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Impact of Summer Storms on Rainwater Collecting Lakes in Gansu, China

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By

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Abstract

The rapid population growth in China during the last decades has put an enormous pressure on cultivation production and water supply. Many regions in China are therefore facing water scarcity and shortage of arable land. One of such regions is Gansu and it is considered as the driest and poorest province in China. This arid and semi-arid region is signifying a very uneven annual precipitation pattern and the majority of the rainfalls occur during summer. Rainwater harvesting is therefore necessary in order to make maximum utilization of the rainfall. Rainwater harvesting (RWH) is a technology used for collecting and storing stormwater for domestic use, irrigation and flood control. The local government of Qingyang in Gansu has sponsored a pilot RWH project and it involves the man-made lake *Tian Hu*, which consists of three reservoirs: the Sun, Moon and Star. The man-made lake serves as storage where stormwater is harvested from a highway and a square.

From heavy rainstorm events in the past, the storage of the Sun reservoir of Tian Hu was filled to its maximum during less than one hour. With experience of this a great volume of the harvested rainwater is wasted during these heavy rainfalls due to an insufficient storage capacity. In this study the main focus is put on calculating the quantity of this flood water generated from heavy rainfall events. The focus is also put on identifying the response time and location of floods in the existing conveyance system of Tian Hu. The numerical computer model SWMM (Storm Water Management Model) has been chosen to analyse the impact of different rainfall events on the conveyance system and the reservoirs of Tian Hu. In order to represent the rainfall pattern of Qingyang, simulations of daily and 3-hours rainfall pattern is applied in SWMM. Two major catchments areas are created in SWMM; the Century Avenue Catchment and the Tian Hu Catchment. The establishment and properties of the catchment areas are determined with different field measurements; infiltration, soil moisture content and field capacity.

The field measurements show expected soil types around Tian Hu which are silt and clay. The measured infiltration rate show similar trend as typical infiltration rates of loess soil. It is necessary to implement more sampling tests and use modern instruments in order to obtain more accurate results for future research.

The simulations of different rain events in SWMM show different impacts on the two catchments of Century Avenue and Tian Hu. The simulations with 3-hours rainfall confirm that the maximum rain intensity the Century Avenue Catchment can handle is below 61 mm/h and the maximum generated runoff is 20 cubic meters per second.

The flow generated from the Century Avenue Catchment carries on down to Tian Hu and provides as the major input to the artificial lake. Simulations of daily rainfall pattern resulted in more floods in the Sun reservoir than the other two (Moon and Star). The floods in the Sun reservoir usually appear during June to September. The excess water simulated and gathered in an imaginary storage proves a volume which is five times larger than the actual lake. This strengthens the evidence that the existing construction of Tian Hu is under dimensioned. The impact of overland flow generated from the surrounding subcatchments is significantly contributing to 20-40 % of the reservoir capacity, thus overland runoff should not be neglected and be included when planning future artificial lakes in Qingyang. Furthermore, the annual evaporation loss is estimated to 1000 mm or 44 000 m^3 in Tian Hu. Finally when simulating with extreme rain scenarios the Tian Hu is reaching maximum water levels after 6 hours.

Keywords: SWMM, Computer simulations, Heavy rainstorms, Stormwater, Man-made lakes, floods, Tian Hu, Xifeng, Gansu, China.

夏季暴雨对人工湖收集雨水的影响
-案例分析：中国甘肃

Shirly Cheung and Martin Schjånberg

2007年6月 瑞典隆德

摘要

人口的迅速增长给中国的农业生产和供水需求带来了巨大的压力。因此许多地区都面临着水资源不足的危机。甘肃是中国最干旱最贫穷的省份之一。它的年降雨时空分布极不均匀，大部分都发生在夏季。为了最大程度地利用雨水资源，雨水收集是必要的途径。甘肃省西峰市利用人造湖-天湖（由日，月，星三个湖组成）集蓄来自高速公路和世纪广场大道的雨洪水，不仅用于城市景观 和灌溉，而且还有控制城市洪水之功效。

天湖建成两年后，西峰发生了50年一遇的暴雨，仅在不到一个小时内，天湖之一的日湖就达到的它的最高限。由于该湖的容量不足，大量的雨水被浪费了。这项研究主要注重计算降雨产生的径流量以及产生的时间和区域。计算机模型SWMM（暴雨管理模型）被用于分析不同降雨对现有人造湖集雨系统的影响。为了探讨庆阳西峰市的降雨特征，模型中采用了日降雨和三小时降雨以及划分了两个主要集流面，世纪大道和天湖。实地测量内容包括集流区域主要测定渗透性，土壤含水量和持水量。

实地测量显示在天湖周围土壤类型是淤泥和粘土。渗透率呈现与黄土渗透率相似的趋势。为了将来获得更精确的结果，更多的样品测试和更先进的仪器是必须的。

在SWMM 模型中，不同的降雨模拟对两个集流面-世纪大道和天湖显示不同的影响。3小时降雨对于世纪大道来说，它能承受的最大降雨强度是每小时61 mm 以下，最大径流是每秒20 m^3.

天湖所集蓄的雨水主要来自世纪大道产生的地面径流。利用日降雨曲线模拟计算的结果是日湖比其它两个湖（月湖和星湖）更易受洪水影响。日湖发生洪水主要在六月至九月。在计算机模拟中，过量的水被蓄存在一个虚拟的的湖中，这个湖的容积是现有人工湖的五倍。这个计算结果表明现有的天湖系统容量过小。天湖周围田野中产生的径流量可以高达天湖系统容量的20-40%，所以当将来庆阳计划建造新的人工湖时，周边地面径流不能忽视。另外，天湖的水面年蒸发损失估算为1000 mm（相当于44 000 m^3）。当用极端降雨情景模拟计算时，现有天湖系统在6 小时后就达到最大水位。

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1 Introduction

1.1 Problem Statement

The economic growth during the last decade in the People's Republic of China has led to great exploitation of natural resources. Due to the increasing population growth and thereby larger consumption per capita a great pressure has been put on agricultural production and water supply. Many regions of China are now facing scarcities of water and arable land. Conservation of the environment and sustainable utilization of natural resources are major issues of concern in present China.

On the other hand, many regions in China are still facing severe water shortage and thus, poverty (Gromark and Larsson, 1999). One of such regions is Gansu province, which is the driest and poorest region in China. The major reason for poverty is water deficiency. This region is situated on the Loess Plateau where loess is representing the silty-soil type and is also known to have a high erosion rate. The annual precipitation in Gansu varies from 300 to 800 mm where as nearly 70 % of the rainfall occurs between July and September (Xifeng Water Authority, 2006). Due to the uneven rainfall pattern it affects the crop productivity as the majority of the cultivated land is dependent on irrigation. However, the uneven distribution and the heavy rainstorms, which usually are concentrated in the three months of summer, do often lead to floods and a great amount of this generated flood water can be used for more crucial purposes such as irrigation. Due to big difference in levels of the topography in the Loess area of Gansu the cost of constructing water conveyance systems is very high and they would be difficult to build. Therefore the most available water source is rainwater. Since precipitation is the main water source for agricultural production, the most suitable approach to deal with the current lack of water issues of the Loess Plateau is to maximize rainfall utilization in the area. Different techniques of rainwater harvesting would be the promising way to improve the standard of agricultural and ecological systems in Gansu.

Rainwater harvesting (RWH), in its broadest sense, is a technology used for collecting and storing rainwater for human use from rooftops, land surfaces or rock catchments using simple techniques such as jars and pots as well as engineered techniques (The Global Development Research Center, 2007). RWH has a long history and its origin seems to stem from the early civilizations of the Middle East and Asia several thousand years ago (Gould and Nissen-Petersen, 2002). Traditionally, RWH has been practised in arid and semi-arid areas, and has provided drinking water, domestic water, water for livestock, water for irrigation and a way to refill ground water tables.

Since the early 1980's, there has been an important trend of growing international collaboration regarding the development and promotion of RWH systems worldwide (Gould and Nissen- Petersen, 2002). There has also been a growing interest of many local government authorities to invest in the implementation of the RWH technology, e.g. China, Thailand, Burma, Japan, Botswana and Kenya (Ibid.)

The situation in mainland China regarding RWH has been improved successfully during the last decade. Since the 1980s, research, demonstration and extension projects on rainwater harvesting have been carried out with very positive results (The Global Development

Research Center, 2007). The regions where RWH projects are being carried out on include 15 provinces, autonomous regions and municipalities in the north, northwest, and southwest China and in the coastal area and islands (Zhu et al., 2004). One of these RWH-projects is called ¨*121 Rainwater Catchment Project*¨ which is sponsored by the provincial government of Gansu in 1995/96. The main purpose of this project was to provide the farmers one rainwater collection field, two water storage tanks and also one piece of crop land. This project has proven successful in supplying water for 1.3 million people in Gansu (The Global Development Research Center, 2007). Up to present day seventeen provinces in China have adopted the rainwater utilization technique, building 5.6 million tanks with a total capacity of 1.8 billion m^3, supplying drinking water for approximately 15 million people and supplemental irrigation for 1.2 million ha of land (Ibid.).

One example where local government has sponsored a RWH project is the man-made lake *Tian Hu* in Xifeng district of Qingyang city in Gansu. The overall focus in this thesis is put on analysing the impact of different rain storms on the existing conveyance system and the reservoirs of Tian Hu. The Tian Hu was completed in 2004 and serves as a storage for storm water collection. This project is regarded as a pilot project for RWH systems in this region, but further follow-up projects are already in operation or being planned. The stored water is currently used for irrigation and recreational purposes. The existing semi-arid and arid conditions of the study area involves high annual evaporation rate which reaches 1500 to 2000 mm. Therefore much water from the reservoirs is evaporating which will have impact on storage capacity and water levels in Tian Hu.
During a large storm event in July 2005, the storage of Sun reservoir of Tian Hu was filled to its maximum during less than one hour. With experience of this a great volume of the harvested rainwater is wasted during these heavy rainfalls due to an insufficient storage capacity. The main focus in the thesis is put on calculating the quantity of this flood water generated from heavy rainfall events. The focus is also put on finding time and location of floods in the existing conveyance system of Tian Hu. The numerical computer model SWMM (Storm Water Management Model) has been chosen to analyse the quantification. SWMM is chosen as it can handle both urban and rural runoff simulations. Compared to HEC-HMS (The Hydrologic Modelling System) details in the model were not possible to simulate in HEC, but were easily done in SWMM. The fact that SWMM is free software made it more convenient to use than other retail rainfall runoff models that exist on the market. The possibility to calculate pollutant and sediment transports and build-ups in SWMM were initially a decisive factor due to the existing issues regarding severe soil erosions in the region. The lack of data made it impossible to perform any sediment and pollution transport calculations. The graphical windows oriented interface of SWMM makes it easy to create catchments and pipe systems. Regarding planning, analysis and design related to storm water runoff, combined sewers, sanitary sewers and other drainage systems, this model is the most popular and is used worldwide (Rossman, 2005).

1.2 Objectives

The overall objectives and related questions to be answered in this study are:

- Analyse the soil characteristics from the field measurements established in the adjacent areas of Tian Hu.

- Overview of rainfall pattern during the years of 2000-2006 in Qingyang and enlighten interesting events. This is helpful to building up a basic hydrological database for the area.

- Analyse the impact of daily rainfall and heavy rainfall on the Century Avenue Catchment: Calculate the maximum capacity the conveyance system can handle before it gets overloaded when simulating with either 3-hours or daily rainfall pattern.

- Analyse the impact of daily rainfall and heavy rainfall events on the Tian Hu Catchment: Locate the time when flooding occurs and calculate the time when the maximum capacity is reached when simulating with either 3-hours or daily rainfall pattern.

- Analyse what impact overland flow has on the storage capacity of Tian Hu.

- Quantify the excess water generated when the maximum storage capacity is reached in Tian Hu Catchment: determine whether or not if the man-made lake is under designed.

2 Study Area and Background

Gansu Province

Gansu province is located in the northwestern part of China (Figure 2.1). It is situated between Qinghai and Inner Mongolia and borders to Mongolia to the north and Xinjiang to the west. The landscape is mountainous in the north with small flat areas in the south. The climate of Gansu is characterized by arid to semi-arid conditions which involve very little annual precipitation. The long-term annual mean temperature is about 5.8 ◦C (Li et al., 2004).The winter is long and cold with little rain and snow. In spring, the temperature rises quickly and changes rapidly. In summer, the temperature is high and the precipitation is usually concentrated. In autumn the temperature drops quickly and frost occur early (Zhou, 1992). With an average of 47 persons per square kilometre, Gansu is one of China's most sparsely populated provinces (Zhou, 1992). It has a population of approximately 25 millions where as the majority still live in rural areas. The area around Lanzhou, which is the provincial capital of Gansu, is the most important cultivation district and the agriculture production includes melon, maize, cotton, linseed oil and wheat (Xifeng Water Authority, 2006). However, most of Gansu's economy is based on mining and extraction of minerals. Gansu has special advantages in tapping 15 kinds of minerals such as nickel, zinc, cobalt, platinum, iridium and copper (Chinese Business World, 2007).

Figure 2.1 Provincial map of China with location of Gansu in the northwestern part (Maps of China, 2007).

The most important passage to Xinjiang province and to Central Asia is the Hexi Corridor. The Hexi Corridor extends as long as 1000 km from Lanzhou in Gansu to YumenGuan, which is located at the border of Gansu and Xinjiang. In the plain of the corridor are isolated deformed hills and low mountains which divide the corridor into the Wuwei Plan, the Minqin Plan, the Zhangye Plan, the Jiuquan Plan, and the Yumen-Dunhuang Plan. Because the corridor is narrow and long, the natural scenery in the eastern and western ends differs remarkably (Zhou, 1992). East of Zhangye, there is a layer of loess which becomes thicker from west to east; west if Zhangye, the Gobi area becomes increasingly larger. On the alluvial fans of rivers, springs form oases where there is plenty of water and grass, a dense population and a developed agriculture (Ibid.).

Loess Plateau

The study site in this thesis is located on the Loess Plateau. The Loess Plateau is covering a surface area of 640 000 km^2 and goes through provinces of Gansu, Shaanxi, Ningxia, Shanxi and Ningxia Hui Autonomous Region. This semiarid region in northwestern part of China suffers from severe soil erosions mainly caused by water but also to some extent by wind. This region is a typical and a central area of rain fed farming. Loess, as it is pronounced 'lose', is a type of yellow soft soil which has a silt-like nature and it is known to be one of the most erosion-prone soils in the world. With an annual soil loss of 3.720 ton / km^2, this is 14 times that of the Yangzi River Region (China), 38 times that of the Mississippi River Region (USA) and 49 times that of the Nile River (Egypt) (Li et al., 2002).

The surface and groundwater resources of the Loess Plateau Region are considered either as unavailable or too saline thus not suitable for human consumption and irrigation (Li et al., 2002). Rain fed cropland occupies about 80 % of total cultivated land (Ibid.). In ancient times, the Loess Plateau was initially highly fertile and easy to farm, which contributed to the development of early Chinese civilization around the Loess Plateau. But due to the rapidly growing population the last decades, there has been a great pressure on productive soil resources, forcing the farmers to transfer grassland into crop land. Consequently this has also led to an increase in severe soil erosions and a reduction in soil fertility, which are the major threats to the sustainability of the agro ecosystem in the region (Li et al., 2002).

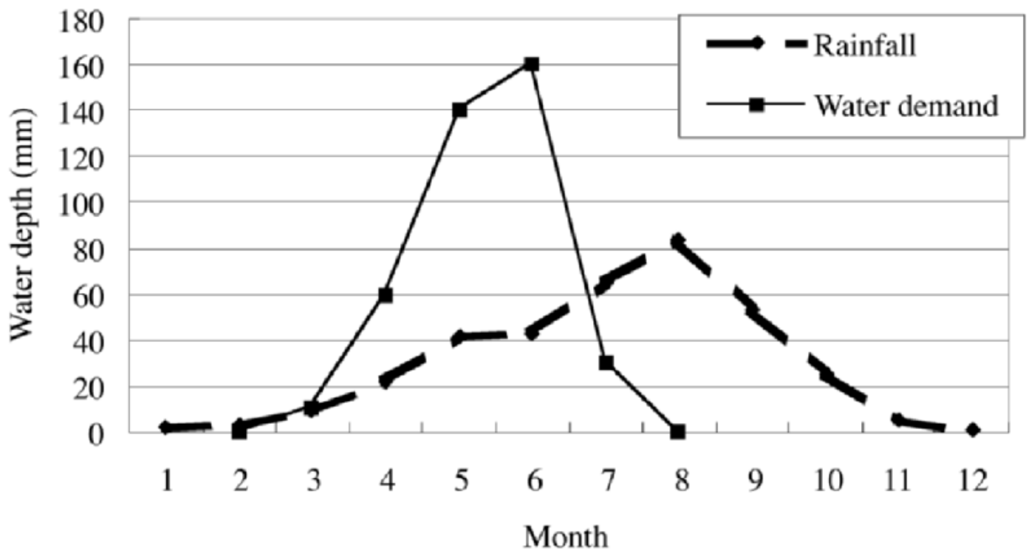


Figure 2.2 The annual distribution of rainfall and crop water demand (Zhu, 2003).

The location of the Loess Plateau belongs to variable zone and continental climate. The annual average precipitation is 545 mm where as the potential evaporation reaches 1500-2000 mm. The rainfall is very uneven distributed throughout the year. The amount of rainfall in July-September represents 70 % of the total annual rainfall. The period of when the crops need the water at the most is between May and early June and the rainfall during this time does only represent 19-24 % of annual precipitation (Zhu, 2003). The relationship between the annual rainfall distribution and crop water demand can be visualized in Figure 2.2. During the last fifty years Gansu has been afflicted by droughts close to forty times. It can be seen that the droughts are more related to the rainfall distribution rather than to the annual amount of rain. For harvesting crops the time of the first occurring rainfall is very important. In many cases, a late arrival of the first rainfall means a severe drought will occur (Zhu, 2003). This means it is immensely important to find a way to manage the rain water and to make sure the water is available even when crops need it the most.

Xifeng district of Qingyang City

Qingyang city is located approximately 300 km in the eastern direction from Lanzhou (Figure 2.3). Qingyang is one of many cities in Gansu that has experienced a quick transition from a small quiet town to intensive urbanisation during the last decades. The main factor that contributes to the restraining of rapid economic development is the delay of the city's infrastructure. Xifeng is the district at the centre of Qingyang, and it is very young and has only a twenty years history. Furthermore, it is the cultural and political centre of Qingyang. Up to present day the city has a population of 300 000 inhabitants whereas one third lives in Xifeng district (Figure 2.4). A way of improving the peoples' living standard in the city is to enlarge the area and to strengthen the infrastructure system. In 2002, the government of Qingyang city decided to construct a new area which is located at the southern part of the city and its main purpose is to support the economic development.

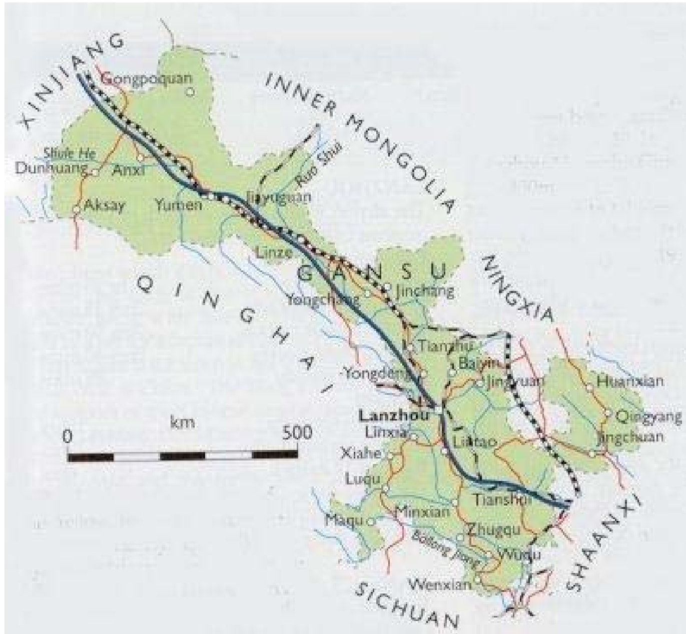


Figure 2.3 Location of Qingyang city of Gansu Province (Paulnoll, 2007).

As mentioned in the previous section the rain is often very intense during the three months of summer and it generates surface runoff and becomes flood water. Another factor that contributes to flood is, as the city is getting larger, impermeable land-surfaces are constantly increasing and the existing drainage pipes can not bear the water load from the storms. Hence causes great soil erosion and much water is getting wasted.

Figure 2.4 The city center of the Xifeng district of Qingyang (Cheung, 2006).

Since the development of enhancing the infrastructure, the city is facing questions such as how to drain and to utilise rainfall and flood water in an efficient way. The cost of constructing new drainage systems for the new area and connect it to the old drainage system would cost too much (Xifeng Water Authority, 2006). Furthermore the water table is declining every year in Xifeng and this is due to over withdrawal of groundwater. This threatens the sustainable utilization of groundwater in the future. Deterioration of water quality and water availability has been consequences of human activities and land-use during the years. Water shortages, flood hazards and water pollution have become more serious in the process of urbanisation (Shi et al., 2006). The existing circumstances forced the government to build a man-made lake which would fight against the drought by rainfall collection.

Rainwater Harvesting

Rainwater harvesting (RWH) is defined as the collection of rainwater and it can be stored for direct use or can be recharged into the groundwater. The main purposes of implementing RWH-systems are collecting rainwater for e.g. domestic use, livestock, plant production or flood control.

A RWH-system consists of three basic components (Gould and Nissen- Petersen, 2002):

- A catchment surface where the rainwater runoff is collected
- A delivery system for transporting the water from the catchment to the storage reservoir
- A storage reservoir where the rainwater is stored until required

The catchment surfaces can vary from simple types within a household to bigger systems where a large catchment area contributes to a reservoir from which water is either gravitated or pumped. The categorisation of RWH systems depend on factors like the size and nature of the catchment areas and whether the systems are in urban or rural settings (The Global Development Research Center, 2007). The only key requirements for catchment surfaces are that they have to be impermeable and do not seriously contaminate the water (Gould and Nissen- Petersen, 2002). In order to convey the rainwater from the catchments a delivery system is necessary. For roaded catchments or other large ground catchments, a network of drains and channels is required to direct runoff quickly and efficiently via an inlet filter for removing coarse debris (Gould and Nissen- Petersen, 2002). Rainwater storage reservoirs can be subdivided into three categories: surface or above-ground tanks, sub-surface or underground tanks, and dammed reservoirs for larger catchments systems (Gould and Nissen-Petersen, 2002).

This thesis work is focused on collecting rainwater from local catchments and storing the runoff in a man-made lake. A more detailed description regarding the artificial lake is explained in the next section.

Tian Hu, the Man-made Lake

As mentioned in the previous section the unevenly distributed rainfall pattern forced the government to focus on how the city could efficiently use the rainwater during the period of water shortages. The construction of the man-made lake Tian Hu was the answer to the problems. The main purposes of constructing Tian Hu were to collect rain water for irrigation, to prevent flooding and for recreation (see Figure 2.5).

Figure 2.5 An example of recreational activity at Tian Hu (Schjånberg, 2006).

In May 2004, the Tian Hu was completed and this was two years after the government of Qingyang had decided to build up a new city area in the south (Xifeng Water Authority, 2006). The rain water is collected from the Century Highway and the Century Square in Xifeng. The total impermeable land surface area of these two parts is 1.22 km^2. The storm water gathers in circular drainage pipes with 2.2 metres in diameters below the ground and flows with the force of gravity down to Tian Hu, which is also located at the southern part of Xifeng district. The total capacity of Tian Hu is estimated to 130 000 m^3 (Xifeng Water Authority, 2006). The total area for this man-made lake project is estimated to 110 000 m^2, whereas the water surface area is 44 000 m^2. Tian Hu consists of three reservoirs, named Sun, Moon and Star. These three lakes are connected according to Figure 2.6.

Figure 2.6 Tian Hu with the three reservoirs of the Sun, Moon and Star.
(Xifeng Water Authority, 2006).

Initially, the collected stormwater flows directly into the Sun through a great inlet, see Figure 2.7. As soon as the storage of the Sun is full the water will continue to flow into the Moon and finally to the Star. There is a gate (Figure 2.8), constructed at the rear end of Lake Star and its purpose is to release some amount of water in cases of overloading. The excess water from the star will flow through a canal to a sand filter. The sand filter is constructed to reduce flow speed to prevent soil erosion in adjacent areas. After the sand filter the water will settle in the soil.

Figure 2.7 Lake Sun of Tian Hu with the inlet from the Century Highway can be seen on the left (Schjånberg, 2006).

Figure 2.8 The gate at the rear end of the Star (Cheung, 2006).

3 Methodology

3.1 Background

The current study consists of two parts, field observations and numerical modelling using SWMM. The field data collected and measured at Tian Hu, Xifeng, are infiltration rates, soil water content and field capacity. These three parameters are necessary input data when using some simulation scenarios functions of SWMM. Infiltration rates are needed for calculations of runoff while soil water and field capacity are needed when establishing a proper model of the catchment. Monthly accumulated precipitation and evaporation were provided by the local metrological stations of Qingyang. Some data on 3-hours rainfall averages were also gained. Furthermore, all geometric information regarding the watershed of Tian Hu was provided by Xifeng Water Authority.

3.2 Field Measurements

3.2.1 TDR

Time Domain Reflectometry (TDR) is an instrument that can be used to determine soil water content and electrical conductivity. The TDR can be applied in a wide range of applications. The most common use is to detect errors in electrical and telecommunication lines (Möller, 2001). The usage of TDR has also become popular within the data industry, where precision is of great importance, as it can pinpoint very small fluctuations in circuit boards (Pacheco et al., 2005). The TDR can be used when performing geotechnical evaluations and determinations of geophysical parameters. The common parameters that are measured with TDR are: level of groundwater, soil moisture, leakage and pollution. The TDR have many points of appliance and a few examples of this are: to detect movements in soil and rock, measurements of settings (Möller, 2001), determining frost depths and slope stabilities (TDR 2001). The soil properties measured by the TDR are used when studying different hydrological processes such as when precipitation infiltrates the soil and later on percolates down to the saturated zone and the water table. The main advantages of TDR regarding the soil water content is that it offers excellent accuracy and precision, thus need very little soil-calibration (WET Sensor User’s Manual, 2007).

The *WET Sensor* (Figure 3.1) is an instrument which is based on the principles of TDR and has been used in this field study in Xifeng, Gansu province of China. This multi-parameter sensor is in use for soils and composts (WET Sensor User’s Manual, 2007). It measures the dielectric properties of the soil and calculates Water content, Electrical conductivity and Temperature (WET). The WET Sensor calculates the water content into a range of 0-100 % and the calculation of the pore water conductivity (EC_p), which is the conductivity of the water within the pores, is based on a formula that minimises the effects of probe contact and soil moisture on the readings (WET Sensor User’s Manual, 2007). The WET Sensor is mainly constructed to be used with HH2 Moisture Meter and it is a device for storing and reading the measured results.

Figure 3.1 The W.E.T Sensor Kit (WET Sensor User's Manual, 2007).

When measuring with the WET Sensor the basic principles are, when inserting the instrument into the soil, a 20 MHz signal is generated to the central rod and produces a small electromagnetic field within the soil. By measuring the speed of the wavelength from the electromagnetic field and using this figure together with equations for wavelength propagation velocity the dielectric constant can be derived directly from travel time (Persson, 1999; TDR, 2001). The *dielectric properties* (ε) are determined from the water content, electrical conductivity and the soil composition around the rods. Dielectric properties describe materials' insulating properties.

Implementation

There are many advantages when using the WET Sensor. It provides rapid measurements after a few seconds and the result of the three parameters can be displayed on the HH2 meter. The rods of the Sensor are also easy to insert into the soil and the whole instrument does have a lightweight design, thus very convenient to carry it out in the fields. A drawback with the sensor is that it only penetrates the earth 6.5 cm. To obtain readings deeper into the earth a shovel and man power has to be used. To get a good picture of how the soil moisture is distributed around Tian Hu, some specific and characteristic spots are located for measurements. At each spot readings from the HH2 meter are taken at the soil surface and at some locations a sample is made at every 20 cm down to a depth of 50 cm. Between each main sample point further measurements are taken at the soil surface to get a better overall view of the soil moisture.

3.2.2 WET Sensor Calibration

The water quantity measured by the WET Sensor is dependent on several factors especially the soil composition. To be certain that the results given by the sensor is accurate the water quantity of the soil is determined in the laboratory. If the result from the WET Sensor coincides with the laboratory tests the sensor is well calibrated. Otherwise it has to be recalibrated the data from the laboratory test. The calibrated values are evaluated further on in the results and discussion section.

When determining the water quantity in a soil sample the weight, the volume (V) and the density of the soil should be known. With a known soil density ρ_s the weight (M) of the soil in the sample can be determined according to equation 1.

$$\rho = \frac{M}{V} \tag{1}$$

By subtracting the soil weight from the total weight of the sample the amount of water is known. The volume of the water can easily be derived from the weight and by dividing the water volume with the total volume of the sample the volume percentage water of the soil can be determined. In most cases the density is unknown and several tests have to be made.

Table 3.1 Parameters b_0 and b_1 for soil calibrations of WET Sensor (WET Sensor User's Manual, 2007).

Calibration	b_0	b_1
Mineral	1.8	10.1
Organic	1.4	8.4
Sand	1.4	8.4
Clay	2.0	11.0

The water quantity in a soil is calculated by the WET Sensor with equation 2. The calibration constants b_0 and b_1 are changed depending on the type of soil that is analysed (see Table 3.1).

$$\theta = (\sqrt{\varepsilon'} - b_0) / b_1 \tag{2}$$

where:

θ = water content (Vol-%)
ε' = dielectric properties
b_0 = calibration constant
b_1 = calibration constant

Implementation

Initially a soil sample of known volume is taken and weighted. The water quantity and dielectric properties are measured with the WET Sensor, and then the sample is put into an oven of 105 degrees Celsius. At even intervals the sample is taken out and weighted and a new measurement is made by the sensor. At each new measurement of the sample an amount of water will evaporate and this will be noted as a weight reduction of the sample. To determine the calibration constants b_0 and b_1 the refractive index, $\sqrt{\varepsilon'}$, is plotted against the water content, θ, and a trend line will be fitted to the graph. The calibration constants will be the offset and the slope of that trend line (WET Sensor User's Manual, 2007).

If the equipment for calibration analyses is not available a simpler test can be performed. Drying a soil-sample of all available water the difference in start and end weight is the total amount of water in the sample. The value from the drying can be directly compared with the initial reading from the Moisture meter and should, if the variables are set right, show the same soil moisture value. An easy way to perform a soil sample drying where no oven or other machinery is available is to use high percentage alcohol. The spirits are poured into the sample and are ignited. When the spirits burn heat is being developed and thus the water will evaporate, see Figure 3.2 This method is rude and will always leave some water left, thus the method will give slightly lower soil moisture values than the Wet Sensor.

Figure 3.2 Drying up the soil-samples with conventional method (Cheung, 2006).

3.2.3 Infiltration test

Infiltration is the phenomena of which water penetrates into a soil or other material of porous characteristics. When doing soil and hydrological analysis the infiltration capacity of a soil is of interest to be able to determine the ratios if water will flow as overland flow, through flow or as groundwater flow. According to the Horton hypothesis (Ward and Robinson, 2000) there will be no overland flow if the intensity of the rain is lower than the infiltration capacity, hence all rainwater will be stored in the soil or move as through flow or groundwater flow. The hypothesis also describe that water will run on top of the soil surface if the intensity of the rain is larger than the infiltration capacity.

Implementation

To determine the infiltration rate of the soils at Tian Hu simple tests are performed. A plastic pipe is used to limit the test to a limited body of soil. The pipe is of known volume and radius (Figure 3.3) and is inserted into the soil with as little disturbance as possible to limit cracks where the water can freely flow. With the pipe inserted to the soil water will only infiltrate down and not to the sides of the specified volume. Water is then applied to the top of the soil and the interval for the water quantity to sink into the soil is timed. The result of the test will be given as a volume of water percolated per time unit.

Figure 3.3 Pipe for infiltration test (Cheung, 2006).

Four points of infiltration tests are set up and at each point an initial measurement of the water level is measured (See Figure 3.4). Initially, after adding water into the pipe, all water is absorbed by the soil almost at once, hence indicates a high infiltration rate. The high infiltration rates could result in drained test tubes before any measurements could be performed. To solve the problem a greater amount of water is added. The higher amount of water added would in turn result in higher infiltration rates as the water pressure will be higher. Three measurements were taken from every test site with approximately 20 minutes intervals. The results are presented in section 4.2.1.

Figure 3.4 Measuring water level in the infiltration pipe (Cheung, 2006).

Furthermore the infiltration tests are conducted during one day and the location for the different measurements was chosen to represent the different types of soils and usages of soils around Tian Hu e.g. agricultural, vegetation and non-cultivated land. The test is to give an overall understanding of the soil properties. The weather and precipitation during this day are under no circumstances representative for a longer period. The instruments and the way to conduct the measurements should be looked upon as possible guidelines when determining the infiltration rates in SWMM. The results are evaluated further on in the results section of this report. It is important to mention that the soil (loess) around Tian Hu have a very special characteristic. If the soil is dry enough a crust can form on the dry soil and subsequently infiltration tends to be small and favouring runoff. Overland flows might occur in relative dry periods with smaller rainstorms even though the soil has neither reached the infiltration capacity nor the storage capacity.

3.2.4 Field Capacity

Field capacity is defined as the amount of water held in soil after external water has drained away and the rate of downward seepage has immensely decreased. This parameter is of interest when creating aquifer properties in SWMM but the lack of groundwater data make it difficult to use. The test is performed due to the purpose of general knowledge.

Implementation

The test for field capacity is made at a point that could resemble the whole catchment and would give a fair test result. Because of the rudimentary method and lack of effective equipment only one measurement is carried out. The lack of effective instruments makes it unreasonable to take several tests and the usage is discussable.

Figure 3.5 A soil sample on top of a filter measuring field capacity (Schjånberg, 2006).

An undisturbed soil sample is put on top of a filter, see Figure 3.5. The net will prevent the soil in the sample-box to fall into the beaker below. External water is added on top until the sample is completely saturated. When the sample has finished draining the weight of the sample is measured. According to the alternative method mentioned in section 3.2.2 the soil sample was dried and the weight was measured once again. The result show how much water the soil can hold against gravity.

3.2.5 Sources of Error

The data obtained from field measurements are quite hard to analyse and due to lack in reference points it is not always possible to draw any conclusions. In most cases values that were slightly modified from literatures were used in the model and this in order to better fit the measured field values. The lack of common measurement points between the days of fieldwork make the process of characterization difficult and in many cases literature studies have to be complemented when contradicting values show on strange samples. Because of the rude instruments used in all field measurements, except soil moisture samples, the values should be accepted but maintaining reservations about its accuracy. However, the values obtained should be regarded as point of direction and to be used together with literature.

3.3 Catchment Modelling using SWMM

The Storm Water Management Model (SWMM) is a dynamic rainfall-runoff simulation model used primarily for urban areas. The model can be used either for single event or long-term (continuous) simulation of runoff quantity or quality (Rossman, 2005). The flow routing of SWMM transports runoff from subcatchment areas to conveyance system (e.g. pipes, channels, storages, pumps). It is then possible for the model to calculate the quantity and quality of the generated runoff within each subcatchment.

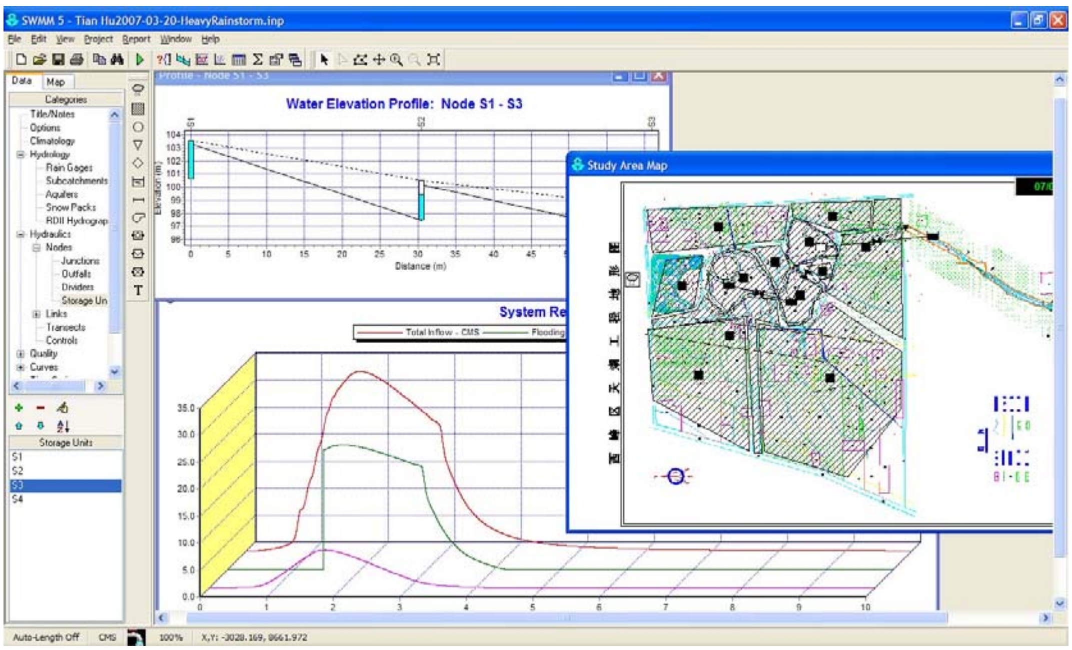


Figure 3.6 The SWMM interface with the study area map, elevation profile and system result graph.

