approaches on the total water cycle. Three nested spatial scales are used in UVQ to describe the components of the urban area. The single allotment (unit block) represents a building and associated paved and pervious areas such as paths, driveways and gardens, the neighborhood (cluster) comprises number of identical unit blocks as well as roads and public open space and the catchment represents the grouping of one or more clusters that may or may not have the same landuse.

Conceptual routines are used to represent rainfall-runoff process. Impervious surfaces are each represented as single stores that overflow when full. The concept of effective impervious area is used to represent the proportion of impervious surface runoff that directly drains to the storm water drainage system. Pervious area soil moisture stores are represented in one of two ways; a partial area saturation overland flow model or a two layer soil store model. The amount of evapotranspiration from pervious areas and of evaporation from impervious surfaces is calculated separately. The inflow of stormwater in to the wastewater system is calculated as a proportion of the total surface runoff generated. The amount of leakage from distribution networks is assumed to be proportional to the daily bulk water use and the amount is directed in to the groundwater store.

All stormwater and wastewater stores, from unit block scale through to catchement scale, are represented as a straight side tank or reservoir. Overflow from the stores is simply the volume of inflow that exceeds the available storage capacity.

Contaminants are all modelled conservatively, with no conversion or degradation within the existing infrastructure. The performance of all treatment process from rain tanks through to catchment wastewater systems is specified in terms of percentage removal of individual contaminant types or by setting output requirements.

4.2.2 Integrated Urban Wastewater Modeling

Recently there are varieties of integrated urban wastewater modeling tools available. Some of them are reviewed briefly as follows.

City Drain

CITY DRAIN is open source software for integrated modelling of urban drainage systems and was developed by Achleitner and Rauch at the Institute of Environmental Engineering at the University of Innsbruck, Austria (Achleitner, 2006).

CITY DRAIN was developed in the Matlab/Simulink © environment, enabling a block wise modelling of the different parts of the urban drainage system (catchment, sewer system, storage devises, receiving water, etc). Each block represents a system element (subsystem) with different underlying modelling approaches for hydraulics and mass transport. The open structure of the software allows adding own blocks and/or modifying blocks (and underlying models) according to the specific needs (Achleitner et al, 2007).

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

A simple method to account for the initial loss is used. The volume of the basin (respectively the height) represents the volume of water retained due to initial losses. The volume of rain exceeding the basin's volume is considered to be the effective precipitation, contributing to the catchment surface flow. Permanent losses such as evapotranspiration can be either considered acting all the time or during dry weather only. Either case, the volume per time step to be evaporated is limited by the initial loss specified.

Muskingum method is used for flow routing in the catchment, sewer and river blocks. The system (catchment, channels and conduits) is considered as a whole. The model has separate blocks for handling the combined and separate sewer systems. The model also has blocks for a combined sewer overflow structures and pumping stations. Mass transport of pollutants is implemented for conservative matter/tracer substances.

The model for the WWTP currently implemented is abstracted as ''black box'' accounting for cleaning efficiencies and maximum effluent qualities. Thus neither flow nor quality delivered to the treatment plant influence the level of treatment. The user is required to define for the substances cleaning efficiencies and the maximum effluent concentration. For reasons of simplicity a ''perfect'' treatment plant in terms of emission standards is assumed. Currently an accurate process description incorporating an ASM 1 type process model is developed to be implemented in CITY DRAIN (Achleitner et al, 2007).

City Drain does not have the capability to model pressurized flow or surface flooding and backwater flow as it uses Muskingum method for flow routing.

KOSIM-WEST

KOSIM-WEST is the implementation of the KOSIM hydrological catchment runoff and sewer transport model into WEST® (Solvi et al, 2005).

In KOSIM model, the sewer system is represented by a number of reservoirs connected in series or in parallel. A conceptual rainfall – runoff model transforms the rainfall series into a flow series for the single sub-basin. Weirs and different types of storage basins may be considered. The hydraulic calculations for these structures are based on the continuity equation, on maximum flow capacities and stage – discharge relations.

Rainfall-runoff simulation in KOSIM distinguishes between impervious and pervious catchment areas. For impervious areas, wetting, depression (represented by a time-variant runoff coefficient) and evaporation losses are considered. Infiltration for permeable areas is simulated using Horton-s approach, which has been adapted for use in long-term simulations (Paulsen, 1986 in CARE-S).

Flow routing on subcatchments is modelled by Nash cascades. Flow between the subcatchments is modelled by translation and addition of inflows from the subcatchments. From this modeling approach, it follows that backwater effects cannot be modelled by KOSIM. Structures such as pumps, overflows and different types of storage tanks can also be modelled. Surface flooding is not modelled explicitly by KOSIM; overflows occurring within subcatchments are assumed to be discharged into the river.

The Belgian simulator platform WEST (Worldwide Engine for Simulation, Training and automation) although originally developed for wastewater treatment modelling, it can be seen as a general simulation environment for computing the dynamics in a network of interlinked elements. The concept puts a limit to the description of water motion and transport processes in the elements but allows to implement more or less freely different conversion models for the different elements (representing catchments, CSO-structures, reactors, clarifiers, river reaches, etc) (Rauch, et.al, 2004).

Integrated Catchment Simulator (ICS)

The Danish Hydraulic Institute (DHI) and Water Research Center in GB (WRc) developed an “Integrated Catchment Simulator (ICS)” in a large EU-funded “Technology Validation Project” (Mark and Williams, 2000). ICS is basically a graphical interface for setting up and running integrated models with feed forward /feed back of information. The present ICS version includes existing models for sewers (MOUSE), rivers (MIKE11), wastewater treatment plants (STOAT) and coastal areas. During the course of this project, these fairly complex constituent models were linked in various stages; first in a sequential way, later in a simultaneous way. The complexity of the submodules, however, currently limits the application of ICS (Rauch, et.al, 2004).

SIMBA

SIMBA is a commercial toolkit for Integrated Urban Water Systems quality simulation and it is delivered by Institut für Automation und Kommunikation e.V. Magdeburg, Germany (http://www.ifak.de) (Freni et al, 2003).

SIMBA allows the holistic consideration of the entire urban wastewater system, including a sewer system, a wastewater treatment plant, receiving water body as well as a sludge treatment. Using information available from the plant, it is possible to set up simulation models for planning, design and optimization of plants within a reasonable time.

SIMBA is an application-oriented tool. Without any knowledge of programming, and assisted by buttons, extensive libraries and menus, the user can build models and simulate plants within a short time following a three-step approach:

- selection of model blocks required
- connection of the blocks with lines according to plant configuration; parametrisation
- simulation, followed by evaluation of plots of pollutant concentrations and loads using the build-in Monitor feature

The aim of the block set SIMBA sewer is the simulation of single dynamic events with interactions between treatment plant and sewer system. Interaction between treatment plant and sewer occurs, in case there is any kind of feedback present. Feedback can originate from hydraulic effects (backwater) or from control of the sewer system using information of the current state of the treatment plant. SIMBA sewer is not a replacement for conventional sewer simulation systems but a special tool to investigate managed sewer systems and integrated systems. SIMBA sewer does not describe the catchment of rain water.

Information about the several influent components to a sewer system (wastewater, surface runoff, infiltration) as flow rates and concentrations must be provided by the user. This influent could be generated by conventional sewer simulation systems and provided as ASCII files for SIMBA sewer. The surface runoff models are not included in SIMBA sewer because usually no feedback exists between surface runoff, transport and storage in sewer systems. SIMBA sewer allows to simulate:

- transport of water and load of dissolved and solid pollutants in sewer networks, through the application of conceptual deposition/resuspension model
- conversion processes, by the mean of depletion curves
- any kind of overflow and storage construction
- controllable inputs and controllers for sewer systems

Modelling of water transport is achieved by the diffusion wave approximation of the Saint Venant equation system - hydrodynamic model including storage, back water effects, change of flow direction, and flow separation in meshed sewer networks. SIMBA is able to simulate any closed or open kind of cross section profile, changing roughness along the wetted perimeter, pressurised flow in case of completely filled pipes.

Synopsis

SYNOPSIS (‘software package for SYNchronous OPtimisation and SImulation of the urban wastewater System’) was developed to assist studies of the urban wastewater system following the need for an integrated perspective. The simulation package consists of three main simulation sub-programs for modelling water flow and quality processes in the urban drainage system, WWTP and river system. A number of auxiliary programs are also used for control, optimisation and file management.

