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Application of City Water Balance model to develop strategies for urban water management in Hanoi, Water balance, Contaminant fluxes

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Master of Science Thesis
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ABSTRACT

Urban water management is facing with a couple of problems such as inadequate water supply, untreated wastewater disposal and storm water management. Particularly, in developing countries it seems to be a long way to go. Integrated urban water management (IUWM) is considered as one the powerful management method to scope those problems. This approach links managing water supply, wastewater and stormwater as a unit of management.
As many urban area in the developing world, Hanoi is dealing with pollution in receiving water bodies, ground water depletion and flooding. With the supported by SWITCH project, this research was conducted for seeking integrated urban water system management by carried out in small typical sub catchment in Hanoi.

City Water Balance model (CWB), being used In SWITCH project to assess the water and contaminant balance within the urban water system, was power tool for this research. Within the mode applications of stromwater harvesting, wastewater recycling and roof-greening was carried out. The climate change scenarios were simulated and analyzed. Last but not least, "WIDEN AND WIN" URBAN WATER STRATEGY FOR HANOI was proposed to start and widen the implementation of above urban water management options towards IUWM.

The study was contributed some significant results. The first one is a specific answer to water and contaminant flows of Hanoi's water system. The second one is a range of sustainable urban water management options including rain water harvesting, wastewater recycling and green roof. Climate change scenario was simulated and compared to calibrated baseline. The third one is the proposed urban water management strategy. This was concretized by Volunteer and Demonstrate plan. Moreover, a database of three water components (water supply, wastewater and stormwater) and interaction among them in the study area of Hanoi's water system were presented through the outcome of the CWB model. Based on these findings this research is valid reference for policy-makers working on Hanoi's water sectors.

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ABBREVIATIONS

m^3	Cubic meter
m^2	Square meter
l/c/d	liter/capital/day
mg/c/d	milligram/capital/day
COD	Chemical Oxygen Demand
TP	Total Phosphorus
TN	Total Kjeldahl Nitrogen
NH_4-N	Ammonium Nitrogen
EMC	Event Mean Concentration
Use1, Use2, Use3, Use4	Water used for toilet, kitchen, bathroom, laundry respectively
POS	Public Open Space
WW	Wastewater
DWWR	Decentralized WasteWater Recycling
MFA or SFA	Mass Flow Analysis or Substance Flow Analysis
CWB	City Water Balance model
IUWM	Integrated Urban Water Management
UWC	Urban Water Cycle
UWS	Urban Water System
CEETIA	Center of Environmental Engineering of Towns and Industry Areas, University of Civil Engineering, Hanoi, Vietnam
SWITCH	Sustainable Water Management Improves Tomorrow's Cities' Health
CSE	Centre for Science and Environment's

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1 Introduction

1.1 Introduction

Urbanization is accompanied by basic needs for a large number of people in a specific area. One of the significant demands is water sectors. Urban water management is facing with a couple of problems such as inadequate water supply, untreated wastewater disposal and stormwater management. Particularly, in developing countries it seems to be a long way to go.

Integrated urban water management (IUWM) is considered as one the powerful management method to scope those problems. This approach links managing water supply, wastewater and stormwater as a unit of management. Interactions among those urban components need to be considered in order to maintain an positive effective, efficient and safe service of water.

Recently there are a number of significant researches in the field of IUWM. SWITCH is one of them. SWITCH has been successes in contributing of sustainable urban water system management in "City of the Future". To continue with previous achievements that were carried out in 15 cities in variously developing countries, Hanoi is the next selected destination.

The major water issues in old Hanoi[1] are related to alarming pollution in receiving water bodies, ground water depletion and flooding during rainy events. This situation is calling for alternative water practices towards IUWM.

City Water Balance model (CWB) is one of the models which is being used on SWITCH project to assess the water and contaminant balance within the urban water system. It has been developed to provide a holistic view of urban water system management.

In this research, the model was used as a tool to simulate different scenarios for Hanoi's water system. Stormwater harvesting, grey water recycling and green roof were formulated as alternative urban water management options. "WIDE AND WIN" URBAN WATER STRATEGY FOR HANOI was proposed to start and widen the implementation of those water practices.

1.2 Case study and Problem statement

1.2.1 Overview of Hanoi's water system practice

Hanoi is commercial and political of Vietnam with population around 3.1 million. The average living space was 5.5m^2 per person and the annual growth rate is estimated 3.5 %. *(HAPI, 2004a,b)*

Hanoi is situated in climatic zone where winter is cold and dry, while from February to March, drizzles and monsoon rains are frequent. It is hot from April to June, while from July to September there are heavy rains causing frequent flooding. Annual average rainfall in Hanoi is 1678mm. Temperatures range from 6^{o}C in winter up to 45^{o}C in summer. Many rivers flow

[1] In this research the author only mention about old Hanoi, so to simply Hanoi will be refer for old Hanoi afterwards

through the city such as Red River, Tolich river, Nhue river. Hanoi also has many lakes including West Lake (Ho Tay), Hoan Kiem Lake *(Goverment of Vietnam, 2004).*

As many urban water system in the world, Hanoi's water system also has three main components: water supply, wastewater and stormwater.

Water supply component

Ground water is the main source of water supply; water works extract more than 600,000m^3/day of ground water *(Berg, 2008).*

It is observed that there are two main problems of Hanoi water supply system:
Quantitative: inefficient water supply due to lack of electricity for pumping
Qualitative: when there is sufficient water volume but the source of water is not potable. Water supply cannot be used to drink directly from the tap, the users have to use other equipments to re-treat or boil it before cooking or drinking. Nitrogen ammonia pollution of some deep wells within the inner city and of many peri-urban shallow wells is of growing concern *(Viet Anh et al., 2004).* Concentration of Arsenic (As) in the groundwater ranged from < 0.1 to 330µg/L, with about 40% of this exceeding WHO drinking water guideline of 10µg/L. Also 76% of ground water samples had higher concentration of Manganese (Mn) than WHO drinking water guideline *(Agusa, 2006).*

Wastewater component

Hanoi has about 700,000m^3/day of domestic wastewater. There are some existing wastewater treatment plant (WWTP) such as Truc Bach (Ba Dinh district); and Kim Lien (in Dong Da) which contribute to treat only 7% of wastewater discharging per day. In other word more than 90% of wastewater is discharging directly in to the rivers, lakes *(Hanoi Natural Resource and Environment, 2009).*

Septic tanks are the most common urban on-site sanitation option in Hanoi. Septic tanks effluents are mainly discharged into the sewage and drainage network *(Viet Anh et al., 2004).* As a consequence, rivers, lakes and ponds in Hanoi are seriously affected by untreated domestic wastewater.

Stormwater component

In Hanoi, rainwater is mixed with sewage system and dealing with over runoff in heavy rainy day. For instance, the existing hydraulic capacity of the drainage system in Hanoi is 174mm/2 days while in 2008 it was observed that some events during 2 day the rainfall was over 600mm *(Nguyen The Thao, 2008).* These events were abnormal precipitation and effected by climate change. Therefore, flooding in rainy day in Hanoi is the problem that needs to be solved properly.

Practically, land surfaces in urban areas are replaced by roofs, streets and other impervious surfaces. Therefore runoff from these surfaces has a high velocity which adds to stormwater drainage problems. This increases peak flow and overland flow volume and decreases groundwater flow and evapotranspiration. Under these conditions, peak discharges increase together with frequency of flooding. Moreover, the surface is washed during rainy days so these runoffs cause the pollution load in the urban environment. *(Parkinson, 2010)*

1.2.2 Problem statement

Due to brief information above, Hanoi's water system is dealing with main listed problems below:

- Water supply is not sustainable in term of quality and quantity (ground water level going down and increase of contaminants).
- Surface water pollution due to over discharge of untreated wastewater especially domestic wastewater
- The runoff exceeds the hydraulic capacity of drainage system and weak maintenance lead to streets are flooded even in small rainy event

1.2.3 Research questions

- How much wastewater and stormwater drain from the study area?
- What are concentrations of different pollutants in fluxes from one sub-catchment of Hanoi's water system?
- Is Hanoi's water system management sustainable in term of water supply, wastewater drainage and stormwater runoff, based on evaluation by CWB?
- Does the IUWM approach improve sustainability for Hanoi's water system, especially by application of stormwater harvesting, green roof and wastewater recycling?

1.2.4 Objectives of the research

Based on the problems which are identified above, objectives of this research are developed. The overall aims are to develop specific sustainable strategies, in line of IUWM, to improve Hanoi's water system by application of CWB.

Specific objectives

- To develop a flow diagram of one sub-catchment of Hanoi's water system.
- To quantify the water and contaminant flows through existing water supply, wastewater and stormwater systems, from source to discharge point.
- To propose alternative strategies based on output of CWB simulation to minimize existing problems of the water system. These strategies will be focused on reduction contaminant flows to surface and ground water, sustainable options for stormwater management and green roof operation.

2 Literature Review

2.1 Urbanization and Urban Water Cycle

2.1.1 Urbanization

Urbanization has been the dominant demographic trend in the entire world. Besides the great benefits from high economic development, high education and good health care services, urban centers also dealing with negative environmental impacts. Those include escalated food risks, polluted surface water, modification of the urban climate and increase water and energy consumption *(Centgraf, 2005)*.
In urban water system (UWC) point of view, inadequate water supply, untreated wastewater and flooding in some cities have been considered as main problems.

2.1.2 Urban water cycle

The urban water cycle provides a good conceptual and unifying basis for studying the water balance and conducting water inventories of urban areas.

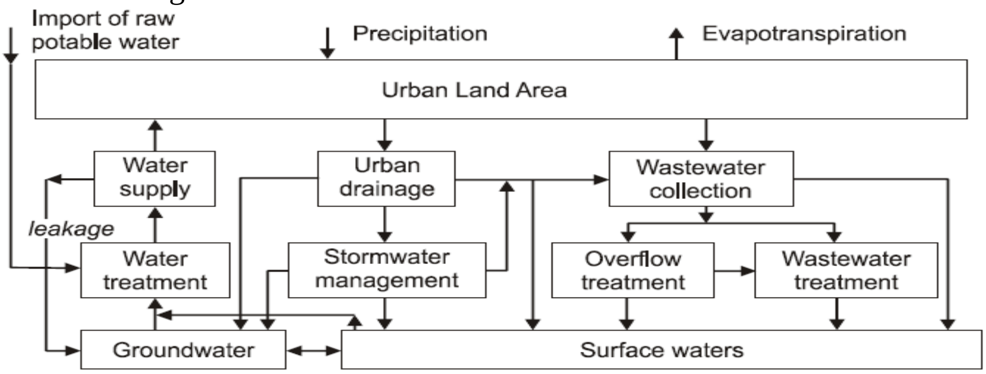


Figure 2.1: Urban water cycle

(Marsalek, 2006)

As we can see, there are two main sources of input water which is municipal water supply and precipitation. Municipal water is exploited from ground water and/or treated from surface water to meet local water demands. It is brought into the city, distributed within the urban areas; some fraction is lost to urban groundwater, and eventually returned to surfaces waters. Precipitation, the second source, follows a longer route through the water cycle. Partly infiltrates into the ground that is contributing to soil moisture and recharge of groundwater. Partly it is converted into surface runoff which may be conveyed to receiving water by natural and constructed conveyance systems. And the rest is removal processes such as evapotranspiration.

Water leaves urban areas in the form of urban waste effluents which include stormwater, combined sewer overflows and municipal wastewaters.

2.1.3 The effects of urbanization on urban water cycle

As mentioned before, when precipitation falls over the land, it follows various routes. Some of it evaporates, returning to the atmosphere, some seeps into the ground, and the remainder becomes surface water, travelling to oceans and lakes by way of rivers and streams.

Impervious surfaces associated with urbanization alter the natural amount of water that takes each route. The consequences of this change are a decrease in the volume of quality of surface water. Rain pours more quickly off of city and suburban landscapes, which have high levels of impervious cover. With natural groundcover, 25% of rain infiltrates into the aquifer and only 10% ends up as runoff. As imperviousness increases, less water infiltrates and more and more runoff. In highly urbanized areas, over one-half of rain becomes surface runoff, and deep infiltration is only a fraction of what is was naturally *(Amold, 1996).* It is become worse in most of developing countries because conventionally, stormwater which is mixed untreated wastewater with rainwater enters directly into receiving water bodies.

2.2 Integrated urban water management

Traditional approach to urban water system has been struggling with management. Primarily, in this approach water follows a one-way part from supply to a single use, treatment and then discharge to the environment. For instance, in Australia the infrastructure is considered delivers potable water, and disposes of sewage, separately to the provision of stormwater

drainage. However, technical literature contains many examples of adverse economic and environmental impacts associated with this approach *(Mitchell, 2006).* Hence, consideration of isolated water sectors in urban system management has to be opposed to the complete holistic or integrated system. Another word, urban water system, compare to traditional approach, is complex adaptive system, more than isolated water systems.

In the view of V.G. Mitchell (2006), the principles of IUWM can be summarized as follows:

- Consider all parts of the water cycle, natural and constructed, surface and subsurface, recognizing them as an integrated system.
- Consider all requirements for water, both anthropogenic and ecological
- Consider the local context, accounting for environmental, social, cultural, and economic perspectives
- Include all stakeholders in planning and decision-making processes
- Strive for sustainability, aims to balance environmental, social, and economic needs in the short, medium and long term

IUWM one hand can support to minimize the negative environmental impacts, on the other hand maximize the urban water system efficiency. The most important benefit of IUWM is the potential by looking for multifunctionality of urban water services to optimize the outcomes achieved by the systems. This way can increase the range of opportunities available in order to able to develop more sustainable systems *(Mitchell, 2006).*

As the part of the solution to success in IUWM, there has been a movement toward methods of water supply, wastewater disposal and stormwater management. An important component of these alternative methods is the utilization of urban stormwater and wastewater for beneficial purposes *(Mitchell, 2004).*

SWITCH has been established as one in many projects to address the challenges of urban water system management. Its characteristic is the integration (holistic) rather than piecemeal design in urban water system. Particularly, within contents of SWITCH City Water Balance model was developed as a useful modeling tool to contribute IUWM. The detail information about this model will be presented in section 2.5.

2.3 Options for improvement in urban water system management

There are a number of options for improvement in urban water system management. However, within the scope of this research, the author mentions only two important options which might be applicable properly for improvement in the study area of Hanoi's water system.

2.3.1 Sustainable sanitation management

The objectives of sustainable sanitation management are to provide proper sanitation at the lowest possible cost for citizens in urban area, to implement pollution prevention over end-of-pipe treatment and to minimize the contaminant flows entering to the receiving water bodies.

To obtain sustainable sanitation management, a system that is separate grey water, black water and/or urine considered as the new approach which shifts the paradigms in wastewater treatment from an approach with centralized mixed systems to decentralized system based on source control and separate treatment of concentrated and diluted household wastewater flow. Grey water recycling and reuse in one of power water management option to tackle wastewater pollution and also contribute to reduce water imported.

A number of researches have carried out in and outside Europe have showed that this approach can result in promising new and cost effective option for wastewater management, preventing pollutant emission to urban environment, enabling the nutrient recovery for agriculture and minimization of pollutant infiltrated into groundwater *(SWITCH, 2008).*

2.3.2 Stormwater management and reuse

Two of the aims of stormwater management and reuse are to reduce the risk flooding in urban areas, to harvest rainwater and stormwater for non-potable purposes and to mitigate any detrimental effects on the quality of receiving water.

Rain water harvesting

There are two main goals of rainwater harvesting. The first goal is to replace drinking water by rainwater for toilet flushing and other purposes. The second is the retention of rain water to reduce inflow in to sewer system in order to either avoid overload in combined sewers or reduce contamination in separate sewer systems.

Traditionally, stormwater in urban areas has been accomplished by constructing storm sewers, through which stormwater is conveyed directly into adjacent surface waters. In recent years there has been an increased concern about the impact of the stormwater runoff on the quality of our surface waters. The solutions that came up were based on the idea of slowing down the runoff by source control measures and by open stormwater drainage systems. These measures have among others been referred to as sustainable stormwater drainage. As illustrated in figure 2 these types of drainage facility can be categorized in four groups *(Stahre, 2003).*

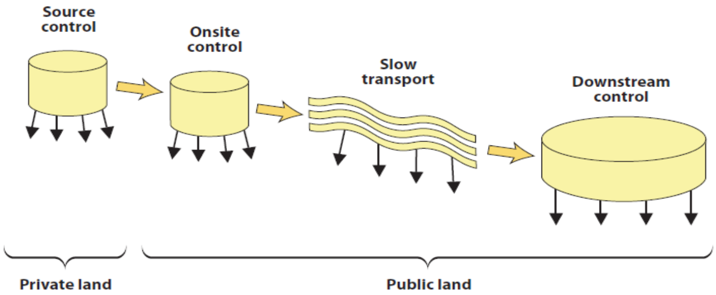


Figure 2.2: Categorization of facilities for urban sustainable stormwater drainage

In this research, the proposed plans will be introduced to have sustainability for Hanoi water system. Based on CWB, detail plan will be tested at different spatial scale, private land refers to unit block scale and public land refers to mini-cluster and sub-catchment in the model.

Moreover, rainwater treatment is much simple and cheaper than surface and wastewater in term of energy consumption, investigation, operation, maintenance and expenditure cost. Many appropriate techniques have developed to collect and treat rainwater in various scales.

Rainwater harvesting could be one option for improvement of Hanoi's water system. It has nearly 1700mm/annual precipitation while local people still dealing with inadequate water supplies (quality and quantity), runoff pollution and flooding during rainy event.

2.3.3 Green roof

Green roof have a long history. The "hanging gardens" of Semiramis are one famous representation. There are two types of green roofs: intensively and extensively. Intensively green roofs or roof-gardens have special structural prerequisites and sometimes are developed

with a high variety in gardening to create a high-quality green space. Extensively greened roofs are a thin layer of soil, usually up to approximately 10cm and adding extra weight of water saturated. Today, 7% of newly constructed flat roofs in Germany are already replaced by greened ones *(Manfred Kohler 2001).*

Green roof is a simple technology which has however huge effects in term of environmental improvement, and source of flooding control. It was proved that improving microclimate of the open space which is huge valid in urban area where stuffy climate occupied. Another positive effect contributes by green roof is the decreasing runoff during storm event; reduce the retention time of stormwater system overflow. Further the role of roof-greening will be satisfied more detail in the discussion part.

2.4 Material Flow Analysis

2.4.1 Overview of Material Flow Analysis

It is showed that using Material Flow Analysis (MFA) or Substance Flow Analysis gave reliable results in identification and quantity substances from point and also non-point discharges. In 1991 Baccini and Brunner developed a Material Flow Analysis (MFA) concept for assessing the anthropogenic metabolism of regions. Since MFA has applied in many fields, particularly the MFA can be used in analyzing multiple sectors and activities and their exchange with air, water and soil *(Obernoster et al. 1998).*

MFA basic equation need to be balanced:
Input + Formation = Output + Degradation + Accumulation
MFA focuses on flows and stocks. Briefly, there are four steps need to be done to perform a MFA. Firstly, system analysis step is to identify and quantify all the stages and flows in the sectors. Life cycle analysis can be used effectively to determine more accurate picture of all stages and flows. Following step is balancing, gaps have to detect and include or estimate in the analysis. Material analysis is the third step. Depending on studied purposes the effects of substances in the flows will be introduced. For instance, the contribution of contaminants in drainage system or stormwater on recycle-reuse urban water system management can be indentified based on MFA. And recommendation is taken as the last step *(Bainbridge, 2009).*Conclusions should be made after the process, for example based on water quality and quantity of the urban water system, alternatives will be presented to reach a better urban water management.

