Using sensor web technologies to help predict and monitor floods in urban areas

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Abstract

Since flooding is worldwide one of the most common natural disasters, a number of flood prediction and monitoring approaches have been used. A lot of research has been conducted on the prediction and monitoring of floods by using hydrological models. The problem is that current hydrological models do not offer Disaster Management officials or township residents with timely data and information. In South Africa, possible flood warnings are usually communicated by Disaster Management officials using traditional approaches such as loudspeakers, radio and Television (TV). Making calls to warn residents about the possible occurrence of floods by using such means are, however, neither sufficient nor effective.

As the result of improved communication, sensor, software and computing capabilities, the use of sensor networks and sensor web for predicting and monitoring environment have been considered in recent years. In order for sensor data such as sensor measurements, sensor descriptions and alerts to be integrated, the Open Geospatial Consortium (OGC) introduced the Sensor Web Enablement (SWE) standards and suggested different specifications with respect to the geospatial sensor web. The first implementation of the sensor web framework is available. In this research, the results of using the sensor web technologies for predicting and monitoring floods in the urban areas are presented.

The aim of this research project is to illustrate how the sensor web technology can help in the prediction and monitoring of floods in the urban areas, particularly in the Alexandra Township (Greater Johannesburg) which has experienced floods each and every year. The focus of this research is on the incorporation of the sensor data into the sensor web technology. The data used as input to sensor web and the hydrological model was historical rainfall data from the South African Weather Service (SAWS). Shuttle Radar Topography Mission (SRTM) free data from the internet was also used in this research.

Alexandra Township residents and Disaster Management officials subscribe to get flood warning notifications via Short Message Service (SMS) to their mobile phones. This is achieved by subscribing to subscription requests in the Jmeter. Residents and officials provide profile, user name and communication protocol, which they prefer, which in this research is SMS along with address. The sensor web has the capability to generate a unique identity and to manage the database of the residents and officials. The registered communication profile, residents and officials need to be sent to the messaging Jmeter. The Jmeter contains information of the township residents and Disaster

Management officials where the alert messages will be sent. Flood warning notifications will be received if the water level exceeds a threshold or certain value about the possibility of floods. Residents will send text messages to Disaster Management officials from the Disaster Management centre to request information about floods by using a unique identity or centre code. Alternatively, mobile phone users will use the web server to browse tables and hydrographs of flood information. Therefore, township residents will benefit by receiving flood-warning notifications via SMS to their mobile phones.

In this research project, the Hydrologic Modelling System (HEC-HMS 3.5) model was used to generate flood hydrographs. This was done by estimating the peak discharge in the Jukskei catchment area. In the process of calibration, two sets of historical rainfall data were used, including the years 1983 to 1993 and 1990 to 2000. Using the hydrological model HEC-HMS 3.5, observed peak discharge and simulated peak discharge were compared. It was found that from 1983 to 1993, the observed peak discharge was significantly lower than the predicted peak discharge. The observed peak discharge obtained from 1990 to 2000 was also lower than the predicted peak discharge. The findings showed that there was an increase in the flood events from 1993 to 2000 due to an increased impervious surface and urbanisation.

The results of the hydrological model indicate that flood hydrographs were successfully simulated. The implementation of the sensor web technology in the prediction and monitoring of floods performed successfully. The research concludes that sensor web technology can be used in the prediction and monitoring of floods in the Alexandra Township.

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List of Acronyms and Abbreviations

ALC	Alexandra Local Council
AML	Arc Macro Language
Casc2D	Cascade of Plains in 2-Dimensions
CSIR	Council for Scientific and Industrial Research
CSMs	Continuous Simulation models
DEM	Digital Elevation Model
EMLC	Eastern Metropolitan Local Council
GDMD	Gauteng Disaster Management Department
GNU GPL	General Public License
GIS	Geographical Information System
GRASS	Geographic Resources Analysis Support System
GUI	Graphical User Interface
HEC-DSS	Hydrologic Modelling System for Data Storage System
HEC-DSSVue	Hydrologic Modelling System for Data Storage
HEC-HMS	Hydrologic Modelling Systems
HSPF	Hydrologic Simulation Programme-Fortran
HRUs	Hydrologic Response Units
IFGI	Institute for Geoinformatics
JRE	Java Run Environment
MFD	Multiple Flow Direction
O and M	Observation and Measurements
OGC	Open Geospatial Consortium
PRMS	Precipitation Runoff Modelling System
RDP	Reconstruction and Development Programmes
SAWS	South African Weather Service

SCS	Soil Conservation Service
SEMs	Single Event Models
SES	Sensor Event Service
SFD	Single Flow Direction
SML	Sensor Model Language
SMS	Short Message Service
SOAP	Simple Object Access Protocol
SOS	Sensor Observation Service
SPS	Sensor Planning Service
SRTM	Shuttle Radar Topography Mission
SWAT	Soil and Water Assessment Tool
SWE	Sensor Web Enablement
SWSL	Sensor web, Web-based geoprocessing and Simulation Lab
Tcl/TK	Tool Command Language
TML	Transducer Markup Language
TOPMODEL	Topography-based Model
TV	Television
UH	Unit Hydrograph
WNS	Web Notification Service
WSN	Wireless Sensor Network
WWW	World Wide Web

1. Introduction

1.1 Background

In both developing and developed countries around the world, the number of people directly affected by floods is increasing. Floods increase in both severity and frequency. Yearly, floods displace people, damage their properties and destroy infrastructures. Many urban areas, with high density of properties and population concentration, are situated in areas that are vulnerable to floods or are defined as floodplains (Lehohla, 2006). Flood plains are almost flat or completely flat areas of land next to a river or stream. Climate change and human impacts are significant factors in flooding in urban areas. Migration from rural to urban areas (urbanisation) and resulting population growth leads to increased flood risk.

South Africa has experienced above average rainfall since November 2010. This has caused damage on a scale not recorded over many previous years (Vogel and Mgquba, 2004). The unusual weather patterns caused by the effects of La Niña, resulted in floods and a huge disruption of municipal services, loss of life and loss of livelihoods (Odur, 2011). The La Niña phenomenon occurs when the temperature of the surface of the sea is cooler than normal in the Equatorial and Central Pacific. La Niña usually causes flood conditions in the Northern part of South America, drought in the Western Pacific region and wet conditions in North America. In 2010, this phenomenon caused a severe natural disaster in Queensland, Australia, Sri Lanka and Brazil. It is estimated that more than 20 000 people were directly affected by floods and 40 people died because of floods (Kalako-Williams, 2011). In seven provinces, 28 district municipalities were declared national disaster areas.

In South Africa, all nine provinces (Western Cape, North West, Northern Cape, Mpumalanga, Limpopo, KwaZulu-Natal, Gauteng, Free State and Eastern Cape) were affected by floods (Odur, 2011). The effects of floods differ at provincial level. During December 2010 and early January 2011, heavy rainfall in KwaZulu-Natal caused houses to collapse in Harding. 1845 Households were affected in Ladysmith. In Gauteng, flooding took place in Benoni during February 2011. There, shacks were constructed on dolomitic soil, the area is sinking because of the heavy rain and 9240 houses were directly affected by flooding (Kalako-Williams, 2011). In the Free State, bridges were washed away and roads were badly damaged during January 2011. This happened in the informal settlements where 350 houses were affected (Odur, 2011). During December 2011, hail, strong wind, severe storms, floods and heavy rainfall was experienced in Limpopo, in the Vhembe and Mopani districts (Nkambule, 2011). About 1540 houses in the Vhembe district were affected. On 10 January 2011, the area around the vicinity of Christiana and Warrenton was badly affected by floods in the North West and 417 families were displaced (Odur, 2011). In the Northern Cape, less rainfall had been experienced. However, extensive damage occurred as a result of floods from overflowing rivers and dams. This affected 995 households in the Kjai Garib area. In the Eastern Cape, less flooding was reported as compared to other provinces during December 2010 and only 500 houses were affected (Ngcobo, 2011).

In January 2000, severe floods occurred due to torrential rain across the Southern African Development Community (SADC) (Vogel and Mgquba, 2004). Between 1998 and 2000, several extremes in weather patterns were recorded (Vogel and Mgquba, 2004). During this period, extreme rainfall and floods were also recorded in different parts of the world, including Australia, Argentina, Indonesia, parts of Europe and Venezuela (Mayekiso, 1996).

In March and February 2009, the water levels of Chobe, Cunene, Okavango and Zambezi rivers in Namibia, increased because of torrential rains (Mandl, 2010). This led to a flood, with a recorded 40-year record level, in the Cuvelai, Kavango and Capivi basins. 750 000 people were affected (Mandl, 2010). Some of the villagers had to be relocated in camps, having been cut off from their villages and more than 50 000 people were displaced. The disaster left 102 people dead and caused severe losses, with livestock remaining stranded and dying of hunger.

In February 2000, a tropical storm hit the coast of Mozambique. The cause of this tropical storm was cyclone Eline that occurred after cyclone Connie. On 22 February, cyclone Eline made landfall, moved over the Limpopo River basin and caused huge downpours (Artan et al., 2002).

The high rainfall from cyclone Eline, added to already saturated wet soil after the passage of cyclone Connie, caused severe floods in the lower part of the Limpopo basin. During this flood, almost one million people were displaced from their homes, properties worth millions of dollars were damaged or destroyed and more than 700 people lost their lives due to floodwater (Artan et al., 2002). Satellite images captured during the flood showed a huge area under water, about 20 km wider than the normal river. In South Africa, the Gauteng province recorded losses worth millions of Rands because of the floods (Vogel and Mgquba, 2004). A lot of infrastructure and public facilities such as roads were washed away.

Possible flood warnings in South Africa are usually communicated by the local disaster risk management centre or local weather office through radio, loudspeaker and TV (Vogel and Mgquba, 2004). If residents think that there is a possibility of flooding in their area, they listen to the radio or watch TV regularly (DEA, 2005). Residents can also contact the nearest weather station. According to officials from the disaster risk management centre, they often use loudspeakers to warn residents about the possibility of flooding (DEA, 2005). Communicating only via TV and radio has severe limitations as these media are often switched off during the night. TV and radio also mostly report a disaster once it is happening or after it has happened. Communicating early warning of potential floods to vulnerable communities and the general public remains a challenge, highlighting the need for an efficient, improved early flood prediction and monitoring system.

1.2 Problem Statement

Floods are one of the most common natural disasters around the world, often happening without any warning signs. In January 2000 alone, many people in Alexandra Township were displaced, their houses were swept away and four people lost their lives (Lehohla, 2006). Problems caused by floods have increased significantly in recent decades because of increased population density, sub-standard settlements, migration, sub-standard infrastructure developments (especially in townships), shacks and unplanned urbanisation (Vogel and Mgquba, 2004). Floods can result from different causes. Floods occur after prolonged or intense rainfall, when rivers and water levels in the rivers rise and rivers overflow their banks (Lehohla, 2006). Floods can also be caused by rising underground water, often associated with long duration of heavy rainfall.

In Gauteng, flooding is common during summer (Mgquba, 2002). Between the 8th and 13th of February, 2000, 146.2*10 m^3 flowed into the Hartbeespoort Dam, located northwest of Alexandra Township (Mayekiso, 1996). The social and financial impact of this flood was severe. The Department of Water Affairs and Forestry estimated that about R192 million had to be spent on emergency supply of drinking water and water services (Vogel and Mgquba, 2004). An obvious result of the extreme rainfall was the severe floods, which occurred across a wide region of Johannesburg, causing widespread damage and havoc. Most of the dams in the region were almost 100% full and some rivers burst their banks (Nkambule, 2011). These rivers included the Jukskei and Sand Spruit. Some of the roads had to be closed while others were severely damaged. While some damage can only be permanently avoided by strict regulations and implementation of such regulation (e.g. insisting on flood plains that can absorb floods; no human habitats allowed within floodlines), not all damage can be eliminated. However, in order to reduce possible loss of life and loss of stock/household goods/homes, there is a need for early flood alerts to help in the prediction and monitoring of floods. Sensor web provides such early alerts about potential/actual floods to Disaster Management officials and to residents of Alexandra living on the banks of the Jukskei River. This enables residents to be able to evacuate before the river floods, threatening their livelihood. Heavy rainfall, water level data or information can be accessed through the sensor web. People can subscribe to the sensor event service of the sensor web to receive timeous notification about any floods.

Floods usually cause damage to businesses and homes if they are built within a natural flood plain of rivers (Rosenberger, 2003). The only way people can avoid flood damage is by moving away from river edges, wetlands and flood plains. The recurring problem is that most people who cannot afford to live within the established town areas, prefer to live close to water (Kalako-Williams, 2011). People continue to live in the areas that are under the threat of flooding because they perceive the value of living close to water exceeds the cost of flooding damage (Mayekiso, 1996). The location of informal settlements on the banks of the Jukskei River exacerbates the risk of the residents of the natural hazard such as a flood (Rosenberger, 2003). Most of the residents who live along the Jukskei River cite lack of (open and free) space where they can go. The space along the river is free, close to their work environment, there is no need for them to pay rent and no need to spend money on transport (Vogel and Mgquba, 2004).

Alexandra Township was used to find out whether the sensor web technology can help in the prediction and monitoring of floods. Flood monitoring and prediction are significant in improving the safety and effectiveness in the Alexandra Township (Vogel and Mgquba, 2004). Issuing of flood warnings by using loudspeaker, TV and radio are not effective and most of the people living in the low-lying areas near the Jukskei River complain that they had been warned too late about floods.

1.3 Research Objectives

The main aim of this research is to find out if the sensor web technology can be used to help in the prediction and monitoring of floods in the Alexandra Township. Disaster Management officials and township residents need to have quick access to data sets or existing information in an emergency such as floods, to be able to process and request data. To receive data or observation, Disaster Management officials need to subscribe to sensor web services. During the subscription stage, Disaster Management officials provide filters depending on what kind of sensor data or information is required. Filters are sensor location, identification or the phenomenon under observation such as the water level. Web services that include Sensor Event Service (SES), Observation and Measurements (O and M) and the Sensor Observation Service (SOS) are used to gain access to sensor data. These web services are responsible for the user notification, subscription, analysis, acquisition and planning about sensor observation when the water level reaches a certain level or threshold value. The SES filters sensor data. When the peak events are found, the notifications are sent to Disaster Management officials and township residents who subscribe to the service.

Specific objectives of this research include:

- To assess if the sensor web technologies can improve historical rainfall data input to models.
- To use sensor web technology to help in the prediction and monitoring of floods
- To try to understand if the sensor web will help in the dissemination of data and information.

1.4 Research Questions

To address the above-mentioned objectives, the research questions below were defined.

- Can the sensor web technology help in the prediction and monitoring of the floods in the urban areas?
- Can Disaster Management officials effectively disseminate information and data to the affected people by using the sensor web technology?

1.5 Hypotheses

The hypotheses that will be tested in this research are:

- The sensor web technologies can be used to help in the prediction and monitoring of floods in the urban area.
- The Disaster Management officials can effectively disseminate information and data to the affected people by using sensor web technology.

1.6 Scope of research and limitations

- Several freely available data sets were utilised to ensure that the objectives of this study were met. These included historical rainfall data acquired from SAWS and Digital Elevation Model (DEM) data downloaded from the internet.
- HEC-HMS 3.5 software was used for data analysis; historical rainfall data was entered into HEC-HMS 3.5 software; the simulation model was run and the simulated results compared with observed rainfall data.
- Geographic Resources Analysis Support System (GRASS GIS) was used in the analysis of topographical data such as the Digital Elevation Model.

1.6.1 Study Area

Alexandra Township is situated in the northeastern suburbs of the city of Johannesburg, close to some of the wealthiest suburbs in Johannesburg. Sandton is only 3 km away (Project Spotlight, 2001). In 1912, Alexandra Township was established and was the closest township to Johannesburg (Figure 1 on page 7). The area of the township covers more than 800 ha (DEA, 2005). The infrastructure of the township was designed to carry a population of 70 000, However, the population has grown to almost 750 000 (Project Spotlight, 2001). Formal houses and residential stands which were intended for one family only now also feature informal shacks in the backyards (Vogel and Mgquba, 2004). Some of these backyard shacks are used for supplementary rental income by the owners of the residential stands since unemployment is high in Alexandra Township. These backyard shacks have been built over current sewers, blocking access for maintenance and, without proper additional sewer access, it overloads the current infrastructure (Project Spotlight, 2001).

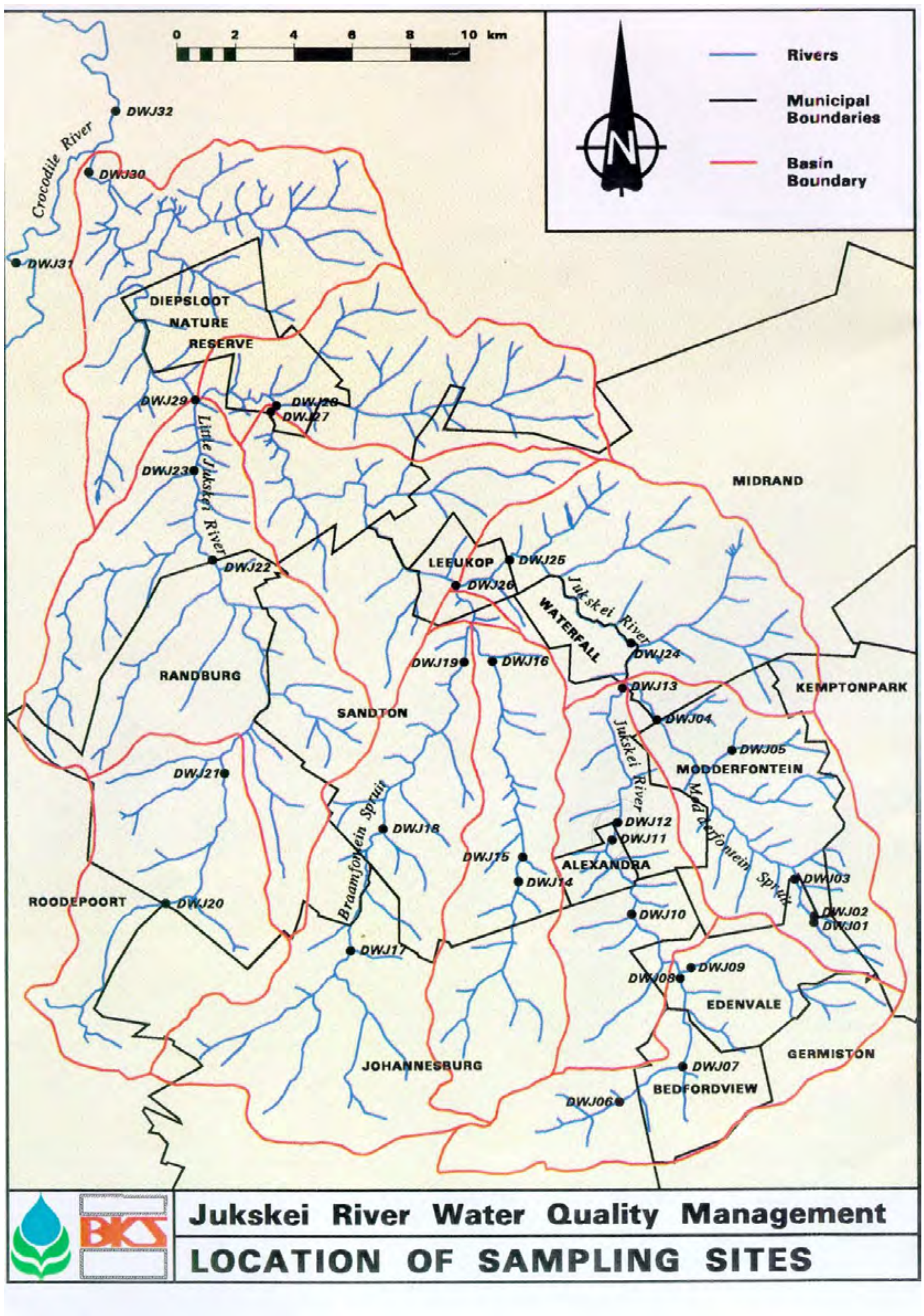

Figure 1: Map of the greater Johannesburg which shows where Alexandra Township, Waterval and Jukskei River are located, Available from:
http://www.google.co.za/imgres?q=images+for+jukskei+river+in+alexandra+Township&sa=X&biw=1272

The Jukskei River is located within the Johannesburg Metropolitan area and forms part of the catchment area of the Limpopo River, which flows into the Indian Ocean. According to Campbell (1996), the catchment area extends to 800 km^2. The river flows in the Northern direction where it links with the Crocodile River. The Jukskei River is regarded as one of the largest of the three rivers, which are found in the North East and Northern suburbs of the Witwatersrand (Vogel and Mgquba, 2004). The source of the Jukskei River lies in the Bezuidenhout valley, which is located in the Eastern part of Johannesburg. The Jukskei River flows through the township of Alexandra. The river separates the township into two sub-catchment areas. These sub-catchments are West bank and East bank. The river then moves on to Midrand and many of the informal settlements are located below the 1:100 year flood-line indicated by white line (Rosenberger, 2003) (Figure 2 on page 8). The river is a good indication of an urban catchment area where most of the problems were caused by and are the results of urbanisation (Campbell, 1996).

Figure 2: Aerial photography indicating how close the residential stands are to the Jukskei River in the Alexandra Township, Johannesburg. Many of the informal settlements are located below the 1:100 year flood-line. The 1:100 year flood-line is indicated in white.

1.6.2 Data

The principal data sets used include, historical rainfall data and SRTM DEM data from the internet. The hydrologically corrected SRTM DEM was used to describe the Jukskei River. The historical rainfall data was used for validation and calibration of flood modelling. The HEC-HMS 3.5 uses three types of data which include grid data, time-series data and paired data. Time-series data is defined as statistical data collected in a regular interval (Suprit, Kalla and Vijith, 2010). For example, historical rainfall data. Paired data are data that can be exchange in a regular format. Paired and time-series data can be entered manually into the model, while grid data can be imported from the external drive. The data required by the Sensor Web Enablement components come from Observations and measurements, whether from in-situ or remote sensors. More details about the data used in this research are provided in Chapter 4.

1.6.3 Hydrological model

HEC-HMS 3.5 has been chosen for this research. HEC-HMS 3.5 is used in the simulation of the precipitation runoff process of the catchment (Mark and Marek, 2011). HEC-HMS 3.5 is a free and open source software for hydrological simulation. The model requires three components of the data model which include the precipitation model, control specifications model and basin model (Scharffenberg and Fleming, 2005). The SWE components use two types of models that include the Sensor Model Language (SML) and Transducer Model Language (TML). Details about the above-mentioned models will be discussed in Chapter 3, section 3.6.1 and Chapter 4, section 4.1.2.

1.7 Limitations

Historical rainfall data leads to delayed responses, meaning that the affected people will receive delayed SMS or notifications. No real-time reporting occurs, due to the use of rainfall data which is historical and which can differ from the latest rainfall data. Insufficient historical rainfall data limits the accuracy of the model analyses.

- Rainfall data directly from the rain gauge from Alexandra Township unavailable and the weather station in Alexandra had been vandalised and is no longer operating. Historical rainfall data from Waterval has been used.

- Data used is historical rainfall data because there is no recent data, which is available for both Alexandra Township and the Waterval.
- Data used is monthly data because the SAWS does not have hourly data available for the selected study area. This means that Disaster Management officials and township residents will receive delayed SMS or notifications.
- Some of the standards of the sensor web are matured and implemented while others are still in an infant stage where the SES has few applications.
- HEC-HMS 3.5 has two major limitations because of the way in which its software is designed and developed: these limitations include a simplified flow representation and a simplified model formulation. Simplification of flow representation maximises the efficiency of the model and at the same time minimises the size of a programme and time of runoff simulation. The choice of simplifying the formulation of the models is done in order to run simulation quickly and at the same time producing precise and accurate results.

1.8 Contribution to knowledge

There is an urgent need for improved prediction and monitoring of floods in urban areas. This is because of an increase in the frequency of and resulting problems caused by floods in urban areas like the severe floods that took place in January 2000. The SAWS reported this flood as the most damaging flood in the South African history. Thousands of people were displaced, their properties damaged and informal settlements washed away. Until a permanent solution is found, it is very important to use the sensor web technology as a platform for development of early flood warning systems. Such system will provide warnings about floods to potentially affected people in urban areas and to the Disaster Management officials. The sensor web technology will provide Disaster Management officials with useful information to determine if there is a high possibility of floods occurring.

1.9 Structure of the thesis

The executed project and the research conducted to evaluate the hypotheses and research questions are described in the body of this thesis.

Chapter 2 describes the issues related to the problems found in the site of the study area in terms of housing, urbanisation, migration and socio-economic-conditions and how these factors contributed to flooding. Chapter 3 describes the literature review about the Disaster Management, different hydrological factors and their applications in the prediction and monitoring of floods; and the application of sensor web in the Disaster Management. Chapter 4 describes the theoretical methodology and the relevant data used in this research. Chapter 5 presents the systems design with the conceptual design and software used. Chapter 6 presents the analyses and results obtained from the hydrological model, GRASS-GIS and the sensor web technology obtained in chapter 5. Chapter 7 presents the discussion of the results and conclusion obtained in chapter 6.

2. Description of the issues related to the problems found in the study site.

2.1 Urbanisation

According to Satterthwaite (Satterthwaite et al, 2009), urbanisation is an increase in the proportion of the national population which lives in the urban area, in this instant the increase in the number of people living around the banks of the Jukskei River. There is a relationship that exists between disasters and level of urbanisation (Pelling, 1999). Urbanisation affects disasters as disasters can also affect urbanisation (Vogel and Mgquba, 2004). It is also necessary to understand how the processes, which shape urbanisation, create the range of hazards. This will help raise the discussion about the vulnerability of the population in the city and particularly groups between them to the hazards of the environment (Mgquba, 2002).

There is a lot of unpublished and published literature which echo the sentiments that lack of resources and poverty in the urban environment are synonymous. Poor people in the urban area are usually located on the periphery of the city in houses that are in poor condition and within dangerous environments (Rosenberger, 2003). These urban poor are less often able to cope with the hazards. The process of urbanisation plays an important role in exacerbating flooding as urbanisation increases the peak flow volume and frequency of floods, decreases infiltration and increases the surface runoff (Project Spotlight, 2001). Figure 3 on page 13 below shows a flood hydrograph before development and after development (Schueler, 1987). It is from the hydrograph that the peak discharge increases after development.

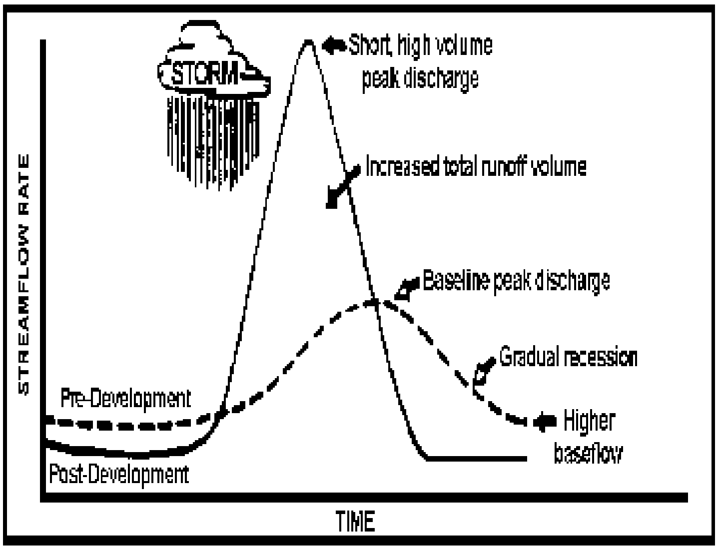

Figure 3: From Schueler (1987). How the process of urbanisation affects the flow of stream flow (Available from: **http://www.krisweb.com/krissheepscot/krisdb/html/krisweb/watershed/urban.htm).**

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The published literature clearly shows that the process of urban development, specifically unsustainable urban development, plays an important role in exacerbating and shaping urban flood. This is caused by increasingly inappropriate storm and waste management, inappropriate land use and artificial hard surfaces (Mgquba, 2002).