The urban drainage sub-model is based on the KOSIM program. The model allows for abstraction of wetting, depression and evaporation losses from rainfall–runoff. Subsequently, flow routing within a sub-catchment (incorporating surface and pipe storage effects) is accomplished using a cascade of linear reservoirs model. Flows between sub-catchments are routed by translation only. Pollutants are considered to originate from rainfall–runoff and domestic and industrial wastewater flows and to be completely mixed throughout the drainage system. No in-sewer processes are represented, neither sediment transport nor biochemical reactions, so any first foul flush cannot be predicted. However, the quality of the wastewater discharging at the overflows is specified with a greater fraction of rapidly biodegradable BOD (in the river model) than is given to the incoming WWTP effluent. Overflows and different types of storage tanks can be specified (if required) at the downstream end of each sub-catchment.

The WWTP sub-model is based on a slight simplification of the IWA Activated Sludge Model No. 1. The model represents the main unit processes of a conventional activated sludge plant: storm tanks, primary clarifiers, activated sludge aeration tank and secondary clarifier. Quality parameters include SS, VSS, COD (in various fractions), NH_3-N and NO_3-N. These data are taken from the output of the urban drainage sub-model (Zacharof et al, 2004).

The river sub-model is based on the DUFLOW shell program. The river hydraulics is represented by solving the St. Venant equations using a four-point implicit Preissmann scheme. Pollutant mass transport is modelled using the advection–diffusion equation. Representation of river water quality is based on an extension of the classic Streeter–Phelps model, including BOD (readily and slowly biodegradable fractions), NH_3-N and DO as key variables. This allows the model to characterise a number of phenomena, including reaeration, deoxygenation, nitrification, sedimentation, sediment oxygen demand and photosynthesis. Discharges into the river originate from three sources: CSO spills, storm tank overflows and treatment plant effluent. Routines convert drainage system and WWTP model quality parameters to those required for the river model. River catchment runoff is modelled by a simplified time-series approach.

The three sub-models are incorporated into one simulation program. The urban drainage system and WWTP are simulated in parallel. The river model is then run separately, as a sequential process. The programs are connected only at the necessary parts. This provides a hybrid of integrated simulation between pure sequential and parallel approaches. The simulation of the integrated system in this manner satisfies the requirements for investigating the relationship between overflows and receiving water quality (Zacharof et al, 2004).

Cosmos

Cosmos is a conceptual simplified model for sewer system simulation. The model is conceptual both in the flow simulation part (i.e., the rainfall-runoff transformation and the subsequent propagation) and in the qualitative one (i.e., the build up and wash of solids). The system (catchment and channels) is considered as a whole (Calabro, 2001).

The main goal of the model was to simulate the urban runoff quality. The model can be divided into four parts: the calculation of hydrological losses, the rainfall-runoff transformation and runoff propagation, the buildup solids during dry weather and their wash off. To calculate hydrological losses the model considers primarily the loss due to retention in small reservoirs and after all others combined into a runoff coefficient. The other hydrological losses (for example, infiltration) are considered less important in the model mainly because urban catchments are mostly impervious and it was considered possible to take them in account as a whole using a runoff coefficient. To simulate the rainfall-runoff transformation the linear reservoir method is used.

4.2.3 Urban stormwater and flood modelling

The hydrological cycle begins with precipitation. Precipitation in the form of rain falling on the land surface is subject to evaporation and initial loss due to interception by vegetation. The excess rainfall is available for *infiltration*, *overland flow* and *depression storage*. Depression storages are small pores and depressions on the land surface, which temporarily store water. Infiltrated water may flow through the upper layer of the soil which is generally the *unsaturated zone* of the soil, or flow deeper into the soil reaching the *groundwater*, or *saturated zone*. Water, which has infiltrated the soil and moves through the unsaturated zone and later becomes surface water, is known as *interflow*. In some urban storm water models, sub-surface flows are not modelled. One reason why sub-surface hydrology is not included in some urban storm water models is that a large proportion of the urban catchment is impervious, with little or no sub-surface flows.

Flooding Types

In general, flooding of land areas may be divided into four broad categories (Balmforth et al, 2006): Coastal flooding, river or fluvial flooding, localised or pluvial flooding and groundwater flooding. Estuarial flooding is a combination of coastal and fluvial flooding. Other less important categories are other causes of flooding arising from operational defects of drainage channels. Often flooding at any one location arises from a combination of the different categories, though this may be difficult to identify precisely.

Coastal Flooding

Coastal flooding arises for a variety of reasons and in addition to the flooding itself can also lead to coastal erosion with associated littoral drift and deposition. Sea level varies on a daily basis due to the gravitational effects of the moon, with a low and high tide occurring approximately twice in 24 hours. The background gravitational effect of the sun also influences the tidal cycle leading to a minimum tidal variation (neap tides) and maximum tidal variation (spring tides) approximately monthly.

It is unusual for daily tidal effects to cause significant coastal flooding, but spring tides have been historically associated with flood events. Separately, low pressure weather systems can lead to additional sea level rise, especially when combined with wind action. A combination of this effect with high tides can lead to severe coastal flooding.

The draining of the fens and the construction of sea defenses has led to significant inhabited areas depending on sea defenses for their safety. Combinations of high tides, atmospheric effects and wave action can cause such defenses to be overtopped or breached. In such cases flooding of land areas can be extensive with significant flood depths and high velocities occurring. This can pose a significant threat to human safety and cause considerable damage. Even where sea defences are not breached, high sea levels can impede the drainage of land behind the defences. Where severe wet weather coincides with a high sea level, it may not be possible to drain such areas by gravity. Either localised pluvial flooding will then occur or pumping will be required to provide the additional drainage head needed to discharge to the sea.

Fluvial Flooding
Rainfall leads to overland flow, and the natural erosion process will form drainage channels which then combine to form watercourses and subsequently rivers. River flow is augmented by percolation from groundwater and this provides the primary source of water during extended periods of dry weather. Rivers will naturally erode their bed until no more sediment can be transported. Where gradients increase, velocities also increase and more erosion occurs and the river channel deepens until stable conditions are once again reached. Conversely where gradients fall, for example as rivers flow out onto flatter land, velocities reduce and deposition occurs. River channels often become wider and natural meanders form. The equilibrium is disturbed during heavy or prolonged periods of rainfall however. River levels rise and may exceed the bank top so that water spreads out alongside the main river channel over what is known as the flood plain. The floodplain naturally provides two functions, conveyance of the additional flow, and storage that attenuates some of the flood effects..

Urban development can severely affect this natural process. Urbanisation in upland areas can lead to greater and more rapid runoff resulting in increased frequency and extent of flooding further downstream. Urbanisation in the flood plain removes important areas that previously served to convey and attenuate floods. When combined with flood defenses, flood flows and velocities in the main channel can be significantly increased, and this can lead to increased flooding downstream. When flood defenses are overtopped or breached, inundation can be sudden and extensive, and may threaten human safety and cause considerable damage. Even where flood defenses are not overtopped or breached, high water levels may inhibit the drainage of the land behind the defenses, leading to localised pluvial flooding. The generation of fluvial flood flow arises directly as a result of rainfall. There is normally a significant time lag between the peak of the rainfall hyetograph and the peak of the flood hydrograph. This lag is smaller in steep upland catchments and greater in flat lowland catchments.

Pluvial Flooding
This is caused by the effects of localised heavy rain generating surface runoff beyond the capacity of the drainage network. It can occur in both rural and urban areas, though its effects are more pronounced and damaging in the latter.

Pluvial flooding may be directly due to overland flow from land saturated by heavy rain. This is more common during long periods of rainfall in winter months, though it also occurs in urban areas during intense summer rainfall. Pluvial flooding can also occur where local drainage channel capacity is exceeded. This may arise where ditches, drainage channel, culvert or sewer capacity is exceeded. It can also occur where there is adequate drainage channel capacity but flow cannot enter the channel at the necessary rate. A good example of this is highway flooding caused by a lack of gully capacity.

The generation of pluvial flood flow arises directly as a result of local rainfall. There is normally only a small time lag between the peak of the rainfall hyetograph and the peak of the flood hydrograph. Pluvial flooding tends to affect local urban areas rather than the wider areas affected by river and coastal flooding

Groundwater Flooding

Groundwater flooding arises as a result of high water table levels leading to the formation of springs that directly flood land areas and property. It most frequently occurs in winter months after prolonged periods of rain. It generally occurs in areas which are underlain by permeable soil or rock, typically in Chalk, Sandstone or Limestone. Groundwater flooding can be extensive, of long duration, involve high volumes of flood water and is very difficult to control. High water levels can also cause basement flooding through infiltration whilst also increasing base flows in drainage systems through infiltration. Although important it only accounts for a relatively small proportion of urban flooding incidents.

Other Causes of Flooding

It occurs not because of high rainfall, but due to operational problems such as channel blockage or collapse. It most frequently occurs in sewers and culverts subject to high levels of sediment or tree route ingress, or due to partial or complete collapse. Another common cause is the blockage of trash screens at the entrance to culverts.