Seelsaen N et al. was successful in application of MFA to show the significant of stormwater pollution, a non-point source of Copper emission, in the contamination of the Upper Parramatta River Catchment in Australia. SFA modelling and SIMBOX (a stationary Input-Output MFA-Model) were applied to model copper flow within study area boundary. Cu-MFA clearly showed that where copper came from and where did it goes or where it was accumulated. Major copper good causing from traffic mainly from highways, from surface runoff such as roof runoff and dissolved copper from sewage system were indentified in the model. According to that the suitable proposed treatments were drawn.

According to Malmborg, Lindqvist and also suggested by municipal and national policy-makers SFA is a power tool that provide and/or organize environmental information. It shows structural inter-relationships between difference socio-economic activities and these activities and the environment. Therefore, it helps managers get the real situation in perspective.

For example, based on proposed framework of indicators and categories of Lindqvist *(2004)* for SFA analysis, a framework categories and indicator of SFA for urban water cycle can be designed as below:

Table 2.1: Framework of categories and indicators for SFA

Categories and Indicators	**Meaning**
Category 1: quantities	Comparison of magnitude of stocks and flows of the contaminants. Tells something about the potential of future pollution problems and indicates resource aspects of the substance
• Total emission	Total amount of emissions to difference sources to water sectors (e.g. households contaminant loads to wastewater)
• Environment accumulation	The increase of a certain environmental stock over the year (e.g. soil under the sewage system)
Category 2: Exposure to humans and the environments	Related to where in the system and within what time scale a flow occurs (e.g. households scale or sub-catchment scale)
• Concentration	The concentration of contaminants in water sectors (e.g wastewater, stormwater)

(Adopted from Lindqvist et al., 2004)

2.4.2 Application of MFA in researches on contaminant flows of UWS

MFA is a powerful tool in holistic management of pollutants. It helps to identify the sources of mass to the city's urban water system, how mass is transferred between components within the city system, where is it accumulated with the system, and how it is passed from the city to the downstream and neighboring environment *(Baker, 2009).*

Amro A. El-Baz et al. (2005) used MFA to simulate and apply ammonium management in Bahr El-Baqar drainage system. MFA was applied to trace and quantify pollution substances, from their generation, through the system, to their discharge to the surface water *(Schaffner et al. 2006).*

There are also a large number of models developed to describe contaminant flow in urban water system. For instance, URWARE (URban WAter REsearch model) includes both theoretical and empirical relations of substance flows; it can simulate 84 substances, providing non-aggregated outflows (emission from air, soil and water) or aggregated environmental impacts of the system structure studied. SEWSYS model (a dynamic pollution load model) simulates transport and treatment processes in sewer systems; it also consists of source modules for stormwater and sanitary wastewater, overflow structures and conventional activated sludge wastewater treatment plant with phosphorus and nitrogen reduction *(Malmqvist, 2006)*

Urban Volume and Quantity model (UVQ) developed to estimate not only the water flows but also contaminant loads within the urban water system. The source of contaminants, their flow paths and the sinks are identified and then the contaminant loads quantified. The presenting of contaminants coincides with the presenting of water balance. Therefore the water distribution

and disposal routes affect the movement and distribution of contaminant directly presented. For pure sewage the contaminant loads (mg/c/d) used refer to emission from water indoor uses (toilet, kitchen, bathroom and laundry) allows the model to account for changes in water demand or quality water used (e.g. is it possible to recycle for non-potable purposes)
For stormwater event mean concentration used because it suitable to describe contaminant flows from specific sources such as road runoff, pavement runoff and roof runoff *(Eiswirth, Wolf et al. 2004)*

Recently, similar conceptual of UVQ CWB MFA approach applied to simulate contaminant balance which is able to estimate the effect of water system configurations on contaminant flows. The model can map the contaminant flows of each component in urban water system. This will help to understand fully the pollutant flows from source to discharge point.

In short, MFA plays an important role to indentify characteristics of contaminant flows in urban water system, helps to keep track of the pollutants: sources and quantities in the urban water components.

2.5 City Water Balance Model

2.5.1 Historical development

Climate change, environmental pollution, energy consumption and population dynamics are considered global challengers. It is necessary to develop simulation tools that can help stakeholder communities to scope future options for IUWM. One of the tool being developed is City Water Balance model (CWB), as a part of the SWITCH project under theme 1.2 "Integrated Modeling and Decision Making for Urban Water Management", to meet this requirement.

CWB concepts are based on previous integrated urban water system models such as Aquacycle and Urban Volume and Quality (UVQ) model. Aquacycle gives a holistic view because water supply, wastewater disposal and stormwater drainage to be considered as components of a single system. Additionally, UVQ model introduces a competition urban water cycle and associated contaminants. Moreover, CWB presents not only a holistic view of urban water system but also an extension to address energy consumption and life cycle cost.

2.5.2 Spatial scales in CWB

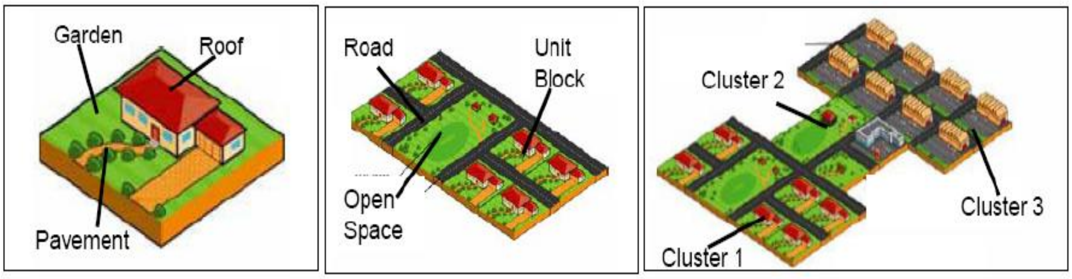
There are three spatial scales in CWB which are listed below:

Unit block: contains single house, industrial site, public or commercial operation. It is also can be garden, roof and pavement areas. This scale represents the smallest unit of urban water management including three main components: water supply, disposal and recycle-reuse operations. The unit block scale allows to cumulative effect of individuals' actions for example wastewater, stormwater use at unit block. Therefore, it is the fundamental spatical scale for modeling purpose.

Mini-Cluster: refers a group of uniform unit blocks that form a local neighborhood or suburb and adds roads and public open spaces to unit blocks. Within the model the cluster can be used to describe the spatial scale at which community water servicing operation are managed.

Sub-Catchment: includes a group of mini-clusters.

Study area: a group of sub-catchments



Unit block scale *Mini-cluster scale* *Sub-catchment scale*

Figure 2.3: Spatial scale of CWB *(Mitchell et al., 2001)*

2.5.3 Processes and representation of CWB

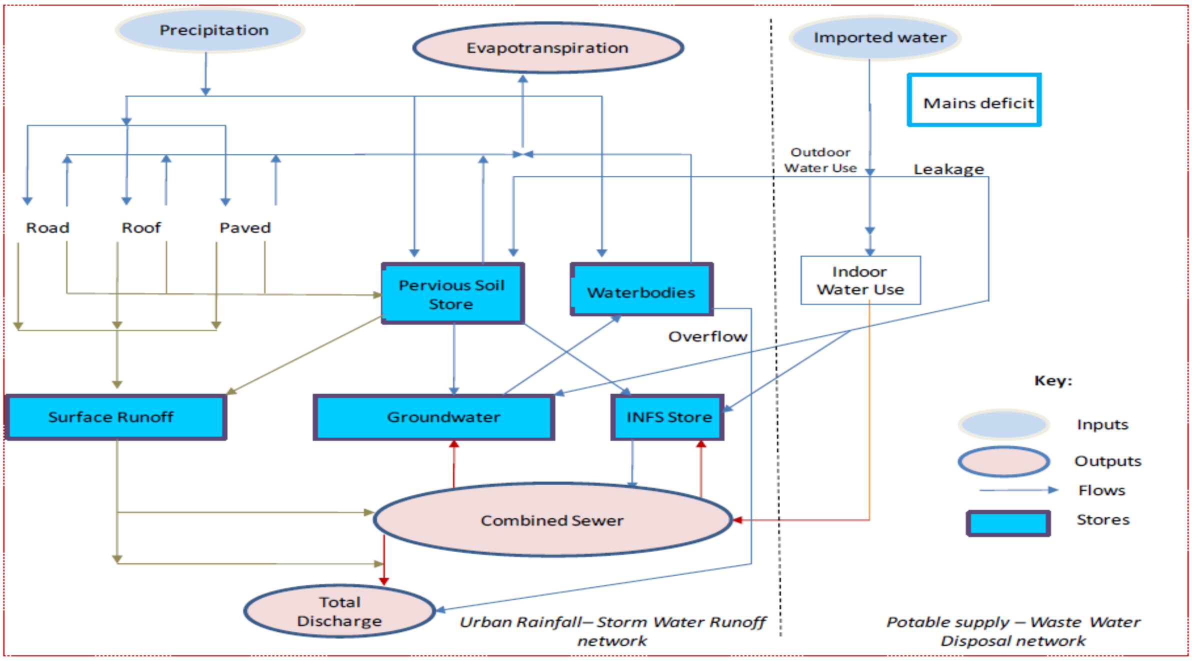


Figure 2.4: Schematic diagram of Stocks and Flows in CWB

(CWB manual, 2010)

Processes of CWB

As we can see from the figure 2.4, the modeling water cycle starts with imported water which is precipitation or water supply to meet local demands. Then it goes through the system in different existing forms such as wastewater, stormwater or evapotranspiration. Water can be stored, before pass through pervious soil in ground water, or water bodies. The outputs water is mainly in form of evapotranspiration and total discharge. The contaminant flows coincide with water flow in the model. To calculate more accuracy quality and quantity of the water components, the model is also taking into account other processes such as interceptions, depression storage, soil infiltration, interflow ect.

Representation of CWB

As mentioned in section 2.1.5 content, CWB is developed from taking advantages of UVQ as the way to simulate contaminant flow of the urban water components. It is very important to investigate whether stormwater or wastewater that is able for reuse based on their quality, or to provide insight into the primary sources of contaminant flow in urban water system.

CWB simulates the integrated water system within an urban area and estimate the contaminant loads (calculated per day) and the volume of the water flows throughout the urban system, from source to discharge point.

In this research, the diagram of contaminant flows, in the study area of Hanoi's water system, though the water, wastewater and stormwater will be presented. By identifying the sources, pathway and accumulation, the diagram is useful reference for better handle or reduction of these contaminants.

2.6 Formulate climate change scenarios

Vietnam is one of 12 countries that is most affected by climate change *(IRIN 2011)* in term of flood, storm and sea level rise.
Based on climate change scenarios that were published by Ministry of Natural Resources and Environment in 2009, increase temperature and precipitation in 2030 and 2050 are two considerations that will be formulated in this study. According to that temperature will go up 0.7^{o}C and 1.2^{o}C and the same trend for precipitation with 2.3% and 4.1% in 2030 and 2050 respectively. CWB will simulate storm water in the urban study area depending on the temperature and precipitation.

3 Description of the study area in Hanoi

3.1 Location and general characteristics

The study area located in Dong Da district, Hanoi capital, Vietnam (figure 3.1). Total area is around 2.5 hectare with an estimated population of 2221 inhabitants. Table lists the key features of this study area.

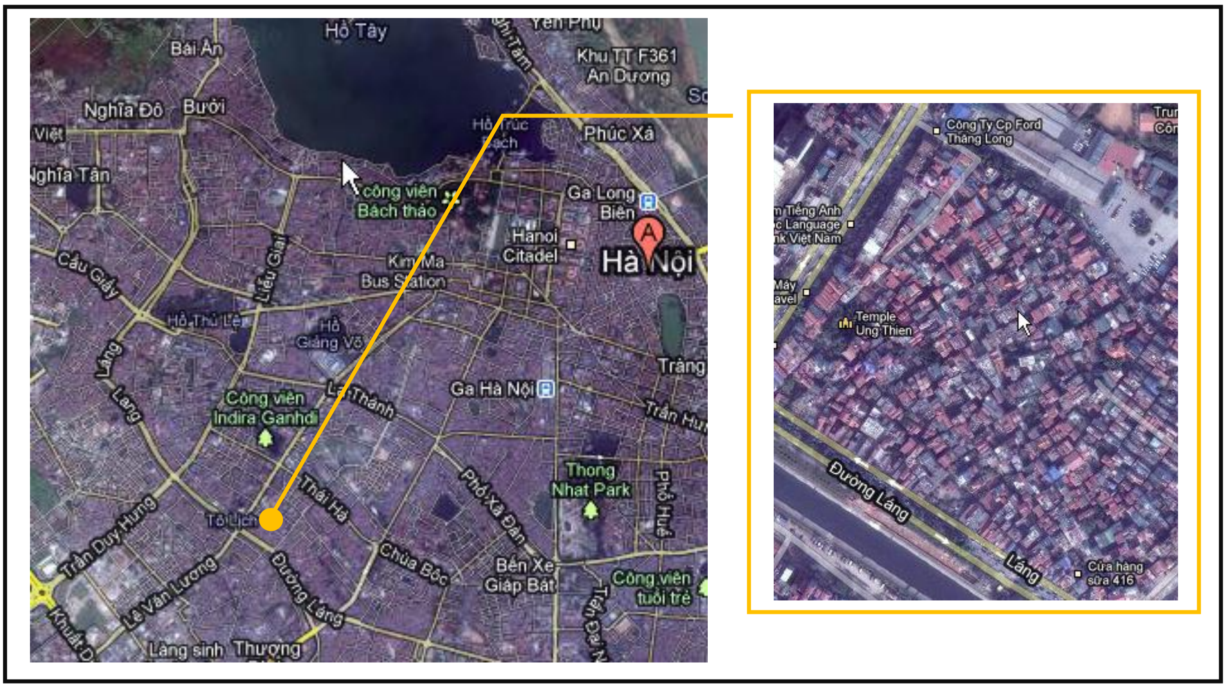


Figure 3.1: Location of study area in Hanoi, Vietnam

Table 3.1: Key features of the study area in Hanoi, Vietnam

Total supplied population	2221 inhabitants
Mean annual temperature and precipitation	24.7°C and 1630mm (period 2005-2010)
Land use	Residential, service (hair solon, private offices, groceries)
Sealed surface	100%
Total water supply (2010), users	121,924m^3, 100% domestic
Drainage system	Combined sewage system
Per capital demand	150.4l/c/d

3.2 Water supply and drainage system

Water supply

100% of water supply is supported by Ngo Sy Lien ground water station. Water abstract from the station was 50000m^3/day in 2010, ground water going down 12.15m to 2020 *(sited by Geology Institute).* According to leader of the station, water is enough to supply but lack of energy for pumping and for treatment process which lead to supply capacity uninsured.

It was recorded that NH_4- N in the station is 8.4 in dry season and 0.2 in rainy season in Pleistocene(qp) level, this is also the majority table of ground water supply for Hanoi. Many experts believe that ammonium exfiltrated from higher layer because ammonium concentration in qp layer is higher than holocen layer (qh). They also complain that water has strange color, which could be heave metal from pipe as iron, manganese. As a result, the inhabitants feel not comfortable to use this water but they do not have alternative choices. To deal with this situation they buy different household water treatments because they believe it helps even to own and use those equipments costly.

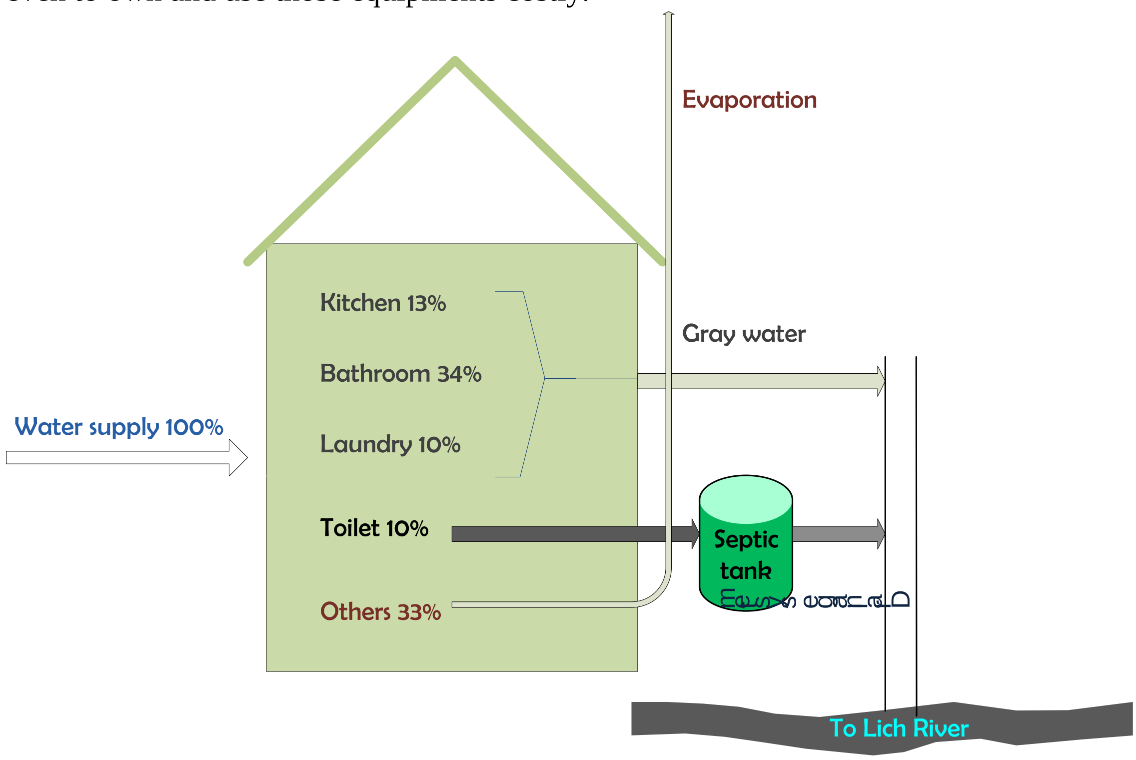


Figure 3.2: Overview of the water system in the study area in Lang, Hanoi

Water consumption patterns of the study area stated in figure 3.2 and will be discussed more detail in indoor water use profile section.

Drainage system

The wastewater discharges through the combine sewer system that is directly entering into To Lich River. As typical domestic wastewater, it is ddivided into two types: black water and grey water. Black water derives from toilet. It is high content of solids and contributes significant amount of nutrients such as Nitrogen, Phosphorus. Grey water consists of wastewater from washing of clothes, from bathing/showering and from the kitchen. 100% of the black water is treated by septic tank. It effluent combined to grey water directly discharged to To Lich River (figure 3.2).

This situation is very common in Hanoi resulting in a large of contaminants loaded to the receiving water bodies. There are two main reasons: firstly, the efficiency of septic tank is low because of weak maintain and high concentration of ammonium. The sediment should be taken out every 1 or 2 years instead 7 or 10 years, therefore in effluent of septic tank there are high amount of suspended solid waste and organic material. Additionally, very high NH_4 content in black water plus pH>7 condition will produce NH_3 that is very toxic for bacteria activities. Secondly, SS, COD, TP made up 50% of total load from grey wastewater are discharged without any treatment *(DESA, CEETIA, 2006)*

In short, To Lich River in this case study and most of rivers in Hanoi is not longer a river instead being drainage canals. This unpleasant situation is still rising in many receiving water bodies in Hanoi.