There are four types of urban flood which have been identified (Pelling, 1999). Firstly, a localised flood which is caused by inadequate drainage. Localised flooding leads to overland surface runoff and ponding. Secondly, small streams contribute to floods in urban areas where the catchment area is entirely in the built-up area. Thirdly, the urban areas experience floods from major rivers where cities and towns are built on the banks of the rivers. Fourthly, the urban areas experience flooding from the sea or by a combination of river flow from inland and high tides (Els, 2011). The first and second types of floods take place in the towns of Africa more often than the third type of flood. The fourth type of flood takes place where the buildings and other infrastructures are built on the mangrove swamps and coastal wetlands (Pelling, 1999).

Altering of streams, rivers and the natural landscape is regarded as the main impact of urbanisation concerning the risk of floods (Pelling, 1999). It is evident from the literature that urbanisation increases the rate of flood in urban areas which involve local human factors. Some of these factors include occupation of floodplains, urban growth and poor storm water and solid waste drainage management which is worsened through the bad practice of refuse dumping into the stormwater system and rivers by ill-informed people (Vogel and Mgquba, 2004). Informal, poorly regulated or unplanned dwellings, particularly those that are located on wetlands and floodplains or rivers and where no proper storm water drainage system exists, are vulnerable to the risk of flood (Vogel and Mgquba, 2004). Poor building standards and inferior housing materials for construction coupled with poor site locations, close to the wetlands or rivers or areas with a high water table increases the vulnerability of poor people to floods (Vogel and Mgquba, 2004). Poor people in urban areas remain vulnerable and negatively affected by floods as they increase in severity and frequency.

Another factor which leads to the increase of flooding is poor infrastructure. Several pipes and drains are regularly blocked with waste in the Jukskei River. This waste is the product of residents living along the banks of the Jukskei River and the result of poor waste disposal structures (Project Spotlight, 2001). Together with poor waste disposal, the shacks also limit the rate of infiltration of water into the soil, leading to an increase in the rate of the river discharge and the surface runoff.

The removal of vegetation in some places in order to build shacks also leads to an increase of the surface runoff (Kilian et al., 2005). Uncovered and drier sections of land are prone to erosion. This land is often located in the low-income townships, and eroded areas loose soil, also contributing to blocking and clogging of the drainage system. As a result, during the process of flood, the drainage system is not able to channel the overflowing water of the Jukskei River in a proper manner and this contributes to the intensity and magnitude of a flood (Vogel and Mgquba, 2004). All the above-mentioned factors increase the risk of these people to floods of the Jukskei River. In South Africa, urbanisation is taking place at an alarming rate, placing the cities of South Africa among the fastest growing cities in the world (Kilian et al., 2005). It is estimated that in 2026, 80% of the population of South Africa will be living in the towns or cities compared to 66% in 1995 (DEA, 2005).

2.2 Housing

The formal accommodation available in Alexandra has been outpaced by its population increase. Informal settlements have been built on any available open space, including the banks of the Jukskei River (Campbell, 1996). Building of informal settlements on the banks of the Jukskei River often causes bank erosion (Figure 4 on page 15). During the rainy season, these eroded materials are washed into the Jukskei River. This means that people living on the banks of the river are at risk to flood hazards such as losing their lives or properties when the banks of the river are flushed away.

Figure 4: Shacks which are built on the banks of the Jukskei River (Available from: http://www.robinchenoweth.com/RobinChenoweth/SA_HOUSING.html).

Insufficient housing for the poor led to urban development in the areas that are actually unsuitable for development, including steep slopes, wetlands and flood zones (Lehohla, 2006). This led to vulnerability of residents to threats such as landslides and floods. For an example, in Johannesburg in the Alexandra Township, more than 5000 residents were living on Jukskei River banks and more than 800 residents were living on the landfill site in 1999 (Wilson, 2002). During heavy rainfall in January 2000 and December 1999, the Jukskei River burst its banks and more than 120 residents were washed away/drowned (Rosenberger, 2003).

The supply of new formal houses in South Africa is very slow. More than 3 million houses were built between 1994 and 2011 which provides shelter to more than 13 million people (Van Niekerk, 2012). The slow supply of formal houses led to the massive increase in the number of people looking for accommodation in backyard shacks, informal settlements, hostels and in formal houses that are overcrowded (Project Spotlight, 2001).

The Alexandra Township consists of three different parts. These parts include East bank, Old Alexandra and Tsunami village (Wilson, 2002). The East bank is located in the eastern part of the Jukskei River and was formed in the 1980s. It is dominated by middle class households (Mgquba, 2002). Old Alexandra is located in the western part of the Jukskei River and the area is largely formed by informal settlements or shacks, blocks of flats and three hostels. Most of the shacks in the West bank have been built below the flood line. When the flood took place in 2000, residents in the West bank remained highly vulnerable to risk and most of their properties were damaged (Project Spotlight, 2001). The Tsunami village largely consists of Reconstruction and Development Programme (RDP) houses and is located in the far east of the East bank. The Old Alexandra area is the one which is most vulnerable to flooding as people built their shacks on the banks of the Jukskei River. The settlement units consist often of shelters which are self-constructed shacks in poor condition. These shacks are mainly constructed of wood and, corrugated iron; very few are cemented and they are closely built next to each other (Mgquba, 2002).

2.3 Migration

The process of migration from rural areas to urban areas led to the major crises (Wilson, 2002). It led to overcrowding, appalling living conditions, shortage of houses, unemployment, development of informal settlements in the outskirts of the big cities and towns such as Johannesburg, Durban and Cape Town; expansion of unplanned urban settlements, problems of sewage disposal and the invasion of land (Lehohla, 2006).

There are two major forces which cause people to migrate from rural to urban areas. These forces are pulling and pushing forces (Singh, 2008). Pushing forces force people to migrate their place of origin or residence. The reasons which cause people to leave their place of origin include lack of infrastructure, drought, lack of education, wars, local conflicts and lack of employment opportunities (Mears, 1997). Pulling forces attract people from different places. These pulling forces include job opportunities, industrial development, regular work which pays better, better facilities for health and better opportunities for education (Kilian et al., 2005).

The largest number of people living along the banks of the Jukskei River does not originally come from Johannesburg or Alexandra Township. Most of the Alexandra residents come from the former homelands and others are from other parts of Africa (Mayekiso, 1996). Movement of people in and out of Alexandra Township continues even today (Kilian et al., 2005). People living on the banks of the Jukskei River in Alexandra are often migrant labourers. There was a significant increase in the number of people moving from rural areas to urban areas in search of jobs, schools and better education (HIV/Aids report, 2005).

2.4 Socio-economic issues

Alexandra Township has a long history of overcrowding and poverty. The rate of unemployment is estimated to be about 32%. Other reports estimate that the rate of unemployment could be as high as 60% (Wilson, 2002). Women are the most affected by unemployment as compared to men. It is estimated that the number of unemployed women is 40% compared to 19% of men (Wilson, 2002). Economic status determines the resilience and coping mechanisms to any disaster. The high rate of unemployment, low income, unstable income and uncertainties in their livelihoods increase their vulnerability to disasters (Kilian et al., 2005). For example, during the flood that took place in 2000 in Alexandra Township, many families lost a large quantity of food because their shacks were leaking (Vogel and Mgquba, 2004). They could not buy more food because they did not have savings, which led them to have to depend on Non-Governmental Organisations for food and other essential household items. During the time of the flood, most people in Alexandra were still unemployed. The salaries of those who were employed averaged at R800.00 per month, which is very low (Mgquba, 2002). The combination of these factors made residents extremely vulnerable to natural disasters. The most critical factors included the high density of shacks along the banks of the Jukskei River, poor socio-economic conditions, low incomes and insecure livelihoods (Vogel and Mgquba, 2004).

3. Literature review

3.1 Disaster Management

Disaster Management is an integrated multi-sectoral, continuous and multi-disciplinary process of implementation and planning of measures which aim to reduce or prevent the risk of disaster; it mitigates the consequences or the severity of the disaster; effective and rapid response to disaster and rehabilitation post-disaster (Leavesley et al., 1996). The reduction and prevention of the risk of disaster is one of the aims which need to be determined through Disaster Management.

The Disaster Management process is very complex and needs effective commitment and collaboration from all the institutions and those affected by disasters (Singh, 1995). The regular occurrence of floods in Alexandra Township shows a lack of broader understanding of the factors which contribute to disasters (Pelling, 1999). Mitigation of disasters usually fails because of lack of ability to locate Disaster Management in a broader framework which links reduction of disasters with the development which is going on and other strategies for planning (Vogel and Mgquba, 2004).

The institutions, which were available in disaster mitigation and hazards in Johannesburg, include SAWS, the Eastern Metropolitan Local Council (EMLC), the Alexandra Local Council (ALC) and the Gauteng Disaster Management Department (GDMD) (Vogel and Mgquba, 2004). Even though there was a re co-occurrence of disasters of different magnitudes and scales including floods in Alexandra, there are few records which exist before the Disaster Management Act of 2002 (Pelling, 1999).

In South Africa, recording of disasters is very poor. Although extreme conditions are experienced on a regular basis such as extreme rainfall, which causes damage to properties and loss of lives, there is little or no information about the event (Vogel and Mgquba, 2004). Despite many attempts to institutionalise the process of recording hazards including floods, little institutional capacity remains to capture the pressures and drivers, which show the risk environments (Mgquba, 2002).

3.1.1 Vulnerability

Vulnerability is the level at which the environment, community, individual, industry, infrastructure, property and resources can be affected negatively by hazard (Els, 2011). Vulnerability is widely regarded as the characteristics of a group or a person in terms of their capacity to cope with, expect, resist and recover from the impacts of the natural hazards (Smith, 1996). In poor urban areas, vulnerability to hazards is the result of floods, as socio-economic and physical factors decrease or increase the ability to adapt and cope with the changes which are brought by floods (Alexander, 1997).

Ariyabandu (2004) identified some factors which determine social vulnerability. These factors include location, livelihood circumstances, social protection and self-protection. Location refers to the geographical proximity to such hazards. The status and position in the community or society is often related to health, ethnicity, race, gender, wealth and other factors (Alexander, 1997). The way in which a group of individuals or society can provide support and assistance and has the ability to protect individuals from harm is known as social protection. This includes technical knowledge and resources, access to information, knowledge and materials (Smith, 1996).

Pelling (1999) defined vulnerability as a combination of levels of resistance, resilience and exposure or the combination of both internal and external factors, e.g. exposure to hazards and levels of adaptation or coping. For Alexandra Township, the poor state of infrastructure, overcrowded conditions, inadequate sanitation and lack of access to resources were cited as the main factors which determine the vulnerability of the residents (Smith, 1996). The capacity for people to respond quickly in times of emergency is closely related to the ability of those people to compete for access to assets, resources, information and rights (Alexander, 1997).

The regular occurrence of floods in Alexandra Township shows both the nature and complex risk of flooding and the vulnerability of residents. Vulnerability is also regarded as a feature of the community because of the frequency of hazards. In the West bank region, vulnerability includes economic vulnerability, physical vulnerability and newly generated vulnerability (Vogel and Mgquba, 2004). The poor conditions in the township are exacerbated by lack of employment, poor infrastructure, poorly constructed shacks, poor health conditions and crime (Mgquba, 2002). This makes residents of Alexandra especially vulnerable to flood hazards. As residents keep on building new shacks along the Jukskei River when other people move out, this leads to the creation of a new vulnerable generation (Smith, 1996). New people who move to the area are not aware of the history of flooding of the Jukskei River.

Many of these vulnerabilities are the result of root causes and are perpetuated by high levels of unemployment in urban areas, inadequate waste management, historic discrimination based on race, past apartheid laws and colonialism, the impact of capitalism, economic pressures towards poor residential location, inadequate housing, low incomes, lack of access to resources, rapid urbanisation, unsafe conditions that include shacks built along the river banks, crowded shack settlements, inadequate emergency measures, no Disaster Management strategy and an increased vulnerability to stress events (Vogel and Mgquba, 2004). The causes of these flood hazards include heavy rainfall, flash floods and tropical cyclones (Vogel, 1996).

3.1.2 Hazards

Hazards are defined as dangerous substances, human conditions or activities which can cause injury, damage to property, loss of life, environmental damage, economic and social disruption, loss of services and livelihoods (Els, 2011). Hazards can be natural events which contain the probabilities that they have negative consequences. Volcanoes and earthquakes are considered true natural hazards (Mgquba, 2002). Hazards such as veld fires and floods are considered unnatural hazards or socio-natural hazards.

Hazards can be classified into three categories: natural hazards, environmental hazards and anthropogenic hazards. Natural hazards refer to the natural processes which take place in the biosphere; examples are earthquakes and volcanoes (Mgquba, 2002). Environmental hazards include the processes which damage or change the ecosystems or natural processes which are influenced by human behaviour or activities, examples are climate change and deforestation (Els, 2011). Anthropogenic hazards originally come from industrial conditions, failure of infrastructures and technological conditions. Hazards are a threat to people. Risks are the measure of that threat or the probabilities of hazards occurring and possibly developing into a disaster (Smith, 1996).

3.1.3 Risk

Risks refer to the scenarios that include threats of possible financial, physical or social loss (Mgquba, 2002). Evaluation of risks becomes necessary because it allows appropriate planning and designing of interventions for future activities for mitigation of risks (Vogel and Mgquba, 2004). Risks also differ in magnitude from low to high. Three factors had been identified which show when people are more likely to be at risk of the impacts of a natural disaster. These factors include marginalised or disadvantaged people. These people are often marginalised because of their class, ethnicity, age or gender; lack of resources or capacity. They are people who do not have the power to mobilise or defend themselves against hazards or fight for their livelihood. They are regularly faced with a lot of hazard exposure (Vogel and Mgquba, 2004).

Identifying people who are at risk or vulnerable and finding solutions to deal more effectively with the mitigation of risk is not easy. This includes differentiating vulnerabilities in the community, determining data, methods and proper framework to explain and explore the vulnerabilities (Smith, 1996). In rural and urban areas, poor people are affected differently by disaster or exposed to risks. Marginalised or disadvantaged people are the ones who are hardest hit and have little chances to recover from the impact (Vogel and Mgquba, 2004). The lack of organisations and institutions that can deal with vulnerable people in an effective manner tends to increase people‘s vulnerability to risk which is also closely associated with the environmental changes. Government seems to lack effective strategies for reducing risk before and after extreme rainfall. This, in turn, results in an increase in problems for many vulnerable people (Mgquba, 2002).

3.1.4 Disaster

A disaster is a disruption of the way in which a society or community functions. It causes environmental, economic, material and human losses which often exceed the ability of the society or community to cope (DEA, 2005). According to the South African Disaster Management Act of 2002, a disaster is a human or natural, localised or widespread, sudden or progressive occurrence that will cause damage to infrastructure, the environment, properties and cause loss of life (Mgquba, 2002).

3.2 Floods

Floods are the natural hazard which temporarily inundates normally dry areas of land. Floods result from the overflowing of artificial or natural confines of a water body or a river (Vogel and Mgquba, 2004). According to hydrologists, flood is a sudden peak in the level of water caused by an increasing discharge (Els, 2011). Once the flood has passed, the level of water will turn back to the base flow. Floods occur if the flow of a river exceeds the carrying capacity for the river channels.

3.2.1 Different types of floods

The origin of the flood or source of the flood, speed of the water flow, course and geography of the area which receives flood can all be used in the description of the flood. The source of flood water can stem from a river, an ocean, heavy rain and swelling/rising underground water (Hewitt, 1997). Long periods of heavy rainfall in the catchment area, resulting in the rise of the water level and overflow of the river banks, are the major cause of the fluvial or river flood (Smith, 2004). This type of flood usually occurs very slowly and covers a large area. It can cause extensive damage to infrastructure but usually only causes lower fatalities (Bunn and Arthington, 2002).

During the intense rainfall, flash flood occurs in the upper reaches of the hilly river basin. Although flash flood is regarded as a subtype of the fluvial flood, it is usually regarded as a separate type of flood because it causes extensive damage to infrastructure and higher numbers of fatalities than the fluvial flood (Smith, 2004). Flash flood occurs frequently but on a small scale. It carries high loads of debris because of its high velocity. This makes the process of evacuation difficult (Bunn and Arthington, 2002).

The main cause of the fluvial flood is the accumulation of rainfall water in the flood plain areas, which are dominated by clay soil (Bunn and Arthington, 2002). This type of flood can cause fewer fatalities and major damages to infrastructure in urban areas. In urban areas, the flood is often caused by a limited or inefficient drainage system for rainfall water. This type of flood occurs rapidly and is defined by its high velocity and rapid runoff. Underground or groundwater flood is caused by water which rises to the surface because of a high water table (Vogel and Mgquba, 2004).

Fluvial flood usually takes place when flooding is not expected, in a location that is not normally vulnerable to flooding. It happens with minimal warning (Pelling, 1999). Fluvial floods occur when the rainfall which is often transformed into runoff, which in turn can normally be removed by the drainage systems, remains on the impervious surface and flows as an overland flow into topographic or local depression to create ponds which are temporary (Els, 2011). Fluvial floods only occur when the rate of rainfall exceeds the maximum capacity for storm water drains to remove the water and the maximum capacity for the surface to absorb water is exceeded (Vogel and Mgquba, 2004). This often occurs after a storm that is of short duration, lasting about three hours, usually a storm of great intensity and greater than 20 to 25 mm/h (Bunn and Arthington, 2002). This takes place after the low intensity rainfall of about 10 mm/h of long duration, particularly if the surface is impervious by being frozen, saturated or developed (Hewitt, 1997).

3.2.2 Causes of floods

According to Smith (2004), there are two types of physical causes of flood. These types include coastal and river flood. Smith (2004) illustrates the environmental hazard which can cause floods. The most significant cause of flood is the atmospheric hazard which creates a large amount of rainfall. The classification of flood according to Smith (2004) differs with the classification of flood by Alexander (1995). He states that there are four major causes of flood, including estuarine flood; the catastrophic cause such as dam burst or the effect of volcanic eruption; coastal flood and riverine flood (Alexander, 1995). The classifications of environments which are vulnerable to flood, include alluvial fans, low-lying inland shorelines, inadequate dams, low-lying deltas, coasts and low-lying parts of major floodplains (Smith, 2004). The causes of the floods also include foreign winds, tropical depressions, hurricanes and heavy rainfall from monsoons (Koutroulis and Tsanis, 2010). Poor drainage, obstructions that include debris and landslides can cause slow floods.

The physical science approach in the study of flood includes hydrological models. Engineers and hydrologists, physical geographers and geologists (Hewitt, 1997) use hydrological models of flood. Hydrological modelling is often used in the riverine types of flood, where discharges form a significant concept. Stream flow or discharge quantities are represented graphically by hydrographs. The application of hydrographs in flood is commonly known as flood hydrograph. Hydrological models are commonly used in the study of flood, particularly relative to the important impacts of flood on society. According to hydrological models of flood, flood can be all water in the wrong place or at the wrong time (Hewitt, 1997). According to Alexander (1995), flood is water above some given point. The disadvantages of the hydrological models are that they only consider one type of flood: the riverine flood. Alexander (2000) identified four factors which influence the severity of flood. These factors include antecedent catchment status of moisture, catchment processes, fixed catchment characteristics and rainfall characteristics.

Antecedent moisture status is based on the moisture saturation of the catchment immediately before the start of rainfall that produces flood. Catchment processes include channel storage, pondage storage and the rate of potential infiltration (Hewitt, 1997). Channel storage is the proportion of the overland flow which is necessary for the flood passage in the system. Pondage storage is the proportion of the overland flow, which is trapped in the pools that are caused by the unevenness of the surface ground. Fixed catchment characteristics include cover, shape, slope and catchment size and the direction of the slope of the catchment with the direction of rainfall movement, which produces weather systems (Alexander, 2000). Rainfall characteristics include movement of rainfall storm, duration, area and depth.

3.2.3 Low-lying or area vulnerable to flood

The areas which are vulnerable to flood along a river, can be either floodway or floodplain (Els, 2011). All areas that surround the channel of the river, which can be flooded during the process of flood, represent the floodplain. According to Alexander (2000), the probabilities of flood decrease as the slope at a point of the floodplain increases. Floodway can be differentiated from the floodplain by its deep water level, high flow velocity and containing debris flow, which often causes erosion (Els, 2011). People are encouraged not to develop any residential area in the floodway except for infrastructure such as bridges.

The vulnerability of people and properties to floods in urban areas remain even though there are hydrological models, which are used in the prediction and monitoring of floods. The physical, economic, social and environmental processes determine the conditions which increase the vulnerability of the community to flood. The required data for modelling flood is usually inadequate or not available at all. This is often a problem in developing countries, including South Africa. The limitation of available data determines which flood modelling method can be used (Vogel and Mgquba, 2004) as data of higher quality requires complex modelling techniques.

3.2.4 Impacts of floods

Most residents are aware of the impact of floods on their lives, including deterioration of health conditions, loss of livestock, destruction of crops, damage to properties and loss of human life. Some of the economic activities come to a halt as communication channels are disrupted and infrastructures such as bridges, roads and power plants are damaged and people are forced to leave their homes (Bunn and Arthington, 2002). Livelihoods can be lost due to disruption in industry. Infrastructure damage can lead to long-term impacts that include disruption to supply of clean water, healthcare, education, communication, transport, electricity and water treatment. Residents can remain vulnerable economically because of loss of income, loss of value of land on the floodplain and reduction in power (Bunn and Arthington, 2002). Families and the victims of floods can also remain traumatised for a long time. For example, loss of family members has an impact on other family members, especially on children. Disruption to social affairs and business, loss of property and displacement from home can cause stress and trauma for a long time (Vogel and Mgquba, 2004).

The impact of flood in Alexandra Township has been categorised into both direct and indirect impact. The direct impact includes deaths, destruction of homes and infrastructures such as roads, loss of clothing, household goods, food and damage to crops and livestock (Mgquba, 2002). Indirect impact includes not going to school or work (impossible to cross the Jukskei River), loss of employment, injuries as a result of falling shacks, living in fear, coping with stress, threatening illnesses as open sewage is flowing through the township (Mgquba, 2002).

3.3 Flood prediction

Flood prediction is an estimation of the height of water expected in the flooded area or a river in a specific place at some specified time in future (Ramirez, 2000). This can be expressed for a specific location, often a rain gauge, such as being greater than the critical value, being close to a specified value or precise value (Els, 2011). The prediction of flood should be seen as one, which has the relevance for a particular area close to the relevant rain gauge. Flood prediction is made by monitoring rainfall, weather, catchment and river conditions, which can lead to the process of flooding (Ramirez, 2000).

This is achieved by measuring the level of rivers and rainfall in the catchment area at a specific location. This is done by using proper hydrological modelling to predict the level of water in future (Bunn and Arthington, 2002). The important issues which need to be considered during the prediction of flood include understanding of a location where prediction is needed, to be sure that the prediction addresses the needs of the people who are at risk, appreciate that prediction of flood is often uncertain, have good communication with the community and the prediction agency about the impacts of flood and the accuracy of prediction (Ramirez, 2000). The prediction of flood is an important part of a good flood warning system. The prediction of flood involves the predicting of water levels in the river to assess the possibility of flooding (Smith, 2004). If there is a possibility of flood, prediction needs to provide the information about the behaviour of the river during flood (Els, 2011). The information can be about the height, which can be reached at the rain gauge in a specific time. The prediction of flood needs to provide the severity of flood which is coming (Bunn and Arthington, 2002).

In recent years, different methods of systems and flood prediction, based on data that has been collected by satellites, weather radars, hydrological and meteorological stations, have been implemented and developed (Joshi, 2005). These flood prediction systems often utilise hydrological models in the prediction of short-term floods because of the combination of predicted and recent rainfall with the aim to increase lead-time of the flood warning that can be delivered. In the context of this research, lead-time is the gap of the time in which flood warning can be provided of imminent floods (Parker and Fordham, 1996) and the flood occurring.

The flood warning process consists of four significant steps that include detection, prediction, warning and response stages (Figure 5 on page 27). The detection stage represents monitoring of real-time data, which is used in the generation of flood events. Monitoring includes meteorological and hydrological data that is collected through satellite imagery, weather radar, climate stations and ground-based stations (Parker and Fordham, 1996). The prediction stage utilises information and data collected during the detection stage in the prediction of water level and time in which the flood events occur. Flood prediction uses meteorological and hydrological models based on data collected in the detection stage and predicted meteorological condition that includes rainfall (Joshi, 2005). The warning stage uses information derived from the prediction and detection stages and issues warnings to Disaster Management officials. Response to flood warnings includes control measures such as mobilising emergency services, evacuating people and flood control reservoir.

In the above-mentioned four stages, flood prediction is the most prominent stage because response and warning depend on it. Nevertheless, the basic predicting system does not include an explicit predicting step and issues flood warning based on the observations that include flows and rainfall from rain gauges (Joshi, 2005). This prediction system is often based on exceedance of a certain value or threshold of meteorological or hydrological parameters. In this case, flood warnings are triggered when a certain value or threshold is exceeded. Disaster Management officials and Alexandra Township residents will be able to understand the situation of floods.

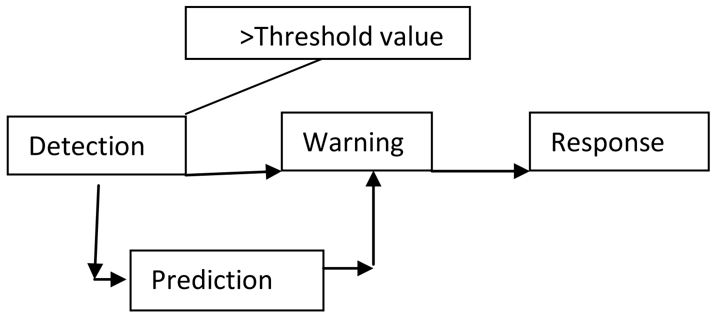


Figure 5: Process of flood prediction based on exceedence value.

The main characteristic of using sensor web in flood prediction is that it targets pre-warnings rather than public warnings at Disaster Management officials of the established Disaster Management, which makes flood prediction effective and easier because it is assumed that Disaster Management officials have good knowledge of warning people about the possible occurrence of floods. The in-situ sensors, which are spatial web enabled, are distributed along the basin of a river to collect near real-time or real-time data and to transmit the data through the infrastructure network. The infrastructure network will provide up-dated data required for issuing warnings and flood prediction. The interpretation and processing of measured data co-located with the instruments is one benefit of the sensor web infrastructure, meaning that real-time decisions can be considered on the data received by a sensor. Below are examples of flood prediction based on threshold or certain value:

- If a river or rain gauge level exceeds certain value or threshold, send alert messages.
- If rainfall around Alexandra Township exceeds certain millimetres and rain gauge level exceeds certain value, send alert messages.

- If the average rain gauge level distributed around Alexandra Township exceeds certain value, send alert messages.

3.3.1 The components of flood prediction

During the process of flood, one requirement is predicting of the levels of the stream, which is expected during a specific time at a key location of a river (Pelling, 1999). Flood prediction can include peak flood level, flood stage and, particularly important, the level which can be exceeded or reached when the river rises. The prediction of the water level as the river recedes is significant to help guide during the post flood event (Pilgrim and Cordery, 1993). Prediction of flood is made for a specific location and time, which is usually expressed as a particular level of a river at a selected rain gauge. This means that the confidence is required about the available flood prediction techniques and data which will allows the hydrological behaviour of the watershed and the behaviour of the river which is to be modelled (Ramirez, 2000). People living along the banks of the Jukskei River and the Disaster Management officials need to know the possibility of flood as accurately as possible. This will help residents and their belongings to remain protected. Often, in the later stage of its development, flood can be predicted with high accuracy because more information and data about the observed rainfall will be available.