Early utilization of runoff models e.g. SWMM, usually faced three drawbacks: time consuming input of data, limited graphical overview, and uncertain calibration processes (Liong et al., 1991). SWMM was initially developed in 1971 and has been upgraded several times since then. Regarding planning, analysis and design related to storm water runoff, combined sewers, sanitary sewers and other drainage systems, this model is the most popular and is used worldwide (Rossman, 2005). The present version of SWMM that is being used in this thesis is version 5 and is produced by the United States Environmental Protection Agency (USEPA). The model is a windows version with graphic user interface, see Figure 3.6. The conditions of the catchment can be represented easily in the model by using available subcatchment drawings tools and related components e.g. weirs, orifices, storage units and dividers. The input parameters can also easily be changed by double-clicking the objects, thus different scenarios can be evaluated efficiently.

3.3.1 Catchment Processes in SWMM

Runoff Simulation

Each subcatchment is considered as a nonlinear reservoir with a single inflow, which is precipitation and losses from the 'reservoir' are infiltration, evaporation, and surface runoff (Rossman, 2005). Until the depression storage and infiltration is exceeded by water depth, no runoff will be generated from the subcatchment. The alternatives provided in SWMM regarding the infiltration into soil are Horton's Equation, Green and Ampt Equation, or NRCS-Curve Number method. When calculating continuous simulations the evaporation rates are used in average monthly values. The runoff hydrograph generated in SWMM are based on the continuity and the Manning's equation, respectively. The continuity equation represents the change of volume or depth on the subcatchment for a time interval, where as the second equation, Manning's, calculates the rate of surface runoff as a function of depth of flow above the maximum depression storage depth (Rossman, 2005).

Flow Routing

After having precipitation inserted as input into the model and when the conveyance system is delineated the model continues out with the flow routing part. The whole drainage system is consisting of conduits and junctions. The inflows can either be provided by runoff as simulated from the subcatchments or defined by the user. The flow routing is governed by the continuity equation and the momentum equation, respectively. SWMM offers either kinematic wave routing or dynamic wave routing. In kinematic routing, downstream conduits have no effect on the upstream conduits, and the flow is allowed to propagate only in downstream direction (Rossman, 2005). The dynamic routing includes that downstream can affect upstream conditions.

3.3.2 Input Parameters in SWMM

In order to simulate runoff from the catchment the model needs different input parameters and the most essential are precipitation and climatology data, different properties for the hydrologic components and run time controls. A general description of the inputs is presented below and a more detailed table of the inputs can be observed in appendix A. It is also possible to categorize the input in either measured or inferred parameters. Measured parameters are parameters which are measured physically, and whereas inferred are parameters which are determined from the application of a model (Choi and Ball, 2002). The measured parameters in this study are e.g. the geometry of the system, field measurements, and precipitation. The inferred parameters correlate e.g. imperviousness of the subcatchment and roughness of pipes.

Rainfall and Climatology Data

Rainfall is the crucial input in SWMM and in this study the rainfall data were provided by the Water Authority of Xifeng district. As the model accepts external data files, the rainfall data from Xifeng could easily be used. Even user-specified rainfall could be used if needed. The format of the rainfall can be of intensity (mm/h), cumulative (mm), or volume. Climatology

data are used in continuous simulations (long-term) and these include daily average temperature, evaporation and wind speed. Even external files of climatology parameters can be inserted into the model.

Parameters for Hydrologic Components

Hydrologic components involve the different elements within the watershed such as: subcatchments, pipes, junctions, orifices, weirs etc. There are available drawings in the model which represent these hydrologic components. The properties in each hydrologic component are defined by giving suitable geometric information.

Run Time Controls

The time step in SWMM is including the duration for a simulation and it can vary from 1 to 60 seconds. A small time step yields in more detailed hydrographs but causes longer simulations. Conversely with a large time steps means less run time but might fail to deliver accurate hydrographs.

3.4 Establishing the Model

The catchment areas in SWMM are divided in two parts; the *Century Avenue Catchment* and the *Tian Hu Catchment*. These two watersheds are described thoroughly in the following sections. The design of the catchment areas is easier done with help of geographic information e.g. blueprints and Geographic Information System (GIS). With GIS, a large amount of cartographic can be applied and analysed (DeBarry and Carrington, 1990), but the total area of the current study can be handled easily with only blueprints.

3.4.1 The Century Avenue Catchment

The model of the Century Avenue Catchment is created for two purposes: the first and main purpose is to create an outflow that will be applied later on to the Tian Hu Catchment. The second purpose is to see what effects different rainstorms have on the conveyance system and to find maximum capacity and limitations in order to improve future projects.

Figure 3.7 (a) The Century Highway of Xifeng. (b) The Century Square of Xifeng. (Cheung, 2006)

The Century Avenue Catchment consists of one extended *highway*, see Figure 3.7(a), and one large *square*, see Figure 3.7 (b). Because of the length of the highway, 4400 meters, it is divided into 11 smaller subcatchments with an area of 2 ha each (Figure 3.8). By dividing the highway water will be accumulated in different spots, and subsequently the flow will be more levelled out and will represent the existing highway in a better way than if only one large subcatchment should be represented. The 11 subcatchments (Sub3 - Sub15 in Figure 3.8) are connected to each other with conduits (C1-C11 in Figure 3.8). All subcatchments, junctions (J1-J11 in Figure 3.8) and conduits comprise the same properties.

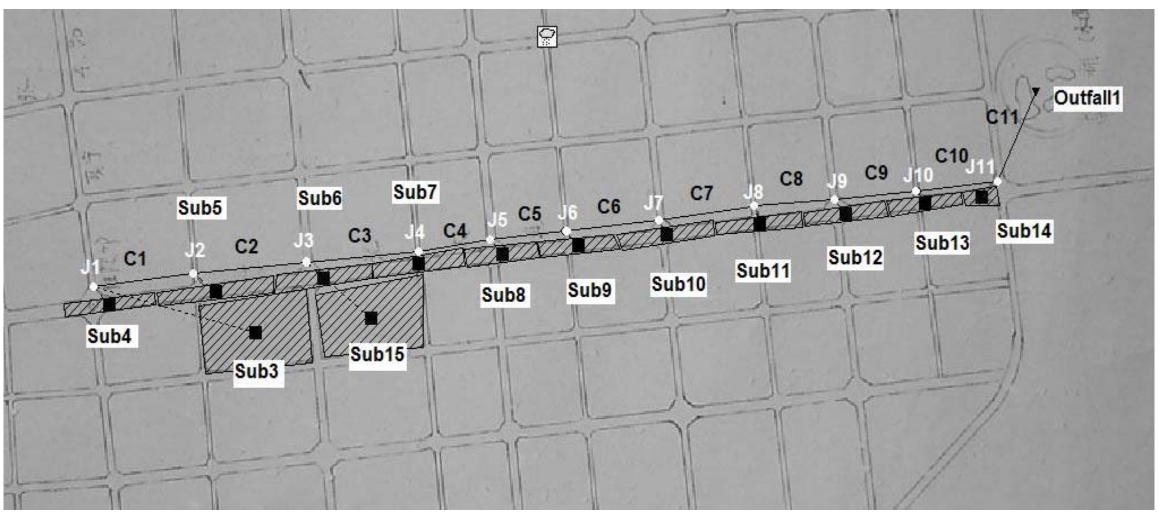


Figure 3.8 Delineation of the Century Avenue Catchment as represented in SWMM model.

The Century Square is only divided into two parts (Sub3 and Sub 15 in Figure 3.8). What is worth mentioning is that the total area of the squares is 100 ha compared to the highways total area of 22 ha. The square will deliver its water in two different junctions for the reason of levelling out the flows. Note that the area of the highway and the square are not according to scale in Figure 3.8.

As the subcatchments are mostly composed of asphalt and large stone slabs the imperviousness of the catchments is close to 100 % and only due to smaller cracks and joints the variable in SWMM were set slightly lower than 100 %. The topography in the area is in general considered as flat and the slope is estimated to 1 %. Elevation data on the highway was given by Xifeng Water Authority and along the length of 4400 meters the elevation will decrease from 1416 m.a.s.l. in the north to 1376 m.a.s.l. in the south.

Because of limited knowledge about the catchments and how they react in the event of rainfalls, it was assumed that water will flow on to the impervious areas. This is partially a false assumption as water will also leave the system when curbs are overflowing and subsequently the stormwater can flow into neighbouring areas by crossing roads. It is also quite possible that water from adjacent areas will flow into the catchment. The rainwater collected from the impermeable surfaces runs through the junctions and down into circular drainage pipes with 2.2 meters in diameters and flows with the force of gravity down to Tian Hu, which is located at the southern part of Xifeng. Tian Hu is located at Outfall 1 in Figure 3.8.

Sources of Error

Due to lack of information on the design of the square and highway, many assumptions had to be made and it is not sure that all assumptions always are the most accurate ones. It is possible that the Century Square has more connection points to the conveyance system and maybe it would have been better to create several smaller catchments with more connection points. Likewise to make Century Highway to resemble the real situation additional subcatchments should have been created for every street gutter on the highway, approximately one junction at every 25 meters.

3.4.2 The Tian Hu Catchment

The model representing Tian Hu is far more difficult to create than the Century Avenue Catchment. Tian Hu has wider ranges of pervious areas and to attain realistic properties for these, the data from the field measurements have to be complemented with literature studies. The Tian Hu Catchment was determined with the help of blueprints of the area and regular visits. The regular study visits to the catchment made it clear that it would be the easiest way to limit the catchment size after the blueprints available of Tian Hu and its surroundings.

Tian Hu is, as mentioned in the introduction, composed by three lakes; the Sun, Moon and Star. The lakes are connected by simple weirs that will transport water between the lakes when they reach certain levels of 2.7 meters for Sun and Moon and 2 meters for Star. The lakes are created in SWMM by placing three storage units and giving them approximately the same volume and area as the actual lakes. The connections are created by placing weirs between each storage unit and giving them the same physical properties as the actual weirs (Figure 3.9). The only difference regarding the length of the weirs in SWMM is that it can not be altered and comes with a fixed length of 30 meters.

Figure 3.9 The appearance of a weir in Tian Hu (Cheung, 2006).

The field measurements on infiltration, soil moisture and also by using visual approximation the surrounding soil was categorized to fit and create the subcatchments around Tian Hu. Three subcatchments were added just on top of the three storage units to represent the lakes own water intake and these subcatchments were given some extreme variables to best represent the actual happening as water is going directly into the storage.

The subcatchments are divided according to Figure 3.10 and the connection between the storage units (S1-S3) and the subcatchments (Sub15- Sub22) are:

- S1 collects runoff from Sub15, Sub17 and Sub22
- S2 collects runoff from Sub19
- S3 collects runoff from Sub20

The two bigger subcatchments in the lower part of the map, Sub15 and Sub21 in Figure 3.10, are generalised as the available map provided when doing the field measurements did only show one third of the area. The rest two thirds of the area has thus no data points and same characteristics as the closest subcatchment are given. Where values contradict each other, characterisation by visual observation has been applied. As the area around Tian Hu is located on the Loess Plateau, the soil type is mainly of loess which has silt-like characteristics. The soil around the man-made lake is primarily used for farming purposes and there are great fields of corn and wheat. The imperviousness, area and infiltration rate for each subcatchment are presented in Table 3.2.

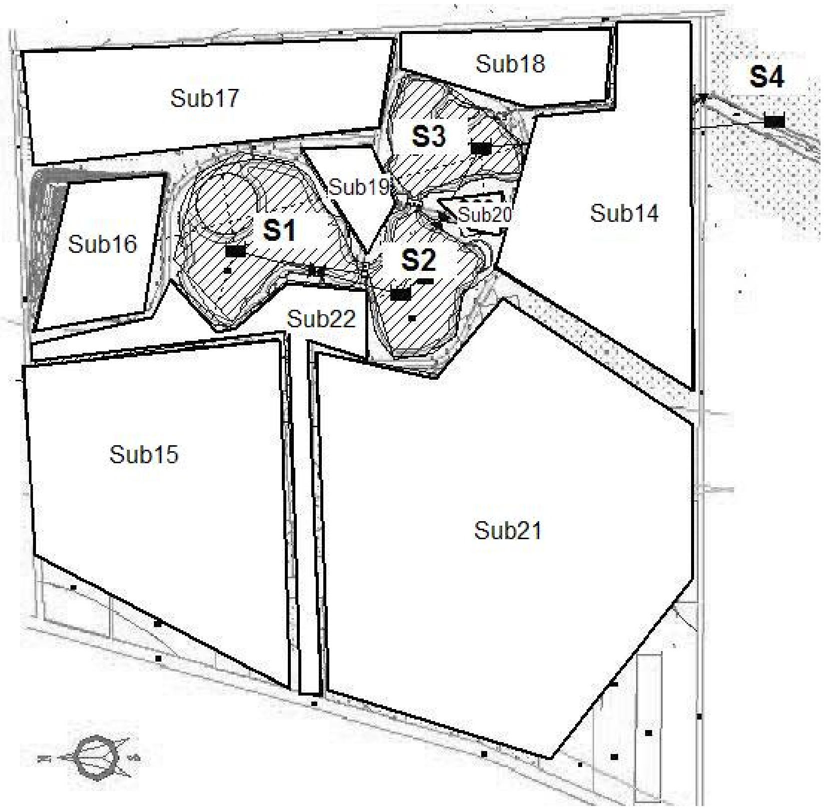


Figure 3.10 Delineation of the Tian Hu Catchment as represented in SWMM model.

Table 3.2 Estimation of area, impermeability and infiltration rate of subcatchment 15, 17, 19, 20 and 22.

Subcatchment	Area (m^2)	Impermeability (%)	Infiltration Rate (mm/h)
Sub15	84000	5	5-60
Sub17	42000	15	5-30
Sub19	7000	3	10-20
Sub20	2000	2	10-20
Sub22	14000	75	0.5-3

The reason for excluding subcatchment 16 (Sub 16 in Figure 3.10) is due to the available drainage system which gathers the runoff away from the lakes. The miscellaneous subcatchments (sub14, 18 and 21) are excluded from the simulations due to the topography which would transport the overland flow away from the lakes.

Sources of Error

The estimation of Tian Hu Catchment is quite generalized. Due to lack of information regarding surface area, flow path and soil type the characterization of each subcatchment should be accepted but maintaining reservations about its accuracy. The sources of error regarding the soil properties are discussed further in section 3.2.5. Some misunderstandings with the interpreter might have affected the understanding of the situation and the area.

3.5 Simulation Scenarios

The simulation scenarios in SWMM that are of interest in this thesis are using the two major inputs of:

- Daily Rainfall 2000-2006
- 3-hours Rainfall

The simulations are divided in two parts. The *first* simulation includes the Century Avenue Catchment. The major input parameter here is the rainfall and the output is the runoff generated from the rain which flows through the system. The *second* simulation involves the Tian Hu Catchment. The output runoff from the first simulation is applied as the major input parameter together with precipitation data. The importance of choosing the two rain events above is to compare the lakes capacity respond to either ‘normal’ daily rainfalls or ‘extreme’ rainfall.

The precipitation data available ranges from 1981 to September 2006 but the years that have been studied closer are from 2000 to 2006. This is due to the fact that the area has experienced heavier rainfall events during these years. As the study focuses mostly on extreme rainfalls the chosen time span implements both years with high and low precipitation thus comparisons can be made.

The annual rain distribution over the years 2000 to 2006 is fairly even ranging between 490 to 600 mm as can be seen in Figure 3.11. The exception to this is the year 2003 which has much higher precipitation than the other years; also 2006 might prove an exception as rainfall data only dates to September.

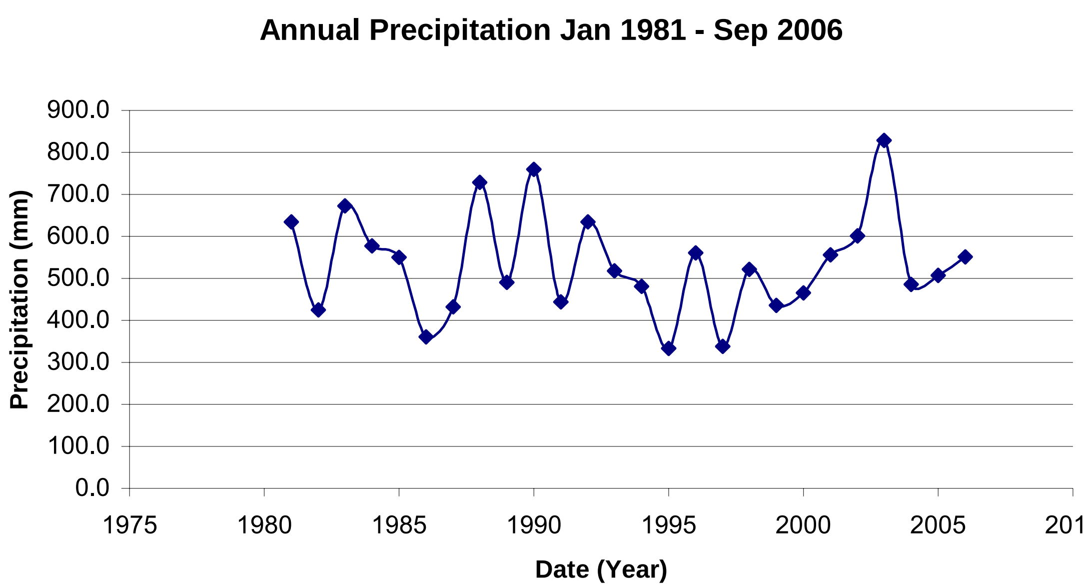


Figure 3.11 Measured annual precipitation for Qingyang, from January 1981 to September 2006.

When analysing annual precipitation it is hard to see any patterns but when looking at monthly precipitation it can be seen that large amount of the annual rainfall is concentrated to summer period see Figure 3.12. The result of the higher concentration of precipitation in the summer will make the area of Qingyang more exposed to drought in the winter and to heavy rainstorms and floods in the summer. From the Figure 3.12 it is also possible to locate some special events like the years 2001, 2003 and 2006 where some months have noticeable high precipitation.

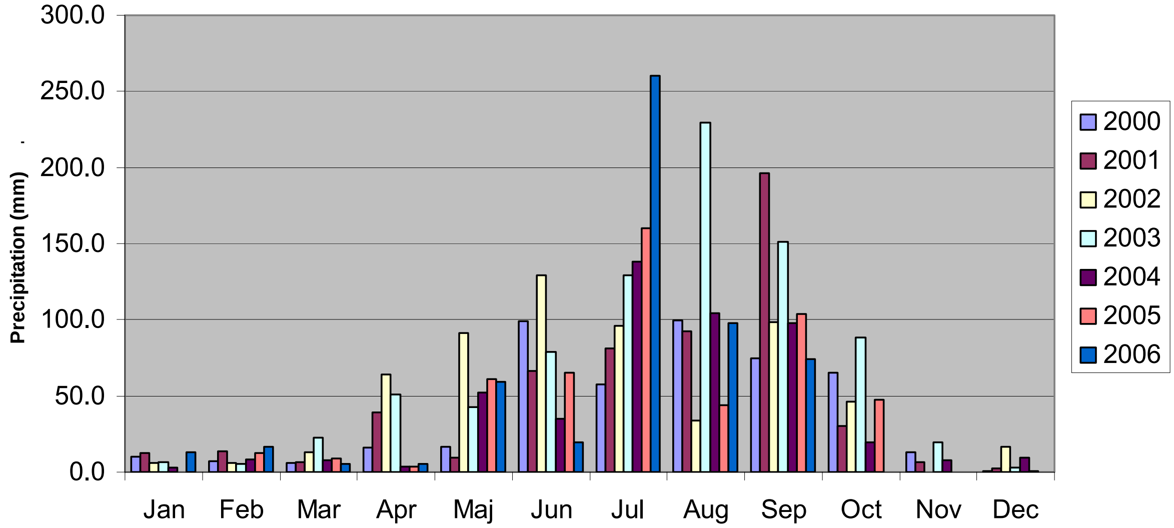


Figure 3.12 Monthly precipitations over Qingyang from January 2000 to September 2006.

With only monthly accumulated rainfall data available the modelled pipes and flow systems would lead to overloading and cause floods, and subsequently leading to biased analyses and results in SWMM. In order to obtain more accurate results daily rainfall data pattern is necessary throughout the months. To obtain daily distribution pattern the Giovanni from NASA is of interest. Giovanni is a web-based application which provides precipitation data of annual rainfall down to 3-hours rainstorms from all around the world and the resolution that covers the areas are down to 28x28 kilometres. One of Giovanni's interfaces that are being used is called *Agricultural Online Visualization and Analysis System* (AOVAS). Daily rainfall data from Giovanni is used and fitted to the monthly rainfall of Qingyang. The daily rain pattern received can be observed in Figure 3.13. In order to transform the monthly accumulated data (MD) to daily pattern, a constant is derived by summing up the daily rainfall data (SDD) from AOVAS for each month and then a constant *c* is derived from equation 3:

$$c = \frac{MD}{SDD} \qquad (3)$$

where:

MD = monthly data from Qingyang
SDD = summarized daily data from AOVAS
c = constant.

The constant is then being multiplied with the daily precipitation data to receive the same monthly values as for the Qingyang area.

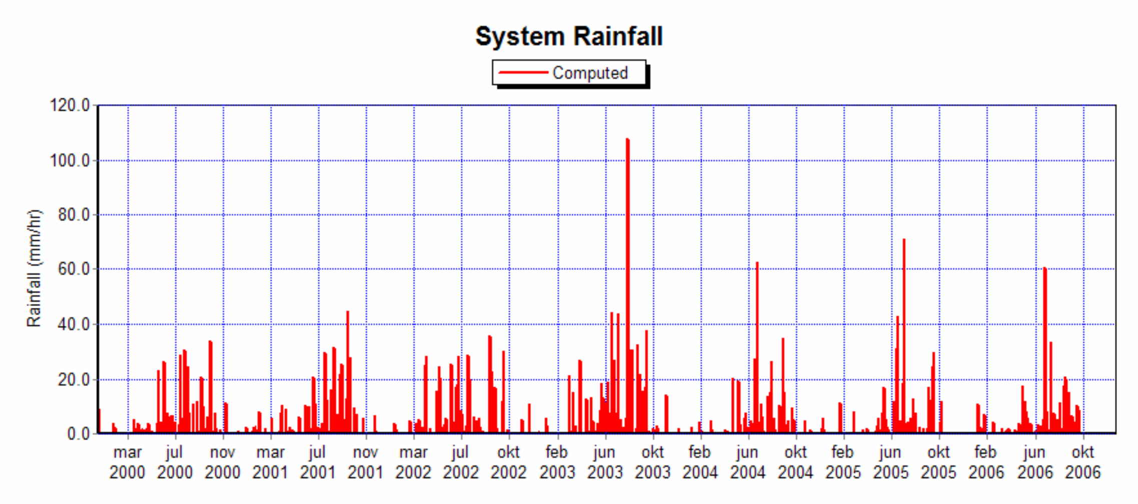


Figure 3.13 Daily precipitation distributions during 2000 - 2006 over Qingyang using rainfall data from Giovanni (NASA, 2007).

Applying the Giovanni precipitation pattern an increasing amount of heavy rainstorm the last four years could be seen. When the data is applied in SWMM it is possible to analyse several rainstorms of different intensity. Analysing meteorological and hydrological data it is important to look on a time span of several years. By analysing a longer period annual variations will not have a great impact on the final result. Although long term studies is more accurate to find fluctuations between different years and to find regional variations and patterns to make forecasts, short term studies can be used for analysis of extreme situations for example the effect a specific or a series of rainstorms have on a catchment. Important to remember is that the variations do not resemble the real metrological conditions in Qingyang but are made to simulate variations in rainfall.

4 Results and Discussion

4.1 Background

The results will be presented in the following order: field measurements, SWMM Simulations and each section include both results and a discussion. The results from each section will be important for the following sections and should be read in order of presentation.

4.2 Field Measurements

The water content readings were performed around Tian Hu Catchment to get a good coverage as possible. The different measuring points of soil sampling, soil moisture readings and infiltration can be seen in Figures 4.2 (a), 4.2 (b) and 4.6, respectively.

4.2.1 Characterisation of Soils

The land use around Tian Hu can be generalized in four major groups:

- crop fields
- fallow fields
- miscellaneous vegetation area
- impermeable and semi-impermeable area

The crop fields and the miscellaneous vegetation area are quite porous as they are being continuously maintained, while the fallow fields represent drier and hard properties see Figure 4.1. To characterize the soils there are three methods that have been used: soil sampling, infiltration tests, and making use of visual observations.

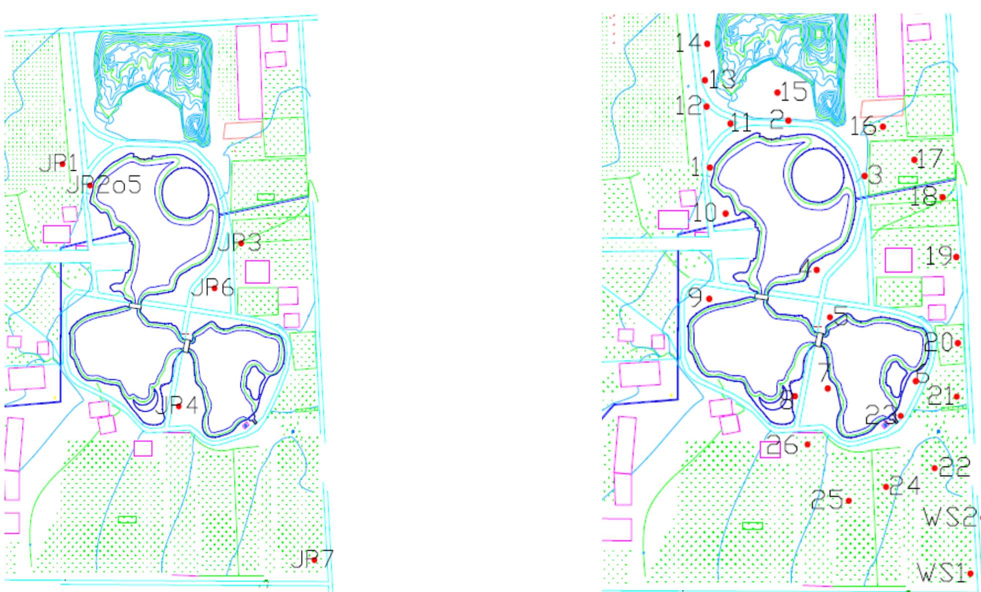
Figure 4.1 Different land use around Tian Hu; crop, miscellaneous vegetation and fallow fields, respectively (Cheung, 2006).

Soil Sampling

The soil samples were taken with the purpose of calibrating the Wet Sensor readings. The samples are performed according to the method mentioned in section 3.2.2 and the results are presented in the Table 4.1. From the table it can be seen that the measured samples (JP1- JP7 in Table 4.1) show a much lower amount of soil moisture than the Moisture meter. The difference can be explained by the predefined variables in the Moisture meter were set to sandy soil, while the soils in Tian Hu is actually more of a silty-clayey type. Table 3.1 in section 3.2.2 shows the difference in calibration constants between sandy and clayey soil. By correcting the constants b_0 and b_1 the Moisture meter readings would match the measured soil sample values thus the proper soil characteristics can be evaluated. What seems unusual when analysing the samples is that two samples taken close to each other, JP2 and JP5, showed of very different characteristics. On the other hand when comparing JP2 with JP6 they show of similar properties. The properties and the locations of the soil samples can be found in Table 4.1 and Figure 4.2 (a), respectively.

Table 4.1 Comparison in measured soil moisture between soil sample and WET sensor test.

Station	Soil sample	Moisture Meter	Corrected Variables	
	Measured (%)	Original Value (%)	b0	b1
JP1	17.5	38.4	2.7	11
JP2	19.2	27.7	2.0	9.0
JP3	14.8	34.8	2.7	11
JP4	16.8	33.8	2.4	11
JP5	14.7	31.1	2.4	11
JP6	16.9	22.8	1.8	9.0
JP7	12.3	29.4	2.4	12



(a) (b)

Figure 4.2 (a) Location of soil sampling points in Tian Hu October 2006.
(b) Location of WET Sensor readings in Tian Hu October 2006.

Due to the rudimentary way of determining the soil moisture of the samples it is difficult to make any conclusions apart from the result obtained in the Moisture Meter. The values from the Moisture meter are too high and should be corrected with 10 to 20 percentages less soil moisture.

WET Sensor

With the results from the WET Sensor it is possible to simulate groundwater changes and flows. Because of the very deep groundwater levels at the Loess plateau, sometimes 100 meter in difference, no use of the soil moisture results can be used in SWMM and to expect accurate results.
In Figure 4.2 (b) the locations of the WET Sensor measurements are displayed. Comparing the moisture readings in Figure 4.3 and the daily precipitation in Figure 4.4 it can seen that the soil moisture follows the precipitation. Right after a rain there will be an increase in soil moisture. This pattern can be observed on 17 and 23 October (2006) but the rain coming on the 1st November does not seem to have any impact on the soil moisture in station 2, 5, X and station 21. Station X represents Soil Sample 1 (JP1) and Infiltration point 1 (Inf1) which can be found in Figure 4.2 (a) and 4.6 respectively. Because of the resolution used for Figure 4.4, the maximum resolution for Giovanni is 770 km^2, it is possible that the rain on the 1st November never reached Tian Hu Catchment.

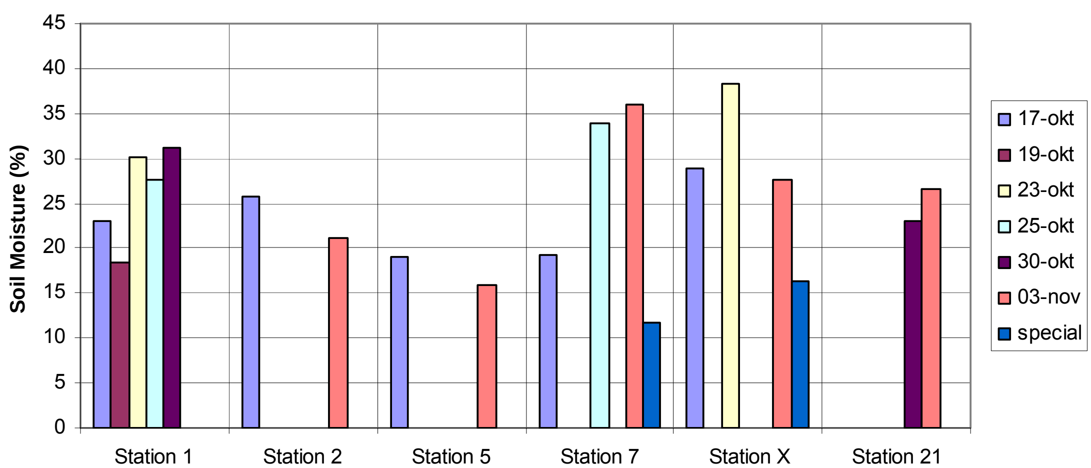


Figure 4.3 WET Sensor readings from reference stations in Tian Hu Catchment 2006.

There are still results in Figure 4.3 that contradicts the above statement of soil moisture following precipitation patterns. Where the pattern show a decline in soil moisture for most stations, 2, 5 and X, between 17 of October and 3 November, the station 7 show an increase of soil moisture. The reasons for this exception is not clear but the last day when measurements were taken, some irrigation were being performed and it is possible that station 7 had some watering the previous days.

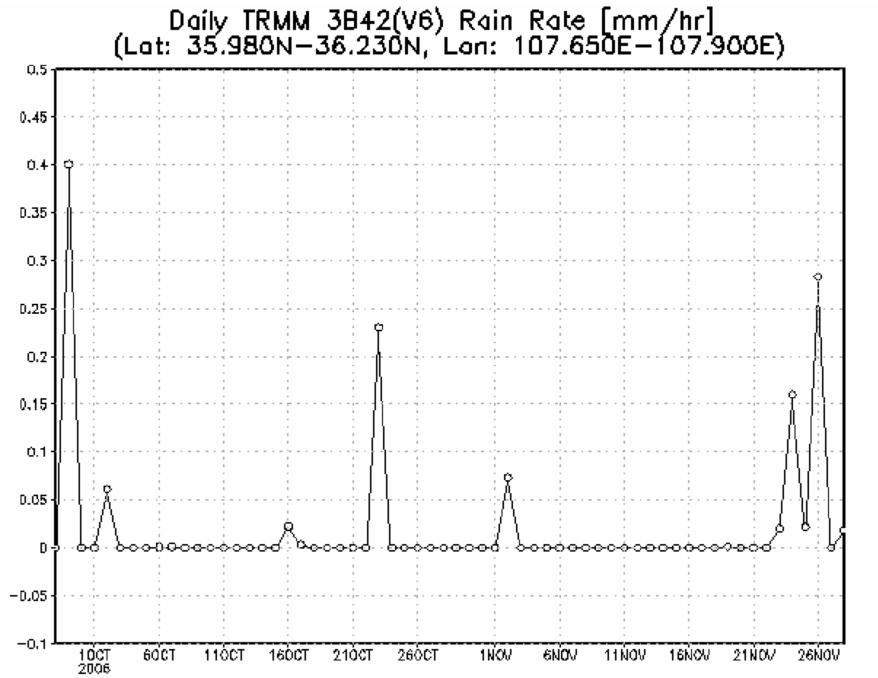


Figure 4.4 Daily rainfall intensity in October and November of Qingyang in 2006 (NASA, 2007).

Trying to find any patterns from the Moisture meter data is very difficult if not impossible. The results have too few measurement points and too few reference points that can be used to find patterns. To further emphasize what has just been stated, it can be mentioned that several tests taken close to each other could differ with several percentages. Figure 4.5 below show the average soil moisture from all stations at the different time when measurements were taken. The two dates of 17 and 25 October show that there are not any big differences in soil moisture over time and over the area. The miscellaneous dates in Figure 4.5 only have a few measurements and the statistic reliability is low due to the fewer sample points.

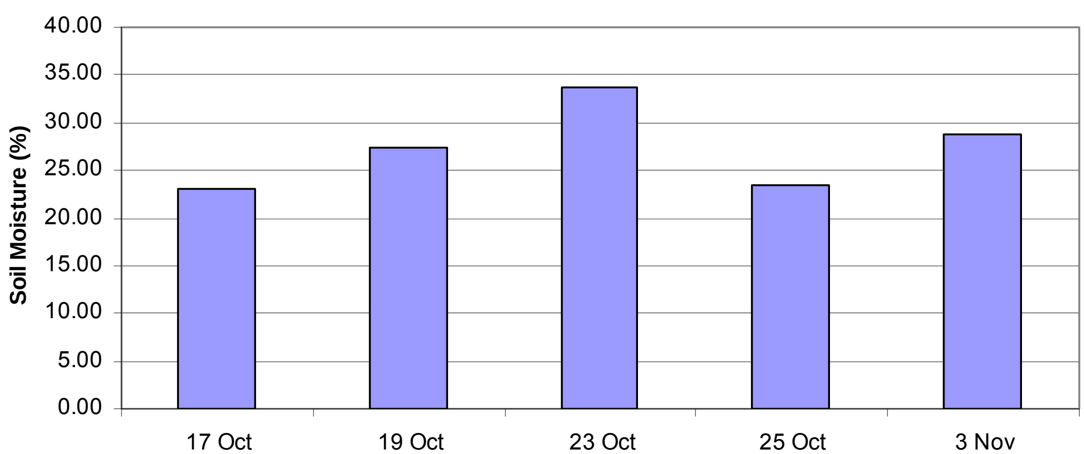


Figure 4.5 The average soil moisture content from all stations in Tian Hu Catchment 2006.

Infiltration Tests

Four infiltration tests are made and they are taken in locations seen in Figure 4.6. The tests are taken at points that were thought to be representative for larger areas. From the infiltration tests all four samples show different characteristics.

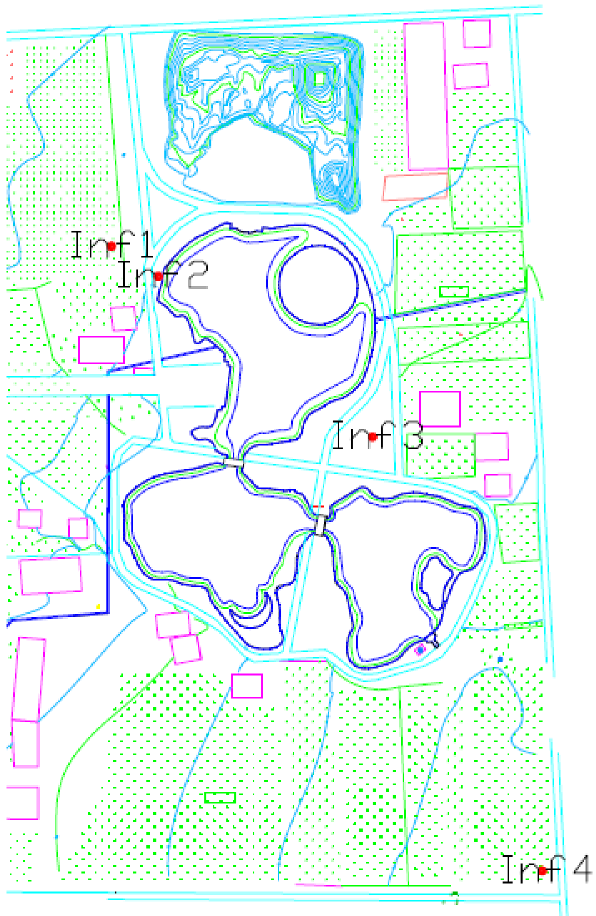


Figure 4.6 Location of infiltration tests in Tian Hu Catchment.

Infiltration station 1 (Inf1 in Figure 4.6) is taken in an old cornfield with sparse vegetation and quite hard soil. This test was performed over a longer time and with fewer readings than the others. The infiltration rates from station 1 can be used when infiltration has reached equilibrium and when water has been lingering more than 3 hours. The other infiltration tests 2, 3 and 4 are better to use when analysing shorter rainstorms.