4 Research methodology

The research was carried out by the following steps (Figure 4.1)

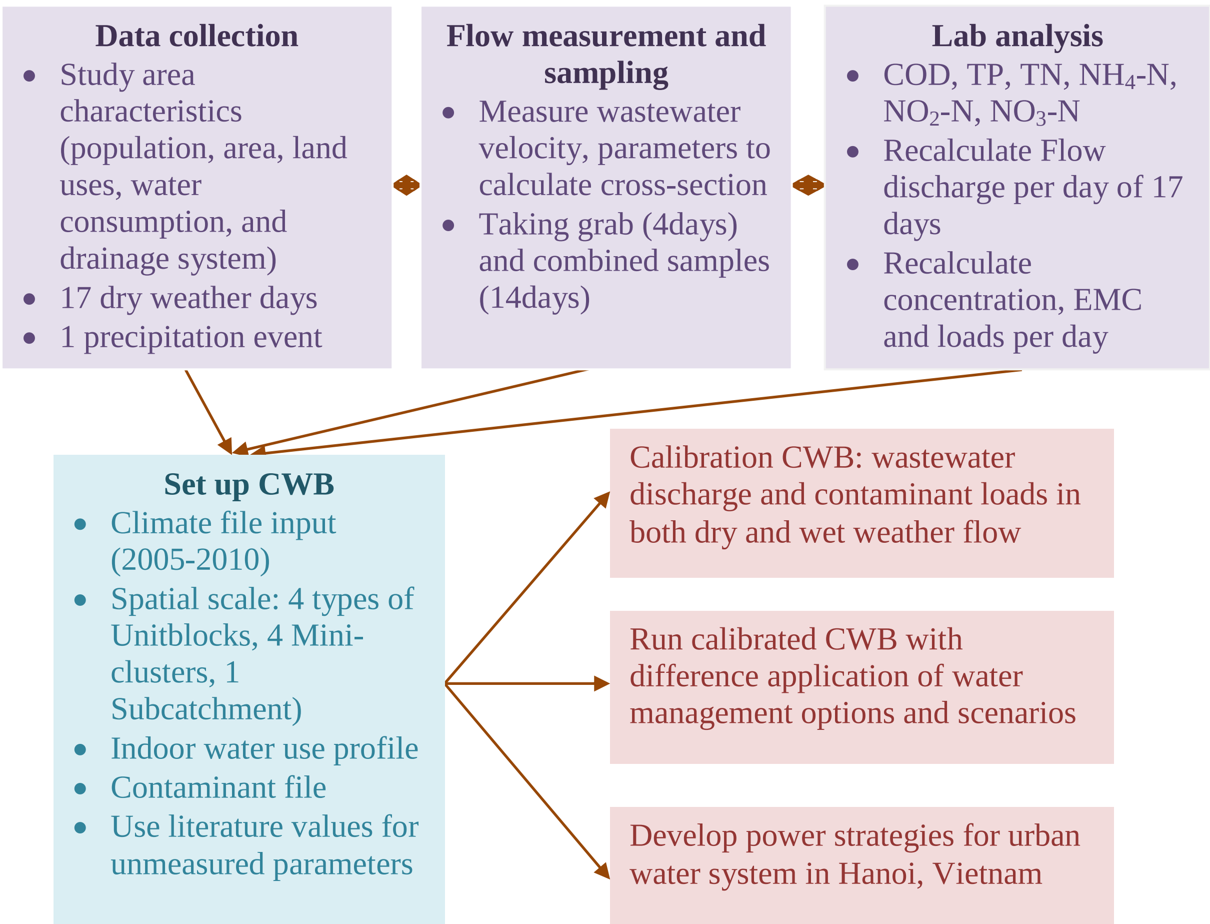


Figure 4.1: Summery approached methodology of the research

4.1 Data collection

Site investigation, data collection and analysis sample were carried out through 3 months field visit in Lang, Hanoi, Vietnam. Site visit was done to comprehend the whole characteristics of the study area which is needed for the input model.

The first step is to investigate the study area characteristics in term of wastewater system, infrastructure, pavement area, impervious area, house types, and distribution of population...

Measurement, sample and analysis samples are the second step. In this study the author measured 17 days of dry weather flow rate and caught 1 precipitation event referred to wet weather flow. The 17 sample days reflected 7 days in one week (3 Mondays, 3 Tuesdays, 2 Wednesdays, 2 Thursdays, 2 Fridays, 2 Saturdays, and 3 Sundays). The frequency of the dry flow measurement in one day ranged from one hour to two hours and started around 6a.m to 8p.m. Since safety conditions the author could not measure flow during early morning and night time.
For wet weather flow, the frequency was shorter than dry weather flow, it was from thirty minutes to one hours. The measurement carried out before the beginning till the precipitation stopped.

4.1.1 Flow measurement and sampling

To calculate total discharge for one day of the study area, velocity of wastewater was measured by NEW Flowatch Flowmeter and the height of wastewater flow measured by ruler. Dry weather flow and wet weather flow were measured at a fixed discharge point in the open drainage system. Wastewater and stormwater samples were taken coincided with flow measurements. (Figure 4.2)

Figure 4.2: Flow measurement and taking sample

Each sample was stored in 500litter plastic bottle. There are two types of sample: grab samples and combined sample. Every hour or every two hours from 6am to 8pm samples were taken one time; those samples are considered as grab sample. Due to the limitation of fund and time the author analyzed grab samples for 4 days (including one rainy day). Mixing of all grab samples in one day and then took 500l defined as a combined sample of that day. Consequently, 14 combined samples were taken and analyzed.

4.1.2 Laboratory analysis

After taking and preservation the samples were brought to the Environmental laboratory of Vietnam Forestry University, Hanoi, Vietnam. Here, parameters: COD, total phosphorus (TP), total nitrogen (TN), nitrate nitrogen (NO_3^--N), nitrite nitrogen (NO_2^--N), ammonia nitrogen (NH_3-N) were analyzed. The method was used to analysis listed in table 4.1

Table 4.1: Application analysis methods in the laboratory

Parameters	Preserved samples	Analysis methods
COD	Cool to 4^oC	Closed Reflux, Colorimetric method
TP	Cool to 4^oC	Digestion and ascorbic acid spectrophotometric method
TN	H_2SO_4, dark condition	Macro-Kjeldahl method
NO_3^--N	H_2SO_4	Spectrophotometric method *(nitrate reacts with sulfanilic acid and N-1-naphthylethylenediamine to produce red color)*
NO_2^--N	Cool to 4^o	Spectrophotometric method *(nitrite is determined through formation of a reddish purple azo dye produced at pH =2 - 2.5 by coupling diazotized sulfanilamide with N-(1-naphthyl) ethylenediamine dihydrochloride)*
NH_3-N	H_2SO_4	Spectrophotometric method *(Blue compound is formed by the reactions of ammonia, hypochlorite and phenol catalyzed by sodium nitroprusside)*

In the laboratory spectrophotometer, Spectro UV-VIS Dual Beam 8 auto cell UVS-2800, was used to measure the absorbance of the samples and calculate concentration.

Figure 4.3: Analysis samples in the laboratory and conductivity measurement

4.1.3 Meteorological data

Climate data input file is a daily series of precipitation and potential evaporation data. The available data is from year 2005 to year 2010. Precipitation data from 2005 to the middle of October 2010 of the study area was obtained directly from Lang' meteorological station which is the nearest station to the study area. Three last month precipitation in year 2010 was monitored by rain gauge (figure 4.4)

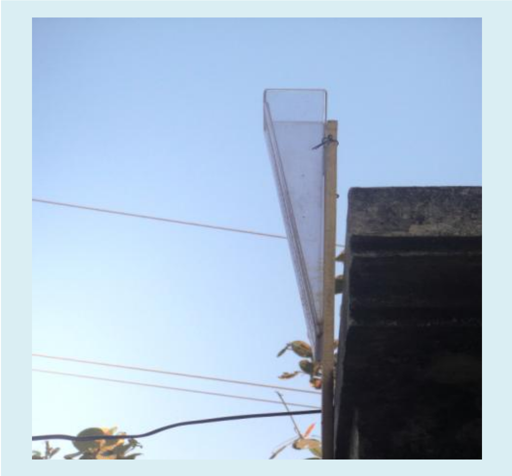


Figure 4.4: Precipitation measurement

4.2 Discharge calculation

Based on velocity: v (m/s) and cross-section area: A (m^2), discharge: Q (m^3/day) was calculated by the continuity equation: Q = v*A*86400

As mentioned before the flows during early morning (1a.m to 5a.m) and night time (9p.m to 0a.m) could not be measured. Adapted from typical dry weather flow diurnal profiles of 61 households in Hanoi *(Anh 2009)*) the lacking data were calculated based on coefficients and measured flows at 6a.m and 8p.m which expressed detail below:

$Q_{09p.m} = 0.86*Q_{8p.m}$
$Q_{10p.m} = 0.68*Q_{9p.m}$
$Q_{11p.m} = 0.66*Q_{10p.m}$
$Q_{00a.m} = 0.70*Q_{11p.m}$

$Q_{01a.m} = 0.3*Q_{00a.m}$
$Q_{02a.m} = 0.5*Q_{01a.m}$
$Q_{03a.m} = 0.8*Q_{02a.m}$
$Q_{04a.m} = 0.8*Q_{02a.m}$
$Q_{05a.m} = 0.4*Q_{06a.m}$

Note:
$Q_{9p.m}$: flows at 09p.m and etc...

CWB run with daily time step therefore total daily discharge was recalculated by taking average all of measured flows and calculated flows within that day. Then the average flows of the 17 days will be used as typical daily discharge of the study area and for the model calibration step.

4.3 Contaminant concentration and load calculation

4.3.1 For dry weather flow

For grab samples (excluding the rainy day), the average concentration of grab samples within one day assumed is concentration of combined samples.

For the 14 rest combined sampling days the concentrations were used directly to represent for these days.

Contaminant load of 17 observed days was calculated from equation (1):

Concentration of combined sample (kg/m^3) * Discharge (m^3/day) = Load (kg/day) (1)

4.3.2 For wet weather flow

Constituent concentration of grab samples in rainy event was calculated based on Event Mean Concentration (EMC) that was developed by Huber and Dickinson, 1988:

$$EMC = \frac{\sum_{t=1}^{n} Q(t)*C(t)}{\sum_{t=1}^{n} Q(t)} \qquad (2)$$

Where: t: total number of grab sample during precipitation event
Q(t): flow at time t
C(t): constituent concentration at time t

Similarly, the load calculation based on equation (1) except contaminant concentration of combined sample EMC was alternative used.

4.4 Model calibration processes

Due to the large number of parameters relevant to water supply, wastewater, stormwater and the processes interaction among them in CWB, each calibration parameter can effect to more than one of the simulated outputs. Therefore, a good understanding of the relations between the model parameters and attention to the sensitive parameters that could be the most making changes to outputs is crucial.

Table 4.2: Overview input files for CWB, including indication of data sources and calibration parameters for the study area in Lang, Hanoi

File name	Parameters	Unit	Data sources	Used for calibration
Study area.txt			A	
Subcatchment_flows.txt			A	
Unitblock _defaults.txt	Number of unitblock types	[-]	A	
	Label	[-]	A	
	Split usage	[-]	A	
	Roof, paved, pervious space	[m^2]	A	
	Effective roof, paved area	[0-1]	C	Yes
	Roof, paved initial loss	[m]	C	Yes
	Proportion irrigated modifier, trigger-to-irrigate modifier	[0-1]	A	
	Occupancy factor	[-]	A	
	Prop use2, use4 hot	[0-1]	A	
	Prop use3 hot	[0-1]	C	
	Amount use1, use2, use3, use4	[liter]	B	
	Proportion lost use1, use 2, use3, use4	[0-1]	B	
UB_additional.csv	UB number	[-]	A	
	Percent POS, road	[%]	A	
	Proportion wood, POS irrigated, trigger-to-irrigate POS	[0-1]	A	

	Supply garden, POS with imported water	[1 or 0]	A			
Minicluster_defaults.txt	Number of default MC_parameter sets	[-]	A			
	Name for each default set	[-]	A			
	Proportion of surface runoff as inflow	[0-1]			C	Yes
	Sewer exfiltration proportion	[0-1]		B		
	Infiltration store recession constant	[-]			C	
	Woods intercept	[m]	A			
	Woods potential evapotranspiration rate	[m/day]	A			
	Leakage proportion	[0-1]		B		
	Road initial loss	[m]			C	
	Effective road area	[0-1]			C	Yes
	Recharge, infiltration store index				C	
MC_assigns.csv			A			
Soil_types.txt				B		
Soil_vertices.txt			A			
Climate_data.csv			A	B		
Aquifer.csv				B		
MC_vertices.txt			A			
Contaminant_1.txt to Contaminant_4.txt	Contaminant label		A			
	Number of default sets		A			
	Label		A			
	Road runoff, roof first flush, roof runoff, pavement runoff	[mg/L]			C	Yes
	Fertilizer to garden, to POS	[mg/m^2]	A			
	Evaporation	[mg/L]			C	
	Use1, Use2, Use3, Use4 load	[mg/c/d]		B	C	Yes
	Groundwater	[mg/L]		B		
Cont_study_area.txt	Number of contaminants		A			
	Conc.Cont_1 rainfall...	[mg/L]			C	
	Conc.Cont_1 imported water	[mg/L]	A			
Assign_file_list.txt			A			
Assignments_Hanoi.csv			A			

A: site specific, measured and recalculated for the study area, B: literature data from national study area, C: literature from international studies

Two main steps were performed for calibration process. Firstly, water flow quantities were calibrated to meet locally measured data. This includes dry weather discharge and wet weather discharge. Secondly, contaminant concentrations and loads had to be adapted to observed data.

Table 4.3: Overview values of default and calibration parameters required for CWB in Lang, Hanoi

File name	Parameter		Unit	Default value	Calibrated value
Unitblock _defaults.txt	Effective roof area		[0-1]	0.95	0.98
	Effective paved area		[0-1]	0.4	0.98
	Roof initial loss		[m]	0.0005	0.0001
	Paved initial loss		[m]	0.0035	0.0001
Minicluster_ defaults.txt	Proportion of surface runoff as inflow		[0-1]	0.6	0.99
	Effect road area		[0-1]	0.75	0.98
	Road initial loss		[m]	0.0035	0.0001
Contaminant _1.txt to Contaminant _4.txt	Road runoff	COD	[mg/L]	107	170
		TP		0.4	0.9
		TN		3	6
		NH_4-N		0.5	4
	Roof first flush	COD	[mg/L]	132	190
		TP		0.4	0.9
		TN		12	20
		NH_4-N		6.8	10
	Roof runoff	COD	[mg/L]	66	95
		TP		0.2	0.5
		TN		6	10
		NH_4-N		3.4	5
	Pavement runoff	COD	[mg/L]	66	95
		TP		0.4	0.9
		TN		3	6
		NH_4-N		3.4	5
	Use1 load	COD	[mg/c/d]	18000	20500
		TP		560	350
		TN		6362	2750
		NH_4-N		5075	800
	Use2 load	COD	[mg/c/d]	7000	No change
		TP		30	
		TN		110	
		NH_4-N		26	
	Use3 load	COD	[mg/c/d]	8000	No change
		TP		10	
		TN		214	
		NH_4-N		62	
	Use4 load	COD	[mg/c/d]	10000	No change
		TP		360	160
		TN		152	No change
		NH_4-N		16	No change

5 Results

5.1 Measurement results

5.1.1 Indoor water use profile

Despite from household to household the residential indoor water consumption is variation; to represent the indoor water use profile, a typical pattern based on indoor water use components is reasonable option. Those components include flushing toilet, cooking in the kitchen, taking bath and washing clothing.

In CWB those patterns named Use1, Use2, Use3 and Use4 referred to water use for Toilet, Kitchen, Bathroom and Laundry respectively. Current CWB version does not set up yet for other usages.

Total urban water consumption in the study area is 121,924m^3 (from the bill meter) in year 2010 (collected from Hanoi Water Company) or equal 334m^3/day. This number does not include leakage happening within the study area.
Population of the year 2010 is 2221 (collected from the group leaders).
Therefore, average water consumption per capital per day:

$$(121,924/2221)/365 * 1000 = 150.4 \text{ liter/capital/day}$$

However, in the study area there is a larger number of other water use patterns without discharging such as cooling in summer, dust treatment, bonsai irrigation, washing motorbike... Many people also complained that they have to pay for "invisible" water because when pump was pumping no water came in but bill meter still ticking.
Therefore, the indoor water usage profile was estimated based on indoor water use profile for 20 typical households in Hanoi (CEETIA, 2006) with 33% of water supply was used for above purposes or the other reasons. Water used in the CWB for case study was assumed below:

Table 5.1: Indoor water use for the study area in Lang, Hanoi

Pattern water uses	liter/capital/day	m^3/study area/day
Toilet	15	33
Kitchen	20	44
Bathroom	51	113
Laundry	15	33
Other uses	49.4	110
Total	150.4	334

One important habit water practice in the study area was they reuse partly water from kitchen to irrigate bonsai. However, no measurements carried to define this amount and the model does not have this type of parameter. Based on information during site visit, this amount was adjusted and expressed through proportion lost use2 parameter in Unitblock_default.txt file in CWB with 0,05 value (equal to 0.05*20*3.6 = 3.6 liters per household).

5.1.2 Spatial scale data

Mini-cluster define

Based on site visit, the subcatchment was divided to 4 mini-clusters according to different spatial characteristics. Mini-cluster number 1 and 4 are also unitblocks in this research, they

refer to one nursery, one community center because in CWB one mini-cluster has only one type of unitblock. Mini-cluster 2 and 3 are the representation of semi-detached no garden and terraced no garden residential. No public open space (POS) was recorded in the subcatchment. Two types of these houses and the limitation of pervious area are also very common in Hanoi capital

Total study area, total area of different land uses and number of unitblocks in each mini-cluster were measured and collected from Land administration office of Lang Ha, Dong Da district, Hanoi during the field visit. Average area per unitblocks gained from total area of unit block divided by number of unitblocks. More specifically, features of 4 mini-clusters were described in detail in the table 5.2

Table 5.2: The mini-clusters defined for the study subcatchment

Mini-cluster number	Total area (m^2)	Total area of unitblock (m^2)	Number of unitblocks	Average area per unitblocks (m^2)	Public open space (m^2)	Road area (m^2)
1	280	40	1	40	0	0
2	17090	15698	470	33.4	0	1102
3	6422.7	5600.7	147	38.1	0	702
4	270	195	1	195	0	0

Unitblock defination

Number of unitblocks was counted directly during site visit. Population of each mini-cluster was collected from the group leaders in the study area. Average occupancy per household equal total population of each mini-cluster divided total number of unitblocks in that mini-cluster.

The result was summarised in table 5.3

Table 5.3: Unitblock types and number of unitblocks in each mini-cluster

Mini-cluster number	Unitblock types	Population of mini-cluster	Average occupancy per household	Number of unitblocks
1	Community center	0	0	1
2	Terraced no garden	1692	3.6	470
3	Semi-detached no garden	529	3.6	147
4	Nursery/Primary School	152	152	1

As mentioned before, a pervious area is very limited in Hanoi (is zero in this case study). This was also similar to unitblocks (showed in column 4 of table 5.4).

Table 5.4: Unitblock characteristics

Mini-cluster number	Average area per unitblock (m^2)	Average area of roof (m^2)	Average area of garden (m^2)	Average area of pavement (m^2)
1	280	40	0	240
2	33.4	33.4	0	0.62
3	38.1	38.1	0	0.82
4	270	195	0	75

Total area of roof, pavement and garden was gathered from the group leaders, from residents and from measurements. After that average area per unitblocks, average area of roofs, gardens and pavements were calculated.