3.4 Hydrological modelling

Flooding is an important subject in the study of hydrology. This type of event can be predicted by using hydrological models. The hydrological models (Singh and Frevert, 2006) simulate natural processes such as sediment, flow of water, nutrients, microbial organisms and chemicals in a watershed. In general, hydrological models are used in the prediction of the stream flow (output) of a catchment or river basin (system) in response to the amount of precipitation (input). The spatial and temporal variations of both input and system are considered as the driving forces of physically based hydrological modelling (Pelling, 1999). During flooding, it is very important to establish the extent of floods which the rainfall has caused. The process of simulating floods from rainfall is an important knowledge to acquire to help fix the reservoir.

A hydrological model is an important tool used in planning, simulation and management of runoff processes and rainfall. It is designed in a simplified way for both qualitative and quantitative modelling of any hydrological processes. Whenever rainfall occurs, a part of it is intercepted by trees and evaporates without reaching the surface. The remaining appears as runoff (Maity, 2009). Runoff flows through the slope and eventually appears as flow in rivers. Conversion of rainfall into runoff and its routing through the slope and river come under the ambit of hydrological modelling (Knocke, 2011). There are many models available with different complexities. Complex models require extensive data and parameterisation along with certain expertise in the discipline of hydrology (Suprit, Kalla and Vijth, 2010).

Hydrological models have the five basic components that include governing laws, watershed geometry, input, output and boundary conditions (Knocke, 2006). The interaction between water network, soil, vegetation, geomorphology, land geology and atmosphere is very complex. This complex interaction makes developing and carrying out of the models very difficult and means that it only provides general estimation of runoff response and results of the flood conditions (Pilgrim and Cordery, 1993). There are simple techniques in the applications of flood prediction which are available for modelling. These hydrological models are classified according to their temporal and spatial scale, overlying modelling process and method of solution (Singh, 1995).

The process of hydrological models can either be distributed or lumped which is developed through mixed, stochastic or deterministic steps (Table 1 on page 31). In the lumped models, geometric characteristics, input and spatial variability is considered and each catchment contains one value assigned to each attribute (Daniel et al., 2011). Contrary to lumped models, distributed models take account of spatial variability in the catchment boundary. The number of parameters and variables required to run the distributed models, are higher than those of the lumped models for the same basin.

The process of data demands generates difficulty in the validation, calibration and parameterisation of the distributed models (Moliere et al., 2002). This is because spatial data is not available for the entire Alexandra area. In the majority of the hydrological models, most of the components are lumped while few of the inputs and processes, which are connected with the output, are distributed. Deterministic models are only used if all procedures, parameters and input variables are known and assessed, as they are free from random error (Daniel et al., 2011). On the other hand, stochastic models are used in the description of this random error and address uncertainty as they are based on probabilities.

Hydrological models can be categorised on time scale, model use and land use, description of the process and techniques of the solution. According to Singh and Frevert (2002), flood analysis models can be grouped into four basic categories: flood frequency analysis, reservoir regulation, continuous precipitation runoff and event based runoff models. In this research, distributed and lumped models are considered for flood prediction. Spatial scale differs between small catchment areas of less than 100 km^2**,** to medium size catchment of 100 km^2 to 1000 km^2 and to large catchment of greater than 1000 km^2 (Knocke, 2006). In a hydrological model, temporal scale is broken down.

According to Singh (1995), hydrological modelling has three main applications that include runoff precipitation, management practices and planning purposes. Each of these applications starts with rainfall over the catchment area, followed by determination of excess runoff after all the abstractions are considered and then finally, the chosen hydrological models are applied in the simulation of runoff hydrographs. There are many methods available for hydrological modelling of flood. Most of these models involve the usage of the arbitrary formulas and relationship as the building blocks of flood estimation and runoff prediction (Moliere et al., 2002).

Knocke (2006) identified three major methods for estimation of rainfall to runoff responses for the catchment area and the potential results of floods. These methods include unit hydrograph techniques, regression analysis and statistical analysis of the gauge data. The unit hydrograph techniques determine the rate of the peak runoff per unit of runoff in a given drainage area by using physical characteristics of the catchment. Regression analysis correlates the characteristics of the catchment to flood discharge and streamflow by using the streamflow data (Daniel et al., 2011). Statistical analysis of the gauge data fit the probability distribution to the recorded flood data, which uses the results of distribution in the estimation of floods (Moliere et al., 2002). The last two procedures are very effective in the catchment area which has a stream gauge close to the outlet. This is because they are strongly based on the historical flood discharge and data from the streamflow. The first procedure can be used in all catchments because the characteristic of the runoff is determined on stream characteristics and physical land and the hydrographs are simulated without any help of the recorded discharge data (Knocke, 2000).

Hydrological models can be grouped into three different categories depending on the applied modelling approach (Daniel et al., 2011). These three model categories work in either the distributed or lumped environment. These models are processed in a different temporal and spatial scale. Most of the hydrological models have been developed to help in the prediction of hydrological responses by using one of the hydrological techniques that include three- and two-dimensional groundwater models, contour-based models, TIN-based models, grid-based models,

models that subdivide catchments into hydrological response unit and lumped models that help in the integration of the whole area which is to be modelled (Daniel et al., 2011).

Table 1: Classification of hydrological models.

Continuous or event	Continuous models are used in the simulation for long periods and account for catchment response between and during rainfall events. Event models are used in the simulation of a single storm event with a time span of a few hours to a few days.
Stochastic or deterministic	Stochastic models are used in the description of random variations that include the effect of uncertainties within the output. Deterministic models are used when the certainty is known and processes, parameters and all inputs are regarded as free from random variations.
Fitted parameter or measured parameter	Fitted parameter models include parameters which are determined by optimisation techniques or through empirical calibration and their parameters cannot be measured. Measured parameter models include parameters that can be indirectly or directly measured.
Conceptual or empirical	Conceptual models are based on the knowledge of biological, chemical and physical processes which act on the input in order to produce the output. Empirical models are based on the observation of the input and output with no explicit representation of the conversion processes.
Distributed or lumped	Distributed models account for spatial differentiation of hydrological and characteristics processes. Lumped models ignore or average spatial differentiation of these characteristics.

There are three major applications of hydrological modelling that include rainfall-runoff prediction, management practices and planning purposes (Singh, 1995). Each of these applications start with some amount of rainfall over the catchment area, excess runoff that is found after the removal of all abstractions that include infiltration and surface storage and the application of the hydrological model that has been chosen for the simulation of runoff hydrographs (Knocke, 2006).

HEC-1 is the first main flood hydrological model for a flood hydrograph programme. The Hydrologic Engineering Centre of the United States Army corp of Engineers developed it. The HEC-1 is a single-event lumped hydrological model, which includes reservoir routing and river, transformation of excess rainfall into streamflow, interception and infiltration and hydrological simulation for precipitation (Daniel et al., 2011). The model incorporates kinematic wave and Unit Hydrograph (UH) methods for computing rainfall runoff. It includes kinematic routing, modified pulse and muskingum procedures. Computing of this model is done in a fixed interval, which must be in the order of minutes (Scharffenberg and Fleming, 2005). The output of this model is the hypothetical and flood hydrograph for rainfall events.

The HEC-1 does not have the capabilities to work in real time. The integration of HEC-1 components with loosely coupled Geographical Information System (GIS) is still under development. HEC-HMS is an advancement from HEC-1 and increases the influence of GIS in hydrological modelling. HEC-GeoHMS is a tool developed to link HEC-HMS and GIS (Scharffenberg and Fleming, 2005). The interface of HEC-HMS 3.5 consists of watershed explorer, component editor, message log and desktop (Balyan, 2009). All components of the HEC-HMS 3.5 project are accessed through the watershed explorer. The component editor is used to enter specified data in the model component. All errors, warnings and notes are shown in the message log. The basin model, global editors, graphs, time-series tables and summary tables windows are found in the desktop (Balyan, 2009).

Another hydrological model closely related to flood, is RORB. The model was developed in 1975 as a storage catchment model and loss model (Merz, 2007). This model is also known as two-part model because it consists of the above two mentioned parts. This is a continuous lumped model. It functions by first converting input rainfall to excess runoff and then to catchment network by using questions. The streamflow is then routed through the watershed by using routing and storage methods. The model analysis is done at a scale of about 0.5 square kilometres and a fixed interval of temporal scale which can be an hour (Knocke, 2006). Output of this model is the surface runoff hydrograph. The surface runoff hydrograph is stored in a log file and is available for display. This model can be connected with GIS capabilities. For example, the RORB was used to generate flood hydrographs by using rainfall data from the Waimakari catchment (Griffiths et al., 1989).

The Precipitation Runoff Modelling System (PRMS) model is used in the evaluation of the rainfall effects, land use and climate on hydrological response (Leavesley et al., 1996). PRMS is a continuous, distributed, modular design and a deterministic model. The PRMS models and kinematic wave approach are used in the modelling of hydrographs and the Green-Ampt infiltration formula in the modelling of losses. It simulates runoff to determine the results of soil and water relationship, flood peaks and flow regimes.

The output of this model are the streamflow hydrographs (Knocke, 2006). These hydrographs derive in daily water balance of a catchment sub-region. The interval for computing can be a minute. The output discharge is shown as either a mean daily value or mean storm value. The model has some connection with GIS. This model divides the catchment into basin and sub-basin characteristics that include precipitation distribution, land use, type of soil and type of vegetation, elevation, aspect and slope. PRMS contains two levels of partitioning (Knocke, 2006).

The first level of partitioning divides the catchment into Hydrologic Response Units (HRUs). This means that the sum of all HRU responses which are weighted in a unit area will produce the streamflow and daily system response for a catchment (Leavesley et al., 1996). The second level of partitioning is used in the simulation of the storm hydrographs in which the catchment is conceptualised as channel segments and planes of interconnected flow. For example, the PRMS was used in the Buffalo Creek area to produce estimates of flood discharge by using precipitation as input (Yates et al., 2001). This was done by delineating the watershed into HRUs and channel segments by using the component of GIS. Its weaknesses include its design for a single storm event and its usage of a one-dimensional flow equation.

The Topography-based Model (TOPMODEL) is a single-event hydrological model and semi distributed hydrological model. Different versions for TOPMODEL are available; these include TOPSIMPL and TOPMODULAR (Boughton and Droop, 2003). The model was developed to help in the prediction of the storm runoff in a watershed. The temporal scale for predicting storm runoff is an hour (Ludwig et al., 2003). It uses lumped watershed and distributed topographic index parameters in the prediction of the storm runoff. The primary applications of the model include analysis of land surface, predicting flood frequency, prediction of geochemical characteristics and simulation of dry or humid catchment responses (Ludwig et al., 2003). The model has been incorporated in GRASS GIS framework. Incorporation was done to simplify this model. For example, the TOPMODEL has been applied in the prediction of flood frequency in the three catchments where there is limited data in the Jizera Mountain, Czech Republic (Blazkova and Beven, 2004).

The Soil and Water Assessment Tool (SWAT) is regarded as a modification of the SWRRB model for monitoring and predicting effects of chemical, sediment and management practice on water yields in an ungauged catchment (Daniel et al., 2011). This model is a continuous physically-based hydrological model. SWAT contains components that make it a very strong simulation tool in the quality of water in a stream. The model operates on the scale of a specific daily time in the simulation of the total streamflow on a sub-catchment scale. SWAT is integrated with GRASS GIS like the TOPMODEL to use the raster functions, which are found in GRASS GIS (Ogden et al., 2001).

The GIS components in the integration of the SWAT-GIS system include reduction of computing time for the SWAT-GIS model, analysis tools and transfer of input data from GIS to SWAT and management and data development (Ludwig et al., 2003). For example, in Aguan River, Honduras, SWAT has been used in the prediction of the streamflow. It was found that there is a close relationship between observed discharge and predicted discharge (Rivera et al., 2007). They use SWAT in the prediction of streamflow because the town (Santa Rosa), situated close to the Aguan River, was nearly washed away. SWAT weaknesses include failure of adequately simulating single event rainfall and lack of explicit spatial representation.

The CASCade of Planes in 2-Dimensions (CASC2D) operates as a runoff catchment model (Ogden et al., 2001). The CASC2D is generally used in the prediction of the surface runoff in semi-arid to arid basins. It uses both one- and two-dimensional channels to simulate sediment and water over the land grid. Both continuous and single event simulation models are possible. It divides the catchment into cells and sediment and water is routed from each. Gridded Surface Subsurface Hydrologic Analysis (GSSHA) adds ability to CASC2D so that it is able to simulate both unsaturated and saturated groundwater.

GSSHA is an enhancement of CASC2D (Daniel et al., 2011). This model is considered as a physically and distributed raster hydrological model. The model consists of two components that include routing procedures and an infiltration model (Sharif et al., 2006). The infiltration model is used to account for soil moisture by using the Green-Ampt method. Routing procedures are used for channel routing and overland flow. Computation of CASC2D includes soil moisture content, infiltration rate and depth, rainfall intensity, time-series maps and discharge hydrographs (Daniel et al., 2011). Weaknesses of the model include its numerical schemes which require lots of data and computationally intensive generation of poor sediment results. For example, the CASC2D has been used in the prediction of floods in the Quebrada Estero watershed found in the city of San Ramon, located in the Northern Valley of Costa Rica (Marsik and Waylen, 2006). The Quebrada Estero watershed caused flooding to the city of San Ramon a decade ago.

The Hydrological Simulation Programme-Fortran (HSPF) is used in the simulation of hydrological and other processes related to the quality of water. It includes impervious and pervious land surface in the streams where the movement of water is simulated as groundwater flow, interflow and overland flow (Daniel et al., 2011). This model uses HRUs which is based on the storage capacity and uniform climate factors. Its period of simulation can range from a few minutes to hundreds of years. The results of simulation include sediment load, rate of runoff, concentration of pesticides and nutrients and history of water quality and quantity at any point in a catchment. The three types of sediment, simulated by this model, include clay, silt and sand. Some of the model strengths include representation of stream processes, watershed land and sources of water pollutant, atmospheric and point sources, its adaptability and flexibility to a broader range of catchment conditions (Ogden et al., 2001). Its weakness is that it is not a fully physically or distributed based hydrological model. This model also requires a lots of data and its manual does not provide information on how other parameters can be estimated.

3.4.1 Different types of hydrological models

3.4.1.1 Single event models

Single Event Models (SEMs) are used to simulate floods from a single storm-flood event. SEMs are usually used in the urban areas where there is flood damage, because time of the year is not significant and the design of the project is for the rare frequency (Kao and Chang, 2011). SEMs are designed to simulate floods from a single storm flood event. They do so by simulating flood hydrographs for a single storm event (Chetty and Smithers, 2005). This is often done by using the concept of hydrographs. Hydrographs are graphs that are used to show how the flow of water in a drainage basin responds to the length of time of rainfall (Ramirez, 2000).

In urban flood analyses, the SEMs are used to predict flood extent from a single storm flood event (Kao and Chang, 2011). Most of the single event analysis model estimations are based on assumptions about initial loss at the start of the rainfall and continuing loss during the rainfall. Initial loss is the amount of precipitation, which cannot appear as direct runoff. The continuing loss is the average rate of loss, which occurs throughout the storm event (Iiahee and Imteaz, 2009). SEMs are based on the hydrographs and can be vulnerable to the important errors because of the subjective nature of the stream flow partitioning in a short section of the stream flow during the flood events. SEMs use historical rainfall as their data input to produce the hydrographs as their output. Examples of SEMs include unit hydrograph, SWMM, HEC-HMS and Soil Conservation Service (SCS) curves.

3.4.1.1.1 Limitations of the SEMs include:

- Design-based approaches account for the probabilistic nature of the input rainfall, but do not consider the probabilistic behaviour of other inputs and parameters such as rainfall duration, losses and baseflow.
- SEMs greatly simplify essential catchment conditions before the occurrence of an event, even when a rainfall-runoff model is used to specify the entire hydrograph of the flood eventually.
- Uncertainty is present in inputs such as storm duration, the spatial and temporal distribution of the design storm and model parameters.
- SEMs flood hydrograph models such as the unit hydrograph, based on surface runoff only, can be prone to significant error because of the subjective nature of streamflow partitioning in a short section of streamflow during a flood event. This is most likely when the baseflow component of flow is large.
- There is subjectivity in selecting critical storm duration to fix the rainfall intensity and then selecting a temporal distribution of that rainfall in event-based flood estimation approaches.

3.4.1.2 Continuous simulation models

Continuous Simulation Models (CSMs) are used to predict and simulate continuous flood frequencies. CSMs contain some features, which are not available in the SEMs. This includes calculation of the total flow during the events of floods and calibration may be done without any separation of the base flow and the surface runoff (Cameron et al., 2000). CSMs use hydrological models to predict continuous discharge levels, estimation of the flood frequencies and are usually used when the damage in agriculture is very extensive, because the duration in which the flood takes place is very important when coming to the calculation of the surface runoff (Kao and Chang, 2011).

Like the SEMs, historical rainfall is used by the CSMs as the data input and can either be generated from the stochastic models of the rainfall or through observations. The stochastic models are models that use the data, which is available to generate from more random rainstorms (Cameron et al., 2000). The time-series, which are simulated by using the CSMs, may be analysed by using the flood frequencies analysis. A flood of this nature is not suitable for the single-event modelling (Kao and Chang, 2000). CSMs emerged in the middle of the 20th century with manual calculation for surface runoff.

Different countries use different CSMs because hydrological processes are not the same in their regions. For example, in South Africa the Agricultural Catchment Research Unit (ACRU) model is used to simulate major processes of hydrological cycle that include peak discharge, streamflow volume, reservoir yield, hydrograph, crop yield and sediment yield (Smithers et al., 1997). The peak discharge is simulated from the individual catchment by using the unit hydrographs where rainfall data, recorded with the increments of less than one day, is not available. The distribution of rainfall, which developed in the Southern African region, disintegrates the total rainfall in the short interval. This allows the generation of storm flow hydrographs for each individual interval.

CSMs simulate multiple storm events over time. CSMs represent processes that convert input catchment rainfall into streamflow (Smithers and Shulze, 2001). During floods, the CSMs calculate the total flow hourly, daily and occasionally. This involves flood hydrograph models for determining time distribution of the flood of the catchment area for determining flood generated from rainfall. One of the most significant characteristics of the CSMs is the use of the water budget for the catchment area so that antecedent soil moisture is known. Water budget refers to the relationship between the output and input of water in the region.

3.4.1.2.1 Applications of CSMs include:

- Extension of streamflow records where the record length of streamflow data is shorter than available climate data and the continuous simulation approach is seen to be a logical method of extending the streamflow record.
- Generation of streamflow series for ungauged sites using continuous simulation has been used. The method relies on the fact that adjacent catchments are most likely to have similar subterranean characteristics, so that if a detailed simulation model is developed on a catchment with observed streamflow data, subsurface and groundwater characteristics can be transferred to the ungauged site with a relatively high degree of confidence.
- Analysis of the effects of catchment modifications such as urbanisation or land use change on runoff.
- Long-term forecasting of runoff for operational purposes, where a statistical representation of future conditions maybe produced.

In hydrology, CSMs are regarded as the simulation of the wetness and dryness of a catchment occasionally sub-hourly time, hourly and daily in the estimation of losses from rainfall (Chetty and Smithers, 2005). Loss is the amount of precipitation, which does not appear as direct runoff (Iihee and Imteaz, 2009). The common factors of loss include variables such as infiltration, interception, evaporation and loss from streambed. The above-mentioned variables occur before the surface runoff. CSMs can overcome the limitations of the single-event analysis models such as lack of knowledge of antecedent soil moisture (Boughton and Droop, 2003). CSMs overcome this problem by including all periods of streamflow such as floods and droughts. CSMs models take historical rainfall records like SEMs as their data input. Examples of CSMs include HSPF, TOPMODEL and PRMS.

3.4.1.2.2 Advantages of CSMs include:

- Initial or antecedent moisture is explicitly accounted for or at each time-step and its influence on runoff generation
- Frequency analysis of the variable of interest is undertaken by statistically analysing the time-series of model output, as opposed to assuming that the return period of the output is equal to that of the input rainfall.

3.4.1.2.3 Disadvantages of CSMs include:

- Loss of sharp events if the time-scale is too large
- Extensive data requirements, which result in significant time and effort needed to obtain and prepare the input data
- Management of a large amount of data and of time-series output
- Expertise required to determine parameter values such that historical hydrographs are adequately simulated

3.5 GIS in modelling floods

GIS is a technology which integrates both computer science and cartography. The GIS software is used in analysing, processing and gathering geographic/spatial information (Longley et al., 1999). The GIS technology is regarded as a computer method for the creation of digital maps, digital analysis and creation of a database for spatial features and visualisation of spatial data. GIS consists of specific software for GIS and hardware, users, attributes and geographic data. Its source of information includes manually gathered data, maps or satellite images (Maguire, 1999).

Nowadays, computers are no longer only part of the research environment and processes but are the research environment. Decision makers and scientists often use GIS as one of the research mechanisms throughout their entire projects instead of relying on the computerised systems and programmes for automated analysis. Whenever there is a manipulation of geographical information in a digital form, the term GIS is applied because of its increased usage and involvement in research

(Knocke, 2006). The meaning of the term GIS can be interpreted differently depending on the field in which it is applied. Longley et al., (1999) identified five categories of the current interpretations. These interpretations include advancement of GIS capabilities and technology involved; GIS principles and its way of representing the world; analysis and management of spatial data; application of a specific software for gaining insight about the earth and science to study issues by using digital information to observe the earth (Maguire, 1999).

The functions of GIS are based on the assumptions that the earth may be described as a set of basic entities that include pixels, polygons, lines and points, which contain a set of values of attributes to describe their characteristics (Knocke, 2006). The main advantage of using GIS is its ability for developing powerful models at different temporal and spatial scales, which involve complex interaction among dynamic phenomena and static geographical entities through which these entities evolved (Longley et al., 1999). Another advantage is that it contains a programming language, which is associated with it for customisation (Maguire, 1999). The combination of programming customisation and the built-in GIS functionality can be also useful as input rainfall parameters and model programme can create a catchment.

GIS is differentiated from other modern processing system of data by its ability of spatial data manipulation (Ramirez, 2000). Its capability makes GIS an important tool in hydrological modelling. Both hydrological and geographical data can be very complex as they need to include some information about possible topological connection of objects which have been recorded together with their attributes (Ogden et al., 2001). GIS helps during all stages of Disaster Management of floods, including post disaster activities, mitigation, prevention and preparation (Haile, 2005). It helps in the provision of user environment, graphical-oriented data that is more interactive and powerful. Hydrological models benefit from GIS because of integration of the models and GIS.

Flood events involve an interaction between hydrological and meteorological data. There is a wide range of hydrological modelling techniques available in the facilitation of such data and the prediction of flood conditions. Each hydrological modelling technique has its own specific data required for implementation. Weather and hydrological data comes in different formats and storage structures (Carrara et al., 1999). It is usually not easy to transform such data to the correct format for each specific model platform. This can require the users to use an external device, which can format the data or to collect the required data into other format.

Some of the above-mentioned issues can be overcome by using GIS (Knocke, 2006) as GIS has the ability of developing the most advanced terrain models, delineation of the stream network and catchment boundaries, overlay and extract the characteristics of the catchment internally, analyse and incorporate spatial data rather than the traditional models (Carrara et al., 1999). These abilities made GIS a significant component of hydrological modelling. Three issues need to be considered when GIS is integrated with hydrological and environmental modelling. According to Goodchild (Goodchild et al., 1996), considerations include issues of systems that include user interfaces, GIS functionality, data models GIS design; issues of modelling that include developing and structuring of models and issues of spatial data that include accuracy, resampling, common formats, access and availability (Knocke, 2006).

GIS has contributed a lot to hydrology, in the topics such as integration of GIS and hydrological models, hydrological models and loosely coupled GIS, estimation of hydrological parameters and hydrological assessment. GIS started to have an influence on hydrological modelling by serving either as a front-end application for computing of the parameters of the catchment to place in the external hydrological models or displaying of the results from the external hydrological models as back-end application (Carrara et al., 1999). The integration of loosely coupled GIS in hydrological processes has led to the modification of formats of layers of models, how the models handle temporal and spatial data and how their external models interface function by hydrologists (Knocke, 2006).

Advances in the capabilities of GIS, costly task, data availability and programming language made the integration of loosely coupled GIS and hydrological processes less tedious (Knocke, 2006). These advances have led specialists of GIS to approach hydrological modelling from embedded prospectives so that the issue of integration and transformation between external model interface and GIS framework can be eliminated. Problems, which impede the use of GIS in hydrological modelling, include platform dependency, customisation, interfacing and complexity (Sui and Maggio, 1999).

The data, software and hardware can be extremely expensive for individuals and the training required for using the GIS software package. Over time, the GIS software becomes more versatile and useful models and user interfaces have been added. This addition increases the complexity of the interfaces (Ogden et al., 2001). The GIS industry focuses on data handling and system functionality in its early development. It becomes clear that the GIS evolution cannot continue without the development of better user interfaces. Some vendors, with offerings that include

ArcView from ARC/INFO (Sui and Maggio, 1999), have developed new interfaces. Although this product represents significant advances, most modellers are reluctant to use GIS in the process of modelling because of the complex technique to develop efficient integration to support the effort of modelling.

The term customisation is used in the description of the process in which GIS software is modified to satisfy corporate, user and departmental requirements (Sui and Maggio, 1999). Most organisations require a system that is unique in many ways with consideration to its own goals and objectives, requirements and problems. At present, most simulation and the GIS software process of customisation require technical expertise and are time-consuming in many languages, usually produce poor results and are expensive. Al-Sabhan (Al-Sabhan et al., 2003) discusses some of the use of GISs with the increased complexity in hydrology. He shows that most hydrological routines are not available in some GISs and that the user cannot directly introduce new routines (Sui and Maggio, 1999). The last point, which needs to be considered, is that most of these GISs and hydrological models cannot support multiple platforms. Many systems depend in a specific hardware and computer platform configuration. Therefore, platform dependence restricts users on software and data sharing (Ramirez, 2000).

Many researchers have extensively analysed and discussed the approaches of integrating hydrological models with GIS (Ramirez, 2000). This integration of hydrological models and GISs is documented in literature. Two methods for integrating hydrological models with GIS are available. These methods include loosely coupled and tightly coupled. A GIS is linked to an external model in a loosely coupled manner where operations are done with programming languages that include Fortran or C which are more suitable for this type of mathematical calculation. In order for an external model to be used from GIS, the model calculates some parameter values which are then stored in the GIS database (Ogden et al., 2001).

This method usually involves a hydrological model such as HEC-2 and a standard GIS package. It has been confirmed that this integration provides access to differences in the data models. Analytical tools and the way relationships among variables are handled in GIS and hydrological model soon becomes apparent (Sui and Maggio, 1999).The mismatch also affects benefits, cost and quality of the modelling results. This is because engineers and modellers have a very different conceptual approach to their disciplines and the real world. This type of integration needs several programmes that exchange data from one application to another (Ogden et al., 2001). One of disadvantages of this approach is that no conversion among the hydrological model and GIS, no data exchange and no common graphical interface happens, which is very cumbersome (Sui and Maggio, 1999). This method can also involve considerable change in data structure and change in data formats, particularly if the model is from another source.