The values from infiltration test 2, 3 and 4 are illustrated in Figure 4.7 and its trend can be seen separately in appendix B. Even though infiltration station 3 seems to keep a steady infiltration speed all tests show a decrease in infiltration rate. Infiltration station 4 was taken in a newly ploughed field with very loose top soil. When the initial top soil is fully saturated the underlying soil layer will determine the continuing infiltration. Finally the infiltration rate will level out to approximately the same speeds as in station 1 and 3.

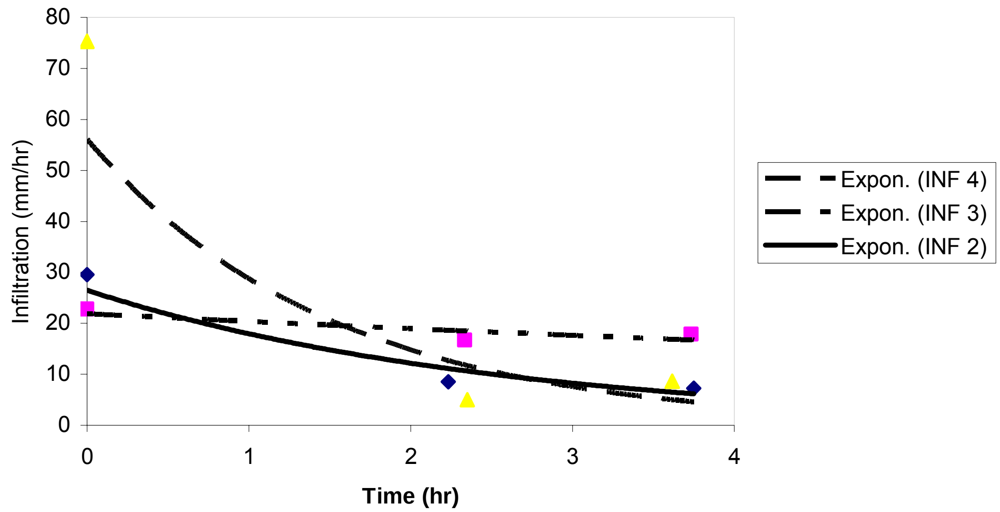


Figure 4.7 Infiltration rate of Station 2, 3 and 4.

The constant infiltration rates for infiltration station 3 are difficult to explain. There are no signs of high initial infiltration and the speed does only decline slightly. The area where the test was taken is sparsely vegetated with shrubs and small tress. No ground hugging vegetation or any large root systems were visible that could explain the even rates.

Because of the small amount of tests performed and the varying results some literature comparisons on infiltration rates are made. Most articles and graphs show on higher initial infiltration rates but the rates level out as almost the same as the test in Tian Hu. The difference in initial rate is most likely due to the difference in time steps between measurements. The infiltration tests of Tian Hu should be compared to trend line 2 in Figure 4.8. In section 3.2.3 it is mentioned that the dry soil on top layer tends to form a crust and this makes the infiltration rate difficult to comprehend in a larger scale.

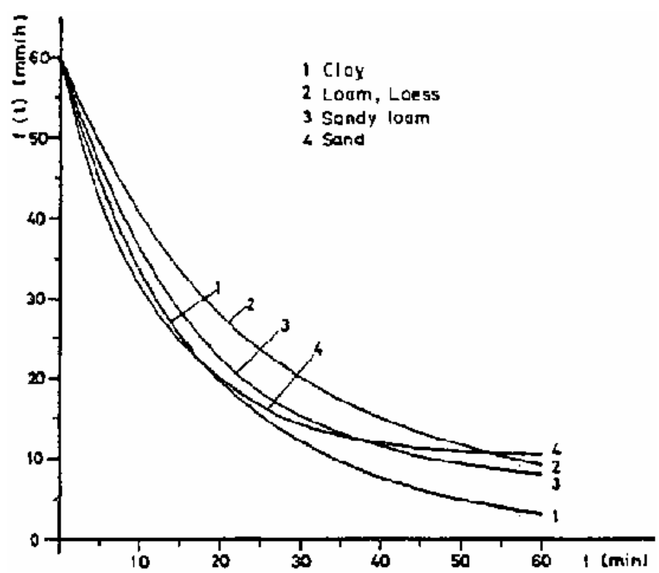


Figure 4.8 Infiltration rates for different soil types
(Food and Agricultural Organisation of the UN, 2007).

When taking the information and results in previous chapters 3.4 and 4.2 into mind it is possible to get an overview how the Catchment of Tian Hu works. Determining the proportions and characteristics of the subcatchments three aspects are important to have in mind: runoff flow path, infiltration capacity, general soil properties and relations between impervious and pervious surfaces. Tian Hu is divided into 9 subcatchments, as mentioned earlier. Each subcatchment is primarily divided according to the flow paths with secondary divisions to the other aspects. The subcatchments in the north, Sub15 to Sub17 and Sub22, see Figure 3.10 on page 25, are divided by their soil characteristics and the flow paths would follow naturally. Subcatchment Sub14, Sub18 and Sub21 withhold the same soil properties and flow paths but their ratios between impervious and pervious surfaces differ. Finally the smallest subcatchments closest to the lake Sub19 and Sub20 have properties that differ from all the other subcatchments but are on the other hand similar to each other regarding flow paths and soil properties.

4.3 SWMM Simulations

The results from the simulations of the two rainfall patterns on the Century Avenue Catchment will be presented as they have a great importance in the later analyses on Tian Hu Catchment. The two rainfall events mentioned in simulation scenarios section are analysed and discussed.

4.3.1 The Century Avenue Catchment

The catchment of Century Highway and Century Square is of interests from several points of views. In this thesis the Century Avenue Catchment provides a second catchment, Tian Hu, with an additional inflow. The Century Avenue Catchment is also of interest on a local basis as the results can be helpful to the local authorities for management and for additional constructions of man-made lakes and large scale rainwater harvesting.

Daily Rainfall Analysis 2000 to 2006

To see how the system handles different rainstorms SWMM provides very good and easily overviewed graphical result charts. By comparing total inflow with total outflow and flooding of Century Avenue Catchment some limitations in the system can be spotted. From Figure 4.9, where the three parameters described earlier, are visualized it can be seen that in 2003 a flooding (staples in the middle) of Century Avenue Catchment is the result of a very heavy rainstorm (staples in the back). While there are no visible signs of flooding in the graph some minor floods are reported by SWMM in 2004 to 2006. By comparing the dates where flooding occurs with the relevant rainstorm the conclusion can be drawn that the system can handle inflows of approximately 20 CMS (Cubic Meter /Seconds) which corresponds to a rainstorm intensity of 42 mm/h.

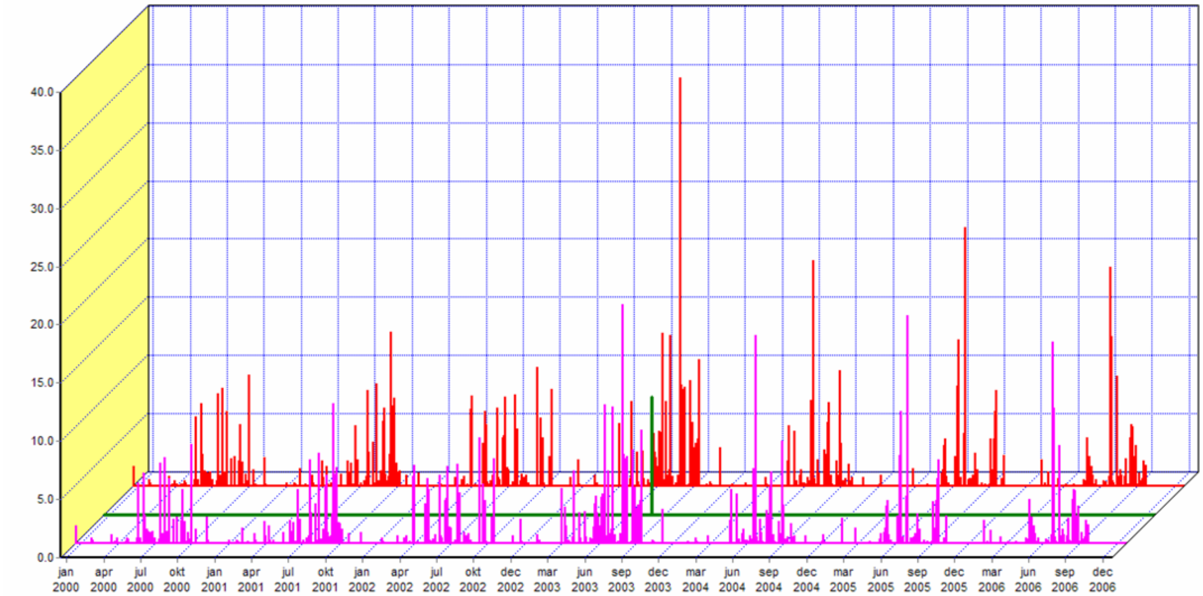


Figure 4.9 Total Inflow (In the back), Total Outflow (At the front) and System Flooding (In the middle) in unit CMS from 2000 to 2006. Flooding can be seen in 2003.

Analysing the flooded junctions in the system (see Figure 4.10) two phenomena are noticed: the first one is the heavy flooding of J3 and J10 in 2003 and the second one is flooding of the J6 and J10 in 2005 (see SWMM's status reports of 2003 and 2005 in appendix C). The flooding in 2003 can be explained by massive inflow from Sub 15 and that it will coincide with the flows coming from the subcatchment 3 (Sub3). This is resulting in fast overload of the conduits and junction capacities and thus results in flooding of J3. Note that Sub3 and Sub15 represent Century Square and stand for 83 % of the total surface of the Century Avenue Catchment. Further the flood in J3 will act as an obstacle as water will both be accumulated on the top of the junction and also from the pipes upstream from the junction. This results in restricting of the inflow to downstream nodes. The flow from the flooded J3 will have very high close to maximum flow. At every new junction more water will be added to the flow which will reach the critical capacity in J10, thus resulting in flooding in the junction.

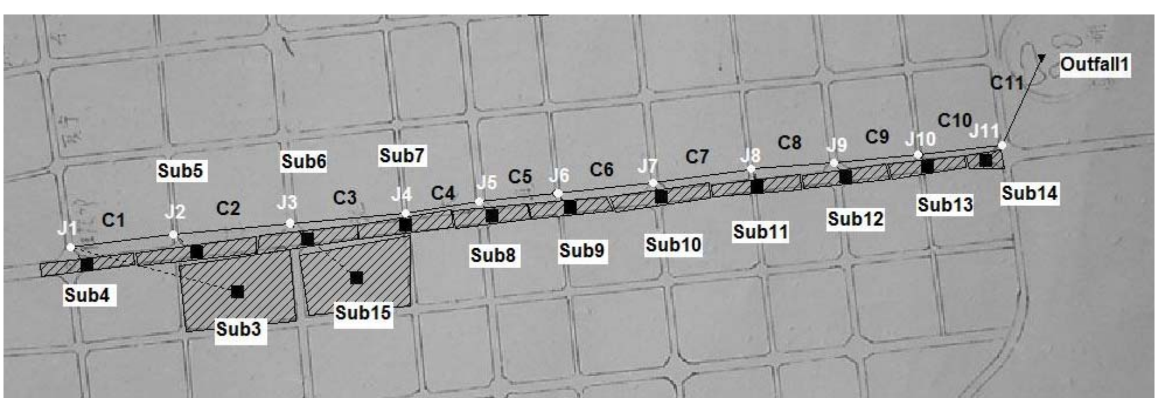


Figure 4.10 The Century Avenue Catchment systems with subcatchments, junctions and conduits.

Examining the status reports in SWMM of flooding in 2004 to 2006 (see SWMM's status reports of 2004 and 2006 in appendix C) it is interesting to discover that J3 is not the junction that gets initially flooded but instead the junctions closest to the outlet are flooded. In these cases there are no extreme rainfalls that will chock the system but it will reach its capacity by accumulating flow from all the subcatchments. This kind of flooding is less rapid than the rain event in 2003. Even if the volume of flood water on single junctions is lower, the system as a whole will be more affected and hence more junctions will be flooded.

The total inflow to the system is mostly determined by the large subcatchments 3 and 15. The inflow from the highway is a minor contribution and thus will subcatchment 3 and 15 be decisive when determining the flow pattern for the system. It is thus interesting to see the importance of the smaller catchments that their contribution will result in a flood in J10 because of the added flow.

Interesting to notice is that the total outflow from the system does not differ a lot between 2003 and 2005 and it can be concluded that the higher generated runoff will just be wasted as the system can not cope with them. The Figure 4.9 shows that a maximum capacity of the system can be put at approximately 20 CMS.

3-hours Rainfall Analysis

From previous chapter some conclusions can be drawn about the limitations of the system, but the analyses do not take into account the different variations of rainstorms. The simulations in SWMM use a constant intensity over one hour of time. By introducing different types of rainstorms but with the same accumulated volume of water further conclusions can be drawn on the Century Avenue Catchment.

The design storm is based on data from Xifeng Water Authority. The mean intensity, 64mm/h, and duration, 3 hours, is known but not the distribution and thus three different distribution patterns are tested: *mean average* (square), *triangular* variation and *normalized* variation, see Figure 4.11 (Berndtsson, 2007) .

The three design rains have the same amount of accumulated rainfall, but the intensity of the rainfalls vary between each design rain; the square design rain have a steady intensity of 64mm/h for three hours, the triangular design rain has an increasing intensity from 0 to 120 mm/h in one and a half hour and then it will decrease to 0 mm/h again, the normalized design rain have an even intensity of 50 mm/h and will after one hour and 20 minutes have a rapid increase of intensity up to 450 mm/h. This high value of intensity will last for 15 minutes and will there after decrease back to an intensity value of 50 mm/h.

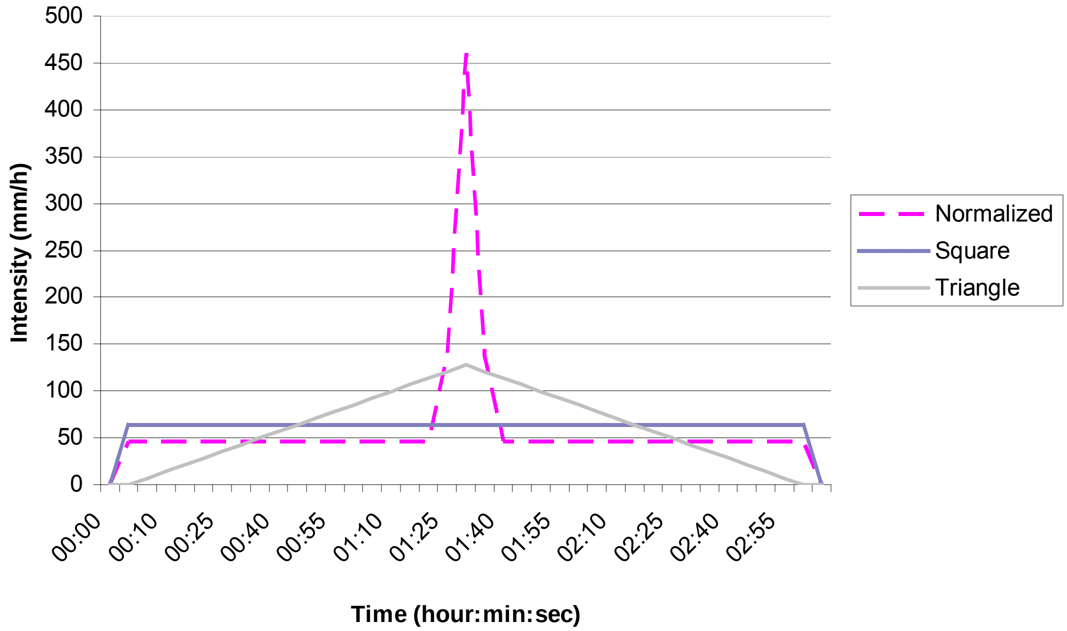


Figure 4.11 Design rainstorm of normalized-, square- and triangular pattern, respectively.

Square Design Rain

The three design rainstorm events show different characteristics of the catchment and distribution system. The steady rain delivers the largest volume of water to the outflow, with small flooding but during a longer time, see Figure 4.12, and only 6 out of 11 junctions are flooded, see Table 4.2. The square design rain reaches peak values in flooding, outflow and inflow according to Figure 4.12.

Table 4.2 The results in all junctions when simulating with square design rain.

	Average depth (m)	Maximum depth (m)	Time of max occurrence (hr:min)	Total flooding (ha-mm)	Total minutes flooded
J1	0.38	1.09	03:04	0	0
J2	0.38	1.12	03:04	43.61	0
J3	0.72	3.00	01:45	169.38	76
J4	0.74	3.00	01:39	171.46	80
J5	0.75	3.00	01:35	181.29	82
J6	0.77	3.00	01:32	34.55	88
J7	0.77	3.00	01:29	0.38	89
J8	0.76	3.00	01:26	0	0
J9	0.73	2.66	01:36	0	0
J10	0.73	2.19	01:39	0	0
J11	0.45	1.30	01:39	0	0
Outfall 1	0.45	1.30	01:40	0	0

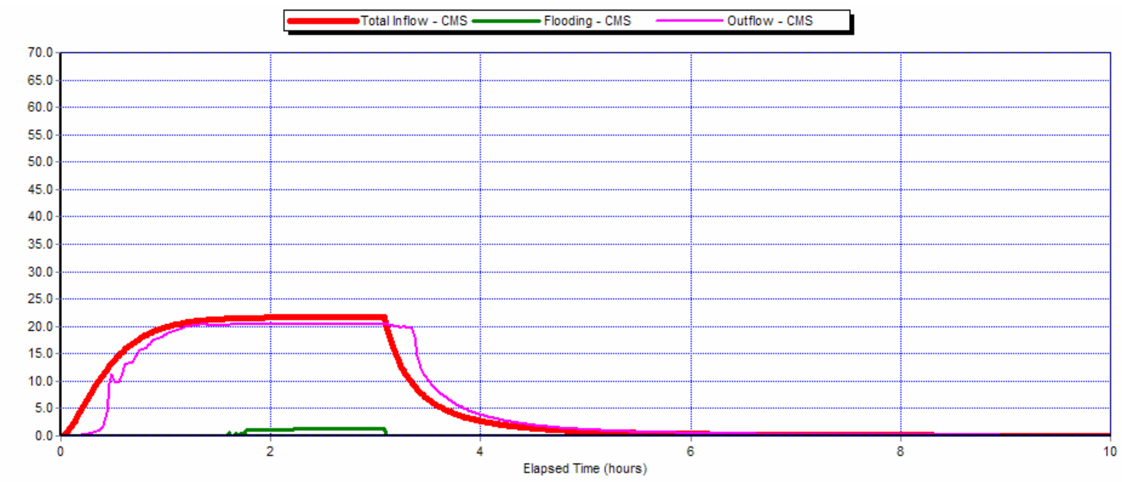


Figure 4.12 Total inflow (red), total outflow (magenta) and flooding (green) in CMS when simulating with square design rain.

The flooding occurs when the downstream junctions reach their capacity first according to table 4.2. When looking at the system profile the system is slowly filled from J11 to J1. If the rain would continue for more than 3 hours all junctions would eventually be flooded.

The square design rain is close to be a perfect rain for the Century Avenue Catchment. Flooding is almost minimal and inflow and outflow values differ very little. By running a quick simulation it is easier to discover that a steady rainfall of 61mm/h will result in modest flooding while a rain with the intensity of 60 mm/h will not flood the system at all.

Triangular Design Rain

The triangular design rain with a steady increase in rain intensity generates the lowest volume of water to the outflow and also the highest volume of flooded water, see Figure 4.13. The time of flooding starts earlier than the previous design rain but last for a shorter period, see Table 4.3.

Table 4.3 The results in all junctions when simulating with triangular design rain.

Junction	Average depth (m)	Maximum depth (m)	Time of max occurrence (hr:min)	Total flooding (ha-mm)	Total minutes flooded
J1	0.35	1.57	01:45	0	0
J2	0.36	1.79	01:46	0	0
J3	0.62	3.0	01.16	4087.76	78
J4	0.63	3.0	01:17	240.38	77
J5	0.64	3.0	01:18	241.50	78
J6	0.64	3.0	01:18	243.05	78
J7	0.64	3.0	01:18	203.24	71
J8	0.64	3.0	01:18	34.67	41
J9	0.61	3.0	01:18	0.26	0
J10	0.61	2.33	01:35	0	0
J11	0.38	1.33	01:36	0	0
Outfall 1	0.38	1.33	01:35	0	0

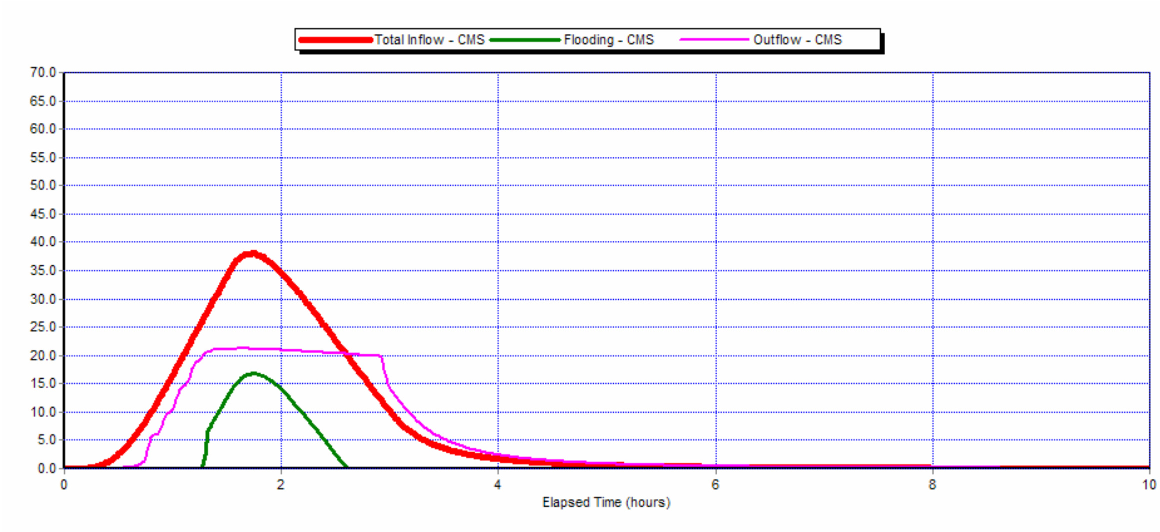


Figure 4.13 Total inflow (red), total outflow (magenta) and flooding (green) in CMS when simulating with triangular design rain.

When analysing the system profiles (see appendix D) the whole system is very close to flooding. At one hour and 16 minutes the flow reaches its capacity in J3 (see Table 4.3), which will result in a flood.

In the case of the triangular design rain the junctions will be flooded accordingly: J3 will be flooded initially as the combined flows will reach maximum capacity in J3. The high flow will continue down the system and flood J4 but will then diminish a little. As the rest of the system is also close to maximum capacity junction eleven (J11) will be flooded as the accumulated rains from J1 to J10 reach the junction.

This scenario describes the flood procedure with high intensity rains and the reason why local junctions can be flooded while the rest of the system is unaffected. Assuming that the rain would last for a shorter time the junctions downstream would never be flooded.

Normalized Design Rain

Like the triangular design rain the system for normalized design reaches its limit at junction J3 where the total amount of inflow reaches the maximum capacity. Junction J3 is flooded slightly after one and a half hour when the accumulated flow from subcatchment 3, 4, 5, 6 and 15 reach the junction. The accumulated flow will reach J3 slightly after the peak in rainfall, see Figure 4.14. In this case one single junction is flooded quickly as it reaches its capacity and junctions downstream and upstream is gradually filled, see table 4.4. Upstream from J3 the system is flooded because of the flood prevents further inflow. In downstream the junctions are flooded because they gradually reach their capacity.

Table 4.4 The results in all junctions when simulating with normalized design rain.

Junction	Average depth (m)	Maximum depth (m)	Time of max occurrence (hr:min)	Total flooding (ha-mm)	Total minutes flooded
J1	0.39	3.0	01:33	305.41	11
J2	0.39	3.0	01:34	89.96	12
J3	0.59	3.0	01:31	2841.70	39
J4	0.60	3.0	01:32	137.26	39
J5	0.61	3.0	01:33	132.67	40
J6	0.62	3.0	01:34	121.74	40
J7	0.62	3.0	01:34	82.92	24
J8	0.62	3.0	01:35	49.09	12
J9	0.61	3.0	01:35	13.11	4
J10	0.65	3.0	01:35	0.14	0
J11	0.41	1.41	01:37	0	0
Outfall 1	0.41	1.40	01:37	0	0

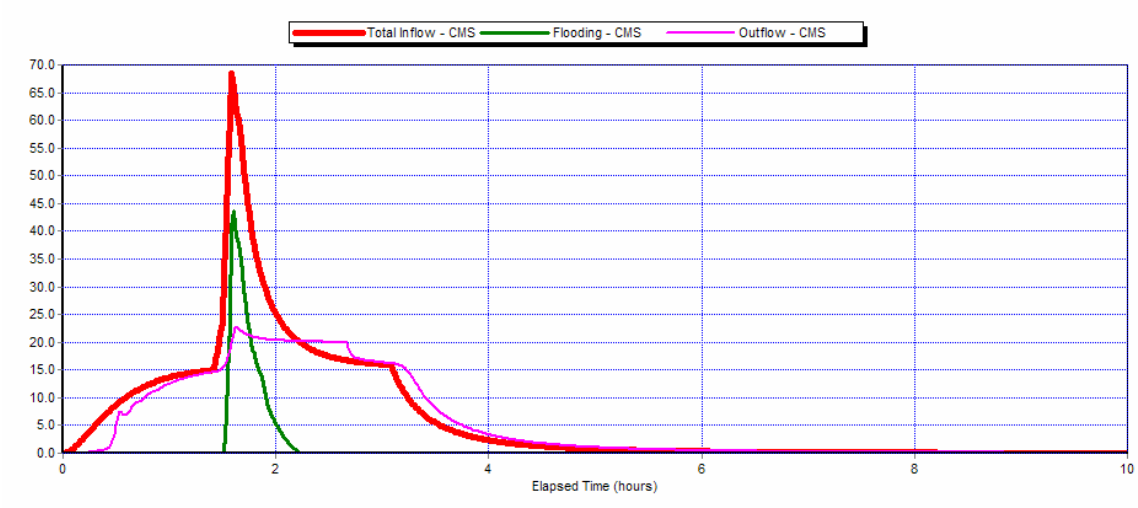


Figure 4.14 Total inflow (red), total outflow (magenta) and flooding (green) in CMS when simulating with normalized design rain.

The normalized rainstorm affect the system in more junctions flooded but the time span is shorter than for the two other cases, see Figure 4.14. The volume flooded water is less than the triangle design rain but higher than the acquired design rain. The total volume of water to the outlet is slightly higher than that of the triangular rain storm but with a higher maximum peak in outflow.

Discussion

The first case with a square design would slowly fill the system until it reaches its capacity and would almost run at max capacity throughout the whole system. The second and third cases show similar results as the discussion regarding the daily rainfall in 2003. Floods will occur when the flow at any point in the system reaches about 20 CMS, as this is the maximum capacity, see Figure 4.15. High intensity rains will reach the 20 CMS limit in specified junctions as J3. The limits are reached quickly due to the larger collecting surface area of the Century Square, while junctions downstream will flood because of accumulated flows slowly reaches 20 CMS.

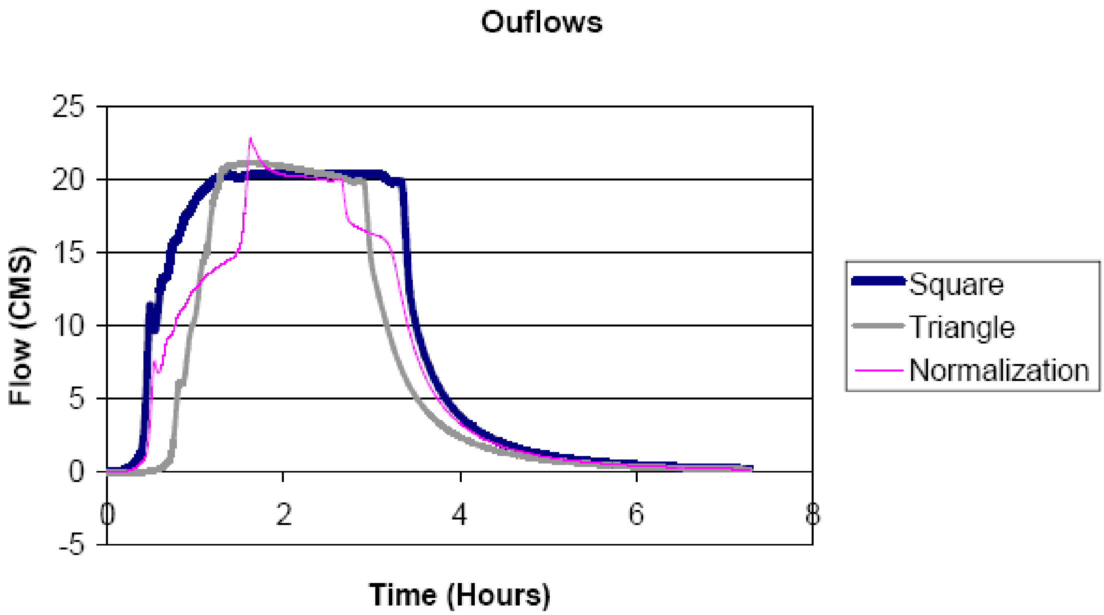


Figure 4.15 Outflows from Century Avenue Catchment depending on different design rain patterns.

4.3.2. The Tian Hu Catchment

Daily Rainfall Analysis 2000 to 2006

The simulations of Tian Hu Catchment are using two major input data such as; daily design rainfall of 2000-2006 and daily external inflow data from the simulations of the Century Avenue Catchment. The simulations are run separately for each year, and each year two simulations are performed apart from the daily rainfall; one with external inflow and another without external inflow data.

The results which are obtained from the simulations and will be discussed further on are:

- Detection of floods
- Amount of excess water collected
- Impact of overland flow on storage capacity

Detection of floods

The impact and prediction of floods are necessary to analyze in order to achieve appropriate planning decisions for future hydrological constructions. The simulations in SWMM confirm that flooding occurs in Tian Hu catchment. The flood-hydrographs show a similar flow-pattern almost every year and the floods mostly occur between June and September, see results in appendix E. This result was expected as the majority of heavy rainfalls of Xifeng often appear within this period annually. Even though floods occur in all three storages the majority of the floods occur in Sun (S1). This is due to the primary input source, the collected stormwater from Century Highway, flows initially into the Sun. What is worth mentioning are the years in 2000-2002 show slight deviations from the years in 2003-2006. The obtained graphs of flooding show that the maximum peak flows in 2000-2002 are much lower (~7-10 CMS) than the latter years (~17 CMS). The reasons are higher peaks of rain intensity during the last four years and increased intensity lead to increased water quantity and hence floods.

Due to overloading of the lakes a great amount of water gets wasted. In order to quantify the amount of flood water generated an extra storage 4 (S4) is implemented in SWMM, see Figure 4.16. This fourth storage will serve as collection storage for flooded water in the model. The simulations result in a volume of approximately 420 000 – 550 000 m^3 is being wasted annually and the volume graphs are presented in appendix F. A deviant value of 800 000 m^3 appears in 2003 and this is not unexpected as the magnitude of the intensity during this particular year reaches up to more than 100 mm/h. A further discussion regarding the utilization of excess water in S4 is available in section 4.3.4.

Overland Flow

When simulating Tian Hu Catchment, including both external inflow and runoff generated from the subcatchments, the results show more or less the same water depths fluctuations in the lakes during the six years of analyses. The simulated water depths for each year can be visualized in appendix G. One can see that the maximum depths (3m for the Sun and the Moon, and 2m for the Star) are reached in all three storages and this was expected due previous flooding discussion. According to section 2, The Sun (S1) is filled up first and it follows by the Moon (S2), and hence afterwards by the Star (S3), and this can be visualized in appendix G. The connection between the lakes can be seen in Figure 4.16.

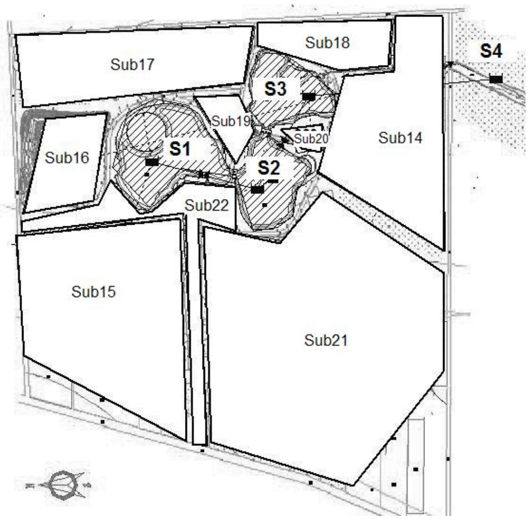


Figure 4.16 Delineation of the Tian Hu Catchment as represented in the SWMM model.

However when *excluding* the external inflow, and the only input would be the surface runoff from the subcatchments, the impact of overland flow can be analyzed. Overland flow is the result of when rain falls on the surface and moves along the land surface towards a stream or river. Overland flow rates and volumes are very dependent on precipitation rates, duration of a storm event, and spatial distribution of precipitation (Cech, 2003). Ideal conditions that favour overland flow are found on moderate to steep slopes in arid and semi-arid areas. The surface of arid and semi-arid climate is representing a sparse vegetation cover which makes it more exposed to raindrop impact and crusting processes (Ward, 2000).

The simulations result of how the water levels fluctuate in the three reservoirs during 2000-2006 can be seen in Figure 4.17. The water level of 2.7 meters is the level when water is passing over from the Sun to the Moon reservoir, and this can be seen in Figure 4.17. This is occurring in August 2003, September 2005, and July 2006. This explains the difference in water depths between the Moon and the Star. The sudden increase in August 2003 does also depend on the fact that there is a high intensity amount of precipitation of 100 mm/h, see Figure 4.18.

The result also shows that the maximum water levels in all three lakes are never reached (3 m for the Sun and the Moon, and 2 m for the Star. The dips in Figure 4.17, except the ones mentioned above, show an indication of evaporation losses from the surface water. Worth mentioning is that, in the Sun and the Moon reservoir, it evaporates almost 1000 mm of water during some period of the year. As this study region is of semi-arid and arid conditions, which involves high annual evaporation rate, the great decrease in water depths in the reservoirs can be explained.

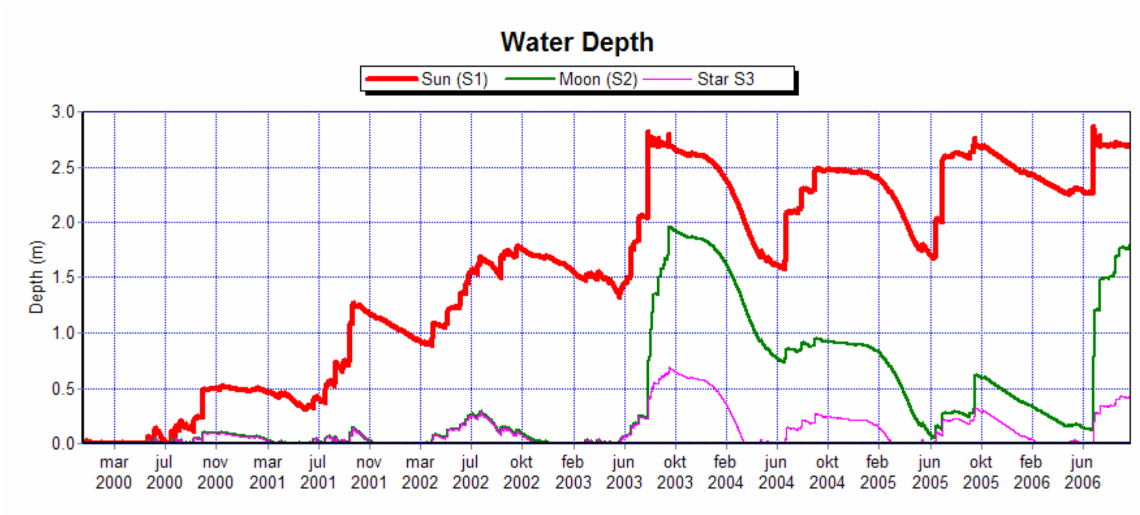


Figure 4.17 The simulated water depths of the Sun, Moon and Star in 2000-2006 depending on overland flow.