5.1.3 Flow measurements

The line graphs in figure 5.1 show municipal wastewater generated within 24 hours of 17 dry weather days. To draw these graphs, there are two types of flow data used. The first one is measured flow and the other one is calculated based on assumption in section 4.2.4.
It is quite clear that there were two main peaks sewage discharge during daytime; it comprised 65% of observed days or 11 per 17 days, and it showed more obviously in figure 5.2 where the combination of 17 days is presented. These peaks are coinciding with high household activities in the morning (normally from 6am to 8am period) and early evening (4pm to 8pm) while in the night and early morning minimal flow occurred.
The values at morning peak were varied by observed days: 47%, 35%, 12% and 6% were wastewater flows in categories of 400-500m^3/day; 300-400m^3/day, 500-600m^3/day and higher than 600m^3/day respectively. Before wastewater rising sharply to top of about more than 400m^3/day even reaching to almost 600m^3/day, it was consistently below 100m^3/day. However, for the next eight hours, wastewater generated had a decreasing trend reaching a daily low of around 100m^3/day. It should be noted that wastewater in this period was much fluctuated among days. For example, the first Monday the morning peak felt down only one big step to about 100m^3/day while two other Mondays they went down slower to 300m^3/day before stopped nearly 100m^3/days.

From 4pm to 8pm, the evening peak occurred. Very similar to morning peak the wastewater generated about 1.5 times higher than midday period (figure 5.2).

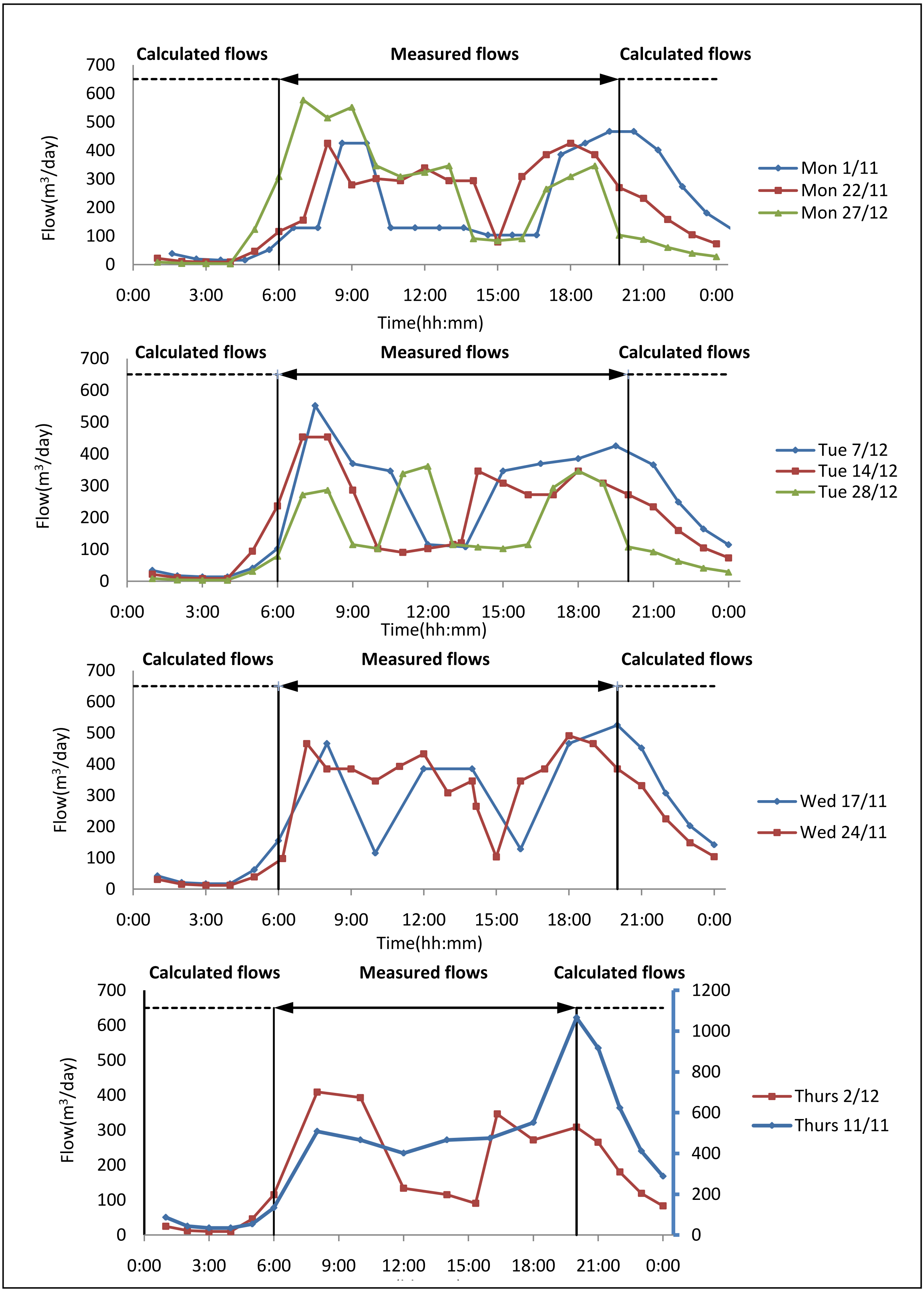
This was follow by a drop from 9pm onward to early morning. On the other word, from 12pm to 4am period, the wastewater produce remained relatively steady at low level.

One remark on Sunday 7th November, the morning peak reached 904m^3/day and 1066m^3/day in the evening peak on Thursday 11th November. They were the two highest recorded numbers and all other measured flows during these days also at high level compared to others. The explanation for that these two days could be the quarter total sanitation days because there was an announcement on the notice board in the study area showed that 2 first weeks in November was cleaning time (they have to clean service road together and before their houses, this is very common in Hanoi where a group of people living together and they normally do that at the end of the year or before the big celebrated days). Therefore, higher water quantity might be used for cleaning purposes.

On weekend days the flows between two peaks did not show big change as weekdays and the morning peaks seem happened later than weekdays. Most of people stay at home and busy with cooking, cleaning during whole daily time could be a reasonable explanation for this state.

The lowest wastewater discharged was on Friday 24th December, it is on Christmas. This was clear that this day most of people went out so water consumption reduced significantly by only 60% of the average discharge day (130.0m^3/day compared to 215.0m^3/day).
On Sunday 26th December, showed an unusual line graph, it had one morning peak only. Afterwards a plateau of base flow 100m^3/day was presented. No electricity could be a good reason to explain for this. Most of houses would not have energy to pump water to the top where store water tank located so they might have to minimize water use during that time.

Two conclusions can be draw from this result. The first is the highest wastewater discharge in the morning and early evening period and the other useful conclusion is average wastewater discharge was 215.0m^3/day.



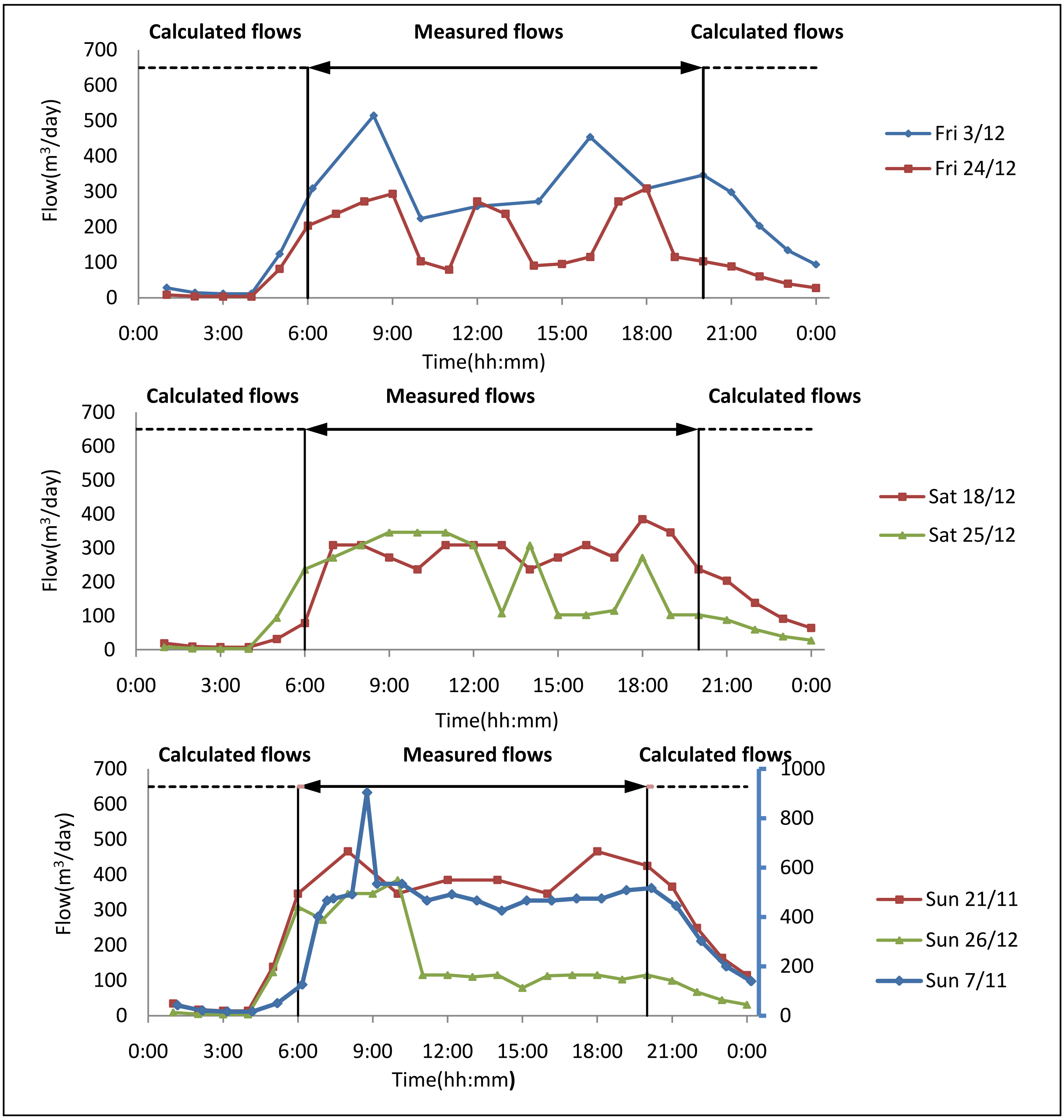


Figure 5.1: Dry weather flow diurnal profile of 17 measured days

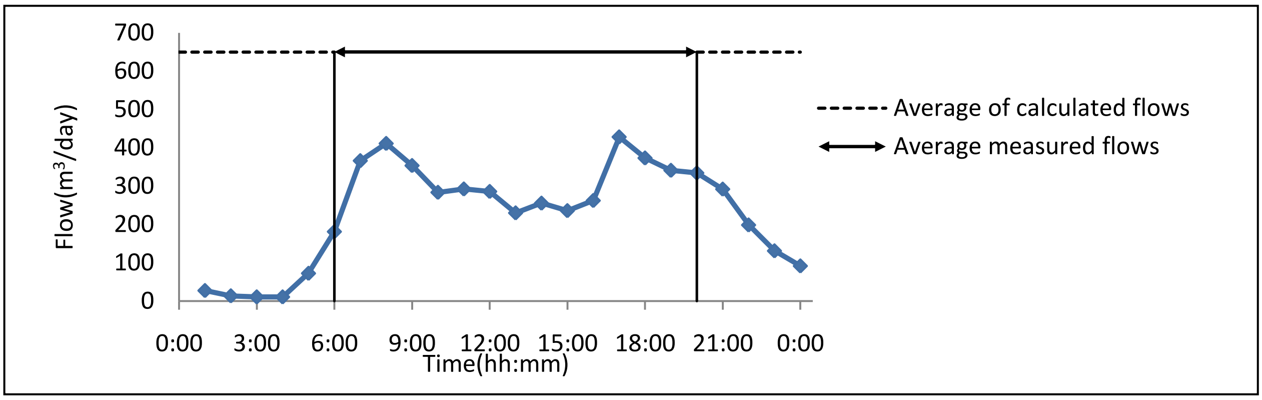


Figure 5.2: Average typical diurnal domestic wastewater flow pattern of 17 measured days

Compared with typical diurnal domestic wastewater flow from literatures, the typical diurnal domestic wastewater in the study area was similar observation. There were 2 main peaks occurring in the morning and in the evening. However, the time to reach peaks in the literature materials seems later than in this experiment area. Morning and evening peak of average diurnal of the 17 measured days appeared before 9am and 6pm respectively. While in the literature they were normally happening after 9am and 6pm. The explanation could be the time to start and finish working days in the case study earlier so concentration of water usage demand happening earlier.

Wet weather flow

As previous described, one rainy event was caught. The result was expressed in figure 5.3 together with average of 17 measured dry weather flows. The wet weather flow (659.0m^3/day) made up 3 times higher than the dry flows (215.0m^3/day).

It confirms that in combine sewage system stormwater comprises highly amount of total discharge, particularly, countries with high rainfall as Vietnam. Vietnamese center for hydro meteorological forecasting reports that around 1700mm precipitation per year in Hanoi. Clearly, we are wasting a huge amount of good water quality as rainfall which can be simply treated for non-potable purposes such as flushing toilet, laundry, washing or even use for alternative potable water.

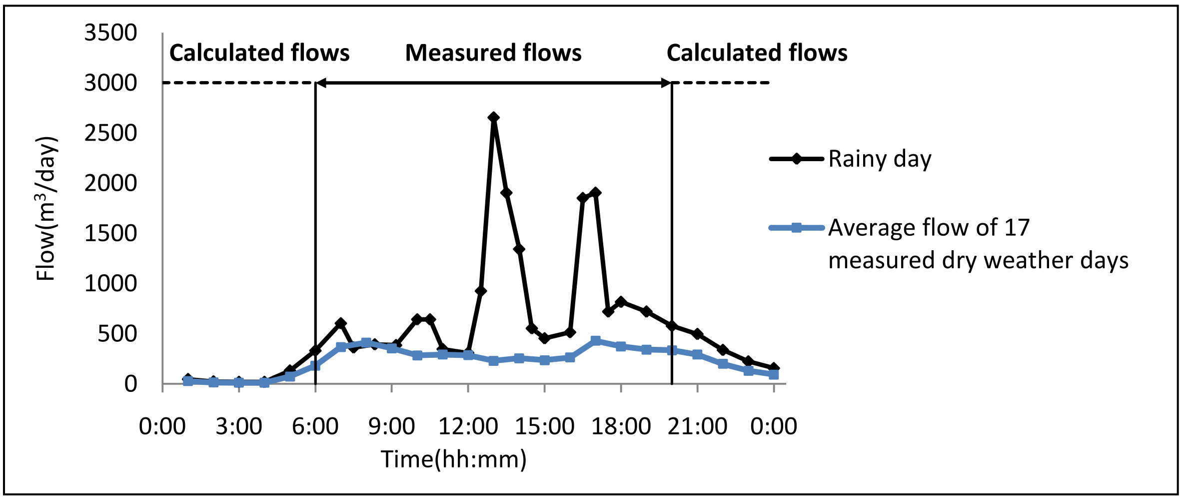


Figure 5.3: Flow fluctuation in the rainy day

5.1.4 Concentration of contaminants

Chemical oxygen demand

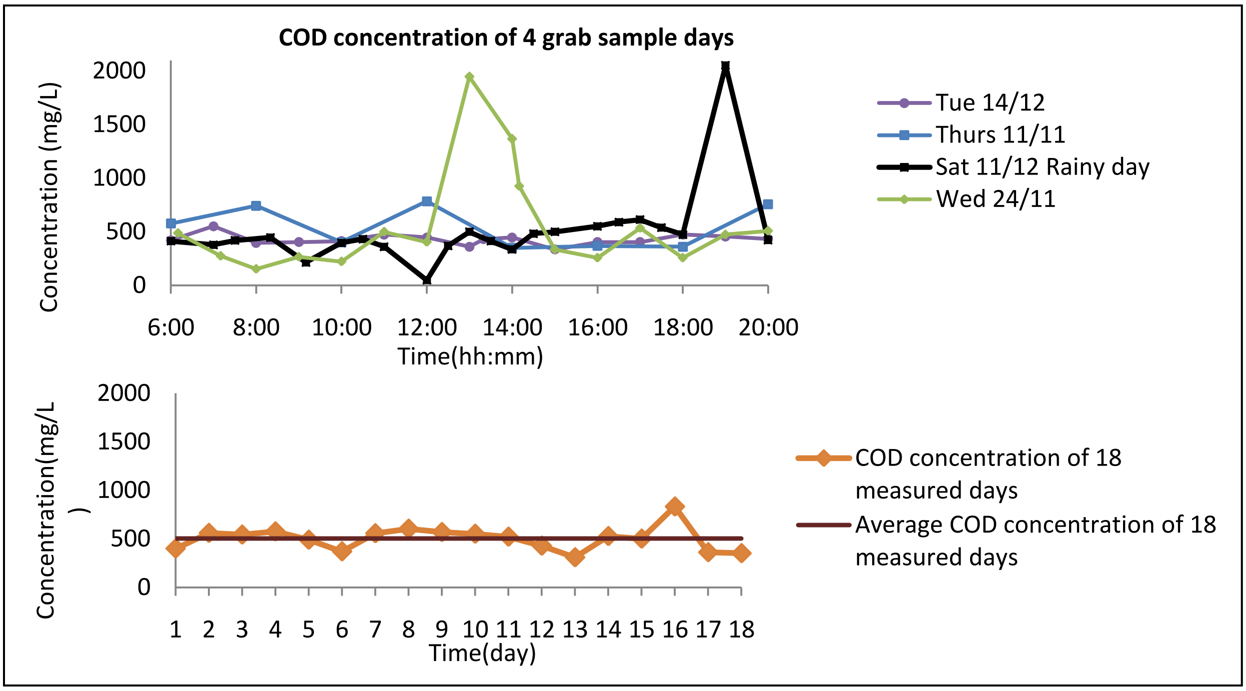


Figure 5.4: COD concentration results

In the first line graph (figure 5.4), generally there was not fluctuation of COD concentration over time as diurnal flows. Based on untreated domestic wastewater characteristic (Appendix 8), majority of COD concentration belongs to medium to strong (500mg/L-1000mg/L), weak to medium (250mg/L-500mg/L) categories. They made up 69% and 19% respectively. There were two strange peaks which very strong pollution (around 2000mg/L), this phenomenon could be explained by sediments that were flushed from the system when the pressure of wastewater flow strong enough, therefore, this wastewater extremely high amount of COD.

Similarly, the second graph where the 17 daily series presented, COD concentration remained relative unchanged around 500mg/L. It means that untreated domestic wastewater in that area was medium pollution. One remark, on Sunday 26th December (16th day in the line graph) COD concentration reached 833 mg/L the highest one. This day showed the unusual diurnal flow profile which analyzed in previous section. Minimization of water usage could make reduction of dilution. Consequently, concentration was increased.