Tightly coupled models are developed completely in a GIS environment through a macro language such as ESRI Arc Macro Language (AML) (Ramirez, 2000). This kind of programming is usually not able to implement the complex applications and does not support the same capabilities of procedural programming language. Unlike loose coupling, tight coupling does not require editing or file conversion even though it requires data management and a great deal of programming. However, tight coupling models need the construction of appropriate interface that can interact with the data structure of the GIS system (Ogden et al., 2001).

The recent advancement in ITC and GI Science has enabled the use of GPS, Remote Sensing, GIS and other related technologies in Disaster Management through data analysis, integration and capture. The integration of these technologies with other technologies that include Simulators, the World Wide Web (WWW) and SDSS has created an effective Disaster Management (Joshi, 2005). The models, methods, visualisation and processing techniques used by the above-mentioned technologies have proved to be useful tools in post-disaster recovery, crisis management and pre-disaster planning. However, the issues of timely data and information required for these tools remain a challenge. Data integration and acquisition is the most important contribution area required for emergency response and preparedness (Joshi, 2005). The nature of emergency and disaster situations requires temporal data for effective management and planning of such phenomenon. There is a significant need for information and real-time data. GIS provides tools for processing, archival and collection of spatial data for hazards such as floods. An example of GIS used in flood prediction and monitoring includes DISMA and Pold Evac (Parker and Fordham, 1996). These GIS applications do not support real-time data integration, which is important for effective flood prediction.

3.6 Framework for sensor web interoperability

Over the past decade, sensor technologies have improved significantly. Sensors are portable, more reliable, lighter and smaller (Veljković et al., 2012). Sensors can either be marine or terrestrial, airborne, orbital; can be fixed or mobile (Van Zyl, Simonis and McFerren, 2009). Some examples of heterogeneous sensors include remote sensors mounted on orbiting satellites, webcams, stress gauges mounted on bridges, air pollution monitors and flood gauges (Percival and Reed, 2006). Observation of most phenomena can take place at various scales that include local, regional and global (Delin et al., 2005). They are able to measure and monitor certain features of the phenomenon, which is under observation and can be located anywhere.

All around the world the discussion about the nature of sensors is continuing (Van Zyl, Simonis and McFerren, 2009). A sensor is an entity, which reacts with some chemical or physical stimulus (Van Zyl, Simonis and McFerren, 2009). For example, a rain gauge represents a sensor and when it is combined with data logger it forms a sensor system. The problem with a sensor from both remote and in-situ platforms is that it provides discrete spatial and temporal observation related to the physical properties usually regarded as phenomena. Another problem with a sensor as a sensor resource is that, if a sensor resource fails, an observation regarding the phenomenon is lost.

The sensor network, which is described as sensor nodes connected together, is applied in different application areas (Van Zyl, Simonis and McFerren, 2009). Sensor networks provide a dynamic and robust approach to observations. This is because a sensor network deploys a network of sensors rather than a single sensor resource. A sensor network uses an internal communication system. Some of the most significant areas of application of this sensor network include environmental monitoring. Data collected by a sensor is processed and analysed in the control centre where they are sent. The results obtained show if there is a need to react in time to mitigate or prevent the catastrophic situation in the field. However, collecting and sending data through a sensor network is not enough. This is because the sensor network is usually deployed in isolation, for single purpose and use and this refers to the utilisation of the sensor network and the way the sensor network is viewed by the world.

Therefore, the sensor web overcomes the limitation of the sensor network. It provides an umbrella function above the sensor network, sensor system and sensors. The sensor web has some basic features that include sensing, autonomy, dynamic configuration, access and standard based interaction (Si et al., 2011). The main objective of the sensor web is its ability to sense. The sensor web can be able to operate without any external intervention because of its autonomy. All elements or components, which are found in the sensor web, can be able to interact through the standard services like the web service of the OGC. Co-ordinated measurements, remote or in-situ data must be accessible through the mechanisms provided by the sensor web (Si et al., 2011). To reduce the scale of disasters caused by floods in urban areas, sensor web technologies need to be extensively investigated to evaluate the suitability for improving flood monitoring and prediction.

The sensor web, a set of information technologies, is an information infrastructure that integrates heterogeneous systems of sensors both in-situ and remote devices for collecting, retrieving, sharing, visualising and manipulating sensor observations of different phenomena (Van Zyl, Simonis and McFerren, 2009) (Figure 6 on page 47). The sensor web technologies bring opportunities to improve environmental monitoring and protection (Markovic et al., 2009). The purpose of the sensor web includes data access and sensor discovery, triggering of events by sensor conditions, integrating heterogeneous sensors into information structures and composing data flow among components of the system (Kussul et al., 2009). Sensor systems are an important tool for monitoring and capturing data on the environment (Jirka and Remke, 2009). The standards developed by the OGC are used to govern the sensor web technology. The standards that are already approved by the OGC include SML, TML, O and M, SOS and Sensor Planning Service (SPS) (Kussul et al., 2009). Standards that are still at the draft stage include SES and Web Notification Services (WNS).

The sensor web is a concept that describes the types of sensor network suitable for environmental monitoring (Veljković et al., 2012). Sensor web is an intra-communicating system of wireless sensor pots that are distributed spatially so that they are able to explore and monitor new environments. The main advantage of the sensor web is the ability of all sensors to share data which is collected by a single sensor in the network. On the sensor web, if one sensor is not working, other sensors will realise such event and continue with their activity of collecting data. Therefore, the sensor web is regarded as an ―intelligent sensor network" which collaborates with sensor nodes that are able to maintain themselves (Veljković et al., 2012). Another significant advantage of the sensor web is that sensor measurements can be found on the website. This makes it easier for developing web systems for online processing and accessing of sensor data.

The SOS infrastructure sends notification when the water level exceeds a certain level. Sensor data was delivered to SES, which in turn analyses the received data, checking if there is some compliance from the criteria defined by the user. The criteria were submitted by a web-based interface. This web-based interface provides users with options to define different alert condition and to enter a communication endpoint.

3.6.1 Sensor web enablement

The SWE initiative of OGC has set standards, which allow the integration of sensor data and of sensors into spatial data infrastructures (Jurrens, Broring and Jirka, 2007). The SWE framework comprises of three specifications that include:

- Observations and measurements, which are used for encoding sensor measurements. These encoding measurements include identifying sensors, which are reporting observation, phenomena being observed, time of observation, geographical region containing the sensors and the geographic region containing the features being observed (Kaslow, 2011).
- Sensor Model Language, which is a metadata language for describing the characteristics of sensors. SensorML is a description of the basic conceptual structure of platforms, components and process models (Mckee and Botts, 2003).
- Transducer Markup Language is used for exchanging metadata and sensor data among a sensor processor and sensor system (Krianaki and Yurish, 2006).

The four web services specifications include SOS for gaining access to sensor data, SES for subscribing to events alerts, SPS for controlling sensors and WNS for message interchanges among the SWE components (Jirka and Remke, 2009). These SWE components are used in the fulfilment of the services that include services such as register, discover, get capabilities service, get sensor description, get observation, get time-series data, task sensors and subscribe to alerts (Botts and McKee, 2003).

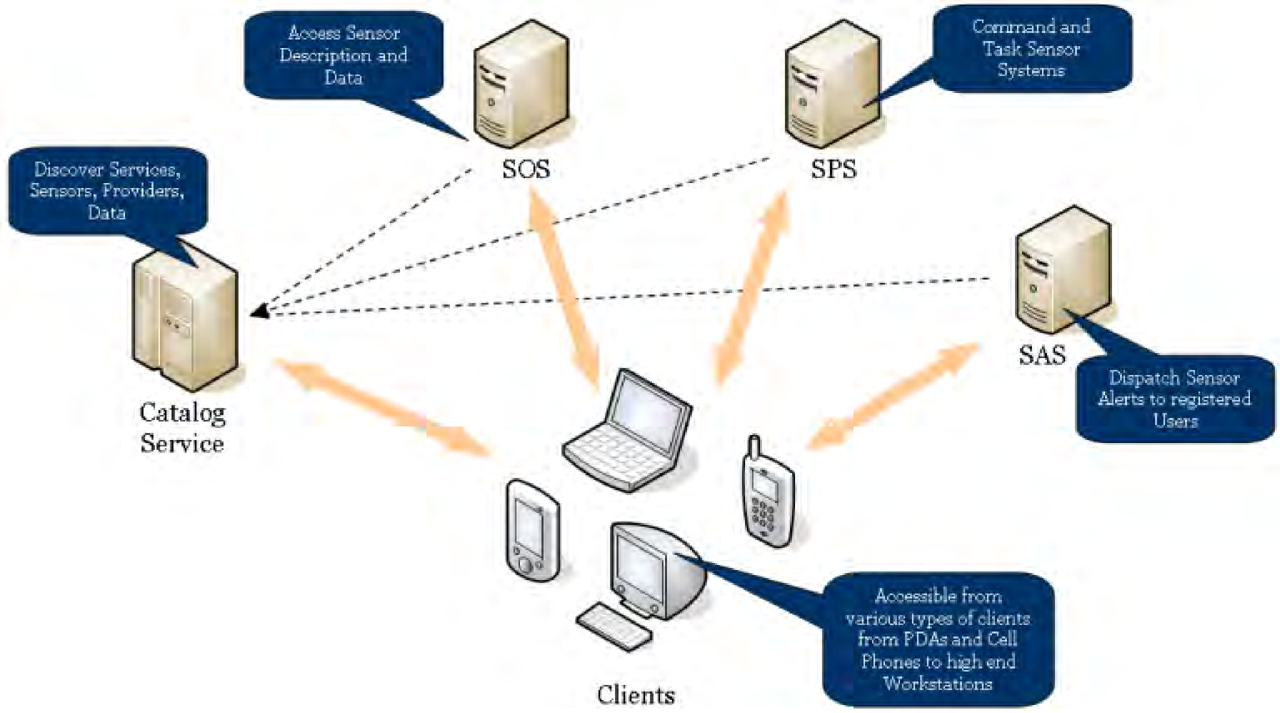


Figure 6: The OGC SWE standards (Henson et al, 2009)

3.6.1.1 Sensor Observation Service

The SOS is a collection of readings from live in-situ, mobile, fixed or remote sensors that make it possible for sensor data and sensor archives to be accessible via the web (Na and Priest, 2006).

The SOS provides access to sensor data directly from the database or sensors and sensor system in a consistent way for all sensor systems that include mobile, fixed, in-situ and remote sensors. It provides clients with the opportunity to retrieve time-series and real-time data by providing temporal, spatial and receiving filtered data and attribute constraints (Van Zyl, Simonis and McFerren, 2009).

The SOS uses SensorML, O, and M to provide its results. The SOS consists of three mandatory core, which include DescribeSensor for providing the properties of sensors, GetCapabilities for proving capabilities of the systems and GetObservation for providing observations from the sensors, and the two non-mandatory operations that include InsertObservation and RegisterSensor and six enhancement operations, which are mandatory and include GetFeatureOfInterestTime, DescribeResultModel, DescribeObservationType, DescribeFeatureOfInterest, GetResult and GetFeatureOfInterest. DescribeSensor provides information in detail about the sensors and processes which generate observations and measurements. The operation of GetObservation provides access to sensor measurements and observations through spatio-temporal query, which can be filtered by the phenomenon of interest. The GetCapabilities allows users of the SOS to gain access to metadata. Non-mandatory operations such as InsertObservation and RegisterSensor are used in the support of transactions.

The SOS has capabilities to filter, request and retrieve sensor observations. The filter may be on phenomenon, time or sensor for example. Observations are defined by three entities that include feature of interest, event time, procedure and observed property. Feature of interest refers to the entity measured here, being the water level or flood. Event time refers to when the measurement has been taken. Procedure refers to how the measurement or observation has been measured. Observed property refers to the measured characteristics. In summary, the main purpose of the SOS is to access metadata and its features include:

- transactional profile
- build-in PostGIS: PostGIS is an OGC compliant spatial database extension for the PostgreSQL, open source and freely available (Hsu and Obe, 2013).
- framework for data input in the SOS

Data from the SOS can be accessed through its client, which is known as the ThinSweclient2.0. The data can be accessed through different formats that include:

- time-series in the form of a diagram
- time-series in the form of a table
- as pdf, csv files and in excel

3.6.1.2 Sensor event service

The SES defines an interface that allows sensor nodes to support and advertise corresponding metadata and alerts. Alerts are notifications of a particular observation event that occurs at a feature of interest. The intention of SES is to bring subscribers to notifications and sensors together, which works in this way: subscribers may subscribe to the sensors through hypertext transfer protocol (http) on the one hand and on the other hand, sensors may advertise themselves through http in SES

(Bredel, 2010). Communities or local residents will transfer the data from the sensor to the SES, which will filter some of the data coming in with regard to the criteria specified.

Purpose of the SES is to send notifications which match the filtering criteria. They are defined by the people who subscribe to the endpoint notification for subscription. The role of the SES involves three entities that include the information consumer, information broker and information producer (Figure 7 on page 49). The purpose of the information producer is to act as a map to sensors, detect situation of interest, generate the message that describes an event and reports it (Echterhoff and Everding, 2008). The information producer is registered with one of the information brokers before it reports an event. This means that the information producer needs to provide information about itself and of the messages, it creates.

The information brokers provide an interface that facilitates the functionality required for registering the information producer, receiving notification from information producers and subscribing for notification, which is based on the filtering criteria. The information consumers or subscribers are the recipients of the events that match the criteria, which are defined in the subscription. The information broker should be able to handle the messages, which are coming in the format of O&M.

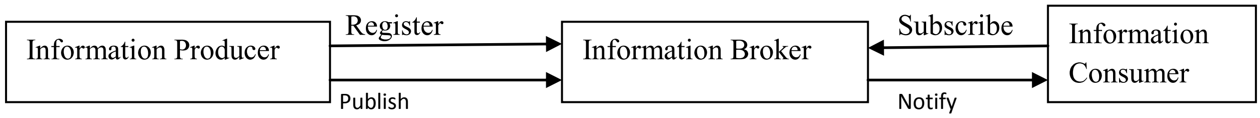


Figure 7: An overview of the Sensor Event Service (Echterhoff and Everding, 2008).

The specifications of these alerts criteria through local residents may be made using the form of the web base. In such a form, local residents may specify the conditions of the alerts in which they are interested (Jurrens, Broring and Jirka, 2007). For example, we want to receive the alerts when the level of water reaches above 200 mm in the rain gauges. Such format may allow the channels of communication and the way the alerts should be sent. Examples are communication via emails or SMS. Therefore, if the SES finds conditions of the alerts which match, the alerts may be sent. The main feature of the SES includes dispatch alerts through XMPP which stands for extensible messaging.

3.6.1.3 SensorML

The SensorML is used in the provision of encodings and models to describe any type of processes in post processing systems or in sensors. This means that the basic description of all sensorMLs is the type of the process. The type of the process is defined through its output and input elements and other parameters, which are added. The added metadata includes technical data or calibration information and quality attributes which can be embeded in the sensorML description (Jirka et al., 2009).

3.6.1.4 Web notification service

The main function of WNS is to be able to define a service, which enables asynchronous interchange of messages between the SWE components. The service provided by the WNS is only useful if there is multiple collaboration of services. These are needed to satisfy the requests of the clients (Jirka et al., 2009). It can also act as a protocol transducer by converting the HTTP to XMPP message. Protocols such as phone calls, SMS and emails are also enabled by the WNS. Two communication patterns are defined by the WNS. These communication patterns include one-way notification and two-way notification (Simonis and Echterhoff, 2007). The one-way notification is considered a simple notification because a sender cannot expect any response from a receiver. In the two-way notification, the sender needs to create a response and needs to send it to the caller (Jirka et al., 2009).

3.6.1.5 Sensor planning service

The SPS is used in the provision of standardised interface to task sensors and sensor systems for acquiring observation in a certain area at a certain time. Before a task is submitted to SPS via the submit operation, clients can make any request about the information which is required to prepare task requests that are valid (Jirka et al., 2009). The GetFeasibility operation is used to check if the execution of tasks is feasible for a particular sensor. The SPS offers the DescribeResultAccess operation, which is used in the determination of the access point to the data, which has been collected (Simonis and Echterhoff, 2007). It also contains an interface, which has the function to manage tasks, which are submitted. The SPS provides a set of capabilities for submitting data collection tasks and for determining the feasibility of collection tasks (Kaslow, 2011). The WNS provides asynchronous delivery of alerts and messages. The SWE components are commonly used with in-situ sensors such as weather stations, rain gauges and surveillance cameras.

3.6.2 Sensor web for Disaster Management

Hazards and disasters are unavoidable although a lot of effort has been made in emergency response and Disaster Management (Si et al., 2011). A multitude of hazards and disasters bring with them huge loss and damage to properties and human lives each year. These disasters can be man-made disasters or natural hazards. The aftermath of each disaster has shown the urgent demand for efficient and effective Disaster Management (Pelling, 1999). Updated and timely information about the disaster is essential if it is to lead to efficient actions and effective emergency response. Information and timely data of disasters will empower Disaster Management officials and disaster managers to take action in time and to make better decision (Si et al., 2011). Unfortunately, most Disaster Management has shown that providing information and timely data to Disaster Management officials and disaster managers remains sketchy.

The emergence of sensor technologies such as the sensor web technology provides an opportunity for solving this problem. Even though the sensor web research is still at its infancy stage, the practical application and deployment of the sensor web have shown the great potential of such systems. Decision-making, monitoring, sensing and good Disaster Management need to be integrated to become effective (Si et al., 2011). Currently, the sensor web focuses on monitoring, real- time sensing and data collection of the targeted disasters with little research conducted so far in the processes of emergency response and decision making in terms of Disaster Management.

Specifically related to Disaster Management, some of the sensor web applications focus on detecting disaster events, sensing and collecting of disaster monitoring data. Therefore, detection, monitoring and sensing are only parts of emergency response and Disaster Management completes the cycle of Disaster Management (Pelling, 1999). Actions, counter measures, response taken by Disaster Management officials and disaster managers all play an important role in the success of Disaster Management.

3.6.3 Sensor web for early warning and flood management

In the Wupperverband, North Rhine-Westphalia, Germany, the SWE components were used to build a warning and monitoring system for flood along the Wupper River. The main responsibilities of the Wupperverband are to manage water in the Wupper River. Their activities include water level management and flood protection (Jirka and Remke, 2009). In building the warning and monitoring system, three different functionalities were considered. These functionalities included displaying of precipitation and water level gauges data in the time-series and providing the real-time notifications when the level of water exceeds alarm values (Jirka, Broring and Stasch, 2009).

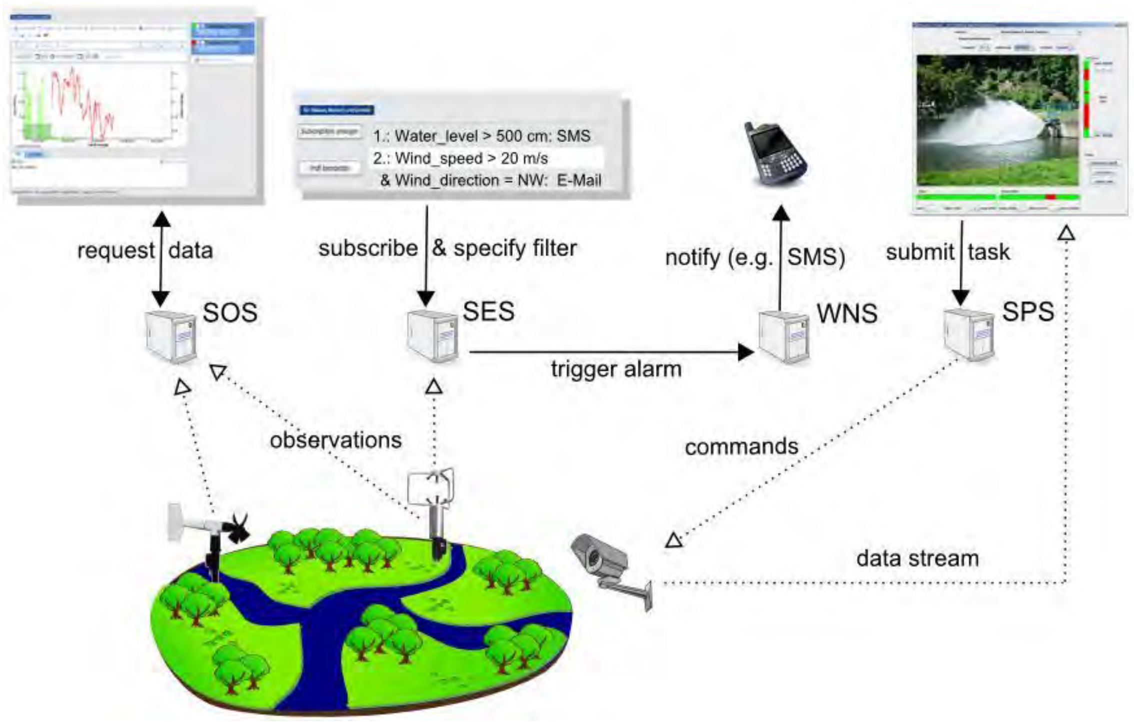


Figure 8: The application of the SWE components to hydrology (Broring et al., 2011), (Available from: http://www.mdpi.com/1424-8220/11/3/2652).

Displaying of precipitation and water level gauges data was achieved by using SOS, which is part of the sensor web technology. This was achieved because the data for precipitation and water level was already measured and made available in their database (Figure 8 on page 52). The data was transferred from the sensor to a server. The web-based client, part of the SOS, was used in the visualisation of the data as graphs (Jirka, Broring and Stasch, 2009). Real-time notifications, if the water level reaches a certain level, are achieved by using the same data (precipitation and water level) for this purpose. Data is transferred to an SES which filters the data according to the alert criteria which the users specified (Jirka, Broring and Stasch, 2009). Users can specify the conditions for which they request alerting and which they are interested in. For example, the user may want to receive an alert if the water level is above 100 cm.

4. Theoretical Methodology

This chapter describes the theory on how hydrological models are used and selected, requirements of hydrograph models, specific requirements of HEC-HMS 3.5, and justification for using HEC-HMS 3.5, requirements for the SWE components, data collection and data processing and how GRASS-GIS is used in the analysis of the watershed.

4.1 Model selection

Hydrological models are used for different purposes that include flood forecasting and water management (Table 2 on page 55). These models are able to capture the impacts of both anthropogenic and natural disturbances. They can also be applied in different scales, which range from local to global. The main drawback and difficult task of hydrological models is estimation of their parameters (Bardossy and Singh, 2008). This is because hydrological processes are non-linear in nature.

Selecting the appropriate model is an important part of this research work. There are different criteria, which exist for choosing the appropriate models. According to Simonovic and Cunderlik (2004), the choice of the model depends on the needs and requirements of the project or research under interest. Some of the criteria, according to Simonovic and Cunderlik (2004), include:

- availability of input data
- required output of the models
- model structure and price
- availability of the model

Table 2: Selection of relevant hydrological models based on certain criteria such as applications, components, spatial and temporal scale and their availability (Daniel et al., 2011).

Model	Applications	Components	Spatial scale	Temporal scale	Free?
TOPMODEL	Excellent in the representation catchment characteristics and hydrological response		Semi distributed	Event based	Yes
SWAT	Excellent for calculating TMDLs, also suitable for agriculture watershed	Reservoir and channel routing, sedimentation, weather, hydrology, crop growth and nutrients	Semi distributed	Continuous, daily	Free
CASC2D	Is suitable for both watershed and agriculture	Sediment transport, channel routing, 2D flow routing, rainfall excess, spatially different rainfall	Distributed	Event-based	Not free
HSPF	Is used for both watershed and agriculture	Mixed and stream channels reservoir, simulation of pervious and impervious areas, runoff and water quality	Semi distributed	Continuous	Free
PRMS	Is used for agricultural	Channel reservoir flow,	Distributed	Event-based	Free

	watershed and facilitates integration of other models	sediment and overland flow transport, soil erosion, surface runoff and hydrology			
RORB	For modelling floods in both rural and urban areas	Routing and catchment channels	Distributed	Event based	Free
HEC-1/HEC-HMS	For modelling floods and impacts in urban watershed	Runoff transformation and routing, baseflow, losses and precipitation	Semi distributed	Event-based	Free

4.1.1 Requirements of the hydrograph model

The requirements of the data input differ according to the selected mathematical models for each phase of the hydrological cycle. Some of the hydrological models require less data while others require an extensive amount of data. The difference in models is intended to allow the programme to adapt to any amount of data, which is available during the period of study (Moliere et al., 2002). Historical rainfall data or meteorological data, SRTM DEM and starting and ending time are some of the minimum requirements of the application of the hydrograph models (Maity, 2009). Table 3 on page 57 below shows all the software used and their functions in this research.

Table 3: Software used in this research.

Name	Function
ArcGIS 10.1	For mapping
GRASS GIS 6.4.1 and GRASS GIS 6.4.2	For analysing the watershed by using SRTM DEM and visualisation.
HEC-DSSVue	For storing and retrieving paired and time-series data.
HEC-HMS 3.5	For simulating and describing the runoff in an urban area. It converts rainfall input into flood hydrographs.
Sensor web	For producing time-series data in the form of table, time-series in the form of diagram, excel, csv files and as pdf and for providing alerts if the water level exceeds a certain threshold.
Python	For coding.
Quantum GIS 1.7.4	For visualisation of the Jukskei stream and Jukskei basin.

4.1.2 Specific requirements for the HEC-HMS 3.5

The specific requirements from the HEC-HMS 3.5 include flood hydrographs. In this research project, the HEC-HMS 3.5 model will be used to generate flood hydrographs. This will be done by estimating the peak discharge in the Jukskei catchment area. In the process of calibration, two sets of historical rainfall data will be used, including the years 1983 to 1993 and 1990 to 2000. Using the hydrological model HEC-HMS 3.5, observed peak discharge and simulated peak discharge will be compared.

4.1.3 Justification for using HEC-HMS 3.5

The HEC-HMS 3.5 is free and open source software for hydrological simulation (Scharffenberg and Fleming, 2005). The reasons for choosing HEC-HMS 3.5 include that it is open source, which means it can be freely downloaded; it has a user-friendly graphical user interface and its ability to model a catchment. Downloading the HEC-HMS 3.5 directly from HEC comes with documentation and the future enhancement of software is always in progress. The model input is precipitation, SRTM DEM and starting and ending time and, the output is flow discharge which is shown as a hydrograph (Bardossy and Singh, 2008). The models contain an interface, which is rich in different tools and which are used to enter parameters and data boundary conditions. Directory of the models are used to store the data that is entered by users. Other advantages for using HEC-HMS 3.5 include (Scharffenberg and Fleming, 2005):

- Missing rainfall data can be replaced adequately by interpolation and flow rate can be calculated in the area that does not have a rain gauge for measuring water levels.
- Choice to select the parameters, which are to be used by circumstances and appropriate places.
- Peak flow rate value of the study can be obtained quickly.

4.1.4 Requirements for the SWE components

Almost all the SWE components require these programmes: Microsoft Windows, Ubuntu Linux, Java Development Kit (JDK) 1.5 or Java Runtime Environment (JRE) 1.6, Apache Tomcat 6.021, PostGIS 1.1 or higher, PostgreSQL 8.1 or higher, Apache Maven 2.1 or higher and Subversion Client (SVN Client). The JDK is a bundle of software, which is used in the development of java-based software. The JRE is used to implement the –java virtual machine” which is used to run the programmes of java (Mitchell, 2000). The java virtual machine is used in the interpretation of binary code of java (Rouse, 2006). The JDK has one or more JRE, which contains different tools for development that include libraries, debuggers, deployment and bundling tools and compilers of java source.