Stormwater and flood modelling

Traditional practice has been to remove all surface water runoff and wastewater flows from the urban area as quickly as possible via piped drainage systems. Alterations to the form of the landscape by human activity results in increasing runoff volumes, reduced times for flows to reach their maximum and the increase in peak flow rates. Consequently, urban areas are more susceptible to flooding affecting all land use activities. Provision of storm water infrastructure, which may consist of a network of drainage pipes, channels and retarding basins, is essential to protect both property and lives from flooding. In many instances, the infrastructure is only designed for a particular storm event, usually the 1 in 2 year or 1 in 5 year event or the 1 in 10 year storm event for commercial and industrial areas.

It has been emphasized that (Zoppou, 2001) the dependence of water quality on water quantity for at least two reasons. Firstly, in most water quality models, pollutant concentrations and loads cannot be estimated without having estimated the flows. It is for this reason that most water quality models include a hydrologic or hydraulic component. The hydrologic or hydraulic components simulate the movement of water through the urban catchment to various degrees of complexity. Secondly, procedures to mitigate quantity and quality are often complementary. For example, a retarding basin operates to reduce flood peaks as well as serve as a sediment trap. In a few urban storm water models, greater emphasis is placed on modeling pollutants rather than accurately modelling storm water flows. It is important to have realistic hydraulic or hydrologic models which have the appropriate spatial and temporal resolution required for the problem.

Three main types of urban flood modeling approaches can be identified (Guinot V. 2005). The first type of approach aims to determine a reduced set of specific flow variables (such as a peak discharge or a total flood hydrograph for a specifically delimited urban zone). The simulation results may then be interpreted in the light of the local topographical features in order to produce risk maps. Empirical models such as the unit hydrograph method are often used because of their simplicity and rapidity.

In a second approach, a conceptual distinction is made between runoff production and flood routing. In semidistributed, conceptual models the urban area is decomposed into subcatchments that contribute individually to runoff production. The runoff at the outlet of the various subcatchments is routed to the catchment outlet by means of a reservoir-based method or a kinematic wave-based approach. This approach has the advantage over the former in that the flow distribution (and consequently the distribution of the estimated risk) can be spatialized in greater detail. However the parameters of the routing methods used in such models do not often bear a physical meaning, which makes the analysis of urban development scenarios rather difficult.

The third category is that of physically based, distributed modeling. Physically based models have the advantage that the embedded flow parameters have a direct physical meaning and that scenario-based analyses thus become possible. Such models may be one dimensional, two-dimensional or a combination of both. The use of three-dimensional Computational Fluid Dynamics (CFD) models in urban areas is also reported for the detailed investigation of the local features of the flow.

Available storm water models represent a wide range of capabilities, spatial and temporal resolutions. The models can be classified according to the type of the modelling that the model can perform, how water quality and quantity components are simulated in the model, the water quality constituents that are modeled, additional features that a model may possess and accessibility of the model (Zoppou, 2001).

There are literally hundreds of models developed by academic institutions, regulatory authorities, government departments and engineering consultants that are capable of simulating water quality and quantity in an urban catchment. Most urban runoff models are physically based models. Very few serious models of urban storm water rely on statistical techniques, such as regression analysis (Zoppou, 2001).

Urban storm water models should be capable of simulating flows and the transport of pollutants over impervious and pervious areas, through channel and pipe networks and through storages. They should be able to produce results summarising the behavior of the catchment response as a function of time and at several locations throughout the catchment.

4.2.4 Wastewater Modelling

The impact of urbanization on receiving environment when expressed in terms of water quality parameters have been well documented over the past two decades. Receiving environment is affected by impacts from stormwater runoff, combined sewer overflows, wastewater treatment plant and industrial effluent.

Pollutants in urban areas basically are assumed to originate from two sources, which are rainfall-runoff, domestic dry weather flow and industrial dry weather flow. The simulation of mass transport is addressed by solution of the advection-dispersion equation. Several commercial software providers offer in addition to their hydrodynamic urban drainage modelling software a tool for water quality modelling. Yet these quality modelling tools are not common practice in urban drainage design.

The most common water quality parameters that are modelled in urban storm water models are: BOD, total coliforms, total P and N and both suspended and bed sediment transport. The non-urban models include arbitrary conservative pollutants and the modelling of aquatic organisms. Because the effect of pollutants on organisms is important, temperature, DO and ammonia are also included in non-urban models

4.2.5 Wastewater Treatment Plant Modelling

The increase of sensitiveness to environmental problems in the last decades and the consequent more stringent environmental regulations adopted have had a high impact in the wastewater field (Lindblom et al, 2005).

Typical WWTP consists of three phases of treatment: mechanical, biological and chemical. Before biological treatment the wastewater passes through mechanical treatment where coarse particle, inorganic solids and suspended particulate matter are removed. Chemical treatment may be implemented before, after or into biological treatment.

Wastewater treatment process is very complex due to its specific features such as: highly non-linear and multiple time scale dynamics, varying influent flow, high dimension of state vector. To find the optimal plant design and control combination, models and simulation software have begun to be used in the WWTP field in the last decades.

WWTP model can be used for many purposes:

- Process optimization
- Bottleneck identification
- Testing Control strategies
- Scenario/extreme event evaluation (rain, snow melting, breakdown of components etc.)
- Cost estimations

- Upgrade/design modification
- Changes in wastewater load/composition

The WWTP model can be used to test numerous of situations as a preventive measure, it can also be used to verify responses that will occur in the nearest future. Long-time effect of a short-term event (e.g. rain) can be modelled before the event has even taken place which will give the operators at the WWTP the possibility to adjust operation strategies according to the expected events and even model the effects of a numerous of scenarios that could be taken place.

WWTP models are suitable for taking a central role in all the phases of the life of a treatment plant: engineers need them in plant projecting, since the support of pilot plant experiments is often limited. During the plant operation phase, models help to indicate impacts of external disturbances on the plant, as well as the impact of operational decision, and allow to try several operation conditions in order to solve plant problems, to find the solution that gives the lowest environmental impact (saving more energy, producing less sludge, etc.) and to gear the plant to the new regulations.

4.2.6 Water Supply and Distribution Modelling

A water supply system is a system for the provision of piped water for drinking or general domestic use in incorporated municipalities or unincorporated communities. A water supply network is a system of engineered hydrologic and hydraulic components, including a geographical area that collects the water, a raw water reservoir where the water gathers, a means for delivery from the source to a point of treatment, water purification, transmission from treatment to treated water storage and distribution through piping from storage to consumption. Water distribution system is a system of piping, valves, storage tanks, pumps and appurtenances by which water is convoyed for domestic and municipal use by a common distribution system. A water supply and distribution model have the capability to simulate the variations in flow and pressure in the potable water supply pressurized pipe network. They can also represent dynamic operations of the pumping operations, valves, control valves and reservoirs. Water supply modelling is usually used in two main areas, in substantiating new infrastructure and dealing with daily operational planning. The constructed models often represent the hydraulic behavior of the real system. To ensure that the simulation represents the true operation of the real network, the models are calibrated before they are used in the analysis. With such models, every possible option can be simulated and the best solution can be evaluated for implementation. The water supply and distribution models are also extremely useful in providing supporting daily operations for looking at contingency planning, operational maintenance and emergency situations such as fire fighting and pollution management. Such models are built from system data and their instantiation involve manipulating data from a number of different resources. The latest generation of water supply modelling software tends towards the link with Geographical Information System (GIS). With this link it is possible to build the model network automatically from asset information database. This link helps to reduce effort in constructing the network and making the job of instantiating, calibrating and extracting the results much easier. Not only that, the links to live data sources makes the job of calibration much easier.

4.2.7 Receiving Water Modelling

The purpose of receiving water modeling is primarily to predict receiving water quality under different CSO pollutant loadings and flow conditions in the receiving water. The flow conditions, or hydrodynamics, of the receiving water are an important factor in determining the effects of CSOs on receiving water quality.

A receiving water model should be selected according to the following factors:

- The type and physical characteristics of the receiving water body. Rivers, estuaries, coastal areas, and lakes typically require different models.
- The water quality parameters to be modeled. These may include bacteria, DO, suspended solids, toxics, and nutrients. These parameters are affected by different processes (e.g., die-off for bacteria, settling for solids, biodegradation for DO, adsorption for metals) with different time scales (e.g., hours for bacterial die-off, days for biodegradation) and different kinetics. The time scale in turn affects the distance over which the receiving water is modeled (e.g., a few hundred feet for bacteria to few-miles for DO).
- The number and geographical distribution of CSO outfalls and the need to simulate sources other than CSOs.