Total phosphorus

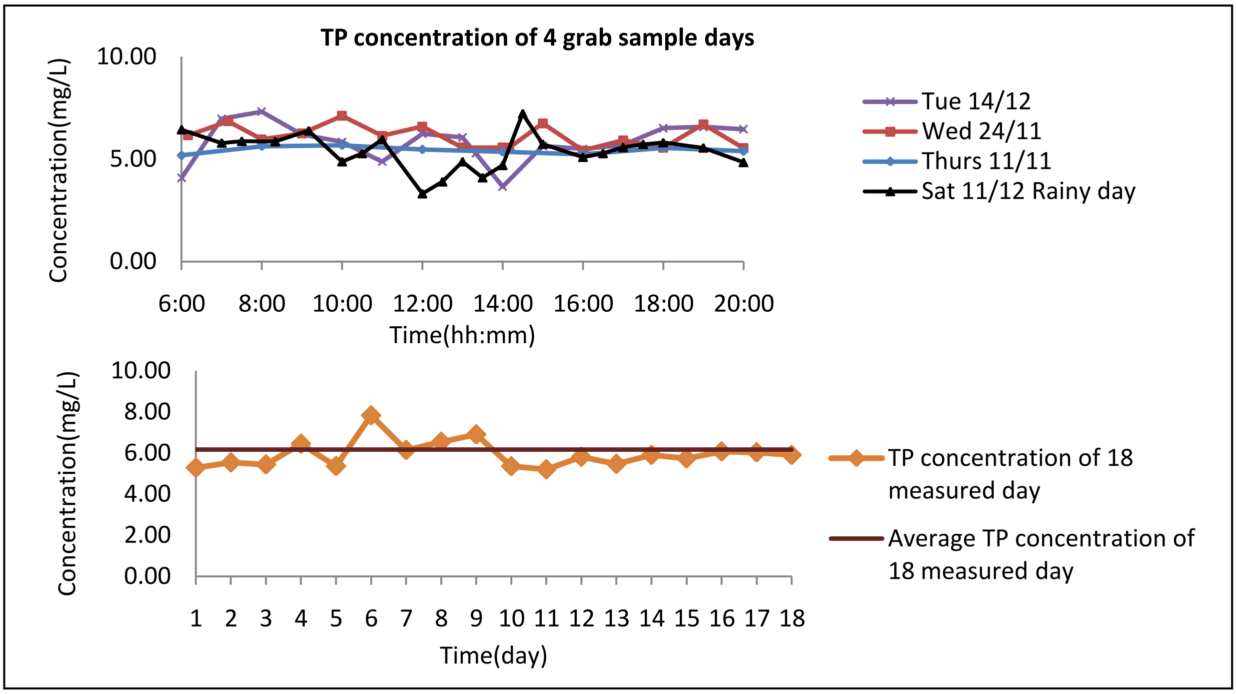


Figure 5.5: Total Phosphorus concentration results

Repeatedly, no fluctuation of TP concentration during daytime was recorded (first graph of figure 5.5). The concentration within a day and among those days small changed but still ranged in weak and medium pollution level.

Comprised 95% of typical daily TP concentration (second graph) was from 4-8mg/L which was also between weak and medium pollution level.

In rainy day (day 11th), TP concentration did not show any difference compared to others.

Total nitrogen

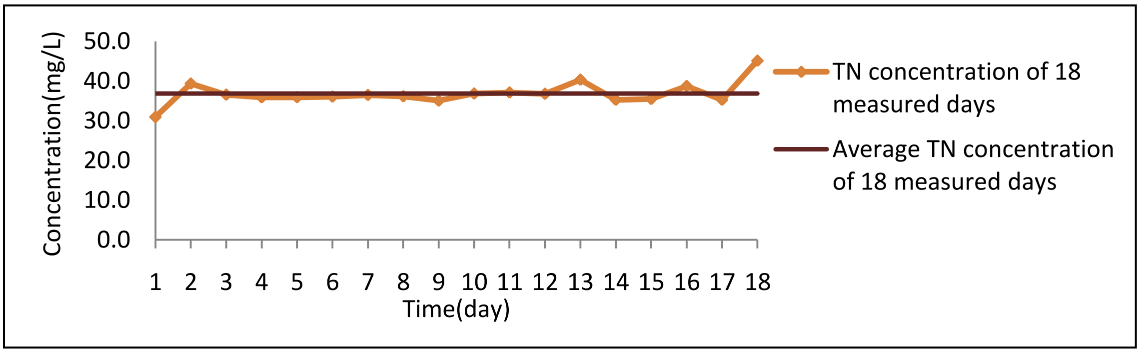


Figure 5.6: Total Nitrogen concentration results

Total nitrogen content was approximately the same every observed day with average value was 36.9mg/L. It was close to medium level of the untreated domestic wastewater.

Ammonium

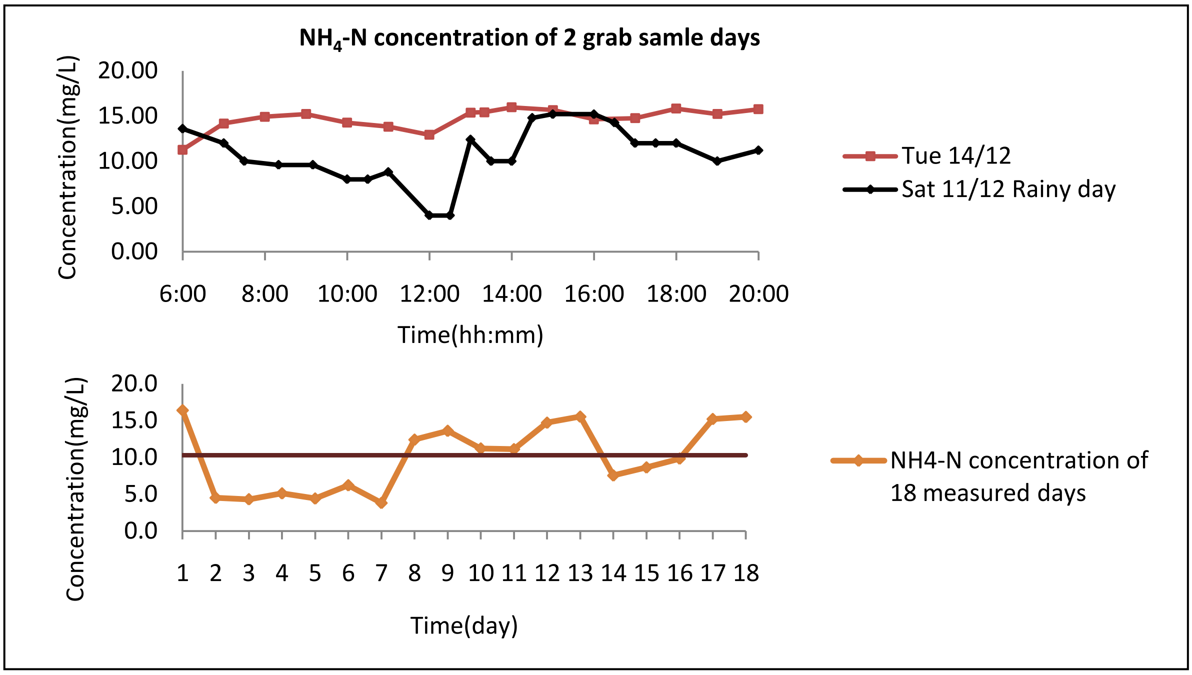


Figure 5.7: Ammonium nitrogen concentration results

Ammonium nitrogen concentration was a fluctuation than other contaminants during daily time and also among days. Ammonium known as unstable contaminant in term of chemical and biological, the results could be more or less affected during process of preserved and analyzed sample.

Nitrite nitrogen

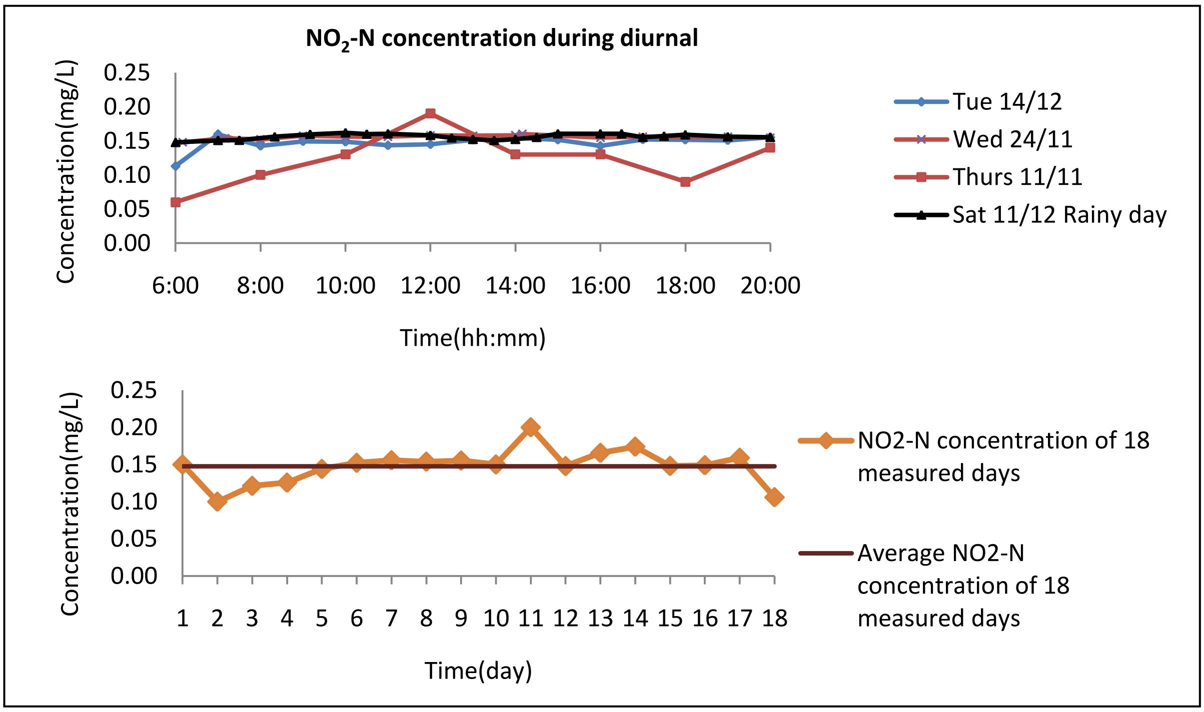


Figure 5.8: Nitrite nitrogen concentration results

Concentration of nitrite nitrogen recorded at small amount. They were not varying with diurnal flow rate and among the measured days. According to the untreated domestic

wastewater characteristics these concentration expected to be zero. So the analyzed nitrogen amount was satisfactory.

5.1.5 EMC assessment

EMC utilized to represent for runoff concentration. EMC and pollutant loads during storm event were calculated based on the equation (1) and (2).

Table 5.5: Summary of EMC in the rainy event with literature review

EMC	**Location**	**COD** (mg/L)	**TP** (mg/L)	**TN** (mg/L)	**NH_4-N** (mg/L)
Duong, 2011	Hanoi	522.0	5.2	0.2	11.0
Choe et al, 2002	Korea	501.4	1.88	14.08	-
Pitt et al, 2004	USA	54.5	0.31	1.5	0.31
Marla C etal, 2101	Korea	33.3	0.8	4.3	-
Ellis and Mitchell, 2006	UK	80	-	-	0.56
Pagotto et al, 2000	France	80	6.7	-	1

(Adopted from Mi-Hyun Park's summary)

COD EMC obtained in this study was a small deviation (4%) in comparison to other urban sites in Korea (Choe et al., 2004). TP was 2.7 times greater whereas TN 74 times smaller. In other comparison to results published by Pitt et al. in 2004 in USA, COD, TP and NH_4-N EMC was 5, 20 and 10 times higher while TN was 10 times smaller. It was observed that a large variability of contaminant concentrations existed between different study areas, which resulting from a complex interaction between many causes *(Marla C. Maniquiz 2010).* It is challenge to distinguish between the influences added of variables such as rainfall pattern, traffic density, types of seal area etc.

5.2 Flows and contaminant calibration

5.2.1 Flow calibration

For dry weather flow, under the assumption that 33% water used for the other usages (excluding in toilet, kitchen, bathroom and laundry usage) not discharging to the sewage system and 0.05 is proportion lost use2, the simulated discharge reproduce satisfactorily the measured discharge. Therefore, the result confirms that the input indoor water uses at unitblock scale were valid.

For wet weather flow, since no pervious area in the study area so characteristics of impervious area will major affected on storm discharge.

CWB calculates the surface runoff formulated by the impervious area and its drainage features. Nevertheless, no data available, it was defined with 99%. Effective of roof and paved area at uniblock scale and road at mini-cluster scale refer to the part of the impervious area that is connected to drainage system. Site visit showed that 98% are connected the combined sewage system.

Depending on surface materials, the service road and roof and paved area is very similar; they all covered by thin layer of cement and brick. Based on published research, the initial losses were defined 0.1mm.

At unit block and mini-cluster scale those parameters listed in table 4.3. Since data available limitation, those values were assumed quite higher than default because this time was dry season this rainy event was the first one after a long time no rain. Therefore, on surface of roof, road and pavement could be accumulated pollutants.

With 10% difference (table 5.6) the discharge modeled produces a satisfactorily the discharge measured during the dry weather period but the model was not designed to simulate changes among 17 measured days. Discharge quantities measured of the catchment this period varied from 130.0m^3/day to 386.0m^3/day due to the fact that daily demand changes such as holidays, weekends...was not clarified. The model instead calculated a constant discharge of 215.0m^3/day.

Table 5.6: Measured and simulated discharge

Dry weather discharge (m^3/day)		Difference (%)	Wet weather discharge (m^3/day)		Difference (%)
Measured	Modeled		Measured	Modeled	
215.0	238	10	659.0	452	31

It was very complicated when calibration stormwater discharge during the rainy event. The modeled storm discharge (452m^3/day) was one third smaller than recorded value (659.0m^3/day). Therefore, the inflow of stormwater to the sewer could not be fully estimated. This can be explained by following possible reasons: error precipitation and study area measurement, or overflow from outside of the study area transferred to. Two first reasons were challenge to evaluate because mistake could be made during site investigation and no existing information supported to correct them. Therefore, these considers as uncertainties of the set up model. For the last reason, since weak urban water management, the combined sewage system is frequently exceeded during rainy event. The study catchment located at lower position than an adjacent catchment so its overflow could be transferred to the study catchment. Based on comparison between observed and modeled discharge quantities during dry and wet weather, we estimated 30% of measured stormwater could be the overflow.

5.2.2 Contaminant calibration

As we know that black water contain very high amount of organic and suspended solid waste. And as mentioned the drainage system in Vietnam it make up 50% of the total loads compared to others. Therefore, load from toilet was calibrated to match measured data (except total phosphorus, it will be explain later).

As described in table 4.3, calibrated COD load from toilet was changed to a higher value than default COD load because based on national published document the efficiency of septic tank will be reduced by the time usage. So the effluent from the septic tank could be higher than the initial designed capacity expected.

By contrast, TN, TP, NH_4-N load has much smaller than default value. Since no data available for the study area even for national scale and they are also vary from countries to countries, from culture to culture based on features of food consumption. Therefore, these loads had to be verified with international data to match observed values.

For TP load from laundry, national literature showed that 63% load from grey water derived from laundry. In recent year, however, with government' enforcement to minimize phosphorus compound in cleaning detergents and based on weak and medium measured concentrations of contaminants (expressed detail in 5.1.4 section); consequently this percentage could be reduced. Supported by that information, TP load from laundry was estimated 160mg/capital/day instead of 360mg/capital/day.

For dry period

As summarized in table 5.7, with small deviations compared between measured and modeled concentrations and loads of contaminants, it confirmed that input calibrated loads for this case study were valid.

Table 5.7: Measured and modeled concentration in the dry weather period

Contaminant	Dry weather					
	Conc. (mg/L)			Load (kg/day)		
	Measured	Modeled	Difference (%)	Measured	Modeled	Difference (%)
COD	502	455	9	108	107	1
TP	6.0	6.0	0	1.3	1.3	0
TN	37.0	37.0	0	8.0	8.0	0
NH_4-N	8.6	8.0	7	2.0	2.0	0

For wet weather

By contrast, model was failed to simulate concentrations and loads during rainy event, its prediction matched only around 50% compared to measurements (table 5.8). This result directly neglects two first reasons stated above. Since rainfall quantity and total study area will not much affect on contaminant loads, it contributes quantity of stormwater instead quality. The overflow stormwater from the adjacent catchment and first flush could be a reasonable explanation for this poor simulation. Theoretically, the concentrations and loads from stormwater normally are lower than pure sewage because they would be diluted by rain water. However the first flush could contribute more polluted, especially if after long time it has no precipitation so contaminants accumulated. Moreover, if the overflow occurred the contaminants could be added to the drainage system of the study area. However, no experiment carried out to clarify this amount.

Table 5.8: Measured and modeled concentrations in the wet weather

Contaminant	Wet weather					
	Conc. (mg/L)			Load (kg/day)		
	Measured	Modeled	Difference (%)	Measured	Modeled	Difference (%)
COD	522	270	48	343	2	42
TP	5.2	2.0	65	3.0	127.0	63
TN	37.0	25.0	32	24.0	12.0	51
NH_4-N	11.0	6.0	46	7.0	3.0	59

5.3 Baseline scenario

After calibration processes, baseline scenario were constructed based on the physical characteristics, water patterns used in table 5.1 and 6 years (2005-2010) climate file input.

Table 5.9: Water supply, discharge and load results of baseline scenario

Water supply (m^3/day)	Stormwater discharge (m^3/day)	Total discharge (m^3/day)	Contaminant loads (kg/day)			
			COD	TP	TN	NH_4-N
238	115	351	118	1.4	9.5	2.5

The result (table 5.9 or appendix 1) showed a large volume of stormwater runoff. 100% of impervious surface generated surface runoff quantity of 1760mm/year, equal 99% of total precipitation. Roof runoff was the largest contribution made up 94% of total pavement area and 92% of total precipitation.

The high stormwater volume significantly increased the water volume in sewage system. Storm water contributed 1742mm/year and 33% of the total discharge. As described before, the study area is typical residential for Hanoi with high portion of impervious area, over capacity of combined sewage system. As a consequence, overflow and flooding often happen in Hanoi.
As we can see in the table, every day we discharge a non-small amount of contaminants directly to To lich River. There are a thousand of such subcatchments generating pollution to the river day by day resulting to over sefl-cleaning capacity of its water ecosystem. Therefore, river is not itself sewage drainage instead. This is current challenge for Hanoi; this situation is calling urgent solutions.

5.4 Climate change scenario

Climate change scenario was established by the physical characteristics and climate file 2009 adapted from scenarios of climate change for Vietnam of Vietnamese Natural resource and Environment Ministry. According to this temperature and precipitation in 2030 was adapted based on the medium emission of carbon dioxide scenario.

Table 5.10: Result of climate change scenario

Parameter	Unit	Scenarios		
		Baseline 2009	Climate change 2030	Climate change 2050
Stormwater discharge	m^3/day	104	107	109
Total discharge	m^3/day	340	343	345

Table 5.10 showed that there is an increase trend of stormwater discharge, as consequence total discharge will go up. This result one more time convinces that storm water harvesting and green roof are bright line.

5.5 Water management options

5.5.1 Household scale applications

There are a number of water management applications in CWB, including rain tank, wastewater recycling, septic tank, porous paving, swale, soakaway, green roof, and borehole. In this research rain tank, green roof and wastewater recycling will be tested. As mentioned in the describe study area and spatial scale data content: septic tank have been used, no pervious area and very limited pavement area. Moreover, with 89% of total area is roof area and abundant precipitation quantity, rain tank and green roof, therefore, are the most interesting operations for urban water management in the study area. Additionally, receiving water bodies, To Lich River in this case, is reaching to high warning pollution so wastewater recycling definitely plays very an important role.