Apache Tomcat is a web container, which is used to run java server pages and servlet applications (Vogel, 2008). A servlet is a java programme which runs the application server on a web. It acts as a layer between applications on the http server and http client (Vogel, 2008). Apache Tomcat provides the users with a default port 8080 http connector. The port 8080 is used to validate whether a Tomcat has been thoroughly installed by using the url http://localhost:8080. Apache maven is a tool used in the building of artifacts that are deployable from the source code (Shatzer et al., 2008). Maven is regarded as a management tool because it includes a model of project objects such as project lifecycle, set of standards and dependency management system. Subversion client is a system which is designed to replace CVS files. It is not difficult to use SVN client because it does not require a command line to run (Steveking, 2012). The thinsweclient is a web based client open source, which is used to display data as time-series, load data from more than one SOS and it forms part of SOS (Jirka and Broring, 2011). The thinsweclient can be applied in different fields that include weather data, air quality and hydrology.

A Jmeter is a free and open source software tool, written in java. It consists of a thread group which is a ―basic element of a Jmeter test plan" (Goucher, 2007). In a Jmeter, samplers do the actual work. Samplers are used to execute command in Jmeter and to return the results as a sample. They do the work by interacting with the loaded server. Samplers, which are found by default in Jmeter, include http request, which is used to test the web. All the information which the samplers produce is ―consumed by listeners" (Goucher, 2007). The listeners provide access to information that Jmeter gathers. Examples of the most common listener ports include simple data writer, view results tree and graph results.

4.2 Data collection

The data, which is used by HEC-HMS software version 3.5 for modelling, involves hydrological or rainfall data, available from the SAWS. The data provided ranges from the year 1983 to 1993 and from the year 1990 to 2000. The above mentioned data was used because the SAWS did not have the most recent data from the stations around the Jukskei River. The two sets of data were used to compare the peak discharge from the flood hydrographs. From the data provided, the plotted hydrograph with flow (Q) versus time (T) to find the highest peak, was generated. Before any hydrological analysis, it is essential to make sure that available data is homogeneous, sufficient, correct and complete without any values missing. This is because errors that result from an inappropriate data processing will lead to bias in the results (Maity, 2009).

4.2.1 Historical rainfall data from SAWS

Apart from the SRTM DEM, meteorological data such as historical rainfall data is also required, because floods are a direct consequence of intense-rainfall events. The South African Weather Service has installed a network of Automatic Weather Stations (AWSs), which record weather data on an hourly and daily resolution at different locations spread over South Africa. Some of their data is available freely to users by completing the disclosure form. Along with rainfall data, the SAWS records other data like temperatures, wind speed, humidity and pressure. Rainfall intensity can be calculated from the AWS data.

Table 4: The data which has been collected in the Jukskei station prior to the flood event (Adapted from SAWS, 2010).

A	B	C	D	E	F	G	H	I	J	K	L	M	N
Rainfall (mm)	Station:Jukskei	Latitude	Longitude										
		-26.03194	28.11189										
Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
1983	84.5	131.7	98.9	109.6	11.8	0.4	2.5	0.6	7.7	44.5	38.5	103.9	634.6
1984	138	92.5	126	2.5	5.1	6.1	0	2	13.7	66.9	54.4	88.3	595.5
1985	109.2	91.7	21.7	20	0	5.4	0	15.2	14.7	25.1	114.6	91.8	509.4
1986	145.7	64.8	137.9	31.6	0.8	0	0	0.4	29.8	148.7	111.3	97.5	768.5
1987	59.4	128.8	85	125.2	32.1	1	2.5	0	4	43.2	37.8	115.1	634.1
1988	154.5	119.9	126.6	14	0.7	5.4	0		12.4	51.8	37.1	100.3	622.7
1989	57.5	30.3	30.5	21.8	0	0	0	17.5	11.7	29.7	156.5	108.6	461.1
1990	54.4	61.8	109.5	25.2	0	0	0	4	34.5	201.7	78.8	134.5	704.4
1991	46.5	67	57.5	36	0	39.5	0	30	7	9.5	0	54	347
1992	185	81.5	143	0	5	0	0		51.6	184.8	16.1	77.6	744.6
1993	17.5	60.5	36	92	8	0	13	7	0	86	39.5	39.5	399

Monthly historical rainfall data is used in this research because there is no hourly data available around the Jukskei River. The hydrological models use the historical rainfall data as input to produce hydrographs of the floods at the site of the rain gauge or the elevation of the surface of the water at the point of the highest mark of the water (Kao and Chang, 2011). If the output of the models is close to the water surface elevation or known discharge, the models are considered well calibrated and ready to use in the development of the relationship between the frequencies and the discharges. In order for this historical rainfall data to be used by the hydrological models, it needs to be transformed into runoff. The rainfall data for simulation of flood, which will be used, dates back to between 1983 and 1993 (Table 4 on page 60). Another set of historical rainfall data, which will be used in this research, is from 1990 to 2000 (Table 5 on page 61). The two sets of data will be used to compare the peak discharge from the flood hydrographs. This rainfall data has been collected after the flood event.

Table 5: The data which has been collected in the Jukskei station after the flood event (Adapted from SAWS, 2010).

.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Rainfall (mm)	Station: Jukskei	Latitude	Longitude										
2			-26.0319	28.11189										
3	Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
4														
5	1990	81.9	77.4	115.2	28.9	11.6	2.4	12.6	12.9	1.5	69.1	21	53.8	577.6
6	1991	123.9	106.6	86.1	4.4	1.4	24.9	0	0	38.3	80.8	35.7	83.2	585.3
7	1992	71.1	56.3	49.6	17.9	0	0	0.6	77.7	1	65	227.3	65.9	632.4
8	1993	11.8	93.9	35.5	34	0.3	1	0	14.9	4	180.1	63.8	186.8	626.1
9	1994	23.2	190.3	84.2	22.1	0	0	0	0	4	103.8	50.9	166.4	727.5
10	1995	86.9	70.6	138.7	30	4.2	0	0	7.9	2.6	114	148.2	220.4	868.2
11	1996	51.2	322.5	59	63.4	24	2.2	0	13.7	0.4	46.3	86.2	114	782.9
12	1997	74	35.4	333.9	30	2.5	7.6	7.3	3.3	28.4	34.7	146.2	105.4	808.7
13	1998	32	78.2	26.6	12.2	0	0	0	0	32.2	75.2	208.2	130.1	594.7
14	1999	125.3	25.3	55.4	41.6	2.1	5.3	0.8	3.4	8	15	0	170	452.2
15	2000	15	263	164.5	33.8	3	2	0	4.5	39.4	117	114.8	170.8	757
16														

4.2.2 SRTM data from the internet

SRTM data with different resolution is distributed and depends on which part of the world you are interested in. The hydrologically corrected SRTM DEM (Figure 9 on page 62) was downloaded from this url (http://glcf.umiacs.umd.edu/data). For example, three arc seconds (approximately 90 m resolution and the vertical height accuracy of 10 m) is the spacing between the data points which represents the entire planet and in United States of America (USA), they use 30 m resolution (http://srtm.usgs.gov/). Topography plays an important role in the determination of how much and where water flows on the surface of the Earth (Suprit, Kalla and Vijith, 2010).

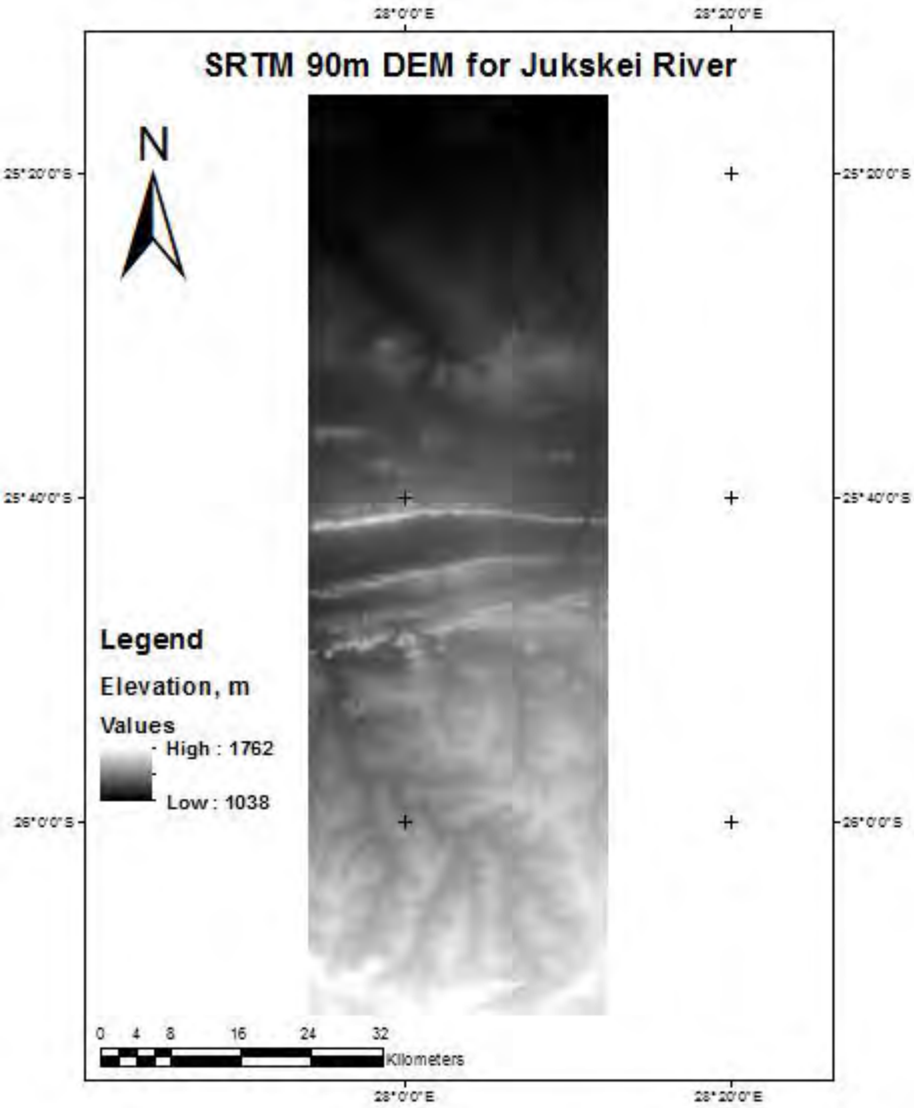


Figure 9: SRTM DEM of the study area which is the entire Jukskei basin Available from: (http://glcf.umiacs.umd.edu/data).

The prediction of flood inundation is not straightforward since the flood inundation extent is highly dependent on topography and it changes with time. The SRTM DEM represents the topography of an entire planet: the whole region is divided into pixels of a given size and each pixel is given a height value connected to a standard reference (Suprit, Kalla and Vijith, 2010).

Due to the technique used in data acquisition, SRTM DEM contains data holes and as a consequence, it cannot be used directly in the watershed analysis programmes (Spruit, Kalla and Vijith, 2010). The data holes indicate that there are no data values. These data holes are caused either by smooth surface like sand or water bodies with poor reflection of signals from radar or by shadow from high mountains, which obscure signals from radar. In order to be usable in the hydrograph model the SRTM DEM should be free from data holes. It is important to fill the data holes because they block the measured flow of water instead of allowing the measured water to flow out of them. If the data holes are not filled, they can cause the stream network to be incomplete. The data holes are filled by using the script r.fillnulls. It fills the holes by extracting the rings of values, which are found around the holes and interpolating —values across the data holes by using Regularized Splines with Tension (RST)" with the use of the script v.surf.rst (Wegmann, 2005). The module v.surf.rst integrated in GRASS GIS is used for interpolation. This method is used because it minimises errors. The v.surf.rst is a radial basis function method for interpolation of scattered data. It interpolates surfaces from the data, which are collected from scattered points.

The RST is deterministic interpolation because it fits a mathematical function through input data to create smooth surface (Wegmann, 2005). The module is used because it provides flexibility in the processing of data and it can be used in the areas where there is insufficient data. The parameters of this module includes smooth and tension. Behaviour of the RST is controlled by smooth and tension (Wegmann, 2005).

4.3 Data processing and Modelling

The HEC-HMS 3.5 model is designed to simulate and describe the process of runoff in an urban area (Moliere et al., 2002). A flood model is the means to understand behaviour of the floods in a particular area. Simulation by model can provide us with flood extent and depth. Models for predicting floods represent hydrological processes in the floodplain and river channel (Els, 2011). An accurate representation of the actual processes is of great importance in the prediction of flood depth and extent. Modelling of data is central to the application of information technology; this is because the data is regarded as a means of representing the real world in the computer (Scharffenberg and Fleming, 2010). The historical rainfall data is stored as a precipitation gauge in the project. The model starts with the processing and acquisition of HEC-HMS 3.5. The HEC-HMS 3.5 modelling can be considered with different values of the time-series that include hourly, daily, annual and values by minutes (Moliere et al., 2002).

The HEC-DSSVue (Hydrologic Engineering Centre Data Storage System) is an application which is used for storing and retrieving paired and time-series data of HEC-DSS database file (Scharffenberg and Fleming, 2005). The HEC-DSSVue database consists of six parts, which include part A (Name of the project), part B (Identifies the location of the rain gauge), part C (Type of data), part D (Date of starting), part E (Time interval) and part F (Description of data by a user).

Pathname for storing data is unique and this includes /part A/part B/part C/part D/part E/part F (Scharffenberg and Fleming, 2005). It is much easier for the users and models to manage and query the data by using these parts. It allows the users to download, store, edit, tabulate, manipulate and display large amount of time-series hydrological data (Els, 2011). Data from the HEC-DSSVue can be accessed by the HEC-models. The users can enter data manually or import data into DSS.

4.4 Calibration of the model

Hydrological models incorporate all components to simulate the hydrographs of the discharge and determine the discharge and frequencies relationship through the catchments or watershed (Moliere et al., 2002). The models should be operated before the development of this information for the storm flood event, if the inputs and the outputs are known to ensure that the models are producing the actual floods (Pechlivanidis et al., 2011). Therefore, the process of calibration is carried out to assess if the models are necessary to predict and monitor floods (Pechlivanidis et al., 2011).

All these models use historical rainfall data as their input from one or more storms, which consist of the number of routing reaches and the number of the sub-areas (Koutroulis and Tsanis, 2010). The models determine the excesses and the losses of the rainfall, transform the excess to the hydrographs of the discharge, combine and route the hydrographs through the watershed or the catchments. Generated hydrographs are usually compared with the recorded hydrographs at the gauged location in the catchments or the watershed (Moliere et al., 2002). If the models reproduce well-known hydrograph calculations at the site of the gauges, the models are considered to have been correctly calculated. When the reproduction of the storm events is not good, adjustment of the models can be considered to find an improved simulation (Pechlivanidis et al., 2011).

In the calibration, one can increase the confidence that the application of the frequency of the rainfall to model must result in the representation of the runoff hydrographs of those frequency events. The process of calibration is complete if the discharge hydrographs, which is measured against the calculated one, can be compared (Pechlivanidis et al., 2011). When there is an absence of the gauged data, comparison of the calculated versus calculated peak discharge by the regression analyses or higher watermarks calibrate the models (Koutroulis and Tsanis, 2010).

4.5 GRASS GIS

GRASS GIS is an open source and free GIS software, which can be downloaded and installed. It is flexible and versatile GIS software capable of analysing and managing geographical data, image processing, graphics and visualisation and spatial modelling in multiple dimensions (Mark and Marek, 2011). GRASS GIS handles data in different formats, which includes both raster and vector data or raster data (Suprit, Kalla and Vijith, 2010). It is released under the GNU public license (GPL). The GRASS GIS can be used on a variety of operating systems which include Windows, GNU/Linux and Macintosh (Neteler and Mitasova, 2011).

GRASS GIS originated from the United States Army Construction Engineering Research Laboratory. Now one of the most prevalent software available, GRASS is an official project of the Open Source Geospatial Foundation. The GRASS Development Team, a multinational team, manages GRASS GIS and users can contribute their modules such as r.watershed, which is contributed by the user (Neteler and Mitasova, 2011). The r.watershed is used for watershed analysis. The input for r.watershed includes threshold value and SRTM DEM. The threshold value is used to determine the minimum size of the watershed (Suprit, Kalla and Vijith, 2010). The large threshold value gives maps of the stream network with less detail. The low threshold value gives maps of the stream network with more detail. The watershed analysis is used to determine the stream network and basin geometry from the SRTM DEM. The basin geometry includes drainage map, stream map and basin map. The method is based on existing GRASS modules, especially the terrain analysis modules. The method can be carried out both in the command line interface or GUI. GRASS GUI is developed with the Tool Command Language (Tcl/Tk) and wxPython packages (Neteler and Mitasova, 2011). A future goal is to develop the analysis presented here as a software package which can be used in different operating systems such as GNU/Linux and Windows. A free and open source cross-platform utility like Python integrates all the steps and the calculations as one software package (Suprit, Kalla and Vijith, 2010). According to Lucca and Valentini (2009), some of the reasons of using GRASS GIS include:

- is an open source software GIS
- programmes can be freely run for any purpose
- source code can be accessed easily
- copies of GRASS GIS manual can be redistributed free of charge

- programmes can be improved and the improved programmes released to the public
- the software can be used without any worry about licence

The PostgreSQL and PostGIS were installed for creating and storing the database. The sosDatabase was created and the test.sql was opened and executed to insert the observations into the sosDatabase. The Tomcat 6.0 and the JRE 6.0 were installed to help in the deployment of the 52nSOSv3_WAR file. TortoiseSVN was installed to download and install the SWEthinclient2.0 and run apache-ant. RegisterSensor operation from the 52° North SOS implementation was used to register sensor through the SOS transactional profile and the new observations were inserted through the insert generic observation. Insert generic observation was used because the 52° North SOS implementation requires generic values. Clients are allowed to register new sensor systems as part of the SOS transactional profile through the RegisterSensor operation. This means that sensor observations can be inserted easily to sensors that have already been registered. The request for RegisterSensor includes the description of the sensor system such as TML or SensorML document and O and M template for publishing observations for the sensor by using the InsertObservation.

The SOS interface is used to access sensor observations, provides the users with temporal and spatial extent of data, discover sensors which are available. The SOS acts like a connector between the users and sensors using the available observations. The transactional profile is used to insert observations into the SOS. The SPS is used to manage and control the operation of the sensors. The SES is a web service used to allow users to receive alerts and subscribe to sensors based on threshold value. The WNS is used to send notifications to the end-users.

5. Systems Design

This chapter describes how the system is designed in this research project (Figure 10 on page 67). It shows how both historical rainfall data and DEM are processed by using hydrological model (HEC-HMS 3.5) to produce flood hydrographs, GRASS-GIS to produce watershed analysis results, and sensor web to provide access to sensor data, information, measurements; and to provide alert notifications through SMS or e-mails.

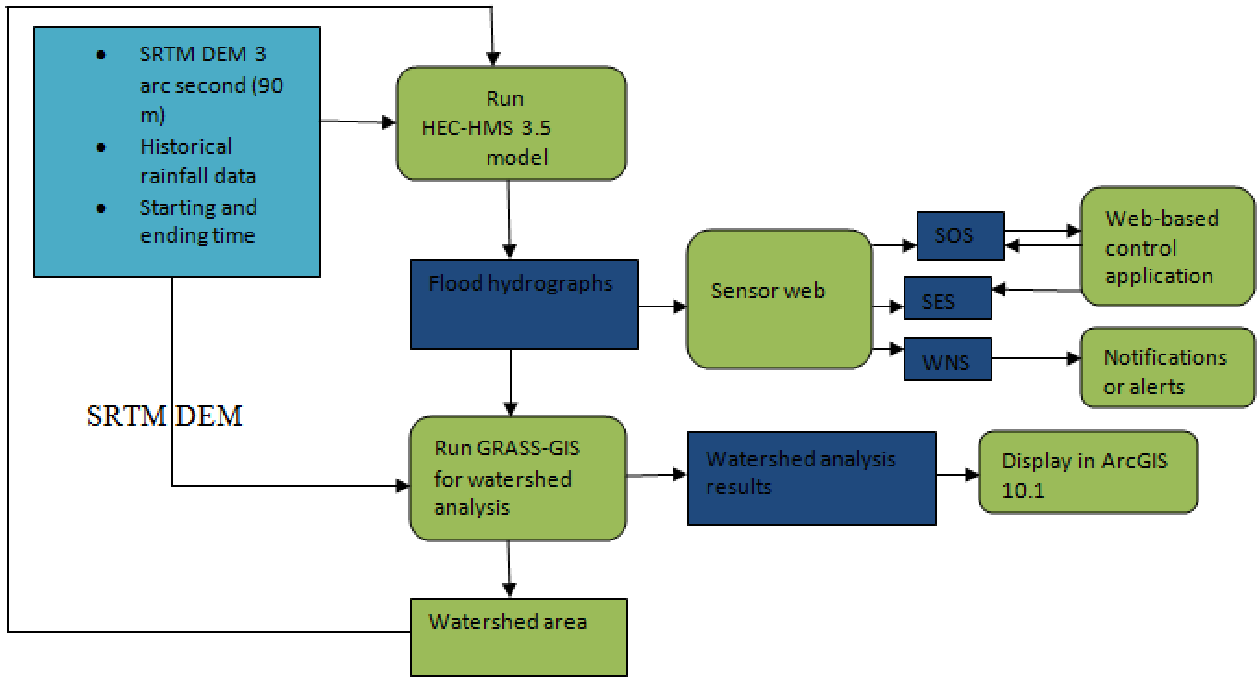


Figure 10: An overview diagram which indicates the systems design and the software used.

5.1 Hydrological modelling with HEC-HMS 3.5

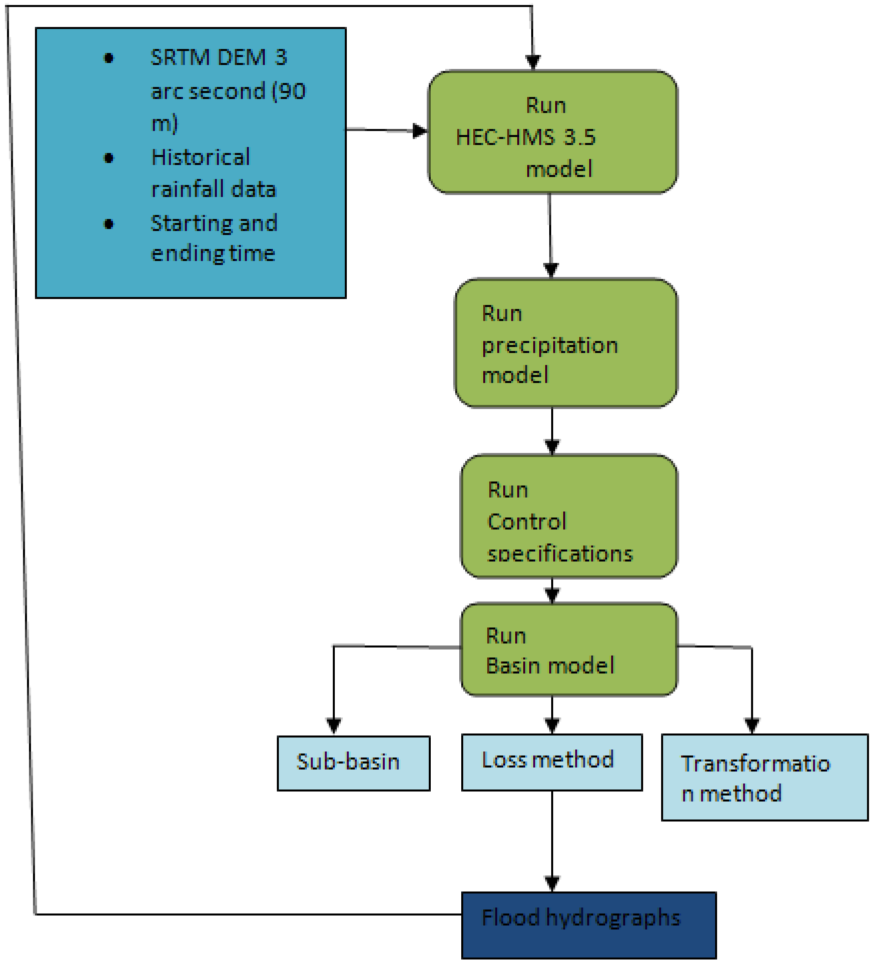


Figure 11: Process diagram showing the steps to run the HEC-HMS 3.5

In practice, setting up such models is not easy because they require extensive data including stream channel geometry. Even-though inundation areas are expected to differ along the river course, reach and localisation of rainfall event, for a first approximation the areas nearest to the stream channel can be identified from SRTM DEM (Suprit, Kalla and Vijith, 2010). For the Jukskei and also most of the rivers in Gauteng, the river channel width in upstream areas is of the order of ten metres. Despite resolving the stream network accurately, the SRTM DEM cannot resolve the cross-channel geometry as its resolution is not fine enough.

The HEC-HMS 3.5 is used to convert rainfall data input into flood output (Wang and Chen, 1996). The HEC-HMS 3.5 is fitted with hydrological rainfall data, sub-basin data and starting and ending time. Figure 11 on page 68 shows steps required to run HEC-HMS 3.5. These steps include starting of a new project, run precipitation model, run basin model, run control specifications, creating and executing a run; and view graphs, tables, and printing of the results (Scharffenberg and Fleming, 2005). The above mentioned steps are described in details below. Hydrographs of outflow are generated over a long period from the input historical rainfall data. Many different mathematical models have been included in the programme to represent the components of the hydrological cycle (Els, 2011). Depending on the specific watershed study, individual components can be used or left out to simplify the process of modelling, if possible. Some of the main categories, which are available in the modelling system, include potential evapotranspiration, precipitation, canopy interception, snowmelt, infiltration, surface storage, baseflow, surface runoff, channel seepage and channel routing (Scharffenberg and Fleming, 2005).

The HEC-HMS 3.5 software can only be started if all the required data has been collected, analysed and modelling can also be performed. The Graphical User Interface (GUI) shows tool bars, menu bars, component editor, message log and watershed explorer. A new project needs to be built to start with the analysis in HEC-HMS 3.5. This must be done in the screen for project definition, which works to build and carry out the projects, if dataset, analysis tools and components such as gauge discharge and rainfall gauge are available. The description of the projects can be changed rather than project attributes at project definition. To build a new project, users need to select *File New Project* from HEC-HMS 3.5 and the new screen for a project will pop-out (Figure 12 on page 69). The users can enter the details and project name. After all the details related to the project are inserted, the users need to click OK in order for a new project to be created.

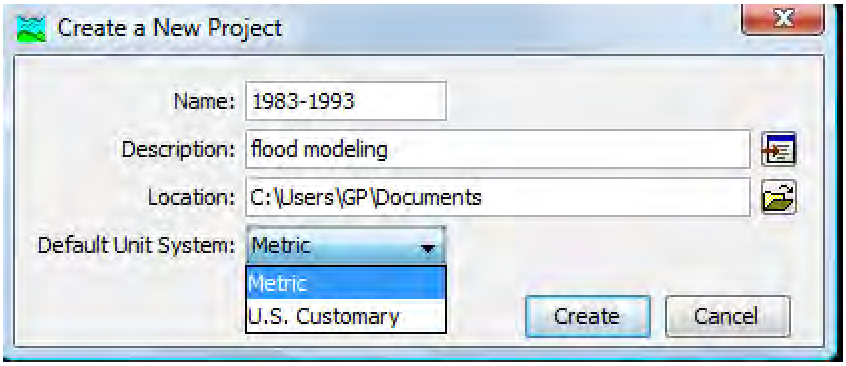


Figure 12: The new project which has been created and defined by a user.