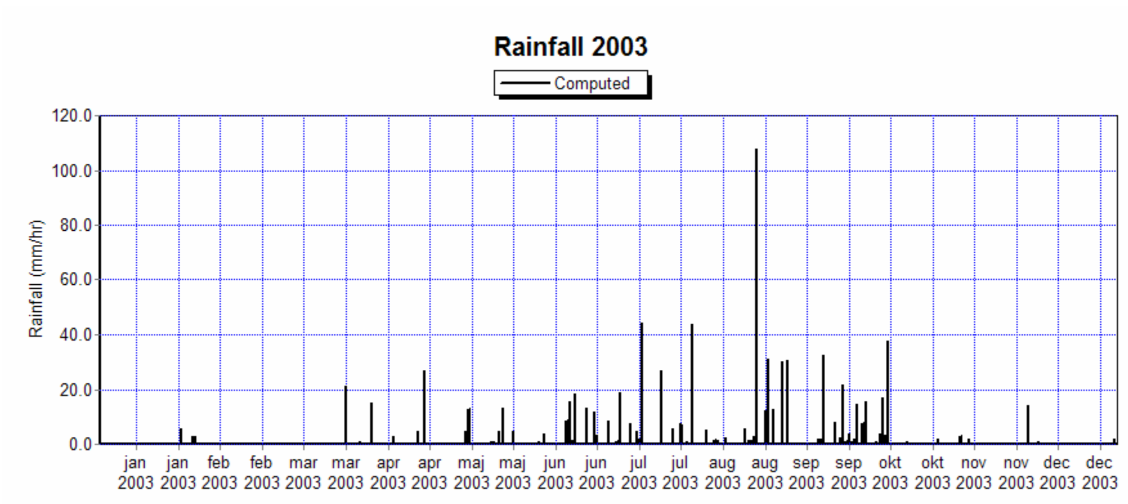
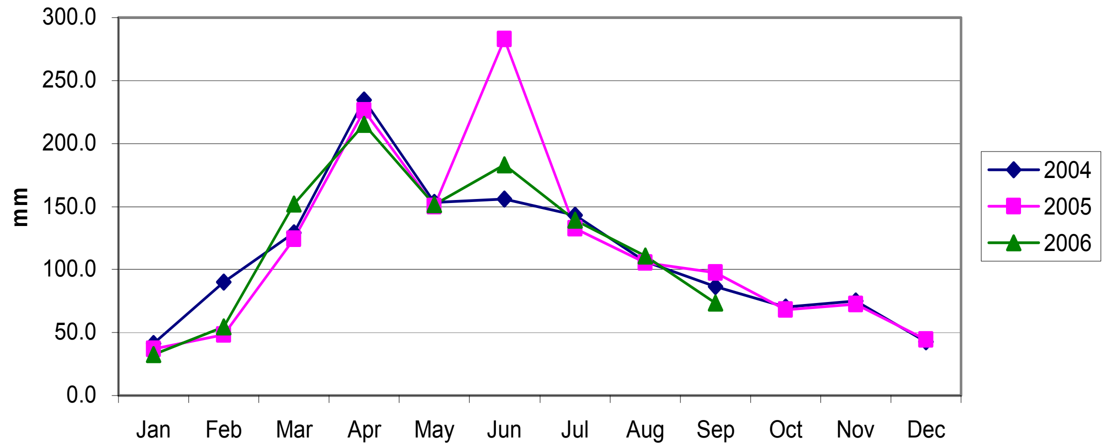
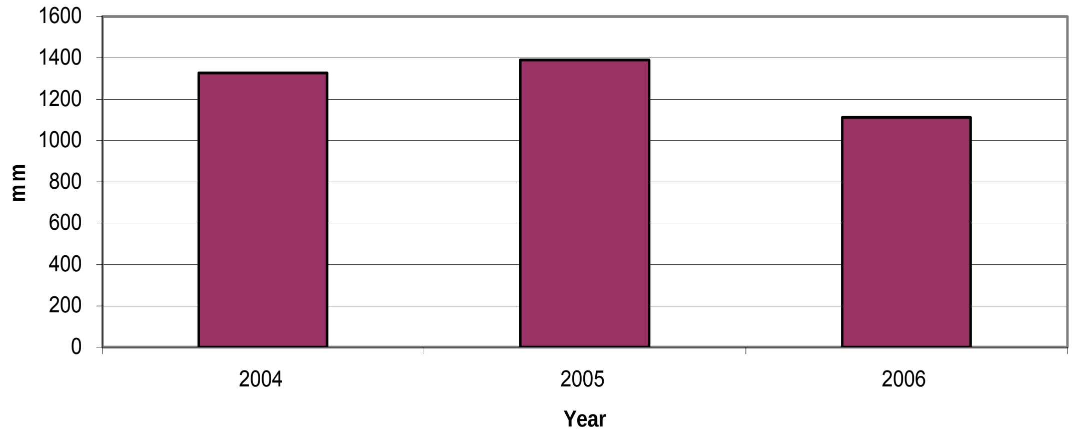


Figure 4.18 The daily rainfall pattern in Xifeng, Qingyang in 2003, according to Giovanni's rainfall pattern.

The impact of evaporation losses is obvious when there is no external inflow from the Century Avenue Catchment. From the overland flow results simulated evaporation losses of 1000 mm in water depth is discovered by observing the water levels in Tian Hu during the dry season, October to June. This number correlates well with the evaporation data which show evaporation of 1300 mm annually, see Figure 4.19. 1000 mm of water in Tian Hu is representing water losses of approximately 44 000 m^3 annually. The minimum annual external inflow from the Century Avenue Catchment in 2000-2006 is in total 500 000 m^3 and it clearly compensates the evaporation losses. What is noticed is that the majority of the evaporation losses occur between the end of October to the beginning of June. During this period there is almost no precipitation or external inflow to Tian Hu. The decrease of water depth of the man-made lake will therefore be pronounced.



(a)



(b)

Figure 4.19 (a)Average monthly potential evaporation 2004 to September 2006 in Qingyang. (b) Annual potential evaporation in Qingyang 2004 to 2006.

Generally speaking the runoff from the subcatchments seems to have some impact. The runoff, infiltration and evaporation from the subcatchments are illustrated in Figure 4.20. From the status reports of 2000-2006 in SWMM one can see in Figure 4.20 that a great deal (70 %) of the rainfall infiltrates the soil, 25 % generates as overland flow, and only 5 % evaporates. The low amount of evaporation is because in SWMM only free surface water from the subcatchments will evaporate. In reality a large amount of water stored in the soil will also evaporate eventually. The values are taken from the appendix H. Worth mentioning is that the higher the intensity is the more likely overland flow will occur. As heavy rainstorms appear only occasionally most of the rain will therefore infiltrate.

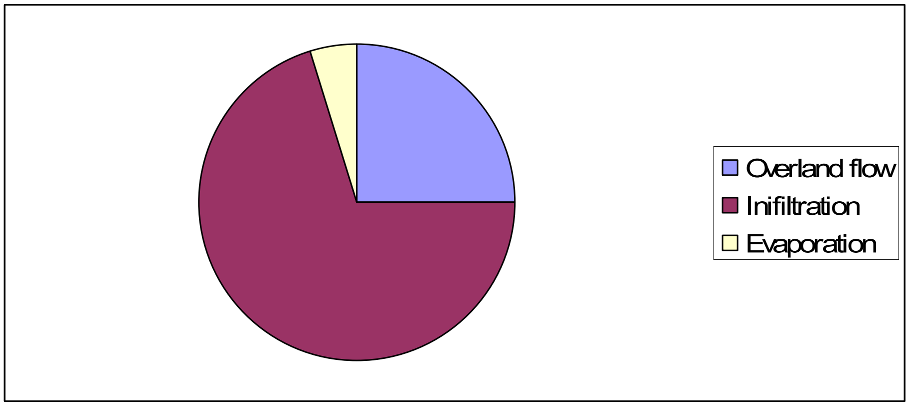


Figure 4.20 Ratio of different water losses from the subcatchments in Tian Hu.

A more overall view regarding the storage capacity of the lakes can be observed in Table 4.3. The Table shows the percentage of maximum storage capacity being reached in the three lakes during the years. The average value for each lake show a range between 20-40 % of the storage capacity is filled when having input depending on overland flow only. Where as the storage capacity when including the external inflow show a range of 50-80 %.

Table 4.3 The average full storage when simulating with or without external inflow.

Year	External flow			Without External flow		
	S1 (%)	S2 (%)	S3 (%)	S1 (%)	S2 (%)	S3 (%)
2000	75	56	49	14	17	27
2001	78	66	58	36	21	32
2002	79	66	60	31	23	36
2003	72	66	58	90	38	53
2004	67	56	50	37	19	30
2005	71	55	50	48	21	31
2006	79	61	54	52	22	34
Average	**74**	**61**	**54**	**43**	**23**	**35**

Therefore one can say that overland flow have some significant contribution to storage capacity of Tian Hu. Furthermore the time when overland flow occurs is often during summer period May and September. The hydrographs of e.g. 2000 (Figure 4.21) shows that majority of the runoff is generating from the subcatchments which are linked to the Sun (Sub15, 17 and 22, in Figure 4.21).

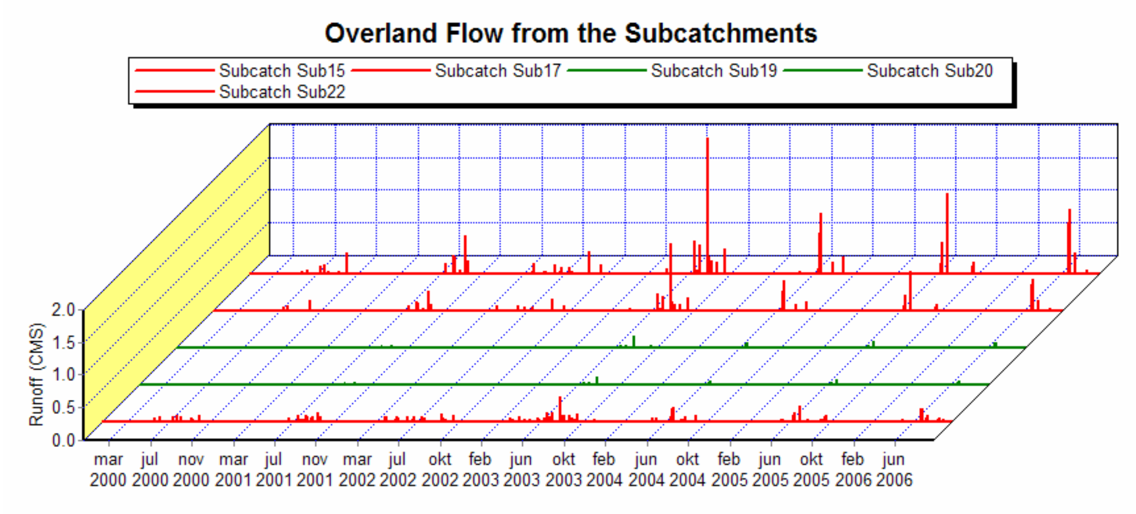


Figure 4.21 Simulated subcatchment overland flow of Tian Hu Catchment in 2000-2006.

3-hours Rainfall Analysis

To see what impact the inflow from Century Avenue Catchment have on Tian Hu two analyses are run, one where the inflow from Century Avenue Catchment is removed and another where it is active. Both simulations are run for square, triangular and normalized design rain, respectively.

As the lakes reach the same maximum height for all three design storms the conclusion can be drawn that the infiltration capacity of the catchment will affect the system in a very little extent during heavy rainfalls. As water levels fluctuate from year to year it is interesting to see what levels a single rainfall can give rise to. Without the external inflow to Tian Hu, the lakes will not be filled even though it is under the criteria that the lakes are empty when the rainstorm occurs. The water levels for the three lakes are represented in Figure 4.22(a-f) regarding the 3-hours design rains.

Adding an external inflow from Century Avenue Catchment, there is a much bigger impact on water levels and on the system as a whole. Both the Sun and the Moon will be flooded in all three cases. Which storm that has the biggest impact can thus be seen by observing the water level in the Star (S3) and the comparison can be seen in Figure 4.22 (b), (d) and (f).

In Figure 4.22 (a – f) the water levels in the lakes can be seen. The lakes are limited to a depth of 3 meters and the weirs between the lakes start letting out water at a depth of 2.7 meters for Sun and Moon. Water will spill out of Star when it reaches a depth of 2 meters. It can be seen that all the lakes reach their maximum depths which is a sign of flooding.

The Figure 4.22 (a- f) does also show the time for all lakes to reach their final depths, which are after approximately 6 hours. The Sun reaches its capacity after only one hour; the Moon reaches its capacity after three hours and the Star reaches its final depth after 6 hours. Even though the rain stopped after three hours, water from Century Avenue Catchment will continue to contribute to the system for another two hours as can be seen in Figure 4.15, page 42, as the inflows to Tian Hu match the outflows from Century Avenue Catchment.

From the Century Avenue Catchment modelling the square design rain resulted in the highest outflows and it is no surprise to see that the square design rain will have the biggest impacts. As can be seen in Figure 4.22(b) the square design rain will reach the capacity of the Sun the fastest and will also result in the highest floods. The other two rains have more modest effects but will still flood Tian Hu and not to forget they have higher impacts on the Century Avenue Catchment.

Something that can not be simulated in the model is how floods will affect the system. In a real situation the storage units would overflow and spill into the next unit and this could not be modelled in a realistic way.

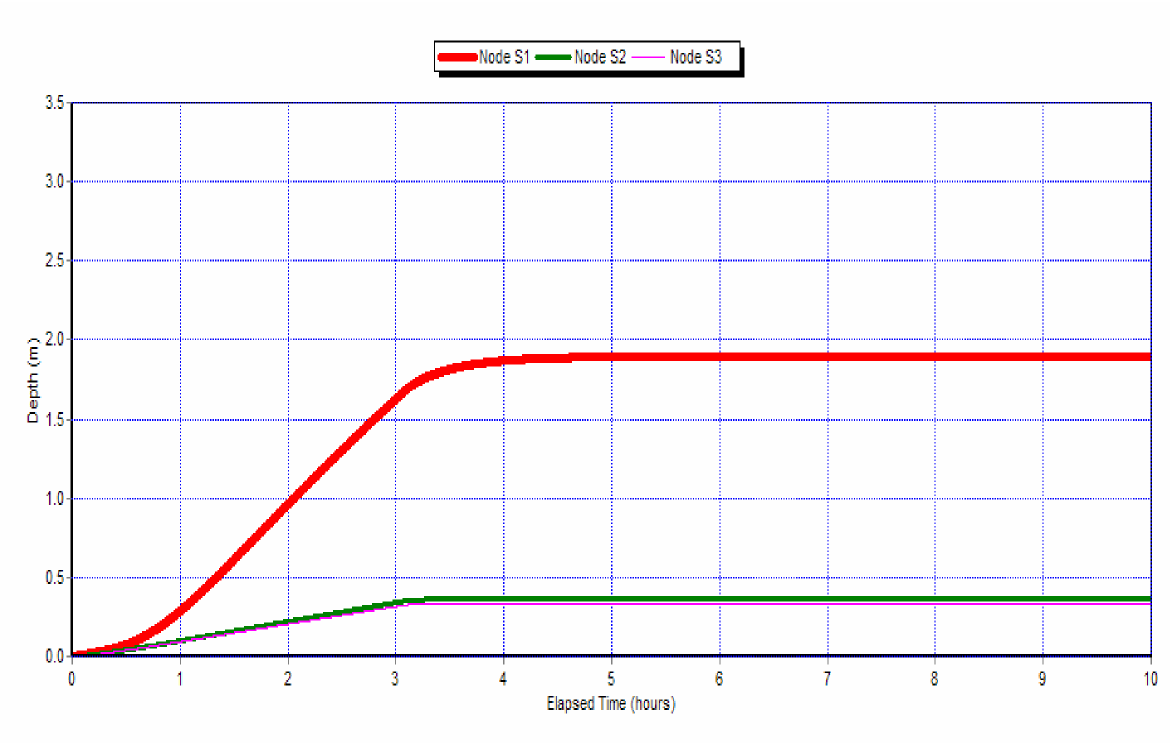


Figure 4.22 (a) Water depths attained in Tian Hu with square design rain - without external inflow.

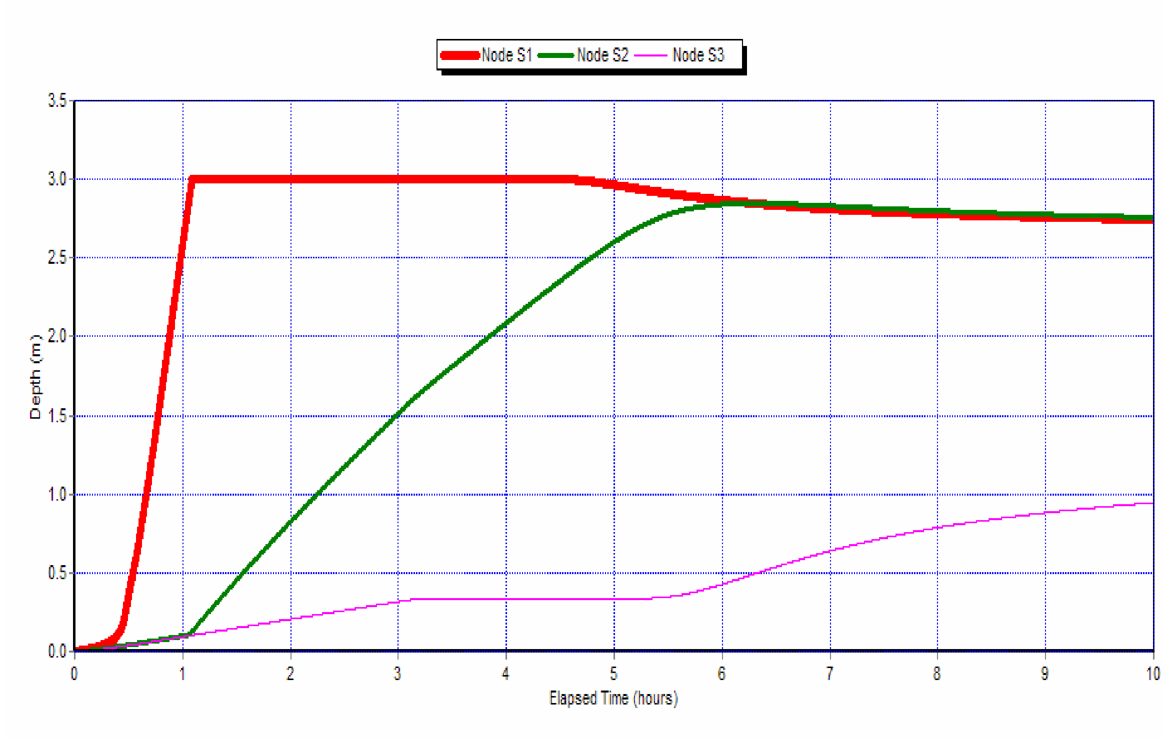


Figure 4.22 (b) Water depths attained in Tian Hu with square design rain - with external inflow.

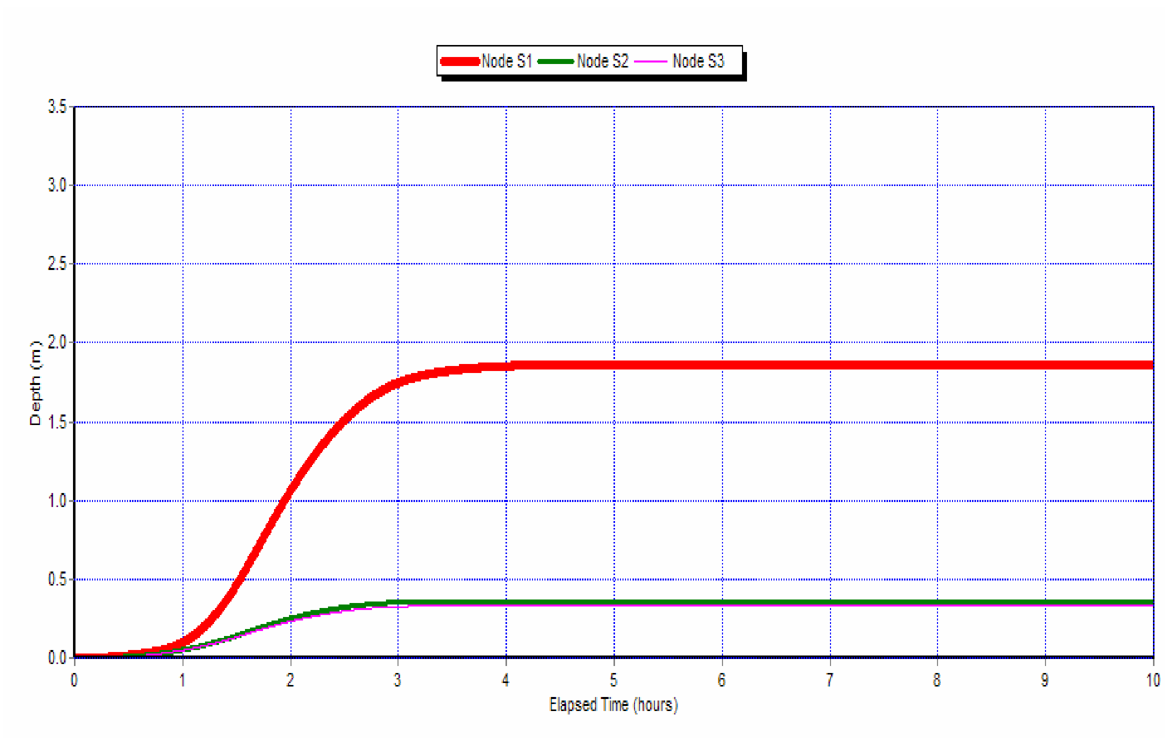


Figure 4.22 (c) Water depths attained in Tian Hu with triangular design rain - without external inflow.

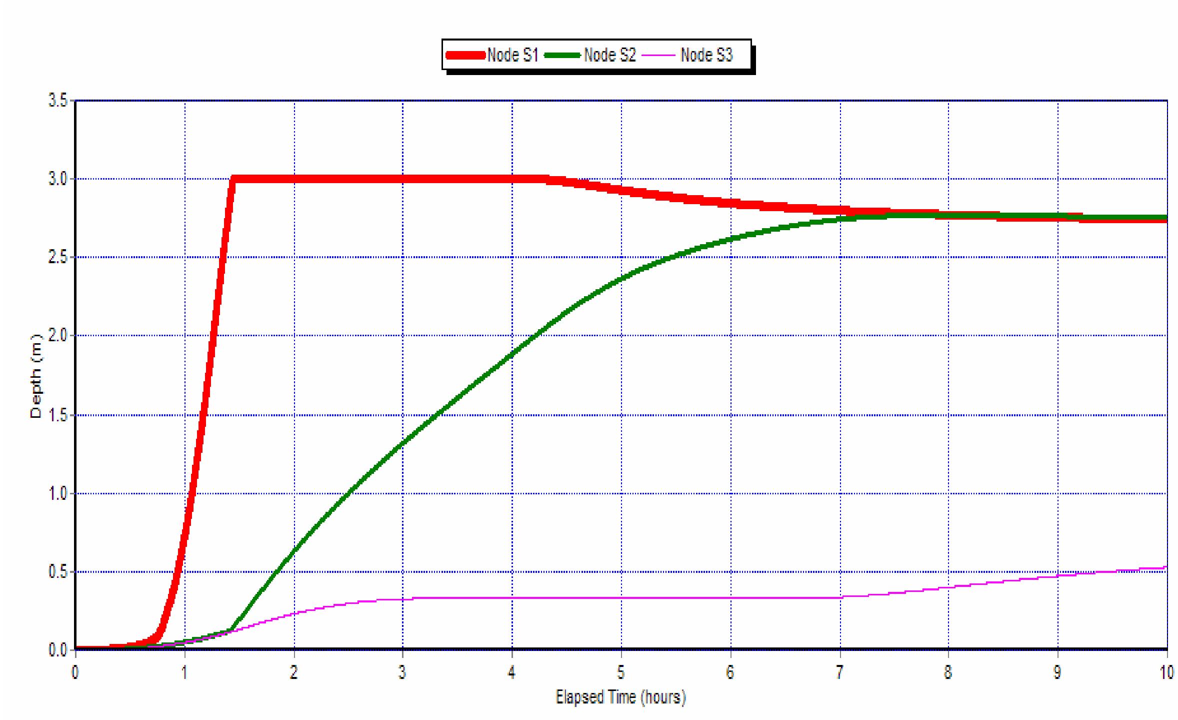


Figure 4.22 (d) Water depths attained in Tian Hu with triangular design rain - with external inflow.

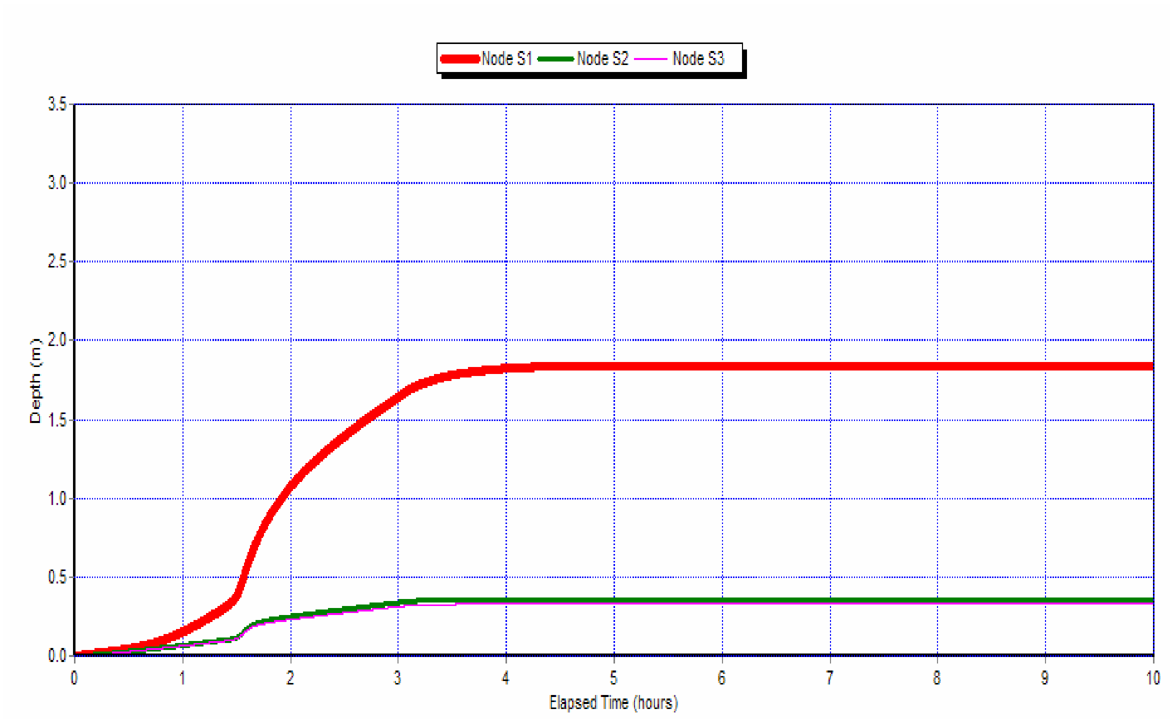


Figure 4.22 (e) Water depths attained in Tian Hu with normalized design rain - without external inflow.

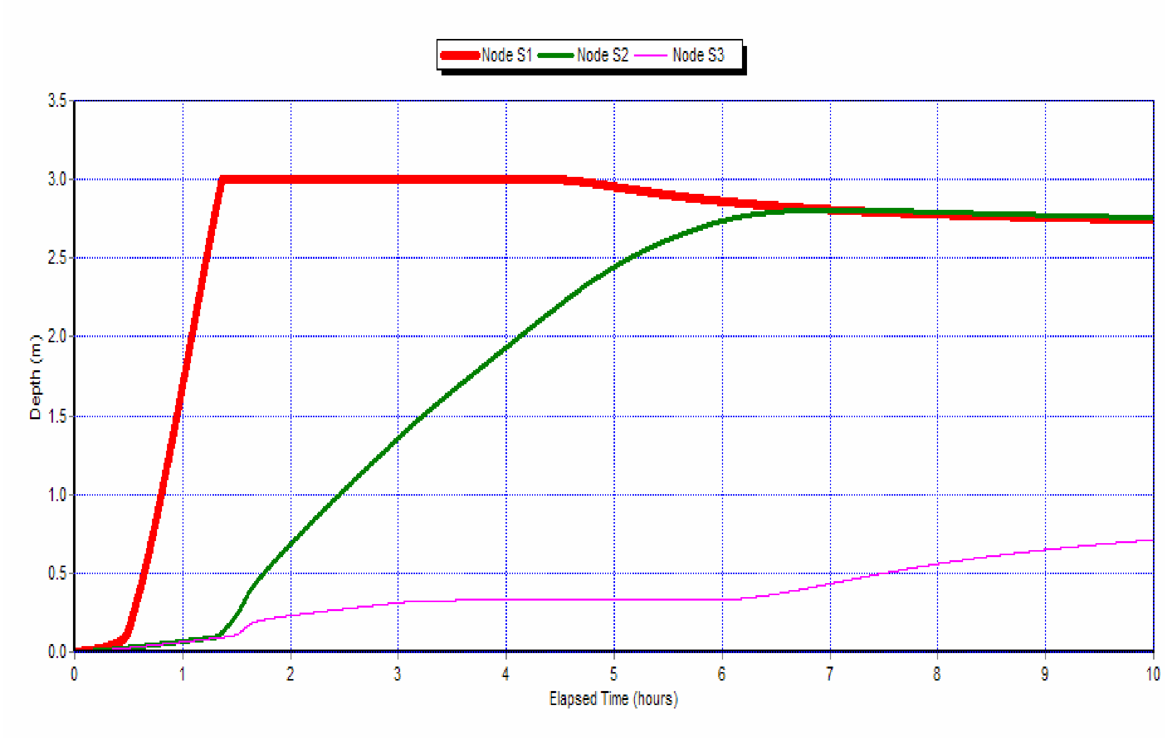
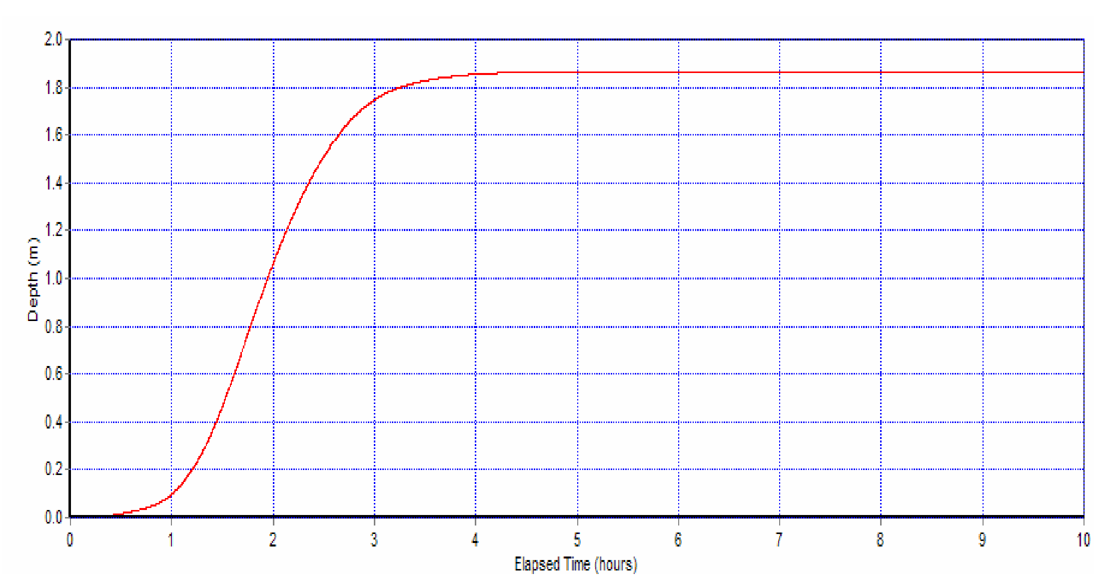
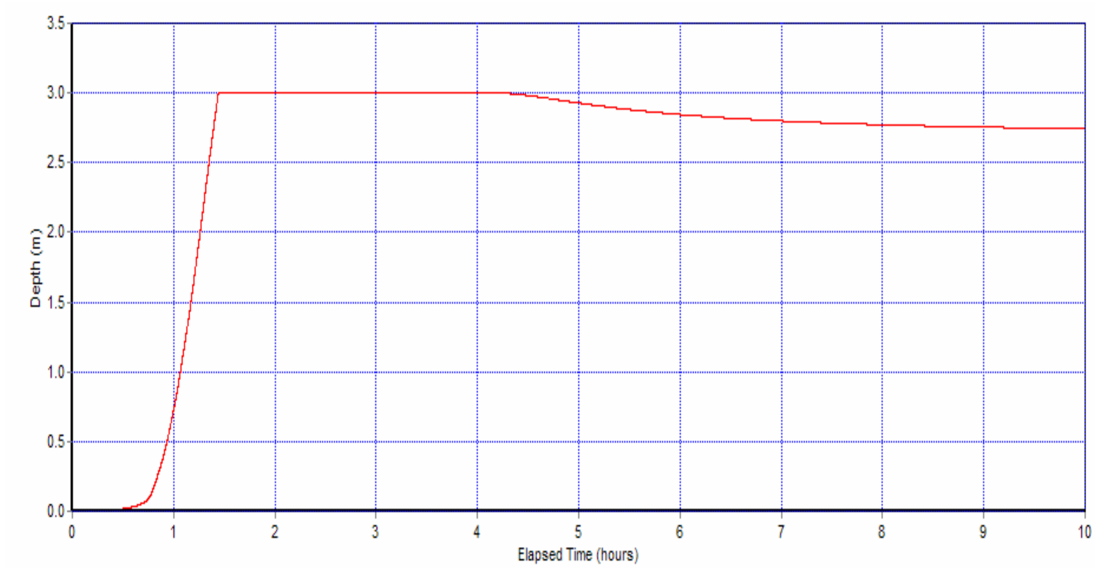


Figure 4.22 (f) Water depths attained in Tian Hu with normalized design rain - with external inflow.

In all three design rains the Sun is filled in approximately one and a half hour and the Moon will be filled five to six hours later. By comparing the cases with and without inflow it is seen that the inflow from Century Avenue Catchment will raise the water level in the Sun.
When excluding the inflow from Century Avenue Catchment the water level in the Sun will rise to 1.8 meters in four hours for the triangular design rain, see Figure 4.23 (a). With an added inflow the same level will be reached in approximately one hour and fifteen minutes, see Figure 4.23 (b).



4.23 (a) The water depth in the Sun and excluding external inflow from the Century Avenue Catchment.



4.23 (b) The water depth in the Sun and including the external inflow from the Century Avenue Catchment.

The total inflow to Tian Hu after one hour is 1.0 CMS but when adding the external inflow from Century Avenue Catchment the flow will reach 11 CMS. The difference can be observed by comparing Figure 4.23 (c) and (d).

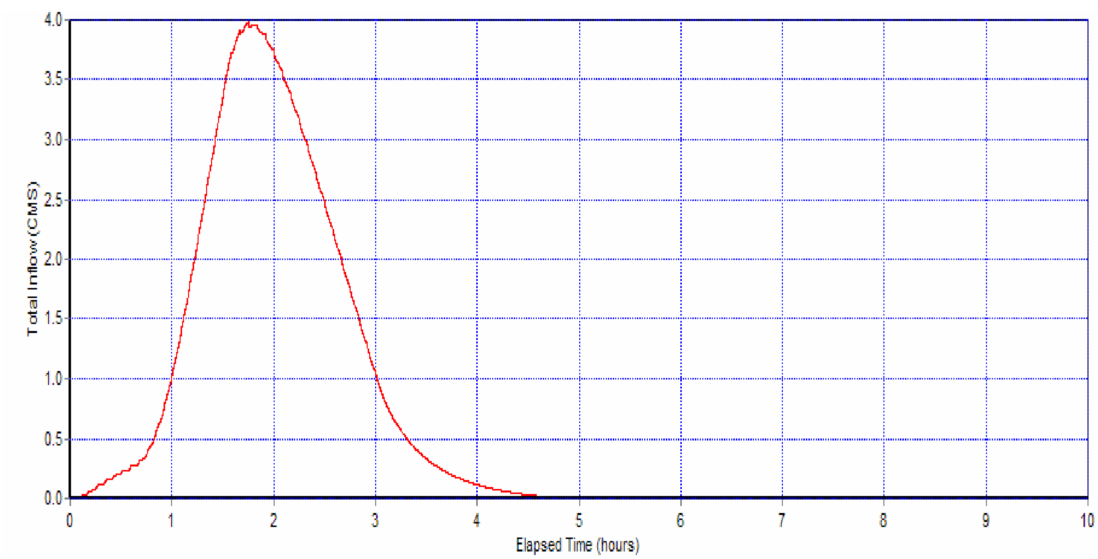


Figure 4.23 (c) The total Inflow to the Sun and excluding external inflow from the Century Avenue Catchment.

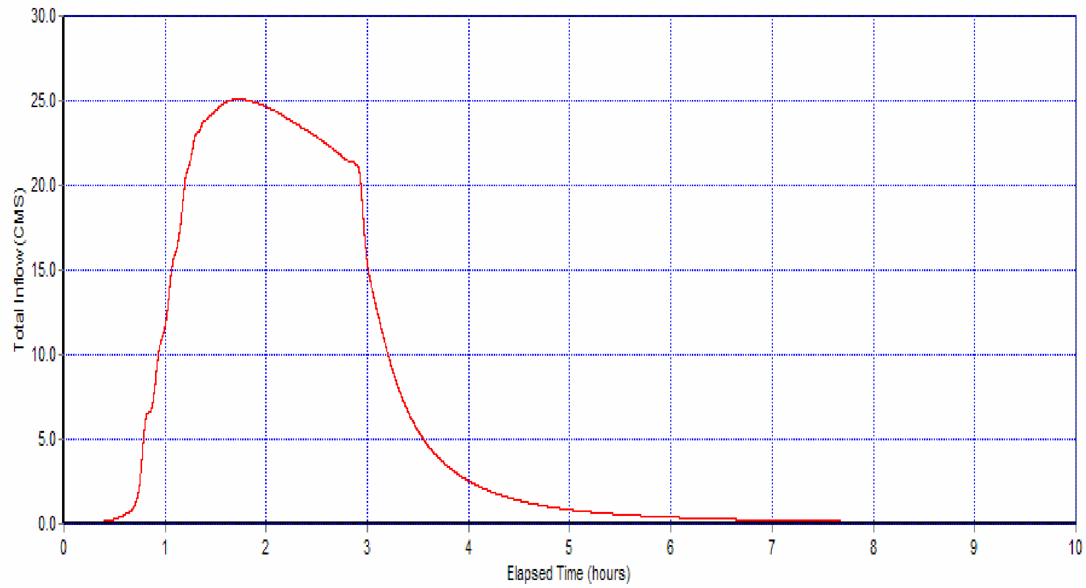


Figure 4.23 (d) The total inflow to the Sun and including external inflow from the Century Avenue Catchment.

The link between the storage units is restricted to a flow of 2 CMS, see Figure 4.24. Due to the lower inflow value of both the Moon and the Star the risk of flooding is reduced. When considering the flow path and the construction of Tian Hu, it is possible to imagine a higher flow into the Moon as water will spill over the embankments. A fast simulation with a higher flow allowed results in flooding of both Sun and Moon which in turn will result in an even higher water level in the Star.