Rain tank operation

It is clear that water supply[2] will be significant reduction by rain water harvesting (table 5.11). For rain water used for flushing toilet only (for use1 in the table), water supply can be saved 11%, 12%, 13%, 14% when set up tank 1m^3, 3m^3, 5m^3, 10m^3 volume respectively. As we know that water for this purpose was 33m^3/day (equal nearly 14%) (table 4.2) so the tank with 5m^3 or 10m^3 volume could be good choices. With annual precipitation around 1700mm if the

[2] Water supply refers to total water supply per study area per day unless otherwise stated

tank larger than 10m^3 rain water will be caught more. It means that we have to spend more money for setting up the tank while demand from this water is lower than the tank caught. As a result, the rest of rainwater is waste. In short, 5m^3 or 10m^3 tank volume is the optimal solution

Table 5.11 showed that increase rain tank volume 3 times for instance from 1m^3 to 3m^3 but water supply replaced by rainwater slightly increase 1.16 times because small amount of the water used for flushing toilet only so most of rainwater quantity became overflowed. Moreover, in the current CWB version, the retention effects of rainwater harvesting do not set up yet. The tank must be full as often as possible during dry weather to maximize usage efficiency and empty as often as possible during wet weather to optimal catch rain water. And due to the limitation data available of energy and cost, to come up the final best tank volume, therefore, further researches focus on technologies and cost-benefit analysis need to be done. Nevertheless, the results are significant references for those next steps.

As the assumption made before, 33% of water supply could be used for the other purposes that their wastewaters evaporated. Hence, the overflow will be lower than the values stated in the table or in other word stormwater discharge minimized. Overflow volumes equal 35%, 33%, 32%, 31% of water supply that can be used for those purposes if tank with 1m^3, 3m^3, 5m^3, and 10m^3 volumes operated.

For rain water used for all indoor water consumptions (for use1, use2, use3, use4 in the table), so water supply can be replaced by 32%, 39%, 43%, 48% of rainwater with 1m^3, 3m^3, 5m^3, 10m^3 tank volume respectively.

As a result, the overflows will be impressively decreased; these numbers and the amount of water consumption were proportional. The more rainwater can be used the more water supply can be saved and the less stormwater overflow. This observation supported that rain water harvesting plays a key role not only in stress diminution for water supply source but also solution for over capacity of the drainage system. It is more clearly through lower volumes of stormwater discharge.

Table 5.11: Results of rain water harvesting options at household scale

Parameter	Unit	Baseline	For use1				For use1 and use2 and use3 and use4			
			1m^3	3m^3	5m^3	10m^3	1m^3	3m^3	5m^3	10m^3
Water supply	m^3/day	238	213	209	206	204	162	154	148	139
Stormwater discharge	m^3/day	115	90	86	83	79	54	32	25	17
Total discharge	m^3/day	351	326	322	319	317	275	267	261	252
Reduction water supply	m^3/day		25	29	32	34	76	84	90	99
Overflow	m^3/day		82.7	78.4	75.4	73.6	46.0	23.5	17.1	8.8

Wastewater recycling

In this research, the wastewater recycling option formulated by the grey water and reused for flushing toilet. Beforehand, grey water characteristics were recalculated based on information from calibrated model (table 5.1 and 4.3).

In table 5.12, the reduction requirement calculated based on the difference between the contaminant concentrations and the proposed non-potable water criteria. These values were applied for treatment efficiency in the later simulations.

Table 5.12: Grey water characteristics

Parameters	Unit	Value	Proposed non-potable water	Reduction requirement (%)

				criteria[3]	
Grey water discharge		l/c/d	86		
Contaminant loads	COD	mg/c/d	25000		
	TP	mg/c/d	200		
	TN	mg/c/d	476		
	NH_4-N	mg/c/d	104		
Contaminant concentration	COD	mg/L	291	180	38
	TP	mg/L	2.3	0.4	83
	TN	mg/L	5.5	1.5	73
	NH_4-N	mg/L	3.4	0.6	82

The grey water equal 80% (figure 3.1) of water supply (excluding water used for other purposes). As calculated before, around 14% (or 33m^3/day) of total water consumption was used in toilet that relatively 17% of grey water should be treated for the replacement. It means that each household treat 0.054m^3/day (equal 15(use1)*3.6(capital/house)) would be good enough. In other word, partly grey water recycled and reused for flushing toilet, the rest continues discharge to the sewage system.

At household scale grey water discharged:
[20(use2)+51(use3)+15(use4)](l/c/d)*3.6(capital/house)=310(l/house/day)≅ 0.3m^3/house/day
The assumption made that 110m^3/day (table 5.1) of water supply was used for the non-indoor house purposes. As a light, if each house clean 100% (equal 0.3m^3 or 185m^3/day/study area) of grey water then water supply for flushing toilet and for those water using practices will completely replaced. That was proved by reduction water supply and overflow volume in table 5.13.

Table 5.13: Result of wastewater recycling application at household scale

Parameter		Unit	Baseline	WW recycling	
				0.054m^3	0.3m^3
Water consumption		m^3/day	238	203	203
Total discharge		m^3/day	351	316	316
Reduction water supply		m^3/day	0	35	35
Overflow treated water		m^3/day		0	150
Contaminant loads	COD	kg/day	118	96	87
	TP	kg/day	1.4	0.97	0.94
	TN	kg/day	9.5	8.1	7.9
	NH_4-N	kg/day	2.5	2.5	2.5

Table 5.13 laid out that COD, TP, TN and NH_4-N loads went down varied from contaminant to contaminant. The load reductions of 0.054m^3 grey recycling were 18%, 31%, 15% and 0% respectively compared to baseline. There was a varied load reductions because one hand the treatment efficiency set up on the other hand the different loads from grey water compared to black water. For instance, COD emission from three first patterns was 25000mg/c/d (table 4.3) that is 10% higher than emission from toilet (20500mg/c/d) but the removal was only 0.38. While TN loaded from grey water was 60% lower than from black water and the removal was 0.73. Consequently, the higher load reduction of TN compared to COD was presented.
Table 5.13 showed that quantity of the grey water recycling of second option (0.3m^3) was almost 6times higher than the first option (0.054m^3) but a small different load between two options cited. This can be explained that most of contaminant was from toilet plus the

[3] Since non-potable water quality standard for all the contaminants not yet officially clarified so rain water quality (in the calibrated CWB) were referred to the proposed non-potable water criteria

overflow of treated grey water (150m^3/day) mixed with effluent of septic tank. Appropriately, the contaminant loads were diluted a bit compared to the wastewater which was a compound of non-treated grey water and septic tank output.

However, in reality the overflow of treated grey water will not be recommended discharge to sewage used for the non-potable purposes instead.

Green roof

There are many green roofs can be set up depending on substrates, plants or designs. For example, soil types and thickness of soil layers. In CWB model green roof was setting up with 3 parameters: roof recovery (%), soil thickness (m) and drainage rate (m/day). In the study area, around 30% of total roof area occupied by water supply tank so 70% covered roof area will be performed. Together with 0.35m of soil layer and 0.15 m/day of drainage rate was tested.

Table 5.14 showed that green roof operation was leading to positive changes in urban water cycle. Evaporation 44times increase and stormwater discharge decrease 37% compared to baseline.

CWB was not designed to mimic the role of green roof in slowing down overflow during rainy event.

However, the numbers presented in the table was good enough to conclude that green roof contributes non-small benefit for the urban environmental problems through reduction of inflow into the sewage system and improve unpleasant air environment in urban area by increase evaporation.

Table 5.14: Result of green roof application in the study area

Parameter	Unit	Baseline	Green roof 70% covered	Positive effect
Evaporation	m^3/day	1	44	↑ 43
Stormwater discharge	m^3/day	115	73	↓ 42

5.5.2 Mini-cluster scale applications

Similarly to unitblock scale, there are 6 options can be operated at mini-cluster scale, they are listed in stormwater harvesting, wastewater recycling, soakaway, porous roads, swale and filterstrip. Within this research wastewater recycling will be considerations.

Percentage of road area was small compared to total study area (table 5.2) so soakaway and porous road will not bring significant positive effects to tackle overflow in the drainage system.

No pervious area (POS) in the study area (table 5.2) so it is not possible to set up swale and filterstrip properly.

Stormwater harvesting will not be tested at mini-cluster scale. Since if stormwater collected at mini-cluster then after that we have to set up the contributing system to supply this water to households. That will take much costly than collect rainwater at unitblock scale. However, it is aware of that stormwater harvesting at mini-cluster scale will contribute significant efficiency if larger water use demand concentrated within one location instead spreading out. For example, industrial area, offices, hospital, station, prison etc. could be suitable applications.

Wastewater recycling

Basically, mini-cluster wastewater recycling has similar benefits to unitblock scale. The treated grey water can be reused for non-potable purposes and minimizing pollution emission to the receiving water bodies. At this scale the treated grey water would not be recommended return to flushing toilet in households by the same reason of contributing cost of stormwater harvesting. Therefore, the treated water should be supplied for the public toilet, car washing services, irrigation or public cleaning activities in or close to the study area.

Total grey water generated (table 5.1) in the study area was:
(15+51+20)(l/c/d)*2221(capital) = 191(m^3/d)
The removal efficiency was applied as the same at unit block scale with 0.38, 0.83, 0.73, and 0.82 for COD, TP, TN and NH_4-N respectively.

Table 5.15: Result of wastewater recycling at mini-cluster scale

Parameter		Unit	Baseline	WW recycling
Water consumption		m^3/day	238	238
Total discharge		m^3/day	351	351
Reduction water supply		m^3/day		0
Overflow treated water				191
Contaminant loads	COD	kg/day	118	73
	TP	kg/day	1.4	0.45
	TN	kg/day	9.5	3.6
	NH_4-N	kg/day	2.5	2.5

In term of water quantity, no water reduction was stated because this water would not be used for flushing toilet at households scale. The volume of 191m^3/d will be supplied for the non-potable purposes as mentioned before.

Nevertheless, water quality aspect there was significant load reduction of contaminants. It confirmed that grey water has negative effects on the water pollution.

5.6 Develop strategies for urban water management in Hanoi

In light of the gained results from application of the water management options, the overall proposed strategy named "WIDEN AND WIN" URBAN WATER STRATEGY FOR HANOI will be recommended. This strategy aims to plan for implementation of stormwater harvesting, wastewater recycling and green roof in Hanoi properly.

Table 5.16: Overview of WIDEN AND WIN URBAN WATER STRATEGY FOR HANOI

	Name	Time	Objectives
Stage 1	Testing and Learning	Now to 2015	• Set up experiments for stormwater harvesting, wastewater recycling and green roof at unitblock and mini-cluster scale • Public ideal models of the water management options at small and larger scale • Conclusions about advantages, disadvantages and solutions for those applications
Stage 2	Widen and Win	2015 onwards	• Widen stormwater harvesting, wastewater recycling and green roof

	for all Hanoi capital

There are two main stages (table 5.16) should be carried out to ensure the strategy's success. The detail activities support two stages described below.

5.6.1 Stage 1 - Testing and Learning projects

Set up experiment for stormwater harvesting

Rainwater usage has had long history not only in the world but also rural area of Vietnam. There they consider this water as the most saving water source therefore it used for potable purpose only. The open question is why in urban area large amount of this water wasting and even viewing as a burden for combined sewage system while they are still dealing with both quantity and quality issues of water supply. During the site visit, the author talked to local people and recognized that some of them have no idea about rainwater usage but most of them willing to use if they received fully guides. However, this group also is considering about poor quality of rainwater (they believe because of the air pollution) and how to set up stormwater harvesting in their house suitably.
It is clear that stormwater harvesting contributes benefit for users and in social aspect it is highly welcome. Therefore, the rest of the work belongs to government, scientists and engineers who have to take responsibility to show them rainwater collection properly.
According to that the author suggests two detail plans below:

- **Volunteer plan**

Volunteer plan, basically, as name itself, built up on voluntary of the involvers who willing to take activities to support community in environmental improvement. In this case those people who care about water environment will be major "champions".
Table 5.17 present the volunteer plan should be carried out. The first step is a selection some volunteer households to set up rainwater harvesting. For houses with 3 or 4 inhabitants tank volume can be from 5 to 10 m^3 (reference from the result of rainwater harvesting at unitblock scale). However, it is flexible depending on precipitation and consumption quantity. After select and adapt rainwater harvesting technique for the experiment location. The involvement of scientist, engineer inside or outside of Vietnam and local people will be clarified. Those people who will do jobs related to their background. For instance, monitor rainwater quality, quantity and treatment will be done by environmentalist while engineer will satisfied technical parameters to operate the tank etc.
This plan should be carried out at least one year to ensure rainwater in both dry and wet season caught. At the end all results in term of cost-benefit, technology will be integrated and open published through different performance such as media, user manual, handbook, technical design criteria or scientific article.

Table 5.17: Volunteer plan for supporting stormwater harvesting strategy in Hanoi

Prepare step	Select volunteer experiment location	Call funding	Call involved volunteers	Choose international and national technologies
Implement step	• Monitor rainwater quality, quantity • Choose the best treatment if necessary	• Local fund • International fund	• Scientist • Engineer • Local people	• Design: tank location, volume. operation
Integrate and publish results	Handbook, use manual, technical design criteria or paper			

- **Demonstration plan**

Initially, the demonstration plan is similar the Volunteer plan. However, boundary and organization are more upgraded. Results of this plan will introduce an ideal model of rainwater harvesting. Here, every people interesting to rainwater collection feel free to come, learn and will be transferred technology.

Location to carry out the plan is the whole area, could be 2 or 3 hectares as the study area of this research (considered as mini-cluster scale) instead of the some volunteer houses as former plan. The local government will play a crucial role to ensure the plan worked out properly. Their responsibilities are preparing and setting up the whole package such as call fund, concretize plan, and organize involvers.
Consequently, rainwater-village will be widely presented.

Set up experiment for decentralized wastewater recycling (DWWR)

It is good time for setting up decentralized wastewater recycling. In general, we have to admit an unpleasant thing that in Vietnam many people only care about cleaning inside their houses. They seem forget that responsibility to keep cleaning for their neighbor 'houses and public area are not less important. Therefore, wastewater just discharge out of their house wherever it goes does not important to them. However urbanization is happening faster than infrastructure improvement and over drainage capacity. Very popular situation is wastewater goes back into their house particularly in rainy events. Additionally, their live improving, enhance acknowledges so they started re-thinking about ambient environment.

In light of the two plans above, volunteer and demonstration plan should be carried out. The difference with above plans is carried contents.

- **Demonstrate plan**

Table 5.18: Demonstrate plan for decentralized wastewater recycling

Prepare step	Select demonstrate location	Prepare funding	Select technologies
Sponsor Implementation	• Local gorvernment • Sewage and drainage system company	• Local fund • National fund • International fund	• Scientists in Institute of Environmental Science and Engineering • Experts from GTZ (a Germany consultant company)
Integrate and publish results	• Present value of DWWR • Present technical parameters to set up DWWR • Result of cost analysis of DWWR options	Performance	Media, handbook, use manual, technical design criteria or paper

Institute of Environmental Science and Engineering (IESE) and GTZ (Deutsche Gesellschaft fuer Technische Zusammenarbeit) are famous organization in wastewater treatment. IESE developed some well-known wastewater treatment in Vietnam condition. For instance, one of their sub-project *DESA* (Decentralized Sanitation) they developed BAST (baffled septic tank) and BASTAF (Baffled Anaerobic Septic Tanks with Anaerobic Filter). One of branch of GTZ focusing on Wastewater and Solid Waste Management and they have many experiments, experts in working in Vietnam. Therefore, they should consider as the first choices for the demonstrate plan.

Set up experiment for green roof operation

Once more, green roof operation strategies will be concretized through volunteer and demonstration plan.

Green roof is the newest urban water management in Hanoi compared to two above options; so far it is nearly new path where almost no one goes on. This is challenges for setting the proposed plans. However, with calling supports from environmental organizations such as Go Green, Vietnamese Environmental Protection Fund etc. is the keys to ensure success of the proposed plan.

The difference of green roof parameters should be performed. Depending on material, drainage rate, plants and percentage cover difference green roof will be tested. For instance different soil types should be performed. Botanist will contribute in selection of suitable plant etc.

5.6.2 Stage 2 - Widen and Win project

According to stage 1 results stage 2 will be carried out to widen the urban water management options for whole Hanoi. From households to buildings, from offices to hospitals, school etc. has to make the suitable water management options and implementing. To expand the application of those management options it needs enforcements not only from human resource, technology and fund but also from the government support tools such as regulation, policy and law. These play crucial role in success of the strategy so they should be seriously cared.

6 Discussion

In this section, discussions about how above water management options can significant contribute to implementation of integrated urban water management in Hanoi. Suggestions for improvement CWB limitations and some further crucial supports for success of the proposed strategies will be focused on.

6.1 Water management options and IUWM

As described before (table 5.11) imported water in the study area significant reduces by implementing different rainwater harvesting tank volumes. Benefits from rainwater harvesting were proved in many areas in the world. Tokyo is one of such area, the water practices have met 20-60% of their local water demand *(Furumai 2008).* Furumai also stated that at large-scale storage rainwater very useful measure for water demand in emergency case. Additionally, in Tokyo rainwater harvesting is considering as environmental education to citizens aware of sustainable urban water management. One research carried out in Metropolitan Area of Barcelona (Spain) showed that rainwater can meet more than 60% the landscape irrigation demand in both single and multi-family buildings *(Domènech and Saurí 2011).* In the same way, in Jordan by collecting rainwater from roofs of residential buildings helped saving 5.6% of total domestic water supply *(Abdulla and Al-Shareef 2009).* Those are only few evidences to confirm that stormwater collection has been bringing huge values.

The second important option of urban water management (table 5.13), that is wastewater recycling showed that it can significantly contribute not only imported water reduction but

also contaminant loads. This was acknowledged in many cases. Again, in Tokyo Furumai's research stated that a huge water volume has been utilized for various purposes such as washing, water-cooling, toilet flushing etc. The number in table 6.1 illustrated that

Table 6.1: Facilities of water recycling for miscellaneous purposed in Tokyo (March, 2002)

Recycle type	Number of facilities	Recycled water use (m^3/day)	Recycle percentage (%)
Individual building	293	43,809	22
Block-wide	170 (50 blocks)	20,167	22
Large-scale	97 (4 regions)	17,067	27
Total	560	81038	23

Enedir Ghisi stated that by using treated grey water the potable water savings range from 28.7% to 34.8% in a multi-storey residential building in Florianopolis, Brazil *(Ghisi and Mengotti de Oliveira 2007)*. It was reported that 48% fresh water supply by Nagpur Municipal Corporation can be saved by using treated grey water in Nagpur, India *(Mandal, Labhasetwar et al. 2011)*. Additionally, the implications of household grey water treatment and reuse helps saving of up to 43% potable water in Denmark. They are still much more published reports proved the potable water saved through reclaimed wastewater.

Last but not lease, green roof operation (table 5.14) was presented what we will be gained from this option. Manfred Kohler fought out that in hot and humid tropical countries green roof significant improves microclimate and cut the peak load. For microclimate improvement he showed that surface-temperature of household was lowers since higher evaporation. For instance with 10cm of substrate, an evapotranspiration of 90% of the summer precipitation and 75% of the annual precipitation. Furthermore, by comparing surface temperature of a greened roof with a conventional tarboard roof Centgraf stated that missing evapotranspiration increases the thermal radiation caused by higher surface temperature. Pave area like concrete and the ability of such surfaces store heat. Green roof was also contributing in overflow slowing down because the runoff on pervious surface was slower than pavement area. Bustorf proved that depending on the soil layer and the saturation of the soil the intensity of stormwater runoff from green roofs is 80% lower than from conventional flat roofs. In brief, roof-greening means much more than such conventional surface of buildings.