Receiving water models vary from simple estimations to complex software packages. Many of the simpler approaches to receiving water evaluation assume steady flow and steady or gradually varying loading. These assumptions may be appropriate if an order-of-magnitude estimate or an upper bound of the impacts is required. The latter is obtained by using conservative parameters such as peak loading and low current speed. If water quality standards attainment is predicted under realistic worst-case assumptions, more complex simulations may not be needed.

5 Problem Definition

Urban water is a complex field, which includes provision of safe water supply and sanitation, sustainable use of water resources, pollution control, stormwater and wastewater network management and flood prevention. Working with complex systems such as urban water systems requires a wider knowledge than just knowledge of a particular component of the urban water cycle. Indeed, specialized knowledge is necessary but not sufficient to solve complex problems. Two separate and specialized models, while perhaps successful in isolation, often fail in representing the complexity of the real world. The failure of these two kinds of specialization is not so much because they are wrong, but because they are incomplete. This is because they are disconnected from the other knowledge, which they must be consonant, and from the wider systems with which they must co-operate. This idea of the whole processes (i.e., holistic consideration) is very important to solve complex problems.

In a complex urban environment, appropriate numerical tools are required to predict the behavior of the complete system under historical and future scenarios and to describe the complex water-related interactions, and to allow management strategies to be developed. Typically, two types of models are used: *simplified* (or strategic) and *detailed* ones. Simplified models are normally used for strategic planning purposes, whereas, detailed models (e.g., sewers, treatment plants and receiving waters) are needed to describe the system's performance according to the specific local needs and objectives.

Traditionally, the modelling practice would consider the analysis of a single component within the urban water cycle and there is no adequate consideration of other components and their interactions. The challenge today is to move from such individual consideration of system performance to an integrated analysis of the entire urban water system. Integrated modelling is defined here as modelling of the interaction between two or more physical systems having different characteristics. For example, a mathematical computer model, which contains representation of the sewer system, the wastewater treatment plant (WWTP) and the receiving waters would represent such modelling system. The shift towards the integrated modelling systems comes on one hand because of the need to manage urban water cycle on a holistic basis and on the other hand because of the advances in urban hydroinformatics technologies which have enabled to model different phases of the entire cycle and optimise them globally.

Three possible ways of model integration may be identified as (i) loose coupling, (ii) tight coupling and (iii) fully integrated. Loose coupling integrates models with common file exchange usually in ASCII format. This type of integration requires a number of programs that exchange data from one application to another and possibly a data base management system (DBMS) and/or number of transfer files. A disadvantage of this approach is that there is no common graphical interface and the data exchange and conversion between the models can be very cumbersome. Loose coupling may also involve considerable work in changing data formats and data structure, particularly if the models have been obtained from different source. In tight coupling models integration is controlled by a system that provides a graphical user interface for viewing and controlling the integration. Unlike loose coupling, tight coupling does not require file conversion or editing; however, it is a complex process and requires a great deal of programming and data management plus a customised menu-driven user interface for display. In fully integrated systems, all the components are embedded in one single unit. This requires all the models be programmed and act as a component of the core program.

One of the main issues of integrated modelling is the compatibility between different sub-models. This is due to the fact that the different systems will have different processes of interest evolving at various space and time-scales, bringing along different parameters and variables. Implementing links between model domains and different types of models and data can be a difficult task, because spatial and time scales may not correspond. Linking different models on a common time and/or spatial scale may require large amounts of data and/or considerable averaging or interpolating in space and time. Routines to carry out such procedures must be supplied and it must be ensured that the links between models do not become sources of errors. Such procedures may increase execution time, but in general the framework should be designed to improve the quality of and shorten the modelling process.

Although the basic principles are known, the development of integrated models still is a challenging task. The main bottleneck is the complexity of the total system that prevents a simple linkage of the existing physically based models of the individual subsystems to an entity (Rauch et al, 2001). Another problem encountered when creating an integrated model is the fact that the existing models are quite complex and require sophisticated integration algorithms to solve them. This results in long calculation times, making these models impractical to use, especially within optimisation problems where a lot of simulations need to be performed. Model integration also can in practice be difficult for many reasons related to data formats, compatibility of scales, ability to modify source codes, etc. To overcome such difficulties, there are attempts by commercial software companies to develop the links between different detailed physically-based models (Moore et al, 2004) to enable development of integrated modelling. However, efforts in instantiating such models and their linking and running, which usually takes substantially long period of time, is far too impractical for strategic planning purposes where simulation of different scenarios and optimization are required.

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

Since there are several limitations which make the use of detailed physically-based models, which are based on the conservation of mass and momentum, inefficient and impractical for strategic planning purposes, such models need to be replaced by fast surrogate (an approximate substitute) models. The weakness of fast surrogate models is the low content of encapsulated knowledge of physical processes that they posses and this shortcoming has to be compensated by more extensive calibration (Meirlaen et al, 2001). Once fit for purpose, the surrogate models can be then used as a strategic planning tool for different scenario analysis and decision making.

Surrogate models require much more data for calibration than physically-based models. Since the collection of such data can be very expensive and time consuming, one way of approaching this problem could be to calibrate the physically-based models with less data and generate sufficient virtual data using the physically based models for calibration and validation of surrogate models. If this is done for every urban wastewater system component, the knowledge of the physically-based models can be transferred to the surrogate models and as such they could be efficiently used for strategic planning and decision making (see for example, Meirlaen et. al., 2001).

Rapid urbanization and its implications for both water quality issues and floods have increased the need for modeling of urban drainage systems. Because of the dependency of water quality on water quantity due to the reasons that pollutant concentrations and loads cannot be estimated without having estimated the flows and procedures to mitigate quantity and quality are often complementary, estimation of urban flows in reasonable accuracy is very important for integrated urban wastewater systems modelling. As it is apparent from the review of modelling tools for integrated urban wastewater systems, most of the modeling tools employed conceptual models to estimate the urban flows due to the advantage they possess from computational intensity point of view. However, due to their conceptual nature, these models cannot provide accurate results compared to the physically based ones especially in conditions of surcharge flows, surface flooding and significant backwater effect.

Calibrating surrogate models with results of the physically based models for different flow conditions may improve the shortcomings of the conceptual models.

Of the three types of urban flood modelling approach identified by (Guinot V., 2005), the physically based models, which are based on the conservation of mass and momentum, have the advantage that the imbedded flow parameters have a direct physical meaning. However since such models need detail input of the system being modeled and are computationally intensive, they are more suitable for detailed urban flood modelling and analysis rather than strategic modelling practice. Moreover since conceptual models are relatively easy to use in integrated modelling practice, including urban flood modelling capability using conceptual modelling approach to the integrated urban water modelling tools is a big advantage and a challenge.

In conceptual flood modelling approach, the urban area decomposed in to subcatchments that contribute individually to runoff production and the runoff at the outlet of various subcatchments is routed to the catchment outlet by means of conceptual hydraulic models such as a reservoir based method or a kinematic wave based approach. After the total flood hydrograph for a subcatchment determined, it may then be interpreted in light of topographic features of the subctachment in order to produce risk maps. In this way flow distribution and consequently the distribution of the estimated risk can be spacialized.

6 Objective of the research

6.1 Overall Objective

The overall purpose of the this research is to develop a modelling framework that enables conceptual modelling of integrated urban wastewater systems (sewer network, wastewater treatment plant and receiving water) and urban flooding for providing decision support in strategic planning for integrated urban water management.

6.2 Specific Objectives

Specific objectives of the research are:

(i) to develop a modelling framework for better simulation of urban drainage systems using conceptual models;

(ii) to develop a methodology to estimate the parameters of the conceptual urban drainage model from catchement and rainfall characteristics;

(iii) to develop conceptual wastewater treatment model and receiving water model to be integrated with the sewer model

(iv) to improve the ability of the sewer model to be developed in simulating surcharge conditions and surface flooding;

(v) to develop a methodology to quantify flood hydrograph from the conceptual sewer model and to produce flood (risk) map by analyzing the topographic features of subcatchment under study;

(vi) To demonstrate the functioning of the modelling tool on two selected SWITCH demo cities.

7 Methodology

Review of relevant literature and current practices particularly topics that relate to integrated urban water systems modelling will be the beginning of the research. Integrated urban water modelling practices, problems and advances will be reviewed in detail to gain full understanding of the gap where this research fits. Review of integrated urban water systems modelling tools will be made to get understanding of steps and underlying assumptions and identify pros and cons of the methods. From the literature review problem identification, understanding and analysis will be done to formulate the objectives and steps of the research.

Further to the objective formulation, model scope, selection and development needs and requirements will be assessed and further literature review will be made. Analysis of data requirement and data collection needs will be then addressed and specified.