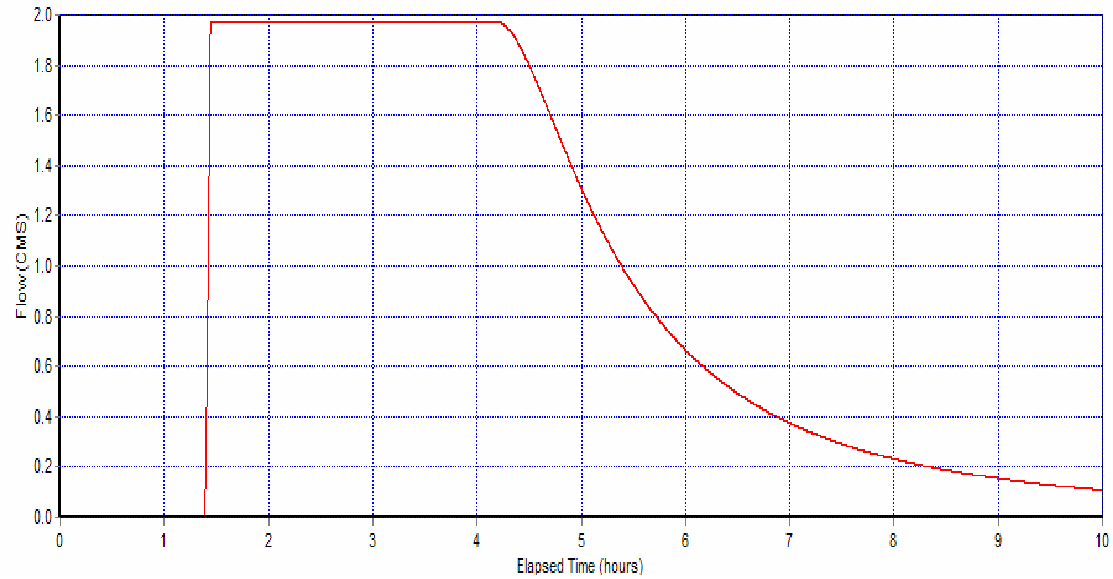


Figure 4.24 The simulated maximum flow of 2 CMS at the weir between the Sun and the Moon with triangular design rain.

4.3.3 Impact of Sediment Transport and Soil Erosion

When overland flow enters the lakes there will be consequences. The concern is the sediment load of Tian Hu. Frequently, some amount of sediments (loess from surrounded area) enters the lake due to powerful rainfalls during summer. It is of interest to prevent sediment runoff entering the lake as nutrients can be bound to suspended matters. Nutrients, like nitrogen and phosphorus are known to have deterioration of water quality due to rapid growth of organic matter and thus lead to considerably higher oxygen demand. The sediment build up do not only decrease the quality but a loss in storage capacity will be a consequence. Some suggestions to reduce the sediments load of Tian Hu are:

- Dredging
- Construction of an embankment
- Implementation of vegetation

Dredging is an operation which is carried out in water in order to minimize sediments. The process involves gathering bottom sediments and disposing them at a different location. Every fourth year this process will be done in Tian Hu according to Xifeng Water Authority. At current situation the sediment runoff around the lake can easily float into the three storages via small openings, see Figure 4.25 (a). Therefore introducing an embankment or some sort of an obstacle in line with the fence that goes round the man-made lake would be an alternative to prevent soil discharge into the lake.


(a)


(b)

Figure 4.25 (a) Small openings in line with the fence. (b) Soil erosion after a rainstorm in Tian Hu (Cheung, 2006).

Different kinds of plants and shrubs have long been recognized as an important mean of controlling soil erosion. Studies on vegetation to prevent soil erosion showed that vegetation will improve the soil condition and stability (Wang et al., 2007). For that reason to enhance the vegetation in the area would be a good way of preventing sediment discharge. But on the other hand vegetation is dependent on water supply and as the area is already dealing with issues of water deficiency this could be difficult to implement. The most convenient thing is to plant trees and bushes with abilities to both survive environments with low soil moisture content and weather of intense rain events. Vegetation is also a good mean to reduce evaporation from soils and water surfaces. Shrubs and grass have good qualities to improve soil conditions (Chen et al., 2007) while trees and larger vegetation reduce evaporation from free water surfaces.

The runoff from the subcatchments will provide approximately the same volume of water in all three design rains. Because of the higher peaks in rainfall intensity for the triangular and normalized design rain more water and higher speeds will be accumulated and it will be easier for material transportation to occur. The higher flows will most certain flush the sediments over the low curbs that exist around the lake. Because of the special characteristics of the soil at Tian Hu there does not have to be any heavy rainfall to cause erosion and sediment transportation. Rainstorms of less intensity and duration can have high impact on the vegetated slopes closest too the lakes, see Figure 4.25(b). It is also quite realistic to assume that sediments will be collected and end up in the lakes when there is a flood.

4.3.4 Utilization of Excess Water

When comparing the collected volume water in storage 4 (S4) with the maximum storage capacity of Tian Hu, see Figure 4.26, one can see that the wasted volume water in S4 is approximately five times larger than the storage volume of Tian Hu. This comparison proves that the Tian Hu construction is under dimensioned. This fact is of great importance and should be taken into consideration when dealing with future reservoir management in Xifeng district of Qingyang.

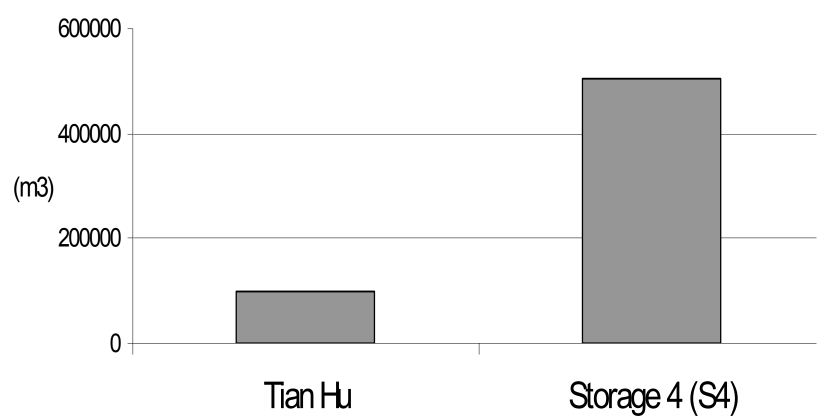


Figure 4.26 Comparison of average storage volume per year in Tian Hu and Storage 4 (S4).

The main purposes for constructing Tian Hu were to increase the amount of recreational areas and also to irrigate the crops in the surrounded area of the lakes. Regarding the Water Authority in Xifeng the amount of water used for irrigation is 2000 m^3 per year. This amount seems small as the excess water is estimated to 500 000 m^3 per year, hence one can conclude there are more than enough collected water for both irrigational and recreational purposes, respectively.

5 Conclusions

In following paragraphs each section begins with a short summary which includes the interesting parts of the results in section 4, and a final conclusion is stated at the end of each paragraph section.

5.1 Field Measurements

Field measurements are conducted to be able to create a realistic model of the Tian Hu Catchment. By comparing some calibration constants, b_0 and b_1, from the soil moisture tests it can confirm that the soil characteristics of Tian Hu are close to silt and clay. Although some tests show good results, other contradict them, more soil samples would be needed to get a better statistical basis. Infiltration tests give a good starting point when categorizing different subcatchments of Tian Hu. The tests confirm soils of harder or looser qualities will affect runoff quantities when running simulations in SWMM. Hence the final conclusions are:

- The field measurements show expected soil characteristics which are rich in clay and silt. Infiltration capacities also tend to fit these types of soils.

- The soil moisture measurements are of some importance when characterizing the subcatchments of Tian Hu.

- A more thorough planning and more sampling tests are necessary for future research. In order to obtain more accurate results a more modern method and instruments are necessary regarding measurements of infiltration and field capacity.

5.2 Overview of rainfall pattern during the years of 2000-2006

When running SWMM and obtaining runoff from the catchments the model needs different input parameters. The most crucial are precipitation and different properties for hydrologic components. Different analyses have been performed in SWMM to investigate the impact of different rainstorm events on both Century Avenue and Tian Hu Catchment. In order to represent the precipitation pattern of Qingyang city this study used daily rainfall pattern of 2000 to 2006. The interesting events during these years can be concluded to:

- The annual rainfall over the years is fairly even ranging between 490-600 mm.

- A noticeable exception of 800 mm of annual rainfall is occurring in 2003.

It is hard to see any patterns when observing annual rainfall distribution but when looking at monthly rainfall data it can be seen that a large amount, almost 70 % of the annual rain, is concentrating on the summer months of June-Sept.

Furthermore, this study uses 3-hours rainfall pattern in order to represent the heavy storms the city has experienced during the last couple of years. The interesting aspects regarding heavy rain events are:

- A noticeable increase of intensity in storms during the last four years (2003-2006).
- 64 mm/h with duration of three hours is the worst storm that has occurred in Qingyang.

5.3 SWMM Simulations

5.3.1 The Century Avenue Catchment

From the analyses of daily precipitation in the period of 2000 to 2006 an increase in heavy rainstorm can be noticed during last four years and by this it can be concluded that:

- These rainstorms will increase the risk of floods during 2003-2006.

Two flood scenarios in the Century Avenue Catchment are identified; when rain intensities reach levels higher than 61mm/h the system will be flooded as the downstream junctions and conduits reach their maximum capacities. The other scenario is depending on the rainfall distribution. Rainstorms of very high intensity over a short time will cause upstream junctions to flood. This is due to the accumulated water will reach maximum capacity in a few single junctions and conduits rather than of a gradual increase of water levels in the whole system. Hence the final conclusions are:

- Rain intensity of more than 61mm/h will flood the Century Avenue Catchment.
- Rainstorms with higher intensity than 61mm/h and, depending on the pattern of the rainstorm, can cause local floods close to the Century Square.

The simulations of both the daily precipitation data and the three design rains confirm that the maximum flows the system can handle are of 20 CMS. Flows higher than the mentioned value will cause floods. Simulations in SWMM also show that rainstorms with an even distribution will generate the largest flows. If the intensity reaches more than 60 mm/h and the duration is roughly one hour and a half, it will cause floods. Storms of high intensity peaks will also lead to higher flow peaks. This means that the upstream junctions run a higher risk of floods because it tends to ‘chock’ and clog the system. Hence the final conclusions are:

- The flow of generated runoff intensity that the Century Avenue Catchment can handle is 20 CMS.

- Rainstorms of at least 61mm/h with duration of one hour and a half will cause floods at Century Avenue.

5.3.2 The Tian Hu Catchment

The simulations with daily rainfall of 2000-2006 for Tian Hu Catchment show that the majority of the floods occur in the Sun. This is due to the external inflow, which is generated from the Century Avenue Catchment, constitutes as the greater input parameter into the reservoir. The moment for floods is mostly occurring during June and September every year and this is expected as this is the wet season of Qingyang and the Loess area in general. As previously mentioned, the rainfall during the last four years of analyses (2003-2006) showed an increase in intensity, and this explains the fact that the flood flows is nearly doubled as the earlier years (2000-2002). The final conclusions regarding daily rainfall simulations are:

- Daily rainfall show that the majority of the floods occur in the Sun reservoir and they often appeared during June to September.

- The higher rain intensity during 2003-2006 is the main reason why the flood water is doubled during these years.

Furthermore, the flood events from simulations of daily precipitation indicate overloading of the man-made lake Tian Hu and hence water gets wasted. By implementing a fourth storage unit (S4) in SWMM the volume of the wasted flood water can be quantified. The simulations show a volume of 420 000 – 550 000 m^3 is collected in S4 annually. This amount of excess water does also show that it is five times larger than the maximum volume (130 000 m^3) of the actual lake. Therefore one can conclude that:

- The existing construction of Tian Hu is under-designed.

- With larger storage capability there will be a higher irrigation potential.

The simulations of when excluding the external inflow from Century Avenue Catchment give an idea what impact adjacent overland flow have on the reservoirs. When using daily rainfall pattern the results show that the subcatchment runoff has little impact on the storage capacity and about 20-40 % of the reservoirs are filled annually. The impact of evaporation losses is noticeable when there is no external inflow from the Century Avenue Catchment. From the overland flow results evaporation loss of 1000 mm in water depth is discovered during the dry season. 1000 mm of water in Tian Hu is representing water losses of approximately 44 000 m^3 annually. The final conclusions are:

- Evaporation loss of 1000 mm in water depths and a volume of 44 000 m^3 is evaporating from the surface of Tian Hu annually.

- Although the adjacent soil areas do not have a decisive contribution to the storage capacity they should not be neglected regarding future reservoir management planning in Qingyang.

The interesting part when simulating with 3-hours rainfall on Tian Hu Catchment is to locate the time when the reservoirs reach their maximum capacity. The simulations from the three design rain pattern (square, triangular and normalized) show that all three lakes reach their maximum capacity after 6 hours. The final conclusions regarding 3-hours rainfall simulations:

- The Sun was filled after one hour
- The Moon was filled after three hours
- The Star was filled after four hours
- The time when all three storages of Tian Hu reach their maximum capacity is after 6 hours

5.3 Final Conclusions

The field measurements show expected soil properties around Tian Hu which are silt and clay. The measured infiltration rate show similar trend as the general infiltration rate of loess soil. It is necessary to implement more sampling tests and use modern instruments in order to obtain more accurate results for future research.

The overview of the rainfall pattern during 2000-2006 of Qingyang is showing that the annual rainfall over the years is fairly even ranging between 490-600 mm. A noticeable exception of 800 mm of annual rainfall is occurring in 2003. The monthly data show that the majority of the rain is falling in the summer months of June to September. Interesting aspects regarding heavy rain events are an increase of intensity in storms during the last four years (2003-2006) and a storm of 64 mm/h with duration of three hours is the worst storm that has occurred in Qingyang.

The simulations of different rain events in the numerical model SWMM show different impacts on the two catchments of Century Avenue and Tian Hu. The simulations with 3-hours rainfall confirm that the maximum rain intensity the Century Avenue Catchment can handle is below 61 mm/h. Furthermore, the maximum generated runoff the conveyance system can handle of Century Avenue is 20 CMS. The flow generated from the Century Avenue Catchment carries on down to Tian Hu and provides as the major input to the artificial lake. Simulations of daily rainfall pattern resulted in more floods in the Sun reservoir than the other two (Moon and Star). The floods in the Sun reservoir usually appear during June to September. The excess water simulated and gathered in the imaginary storage S4, from the daily rainfall simulations, does also prove that it is five times larger than the volume of the actual lake. This strengthens the fact that the existing construction of Tian Hu is under-designed. The impact of overland flow generated from surrounded subcatchments is contributing 20-40 % of the reservoir capacity, thus overland runoff should not be neglected and be included when planning future artificial lakes in Qingyang. The annual evaporation loss is estimated to a volume of 44 000 m^3, which corresponds to a decrease of one meter in water depths of Tian Hu during the dry season. Finally when simulating with extreme rain scenarios the Tian Hu is reaching maximum water levels after 6 hours.

The simulation results and conclusions stated in this study are derived from facts but also to some extent from approximation and simplified assumptions. The simulation results in this study can vary from the actual situations due to many external factors and they are mentioned in the sources of error in the methodology section. Therefore this study could be considered as a preliminary study for future planning of rainwater harvesting systems in Xifeng district of Qingyang.

6 Recommendations for Future Development

- Restriction the inflow of water from Century Square would reduce the risk of floods. The water from the square is the main collector of water, and if this area could act as detention storage, the flow to the Tian Hu would be more modest. By implementing a detention storage a lag in water flow from Century Square will occur, thus the impact on Tian Hu and the surrounding area will be less profound. The flood impact on Century Square will also become smaller and the risk of flooding neighbouring streets and squares will decrease.

- Alternatives to the above statement are to design the pipe system for larger flows. In turn it will demand interference on Tian Hu catchment where the lakes need to be modified: either by increasing the storage capacity or increase the possibilities for water to flow between the lakes. This alternative also demands a better management of the water levels in Tian Hu. If the lakes are emptied before an expected rainstorm the present storage should be able to handle the amount of rainfall.

- To cope with the existing rainfall pattern of Qingyang a larger reservoir than the existing Tian Hu is needed. This in order to make use of rainwater harvesting to its maximum and preventing water to get wasted as this region is already suffering from water deficiency.

- The sediment transport from surrounded soil areas of Tian Hu can be avoided or at least greatly reduced by either constructing an embankment around the lake or plant more shrubs and miscellaneous vegetation which can cope with the existing weather and climate condition of Gansu.

- Overland flow should not be neglected when regarding future reservoir constructions management.

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APPENDICES

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APPENDIX A

Input Parameters in SWMM

(a) Input parameters for the Tian Hu Catchment with Recd. Freq = 0.05

```
[OPTIONS]
 FLOW_UNITS              CMS
 INFILTRATION            HORTON
 FLOW_ROUTING            KINWAVE
 START_DATE              07/01/2004
 START_TIME              00:00:00
 REPORT_START_DATE       07/01/2004
 REPORT_START_TIME       00:00:00
 END_DATE                07/01/2004
 END_TIME                10:00:00
 SWEEP_START             01/01
 SWEEP_END               12/31
 DRY_DAYS                0
 REPORT_STEP             00:00:01
 WET_STEP                00:00:01
 DRY_STEP                00:00:01
 ROUTING_STEP            0:00:01
 ALLOW_PONDING           NO
 INERTIAL_DAMPING        PARTIAL
 VARIABLE_STEP           0.75
 LENGTHENING_STEP        0
 MIN_SURFAREA            0
 NORMAL_FLOW_LIMITED     NO
 SKIP_STEADY_STATE       NO
 IGNORE_RAINFALL         NO

[FILES]
 SAVE OUTFLOWS "C:\Documents and Settings\Martin Schjånberg\Skrivbord\EXJ\Data\Model Data\Swmm projekt\Catchment Tian Hu\outflowTianHu20

[EVAPORATION]
;;Type          Parameters
;;----------------------------
  TIMESERIES    Evaoration

[RAINGAGES]
;;                  Rain      Recd.  Snow   Data       Source           Station    Rain
;;Name              Type      Freq.  Catch  Source     Name             ID         Units
;;----------------------------------------------------------------------------------------
  Gage1             INTENSITY 0:05   1.0    TIMESERIES InflowTriangle

[SUBCATCHMENTS]
;;                                                   Total    Pcnt.             Pcnt.    Curb     Snow
;;Name              Raingage         Outlet          Area     Imperv   Width    Slope    Length   Pack
;;--------------------------------------------------------------------------------------------------
  Sub3              Gage1            S1              1.6      100      500      100      0
  Sub4              Gage1            S2              1.4      100      500      0.1      0
  Sub5              Gage1            S3              1.4      100      500      0.1      0
  Sub14             Gage1            Outfall1        5        5        500      0.5      0
  Sub15             Gage1            S1              8.4      5        500      0.5      0
  Sub16             Gage1            Outfall1        1.4      40       200      0.5      0
  Sub17             Gage1            S1              4.2      15       200      0.5      0
  Sub18             Gage1            Outfall1        2.8      10       200      0.5      0
  Sub19             Gage1            S2              0.7      3        75       0.5      0
  Sub20             Gage1            S3              0.5      2        50       0.5      0
  Sub21             Gage1            Outfall1        13.3     5        1000     0.5      0
  Sub22             Gage1            Outfall1        1.4      75       20       0.5      0

[SUBAREAS]
;;Subcatchment      N-Imperv   N-Perv     S-Imperv   S-Perv     PctZero    RouteTo    PctRouted
;;-----------------------------------------------------------------------------------------
  Sub3              0.01       0.1        0          0          100        IMPERVIOUS 100
  Sub4              0.01       0.1        0.05       0.05       100        IMPERVIOUS 100
  Sub5              0.01       0.1        0.05       0.05       25         IMPERVIOUS 100
  Sub14             0.01       0.1        1          5          25         OUTLET
  Sub15             0.01       0.1        1          5          25         OUTLET
  Sub16             0.01       0.1        1          5          25         OUTLET
  Sub17             0.01       0.1        1          5          25         PERVIOUS   100
  Sub18             0.01       0.1        1          5          25         PERVIOUS   100
  Sub19             0.01       0.1        1          5          25         IMPERVIOUS 70
  Sub20             0.01       0.1        1          5          25         IMPERVIOUS 100
  Sub21             0.01       0.1        1          5          25         PERVIOUS   100
  Sub22             0.01       0.1        1          5          20         IMPERVIOUS 100

[INFILTRATION]
;;Subcatchment      MaxRate    MinRate    Decay      DryTime    MaxInfil
;;-----------------------------------------------------------------------
  Sub3              3.0        0.5        4          7          0
  Sub4              3.0        0.5        4          7          0
  Sub5              3.0        0.5        4          7          0
  Sub14             60         5          4          7          0
  Sub15             60         5          4          7          0
  Sub16             30         5          4          7          0
  Sub17             60         5          4          7          0
  Sub18             60         5          4          7          0
  Sub19             20         10         4          7          0
  Sub20             20         10         4          7          0
  Sub21             60         5          4          7          0
  Sub22             3.0        0.5        4          7          0

[AQUIFERS]
;;                  Por-   Wilt   Field  Hyd    Cond   Tens   Upper  Lower  Lower  Bottom Water  Upper
;;Name              osity  Point  Capac  Cond   Slope  Slope  Evap   Evap   Loss   Elev   Table  Moist
;;--------------------------------------------------------------------------------------------------
  Inf3              0.5    0.14   0.30   0.66   10.0   15.0   0.35   14.0   0.002  0.0    10.0   0.18
  Inf4              0.5    0.14   0.3    0.66   10.0   15.0   0.35   14.0   0.002  0.0    10.0   0.14
  JP3               0.5    0.14   0.3    0.66   10.0   15.0   0.35   14.0   0.002  0.0    10.0   0.15
```

```
;;                                                     Surf                                      Fixed  GW
;;Subcatchment     Aquifer          Node               Elev   A1     B1     A2     B2     A3     Depth  Elev
;;--------------------------------------------------------------------------------------------------------------
  Sub14            Inf4             Outfall1           0      0      0      0      0      0      0
  Sub15            JP3              Outfall1           0      0      0      0      0      0      0
  Sub16            Inf3             Outfall1           0      0      0      0      0      0      0
  Sub17            JP3              Outfall1           0      0      0      0      0      0      0
  Sub18            JP3              Outfall1           0      0      0      0      0      0      0
  Sub19            Inf3             Outfall1           0      0      0      0      0      0      0
  Sub20            Inf3             Outfall1           0      0      0      0      0      0      0
  Sub21            Inf4             Outfall1           0      0      0      0      0      0      0

[OUTFALLS]
;;                 Invert     Outfall    Stage/Table      Tide
;;Name             Elev.      Type       Time Series      Gate
;;-------------------------------------------------------------
  Outfall1         96         FREE                        NO

[STORAGE]
;;                 Invert   Max.     Init.    Shape      Shape                          Ponded   Evap.
;;Name             Elev.    Depth    Depth    Curve      Parameters                     Area     Frac.
;;----------------------------------------------------------------------------------------------------
  S1               100.6    3        0        TABULAR    Sunlake                        0        1
  S2               97.5     3        0        TABULAR    Moonlake                       0        0
  S3               96.3     2.2      0        TABULAR    Starlake2                      0        0
  S4               0        100      0        TABULAR    Fusksjö                        0        0

[WEIRS]
;;                 Inlet            Outlet                            Crest      Disch.     Flap End        End
;;Name             Node             Node             Type             Height     Coeff.     Gate Coeff.     Con.
;;--------------------------------------------------------------------------------------------------------------
  1                S1               S2               TRANSVERSE       2.7        1.2        NO   0          2
  2                S2               S3               TRANSVERSE       2.7        1.2        NO   0          2
  3                S3               S4               TRANSVERSE       2          1.2        NO   0          2

[XSECTIONS]
;;Link             Type         Geom1        Geom2        Geom3        Geom4        Barrels
;;-----------------------------------------------------------------------------------------
  1                RECT_OPEN    3            10           0            0
  2                RECT_OPEN    3            10           0            0
  3                RECT_OPEN    2.2          10           0            0

[INFLOWS]
;;                                                     Param    Units    Scale    Baseline
;;Node             Parameter        Time Series        Type     Factor   Factor   Value
;;------------------------------------------------------------------------------------------
  S1               FLOW             InflowTriangle     FLOW     1.0      1.0

[CURVES]
```

```
;;Name             Type       X-Value    Y-Value
;;-----------------------------------------------
  Sunlake          Storage    0          10000
  Sunlake                     2          14000
  Sunlake                     3          16000

  Moonlake         Storage    0          10000
  Moonlake                    1          12000
  Moonlake                    3          14000

  Starlake         Storage    0          10000
  Starlake                    1          12000
  Starlake                    3          14000

  Starlake2        Storage    0          10000
  Starlake2                   1          12000
  Starlake2                   2          14000

  Fusksjö          Storage    0          100000000
  Fusksjö                     50         10000000
  Fusksjö                     100        1000000
```

```
;;                                                  Surf                                                       Fixed  GW
;;Subcatchment    Aquifer          Node             Elev    A1      B1      A2      B2      A3      Depth  Elev
;;-----------------------------------------------------------------------------------------------------------------
  Sub14           Inf4             Outfall1         0       0       0       0       0       0       0
  Sub15           JP3              Outfall1         0       0       0       0       0       0       0
  Sub16           Inf3             Outfall1         0       0       0       0       0       0       0
  Sub17           JP3              Outfall1         0       0       0       0       0       0       0
  Sub18           JP3              Outfall1         0       0       0       0       0       0       0
  Sub19           Inf3             Outfall1         0       0       0       0       0       0       0
  Sub20           Inf3             Outfall1         0       0       0       0       0       0       0
  Sub21           Inf4             Outfall1         0       0       0       0       0       0       0

[OUTFALLS]
;;                Invert     Outfall    Stage/Table      Tide
;;Name            Elev.      Type       Time Series      Gate
;;--------------------------------------------------------------
  Outfall1        96         FREE                        NO

[STORAGE]
;;                Invert   Max.     Init.    Shape      Shape                          Ponded   Evap.
;;Name            Elev.    Depth    Depth    Curve      Parameters                     Area     Frac.
;;-----------------------------------------------------------------------------------------------------
  S1              100.6    3        0        TABULAR    Sunlake                        0        1
  S2              97.5     3        0        TABULAR    Moonlake                       0        0
  S3              96.3     2.2      0        TABULAR    Starlake2                      0        0
  S4              0        100      0        TABULAR    Fusksjö                        0        0

[WEIRS]
;;                Inlet            Outlet                             Crest      Disch.     Flap End        End
;;Name            Node             Node             Type              Height     Coeff.     Gate Coeff.     Con.
;;----------------------------------------------------------------------------------------------------------------
  1               S1               S2               TRANSVERSE        2.7        1.2        NO   0          2
  2               S2               S3               TRANSVERSE        2.7        1.2        NO   0          2
  3               S3               S4               TRANSVERSE        2          1.2        NO   0          2

[XSECTIONS]
;;Link            Type         Geom1        Geom2        Geom3        Geom4        Barrels
;;--------------------------------------------------------------------------------------
  1               RECT_OPEN    3            10           0            0
  2               RECT_OPEN    3            10           0            0
  3               RECT_OPEN    2.2          10           0            0

[INFLOWS]
;;                                                  Param    Units    Scale    Baseline
;;Node            Parameter        Time Series      Type     Factor   Factor   Value
;;-------------------------------------------------------------------------------------
  S1              FLOW             InflowTriangle   FLOW     1.0      1.0

[CURVES]

;;Name            Type       X-Value    Y-Value
;;-----------------------------------------------
  Sunlake         Storage    0          10000
  Sunlake                    2          14000
  Sunlake                    3          16000

  Moonlake        Storage    0          10000
  Moonlake                   1          12000
  Moonlake                   3          14000

  Starlake2       Storage    0          10000
  Starlake2                  1          12000
  Starlake2                  2          14000

  Fusksjö         Storage    0          100000000
  Fusksjö                    50         10000000
  Fusksjö                    100        1000000
```

APPENDIX A

(b) Input parameters for the Tian Hu Catchment with Recd. Freq = 1.00

```
[OPTIONS]
 FLOW_UNITS           CMS
 INFILTRATION         HORTON
 FLOW_ROUTING         KINWAVE
 START_DATE           01/01/2005
 START_TIME           00:00:00
 REPORT_START_DATE    01/01/2005
 REPORT_START_TIME    00:00:00
 END_DATE             12/31/2005
 END_TIME             00:00:00
 SWEEP_START          01/01
 SWEEP_END            12/31
 DRY_DAYS             0
 REPORT_STEP          01:00:00
 WET_STEP             01:00:00
 DRY_STEP             01:00:00
 ROUTING_STEP         0:01:00
 ALLOW_PONDING        NO
 INERTIAL_DAMPING     PARTIAL
 VARIABLE_STEP        0.75
 LENGTHENING_STEP     0
 MIN_SURFAREA         0
 NORMAL_FLOW_LIMITED  NO
 SKIP_STEADY_STATE    NO
 IGNORE_RAINFALL      NO

[FILES]
 SAVE OUTFLOWS "C:\Documents and Settings\Martin Schjånberg\Skrivbord\EXJ\Data\Model Data\Swmm projekt\Catchment Tian Hu\outflowTianHu2005.TXT"

[EVAPORATION]
;;Type         Parameters
;;----------------------
  TIMESERIES   Evaoration

[RAINGAGES]
;;               Rain      Recd.  Snow   Data       Source           Station    Rain
;;Name           Type      Freq.  Catch  Source     Name             ID         Units
;;-------------------------------------------------------------------------------------
  Gage1          INTENSITY 1:00   1.0    TIMESERIES 2000till2006
```

APPENDIX A

(c) Input parameters for the Century Avenue Catchment with Recd. Freq = 0.05

```
[OPTIONS]
 FLOW_UNITS              CMS
 INFILTRATION            HORTON
 FLOW_ROUTING            DYNWAVE
 START_DATE              07/01/2004
 START_TIME              00:00:00
 REPORT_START_DATE       07/01/2004
 REPORT_START_TIME       00:00:00
 END_DATE                07/01/2004
 END_TIME                12:00:00
 SWEEP_START             01/01
 SWEEP_END               12/31
 DRY_DAYS                0
 REPORT_STEP             00:01:00
 WET_STEP                00:00:01
 DRY_STEP                00:00:01
 ROUTING_STEP            0:00:01
 ALLOW_PONDING           NO
 INERTIAL_DAMPING        PARTIAL
 VARIABLE_STEP           0.75
 LENGTHENING_STEP        0
 MIN_SURFAREA            0
 NORMAL_FLOW_LIMITED     NO
 SKIP_STEADY_STATE       NO
 IGNORE_RAINFALL         NO

[FILES]
 SAVE OUTFLOWS "C:\Documents and Settings\Martin Schjånberg\Skrivbord\Results\TianHu\HeavySq1minut.TXT"

[RAINGAGES]
;;                 Rain      Recd.  Snow   Data       Source           Station    Rain
;;Name             Type      Freq.  Catch  Source     Name             ID         Units
;;----------------------------------------------------------------------------------------
  Gage1            INTENSITY 0:05   1.0    TIMESERIES HeavyRain

[SUBCATCHMENTS]
;;                                                  Total    Pcnt.             Pcnt.    Curb     Snow
;;Name             Raingage         Outlet          Area     Imperv   Width    Slope    Length   Pack
;;-----------------------------------------------------------------------------------------------------
  Sub10            Gage1            J7              2        98       50       0.5      0
  Sub11            Gage1            J8              2        98       50       0.5      0
  Sub12            Gage1            J9              2        98       50       0.5      0
  Sub13            Gage1            J10             2        98       50       0.5      0
  Sub14            Gage1            J11             2        98       50       0.5      0
  Sub3             Gage1            J1              50       98       500      0.5      0
  Sub4             Gage1            J1              2        98       50       0.78     0
  Sub5             Gage1            J2              2        98       50       0.5      0
 Sub6             Gage1            J3              2        98       50       0.5      0
 Sub7             Gage1            J4              2        98       50       0.5      0
 Sub8             Gage1            J5              2        98       50       0.5      0
 Sub9             Gage1            J6              2        98       50       0.5      0
 Sub15            Gage1            J3              50       98       500      0.5      0

[SUBAREAS]
;;Subcatchment   N-Imperv   N-Perv     S-Imperv   S-Perv     PctZero    RouteTo    PctRouted
;;--------------------------------------------------------------------------------------------
 Sub10           0.01       0.1        0.5        0.5        30         IMPERVIOUS 100
 Sub11           0.01       0.1        0.5        0.5        30         IMPERVIOUS 100
 Sub12           0.01       0.1        0.5        0.5        30         IMPERVIOUS 100
 Sub13           0.01       0.1        0.5        0.5        30         IMPERVIOUS 100
 Sub14           0.01       0.1        0.5        0.5        30         IMPERVIOUS 100
 Sub3            0.014      0.1        0.5        0.5        30         IMPERVIOUS 100
 Sub4            0.01       0.1        0.5        0.5        30         IMPERVIOUS 100
 Sub5            0.01       0.1        0.5        0.5        30         IMPERVIOUS 100
 Sub6            0.01       0.1        0.5        0.55       30         IMPERVIOUS 100
 Sub7            0.01       0.1        0.5        0.5        30         IMPERVIOUS 100
 Sub8            0.01       0.1        0.5        0.5        30         IMPERVIOUS 100
 Sub9            0.01       0.1        0.5        0.5        30         IMPERVIOUS 100
 Sub15           0.014      0.1        0.5        0.5        25         IMPERVIOUS 100

[INFILTRATION]
;;Subcatchment   MaxRate    MinRate    Decay      DryTime    MaxInfil
;;--------------------------------------------------------------------
 Sub10           3.0        0.5        4          7          0
 Sub11           3.0        0.5        4          7          0
 Sub12           3.0        0.5        4          7          0
 Sub13           3.0        0.5        4          7          0
 Sub14           3.0        0.5        4          7          0
 Sub3            3.0        0.5        4          7          0
 Sub4            3.0        0.5        4          7          0
 Sub5            3.0        0.5        4          7          0
 Sub6            3.0        0.5        4          7          0
 Sub7            3.0        0.5        4          7          0
 Sub8            3.0        0.5        4          7          0
 Sub9            3.0        0.5        4          7          0
 Sub15           3.0        0.5        4          7          0

[JUNCTIONS]
```

```
[JUNCTIONS]
;;               Invert     Max.       Init.      Surcharge  Ponded
;;Name           Elev.      Depth      Depth      Depth      Area
;;-------------------------------------------------------------------------
  J1             1416       3          0          0          2000
  J2             1412       3          0          0          2000
  J3             1408       3          0          0          2000
  J4             1404       3          0          0          2000
  J5             1400       3          0          0          2000
  J5             1400       3          0          0          2000
  J6             1396       3          0          0          2000
  J7             1392       3          0          0          2000
  J8             1388       3          0          0          2000
  J9             1384       3          0          0          2000
  J10            1380       3          0          0          2000
  J11            1376       3          0          0          2000

[OUTFALLS]
;;               Invert     Outfall    Stage/Table      Tide
;;Name           Elev.      Type       Time Series      Gate
;;--------------------------------------------------------------
  Outfall1       1370       FREE                        NO

[CONDUITS]
;;               Inlet            Outlet                      Manning    Inlet      Outlet     Init.      Maximum
;;Name           Node             Node             Length     N          Height     Height     Flow       Flow
;;--------------------------------------------------------------------------------------------------------------------
  C1             J1               J2               440        0.013      0          0          0          0
  C2             J2               J3               440        0.013      0          0          0          0
  C3             J3               J4               440        0.013      0          0          0          0
  C4             J4               J5               440        0.013      0          0          0          0
  C5             J5               J6               440        0.013      0          0          0          0
  C6             J6               J7               440        0.013      0          0          0          0
  C7             J7               J8               440        0.013      0          0          0          0
  C8             J8               J9               440        0.013      0          0          0          0
  C9             J9               J10              440        0.013      0          0          0          0
  C10            J10              J11              440        0.013      0          0          0          0
  C11            J11              Outfall1         400        0.01       0          0          0          0

[XSECTIONS]
;;Link           Type         Geom1      Geom2      Geom3      Geom4      Barrels
;;----------------------------------------------------------------------------------
  C1             CIRCULAR     2.2        0          0          0          1
  C2             CIRCULAR     2.2        0          0          0          1
  C3             CIRCULAR     2.2        0          0          0          1
  C4             CIRCULAR     2.2        0          0          0          1
  C5             CIRCULAR     2.2        0          0          0          1
  C6             CIRCULAR     2.2        0          0          0          1
  C7             CIRCULAR     2.2        0          0          0          1
  C8             CIRCULAR     2.2        0          0          0          1
  C9             CIRCULAR     2.2        0          0          0          1
  C10            CIRCULAR     2.2        0          0          0          1
  C11            CIRCULAR     2.2        0          0          0          1

[CURVES]
;;Name           Type       X-Value    Y-Value
;;--------------------------------------------------
  Sunlake        Storage    0          22000
  Sunlake                   3          21900

  Moonlake       Storage    0          13000
  Moonlake                  3          12900

  Starlake       Storage    0          11000
  Starlake                  2          10900
```