The data input for HEC-HMS 3.5 is historical rainfall data. Three components are used to define the HEC-HMS 3.5 simulation. These components include basin model, precipitation model and control specifications. The basin model contains the diagram, which consists of the combination of seven different objects that include reservoir, sink, junction, reach, source and the sub basin. Information about the connectivity and properties of the objects are stored in the basin model. Intentionally in the research project, the small basins were merged into one sub-basin that is used because it is the only element used to represent the physical catchment. Information about the time-series consists of rainfall data that is contained in the meteorological model. The data contained in the meteorological model is associated with the rain gauges. Duration and time for simulation properties are defined by control specifications.

5.1.1 Precipitation model

The precipitation model is used to store historical rainfall data required to simulate the processes of the watershed. The HEC-HMS 3.5 has different methods available for distributing measured rainfall data over the catchment area. These methods include gridded precipitation data, single hyetograph, inverse distance gauge weights and frequency storm events. In this study, frequency storm events were used. This type of model is a set of information, which is needed to define historical or hypothetical precipitation and is used in conjunction with the basin model. The precipitation model describes the conditions of the atmosphere over the land surface of the catchment. One of the following options that include specifying gauges and associated weights, specifying gauges and their location and the importation of spatially averaged data, can specify historical precipitation (Scharffenberg and Fleming, 2010). Although the HEC-HMS 3.5 model can use any time-series data, flood modelling can be achieved better by using hourly data. As mentioned before, the two sets of historical rainfall data used as input in HEC-HMS 3.5 were acquired from the SAWS. One set of the historical rainfall data ranged from 1983 to 1993 and another set ranged from 1990 to 2000. The unit for historical rainfall data is recorded in millimetres per hour (mm/hr). The data was collected from 08:h00 in the morning until 15-h00 in the afternoon from the Waterval weather station. The data was collected early in the morning and in the afternoon to avoid the impact of evaporation. The data used was filtered for potential systematics and random errors prior to model implementation. After inserting all the parameters for sub-basin, the next step is to build the meteorological model. To build such meteorological model, users need to select:

Component → *Meteorological Model Manager icon* from the HEC-HMS 3.5 (Figure 13 on page 71). The screen for meteorological model manager will automatically pop-out and historical rainfall data, description and name of the model must be entered.

The HEC-HMS 3.5 is calibrated by using two pairs of historical rainfall data. The historical rainfall data is from the years 1983-1993 and years 1990-2000. HEC-HMS 3.5 models include sub-basin as the only element used in this research. Two methods that are used include SCS unit hydrograph and SCS curve number. Method of SCS unit hydrograph is used in the generation of transformation and the SCS curve number is used in the estimation of loss. The precipitation model includes historical rainfall data from January to December of 1983 to 1993. Other historical rainfall data ranges from January to December of 1990 to 2000. The Waterval rain gauge station is also considered for simulation, validation and calibration because of the historical rainfall data, which is available for this station. Only the years of 1983-1993 and the years 1990-2000 historical rainfall data is used in the process of validation and calibration purpose. Details of evaluating the results are discussed in the chapter of discussion.

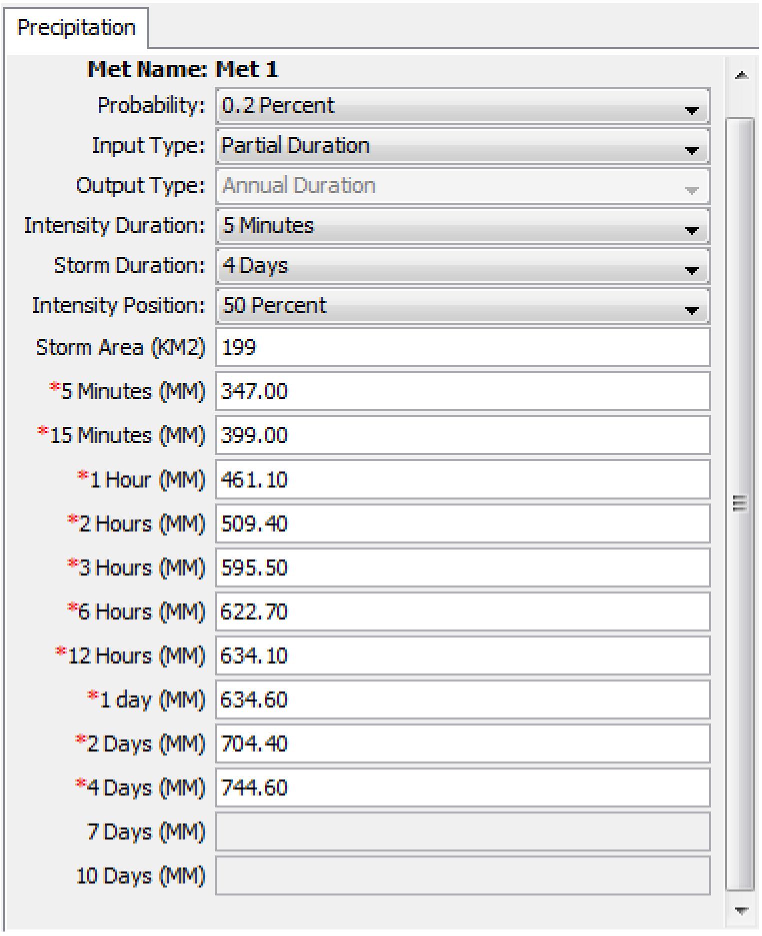


Figure 13: The precipitation or meteorological model which is used to hold the rainfall data.

5.1.2 Control specifications

The control specifications are used in the simulation to define information related to time and including the starting and ending dates and the time interval during simulation. The main function of the control specifications is for setting the starting and ending dates and the time interval. One of the components required to start the process of simulation in HEC-HMS 3.5 software is to determine the control specifications. Date and time need to be entered in the software by users. To build the control specification, users need to select the Component → Control Specifications Manager icon from HEC-HMS 3.5. The screen for control specifications will automatically pop-up (Figure 14 on page 72). The description, date, time interval, start and end times need to be inserted.

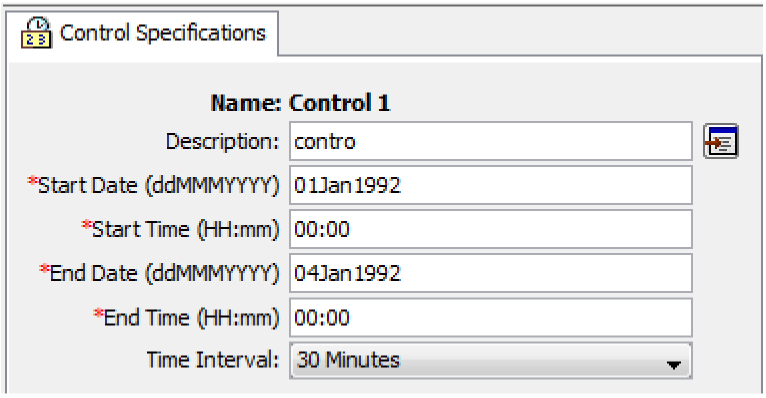


Figure 14: The control specifications which contain information about the time of the model such as when the rainfall is going to start and end and the time-interval.

5.1.3 Basin model

The basic model contains data, which is used to represent the model of the catchment and river basic of the area of the study. This data includes specification of the hydrological elements, which comprise the basin elements, values of parameters for hydrological elements and information on how hydrological elements are connected. The basin model describes the physical characteristics of the catchment. The basin model has the capability of being configured by dragging and dropping icons or tools on a diagrammatic display, which is provided. Hydrological elements that consist of the basin model include routing reach, sub-basin, reservoir, junction, sink, source and diversion (Scharffenberg and Fleming, 2005) (Table 6 on page 73). From the above mentioned elements of the basin model, only the sub-basin has been used. This is because the main reason of using the sub-basin is to find the flood hydrographs. Specification of such hydrological elements and data are those that control the behaviour in the development of the basin model. Spatial data that is used by the basin model includes sub-basin data components such as routing parameters, loss parameters, computation methods and base flow values.

The Basin model processes the pre-processed data by delineating the catchment area and derives the physical characteristics of the stream and sub-catchment or sub-basin in the study area. In this research, the basin model of the Jukskei catchment includes one sub-catchment, which corresponds with the location of one gauge station, Waterval. The physical characteristics of the Jukskei stream include slope and stream length. The physical characteristics of the sub-catchment include the flow path.

Table 6: The elements which consist of the basin model and their applications (Scharffenberg and Fleming, 2005).

Hydrological elements	Function or description
Sub-basin	For catchment where the rain falls
Reach	For streams and rivers
Reservoir	For lakes and dams
Sink	For terminal lakes and outlets
Junction	Confluence
Source	For model sink and springs
Diversion	For withdrawals and bifurcations

In order to build the basin model, users need to select Component → Basin Model Manager icon from HEC-HMS 3.5 (Figure 15 on page 74). Description, area and name can be entered when the basin model automatically pops-up.

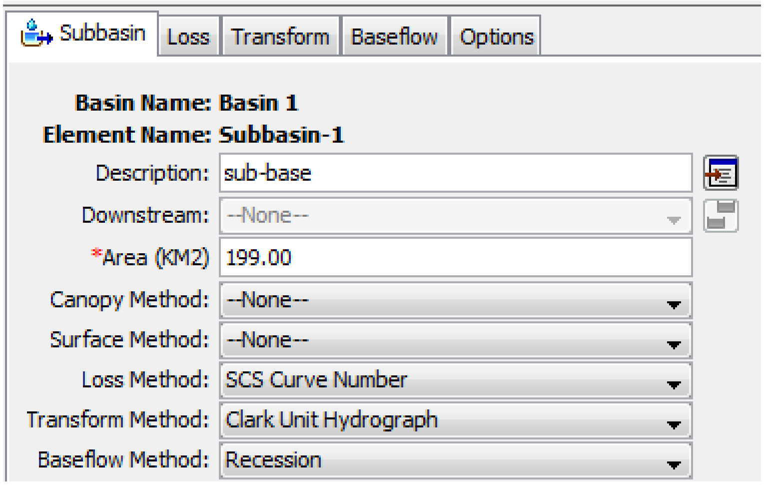


Figure 15: The sub-basin model which provides us with the area and physical attributes of the catchment.

5.1.3.1 Sub-basin

The sub-basin is used in the conversion of the rainfall into runoff. This means that information on the methods used in the computation of the baseflow, hydrograph transformation and the loss rate is required for the sub-basin (Maity, 2009). The loss method requires us to select the process which will calculate the rainfall that has been lost due to absorption by the ground surface. Constant and initial has been chosen for this model. This means that some of the amount of the rainfall will be absorbed by the ground surface while the constant rate will be absorbed in the period of this model. The method of transformation requires us to specify how the excess rainfall is converted to the direct runoff. There is no specification for the baseflow in this model.

After selecting both the transform and loss methods for the sub-basin, the following step will be specification of the parameters for these methods. Therefore, the constant loss rate, percentage impervious and initial loss is required by the sub-basin. The sub-basin does not have an inflow but only the outflow. This is one of the two methods for producing flow in watershed model. The calculation of outflow is done by subtracting from conversion and loss of precipitation data. This is because of the assumption made that the water in a watershed area contains only three elements that include base flow, alteration and loss (Wang and Chen, 1996).

5.1.3.2 Transformation method

This method is useful in the conversion of excess precipitation in a sub-basin into the direct runoff at the outlet of the sub basin. The process of transforming rainfall into runoff in the HEC-HMS 3.5 watershed involves two options that include empirical models and conceptual models. Empirical models are described as traditional unit hydrograph models (Balyan, 2009).Theoretically; empirical models try to link excess rainfall with runoff but do not provide details about the internal processes. Conceptual models in HEC-HMS 3.5 include the kinematic wave model, which is used in overland flow.

The kinetic wave model represents all physical processes that control the movement of excess rainfall over the watershed. The model of Clark unit hydrograph has been chosen for direct runoff because it is simple to use, requires minimum data and it provides a better performance compared to other modules (Scharffenberg and Fleming, 2005). The model is categorized by empirical, lumped, event, and fitted parameters. It is useful for the conceptual model in the transformation of rainfall into the runoff process. The HEC-HMS 3.5 model is conceptual because during simulation, the process cannot be observed. The HEC-HMS 3.5 provides us with the final output from the provided input. Time of concentration is required by the Clark unit hydrograph in the calculation of the surface runoff.

5.1.3.3 Loss method

The loss method is used to determine the amount of water which infiltrated the soil. The HEC-HMS 3.5 generates volume of runoff by generating water volume, which is stored, infiltrated, transpired or evaporated, intercepted and subtracts it from the rainfall. Surface storage and interception are regarded as representing the surface storage of water by crevices, cracks, grass or trees, roofs or parking lots where water cannot move freely as an overland flow (Balyan, 2009). Infiltration represents the water movement from the surface into sub-surface. Transpiration, evaporation, storage, infiltration and interception together are regarded as loss in the HEC-HMS 3.5 programme.

5.2 GRASS GIS

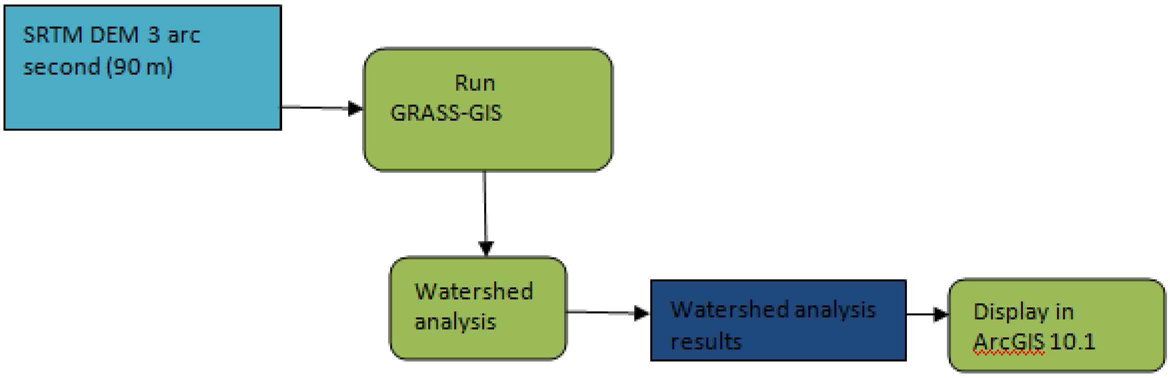


Figure 16: Analysis of SRTM DEM by using GRASS-GIS to find the Jukskei River and the sub-basin.

5.2.1 Analysis of the watershed by using DEM and GRASS GIS

The watershed analysis is the most important step in the determination of the basin geometry and stream network (Figure 16 on page 76). The techniques used in the watershed analysis include r.watershed, d.rast, r.water.outlet, r.to.vect, d.what.vect, r.mapcalc and d.rast.MASK. The r.watershed module allows the users to determine the basin geometry such as stream map, basin map and drainage map from a given SRTM DEM. The input for r.watershed includes threshold value and SRTM DEM. Input parameter threshold is an integer value, which shows the minimum size of watershed basin cells (Spruit, Kalla and Vijith, 2010).

Therefore, a lower value of this parameter produces a more detailed stream network. A large value of this parameter provides a less detailed map of the streams as only one stream per watershed is presented. The large value of the parameter gives the overall basin structure of the river system. The value of this parameter is estimated based on the above criteria and keeping in mind the basin geometry of a river. The Mask map is used to cover the area that is not included in the watershed analysis. The output maps, especially the basin and stream maps should be checked by visual inspection.

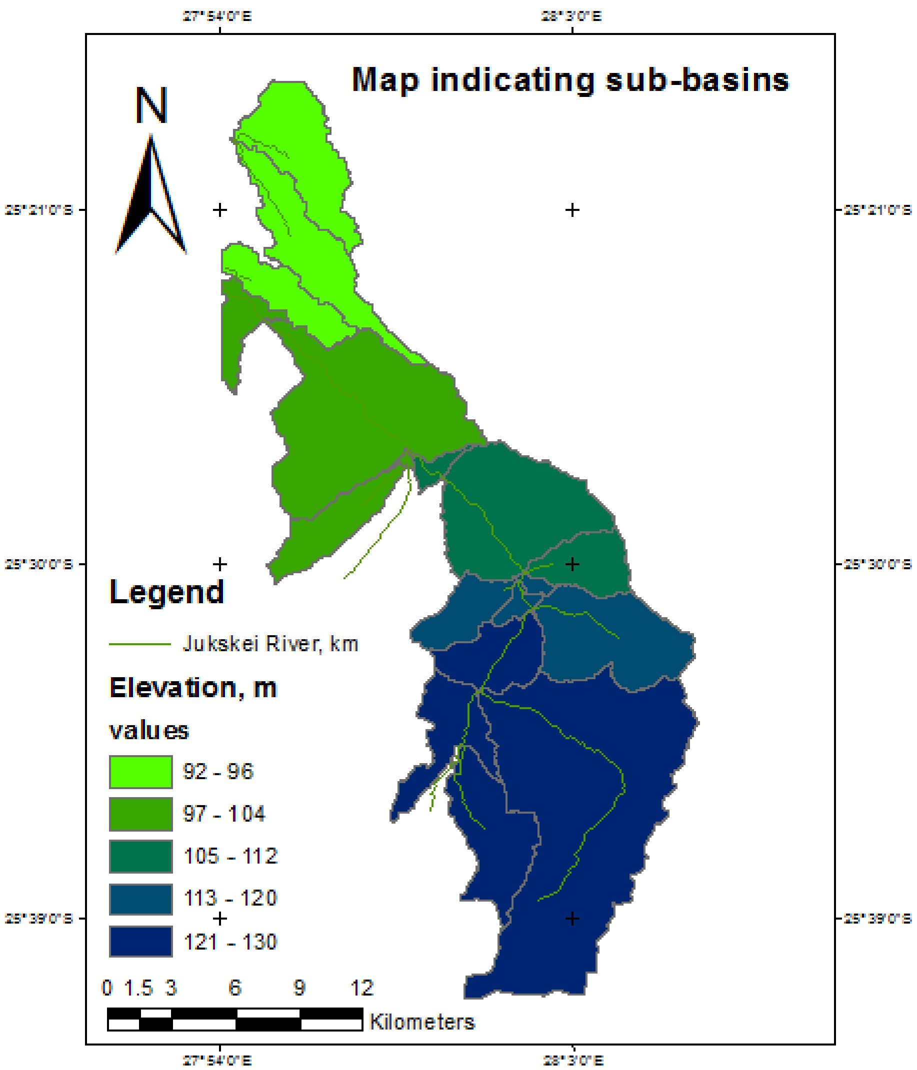


Figure 17: One of the examples of the output map, which in this case is a basin and stream maps.

The r.water.outlet module is used in the creation of the watershed over the selected point on the stream (Figure 17 on page 77). This module needs the drainage map and location (northing (latitude) and easting (longitude)) generated from the above step. The output is the raster watershed (basin) map over the selected point.

To get the watershed divide or basin parameter of the watershed, it is better to convert the raster basin map to vector. The module r.to.vect is in the conversion of raster map to vector map. Note that to visualise the vector map, d.what command is used. The above module was used to convert both the Jukskei stream and basins raster maps to vector maps to be able to run the script for determining the area, which is vulnerable to floods.

After the vector map output is displayed, it can be queried to get the area of the watershed. The command d.what.vect is similar to the earlier discussed d.what.rast and clicking a mouse anywhere in the watershed will provides the area in different units. The module r.mapcalc is used in the creation of mask from the SRTM DEM. Mask map created is used to mask the specific areas, which need to be included in the analysis. Watershed analysis modules for its predefinition require mask map. The created mask is then converted into vector map by using the v.to.rast module in GRASS GIS.

SRTM DEM is used to obtain the basic basin variables such as stream network, accumulation, slope and watershed areas, which also include the basin outlet (Spruit, Kalla and Vijith, 2010). Delineation of areas nearest to the stream channel or areas vulnerable to floods is done in the watershed analysis. The stream network map shows the route of the river and the knowledge of the route is significant not only to calculate the discharge at a point on the stream but also identification of the areas, which are lying near the stream and would be more vulnerable to floods. The stream network also shows the route of the river, identifies areas lying near the stream which would be vulnerable to floods and each stream has a category number which is identified by different colours, the same as those of the corresponding basin.

A category number is a vector ID. Its function is to connect attributes to each object of a vector (Spruit, Kalla and Vijith, 2010). This vector object contains values such as 1, 2, 3, 4 or more categories. These category numbers are found in the attribute tables in the geometry file of each vector object. The category numbers, which were used to mask or select both the Jukskei stream and its sub-basins in this research, include “92, 94, 96, 98, 100, 102, 104, 108, 110, 112, 114, 116, 118, 120, 122, 124, 128, and 130”).

More details of the stream network are found by lowering the threshold value and only one stream per basin will be indicated. Location of the Jukskei River for this study is chosen on the outlet of the river. Another significant variable is the watershed area over a point in the stream. It is obvious that not all the water appears instantly in the stream, as it has to travel from the farthest point of the watershed to the stream. In GRASS, watershed analysis module r.watershed is available for watershed analysis. The r.watershed is used to determine the drainage network and delineates the sub-basin from the DEM. The module shows the location of streams and sub-basins. The module inputs include elevation map, depression map, flow map, and threshold value (Spruit, Kalla and Vijith, 2010). The elevation map shows the elevation of where the analysis is based. Depression map shows the location of real depressions. The flow map shows the amount of surface runoff flow per cell. The threshold value represents the minimum size of the catchment area. The output of the module includes accumulation map, drainage map, basin map and stream map (Spruit, Kalla and Vijith, 2010). The accumulation map represents the number of cells through-out each cell. The drainage map shows the drainage direction. The basin map shows a unique value or label for each sub-basin or basins. The stream map shows the stream network. It uses a "least cost search algorithm designed to reduce the impact to DEM data errors" (Grohmann et al., 2007). The least cost path is a GIS method which extract drainage network from DEM (Spruit, Kalla and Vijith, 2010). It requires a cost function and two points. The results, which are provided by a least cost algorithm, are more accurate in the area, which has a low slope. It is more accurate than the module r.terraflow, but this accuracy comes with the drawback of long computing time. The r.terraflow is used to integrate flow accumulation, assigning flow directions, filling depressions and various other indices which are related to watershed. There are two methods, which are available in r.watershed. These methods include Multiple Flow Direction (MFD) and Single Flow Direction (SFD) (Grohmann et al., 2007). In MFD, each cell contains multiple directions for all down-slope neighbours and is very much complex. In SFD, each cell has been assigned a direction to the steep down-slope neighbour. It allows users to choose between MFD and SFD routing. In this study, the SFD is used because each cell has a single flow direction, no cycle of flow path available, and each cell in the DEM has a flow path until the edge of the DEM.

5.3 Sensorweb

The prediction and monitoring of flood is implemented by using the SOS. It uses the historical rainfall data from the SAWS. The rainfall data from SAWS was measured by using rain gauge as a sensor. To provide access to rainfall data or observations over the area along the Jukskei River, the SOS implementation needs to be deployed around the Jukskei River. The main task of SOS implementation is to serve the rainfall data and other information to the Disaster Management centre and Disaster Management officials, decision makers and township residents around the Jukskei River. Some of the reasons why the SOS is used in this study, include that it is open source software, written in java which means it is platform independent, source code is reusable and clean, it is also part of the sensor web implementations and its implementation is complete and stable. The rainfall data from the river gauge and hydrological models are accessed through the SOS.

The SOS parses the RegisterSensor request and inserts the procedure, offering, phenomena into the database. SensorML, part of the RegisterSensor request, is completely stored in the database as a text value (table procedure). If you use the RegisterSensor, it is not necessary to store a SensorML file in the SOS (conf/sensors/). The response of a DescribeSensor request is the SensorML stored in the database as text. The SOS parses the InsertObservation request and stores the value(s) and FeatureOfInterest into the database.

The database for weather information of the SAWS has records of rainfall data, temperatures and humidity. The PostgreSQL database, together with PostGIS spatial extension, is used to store the rainfall data. Most of the rainfall data is in a single table called observation with station identifier and observation time. Some of the challenges of using the SOS include that the source of data is only relational database of the specific structure, application of the model is complex, which is only based on the Java web applications and structure of the database is far from optimal.

The 52north SOS GetObservation service allows the client to filter measurements or observations according to sensor, space, time and phenomenon. The section of the filter capabilities is used to show what type of query parameters are supported by the service. These capabilities refer to the parameters of the GetObservation service (Na and Priest, 2006). The GetObservation service is the only service that includes the filter expression. This section of the filter capabilities return the document of the metadata service, which contains the information about the supported filters. The response to the GetCapabilities is in the form of xml document. Clients are provided with the metadata by this operation or service about specific services that include the metadata of the data, which has been supplied. The GetCapabilities request retrieves the service metadata requested by the clients about the specific service. The new observations, which were inserted, were from the Jukskei station in Gauteng, South Africa.

The observations were collected from 1983-1993 from the rain gauge. The inserted observations were numeric since the 52° North SOS implementation currently requires the numeric values. Capabilities xml skeleton was adjusted and the title of the SOS was changed through service identification and all the data of the service provider through the service provider so that the GetCapabilities can run successfully. This is because when the server of the SOS experiences an error when performing the GetCapabilities, it will return an exceptional report message. The dssos.config file was configured by changing the username and the password. All the three capabilities requests (DescribeSensor, Getcapabilities and GetObservation) were tested through the SOS test client.

The services provided by the SWE components are applied in the management of the network of hydrologic sensors such cameras, weather station and rain gauges by the provision of access to the sensor data, realisation of events handling and enabled interoperability of the sensor tasking (Broring et al., 2011). The above-mentioned description of the SWE deployment can be applied to other sensor network deployment in the real world. Measurements or observations gathered in the field by different sensor resources are inserted into the SOS. The raw data, which is collected by sensors, is first encoded as O and M, enriched and processed before it is inserted in the SOS in the real world application (Broring et al., 2011). There are often middleware components and system for data acquisition in the real world deployment, which is available between the SWE services and sensors. When the measurements are inserted into the SOS, data can be accessed or retrieved and visualised through the standard interface as maps or time-series graphs.

If the clients are only interested in a specific data that matches some of the filter, criteria defined, for example if the water level exceeds a certain threshold value, the clients can subscribe to the SES (Broring et al., 2011). This is because the SES keeps on publishing the observations continuously if particular filter criteria are matched and the SES forward the sensor data and other information to the clients (Broring et al., 2011). If a particular event occurs, clients can register for alerts. This means that the SES triggers the WNS to notify the clients through the communication protocol defined. For example, users can receive notifications via email or SMS if the water level exceeds certain threshold value at a water gauge station defined. The SPS is used to tasks the cameras at certain point along the Jukskei River or a water gauge. These cameras can be zoomed or rotated and real-time video streams can be accessed by the users through various means of accessing data.

The WNS is used to deliver the alert notifications to Disaster Management officials and Alexandra Township residents. The WNS is used as protocol transducer. This means that incoming messages in the form of encoded XML will be forwarded to Disaster Management officials and residents who registered. This will be achieved by using different protocols such as SMS, E-mail, Phone and Fax notification support available in the WNS (Jirka and Echterhoff, 2009).

The WNS contains three types of pre-defined messages. Firstly, one-way communication where notification message is used and consists of service description and payload with a message. The service description carries more information about the calling service like the URL (Jirka and Echterhoff, 2009). Secondly, two-way communication where communication message is used and consists of CallbackURL, CorrID, Payload and service description. The CallbackURL is used to say where to respond. The CorrID is used to call service in response to an internal request. Thirdly, is the reply message which consists of payload and CorrID (Broring et al., 2009).