As it is discussed in the literature review and problem identification chapters of this proposal, the level of accuracy of the urban drainage (storm water) modelling is fundamental to the overall accuracy of the integrated urban wastewater systems modelling. Thus the stormwater drainage component is the focus of this research.

The approach is to set up a conceptual urban drainage model to be able to simulate the urban drainage component as possibly accurate possible as needed for strategic planning purpose and thereby assisting decision making for integrated urban water management.

Conceptual model represents the hydrological processes that are seemingly important in the system using a simplified, conceptual representation. These models have three notable characteristics: a) their model structure is specified a priori; b) the hydrological properties of the catchments are represented as parameters, which are generally assumed to be constant during each model application; c) (at least some of) the model parameters have no direct, physical meaning and are not directly measurable. Therefore model parameters are usually estimated via calibration, using the fit of the model output time-series to observed data to provide a measure of goodness of fit, using either a manual or automatic procedure (Wheater et al,).

To use mathematical models for design and analysis of urban drainage systems, it is necessary to estimate the model parameters relevant to these systems. The model parameters for gauged drainage systems are generally estimated from calibration of the models. However, this is not possible for ungauged systems due to the absence of rainfall and runoff data. If regional equations (correlating model parameters to the drainage system and other details) are available, they can be used to estimate the model parameters for ungauged drainage systems. To develop such regional equations, it is also necessary to estimate the model parameters for gauged catchments through calibration. Calibration can be performed by visual comparison of modelled and observed hydrographs, or through parameter optimisation.

However, in some circumstances sufficient data may not be available to permit estimation of the model parameters through calibration. On the other hand, physically based models can be calibrated with a reasonable amount of effort. After calibration of the physically base models, simulation results yield virtual data that can be used to calibrate the conceptual model. This can be seen as transferring the knowledge summarised in the physically based model into the conceptual model by means of these virtual data (Meirlaen et al, 2001).

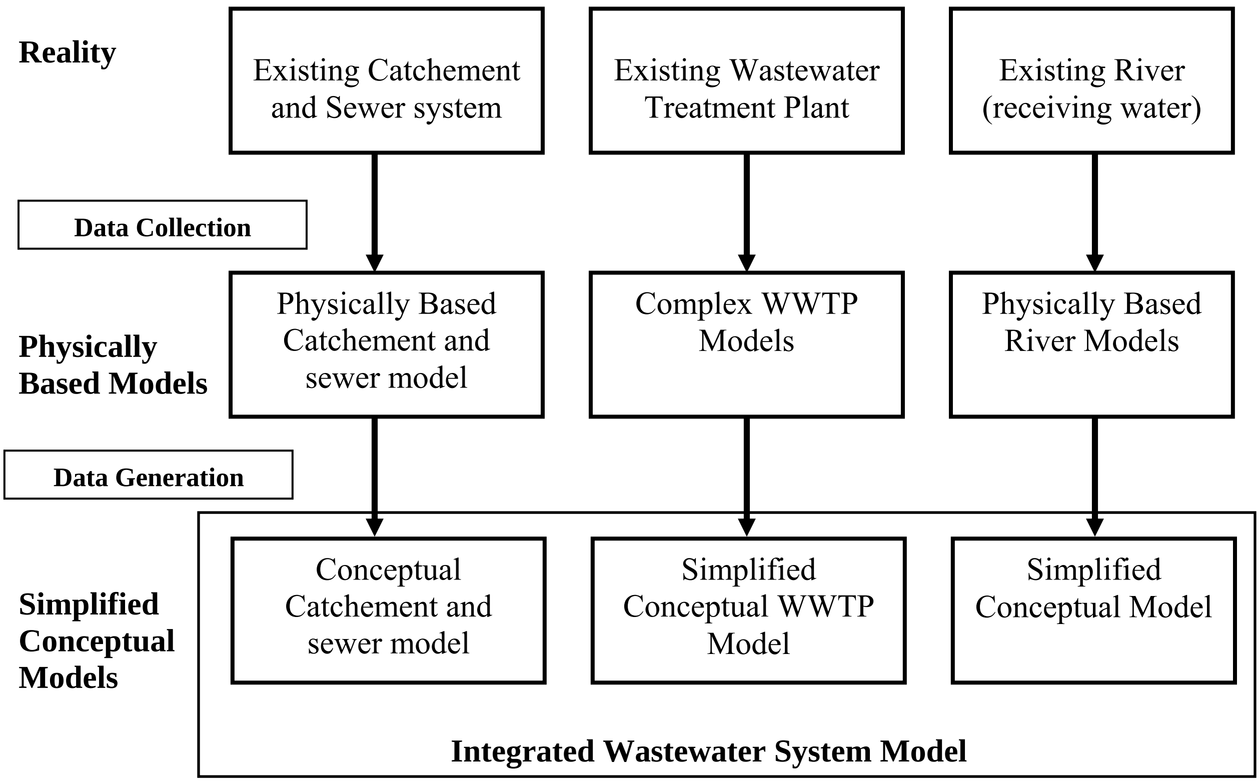

Figure 2. From Reality to Simplified Conceptual Models (Adopted from Meirlaen et al, 2001).

The Urban Drainage Model

Development of a conceptual catchment and sewer model and calibrating and verifying it for several urban drainage catchments and then defining model parameters as a function of measurable catchment properties and (in some cases) storm characteristics would be the major work of this research.

The conceptual sewer model needs to
- Be computationally less demanding;
- Have as minimum number of free parameters as possible;
- Be suitable for linking to other component models (to the WWTP model and the receiving water model).

After the conceptual model is developed, data required for calibration and verification of the model will be collected. For developing a relationship between the model parameters and catchment and storm characteristics, the model needs to be calibrataed and verified for many catchments with different characteristics. To this end many urban drainage catchments (probably close to hundred) with different characteristics such as shape, slope, percentage of imperviousness and landuse type and with different sewer network pattern such as dendritic sewer, looped sewer, sewer networks with pumping stations, retention basins, overflow structures from different climatic regions will be collected.
For each of the collected catchments, physically based models (using the DHI urban drainage model MOUSE) will be built and simulations will be made for different storm events which could result in free surface flow, surcharge flow and surface flooding. The next step is calibrating and verifying the conceptual model against the data generated by the physically based models.

Parameter Estimation

Basically, any kind of modelling can be looked upon as an input to a system that transforms the input into an output. The modelling system can have a firm physical basis built on theories and physical laws of the various hydrological processes, for example, the Boussinesq equation for groundwater flow or the St. Venant equations for channel flow. Alternatively, one can analyze the input and output data and build empirical models that describe the observed relations using, for example, deterministic artificial neural networks (ANN) or autoregressive-moving average (ARMA) linear stochastic models. Between these two opposite approaches, a broad spectrum of modeling systems can be formulated using different process conceptualizations that have a certain degree of physical content, but need observation data to tune or calibrate the model parameters (Rosbjerg and Madsen, 2005).

A conceptual model as defined by (Refsgaard, 1996) is one that is constructed on the basis of the physical processes that we ‘read’ into our observation of the catchment. In a conceptual mode, physically sound structures and equations are used together with semi-empirical ones. However, the physical significance is not usually so clear that the parameters can be assessed from direct measurements. Instead, it is necessary to estimate the parameters from calibration, applying concurrent input and output time series.

Hydrological models describe the natural processes of the water cycle. Due to the large complexity of the corresponding natural phenomena, these models contain substantial simplifications. They consist of basic equations, often loosely based on physical premises, whose parameters are specific for the selected catchment and problem under study. For partly or fully conceptual models, some parameters cannot be considered as physically measured (or measurable) quantities and thus have to be estimated on the basis of the available data and information.

In urban storm water modeling the runoff at the outlet of a subcatchement is sought. This runoff is a function of the input, climatic factors and the catchment physical characteristics. In conceptual modelling the complex physical processes which transform the rainfall over the catchment to the runoff are represented through a number of inter connected mathematical functions each representing a certain component of the hydrology cycle. Each mathematical expression in the models has constants which we call parameters. The values of these parameters estimated either from measurements or through calibration. It is very important that the parameter values of the model, to the highest degree possible be assessed from measurements or available field data we can get hold of. The number of real calibration parameters should be kept low (parameter parsimony) especially if the model is going to be used for unguaged catchments. Therefore it should explicitly be evaluated which parameters can be assessed from available measurements alone and which need some kind of calibration. For the parameters subject to calibration, physical acceptable intervals for the parameter values should also be estimated.

Prediction of ungauged basins is one of the most challenging issues in the hydrology of this century. One of the difficulties of the prediction is the transfer of information from gauged to ungauged areas. Generally, catchments with similar characteristics show similar hydrological behavior. Thus, it is possible to regionalize model parameters on the basis of catchment characteristics, i.e., to provide a regional parameter set where parameter values vary with measurable catchment characteristics. This regionalization can be made using relationships between the parameters of the model and the catchment characteristics.