APPENDIX A

(d) Input parameters for the Century Avenue Catchment with Recd. Freq = 1.00

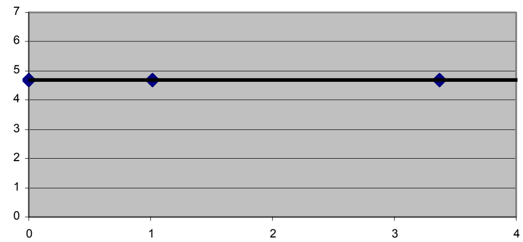
```
[OPTIONS]
 FLOW_UNITS           CMS
 INFILTRATION         HORTON
 FLOW_ROUTING         KINWAVE
 START_DATE           01/01/2005
 START_TIME           00:00:00
 REPORT_START_DATE    01/01/2005
 REPORT_START_TIME    00:00:00
 END_DATE             12/31/2005
 END_TIME             00:00:00
 SWEEP_START          01/01
 SWEEP_END            12/31
 DRY_DAYS             0
 REPORT_STEP          01:00:00
 WET_STEP             00:01:00
 DRY_STEP             00:01:00
 ROUTING_STEP         0:01:00
 ALLOW_PONDING        NO
 INERTIAL_DAMPING     PARTIAL
 VARIABLE_STEP        0.75
 LENGTHENING_STEP     0
 MIN_SURFAREA         0
 NORMAL_FLOW_LIMITED  NO
 SKIP_STEADY_STATE    NO
 IGNORE_RAINFALL      NO

[FILES]
 SAVE OUTFLOWS "C:\Documents and Settings\Martin Schjånberg\Skrivbord\EXJ\Data\Model Data\Swmm projekt\Catchment to determine inflow\outflowJun.TXT"
 SAVE OUTFLOWS "C:\Documents and Settings\Martin Schjånberg\Skrivbord\2006 okt - 2006 okt\ouflow2.TXT"

[RAINGAGES]
;;               Rain      Recd.  Snow   Data       Source           Station    Rain
;;Name           Type      Freq.  Catch  Source     Name             ID         Units
;;-------------------------------------------------------------------------------------
 Gage1           INTENSITY 1:00   1.0    TIMESERIES 2000till2006
```

APPENDIX B

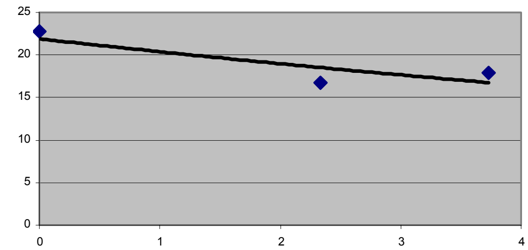
Infiltration rates at Tian Hu

The function of Infiltration rate (mm/hr) over time (hr) in INF1 – INF4

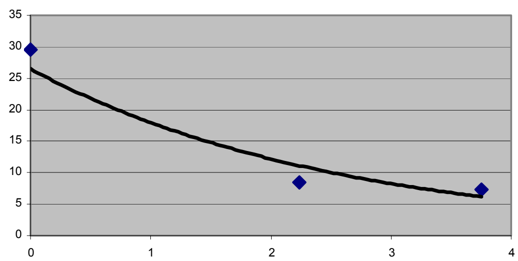
INF 1



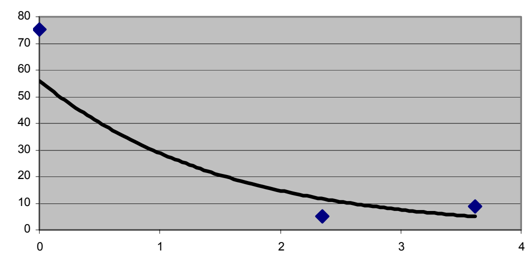
INF 3



INF 2



INF 4



APPENDIX C

SWMM's status reports in 2000-2006

2000

EPA STORM WATER MANAGEMENT MODEL - VERSION 5.0 (Build 5.0.008)

****

Analysis Options

****

Flow Units	CMS
Infiltration Method	HORTON
Flow Routing Method	KINWAVE
Starting Date	JAN-01-2000 00:00:00
Ending Date	DEC-31-2000 00:00:00
Antecedent Dry Days	0.0
Report Time Step	01:00:00
Wet Time Step	00:01:00
Dry Time Step	00:01:00
Routing Time Step	60.00 sec

****

Runoff Quantity Continuity	Volume hectare-m	Depth mm
Total Precipitation	56.815	465.700
Evaporation Loss	0.000	0.000
Infiltration Loss	0.331	2.712
Surface Runoff	56.342	461.819
Final Surface Storage	0.044	0.358
Continuity Error (%)	0.174	

****

Flow Routing Continuity	Volume hectare-m	Volume Mliters
Dry Weather Inflow	0.000	0.000
Wet Weather Inflow	56.277	562.775
Groundwater Inflow	0.000	0.000
RDII Inf	0.000	0.000
External Inflow	0.000	0.000
External Outflow	56.305	563.059
Surface Flooding	0.000	0.000
Evaporation Loss	0.000	0.000
Initial Stored Volume	0.000	0.000
Final Stored Volume	0.000	0.000
Continuity Error (%)	-0.050	

****

Subcatchment Runoff Summary

****

Subcatchment	Total Precip mm	Total Runon mm	Total Evap mm	Total Infil mm	Total Runoff mm	Peak Runoff CMS	Runoff Coeff
Sub10	465.699	0.000	0.000	2.486	461.008	0.19	0.990
Sub11	465.699	0.000	0.000	2.486	461.008	0.19	0.990
Sub12	465.699	0.000	0.000	2.486	461.008	0.19	0.990
Sub13	465.699	0.000	0.000	2.486	461.008	0.19	0.990
Sub14	465.699	0.000	0.000	2.486	461.008	0.19	0.990
Sub3	465.699	0.000	0.000	2.762	461.962	3.78	0.992
Sub4	465.699	0.000	0.000	2.435	460.543	0.19	0.989
Sub5	465.699	0.000	0.000	2.486	461.008	0.19	0.990
Sub6	465.699	0.000	0.000	2.532	460.962	0.19	0.990
Sub7	465.699	0.000	0.000	2.486	461.008	0.19	0.990
Sub8	465.699	0.000	0.000	2.486	461.008	0.19	0.990
Sub9	465.699	0.000	0.000	2.486	461.008	0.19	0.990
Sub15	465.699	0.000	0.000	2.762	461.938	3.78	0.992
System	465.699	0.000	0.000	2.712	461.772	9.60	0.992

****

Node Depth Summary

****

Node	Type	Average Depth Meters	Max Depth Meters	Max HGL Meters	Time of Max Occurrence days hr:min	Total Flooding ha-mm	Total Minutes flooded

J1	JUNCTION	0.01	0.69	1416.69	283	01:00	0	0
J2	JUNCTION	0.01	0.70	1412.70	283	01:01	0	0
J3	JUNCTION	0.02	1.01	1409.01	283	01:00	0	0
J4	JUNCTION	0.02	1.02	1405.02	283	01:01	0	0
J5	JUNCTION	0.02	1.03	1401.03	283	01:02	0	0
J6	JUNCTION	0.02	1.03	1397.03	283	01:03	0	0
J7	JUNCTION	0.02	1.04	1393.04	283	01:03	0	0
J8	JUNCTION	0.02	1.05	1389.05	283	01:04	0	0
J9	JUNCTION	0.02	1.06	1385.06	283	01:05	0	0
J10	JUNCTION	0.02	1.32	1381.32	283	01:06	0	0
J11	JUNCTION	0.02	1.32	1379.32	283	01:07	0	0
Outfal1	OUTFALL	1.36	2.20	1372.20	3	00:08	0	0

****

Node Flow Summary

****

Node	Type	Max Lateral Inflow CMS	Max Total Inflow CMS	Time of Max Occurrence days hr:min	Max Flooding Overflow CMS	Time of Max Occurrence days hr:min
J1	JUNCTION	3.96	3.96	283 01:00	0.00	
J2	JUNCTION	0.19	4.11	283 01:01	0.00	
J3	JUNCTION	3.96	8.01	283 01:00	0.00	
J4	JUNCTION	0.19	8.15	283 01:01	0.00	
J5	JUNCTION	0.19	8.28	283 01:02	0.00	
J6	JUNCTION	0.19	8.41	283 01:03	0.00	
J7	JUNCTION	0.19	8.54	283 01:03	0.00	
J8	JUNCTION	0.19	8.66	283 01:04	0.00	
J9	JUNCTION	0.19	8.78	283 01:05	0.00	
J10	JUNCTION	0.19	8.88	283 01:06	0.00	
J11	JUNCTION	0.19	8.98	283 01:07	0.00	
Outfal1	OUTFALL	0.00	8.98	283 01:07	0.00	

****

Outfall Loading Summary

****

Outfall Node	Flow Freq. Pcnt.	Avg. Flow CMS	Max. Flow CMS
Outfal1	61.54	0.03	8.98
System	61.54	0.03	8.98

****

Link Flow Summary

****

Link	Type	Max Flow CMS	Time of Max Occurrence days hr:min	Max Velocity m/sec	Max/ Full Flow	Max/ Full Depth	Total Minutes Surcharged
C1	CONDUIT	3.94	283 01:01	3.95	0.21	0.31	0
C2	CONDUIT	4.10	283 01:02	3.98	0.22	0.32	0
C3	CONDUIT	7.98	283 01:01	4.75	0.43	0.46	0
C4	CONDUIT	8.13	283 01:02	4.77	0.43	0.46	0
C5	CONDUIT	8.27	283 01:03	4.79	0.44	0.47	0
C6	CONDUIT	8.40	283 01:04	4.81	0.45	0.47	0
C7	CONDUIT	8.53	283 01:04	4.83	0.46	0.47	0
C8	CONDUIT	8.65	283 01:05	4.84	0.46	0.48	0
C9	CONDUIT	8.77	283 01:06	4.86	0.47	0.48	0
C10	CONDUIT	8.88	283 01:07	3.75	0.67	0.60	0
C11	CONDUIT	8.98	283 01:07	7.88	0.25	0.34	0

****

Routing Time Step Summary

****

Minimum Time Step: 60.00 sec
Average Time Step: 60.00 sec
Maximum Time Step: 60.00 sec
Percent in Steady State: 0.00
Average Iterations per Step: 1.00
Analysis begun on: Wed Apr 25 13:40:14 2007
Total elapsed time: 00:02:13

2001

EPA STORM WATER MANAGEMENT MODEL - VERSION 5.0 (Build 5.0.008)

****
Analysis Options
****

Flow Units	CMS
Infiltration Method	HORTON
Flow Routing Method	KINWAVE
Starting Date	JAN-01-2001 00:00:00
Ending Date	DEC-31-2001 00:00:00
Antecedent Dry Days	0.0
Report Time Step	01:00:00
Wet Time Step	00:01:00
Dry Time Step	00:01:00
Routing Time Step	60.00 sec

************************** Runoff Quantity Continuity **************************	Volume hectare-m	Depth mm
Total Precipitation	67.844	556.100
Evaporation Loss	0.000	0.000
Infiltration Loss	0.348	2.851
Surface Runoff	67.349	552.042
Final Surface Storage	0.046	0.378
Continuity Error (%)	0.149	

************************** Flow Routing Continuity **************************	Volume hectare-m	Volume Mliters
Dry Weather Inflow	0.000	0.000
Wet Weather Inflow	67.292	672.923
Groundwater Inflow	0.000	0.000
RDII Inflow	0.000	0.000
External Inflow	0.000	0.000
External Outflow	67.327	673.272
Surface Flooding	0.000	0.000
Evaporation Loss	0.000	0.000
Initial Stored Volume	0.000	0.000
Final Stored Volume	0.000	0.003
Continuity Error (%)	-0.052	

****
Subcatchment Runoff Summary
****

Subcatchment	Total Precip mm	Total Runon mm	Total Evap mm	Total Infil mm	Total Runoff mm	Peak Runoff CMS	Runoff Coeff
Sub10	556.105	0.000	0.000	2.580	551.261	0.25	0.991
Sub11	556.105	0.000	0.000	2.580	551.261	0.25	0.991
Sub12	556.105	0.000	0.000	2.580	551.261	0.25	0.991
Sub13	556.105	0.000	0.000	2.580	551.261	0.25	0.991
Sub14	556.105	0.000	0.000	2.580	551.261	0.25	0.991
Sub3	556.105	0.000	0.000	2.911	552.142	5.29	0.993
Sub4	556.105	0.000	0.000	2.521	550.898	0.25	0.991
Sub5	556.105	0.000	0.000	2.580	551.261	0.25	0.991
Sub6	556.105	0.000	0.000	2.634	551.209	0.25	0.991
Sub7	556.105	0.000	0.000	2.580	551.261	0.25	0.991
Sub8	556.105	0.000	0.000	2.580	551.261	0.25	0.991
Sub9	556.105	0.000	0.000	2.580	551.261	0.25	0.991
Sub15	556.105	0.000	0.000	2.911	552.118	5.29	0.993
System	556.104	0.000	0.000	2.851	551.967	13.30	0.993

****
Node Depth Summary
****

Node	Type	Average Depth Meters	Max Depth Meters	Max HGL Meters	Time of Max Occurrence days hr:min	Total Flooding ha-mm	Total Minutes flooded
J1	JUNCTION	0.01	0.82	1416.82	261 01:00	0	0
J2	JUNCTION	0.01	0.84	1412.84	261 01:00	0	0
J3	JUNCTION	0.02	1.23	1409.23	261 01:00	0	0
J4	JUNCTION	0.02	1.24	1405.24	261 01:01	0	0
J5	JUNCTION	0.02	1.25	1401.25	261 01:01	0	0

J6	JUNCTION	0.02	1.26	1397.26	261	01:02	0	0
J7	JUNCTION	0.02	1.28	1393.28	261	01:03	0	0
J8	JUNCTION	0.02	1.29	1389.29	261	01:04	0	0
J9	JUNCTION	0.02	1.30	1385.30	261	01:04	0	0
J10	JUNCTION	0.02	1.69	1381.69	261	01:05	0	0
J11	JUNCTION	0.02	1.69	1379.69	261	01:06	0	0
Outfal1	OUTFALL	1.36	2.20	1372.20	6	00:37	0	0

****

Node Flow Summary

****

Node	Type	Max Lateral Inflow CMS	Max Total Inflow CMS	Time of Max Occurrence days hr:min	Max Flooding Overflow CMS	Time of Max Occurrence days hr:min
J1	JUNCTION	5.54	5.54	261 01:00	0.00	
J2	JUNCTION	0.25	5.73	261 01:00	0.00	
J3	JUNCTION	5.54	11.21	261 01:00	0.00	
J4	JUNCTION	0.25	11.39	261 01:01	0.00	
J5	JUNCTION	0.25	11.57	261 01:01	0.00	
J6	JUNCTION	0.25	11.76	261 01:02	0.00	
J7	JUNCTION	0.25	11.93	261 01:03	0.00	
J8	JUNCTION	0.25	12.09	261 01:04	0.00	
J9	JUNCTION	0.25	12.25	261 01:04	0.00	
J10	JUNCTION	0.25	12.40	261 01:05	0.00	
J11	JUNCTION	0.25	12.53	261 01:06	0.00	
Outfal1	OUTFALL	0.00	12.53	261 01:07	0.00	

****

Outfall Loading Summary

****

Outfall Node	Flow Freq. Pcnt.	Avg. Flow CMS	Max. Flow CMS
Outfal1	61.66	0.03	12.53
System	61.66	0.03	12.53

****

Link Flow Summary

****

Link	Type	Max Flow CMS	Time of Max Occurrence days hr:min	Max Velocity m/sec	Max/ Full Flow	Max/ Full Depth	Total Minutes Surcharged
C1	CONDUIT	5.51	261 01:01	4.34	0.29	0.37	0
C2	CONDUIT	5.72	261 01:01	4.37	0.31	0.38	0
C3	CONDUIT	11.17	261 01:01	5.16	0.60	0.56	0
C4	CONDUIT	11.36	261 01:02	5.19	0.61	0.56	0
C5	CONDUIT	11.55	261 01:02	5.20	0.62	0.57	0
C6	CONDUIT	11.74	261 01:03	5.22	0.63	0.57	0
C7	CONDUIT	11.92	261 01:04	5.24	0.64	0.58	0
C8	CONDUIT	12.08	261 01:05	5.25	0.65	0.59	0
C9	CONDUIT	12.24	261 01:05	5.27	0.65	0.59	0
C10	CONDUIT	12.39	261 01:06	4.01	0.94	0.77	0
C11	CONDUIT	12.53	261 01:07	8.63	0.35	0.41	0

****

Routing Time Step Summary

****

Minimum Time Step: 60.00 sec
Average Time Step: 60.00 sec
Maximum Time Step: 60.00 sec
Percent in Steady State: 0.00
Average Iterations per Step: 1.01
Analysis begun on: Wed Apr 25 13:52:33 2007
Total elapsed time: 00:02:10

2002

EPA STORM WATER MANAGEMENT MODEL - VERSION 5.0 (Build 5.0.008)

****
Analysis Options
****

Flow Units	CMS
Infiltration Method	HORTON
Flow Routing Method	KINWAVE
Starting Date	JAN-01-2002 00:00:00
Ending Date	DEC-31-2002 00:00:00
Antecedent Dry Days	0.0
Report Time Step	01:00:00
Wet Time Step	00:01:00
Dry Time Step	00:01:00
Routing Time Step	60.00 sec

************************** Runoff Quantity Continuity **************************	Volume hectare-m	Depth mm
	---------	-------
Total Precipitation	73.359	601.300
Evaporation Loss	0.000	0.000
Infiltration Loss	0.348	2.850
Surface Runoff	72.880	597.377
Final Surface Storage	0.044	0.358
Continuity Error (%)	0.119	

************************** Flow Routing Continuity **************************	Volume hectare-m	Volume Mliters
	---------	---------
Dry Weather Inflow	0.000	0.000
Wet Weather Inflow	72.826	728.270
Groundwater Inflow	0.000	0.000
RDII Inflow	0.000	0.000
External Inflow	0.000	0.000
External Outflow	72.865	728.654
Surface Flooding	0.000	0.000
Evaporation Loss	0.000	0.000
Initial Stored Volume	0.000	0.000
Final Stored Volume	0.000	0.000
Continuity Error (%)	-0.053	

****
Subcatchment Runoff Summary
****

Subcatchment	Total Precip mm	Total Runon mm	Total Evap mm	Total Infil mm	Total Runoff mm	Peak Runoff CMS	Runoff Coeff
Sub10	601.302	0.000	0.000	2.578	596.860	0.20	0.993
Sub11	601.302	0.000	0.000	2.578	596.860	0.20	0.993
Sub12	601.302	0.000	0.000	2.578	596.860	0.20	0.993
Sub13	601.302	0.000	0.000	2.578	596.860	0.20	0.993
Sub14	601.302	0.000	0.000	2.578	596.860	0.20	0.993
Sub3	601.302	0.000	0.000	2.910	597.381	4.02	0.993
Sub4	601.302	0.000	0.000	2.518	596.486	0.20	0.992
Sub5	601.302	0.000	0.000	2.578	596.860	0.20	0.993
Sub6	601.302	0.000	0.000	2.631	596.807	0.20	0.993
Sub7	601.302	0.000	0.000	2.578	596.860	0.20	0.993
Sub8	601.302	0.000	0.000	2.578	596.860	0.20	0.993
Sub9	601.302	0.000	0.000	2.578	596.860	0.20	0.993
Sub15	601.302	0.000	0.000	2.910	597.357	4.02	0.993
System	601.302	0.000	0.000	2.850	597.270	10.20	0.993

****
Node Depth Summary
****

Node	Type	Average Depth Meters	Max Depth Meters	Max HGL Meters	Time of Max Occurrence days hr:min	Total Flooding ha-mm	Total Minutes flooded
J1	JUNCTION	0.01	0.71	1416.71	254 01:00	0	0
J2	JUNCTION	0.01	0.72	1412.72	254 01:01	0	0
J3	JUNCTION	0.02	1.04	1409.04	254 01:00	0	0
J4	JUNCTION	0.02	1.05	1405.05	254 01:01	0	0
J5	JUNCTION	0.02	1.06	1401.06	254 01:02	0	0

J6	JUNCTION	0.02	1.07	1397.07	254 01:03	0	0
J7	JUNCTION	0.02	1.08	1393.08	254 01:03	0	0
J8	JUNCTION	0.02	1.09	1389.09	254 01:04	0	0
J9	JUNCTION	0.02	1.10	1385.10	254 01:05	0	0
J10	JUNCTION	0.02	1.38	1381.38	254 01:06	0	0
J11	JUNCTION	0.02	1.37	1379.37	254 01:07	0	0
Outfal1	OUTFALL	1.21	2.20	1372.20	14 05:45	0	0

****
Node Flow Summary
****

Node	Type	Max Lateral Inflow CMS	Max Total Inflow CMS	Time of Max Occurrence days hr:min	Max Flooding Overflow CMS	Time of Max Occurrence days hr:min
J1	JUNCTION	4.22	4.22	254 01:00	0.00	
J2	JUNCTION	0.20	4.38	254 01:01	0.00	
J3	JUNCTION	4.22	8.53	254 01:00	0.00	
J4	JUNCTION	0.20	8.68	254 01:01	0.00	
J5	JUNCTION	0.20	8.82	254 01:02	0.00	
J6	JUNCTION	0.20	8.95	254 01:03	0.00	
J7	JUNCTION	0.20	9.09	254 01:03	0.00	
J8	JUNCTION	0.20	9.22	254 01:04	0.00	
J9	JUNCTION	0.20	9.34	254 01:05	0.00	
J10	JUNCTION	0.20	9.45	254 01:06	0.00	
J11	JUNCTION	0.20	9.56	254 01:07	0.00	
Outfal1	OUTFALL	0.00	9.56	254 01:07	0.00	

****
Outfall Loading Summary
****

Outfall Node	Flow Freq. Pcnt.	Avg. Flow CMS	Max. Flow CMS
Outfal1	54.86	0.04	9.56
System	54.86	0.04	9.56

****
Link Flow Summary
****

Link	Type	Max Flow CMS	Time of Max Occurrence days hr:min	Max Velocity m/sec	Max/ Full Flow	Max/ Full Depth	Total Minutes Surcharged
C1	CONDUIT	4.20	254 01:01	4.02	0.22	0.32	0
C2	CONDUIT	4.36	254 01:02	4.05	0.23	0.33	0
C3	CONDUIT	8.50	254 01:01	4.82	0.45	0.47	0
C4	CONDUIT	8.65	254 01:02	4.85	0.46	0.48	0
C5	CONDUIT	8.80	254 01:03	4.87	0.47	0.48	0
C6	CONDUIT	8.94	254 01:04	4.89	0.48	0.49	0
C7	CONDUIT	9.08	254 01:04	4.90	0.48	0.49	0
C8	CONDUIT	9.21	254 01:05	4.92	0.49	0.50	0
C9	CONDUIT	9.33	254 01:06	4.93	0.50	0.50	0
C10	CONDUIT	9.45	254 01:07	3.81	0.71	0.62	0
C11	CONDUIT	9.56	254 01:07	8.02	0.26	0.35	0

****
Routing Time Step Summary
****

Minimum Time Step: 60.00 sec
Average Time Step: 60.00 sec
Maximum Time Step: 60.00 sec
Percent in Steady State: 0.00
Average Iterations per Step: 1.01
Analysis begun on: Wed Apr 25 13:46:23 2007
Total elapsed time: 00:02:12

2003

```
EPA STORM WATER MANAGEMENT MODEL - VERSION 5.0 (Build 5.0.008)
--------------------------------------------------------------
****************
Analysis Options
****************
Flow Units............... CMS
Infiltration Method...... HORTON
Flow Routing Method...... KINWAVE
Starting Date............ JAN-01-2003 00:00:00
Ending Date.............. DEC-31-2003 00:00:00
Antecedent Dry Days ...... 0.0
Report Time Step ......... 01:00:00
Wet Time Step ............ 00:01:00
Dry Time Step ............ 00:01:00
Routing Time Step........ 60.00 sec
**************************          Volume      Depth
Runoff Quantity Continuity          hectare-m   mm
**************************          ---------   -------
Total Precipitation                 101.040     828.200
Evaporation Loss                    0.000       0.000
Infiltration Loss´                  0.374       3.066
Surface Runoff                      100.518     823.915
Final Surface Storage               0.058       0.476
Continuity Error (%)                0.090
**************************          Volume      Volume
Flow Routing Continuity             hectare-m   Mliters
**************************          ---------   ---------
Dry Weather Inflow                  0.000       0.000
Wet Weather Inflow                  100.458     1004.595
Groundwater Inflow                  0.000       0.000
RDII Inflow                         0.000       0.000
External Inflow                     0.000       0.000
External Outflow                    95.479      954.797
Surface Flooding                    2.848       28.477
Evaporation Loss                    0.000       0.000
Initial Stored Volume               0.000       0.000
Final Stored Volume                 0.002       0.025
Continuity Error (%)                2.120
***************************
Subcatchment Runoff Summary
***************************
------------------------------------------------------------------------------------
               Total    Total    Total    Total    Total       Peak   Runoff
               Precip   Runon    Evap     Infil    Runoff    Runoff   Coeff
Subcatchment   mm       mm       mm       mm       mm        CMS
------------------------------------------------------------------------------------
Sub10          828.208  0.000    0.000    2.764    823.538   0.60     0.994
Sub11          828.208  0.000    0.000    2.764    823.538   0.60     0.994
Sub12          828.208  0.000    0.000    2.764    823.538   0.60     0.994
Sub13          828.208  0.000    0.000    2.764    823.538   0.60     0.994
Sub14          828.208  0.000    0.000    2.764    823.538   0.60     0.994
Sub3           828.208  0.000    0.000    3.132    823.728   14.25    0.995
Sub4           828.208  0.000    0.000    2.699    823.175   0.60     0.994
Sub5           828.208  0.000    0.000    2.764    823.538   0.60     0.994
Sub6           828.208  0.000    0.000    2.822    823.480   0.60     0.994
Sub7           828.208  0.000    0.000    2.764    823.538   0.60     0.994
Sub8           828.208  0.000    0.000    2.764    823.538   0.60     0.994
Sub9           828.208  0.000    0.000    2.764    823.538   0.60     0.994
Sub15          828.208  0.000    0.000    3.132    823.704   14.25    0.995
------------------------------------------------------------------------------------
System         828.208  0.000    0.000    3.066    823.677   35.09    0.995
******************
Node Depth Summary
******************
----------------------------------------------------------------------------------------------------
                          Average  Max     Max       Time of Max    Total     Total
                          Depth    Depth   HGL       Occurrence     Flooding  Minutes
Node     Type             Meters   Meters  Meters    days hr:min    ha-mm     Flooded
----------------------------------------------------------------------------------------------------
J1       JUNCTION         0.01     1.48    1417.48   235  01:00     0         0
J2       JUNCTION         0.01     1.52    1413.52   235  01:00     0         0
J3       JUNCTION         0.02     3.00    1411.00   235  00:28     1488.12   41
J4       JUNCTION         0.02     3.00    1407.00   235  00:31     3.25      3
J5       JUNCTION         0.02     3.00    1403.00   235  01:02     1.73      3
```

J6	JUNCTION	0.02	2.20	1398.20	235 00:27	0	0
J7	JUNCTION	0.02	3.00	1395.00	235 00:38	39.60	25
J8	JUNCTION	0.02	3.00	1391.00	235 00:41	4.42	5
J9	JUNCTION	0.02	3.00	1387.00	235 01:02	1.73	2
J10	JUNCTION	0.03	3.00	1383.00	235 00:24	1308.84	56
J11	JUNCTION	0.03	2.20	1380.20	235 00:35	0	0
Outfal1	OUTFALL	1.36	2.20	1372.20	9 00:31	0	0

****
Node Flow Summary
****

Node	Type	Max Lateral Inflow CMS	Max Total Inflow CMS	Time of Max Occurrence days hr:min	Max Flooding Overflow CMS	Time of Max Occurrence days hr:min
J1	JUNCTION	14.85	14.85	235 01:00	0.00	
J2	JUNCTION	0.60	15.40	235 01:00	0.00	
J3	JUNCTION	14.85	30.19	235 01:00	9.92	235 01:00
J4	JUNCTION	0.60	20.64	235 00:32	0.27	235 00:32
J5	JUNCTION	0.60	20.50	235 01:02	0.14	235 01:03
J6	JUNCTION	0.60	19.92	235 01:00	0.00	
J7	JUNCTION	0.60	20.51	235 01:00	0.30	235 01:00
J8	JUNCTION	0.60	20.65	235 00:42	0.29	235 00:42
J9	JUNCTION	0.60	20.50	235 01:02	0.14	235 01:02
J10	JUNCTION	0.60	20.57	235 00:33	6.04	235 00:33
J11	JUNCTION	0.60	14.89	235 01:00	0.00	
Outfal1	OUTFALL	0.00	14.89	235 01:00	0.00	

****
Outfall Loading Summary
****

Outfall Node	Flow Freq. Pcnt.	Avg. Flow CMS	Max. Flow CMS
Outfal1	61.46	0.05	14.89
System	61.46	0.05	14.89

****
Link Flow Summary
****

Link	Type	Max Flow CMS	Time of Max Occurrence days hr:min	Max Velocity m/sec	Max/ Full Flow	Max/ Full Depth	Total Minutes Surcharged
C1	CONDUIT	14.80	235 01:00	5.58	0.79	0.67	0
C2	CONDUIT	15.36	235 01:01	5.60	0.82	0.69	0
C3	CONDUIT	20.06	235 00:32	5.95	1.07	1.00	43
C4	CONDUIT	20.04	235 01:02	10.73	1.07	1.00	40
C5	CONDUIT	19.76	235 01:14	9.94	1.06	1.00	38
C6	CONDUIT	20.05	235 01:15	10.69	1.07	0.95	37
C7	CONDUIT	20.06	235 00:42	7.72	1.07	1.00	36
C8	CONDUIT	20.04	235 01:02	10.72	1.07	1.00	34
C9	CONDUIT	19.99	235 00:33	9.88	1.07	0.95	31
C10	CONDUIT	14.29	235 01:23	5.99	1.08	1.00	49
C11	CONDUIT	14.89	235 01:00	16.51	0.41	0.45	0

****
Routing Time Step Summary
****

Minimum Time Step: 60.00 sec
Average Time Step: 60.00 sec
Maximum Time Step: 60.00 sec
Percent in Steady State: 0.00
Average Iterations per Step: 1.01
Analysis begun on: Wed Apr 25 13:21:44 2007
Total elapsed time: 00:02:14

2004

EPA STORM WATER MANAGEMENT MODEL - VERSION 5.0 (Build 5.0.008)

****

Analysis Options

****

Flow Units	CMS
Infiltration Method	HORTON
Flow Routing Method	KINWAVE
Starting Date	JAN-01-2004 00:00:00
Ending Date	DEC-31-2004 00:00:00
Antecedent Dry Days	0.0
Report Time Step	01:00:00
Wet Time Step	00:01:00
Dry Time Step	00:01:00
Routing Time Step	60.00 sec

**************************	Volume	Depth
Runoff Quantity Continuity	hectare-m	mm
**************************	---------	-------
Total Precipitation	59.280	485.900
Evaporation Loss	0.000	0.000
Infiltration Loss	0.322	2.635
Surface Runoff	58.810	482.047
Final Surface Storage	0.049	0.402
Continuity Error (%)	0.168	

**************************	Volume	Volume
Flow Routing Continuity	hectare-m	Mliters
**************************	---------	---------
Dry Weather Inflow	0.000	0.000
Wet Weather Inflow	58.752	587.530
Groundwater Inflow	0.000	0.000
RDII Inflow	0.000	0.000
External Inflow	0.000	0.000
External Outflow	58.175	581.758
Surface Flooding	0.456	4.556
Evaporation Loss	0.000	0.000
Initial Stored Volume	0.000	0.000
Final Stored Volume	0.001	0.008
Continuity Error (%)	0.205	

****

Subcatchment Runoff Summary

****

Subcatchment	Total Precip mm	Total Runon mm	Total Evap mm	Total Infil mm	Total Runoff mm	Peak Runoff CMS	Runoff Coeff
Sub10	485.908	0.000	0.000	2.395	481.344	0.35	0.991
Sub11	485.908	0.000	0.000	2.395	481.344	0.35	0.991
Sub12	485.908	0.000	0.000	2.395	481.344	0.35	0.991
Sub13	485.908	0.000	0.000	2.395	481.344	0.35	0.991
Sub14	485.908	0.000	0.000	2.395	481.344	0.35	0.991
Sub3	485.908	0.000	0.000	2.688	482.120	7.78	0.992
Sub4	485.908	0.000	0.000	2.342	480.940	0.35	0.990
Sub5	485.908	0.000	0.000	2.395	481.344	0.35	0.991
Sub6	485.908	0.000	0.000	2.444	481.295	0.35	0.991
Sub7	485.908	0.000	0.000	2.395	481.344	0.35	0.991
Sub8	485.908	0.000	0.000	2.395	481.344	0.35	0.991
Sub9	485.908	0.000	0.000	2.395	481.344	0.35	0.991
Sub15	485.908	0.000	0.000	2.688	482.098	7.78	0.992
System	485.907	0.000	0.000	2.635	481.963	19.38	0.992

****

Node Depth Summary

****

Node	Type	Average Depth Meters	Max Depth Meters	Max HGL Meters	Time of Max Occurrence days hr:min	Total Flooding ha-mm	Total Minutes Flooded
J1	JUNCTION	0.01	1.01	1417.01	195 01:00	0	0
J2	JUNCTION	0.01	1.03	1413.03	195 01:00	0	0
J3	JUNCTION	0.02	1.60	1409.60	195 01:00	0	0
J4	JUNCTION	0.02	1.62	1405.62	195 01:01	0	0
J5	JUNCTION	0.02	1.65	1401.65	195 01:01	0	0

J6	JUNCTION	0.02	1.67	1397.67	195 01:02	0	0
J7	JUNCTION	0.02	1.69	1393.69	195 01:03	0	0
J8	JUNCTION	0.02	1.71	1389.71	195 01:03	0	0
J9	JUNCTION	0.02	1.73	1385.73	195 01:04	0	0
J10	JUNCTION	0.02	3.00	1383.00	195 00:43	455.58	32
J11	JUNCTION	0.02	2.20	1380.20	195 01:14	0	0
Outfal1	OUTFALL	1.32	2.20	1372.20	2 01:03	0	0

****

Node Flow Summary

****

Node	Type	Max Lateral Inflow CMS	Max Total Inflow CMS	Time of Max Occurrence days hr:min	Max Flooding Overflow CMS	Time of Max Occurrence days hr:min
J1	JUNCTION	8.13	8.13	195 01:00	0.00	
J2	JUNCTION	0.35	8.42	195 01:00	0.00	
J3	JUNCTION	8.13	16.50	195 01:00	0.00	
J4	JUNCTION	0.35	16.74	195 01:01	0.00	
J5	JUNCTION	0.35	17.01	195 01:01	0.00	
J6	JUNCTION	0.35	17.27	195 01:02	0.00	
J7	JUNCTION	0.35	17.50	195 01:03	0.00	
J8	JUNCTION	0.35	17.74	195 01:03	0.00	
J9	JUNCTION	0.35	17.96	195 01:04	0.00	
J10	JUNCTION	0.35	18.17	195 01:04	3.87	195 01:05
J11	JUNCTION	0.35	14.64	195 01:00	0.00	
Outfal1	OUTFALL	0.00	14.64	195 01:00	0.00	

****

Outfall Loading Summary

****

Outfall Node	Flow Freq. Pcnt.	Avg. Flow CMS	Max. Flow CMS
Outfal1	60.05	0.03	14.64
System	60.05	0.03	14.64

****

Link Flow Summary

****

Link	Type	Max Flow CMS	Time of Max Occurrence days hr:min	Max Velocity m/sec	Max/ Full Flow	Max/ Full Depth	Total Minutes Surcharged
C1	CONDUIT	8.08	195 01:00	4.82	0.43	0.46	0
C2	CONDUIT	8.41	195 01:01	4.85	0.45	0.47	0
C3	CONDUIT	16.43	195 01:01	5.61	0.88	0.73	0
C4	CONDUIT	16.70	195 01:01	5.63	0.89	0.74	0
C5	CONDUIT	16.99	195 01:02	5.64	0.91	0.75	0
C6	CONDUIT	17.25	195 01:03	5.65	0.92	0.76	0
C7	CONDUIT	17.49	195 01:04	5.66	0.93	0.77	0
C8	CONDUIT	17.73	195 01:04	5.67	0.95	0.78	0
C9	CONDUIT	17.95	195 01:05	5.67	0.96	0.79	0
C10	CONDUIT	14.29	195 01:03	4.18	1.08	1.00	33
C11	CONDUIT	14.64	195 01:00	16.39	0.41	0.44	0

****

Routing Time Step Summary

****

Minimum Time Step: 60.00 sec
Average Time Step: 60.00 sec
Maximum Time Step: 60.00 sec
Percent in Steady State: 0.00
Average Iterations per Step: 1.00
Analysis begun on: Wed Apr 25 13:27:09 2007
Total elapsed time: 00:02:10

2005

EPA STORM WATER MANAGEMENT MODEL - VERSION 5.0 (Build 5.0.008)

****

Analysis Options

****

Flow Units	CMS
Infiltration Method	HORTON
Flow Routing Method	KINWAVE
Starting Date	JAN-01-2005 00:00:00
Ending Date	DEC-31-2005 00:00:00
Antecedent Dry Days	0.0
Report Time Step	01:00:00
Wet Time Step	00:01:00
Dry Time Step	00:01:00
Routing Time Step	60.00 sec

****

Runoff Quantity Continuity	Volume hectare-m	Depth mm
Total Precipitation	61.842	506.900
Evaporation Loss	0.000	0.000
Infiltration Loss	0.273	2.234
Surface Runoff	61.440	503.603
Final Surface Storage	0.045	0.369
Continuity Error (%)	0.137	

****

Flow Routing Continuity	Volume hectare-m	Volume Mliters
Dry Weather Inflow	0.000	0.000
Wet Weather Inflow	61.390	613.903
Groundwater Inflow	0.000	0.000
RDII Inflow	0.000	0.000
External Inflow	0.000	0.000
External Outflow	59.845	598.452
Surface Flooding	0.659	6.593
Evaporation Loss	0.000	0.000
Initial Stored Volume	0.000	0.000
Final Stored Volume	0.000	0.000
Continuity Error (%)	1.443	