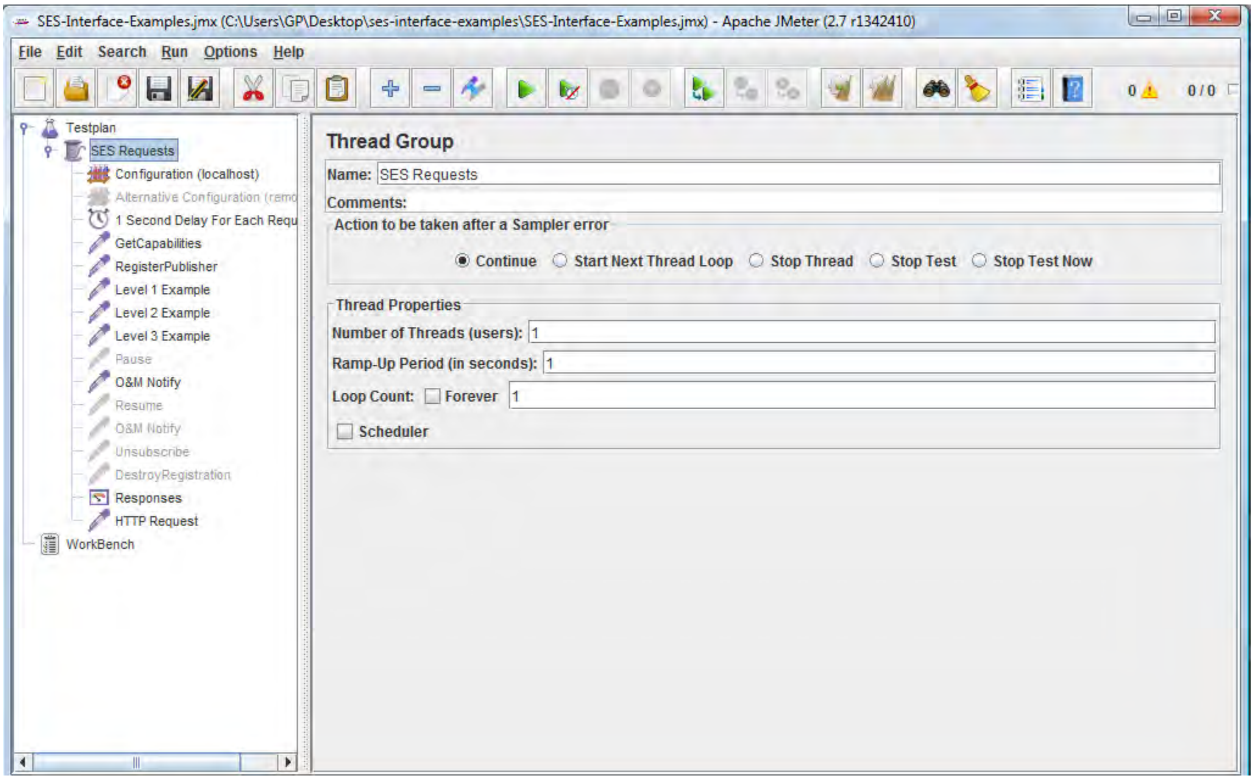
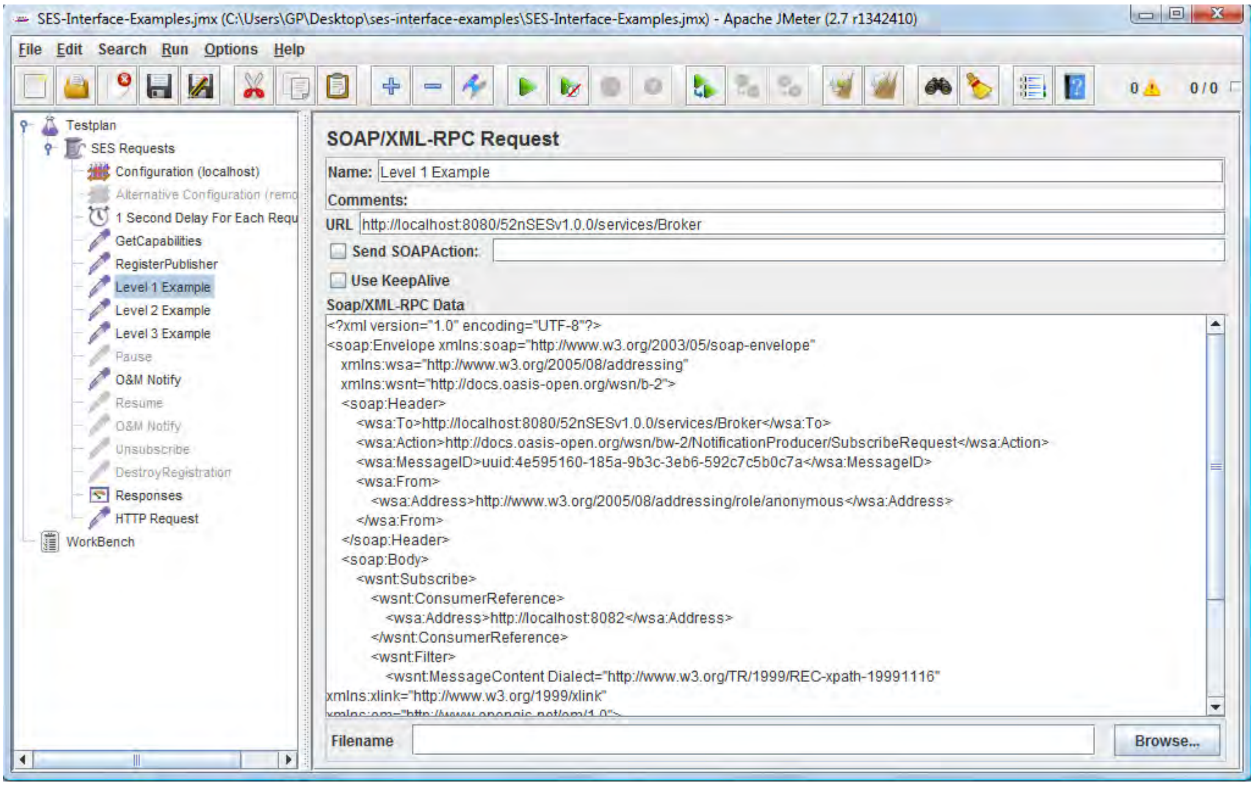


Figure 18: The Jmeter after the jmx file was loaded.

To run the SES, the Jmeter needs to be downloaded and installed. The Jmeter is a small programme used to send the requests. After installing the Jmeter, the jmx file provided is loaded into Jmeter (Figure 18 on page 82). To operate the Jmeter, the URL needs to be inserted twice in each request, firstly in Jmeter URL and secondly in ―wsa" which is the part of the Simple Object Access Protocol (SOAP) header. After the configuration of the Jmeter, the local simplewnsconsumer is started. The local simplewnsconsumer is a small programme, which is used to receive the notification. This can be done through the PortListener programme. The PortListener is a java programme which listens in the port of a computer and writes all the requests received in the text window.



<?xml version="1.0" encoding="UTF-8"?>
<soap:Envelope xmlns:soap="http://www.w3.org/2003/05/soap-envelope"
xmlns:wsa="http://www.w3.org/2005/08/addressing"
xmlns:wsnt="http://docs.oasis-open.org/wsn/b-2">
<soap:Header>
<wsa:To>http://localhost:8080/52nSESv1.0.0/services/Broker</wsa:To>
<wsa:Action>http://docs.oasis-open.org/wsn/bw-2/NotificationProducer/SubscribeRequest</wsa:Action>
<wsa:MessageID>uuid:4e595160-185a-9b3c-3eb6-592c7c5b0c7a</wsa:MessageID>
<wsa:From>
<wsa:Address>http://www.w3.org/2005/08/addressing/role/anonymous</wsa:Address>
</wsa:From>
</soap:Header>
<soap:Body>
<wsnt:Subscribe>
<wsnt:ConsumerReference>
<wsa:Address>http://localhost:8082</wsa:Address>
</wsnt:ConsumerReference>
<wsnt:Filter>
<wsnt:MessageContent Dialect="http://www.w3.org/TR/1999/REC-xpath-19991116"
xmlns:xlink="http://www.w3.org/1999/xlink"

Figure 19: The Jmeter with all the subscriptions level 1, level 2 and level 3.

The user needs to subscribe his/her local simplewnsconsumer in the event service for notification (Figure 19 on page 83). To achieve that, the available requests in the Jmeter need to be adjusted. The level one, level two and level three subscribe requests need to be clicked and the address of the local simplewnsconsumer entered in the field of consumer reference. The results can be viewed on the ―view results tree". To send notification to an event service, the notification needs to be activated by right clicking the mouse and deactivating the subscribe requests (Figure 20 on page 84). The notifications will be received in the local simplewnsconsumer after starting the requests.

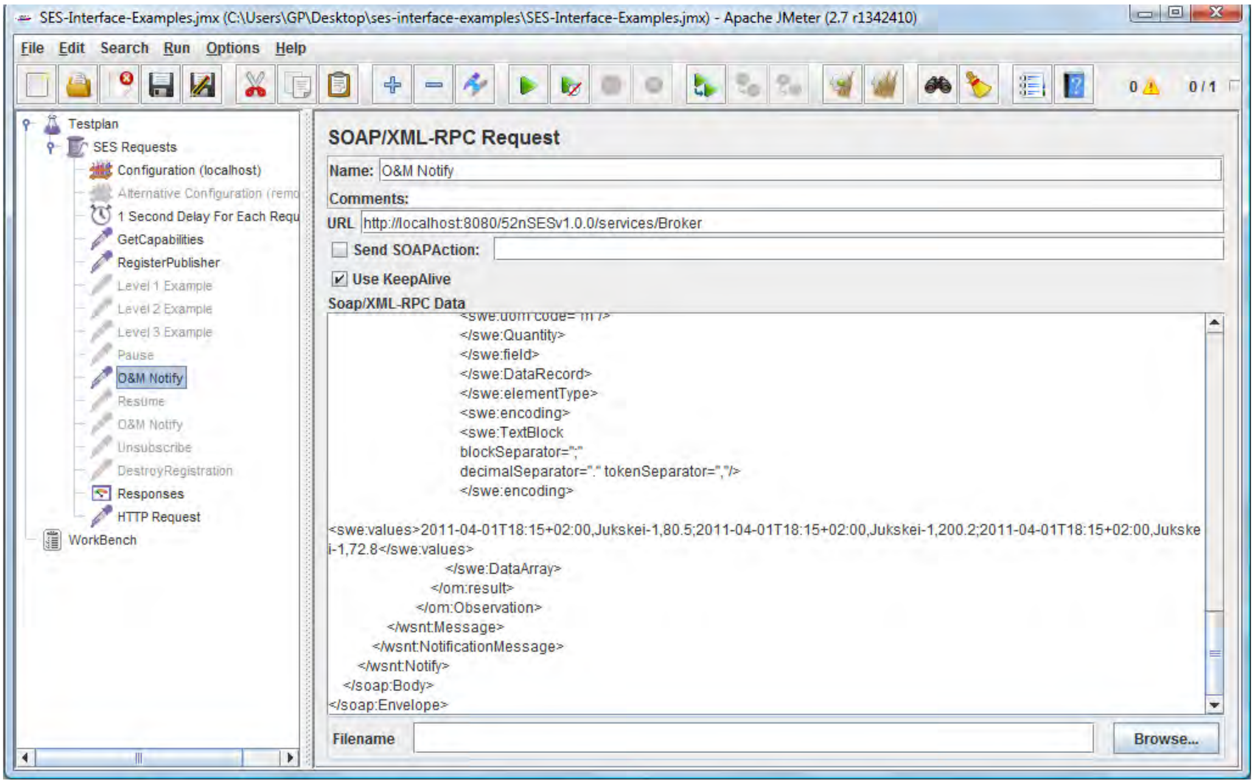


Figure 20: The Jmeter with observations and measurements for sending notifications to users who subscribe to receive those notifications.

6. Results and analysis

This chapter presents the results of the research project. It indicates the results of the hydrological modelling process by using HEC-HMS 3.5, comparison of observed and simulated flood hydrographs with the help of sensor web, the watershed analysis results; and how to access the sensor data, information and measurements from the sensor web.

6.1 The HEC-HMS 3.5 model

6.1.1 Flood hydrographs

The results, which are simulated, are considered for the Jukskei River outlet because the only available data is the observed rainfall data from SAWS. The HEC-HMS 3.5 was run with 30 minutes interval and the conducted analyses were based on the output of the rainfall data. Observed rainfall is compared with the simulated discharge. It can also be seen from the hydrograph that the observed value of 1000 m^3/s and the simulated value of 3644.8 m^3/s with percent error of 2.6% were found (Figure 21 on page 86). The figure also shows the predicted peak discharge in light blue and observed peak discharge in light brown colour. The predicted peak discharge is higher than the observed peak discharge. This result means that the model cannot be considered reliable in the estimation of the peak discharge.

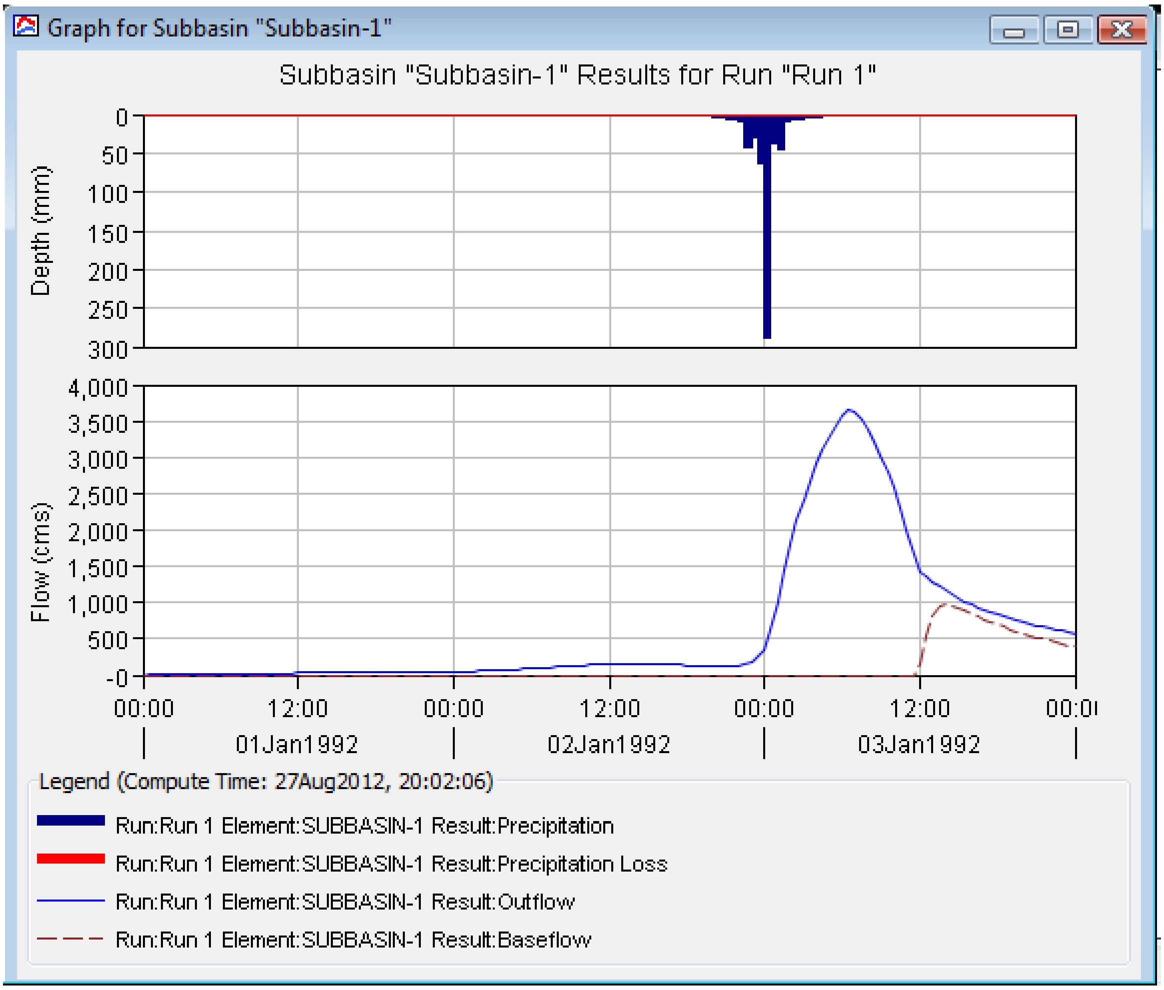


Figure 21: Rainfall observed and predicted runoff during the period of 1983 to 1993.

Table 7 on page 87 shows the maximum peak discharge observed for 1983 to 1993 years compared to predicted peak discharge. The difference between the total loss and precipitation is the total excess runoff measured in millimetres (Scharffenberg and Fleming, 2005). The table also shows discharge, total baseflow, total direct runoff, total excess, total loss, total precipitation, predicted peak discharge, and observed peak discharge plotted in the flood hydrograph in figure 21.

Table 7: Summary results for sub-basin of the historical rainfall data of 1983 to 1993 from the HEC-HMS 3.5.

Observed Peak Discharge	1000 (m^3/s)
Predicted Peak Discharge	3644.8 (m^3/s)
Total Precipitation	694.03 (mm)
Total Loss	10.77 (mm)
Total Excess	683.26 (mm)
Total Direct Runoff	664.68 (mm)
Total Baseflow	145.28 (mm)
Discharge	809.95 (mm)

In this research, historical rainfall data is used in the simulation of the discharge in the HEC-HMS 3.5. The historical rainfall data stems from January to December, although most of the flood events take place in December to March. The results from simulation are considered for the Jukskei catchment because of the available data from the Waterval station. HEC-HMS 3.5 was run with 30 minutes interval. Analysis was conducted based on the historical rainfall data output. Monthly daily-simulated discharge obtained by using historical rainfall data prior to flood event is compared with simulated Monthly daily-simulated discharge obtained after the flood event. This is because historical runoff data is not available for this study area. The runoff or predicted peak discharge obtained by using historical rainfall data of the years 1990 to 2000 is 3277.4 m^3/s and the observed peak discharge is 975.87 m3/s with percentage error of 235.8% (Figure 22 on page 88). Both the predicted and observed peak discharge of 1990 to 2000 years is less than the predicted and observed peak discharge of 1983 to 1993 years. The high values of observed and predicted peak discharge during 1983 to 1993 are attributed to the network of rain gauges which were available by that time or the high rainfall intensity.

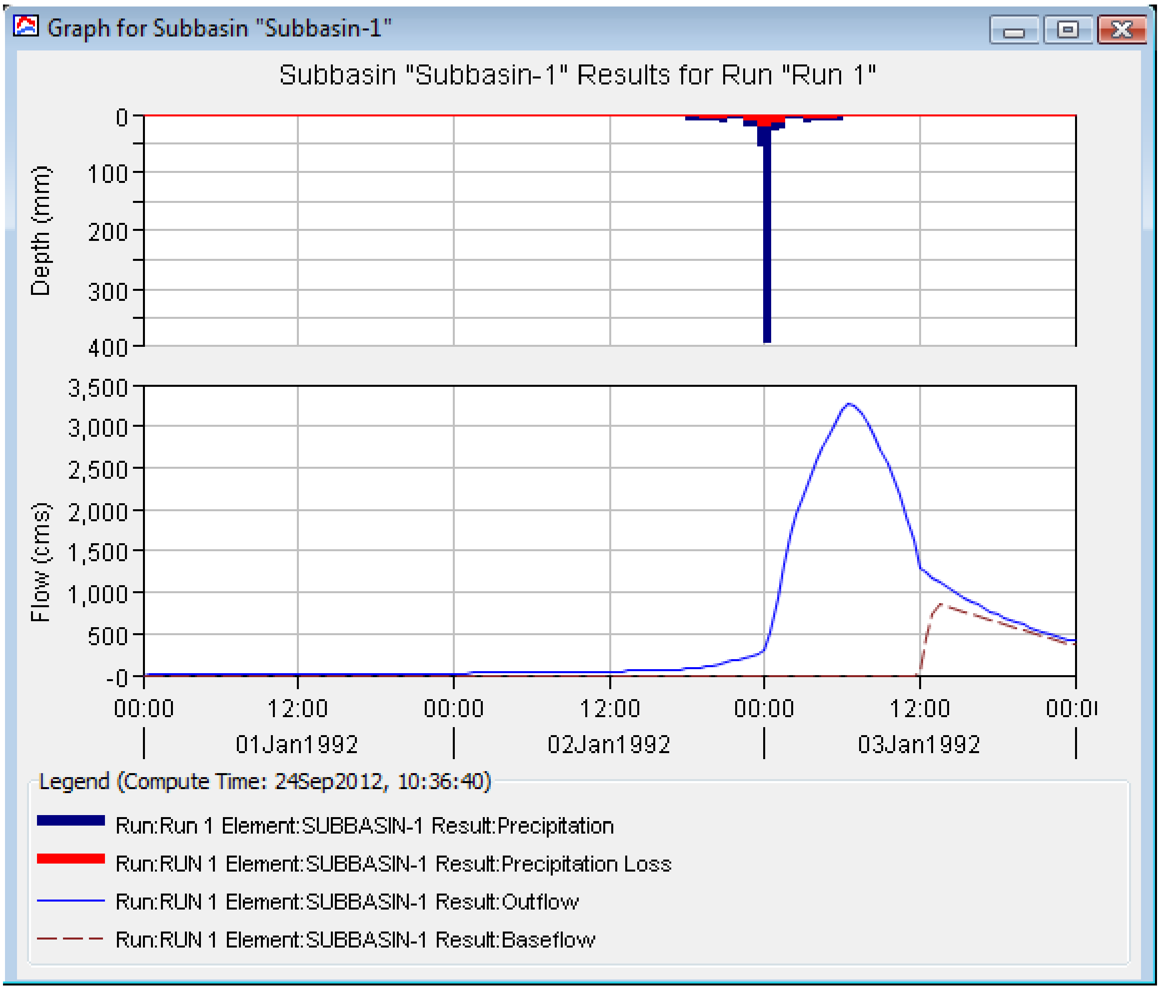


Figure 22: Rainfall observed and predicted runoff during the period of 1990 to 2000.

Parts of the table, which include direct discharge, excess runoff, precipitation loss and precipitation and baseflow, are plotted in the hydrograph (Table 8 on page 89). The maximum peak discharge observed for 1990 to 2000 years compared to predicted peak discharge.

Table 8: Summary results for sub-basin of the historical rainfall data of 1990 to 2000 from the HEC-HMS 3.5.

Observed Peak Discharge	975.87 (m^3/s)
Predicted Peak Discharge	3277.4 (m^3/s)
Total Precipitation	762.32 (mm)
Total Loss	183.73 (mm)
Total Excess	578.59 (mm)
Total Direct Runoff	573.80 (mm)
Total Baseflow	129.25 (mm)
Discharge	703.05 (mm)

6.2 Comparison of observed and simulated flood hydrographs with the help of sensor web

The predicted hydrograph for the Jukskei catchment is reasonably similar to the observed hydrograph. The historical rainfall data was imported from the SOS. Predicted peak discharge is also similar to the observed peak discharge. The runoff period observed throughout the hydrograph was well predicted. Figure 23 on page 90 presents simulated and an observed flood hydrographs for Jukskei catchment. The figure also shows an intense rainfall and runoff period observed during the 1983-1993 flood period where all the simulated flood peaks are larger than the observed peaks. It can also be seen from the figure that simulated hydrograph and observed hydrograph are in good agreement. The simulated model results displayed are stored in the SOS service. This means that there are no discrepancies in the predicted hydrograph, which can be associated with the performance of HEC-HMS 3.5 model, meaning that the HEC-HMS 3.5 uses rainfall data to predict runoff. The runoff, which was predicted during 1983 and 1993, showed that the recorded rainfall reflected the rainfall over the area of the Jukskei catchment.

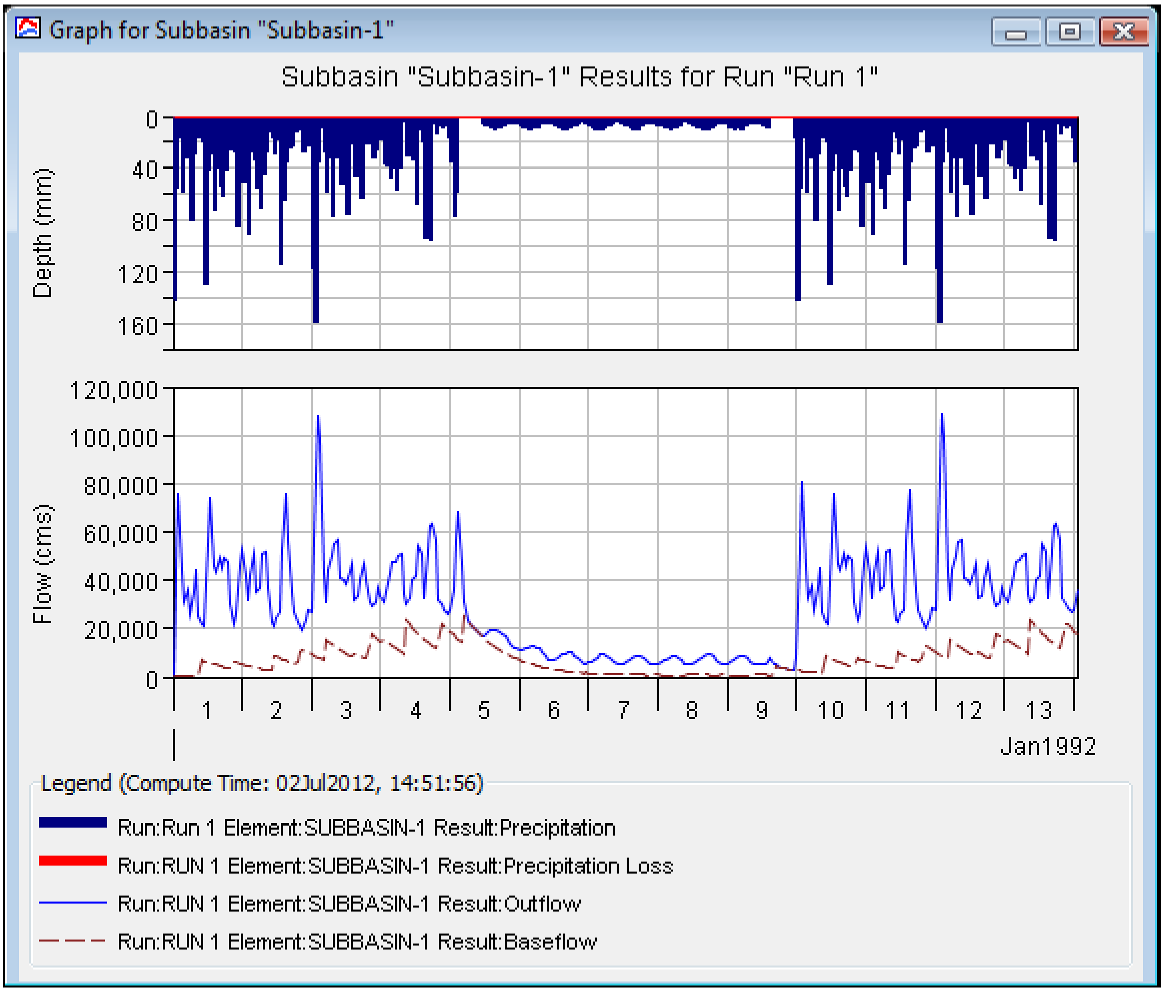


Figure 23: Comparison of observed and simulated hydrographs for the calibration period 1983 to 1993 at Alexandra Township.

Table 9 on page 91 shows the maximum peak discharge observed for 1983 to 1993 years compared to predicted peak discharge from the SOS. It can be clearly seen from all the three tables that the predicted peak discharge in response to the storm event is higher as compared to the observed peak discharge. Two of the largest peaks, which occurred between 1983 and 1993, are 106769.7 m^3/s and 107769 m^3/s as a result of high and intense rainfall of which two of the lowest peaks are 2.4 m^3/s and 2.6 m^3/s result of less intense rainfall.