A parameter optimisation method can be used to calibrate the model parameters using observed or virtually generated data on rainfall-runoff events of the study catchments. Then, these model parameters will be verified using rainfall runoff events, which were not used in the calibration.

Sensitivity Analysis and Uncertainty Assessment

Sensitivity Analysis it is the assessment of the impacts of input changes on output values. Sensitivity Analysis can get useful information regarding the behavior of the underlying simulated system. This information can range from the identification of calibration variables to model reduction or simplification, better understanding of the model structure for given components of a system, model quality assurance, and model building in general.

To calibrate the models effectively, it is important to know the sensitivity of model output to each model parameter. Similarly, when a model is applied to an ungauged catchment, care should be taken to select the “accurate” values for all sensitive model parameters. This information can be obtained from a sensitivity analysis of the model parameters. Sensitivity analysis of model parameters requires the investigation of changes in the model output to the changes in model parameters.

Uncertainty is an unavoidable and inherent element in hydrological modeling.
Uncertainty assessments of model predictions are crucial for a sound use of models in water resources management in practice. The main uncertainty sources are;

- *Input uncertainty* in terms of external driving forces and system data that drive the model such as land use maps, pollution sources and climate data.

- *Model structure uncertainty* is the conceptual uncertainty due to incomplete understanding and simplified descriptions of processes as compared to nature.
- *Parameter uncertainty*, i.e. the uncertainties related to parameter values.
- *Model technical uncertainty* is the uncertainty arising from computer implementation of the model, e.g. due to numerical approximations and bugs in the software.
- *Model output uncertainty*, i.e. the total uncertainty on the model simulations taken all the above sources into account, e.g. by uncertainty propagation.

It is now generally accepted that these uncertainties and their effect on the model predictions should be quantified as part of a hydrological modelling exercise. A reliable estimate of the prediction uncertainty is crucial for making efficient decisions on the basis of model simulations. Ignoring the uncertainty associated with model predictions may result in misleading interpretations when the model is used by a decision-maker for risk assessment.

How to include and combine appropriately all the different error sources in hydrological modeling is a very complex and yet unsolved problem. Ideally, the joint probability distribution of all the important sources should be quantified and used as input to the model to derive probability distributions of the model predictions. However, quantification of the probability distributions for the different error sources is a difficult task, and hence simplifications are needed.

The approaches used for evaluating model prediction are reviewed in (Rosbjerg and Madsen, 2005). These include the classical statistical approach, Monte Carlo-based procedures and the generalized likelihood uncertainty estimation (GLUE) procedure and Markov Chain Monte Carlo sampling.

The classical statistical approach for evaluating model prediction uncertainty is a first-order analysis where the covariance of the model input (forcing and/or model parameters) are propagated through the model using a first order Taylor series approximation of the model operator. For assessing parametric uncertainty, the covariance is usually estimated using a multinormal approximation of the probability density function of the model around the estimated optimum based on a gradient-based search.

While the first-order approach is an efficient solution to quasi-linear models, the method fails when applied to highly nonlinear models. In such cases, Monte Carlo-based procedures have been put forward. In these methods, the statistical properties of the model input are represented by an ensemble estimate, and this ensemble is then propagated through the model to produce an ensemble of model outputs from which confidence limits on the model predictions can be derived. The main shortcoming of the Monte Carlo approach is the slow convergence of the ensemble to the true probability distribution (proportional to the inverse of the ensemble size), and hence the method has huge computer processing (CPU) requirements. Alternative sampling strategies have been proposed such as Latin Hypercube Sampling, which allows a more efficient sampling in the model input space.

Another shortcoming of the Monte Carlo-based procedure is the explicit use of a joint probability distribution for the model input. Other sampling procedures have been proposed that are conditioned on the observations of the modeled system for evaluating the model prediction uncertainties. These methods include importance sampling such as the generalized likelihood uncertainty estimation (GLUE) procedure and Markov Chain Monte Carlo.

The GLUE framework addresses the problem of nonuniqueness in model calibration. That is, many different parameter combinations are equally acceptable in reproducing the observed system behavior, and these parameter sets may often come from very different regions in the parameter space. In such cases, the multinormal approximation of the model parameters around an estimated optimum is inadequate to represent the parameter uncertainty.

Most of the model calibration and uncertainty propagation procedures implicitly assume a correct model structure, and only parameters within that structure are allowed to vary. When significant model structural errors are present, such procedures will provide biased model parameter estimates and unreliable uncertainty predictions. Quantification of these errors is much more complicated, since model structural errors are difficult to isolate from the errors originating from parameter uncertainty. Bayesian statistical inference methods have been proposed to consider jointly the different error sources in a simplified functional form. The GLUE method and Markov Chain Monte Carlo sampling offer another framework to address jointly different error sources, but so far have considered mainly parameter uncertainty.

Regionalization

After the conceptual model is satisfactorily calibrated and verified, the next step is to develop some form of equations to estimate the model parameters using measurable and/or easily obtainable catchment and rainfall parameters. Successful relationship between model parameters and catchment and rainfall parameters depends on;

- accurate estimation of model parameters (for gauged catchments),
- selection of catchment and rainfall characteristics that affect the catchment response to rainfall and the model parameters.
- definition of homogeneous regions,
- degree to which the model parameters are correlated with catchment and rainfall characteristics.

The effect of hydrological cycle is inherently spatially varied and depends on such factors as the shape, size, slope, drainage network, surface cover, soil characteristics and land use patterns of the drainage basin. These factors affect the runoff response to rainfall in both urban and rural catchments, and should be considered in characterizing the model parameters.

Probably the most common approach to ungauged modelling is to relate model parameters and catchment characteristics in a statistical manner assuming that the uniqueness of each catchment can be captured in a unique combination of catchment characteristics. The basic methodology is to calibrate a specific model structure to as large a number of (gauged) catchments as possible and derive statistical (regression) relationships between (local) model parameters and catchment characteristics. These statistical relationships, called regional models, and the measurable properties of the ungauged catchment can then be used to derive estimates of the (local) model parameters. This procedure is usually referred to as regionalization or spatial generalization (Wagener and Wheater, 2006).

If the model can be written in the following simplified form, the regionalization process is described as follows (Wagener and Wheater, 2006),

$$Q = M_L(\theta_L|I) + \varepsilon_L$$

where Q is the simulated outflow, I is a matrix of input variables (e.g. rainfall), M_L is a given (local) model structure, θ_L is a vector of parameters within this structure and $\varepsilon_L$is an error term. The model parameters will usually be estimated through calibration if measured time-series of runoff over a sufficiently long period are available. The required length of the time-series depends, amongst other things, on the complexity of the model structure used and the information content of the available data. However, in principle, the data set should always be sufficiently long to avoid the problem of the parameters only being representative of a particular climate period. If no runoff data are available for a specific catchment, i.e. if it is ungauged, an attempt can be made to calibrate the model structure to a large number of gauged catchments and to find a functional relationship between the (usually individual) conceptual model parameters (dependent variables) and the catchment characteristics (independent variables), i.e. a regional model structure of the following type:

$$\hat{\theta}_L = H_R(\theta_R|\Phi) + \upsilon_L$$

where $\hat{\theta}_L$ is the estimated model parameter at the ungauged site, $H_R(.)$ is a functional relation for $\hat{\theta}_L$ using a set of physiographic and meteorological catchment characteristics Φ, while θ_R is a set of regional model parameters and$\upsilon_L$is an error term. One model, i.e. (regional) model structure and (regional) parameter combination is conventionally derived for each (local) parameter, i.e. the model parameters are assumed to be independent. The regional model structure commonly takes the form of a linear or a non-linear regression equation.

No generally accepted procedure for regionalization of conceptual, continuous model parameters currently exists. However, the following steps are typically found and are therefore given here as the basic outline of a regionalization procedure (Figure 3):

- Decide which (sub-)set of catchments can be described by a single local model structure M_L and a single regional model, i.e. one structure H_R with a specific set of parameters θ_R. Catchments that are very different with respect to their dominant hydrological processes might require different (local) model structures to represent them in a physically (or probably rather conceptually) realistic manner. This segmentation of catchments must be related to the catchment characteristics Φ in order to classify any ungauged catchment. Appropriate characteristics could be size, drainage density, soils/geology, land use, etc.

- Apply the local model structure M_L to each of the gauged catchments and estimate the optimum parameter set (or population) θ_L for each catchment.
- Relate the derived (individual) parameter values θ_{Li} and the catchment characteristics Φ using the regional model structure H_{Ri}. Apply the regional model $H_{Ri}(\theta_{Ri}|\Phi)$ to estimate each parameter $\hat{\theta}_{Li}$ for the ungauged catchment.
- Predict flow in the ungauged catchment using parameter set $\hat{\theta}_L$.