****

Subcatchment Runoff Summary

****

Subcatchment	Total Precip mm	Total Runon mm	Total Evap mm	Total Infil mm	Total Runoff mm	Peak Runoff CMS	Runoff Coeff
Sub10	506.896	0.000	0.000	2.017	502.911	0.39	0.992
Sub11	506.896	0.000	0.000	2.017	502.911	0.39	0.992
Sub12	506.896	0.000	0.000	2.017	502.911	0.39	0.992
Sub13	506.896	0.000	0.000	2.017	502.911	0.39	0.992
Sub14	506.896	0.000	0.000	2.017	502.911	0.39	0.992
Sub3	506.896	0.000	0.000	2.282	503.704	8.98	0.994
Sub4	506.896	0.000	0.000	1.970	502.597	0.39	0.992
Sub5	506.896	0.000	0.000	2.017	502.911	0.39	0.992
Sub6	506.896	0.000	0.000	2.058	502.870	0.39	0.992
Sub7	506.896	0.000	0.000	2.017	502.911	0.39	0.992
Sub8	506.896	0.000	0.000	2.017	502.911	0.39	0.992
Sub9	506.896	0.000	0.000	2.017	502.911	0.39	0.992
Sub15	506.896	0.000	0.000	2.282	503.683	8.98	0.994
System	506.896	0.000	0.000	2.234	503.546	22.29	0.993

****

Node Depth Summary

****

Node	Type	Average Depth Meters	Max Depth Meters	Max HGL Meters	Time of Max Occurrence days hr:min	Total Flooding ha-mm	Total Minutes Flooded
J1	JUNCTION	0.01	1.10	1417.10	197 01:00	0	0
J2	JUNCTION	0.01	1.12	1413.12	197 01:00	0	0
J3	JUNCTION	0.02	2.20	1410.20	197 00:58	0	0
J4	JUNCTION	0.02	2.20	1406.20	197 00:56	0	0

J5	JUNCTION	0.02	3.00	1403.00	197	01:03	0.43	2
J6	JUNCTION	0.02	3.00	1399.00	197	00:59	1.32	2
J7	JUNCTION	0.02	3.00	1395.00	197	00:57	1.11	2
J8	JUNCTION	0.02	2.20	1390.20	197	00:51	0	0
J9	JUNCTION	0.02	3.00	1387.00	197	00:56	0.18	2
J10	JUNCTION	0.02	3.00	1383.00	197	00:36	656.25	41
J11	JUNCTION	0.02	2.20	1380.20	197	00:56	0	0
Outfal1	OUTFALL	1.13	2.20	1372.20	38	00:07	0	0

****

Node Flow Summary

****

Node	Type	Max Lateral Inflow CMS	Max Total Inflow CMS	Time of Max Occurrence days hr:min	Max Flooding Overflow CMS	Time of Max Occurrence days hr:min
J1	JUNCTION	9.38	9.38	197 01:00	0.00	
J2	JUNCTION	0.39	9.72	197 01:00	0.00	
J3	JUNCTION	9.38	19.03	197 01:00	0.00	
J4	JUNCTION	0.39	20.11	197 01:01	0.00	
J5	JUNCTION	0.39	20.29	197 01:03	0.04	197 01:03
J6	JUNCTION	0.39	20.44	197 00:59	0.11	197 00:59
J7	JUNCTION	0.39	20.40	197 00:57	0.09	197 00:57
J8	JUNCTION	0.39	20.06	197 00:55	0.00	
J9	JUNCTION	0.39	20.25	197 00:56	0.02	197 00:56
J10	JUNCTION	0.39	20.04	197 01:11	5.16	197 01:12
J11	JUNCTION	0.39	14.69	197 00:55	0.00	
Outfal1	OUTFALL	0.00	14.69	197 00:55	0.00	

****

Outfall Loading Summary

****

Outfall Node	Flow Freq. Pcnt.	Avg. Flow CMS	Max. Flow CMS
Outfal1	51.32	0.04	14.69
System	51.32	0.04	14.69

****

Link Flow Summary

****

Link	Type	Max Flow CMS	Time of Max Occurrence days hr:min	Max Velocity m/sec	Max/ Full Flow	Max/ Full Depth	Total Minutes Surcharged
C1	CONDUIT	9.32	197 01:00	5.00	0.50	0.50	0
C2	CONDUIT	9.70	197 01:01	5.03	0.52	0.51	0
C3	CONDUIT	19.75	197 01:01	5.75	1.06	0.91	3
C4	CONDUIT	20.00	197 01:03	5.81	1.07	0.93	6
C5	CONDUIT	20.04	197 00:59	5.94	1.07	1.00	8
C6	CONDUIT	20.01	197 00:57	11.11	1.07	0.93	8
C7	CONDUIT	19.88	197 01:08	10.91	1.06	0.93	8
C8	CONDUIT	19.85	197 00:56	11.02	1.06	0.92	7
C9	CONDUIT	19.91	197 01:11	8.03	1.06	0.92	6
C10	CONDUIT	14.29	197 00:55	6.06	1.08	1.00	34
C11	CONDUIT	14.69	197 00:55	16.70	0.41	0.44	0

****

Routing Time Step Summary

****

Minimum Time Step: 60.00 sec
Average Time Step: 60.00 sec
Maximum Time Step: 60.00 sec
Percent in Steady State: 0.00
Average Iterations per Step: 1.00
Analysis begun on: Wed Mar 21 15:30:26 2007
Total elapsed time: 00:02:19

2006

EPA STORM WATER MANAGEMENT MODEL - VERSION 5.0 (Build 5.0.008)

****
Analysis Options
****

Flow Units	CMS
Infiltration Method	HORTON
Flow Routing Method	KINWAVE
Starting Date	JAN-01-2006 00:00:00
Ending Date	DEC-31-2006 00:00:00
Antecedent Dry Days	0.0
Report Time Step	01:00:00
Wet Time Step	00:01:00
Dry Time Step	00:01:00
Routing Time Step	60.00 sec

****
Runoff Quantity Continuity
****

	Volume hectare-m	Depth mm
Total Precipitation	67.234	551.100
Evaporation Loss	0.000	0.000
Infiltration Loss	0.331	2.713
Surface Runoff	66.782	547.395
Final Surface Storage	0.043	0.354
Continuity Error (%)	0.116	

****
Flow Routing Continuity
****

	Volume hectare-m	Volume Mliters
Dry Weather Inflow	0.000	0.000
Wet Weather Inflow	66.729	667.301
Groundwater Inflow	0.000	0.000
RDII Inflow	0.000	0.000
External Inflow	0.000	0.000
External Outflow	65.912	659.125
Surface Flooding	0.543	5.427
Evaporation Loss	0.000	0.000
Initial Stored Volume	0.000	0.000
Final Stored Volume	0.000	0.000
Continuity Error (%)	0.412	

****
Subcatchment Runoff Summary
****

Subcatchment	Total Precip mm	Total Runon mm	Total Evap mm	Total Infil mm	Total Runoff mm	Peak Runoff CMS	Runoff Coeff
Sub10	551.099	0.000	0.000	2.458	546.765	0.34	0.992
Sub11	551.099	0.000	0.000	2.458	546.765	0.34	0.992
Sub12	551.099	0.000	0.000	2.458	546.765	0.34	0.992
Sub13	551.099	0.000	0.000	2.458	546.765	0.34	0.992
Sub14	551.099	0.000	0.000	2.458	546.765	0.34	0.992
Sub3	551.099	0.000	0.000	2.768	547.487	7.55	0.993
Sub4	551.099	0.000	0.000	2.402	546.396	0.34	0.991
Sub5	551.099	0.000	0.000	2.458	546.765	0.34	0.992
Sub6	551.099	0.000	0.000	2.510	546.715	0.34	0.992
Sub7	551.099	0.000	0.000	2.458	546.765	0.34	0.992
Sub8	551.099	0.000	0.000	2.458	546.765	0.34	0.992
Sub9	551.099	0.000	0.000	2.458	546.765	0.34	0.992
Sub15	551.099	0.000	0.000	2.768	547.464	7.55	0.993
System	551.099	0.000	0.000	2.713	547.341	18.80	0.993

****
Node Depth Summary
****

Node	Type	Average Depth Meters	Max Depth Meters	Max HGL Meters	Time of Max Occurrence days hr:min	Total Flooding ha-mm	Total Minutes Flooded
J1	JUNCTION	0.01	1.00	1417.00	187 01:00	0	0
J2	JUNCTION	0.01	1.02	1413.02	187 01:00	0	0
J3	JUNCTION	0.02	1.57	1409.57	187 01:00	0	0
J4	JUNCTION	0.02	1.58	1405.58	187 01:01	0	0
J5	JUNCTION	0.02	1.60	1401.60	187 01:01	0	0

J6	JUNCTION	0.02	1.62	1397.62	187	01:02	0	0
J7	JUNCTION	0.02	1.64	1393.64	187	01:03	0	0
J8	JUNCTION	0.02	1.66	1389.66	187	01:03	0	0
J9	JUNCTION	0.02	1.68	1385.68	187	01:04	0	0
J10	JUNCTION	0.02	3.00	1383.00	186	00:50	542.73	52
J11	JUNCTION	0.02	2.20	1380.20	186	01:12	0	0
Outfal1	OUTFALL	1.17	2.20	1372.20	9	05:02	0	0

Node	Type	Max Lateral Inflow CMS	Max Total Inflow CMS	Time of Max Occurrence days hr:min	Max Flooding Overflow CMS	Time of Max Occurrence days hr:min
J1	JUNCTION	9.38	9.38	197 01:00	0.00	
J2	JUNCTION	0.39	9.72	197 01:00	0.00	
J3	JUNCTION	9.38	19.03	197 01:00	0.00	
J4	JUNCTION	0.39	20.11	197 01:01	0.00	
J5	JUNCTION	0.39	20.29	197 01:03	0.04	197 01:03

****
Node Flow Summary
****

Node	Type	Max Lateral Inflow CMS	Max Total Inflow CMS	Time of Max Occurrence days hr:min	Max Flooding Overflow CMS	Time of Max Occurrence days hr:min
J1	JUNCTION	7.88	7.88	187 01:00	0.00	
J2	JUNCTION	0.34	8.17	187 01:00	0.00	
J3	JUNCTION	7.88	15.99	187 01:00	0.00	
J4	JUNCTION	0.34	16.23	187 01:01	0.00	
J5	JUNCTION	0.34	16.50	187 01:01	0.00	
J6	JUNCTION	0.34	16.75	187 01:02	0.00	
J7	JUNCTION	0.34	16.98	187 01:03	0.00	
J8	JUNCTION	0.34	17.21	187 01:03	0.00	
J9	JUNCTION	0.34	17.42	187 01:04	0.00	
J10	JUNCTION	0.34	17.63	187 01:04	3.33	187 01:05
J11	JUNCTION	0.34	14.63	187 01:00	0.00	
Outfal1	OUTFALL	0.00	14.63	187 01:00	0.00	

****
Outfall Loading Summary
****

Outfall Node	Flow Freq. Pcnt.	Avg. Flow CMS	Max. Flow CMS
Outfal1	53.26	0.04	14.63
System	53.26	0.04	14.63

****
Link Flow Summary
****

Link	Type	Max Flow CMS	Time of Max Occurrence days hr:min	Max Velocity m/sec	Max/ Full Flow	Max/ Full Depth	Total Minutes Surcharged
C1	CONDUIT	7.83	187 01:00	4.78	0.42	0.45	0
C2	CONDUIT	8.15	187 01:01	4.81	0.44	0.46	0
C3	CONDUIT	15.93	187 01:01	5.58	0.85	0.71	0
C4	CONDUIT	16.19	187 01:01	5.60	0.87	0.72	0
C5	CONDUIT	16.47	187 01:02	5.61	0.88	0.73	0
C6	CONDUIT	16.73	187 01:03	5.62	0.89	0.74	0
C7	CONDUIT	16.96	187 01:04	5.63	0.91	0.75	0
C8	CONDUIT	17.20	187 01:04	5.64	0.92	0.76	0
C9	CONDUIT	17.41	187 01:05	5.65	0.93	0.76	0
C10	CONDUIT	14.31	186 01:14	4.20	1.08	1.00	57
C11	CONDUIT	14.63	187 01:00	16.65	0.41	0.44	0

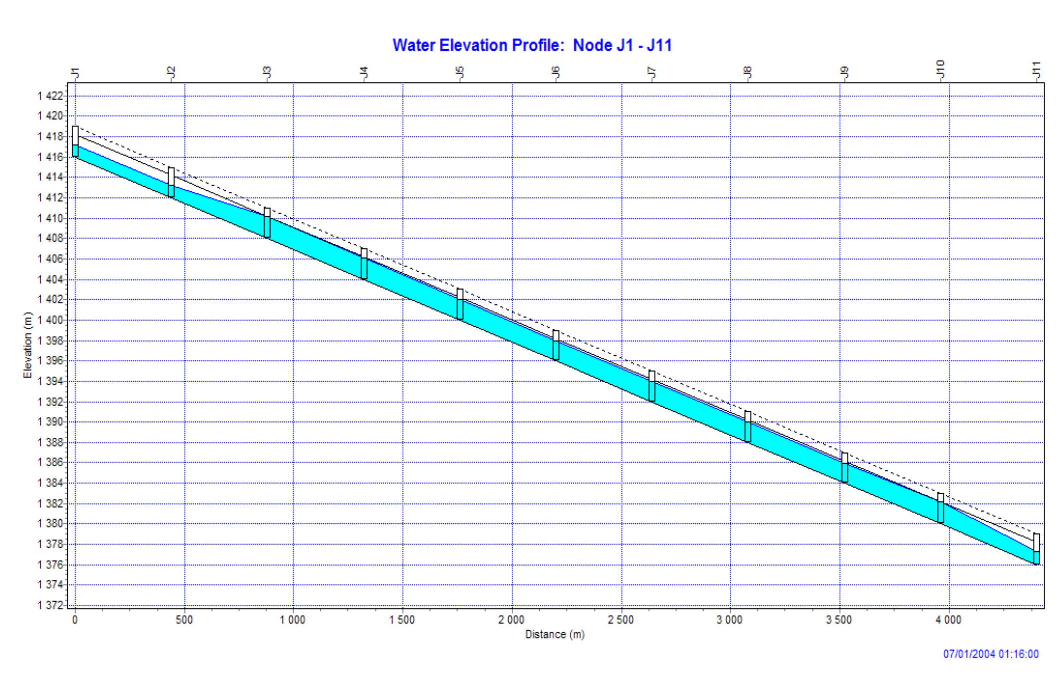
****
Routing Time Step Summary
****

Minimum Time Step : 60.00 sec
Average Time Step: 60.00 sec
Maximum Time Step: 60.00 sec
Percent in Steady State: 0.00
Average Iterations per Step: 1.00
Analysis begun on: Wed Apr 25 13:36:34 2007
Total elapsed time: 00:02:00

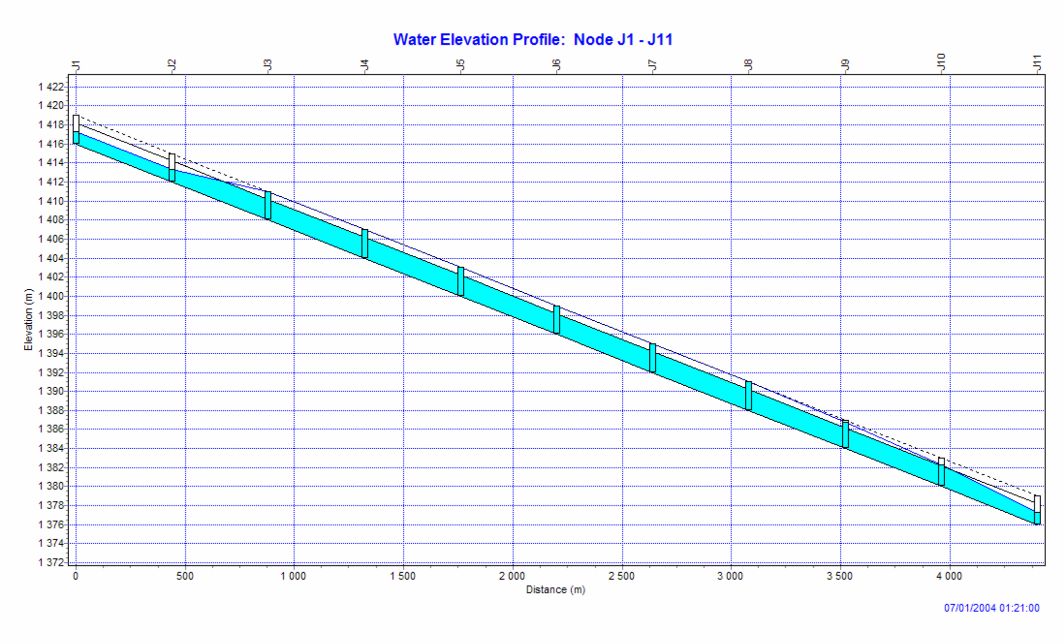
APPENDIX D

System profile when flooded

System profile of Junction 1-11 in Century Avenue Catchment



(a) On the verge of flooding at 1 hour and 16 minutes

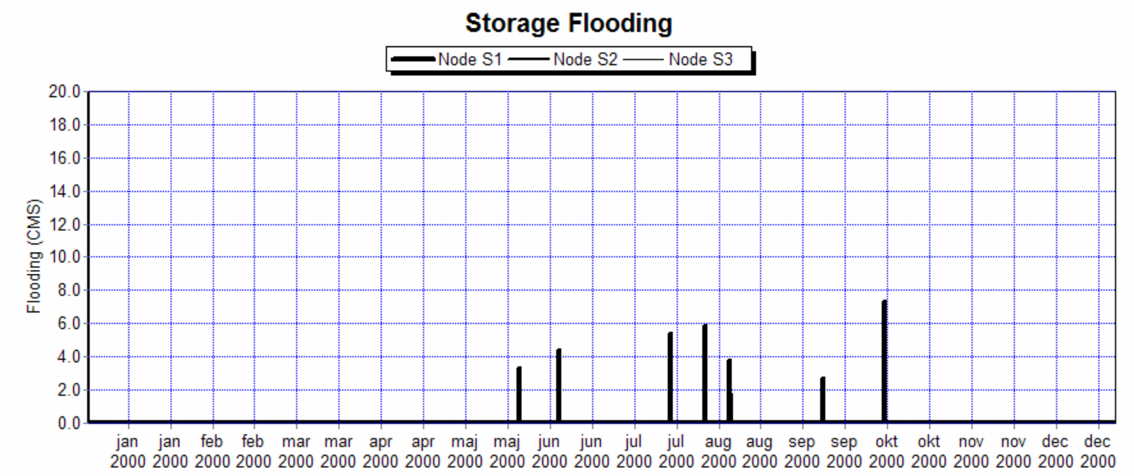


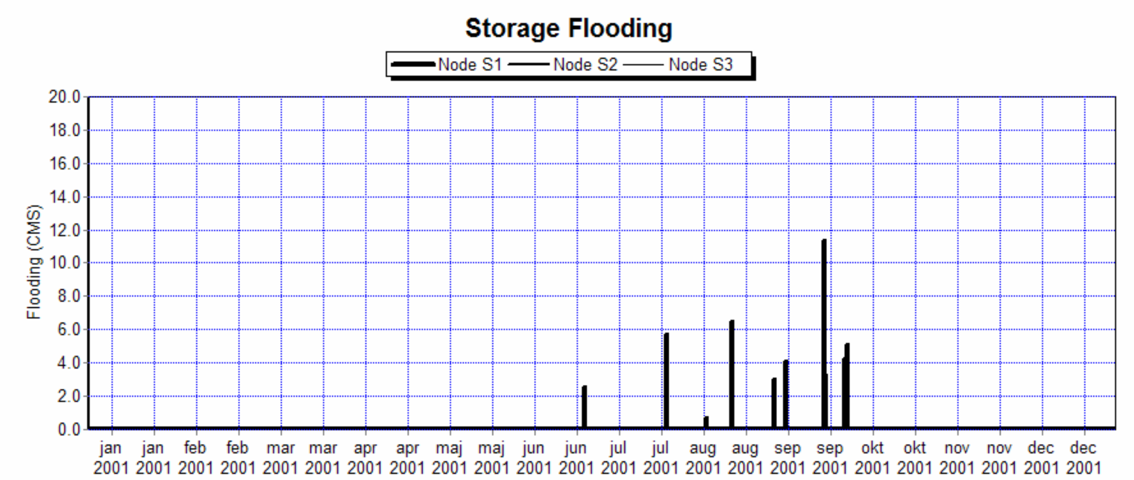
(b) Flooding at 1 hour and 21 minutes

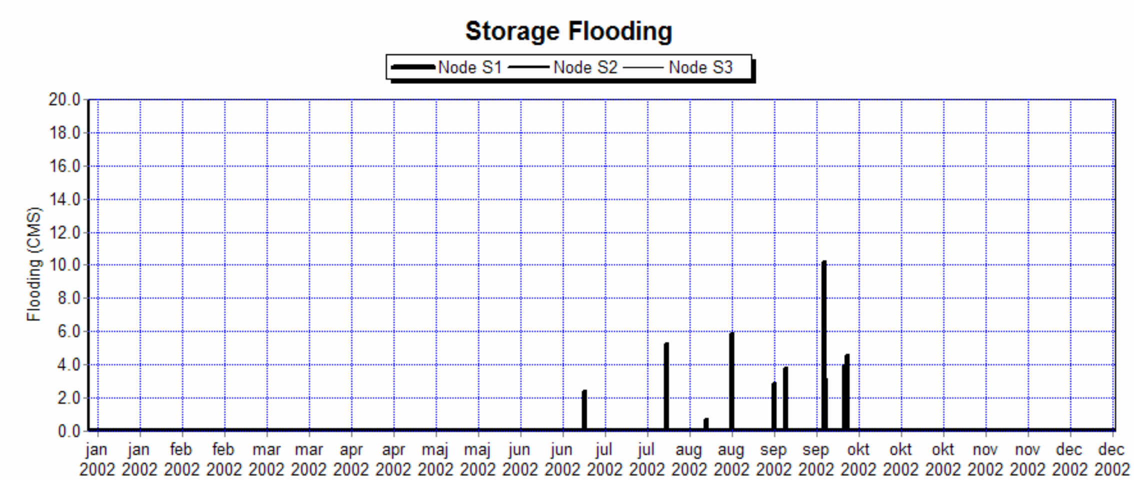
APPENDIX E

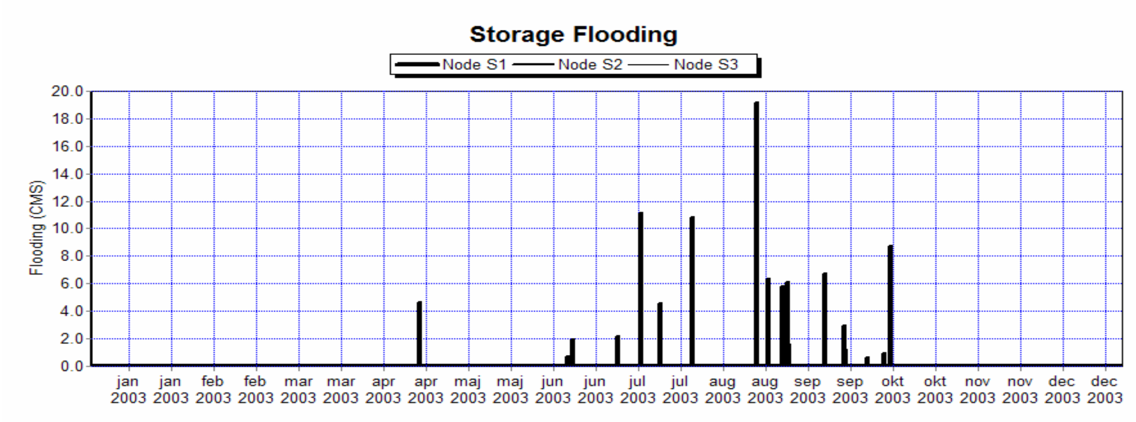
Tian Hu Catchment: Flood diagrams in 2000 – 2006

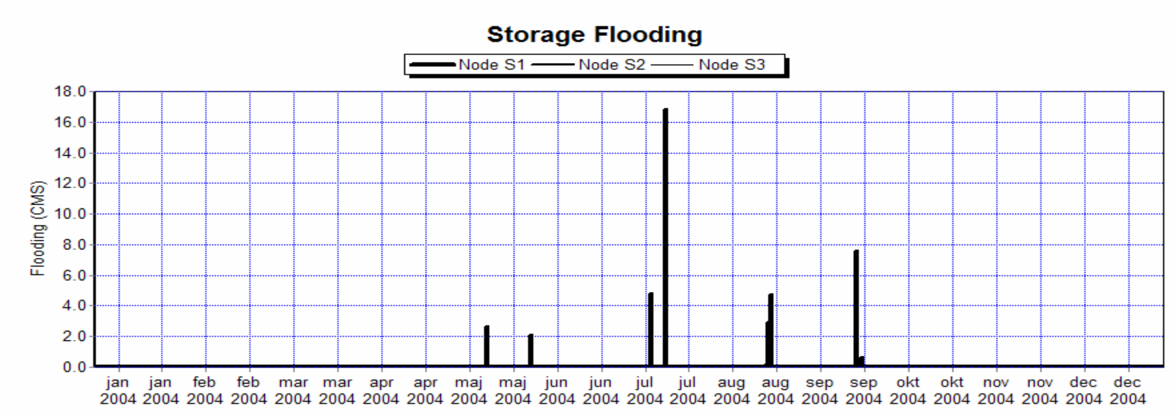
Simulating with daily rainfall pattern.

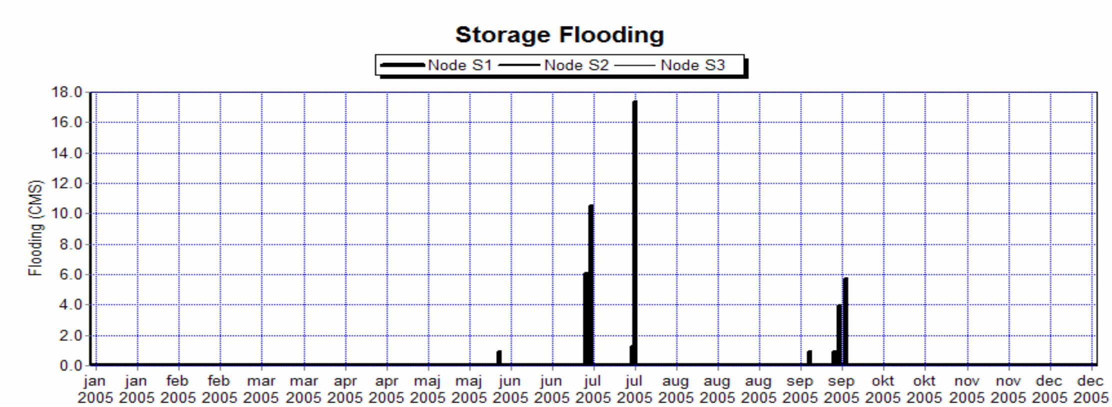


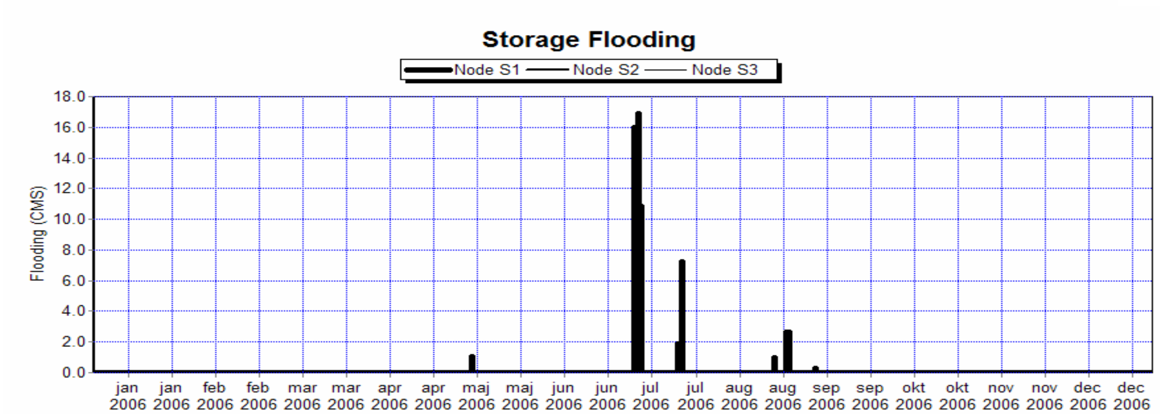





Storage Flooding
Node S1 Node S2 Node S3
Flooding (CMS)
20.0 18.0 16.0 14.0 12.0 10.0 8.0 6.0 4.0 2.0 0.0
jan 2003 jan 2003 feb 2003 feb 2003 mar 2003 mar 2003 apr 2003 apr 2003 maj 2003 maj 2003 jun 2003 jun 2003 jul 2003 jul 2003 aug 2003 aug 2003 sep 2003 sep 2003 okt 2003 okt 2003 nov 2003 nov 2003 dec 2003 dec 2003


Storage Flooding
Node S1 Node S2 Node S3
Flooding (CMS)
18.0 16.0 14.0 12.0 10.0 8.0 6.0 4.0 2.0 0.0
jan 2004 jan 2004 feb 2004 feb 2004 mar 2004 mar 2004 apr 2004 apr 2004 maj 2004 maj 2004 jun 2004 jun 2004 jul 2004 jul 2004 aug 2004 aug 2004 sep 2004 sep 2004 okt 2004 okt 2004 nov 2004 nov 2004 dec 2004 dec 2004

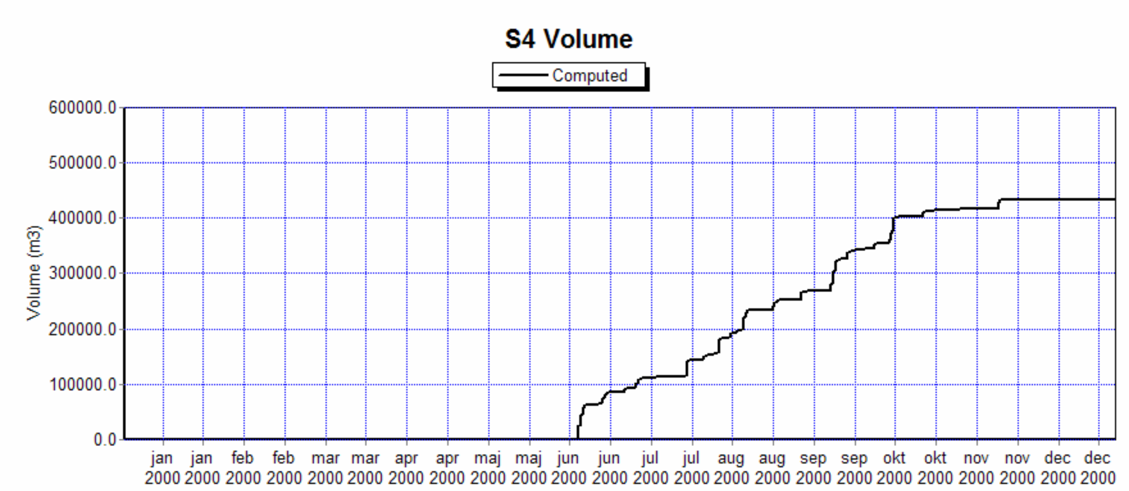

Storage Flooding
Node S1 Node S2 Node S3
Flooding (CMS)
18.0 16.0 14.0 12.0 10.0 8.0 6.0 4.0 2.0 0.0
jan 2005 jan 2005 feb 2005 feb 2005 mar 2005 mar 2005 apr 2005 apr 2005 maj 2005 maj 2005 jun 2005 jun 2005 jul 2005 jul 2005 aug 2005 aug 2005 aug 2005 sep 2005 sep 2005 okt 2005 okt 2005 nov 2005 nov 2005 dec 2005 dec 2005

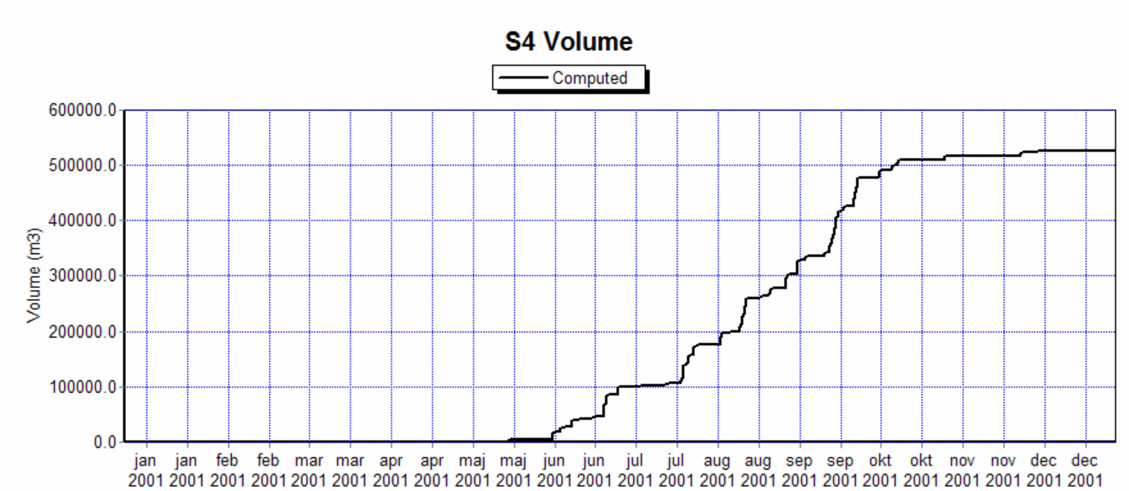

Storage Flooding
Node S1 Node S2 Node S3
Flooding (CMS)
18.0 16.0 14.0 12.0 10.0 8.0 6.0 4.0 2.0 0.0
jan 2006 jan 2006 feb 2006 feb 2006 mar 2006 mar 2006 apr 2006 apr 2006 maj 2006 maj 2006 jun 2006 jun 2006 jul 2006 jul 2006 aug 2006 aug 2006 sep 2006 sep 2006 okt 2006 okt 2006 nov 2006 nov 2006 dec 2006 dec 2006

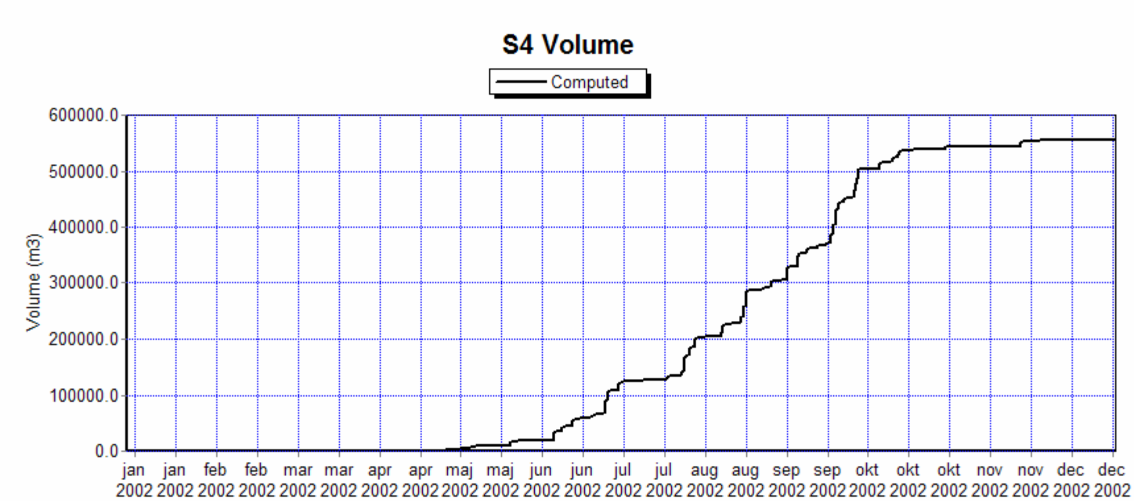
APPENDIX F

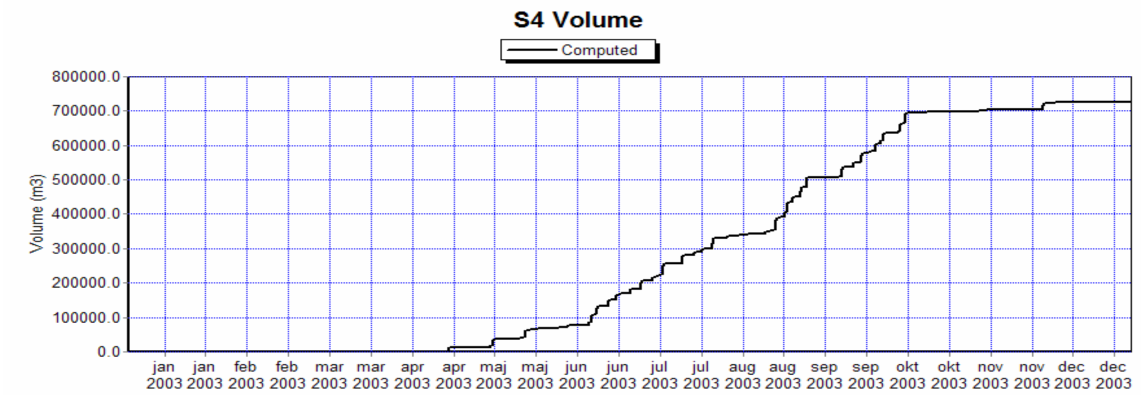
Volume in Storage 4 (S4) in 2000-2006

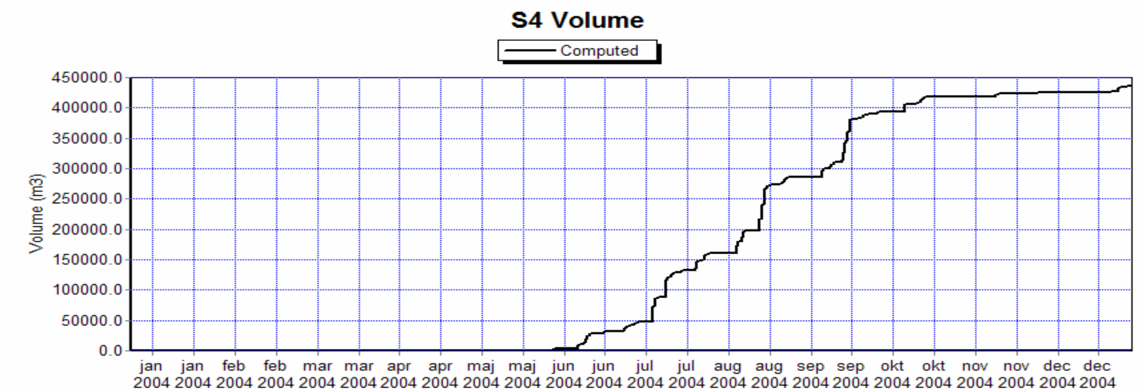
Simulated volume of storage in S4 at Tian Hu between 2000 and 2006