As I have pointed out above, the support information from the literature reviews leads to conclude that the "widen and win" urban water strategy for Hanoi should be valuable choice.
Two question remaining, how stormwater harvesting, wastewater recycling and roof-greening operation can reply IUWM in Hanoi and how the "WIDEN AND WIN" strategy can contribute IUWM? If the first question is answered patently the second question will be solved because this strategy was proposed to support those water management options.
To find out the answer for the first question, let go back to 1.2.1 section to review current Hanoi' water practices and zoom in to the study area characteristics in section 3. In general, we failed in all water management sectors. Unsustainable water supply in term of quality and quantity, ground water going down fast, contaminants was recorded (NH_4-N) and also dealing with lack of energy for the treatment and distribution. Also, small amount (7%) of domestic wastewater is treated consequently serious pollutions in the receiving water bodies. Furthermore, stormwater is wasted and considered as stress for the combined drainage system capacity. This situation needs to be switched off. Therefore the alternative water management needs to be carried out.

Table 6.2: Relevance of the water management options and IUWM features

Urban water management options	IUWM features	Total urban' water cycle benefits for the study area
Stormwater harvesting	Stormwater used for toilet flushing and the other purposes (bonsai irrigation, water-cooling, dust-reducing, motorbike washing). Source control of stormwater.	Depending on tanks volumes and residential demands (table 5.11). For instance, with 5m^3 tank volume, 97% 69% of water uses for toilet flushing and for other uses purposes respectively can be saved. 28% reduction in stormwater discharge.
Wastewater recycling	Treated water for toilet flushing, and the other purposes. Waste water quality and flow management	Estimated 100% replaced by reuse treated grey water for toilet flushing (both options in table 5,13). 18%, 31%, 15% COD, TP, TN loads were reduced respectively from wastewater discharge leaving the site. (option 1 in table 5.13)
Green roof	Use roof-greening for house temperature control. Storm water flow management	Evaporation increased 98%, reduce stormwater discharges and cut the peak load.

(Adopted from V.G. Mitchell)

Table 6.2 showed that how the water management options rely IUWM, it was illustrated by positive effects on total urban' water cycle benefits for the study area. Mitchell (2006) stated that the most important benefit of an integrated approach to urban water systems is the potential to increase the range of opportunities available lead to more sustainable systems. The above urban water management options are the ways we consider all the available opportunities for the study area. As a results, increase water supply source, reduce waste water discharge in both quality and quantity to receiving water bodies and close to natural water cycle by increasing evaporation.

6.2 Suggestions for improvement CWB limitations

During application CWB process, it was recognized indoor water use patterns limit to 4 (toilet, kitchen, bathroom and laundry) while the other use purposes is not stated. In this case study that was estimated 33% of total water supply. So proposed solution was draw (table 6.3)

Table 6.3: Limitation and its proposed solution in CWB

Limitation	Proposed solution
Lack of other water use for non-potable purposes (excluding toilet, kitchen, bathroom and laundry) in Unitblock_defaults.txt	Add Amount5 and Proportion lost use5 parameters in unitblock_defaults.txt Add supply for use5 with imported water parameter in UB_additional.csv file Add use5_cold parameter in UB_Raintank_defaults.txt file Add treat use5, supply use5 parameter in UB_WW_defaults.txt Add supply use5 parameter in UB_Borehole_defaults.txt Add Use use_5 parameter in UB_Greyirrigate_defaults.txt

Amount use5 should be added to refer to all other water use purposes excluding the consumption in toilet, kitchen, bathroom and laundry. Proportion lost use5 refer to total of its wastewater discharge into the drainage system. It could be lost by evaporation or out of the study catchment. Source water for use5 from imported water so to increase power of the water management options at uniblock scale, the number of parameters in rainwater harvesting, wastewater recycling, borehole and grey irrigation options should be added (in table 6.1). In other word, those options can supply water for non-potable purposes should be added to replace imported water supply. For instance, in this study area, use5 refer for water consumption by bonsai irrigation, motorbike washing, cooling, dust reduction. Therefore water quality meet for toilet flushing is good enough to use.

6.3 Further suggestions for urban water management strategies

As analyzed before there are two specific plans should be carried out to ensure success for WIDEN AND WIN URBAN WATER MANAGEMENT STRATEGY.

In general encourage as much people involve as possible however for the time being and near future that is challenge. Firstly maybe they do not care and these are not compulsory. Secondly for those people really care about but they are suspicious about the feasibility of the water management options. They also fear of changes especially in their house structure or in their live area. Therefore some highlight to tackle this issue recommended below:

Table 6.4: List of people high encourage operate the urban water strategy

	Rainwater harvesting	**Wastewater recycling**	**Green roof**
Volunteer plan	Focus on medium and low income people, managers in urban water sector	Focus on high income, high education people environmentalists and managers in urban water sector	Focus on government office buildings, environmentalists and managers in urban water sector
Demonstrate plan	Location with high density of medium, low income people and concentrated industrial zones	Location with concentration of high income people such as new urban area	Location with concentration of series of government buildings, new urban area etc.

It is clear that medium and low income people will be much more interested in rainwater harvesting than higher income group. Rainwater consumption directly reduces the water bill significantly. This was illustrated in this study area with the reduction of 54l/household/day by set up tank 5m^3 volumes.

With similar argument for wastewater recycling high income or high education people or environmentalists should be pioneers. For the rich people they consume much more water than others meaning that they discharge much more. Environmentalists, managers in urban water sector who call, guide people about saving water, water environmental protections etc. That is no doubt why they should be the first to take care of wastewater treatment and reuse.

7 Conclusions

According to urban water system results of study area and the simulation through CWB, it is emphasized that the study fully and well answered all the research questions:

1. Average discharge of 17 dry weather days was 215.0m^3/day and it was 659.0 cubic per wet weather day. Stormwater water three times higher than pure sewage replied the common current situation in Hanoi leading to flooding because of over the combined drainage system capacity.

2. The average concentration of COD, TP, TN, NH_4-N and NO_2-N were 502, 6.0, 37.0, 10.0 and 0.14 mg/L respectively in the pure sewage. These concentrations were medium pollution categories in the typical domestic wastewater characteristics and their emissions directly to the receiving water bodies. This is very common in Hanoi and is challenge for water managers.

3. The EMC of COD, TP, TN, NH_4-N and NO_2-N were 522, 5.0, 37.0, 11.0 and 0.2mg/L respectively in stormwater. It is difficult to conclude those concentrations were high or low because they varied from site to site in the world. However in comparison with the concentrations in the pure sewage they were not much difference.

4. Data was sufficient and reliable to feed CWB. The model was able to describe/simulate satisfactorily the urban cycle in dry weather days in study area. However it was failed to simulate in the wet weather day.

5. Stormwater harvesting significantly contributes to the water supply reduction. 97% of imported water for toilet flushing and 69% of water used for the other purposes (bonsai irrigation, water-cooling, dust reduction and washing motorbike) can be saved by setting 5m^3 tank volumes.

6. Amount of grey wastewater recycling and reuse was sufficient for toilet flushing and the other non-potable purposes. It also reported that 18%, 31%, and 15% of COD, TP and TN loads were reduced respectively.

7. Green roof had positive effects on microclimate and minimized partly the negative effects of the urban water cycle. Evaporation was increased 44 times in comparison with the baseline scenario.

8. The "WIDED AND WIN" URBAN WATER MANAGEMENT STATEGY was proposed towards IUWM. This strategy focused on the detail plans (Volunteer plan and Demonstrate plan) to start and widen stormwater harvesting, treated and reuse grey water and green roof operation for whole Hanoi in the near future. It is very useful references for the policy-makers. There was a strong relationship between the proposed strategy with IUWM features.

9. CWB limitations were concerned and to overcome these some solutions for improvement suggested.

8 Recommendations

To overcome the limitations during research process and improve further research for the study area, some major recommendations were integrated below:

1. The drainage system should be studied more detail. Since exfiltration and infiltration process play very important role in hydraulic and urban water cycle.

2. Overflow from neighbor catchment which can be effected to total discharge in the study area should be cared about

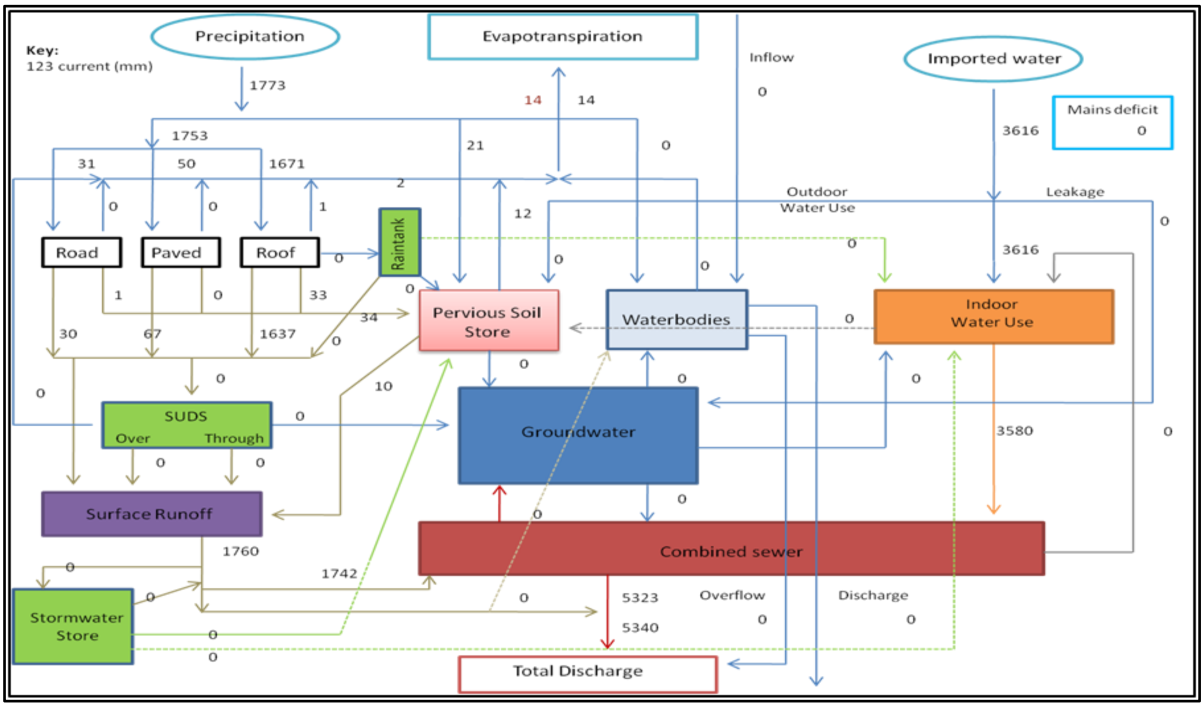
3. It could be better if further research will implement in rainy season so more precipitation events can be caught.

4. Expand research by adding economic and energy aspect to come up the best urban water management practices and strategies

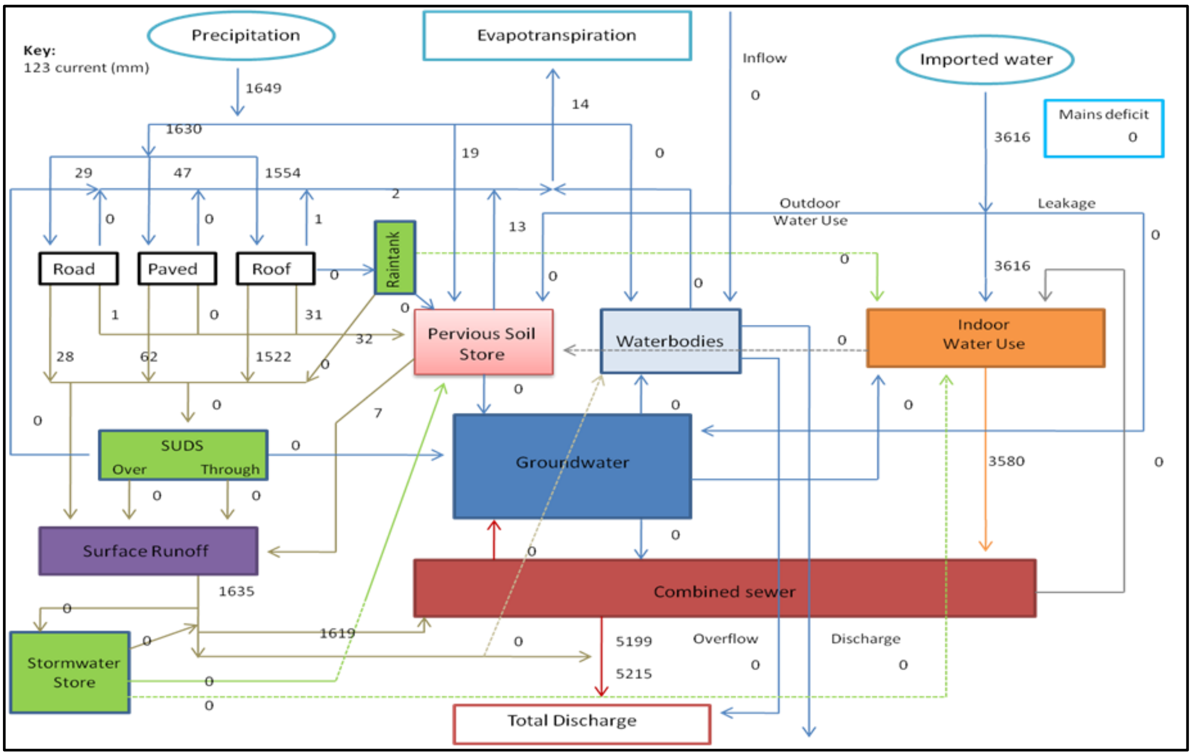
5. Expand research by developing indicators to evaluate proposed strategies.

Appendixes

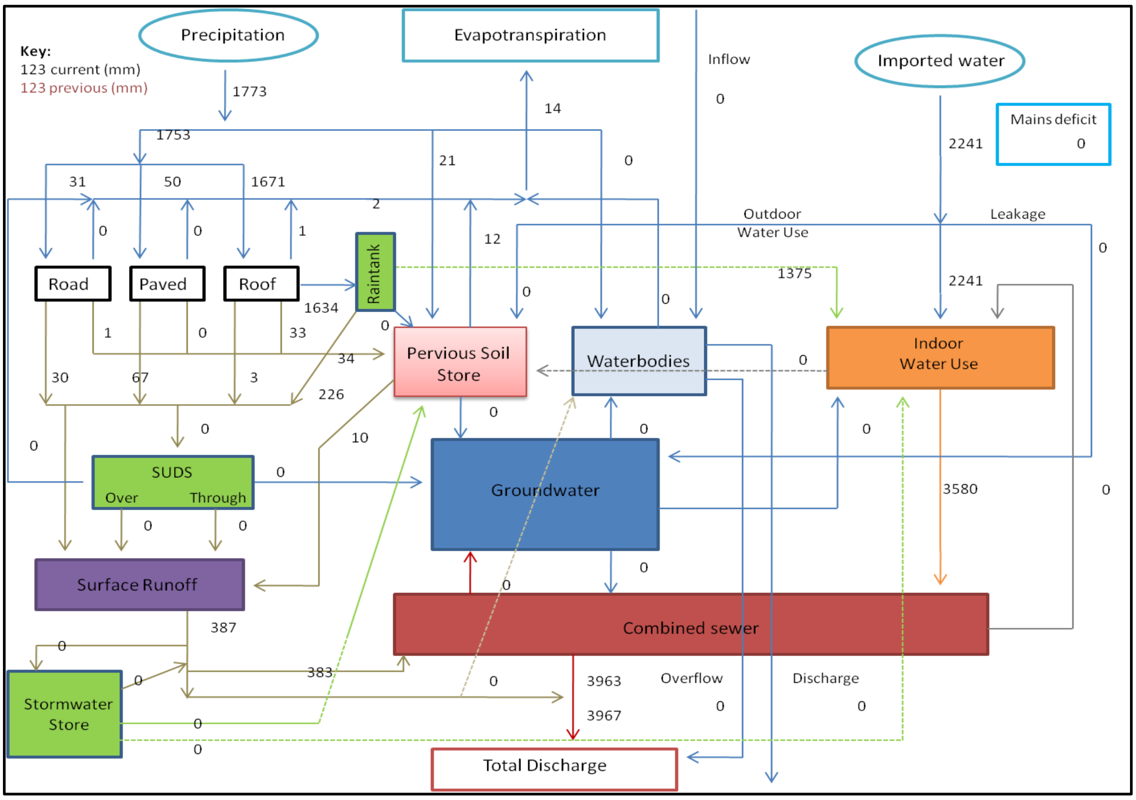
Appendix 1: Water balance diagram for study area in Lang, Hanoi, baseline scenario



Appendix 2: Climate change scenario (2030)



Appendix 3: Rain water harvesting (for 5m^3 tank volume)



Appendix 4: Wastewater recycling (for 100% of grey water)

Appendix 5: Green roof operation (for 70% roof cover)

Appendix 6: Reduction of Contaminants by wastewater recycling

Appendix 6: Flow of 18 measured days

Day	Time	Q(m^3/day)	Day	Time	Q(m^3/day)	Day	Time	Q(m^3/day)
01/11/10	1:36	37.8	**22/11/10**	1:00	21.9	**27/12/10**	1:00	8.3
Mon	2:36	18.9	Mon	2:00	10.9	**Mon**	2:00	4.2
	3:36	15.1		3:00	8.7		3:00	3.3
	4:36	15.1		4:00	8.7		4:00	2.7
	5:36	51.4		5:00	46.2		5:00	123.4
	6:36	128.4		6:00	115.4		6:00	308.6
	7:36	128.4		7:00	155.4		7:00	577.2
	8:36	425.3		8:00	425.3		8:00	514.3
	9:36	425.3		9:00	279.3		9:00	551.8

	10:36	128.4		10:00	301.2		10:00	346.3
	11:36	128.4		11:00	293.8		11:00	308.6
	12:36	128.4		12:00	338.7		12:00	323.5
	13:36	128.4		13:00	293.8		13:00	346.3
	14:36	102.9		14:00	293.8		14:00	90.7
	15:36	102.9		15:00	79.0		15:00	83.6
	16:36	102.9		16:00	308.6		16:00	90.7
	17:36	385.2		17:00	385.2		17:00	265.0
	18:36	425.3		18:00	425.3		18:00	308.6
	19:36	466.3		19:00	385.2		19:00	346.3
	20:36	466.3		20:00	269.7		20:00	102.9
	21:36	401.0		21:00	231.9		21:00	88.5
	22:36	272.7		22:00	157.7		22:00	60.2
	23:36	180.0		23:00	104.1		23:00	39.7
	0:36	126.0		0:00	72.9		0:00	27.8
		199.6			**208.9**			**205.1**