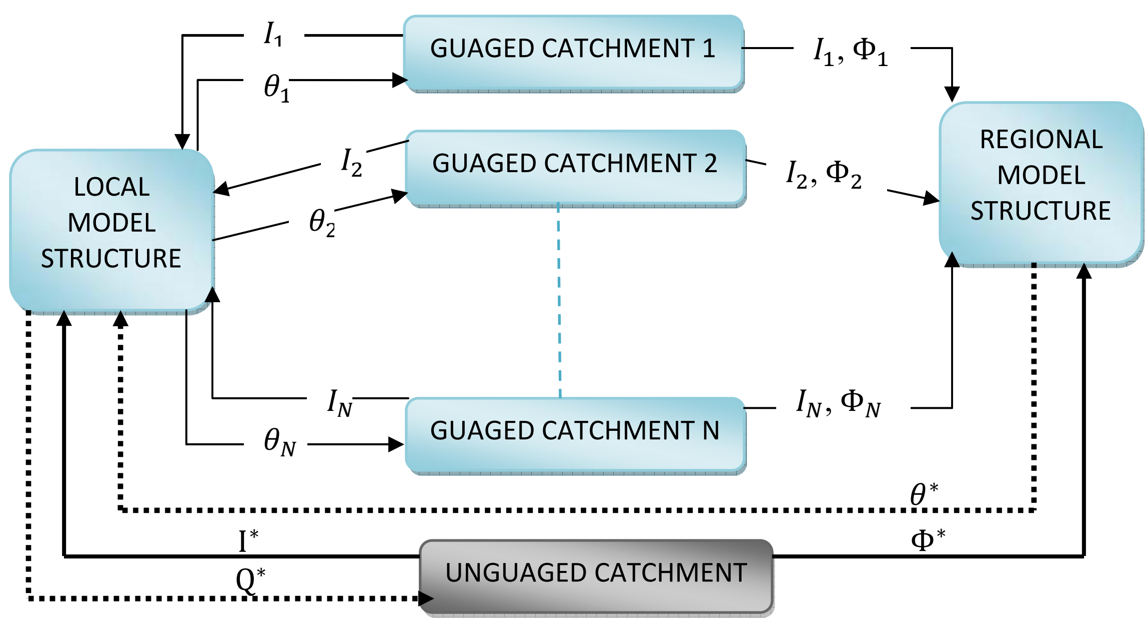

Figure 3. Schematic representation of a regionalization procedure (adopted from Wagener and Wheater, 2006)

In addition to the uncertainty sources outlined above in the modelling practice, other sources of uncertainty will be introduced due to the regionalization procedure. The main uncertainties are: Selection of catchment properties, i.e. what are suitable characteristics to describe and cluster (pool) catchments with respect to their hydrological response? And identification of the regional model structure and its parameters, i.e. what is the nature of the relationship between catchment characteristics and model parameters?

The sensitive model parameters and candidate catchtment and rainfall characteristics should be identified and then, regression analyses would be conducted by relating the influential catchment characteristics to these parameters.

If sufficient data are available, it is desirable to use a split sample procedure. In the split sample procedure, the available data are partitioned into two groups. The first group is used to derive the relationship and then these equations are tested for its ability to reproduce the data of the second group. If the test results lie within acceptable limits, the data and the form of the equation are accepted, and redevelopment of the equation carried out using all available data. If the test results lie outside acceptable limits, the basic assumptions and data used in regional equations are thoroughly checked. Then, only the good data are used for the development of the regional equations, but the confidence in the results is then reduced because of the small data set and lack of verification.

The conceptual urban drainage model will have only the ability to simulate the total flood hydrograph for a subcatchment not its distribution over the subcatchment. Therefore analysis and interpretation of the topographic features of the subcatchment are required to be able to produce flood risk maps.

After the sewer model is developed and the parameters regionalisation is performed, the simplified wastewater treatment plant and the receiving water models of Citydrain model will be adopted and will make the integrated wastewater system modelling tool together with the sewer and catchment model developed here.

Finally this modelling tool will be demonstrated on two SWITCH demo cities, Belo Horizonte in Brazil and Birmingham in UK. In these demonstrations, the ability of the catchement and sewer model will be tested and verified if it can simulate the urban drainage system in acceptable accuracy for strategic planning purpose for both gauged and ungauged urban drainage catchments.

8 Organization

8.1 Research Committee

Prof. D. P. Solomatine will be the promoter of this PhD research and supervision of the research will be done by Dr. Z. Vojinovic. Table 8.1 shows the details about supervision team involved and their field related to the research. Supervision, Training and Education Plan (STEP) form and curriculum vitae of the author are included in this proposal in appendix I and II respectively. Results and research plan will be submitted every year in February to the UNESCO-IHE academic board by PhD annual progress report and planning. This research is part of UNESCO-IHE Sustainable Water management Improves Tomorrows Cities Health (SWITCH) project under theme 1 (Urban Water Paradigm Shift) and sub theme 1.2 (Modelling of urban water system and development of a decision support system).

Table 8-1 Supervision team

Supervision team		Field
Promoter	Prof D. P. Solomatine, PhD	Data-driven modeling in hydrology, hydraulics and water resources Computational intelligence Systems analysis Internet based computing
Supervisors	Z. Vojinovic, PhD	Modelling and management of urban water system. Geographical Information System (GIS) application Decision support systems
	Prof R. K. Price, PhD	Urban water Systems Physical based modeling Knowledge management

8.2 Planning

Research period planned to be around 4 years start from June 2007 to May 2011. Table 8.2 shows detail activities in the research and the summary of the activities are listed below:

1st year:
- i. Research proposal and Integrated Urban Water System (IUWS), modelling approach: Comprehensive review

2nd year:
- i. Modell development and refinment

3rd year:
- i. Data collection and model calibration and testing
- ii. Refinement of the modelling tool

4th year:
- i. Case study and performance tests
- ii. Review comments, analysis and discussions
- iii. Preparation for dissertation

Table 8-2 Detail research activities

	2007		2008				2009				2011				2011	
	3/4	**4/4**	**1/4**	**2/4**	**3/4**	**4/4**	**1/4**	**2/4**	**3/4**	**4/4**	**1/4**	**2/4**	**3/4**	**4/4**	**1/4**	**2/4**
Literature review																
Research proposal																
Requirement analysis :		Analys requirement of the modelling tool														
Conceptual Design : Modelling tool			Detail description about the modelling tool													
Draft modelling tool					Draft Modelling tool											
Final modelling tool development							Final modelling tool									
Data collection and preparation									Data collection and preparation							
Parameter regionalization, model calibration, verification and simulation											Model calibration, verification					
Results discussion and conclusions												Result discussion and conclusion				
Paper to a peer reviewed journal				Urban water publication				Water science & technology publication				Water research publication				
Dissertation and public defence									Thesis writing							Defence

8.3 Budget

The research is funded by SWITCH project and table 8.3 shows detail description about cost and finance related to the research.

Table 8-3 PhD budget

Ph.D Programme	**Euro**
Tuition Fee (Euro 8,400,-@ 4 years)	33,600
Insurance (Euro 38 x 12 month x 4 years)	1,824
Thesis Cost	4,538
Public Defence	2,723
Application MVV	250
Registration Alien Police	188
Extension residence permit 3 years @ 52	156
Handling fee (Euro 455 * 4 years)	1,820
Monthly allowance 12 months @ Euro 1,075 x 4 years	51,600
Book allowance (Euro 300 per year)	1,200
Travel costs in Netherlands (Euro 500 per year)	2,000
Conference/Excursions (Euro 750 per year)	3,000
Miscellaneous (Euro 500 per year)	2,000
Total Ph.D. Programme	104,899

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APPENDIX I – STEP PROGRAMME

Supervision, Training and Education Plan (STEP)

(This form is to be submitted to the Academic Board together with the PhD Research Proposal for approval. A first draft is to be discussed with the PhD Coordinator within one month upon arrival in Delft.)