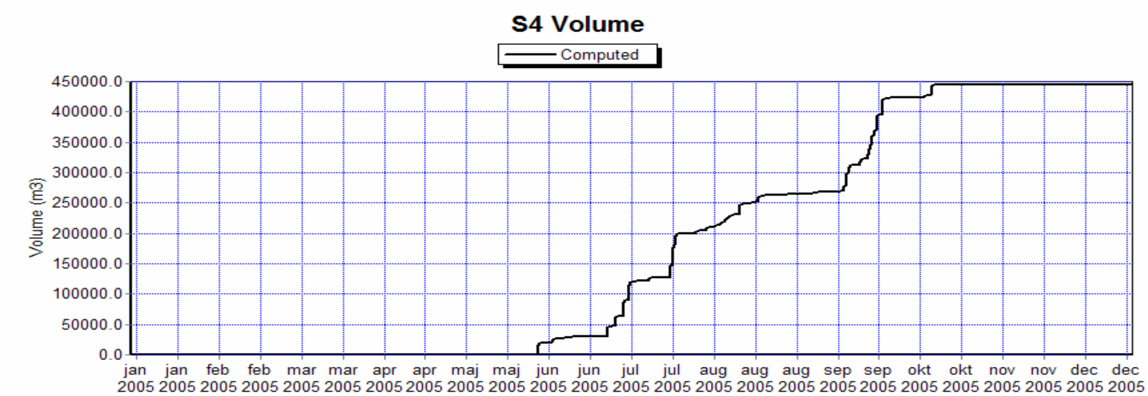


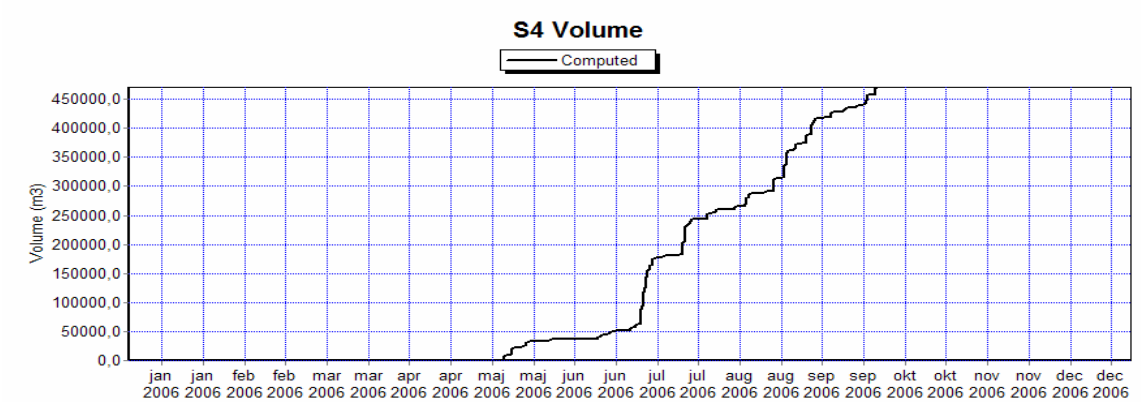





S4 Volume
Computed
Volume (m3)
800000.0
700000.0
600000.0
500000.0
400000.0
300000.0
200000.0
100000.0
0.0
jan jan feb feb mar mar apr apr maj maj jun jun jul jul aug aug sep sep okt okt nov nov dec dec
2003 2003 2003 2003 2003 2003 2003 2003 2003 2003 2003 2003 2003 2003 2003 2003 2003 2003 2003 2003 2003 2003 2003 2003


S4 Volume
Computed
Volume (m3)
450000.0
400000.0
350000.0
300000.0
250000.0
200000.0
150000.0
100000.0
50000.0
0.0
jan jan feb feb mar mar apr apr maj maj jun jun jul jul aug aug sep sep okt okt nov nov dec dec
2004 2004 2004 2004 2004 2004 2004 2004 2004 2004 2004 2004 2004 2004 2004 2004 2004 2004 2004 2004 2004 2004 2004 2004

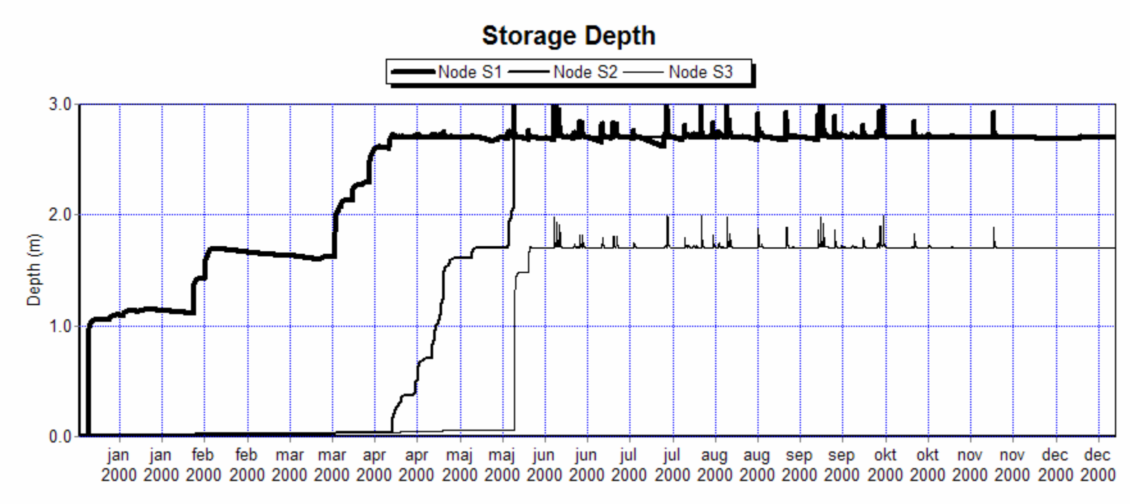

S4 Volume
Computed
Volume (m3)
450000.0
400000.0
350000.0
300000.0
250000.0
200000.0
150000.0
100000.0
50000.0
0.0
jan jan feb feb mar mar apr apr maj maj jun jun jul jul aug aug aug sep sep okt okt nov nov dec dec
2005 2005 2005 2005 2005 2005 2005 2005 2005 2005 2005 2005 2005 2005 2005 2005 2005 2005 2005 2005 2005 2005 2005 2005 2005


S4 Volume
Computed
Volume (m3)
450000,0
400000,0
350000,0
300000,0
250000,0
200000,0
150000,0
100000,0
50000,0
0,0
jan jan feb feb mar mar apr apr maj maj jun jun jul jul aug aug sep sep okt okt nov nov dec dec
2006 2006 2006 2006 2006 2006 2006 2006 2006 2006 2006 2006 2006 2006 2006 2006 2006 2006 2006 2006 2006 2006 2006 2006

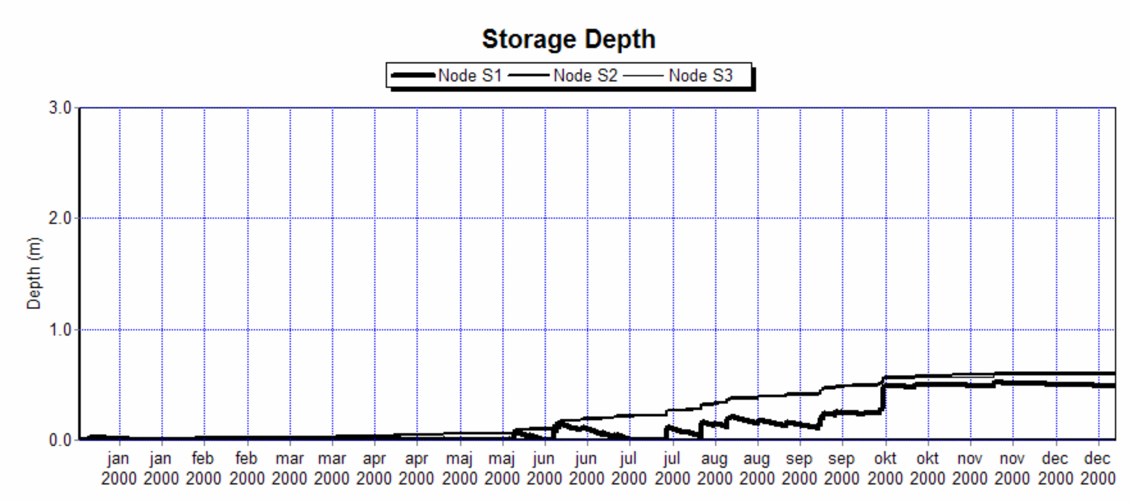
APPENDIX G

Storage depth in Sun, Moon and Star in 2000-2006

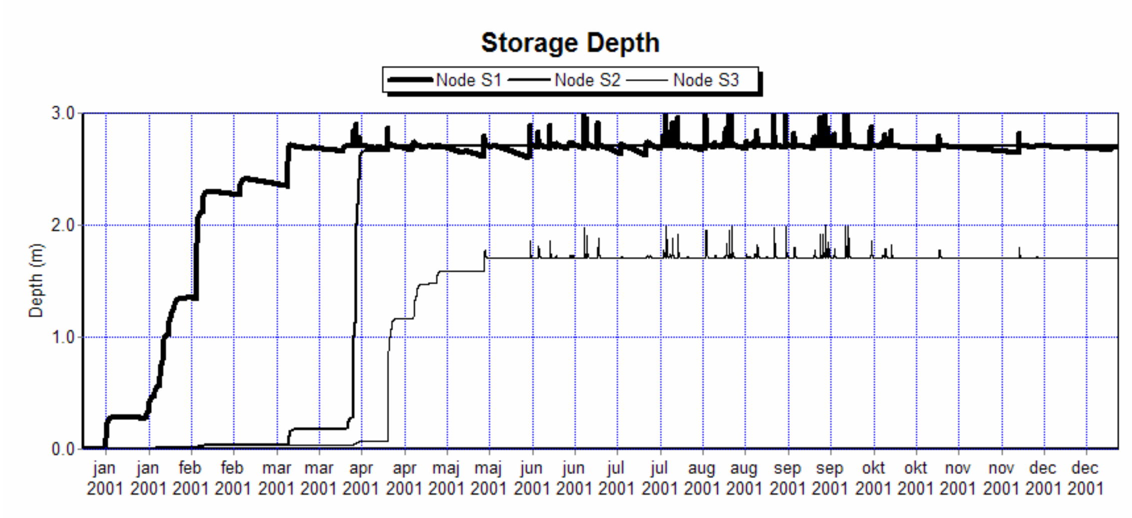
Simulated water depth at Tian Hu Catchment (a) with and (b) without external inflow.



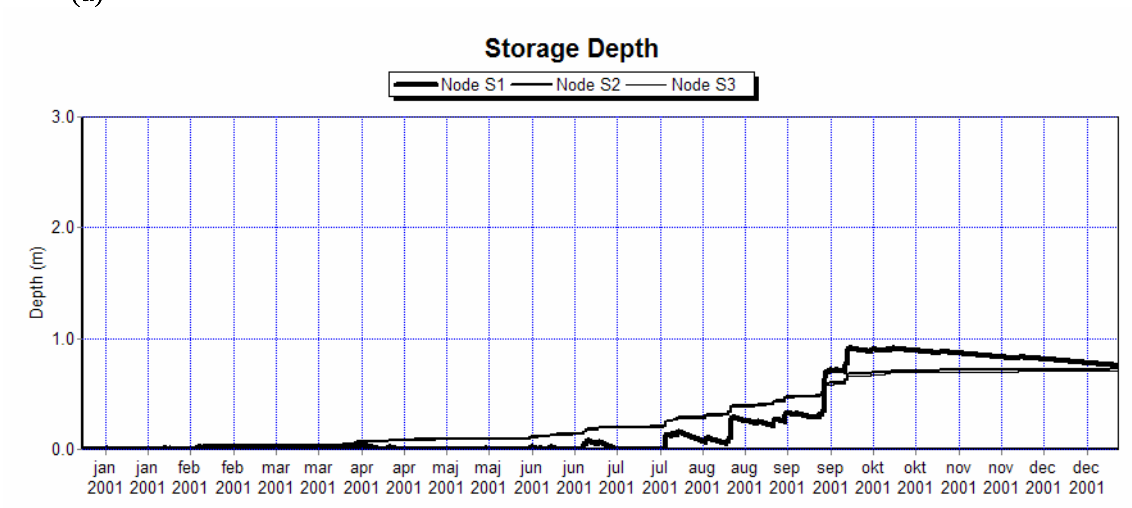
(a)



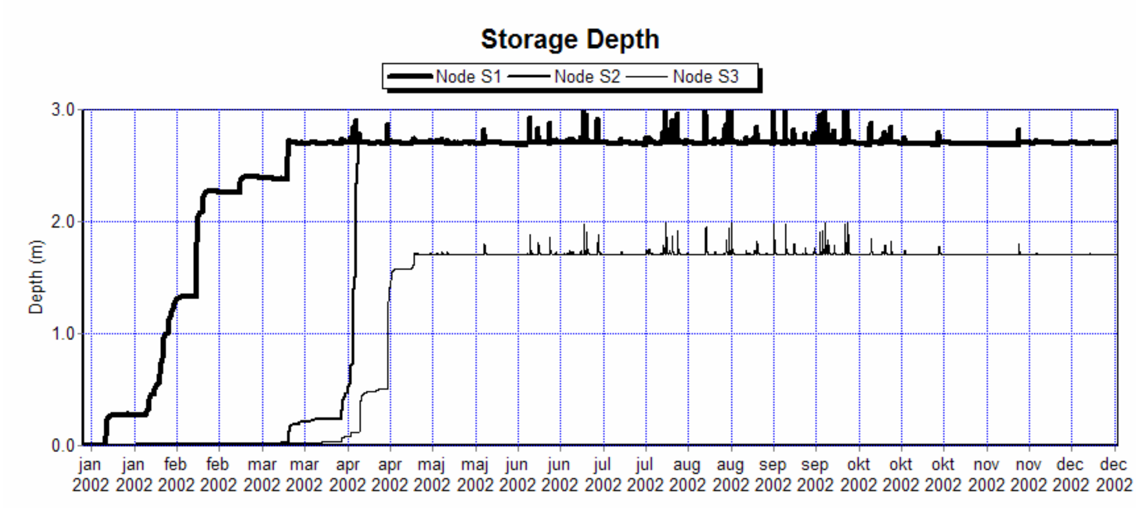
(b)


Storage Depth
Node S1
Node S2
Node S3
Depth (m)
3.0
2.0
1.0
0.0
jan 2001 jan 2001 feb 2001 feb 2001 mar 2001 mar 2001 apr 2001 apr 2001 maj 2001 maj 2001 jun 2001 jun 2001 jul 2001 jul 2001 aug 2001 aug 2001 sep 2001 sep 2001 okt 2001 okt 2001 nov 2001 nov 2001 dec 2001 dec 2001

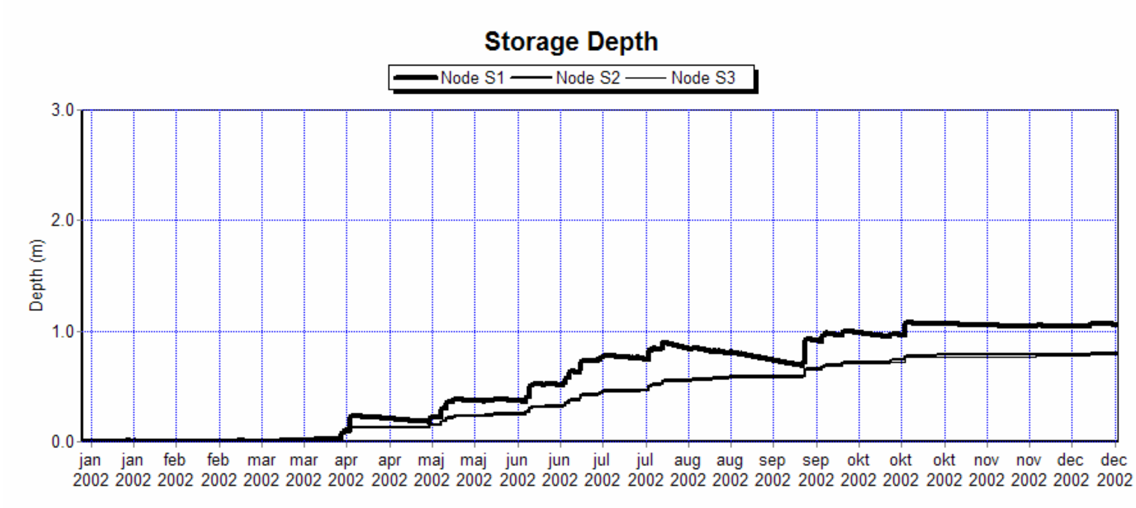
(a)


Storage Depth
Node S1
Node S2
Node S3
Depth (m)
3.0
2.0
1.0
0.0
jan 2001 jan 2001 feb 2001 feb 2001 mar 2001 mar 2001 apr 2001 apr 2001 maj 2001 maj 2001 jun 2001 jun 2001 jul 2001 jul 2001 aug 2001 aug 2001 sep 2001 sep 2001 okt 2001 okt 2001 nov 2001 nov 2001 dec 2001 dec 2001

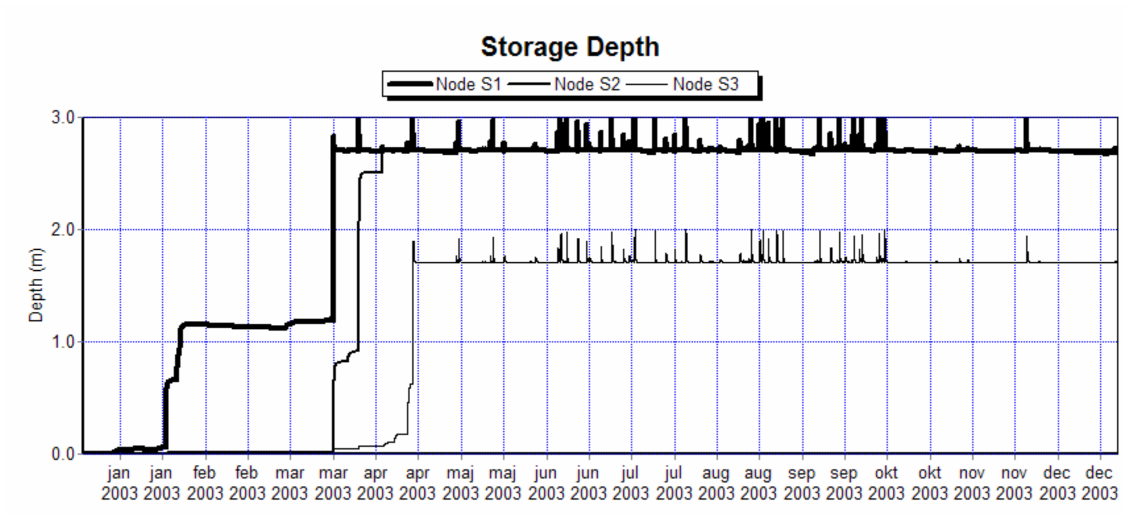
(b)


Storage Depth
Node S1
Node S2
Node S3
Depth (m)
3.0
2.0
1.0
0.0
jan 2002 jan 2002 feb 2002 feb 2002 mar 2002 mar 2002 apr 2002 apr 2002 maj 2002 maj 2002 jun 2002 jun 2002 jul 2002 jul 2002 aug 2002 aug 2002 sep 2002 sep 2002 okt 2002 okt 2002 okt 2002 nov 2002 nov 2002 dec 2002 dec 2002

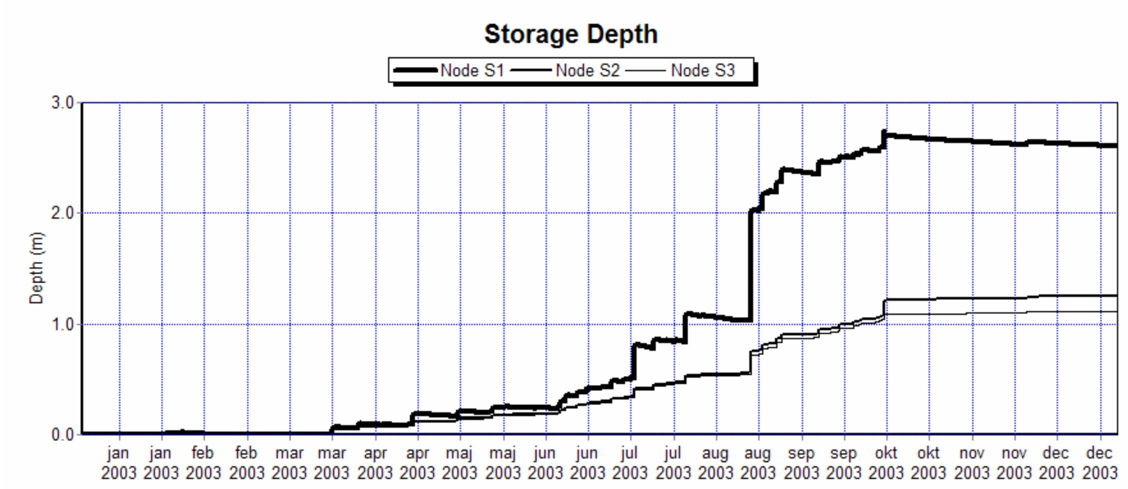
(a)


Storage Depth
Node S1
Node S2
Node S3
Depth (m)
3.0
2.0
1.0
0.0
jan 2002 jan 2002 feb 2002 feb 2002 mar 2002 mar 2002 apr 2002 apr 2002 maj 2002 maj 2002 jun 2002 jun 2002 jul 2002 jul 2002 aug 2002 aug 2002 sep 2002 sep 2002 okt 2002 okt 2002 okt 2002 nov 2002 nov 2002 dec 2002 dec 2002

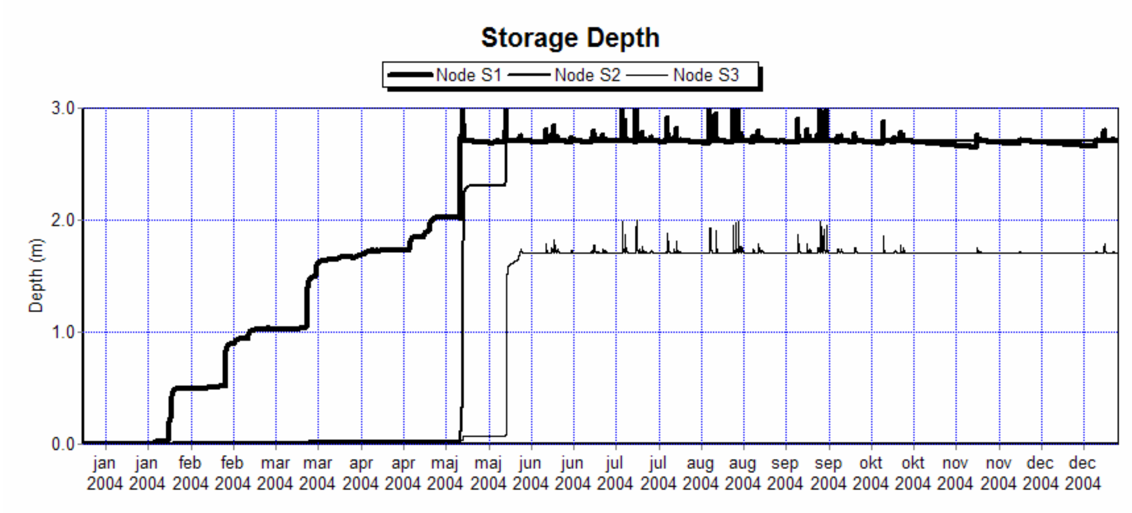
(b)


Storage Depth
Node S1
Node S2
Node S3
Depth (m)
3.0
2.0
1.0
0.0
jan 2003 jan 2003 feb 2003 feb 2003 mar 2003 mar 2003 apr 2003 apr 2003 maj 2003 maj 2003 jun 2003 jun 2003 jul 2003 jul 2003 aug 2003 aug 2003 sep 2003 sep 2003 okt 2003 okt 2003 nov 2003 nov 2003 dec 2003 dec 2003

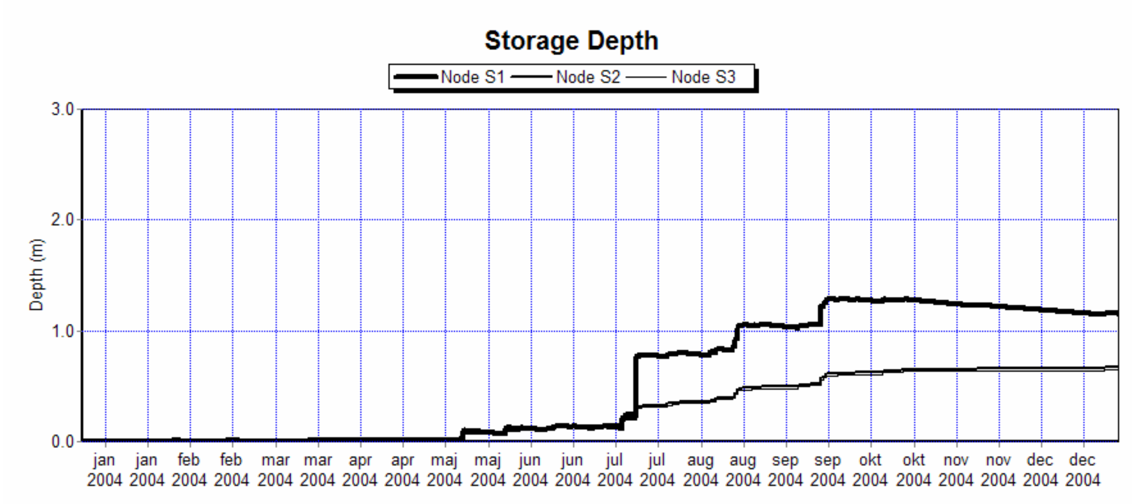
(a)


Storage Depth
Node S1
Node S2
Node S3
Depth (m)
3.0
2.0
1.0
0.0
jan 2003 jan 2003 feb 2003 feb 2003 mar 2003 mar 2003 apr 2003 apr 2003 maj 2003 maj 2003 jun 2003 jun 2003 jul 2003 jul 2003 aug 2003 aug 2003 sep 2003 sep 2003 okt 2003 okt 2003 nov 2003 nov 2003 dec 2003 dec 2003

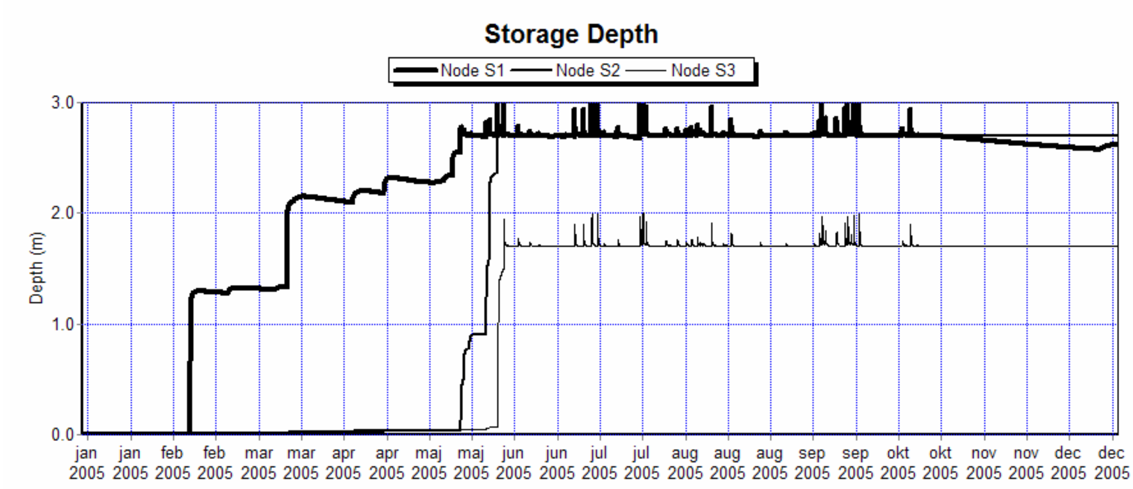
(b)


Storage Depth
Node S1
Node S2
Node S3
Depth (m)
3.0
2.0
1.0
0.0
jan 2004 jan 2004 feb 2004 feb 2004 mar 2004 mar 2004 apr 2004 apr 2004 maj 2004 maj 2004 jun 2004 jun 2004 jul 2004 jul 2004 aug 2004 aug 2004 sep 2004 sep 2004 okt 2004 okt 2004 nov 2004 nov 2004 dec 2004 dec 2004

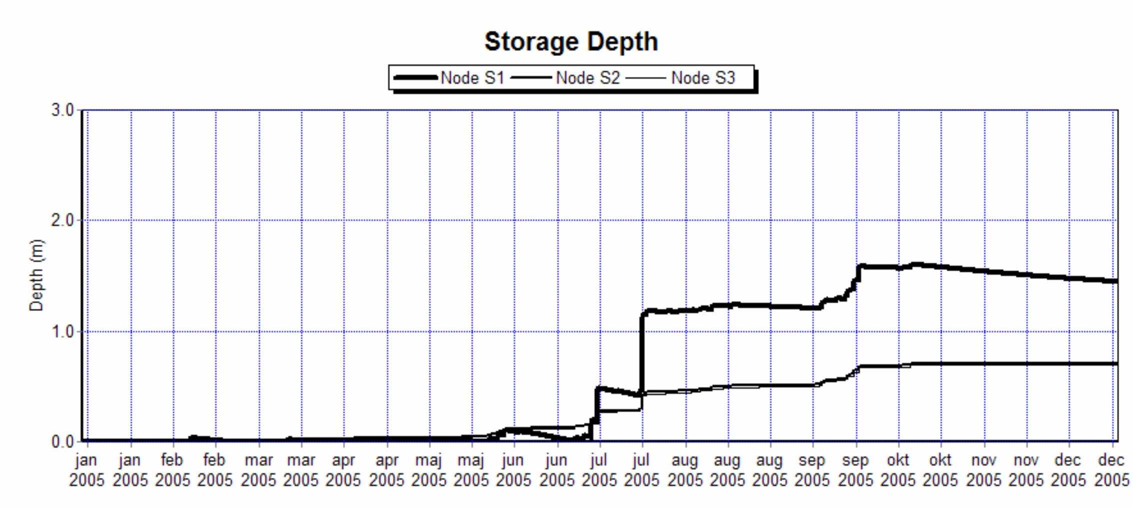
(a)


Storage Depth
Node S1
Node S2
Node S3
Depth (m)
3.0
2.0
1.0
0.0
jan 2004 jan 2004 feb 2004 feb 2004 mar 2004 mar 2004 apr 2004 apr 2004 maj 2004 maj 2004 jun 2004 jun 2004 jul 2004 jul 2004 aug 2004 aug 2004 sep 2004 sep 2004 okt 2004 okt 2004 nov 2004 nov 2004 dec 2004 dec 2004

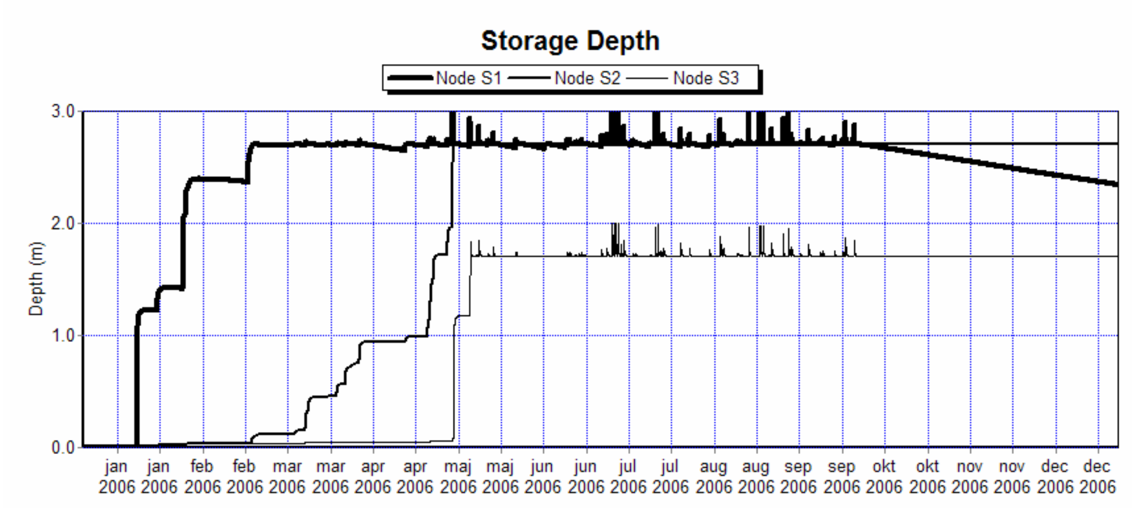
(b)


Storage Depth
Node S1
Node S2
Node S3
Depth (m)
3.0
2.0
1.0
0.0
jan 2005 jan 2005 feb 2005 feb 2005 mar 2005 mar 2005 apr 2005 apr 2005 maj 2005 maj 2005 jun 2005 jun 2005 jul 2005 jul 2005 aug 2005 aug 2005 aug 2005 sep 2005 sep 2005 okt 2005 okt 2005 nov 2005 nov 2005 dec 2005 dec 2005

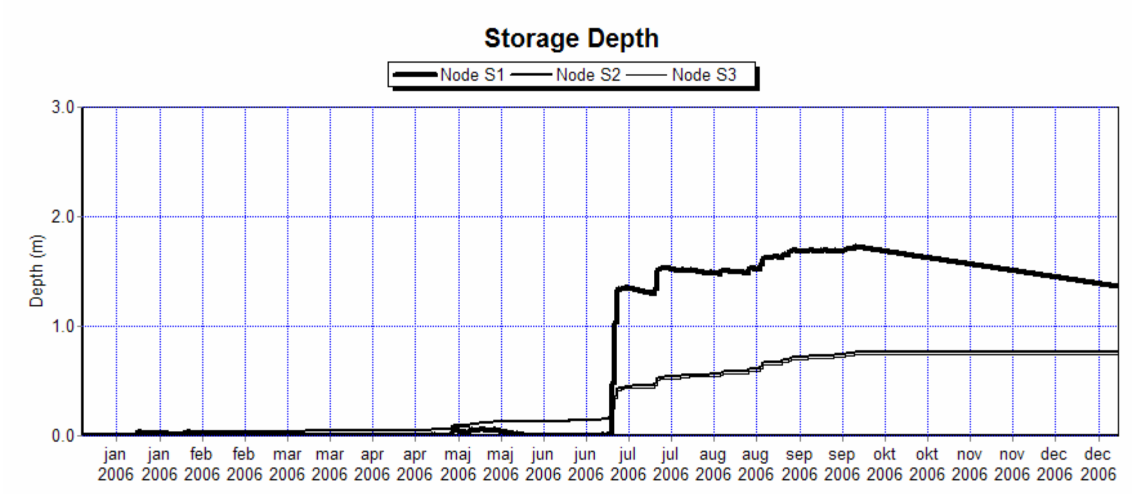
(a)


Storage Depth
Node S1
Node S2
Node S3
Depth (m)
3.0
2.0
1.0
0.0
jan 2005 jan 2005 feb 2005 feb 2005 mar 2005 mar 2005 apr 2005 apr 2005 maj 2005 maj 2005 jun 2005 jun 2005 jul 2005 jul 2005 aug 2005 aug 2005 aug 2005 sep 2005 sep 2005 okt 2005 okt 2005 nov 2005 nov 2005 dec 2005 dec 2005

(b)


Storage Depth
Node S1
Node S2
Node S3
Depth (m)
3.0
2.0
1.0
0.0
jan 2006 jan 2006 feb 2006 feb 2006 mar 2006 mar 2006 apr 2006 apr 2006 maj 2006 maj 2006 jun 2006 jun 2006 jul 2006 jul 2006 aug 2006 aug 2006 sep 2006 sep 2006 okt 2006 okt 2006 nov 2006 nov 2006 dec 2006 dec 2006

(a)


Storage Depth
Node S1
Node S2
Node S3
Depth (m)
3.0
2.0
1.0
0.0
jan 2006 jan 2006 feb 2006 feb 2006 mar 2006 mar 2006 apr 2006 apr 2006 maj 2006 maj 2006 jun 2006 jun 2006 jul 2006 jul 2006 aug 2006 aug 2006 sep 2006 sep 2006 okt 2006 okt 2006 nov 2006 nov 2006 dec 2006 dec 2006

(b)

APPENDIX H

Annual average values of infiltration, evaporation and surface runoff of the subcatchments

Annual averages at Tian Hu Catchment.

Year	Infiltration (mm)	Evaporation losses (mm)	Surface Runoff (mm)
2000	347.7	37.8	83.2
2001	401.2	41.5	117.3
2002	461.8	25.5	118.3
2003	553.4	24.7	256.8
2004	353.8	19.8	115.6
2005	348.9	19.3	142.6
2006	364.5	25.8	165.1