Day	Time	Q(m^3/day)	Day	Time	Q(m^3/day)	Day	Time	Q(m^3/day)
07/12/10	1:00	34.5	**14/12/10**	1:00	22.1	**28/12/10**	1:00	8.7
Tue	2:00	17.2	**Tue**	2:00	11.0	**Tue**	2:00	4.4
	3:00	13.8		3:00	8.8		3:00	3.5
	4:00	13.8		4:00	8.8		4:00	3.5
	5:00	41.1		5:00	94.8		5:00	31.6
	6:00	102.9		6:00	237.0		6:00	79.0
	7:30	551.8		7:00	453.5		7:00	272.1
	9:00	369.5		8:00	453.5		8:00	286.5
	10:30	346.3		9:00	286.5		9:00	115.4
	12:00	115.4		10:00	102.9		10:00	102.9
	13:30	107.8		11:00	90.7		11:00	338.7
	15:00	346.3		12:00	102.9		12:00	361.7
	16:30	369.5		13:00	115.4		13:00	115.4
	18:00	385.2		13:20	120.6		14:00	107.8
	19:30	425.3		14:00	346.3		15:00	102.9
	21:00	365.7		15:00	308.6		16:00	115.4
	22:00	248.7		16:00	272.1		17:00	293.8
	23:00	164.1		17:00	272.1		18:00	346.3
	0:00	114.9		18:00	346.3		19:00	308.6
		217.6		19:00	308.6		20:00	107.8
				20:00	272.1		21:00	92.7
				21:00	234.0		22:00	63.1
				22:00	159.1		23:00	41.6
				23:00	105.0		0:00	29.1
				0:00	73.5			**138.9**
					192.3			

Day	Time	Q(m^3/day)	Day	Time	Q(m^3/day)	Day	Time	Q(m^3/day)
17/11/10	1:00	42.6	**24/11/10**	1:00	31.2	**11/11/10**	1:00	86.4
Wed	2:00	21.3	**Wed**	2:00	15.6	**Thus**	2:00	43.2

	3:00	17.0		3:00	12.5		3:00	34.6
	4:00	17.0		4:00	12.5		4:00	34.6
	5:00	62.2		5:00	39.2		5:00	53.5
	6:00	155.4		6:10	97.9		6:00	133.7
	8:00	466.3		7:10	466.3		8:00	508.4
	10:00	115.4		8:00	385.2		10:00	466.3
	12:00	385.2		9:00	385.2		12:00	401.1
	14:00	385.2		10:00	346.3		14:00	466.3
	16:00	128.4		11:00	393.2		16:00	474.7
	18:00	466.3		12:00	433.4		18:00	551.3
	20:00	525.4		13:00	308.6		20:00	1066.2
	21:00	451.9		14:00	346.3		21:00	916.9
	22:00	307.3		14:10	265.5		22:00	623.5
	23:00	202.8		15:00	102.9		23:00	411.5
	0:00	142.0		16:00	346.3		0:00	288.1
		228.9		17:00	385.2			**385.9**
				18:00	491.4			
				19:00	466.3			
				20:00	385.2			
				21:00	331.3			
				22:00	225.3			
				23:00	148.7			
				0:00	104.1			
					261.0			

Day	**Time**	**Q(m^3/day)**	**Day**	**Time**	**Q(m^3/day)**	**Day**	**Time**	**Q(m^3/day)**
02/12/10	1:00	25.0	**03/12/10**	1:00	28.1	**24/12/10**	1:00	8.3
Thus	2:00	12.5	**Fri**	2:00	14.0	**Fri**	2:00	4.2
	3:00	10.0		3:00	11.2		3:00	3.3
	4:00	10.0		4:00	11.2		4:00	3.3
	5:00	46.2		5:00	123.4		5:00	81.3
	6:00	115.4		6:10	308.6		6:00	203.4
	8:00	409.1		8:20	514.3		7:00	237.0
	10:00	393.2		10:00	223.4		8:00	272.1
	12:00	133.7		12:00	257.9		9:00	293.8
	14:00	115.4		14:10	272.1		10:00	102.9
	15:20	90.7		16:00	453.5		11:00	79.0
	16:20	346.3		18:00	308.6		12:00	272.1
	18:00	272.1		20:00	346.3		13:00	237.0
	20:00	308.6		21:00	297.8		14:00	90.7
	21:00	265.4		22:00	202.5		15:00	95.5
	22:00	180.5		23:00	133.7		16:00	115.4
	23:00	119.1		0:00	93.6		17:00	272.1
	0:00	83.4			**211.8**		18:00	308.6
		163.1					19:00	115.4
							20:00	102.9
							21:00	88.5

							22:00	60.2
							23:00	39.7
							0:00	27.8
								129.8

Day	Time	Q(m^3/day)	Day	Time	Q(m^3/day)	Day	Time	Q(m^3/day)
11/12/10	1:00	46.8	**18/12/10**	1:00	19.2	**25/12/10**	1:00	8.3
Sat	2:00	23.4	**Sat**	2:00	9.6	**Sat**	2:00	4.2
Rainy day	3:00	18.7		3:00	7.7		3:00	3.3
	4:00	18.7		4:00	7.7		4:00	3.3
	5:00	132.4		5:00	31.6		5:00	94.8
	6:00	331.1		6:00	79.0		6:00	237.0
	7:00	602.9		7:00	308.6		7:00	272.1
	7:30	361.7		8:00	308.6		8:00	308.6
	8:20	393.2		9:00	272.1		9:00	346.3
	9:10	385.2		10:00	237.0		10:00	346.3
	10:00	642.1		11:00	308.6		11:00	346.3
	10:30	642.1		12:00	308.6		12:00	308.6
	11:00	346.3		13:00	308.6		13:00	107.8
	12:00	308.6		14:00	237.0		14:00	308.6
	12:30	925.7		15:00	272.1		15:00	102.9
	13:00	2655.1		16:00	308.6		16:00	102.9
	13:30	1904.8		17:00	272.1		17:00	115.4
	14:00	1343.0		18:00	385.2		18:00	272.1
	14:30	553.0		19:00	346.3		19:00	102.9
	15:00	453.5		20:00	237.0		20:00	102.9
	16:00	514.3		21:00	203.8		21:00	88.5
	16:30	1851.5		22:00	138.6		22:00	60.2
	17:00	1904.8		23:00	91.5		23:00	39.7
	17:30	720.0		0:00	64.0		0:00	27.8
	18:00	816.3			**198.5**			**154.6**
	19:00	720.0						
	20:00	577.2						
	21:00	496.4						
	22:00	337.5						
	23:00	222.8						
	0:00	155.9						
		658.2						

Day	Time	Q(m^3/day)	Day	Time	Q(m^3/day)	Day	Time	Q(m^3/day)
07/11/10	1:10	41.9	**21/11/10**	1:00	34.5	**26/12/10**	1:00	9.4
Sun	2:10	20.9	**Sun**	2:00	17.2	**Sun**	2:00	4.7
	3:10	16.8		3:00	13.8		3:00	3.7
	4:10	16.8		4:00	13.8		4:00	3.7
	5:10	50.3		5:00	138.5		5:00	123.4
	6:10	125.8		6:00	346.3		6:00	308.6
	6:48	401.1		8:00	466.3		7:00	272.1
	7:10	466.3		10:00	346.3		8:00	346.3

7:25	474.7	12:00	385.2	9:00	346.3
8:10	491.4	14:00	385.2	10:00	385.2
8:46	904.4	16:00	346.3	11:00	115.4
9:10	534.0	18:00	466.3	12:00	115.4
10:10	534.0	20:00	425.3	13:00	110.4
11:10	466.3	21:00	365.7	14:00	115.4
12:10	491.4	22:00	248.7	15:00	79.0
13:10	466.3	23:00	164.1	16:00	112.9
14:10	425.3	0:00	114.9	17:00	115.4
15:10	466.3		**251.7**	18:00	115.4
16:10	466.3			19:00	102.9
17:10	474.7			20:00	115.4
18:10	474.7			21:00	99.3
19:10	508.4			22:00	67.5
20:10	516.9			23:00	44.6
21:10	444.5			0:00	31.2
22:10	302.3				**131.0**
23:10	199.5				
0:10	139.6				
	367.4				

Appendix 7: Contaminant concentrations of 18 measured days

COD Concentration											
Day	**Time**	**Conc. mg/L**	**Day**	**Time**	**Conc. mg/L**	**Day**	**Time**	**Conc mg/L**	**Day**	**Time**	**Conc. mg/L**
01/11/10		**400**	24/11/10	6:10	488	11/12/10	6:00	413	14/12/10	6:00	420
07/11/10		**560**		7:10	274		7:00	379		7:00	552
11/11/10	6:00	578		8:00	153		7:30	419		8:00	396
	8:00	743		9:00	266		8:20	448		9:00	405
	10:00	403		10:00	222		9:10	214		10:00	413
	12:00	785		11:00	500		10:00	396		11:00	474
	14:00	350		12:00	404		10:30	432		12:00	448
	16:00	368		13:00	1948		11:00	361		13:00	361
	18:00	360		14:00	1367		12:00	49		13:20	431
	20:00	758		14:40	926		12:30	370		14:00	448
Average		**543**		15:00	335		13:00	500		15:00	335
17/11/10		**576**		16:00	257		13:30	413		16:00	405
21/11/10		**490**		17:00	534		14:00	335		17:00	405
22/11/10		**370**		18:00	257		14:30	483		18:00	474
				19:00	474		15:00	500		19:00	457
				20:00	508		16:00	552		20:00	434
			Average		**557**		16:30	591	Average		**428**

			02/12/10		**604**		17:00	613	18/12/10		**309**
			03/12/10		**569**		17:30	538	24/12/10		**528**
			07/12/10		**552**		18:00	474	25/12/10		**501**
							19:00	2052	26/12/10		**833**
							20:00	422	27/12/10		**361**
						EMC		**522**	28/12/10		**351**

Total Phosphorus (TP)

Day	Time	Conc. mg/L	Day	Time	Conc. mg/L	Day	Time	Conc mg/L	Day	Time	Conc. mg/L
01/11/10		**5.28**	24/11/10	6:10	6.16	11/12/10	6:00	6.44	14/12/10	6:00	4.08
07/11/10		**5.54**		7:10	6.85		7:00	5.79		7:00	6.97
11/11/10	6:00	5.18		8:00	5.97		7:30	5.88		8:00	7.32
	8:00	5.63		9:00	6.26		8:20	5.86		9:00	6.21
	10:00	5.68		10:00	7.12		9:10	6.39		10:00	5.84
	12:00	5.47		11:00	6.14		10:00	4.88		11:00	4.88
	14:00	5.36		12:00	6.59		10:30	5.28		12:00	6.24
	16:00	5.23		13:00	5.57		11:00	5.95		13:00	6.06
	18:00	5.55		14:00	5.57		12:00	3.32		13:20	5.28
	20:00	5.39		14:40	5.56		12:30	3.90		14:00	3.66
Average		**5.44**		15:00	6.75		13:00	4.88		15:00	5.64
17/11/10		**6.44**		16:00	5.42		13:30	4.10		16:00	5.50
21/11/10		**5.36**		17:00	5.92		14:00	4.70		17:00	5.69
22/11/10		**7.82**		18:00	5.55		14:30	7.23		18:00	6.52
				19:00	6.70		15:00	5.74		19:00	6.58
				20:00	5.54		16:00	5.10		20:00	6.46
			Average		**6.14**		16:30	5.28	Average		**5.81**
			02/12/10		**6.54**		17:00	5.57	18/12/10		**5.46**
			03/12/10		**6.90**		17:30	5.73	24/12/10		**5.90**
			07/12/10		**5.35**		18:00	5.81	25/12/10		**5.73**
							19:00	5.55	26/12/10		**6.07**
							20:00	4.84	27/12/10		**6.03**
						EMC		**5.20**	28/12/10		**5.90**

Nitrite Nitrogen (NO_2-N)

Day	Time	Conc. mg/L	Day	Time	Conc. mg/L	Day	Time	Conc. mg/L	Day	Time	Conc. mg/L
01/11/10		**0.150**	24/11/10	6:10	0.148	11/12/10	6:00	0.148	14/12/10	6:00	0.113
07/11/10		**0.100**		7:10	0.154	11/12/10	7:00	0.151		7:00	0.160
11/11/10	6:00	0.060		8:00	0.152	11/12/10	7:30	0.151		8:00	0.143
11/11/10	8:00	0.100		9:00	0.157	11/12/10	8:20	0.156		9:00	0.149
11/11/10	10:00	0.130		10:00	0.156	11/12/10	9:10	0.160		10:00	0.149
11/11/10	12:00	0.190		11:00	0.156	11/12/10	10:00	0.162		11:00	0.143
11/11/10	14:00	0.130		12:00	0.158	11/12/10	10:30	0.160		12:00	0.145

11/11/10	16:00	0.130		13:00	0.157	11/12/10	11:00	0.160		13:00	0.152
11/11/10	18:00	0.090		14:00	0.158	11/12/10	12:00	0.158		13:20	0.154
11/11/10	20:00	0.140		14:40	0.160	11/12/10	12:30	0.155		14:00	0.155
Average		**0.121**		15:00	0.157	11/12/10	13:00	0.152		15:00	0.152
17/11/10		**0.126**		16:00	0.155	11/12/10	13:30	0.151		16:00	0.143
21/11/10		**0.144**		17:00	0.156	11/12/10	14:00	0.152		17:00	0.152
22/11/10		**0.152**		18:00	0.156	11/12/10	14:30	0.155		18:00	0.152
				19:00	0.156	11/12/10	15:00	0.160		19:00	0.151
				20:00	0.155	11/12/10	16:00	0.160		20:00	0.155
			Average		**0.156**	11/12/10	16:30	0.160	Average		**0.148**
			02/12/10		**0.154**	11/12/10	17:00	0.155	18/12/10		**0.166**
			03/12/10		**0.155**	11/12/10	17:30	0.157	24/12/10		**0.174**
			07/12/10		**0.150**	11/12/10	18:00	0.159	25/12/10		**0.148**
						11/12/10	19:00	0.156	26/12/10		**0.149**
						11/12/10	20:00	0.155	27/12/10		**0.159**
						EMC		**0.200**	28/12/10		**0.106**

Ammonium Nitrogen (NH_4-N)

Day	**Time**	**Conc. (mg/L)**	**Day**	**Time**	**Conc. (mg/L)**	**Day**	**Time**	**Conc. (mg/L)**
01/11/10		**16.40**	11/12/10	6:00	13.60	14/12/10	6:00	11.27
07/11/10		**4.50**	11/12/10	7:00	12.00		7:00	14.18
11/11/10		**4.30**	11/12/10	7:30	10.01		8:00	14.93
17/11/10		**5.10**	11/12/10	8:20	9.60		9:00	15.23
21/11/10		**4.40**	11/12/10	9:10	9.60		10:00	14.26
22/11/10		**6.20**	11/12/10	10:00	8.00		11:00	13.82
24/11/10		**3.80**	11/12/10	10:30	8.00		12:00	12.93
02/12/10		**12.40**	11/12/10	11:00	8.80		13:00	15.38
03/12/10		**13.60**	11/12/10	12:00	4.00		13:20	15.42
07/12/10		**11.20**	11/12/10	12:30	4.00		14:00	15.97
			11/12/10	13:00	12.40		15:00	15.67
			11/12/10	13:30	10.00		16:00	14.63
			11/12/10	14:00	10.00		17:00	14.76
			11/12/10	14:30	14.80		18:00	15.82
			11/12/10	15:00	15.20		19:00	15.23
			11/12/10	16:00	15.20		20:00	15.75
			11/12/10	16:30	14.27	Average		**14.70**
			11/12/10	17:00	12.00	18/12/10		**15.52**
			11/12/10	17:30	12.00	24/12/10		**7.53**
			11/12/10	18:00	12.00	25/12/10		**8.62**
			11/12/10	19:00	10.00	26/12/10		**9.83**
			11/12/10	20:00	11.20	27/12/10		**15.20**
			EMC		**11.10**	28/12/10		**15.48**

Concentration of measured contaminants					
Day	**COD (mg/L)**	**TN (mg/L)**	**TP (mg/L)**	**NO_2-N (mg/L)**	**NH_4-N (mg/L)**
01/11/10	400	30.9	5.28	0.15	16.4
07/11/10	560	39.4	5.54	0.10	4.5
11/11/10	543	36.6	5.44	0.12	4.3
17/11/10	576	35.9	6.44	0.13	5.1
21/11/10	490	35.9	5.36	0.14	4.4
22/11/10	370	36.1	7.82	0.15	6.2
24/11/10	557	36.5	6.14	0.16	3.8
02/12/10	604	36.1	6.54	0.15	12.4
03/12/10	569	35.1	6.90	0.16	13.6
07/12/10	552	36.8	5.35	0.15	11.2
11/12/10	522	37.1	5.20	0.20	11.1
14/12/10	428	36.8	5.81	0.15	14.7
18/12/10	309	40.3	5.46	0.17	15.5
24/12/10	528	35.3	5.90	0.17	7.5
25/12/10	501	35.5	5.73	0.15	8.6
26/12/10	833	38.8	6.07	0.15	9.8
27/12/10	361	35.3	6.03	0.16	15.2
28/12/10	351	45.1	5.90	0.11	15.5

Appendix 8: Typical composition of untreated domestic wastewater

		Concentration		
Contaminants	**Unit**	**Weak**	**Medium**	**Strong**
Solids, total (TS)	mg/L	350	720	1200
Dissolved, total (TDS)	mg/L	250	500	850
Fixed	mg/L	145	300	525
Volatile	mg/L	105	200	325
Suspended solids (SS)	mg/L	100	220	350
Fixed	mg/L	20	55	75
Volatile	mg/L	80	165	275
Settleable solids	mL/L	5	10	20
Biochemical oxygen demand, mg/L: 5-day, 20°C (BOD_5, 20°C)	mg/L	110	220	400
Total organic carbon (TOC)	mg/L	80	160	290
Chemical oxygen demand (COD)	mg/L	250	500	1000
Nitrogen (total as N)	mg/L	20	40	85
Organic	mg/L	8	15	35
Free ammonia	mg/L	12	25	50
Nitrites	mg/L	0	0	0
Nitrates	mg/L	0	0	0
Phosphorus (total as P)	mg/L	4	8	15
Organic	mg/L	1	3	5
Inorganic	mg/L	3	5	10
Chlorides[a]	mg/L	30	50	100
Sulfate[a]	mg/L	20	30	50
Alkalinity (as $CaCO_3$)	mg/L	50	100	200
Grease	mg/L	50	100	150
Total coliform[b]	no/100 mL	10^6–10^7	10^7–10^8	10^8–10^9
Volatile organic compounds (VOCs)	μg/L	<100	100–400	>400

[a] Values should be increased by amount present in domestic water supply.

[b] See Table 3-18 for typical values for other microorganisms.

Note: 1.8(°C) + 32 = °F.

(Source: Lecture of Ricardo B. Jacquez, Professor, CAGE Department, New Mexico State University)

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With over 40% of the water supply of Western and Eastern Europe coming from urban aquifers, efficient and cost-effective management tools for this resource are essential to maintain the quality of life. However, the increasing concerns about the environmental impacts of water projects and their increasing economic costs mean that traditional planning concepts, which assume unlimited supplies of potable water, must be questioned. This includes the source of the water supply and its appropriate use. Urban transport systems and the provision of water have been identified as the most critical factors that determine the future of cities in this century. The objective of an interdisciplinary research project presented in this paper is to identify and develop systems and technologies and integrative processes and analytical tools, which are commercially valuable, scientifically robust and which improve the cost effectiveness of urban water services, in line with the program's vision of ecological sustainability. As part of this program, a software tool has been developed to estimate the water flows and contaminant loads within the urban water system. This paper presents first modelling results of water and contaminant flows through the existing urban water, wastewater and stormwater systems, from source to discharge point.

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