Date of submission of this report: 22/02/2008

1. PERSONAL DATA

Surname : Seyoum

First names : Solomon Dagnachew

Nationality : Ethiopian Date of birth: 22nd of September 1972

Male/~~female~~

Locker number :-

Email : s.seyoum@unesco-ihe.org / sol_d1972@yahoo.com

MSc degree

Year : 2005

Discipline : Hydroinformatics

University or institute : UNESCO-IHE Institute for Water Education, The Netherlands

Starting date PhD (date of enrolment): 1st June, 2007

Financing (sponsor) : SWITCH Project

2. SUPERVISION

Promoter : Prof. D.P. Solomatine, PhD

Mentors : Z. Vojinovic, PhD

Supervisor : Prof R.K. Price, PhD

Other member(s) :

3. RESEARCH PLAN

Title research project:

Integrated Urban Wastewater Systems Modelling for Strategic Planning Purpose

Problem setting and objective:

Problem setting

- To develop conceptual urban catchment drainage model
- Develop simplified wastewater and receiving water models

- To calibrate the conceptual models on the basis of calibrated and verified physically based model results
- To try urban flood modelling using conceptual drainage model
- Integrating the simplified models to develop integrated modelling tool

Objectives

The overall purpose of the this research is to develop a modelling framework that enables conceptual modelling of integrated urban wastewater systems (sewer network, wastewater treatment plant and receiving water) and conceptual modelling of urban storm water drainage and urban flooding and thereby providing decision support in integrated urban water management.

Specific objectives of the research are:

- to develop a modelling framework for better simulation of urban drainage systems using conceptual models;
- to develop a methodology to estimate the parameters of the conceptual urban drainage model from catchement and rainfall characteristics;
- to develop conceptual wastewater treatment model and receiving water model to be integrated with the sewer model
- to improve the ability of the sewer model to be developed in simulating surcharge conditions and surface flooding;
- to develop a methodology to quantify flood hydrograph from the conceptual sewer model and to produce flood (risk) map by analyzing the topographic features of subcatchment under study;
- To demonstrate the functioning of the modelling tool on two selected SWITCH demo cities.

Time schedule (summary)

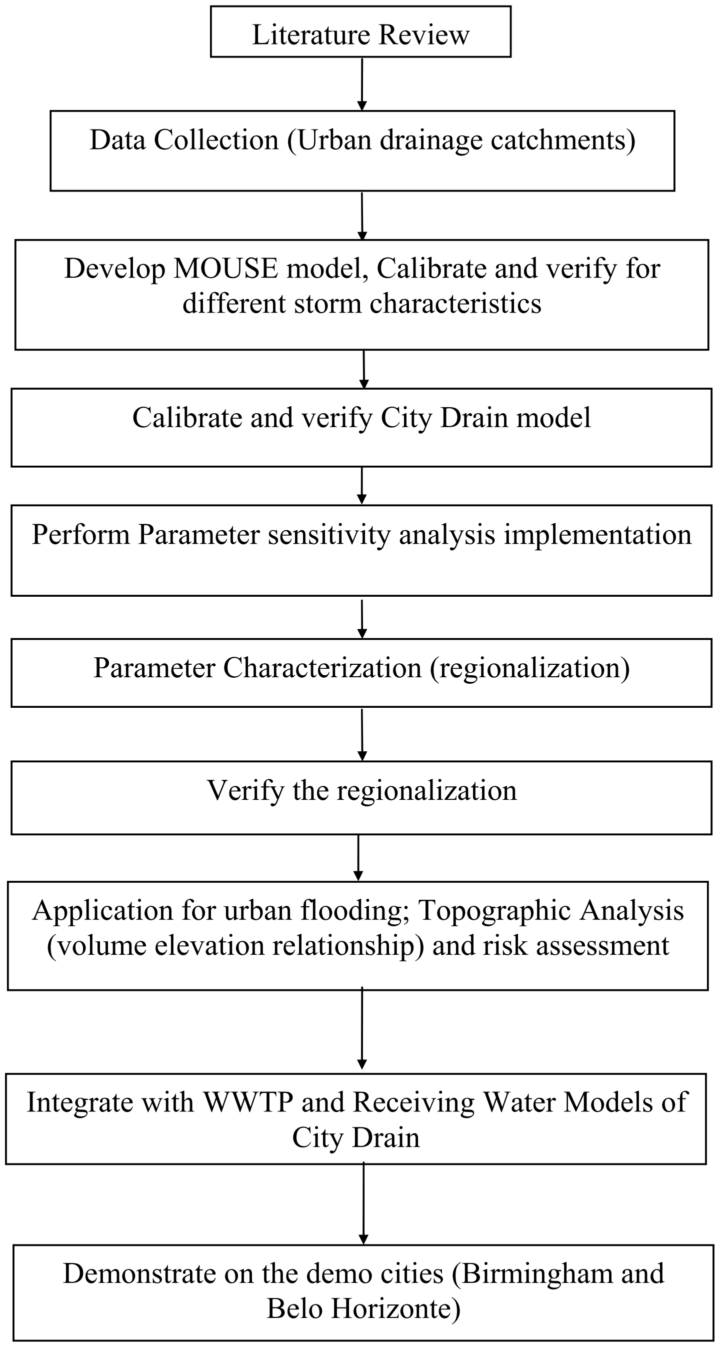
First year: Research proposal and comprehensive review
Integrated Urban Water Systems Modelling practices, Available IUWS modelling tools,

Second year: Model Development and refinement

Third year: Data collection and model calibration and testing

Fourth year: Case study and performance tests
Review comments, analysis and discussions
Preparation for dissertation

Methodology:



4. TRAINING

List modules or courses that are of interest for the PhD research. The list may contain elements of all Master Programmes provided by UNESCO-IHE. Listing a module or course does not give the obligation of actually taking the course, but it helps to formulate in a later stage a suitable training programme.

Name of Module / Course	Name MSc Programme / Specialisation	Time in year (Block #)	Study load (ECTS)
Integrated Urban Water Management	WSE	2	5
Data Driven Modelling	HI	6	5
Urban Drainage & Sewerage	IUE	6	5
Water System Modelling	WSE	11	5
Flood Management	HERB	11	5

5. CONTRIBUTIONS TO THE EDUCATIONAL PROGRAMME OF UNESCO-IHE

The intention to contribute to the educational programme of UNESCO-IHE may be listed here, if appropriate. For those working in a sandwich construction, opportunities to participate in the transfer of knowledge in their own country should be explored.
It is generally recommended not to be involved in teaching activities during the first year after registration.

Type of contribution[1])	Name MSc Programme / Specialisation	Time (year, block)
Urban Water Systems Modelling	IUE	2
Urban Water Systems Modelling	HI	8
MATLAB	HI	8
Groupwork guidance	HI	12
MSc Supervision	HI	15

[1]) Lecturing, supervision of workshop or laboratory sessions, fieldwork, excursion, role play, MSc supervision, groupwork guidance, etc.

APPENDIX II - CURRICULUM VITAE

Personal Detail

Name	SOLOMON DAGNACHEW SEYOUM
Nationality	Ethiopian
Date of Birth	22nd September 1972
Place of Birth	Addis Zemen, Gondar, Ethiopia
Marital Status	Married
Gender	Male
Email	sol_d1972@yahoo.com s.seyoum@unesco-ihe.org

Academic Qualifications

- April 2005, M.Sc. in Water Sciences and Engineering specialized in **Hydroinformatics** from UNESCO-IHE International Institute for Water Education, Delft, The Netherlands.

- July 1994, B.Sc. in **Sanitary Engineering** from Arba Minch Water Technology Institute, Arba Minch, Ethiopia.

Present Position

Research Fellow (PhD)
Department of Hyroinformatics and Knowledge Management
UNESCO-IHE, P.O. Box 3015, 2601 DA Delft, The Netherlands.

Main Discipline

Hydroinformatics, urban drainage, integrated urban water systems modelling

Language

English and Amharic

Employment Record

- **June 2005 to April 2007**: **Desta Horecha Water Supply Engineering Service, Addis Ababa, Ethiopia**
  Position: Office Engineer, Duties: Perform hydrological and water distribution modeling, study and design of water supply project units including intake structures, demand calculations, transmission mains, treatment plants, pumping stations, distribution systems and reservoirs, preparation of technical proposals for various water resources development and management projects including watershed

- **October 1998 to October 2003: Continental Consultants PLC, Addis Ababa, Ethiopia**

Position: Water Resources Engineer, Duties: Held various positions in study, design and construction supervision of urban and rural water supply projects. Hydrological studies and modeling for various projects including irrigation and water supply. management, urban water supply and drainage, irrigation projects

- **October 1994 to September 1998: Bureau of Public Works and Urban Development, Ethiopia**
  Position: Sanitary Engineer, Duties: To participate in a team of professionals responsible for study and design of urban drainage works, urban water supply and sanitation, sanitary plumbing designs, preparation of drainage master plans.

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Computer Skills

- Programming skills in Fortran 90, Delphi, Java and C# languages
- Various simulation modeling software such as: MOUSE, MIKE11, SOBEK, EPANET, WaterCAD, InfoWorks and others
- Data driven models such as Artificial Neural Network, Model Tree, Genetic Algorithm
- Other software: Arc View and AutoCAD