Table 9: Summary results for sub-basin of the historical rainfall data of 1983 to 1993 from the SOS.

Observed Peak Discharge	2.4 (m^3/s)
Predicted Peak Discharge	106769.7 (m^3/s)
Total Precipitation	7808.89 (mm)
Total Loss	29.10 (mm)
Total Excess	7779.79 (mm)
Total Direct Runoff	7749.47 (mm)
Total Baseflow	2322.77 (mm)
Discharge	10072.23 (mm)

The peak discharge is the maximum flow rate volume passing at a certain point during the rainfall event. The peak discharge is 106769.7 m^3/s as provided in the summary table of results. The unit of the peak discharge is shown in cubic metres per second (Figure 24 on page 92). The value of the peak discharge is used in the prediction of the peak flood flow. Difference between the precipitation loss and precipitation are equal to the excess runoff (Merwade, 2007).

Time-Series Results for Subbasin "Subbasin-1"

Project: 1983_1992
Simulation Run: Run 1 Subbasin: Subbasin-1

Start of Run: 01Jan1992, 00:00 Basin Model: Basin 1
End of Run: 04Jan1992, 00:00 Meteorologic Model: Met 1
Compute Time: 26Sep2012, 15:22:08 Control Specifications: Control 1

Date	Time	Precip (MM)	Loss (MM)	Excess (MM)	Direc... (M3/S)	Base... (M3/S)	Total... (M3/S)
01Jan1992	00:30	0.35	0.16	0.19	0.1	0.0	0.1
01Jan1992	01:00	0.35	0.15	0.20	0.4	0.0	0.4
01Jan1992	01:30	0.36	0.15	0.21	0.8	0.0	0.8
01Jan1992	02:00	0.36	0.15	0.21	1.5	0.0	1.5
01Jan1992	02:30	0.36	0.14	0.22	2.2	0.0	2.2
01Jan1992	03:00	0.37	0.14	0.23	3.1	0.0	3.1
01Jan1992	03:30	0.37	0.14	0.23	4.1	0.0	4.1
01Jan1992	04:00	0.37	0.14	0.24	5.2	0.0	5.2
01Jan1992	04:30	0.38	0.13	0.24	6.4	0.0	6.4
01Jan1992	05:00	0.38	0.13	0.25	7.7	0.0	7.7
01Jan1992	05:30	0.39	0.13	0.26	9.2	0.0	9.2
01Jan1992	06:00	0.39	0.13	0.26	10.7	0.0	10.7
01Jan1992	06:30	0.39	0.13	0.27	12.3	0.0	12.3
01Jan1992	07:00	0.40	0.12	0.27	13.9	0.0	13.9
01Jan1992	07:30	0.40	0.12	0.28	15.5	0.0	15.5
01Jan1992	08:00	0.41	0.12	0.29	17.2	0.0	17.2
01Jan1992	08:30	0.41	0.12	0.29	18.7	0.0	18.7
01Jan1992	09:00	0.42	0.12	0.30	20.3	0.0	20.3
01Jan1992	09:30	0.42	0.11	0.31	21.8	0.0	21.8
01Jan1992	10:00	0.43	0.11	0.31	23.3	0.0	23.3
01Jan1992	10:30	0.43	0.11	0.32	24.7	0.0	24.7
01Jan1992	11:00	0.44	0.11	0.33	26.1	0.0	26.1
01Jan1992	11:30	0.44	0.11	0.33	27.3	0.0	27.3

Figure 24: The time-series data generated from the rainfall data of 1983 to 1993 in the HEC-HMS 3.5.

In this research, rainfall data from the years 1983 to 1993 and from the years 1990 to 2000 have been used in the simulation of runoff or peak discharge in the HEC-HMS 3.5 model (Figure 25 on page 93). The SOS provides standardised access to sensor data and metadata. The service provided by SOS acts as a mediator among the sensor data, archive and the client. SOS returns the requested sensor data by the clients as either measurements or observations. SOS interface allows access to sensor types. These include mobile sensors as well as stationary sensors, which gather their data remotely or in-situ. SWE services are represented well by SOS because its responsibilities include access to sensor data and metadata.

Time-Series Results for Subbasin "Subbasin-1"

Project: sure
Simulation Run: Run 1 Subbasin: Subbasin-1

Start of Run: 01Jan1992, 00:00 Basin Model: Basin 1
End of Run: 14Jan1992, 01:00 Meteorologic Model: Met 1
Compute Time: 28Sep2012, 11:43:32 Control Specifications: Control 1

Date	Time	Precip (MM)	Loss (MM)	Excess (MM)	Direc... (M3/S)	Base... (M3/S)	Total... (M3/S)
01Jan1992	00:00				0.0	9.0	9.0
01Jan1992	01:00	0.00	0.00	0.00	0.0	8.4	8.4
01Jan1992	02:00	0.00	0.00	0.00	0.0	7.9	7.9
01Jan1992	03:00	0.00	0.00	0.00	0.0	7.4	7.4
01Jan1992	04:00	0.00	0.00	0.00	0.0	6.9	6.9
01Jan1992	05:00	0.00	0.00	0.00	0.0	6.4	6.4
01Jan1992	06:00	0.00	0.00	0.00	0.0	6.0	6.0
01Jan1992	07:00	0.00	0.00	0.00	0.0	5.6	5.6
01Jan1992	08:00	0.00	0.00	0.00	0.0	5.3	5.3
01Jan1992	09:00	0.00	0.00	0.00	0.0	4.9	4.9
01Jan1992	10:00	0.00	0.00	0.00	0.0	4.6	4.6
01Jan1992	11:00	0.00	0.00	0.00	0.0	4.3	4.3
01Jan1992	12:00	0.00	0.00	0.00	0.0	4.0	4.0
01Jan1992	13:00	0.00	0.00	0.00	0.0	3.8	3.8
01Jan1992	14:00	0.00	0.00	0.00	0.0	3.5	3.5
01Jan1992	15:00	0.00	0.00	0.00	0.0	3.3	3.3
01Jan1992	16:00	0.00	0.00	0.00	0.0	3.1	3.1
01Jan1992	17:00	0.00	0.00	0.00	0.0	2.9	2.9
01Jan1992	18:00	0.00	0.00	0.00	0.0	2.7	2.7
01Jan1992	19:00	0.00	0.00	0.00	0.0	2.5	2.5
01Jan1992	20:00	0.00	0.00	0.00	0.0	2.4	2.4
01Jan1992	21:00	28.27	1.00	27.27	8280.6	2.2	8282.8
01Jan1992	22:00	72.03	0.10	71.93	33219.0	2.1	33221.1

Figure 25: Time-series data generated from rainfall data imported from the SOS.

6.3 Watershed analysis results

First, it is important to identify the areas, which are more vulnerable to floods or low-lying areas in danger of flooding. The red colour shows the areas vulnerable to floods. The blue colour indicates the Jukskei stream (Figure 26 on page 94). This requires a real-time hydrological model with a sufficiently fine grid resolution to resolve the river channel geometry, which predicts the inundation areas based on the transient hydrological variables.

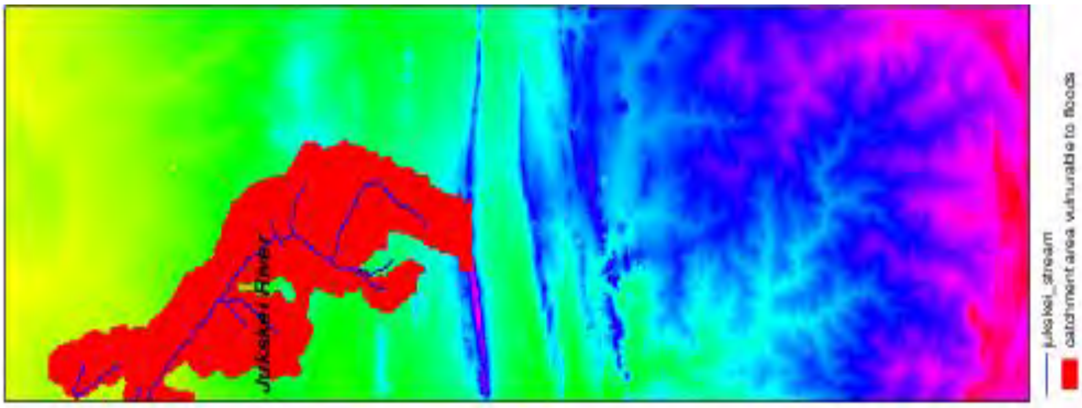


Figure 26: Low-lying areas and the postscript used to select the Jukskei River basin which highlights areas that are more vulnerable to flood in red colour and the stream in blue

As a starting point, the areas which are vulnerable to floods, were identified and mapped, commencing with the stream network according to the calculated slope values from DEM, which is based on an available GRASS GIS script for a modified version of the script (Figure 27 on page 95). These are the areas most likely to be flooded first by floods. Using the DEM, a slope map can be calculated easily in GRASS. The module r.slope.aspect calculates maps of aspect and slope (Spruit, Kalla and Vijith, 2010). This module uses 3*3neighbouring cells to calculate slope. In the next step, GRASS module r.cost is used to calculate the cumulative cost of traversing the slope map starting from the stream channel.

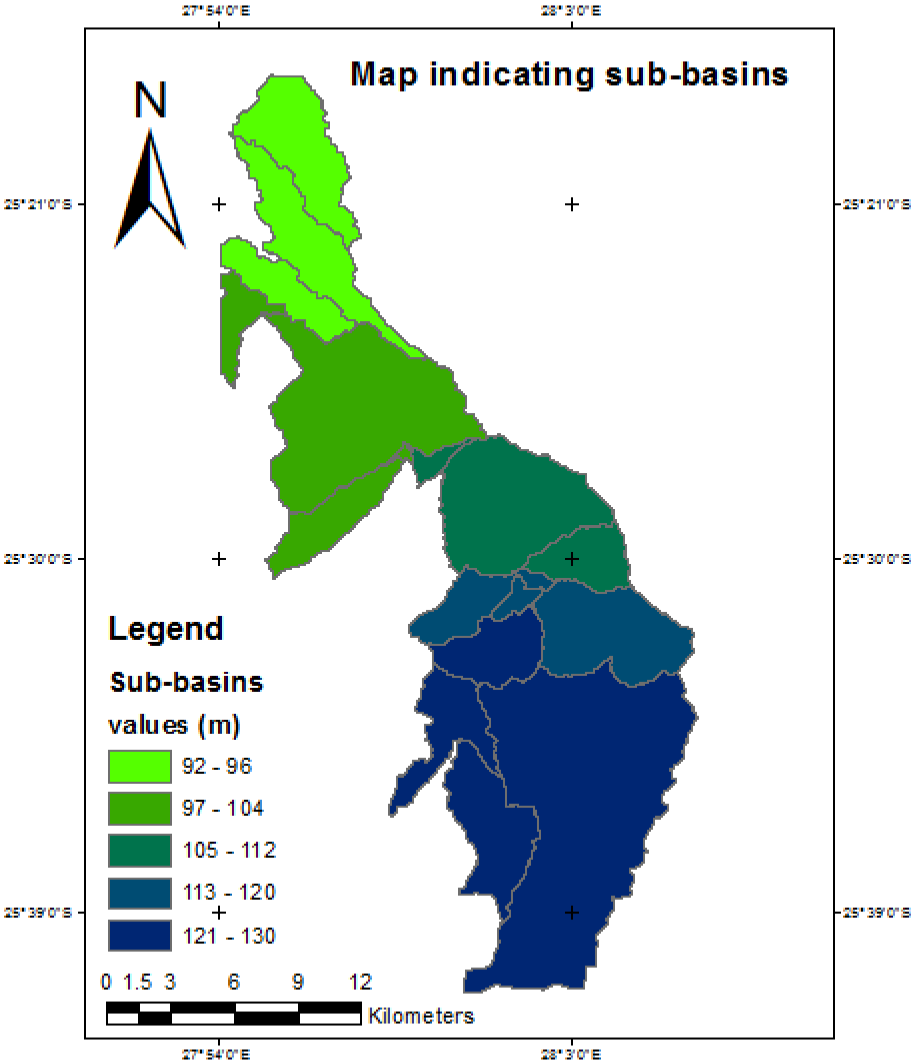


Figure 27: Map indicating the sub-basins surrounding the Jukskei River.

The value of the slope for a cell is the cost of traversing the cell. Cells with low values slope near the flood plain or stream channel will have lower total cost of traversing when compared to cells which are farther away from the stream. This cost will increase as steeper cells will be included with cells that are farther away from the floodplain. Figure 28 on page 96 shows the basin map, indicating the region which has been selected in order to find areas which are vulnerable to floods. Among the many such possible paths, water flows to the path of least resistance or lowest slope cost. The module r.cost produces a map containing the least cumulative cost of traversing each cell from the starting cell, which in this case, are the points on the stream.

The low-lying area has been identified based on the use of the stream network and the basin maps. In the example given for the Jukskei River, the threshold value is chosen as one-fourth the value of mean cost for the map. The resulting area matches quite well with the observations of affected areas, containing all the locations affected during the floods.

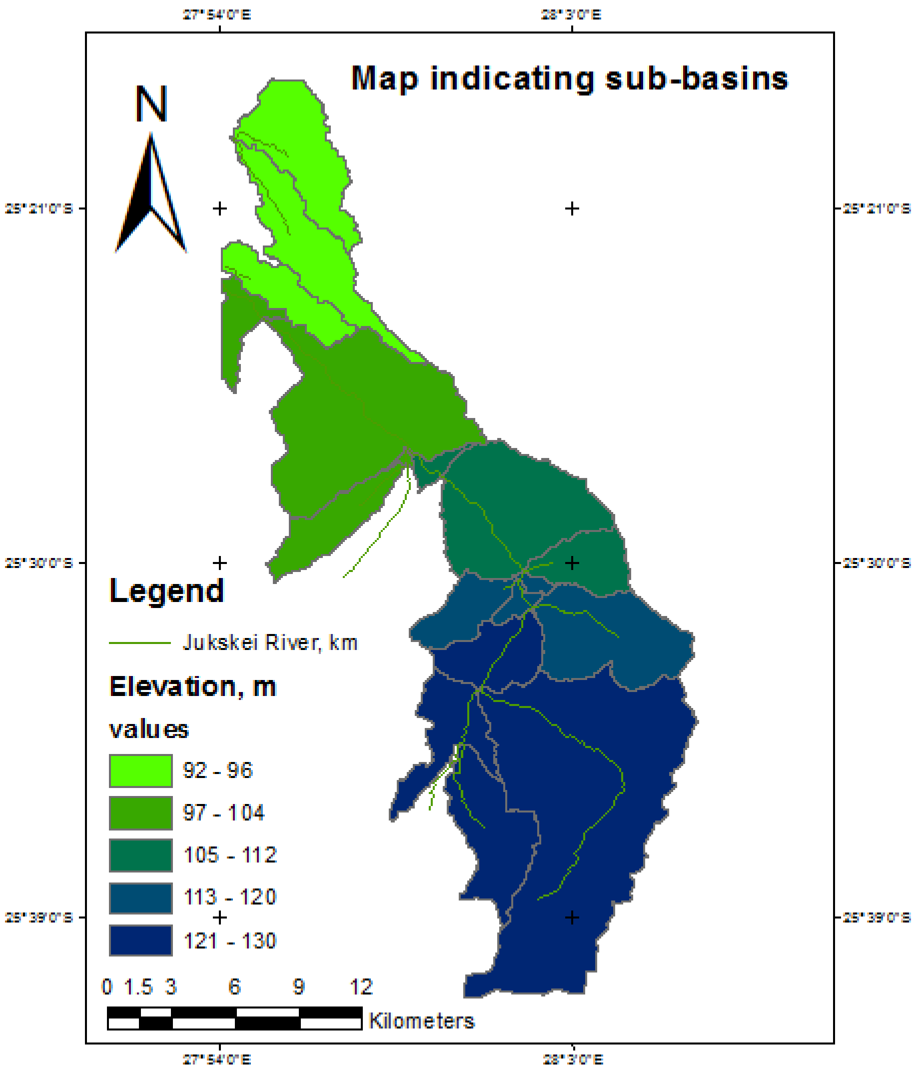


Figure 28: The basin map and stream, indicating the region which has been selected in order to find areas which are vulnerable to floods around the Jukskei River. The information required inthe basin map is controlled by the threshold which is found in the module r.watershed.

6.4 Access to sensor data, information and measurements

Figure 29 on page 97 shows an SOS ThinSweClient 2.0 accessing historical rainfall data in the form of time-series and in tabular form from the SOS service (Table 10 on page 98). Time-series data from the thinsweclient 2.0 can be accessed by using this

URL: http://localhost:8080/ThinSweClient2.0/?sos=http://146.64.28.249:8080/52nSOSv3_WAR/sos&offering=HOBART&stations=Jukskei1&procedures=urn:ogc:object:feature:Sensor:Jukskeistation&phenomenons=urn:ogc:def:phenomenon:OGC:1.0.30:waterlevel&begin=1983-09-09T19:40:16&end=1993-09-09T19:40:16 (Table 13 on page 97). The ThinSweClient 2.0 is a web based clients for SOS (Broring et al., 2009). The capabilities document, also referred to as service metadata, is only retrieved from SOS by the GetCapabilies operation. This will ensure that the clients get access to the information about the service. This also means that historical rainfall data and other information can be accessed from hydrological model by using sensor web technology.

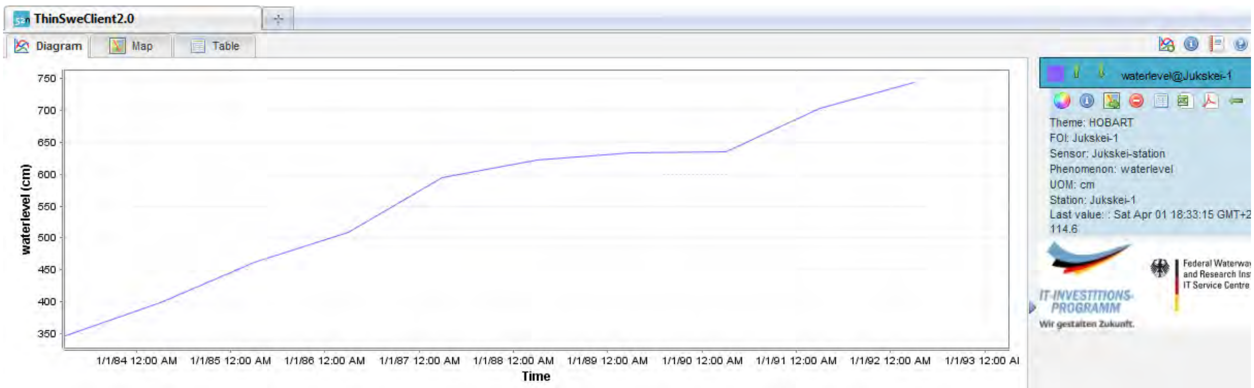
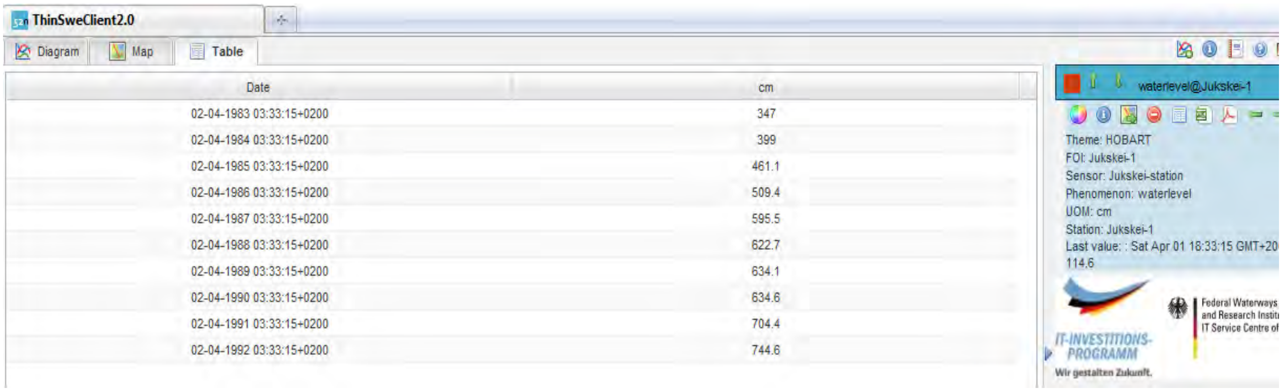


Figure 29: The time-series graph displayed in the form of a diagram.

Table 10: Time-series displayed in the form of a table.



Date	cm
02-04-1983 03:33:15+0200	347
02-04-1984 03:33:15+0200	399
02-04-1985 03:33:15+0200	461.1
02-04-1986 03:33:15+0200	509.4
02-04-1987 03:33:15+0200	595.5
02-04-1988 03:33:15+0200	622.7
02-04-1989 03:33:15+0200	634.1
02-04-1990 03:33:15+0200	634.6
02-04-1991 03:33:15+0200	704.4
02-04-1992 03:33:15+0200	744.6

Therefore, the 52north was used to build a SOS server, which will help to provide the rainfall data and other information over the Jukskei River. The 52north is a source of all implementation of all SWE standards (Jirka and Echterhoff, 2009). It is an open source which is based in Muenster, Germany. The server for providing the SOS capabilities is available through this URL (http://146.64.28.249:8080/52nSOSv3_WAR/). The output of the SOS comes as the xml document in the special scheme specified by the SOS reference document. Results are described by the standard in two different forms that include observation and measurement. The observation form is more suitable for the long time-series homogeneous data. The measurement form is more suitable in a situation where the SOS returns a small amount of the heterogeneous data.

The three tested core capabilities requests (DescribeSensor, GetCapabilities and GetObservation) all produced the expected results. Table 11 on page 98 shows the results that were found when the GetObservation performed, depicting 11 observations. This means that the sensor system has been queried and the observations retrieved in the format defined in the O and M specification by GetObservation.

Table 11: Shows the results of GetObservation when the insert observation is executed.

```
<swe:values>
1983-04-01T18:33:15-07,Jukskei-1,347,12;
1984-04-01T18:33:15-07,Jukskei-1,399,12;
1985-04-01T18:33:15-07,Jukskei-1,461.1,12;
1986-04-01T18:33:15-07,Jukskei-1,509.4,12;
1987-04-01T18:33:15-07,Jukskei-1,595.5,12;
1988-04-01T18:33:15-07,Jukskei-1,622.7,12;
1989-04-01T18:33:15-07,Jukskei-1,634.1,12;
1990-04-01T18:33:15-07,Jukskei-1,634.6,12;
1991-04-01T18:33:15-07,Jukskei-1,704.4,12;
1992-04-01T18:33:15-07,Jukskei-1,744.6,12;
1993-04-01T18:33:15-07,Jukskei-1,768.5,12;
</swe:values>
```

When the SOS receives the GetObservation request, the SOS then returns an exception that shows an error or satisfies the request. In this case, the request has been satisfied. The GetObservation consists of 12 components which include offering a logical arrangement of observations, feature of interest, request, service, srsName, resultModel, result, procedure, event time, version, respond format, observed property (Mckenna, 2007). This means that the sensor data encoded in the O and M was successfully requested and described in a standardised way, as O and M give us concrete encoding rules on how our sensor data described the method as observation or measurement.

The sensor web technology differs from remote sensing techniques. In remote sensing, the catchment can be observed over time in a finite schedule while the data stream in a sensor web provides information on a continuous basis for tracking the motion of the surface water (Delin et al., 2005). The temporal and spatial pattern of the surface water can be monitored and predicted and the results can be incorporated in hydrological models (Delin et al., 2005). This means that the sensor web can ground-truth and augments the traditional use of remote sensing data in hydrological studies.

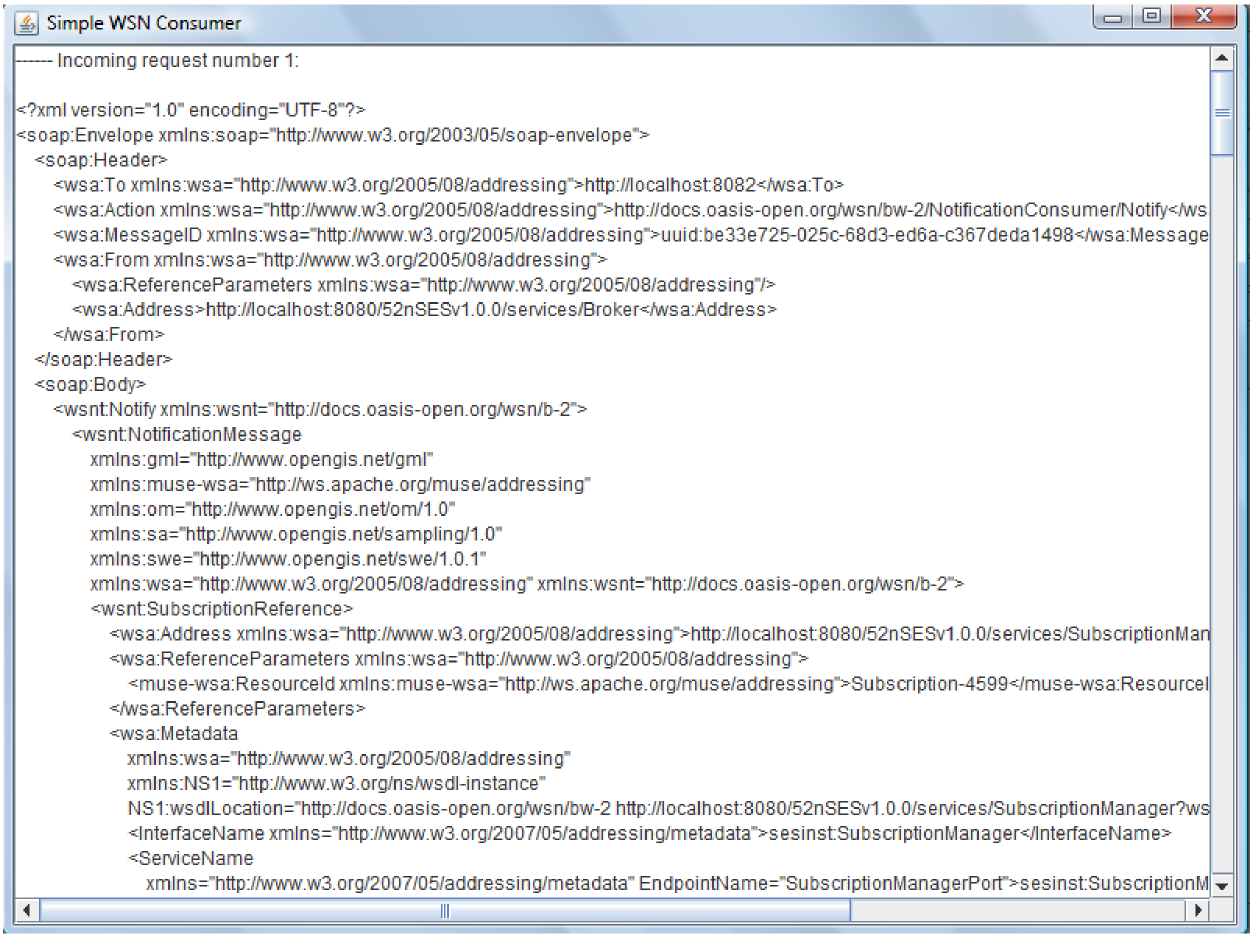


Figure 30: The request notification in the text window of the local simplewnsconsumer from the SES.

Local weather conditions, flight schedules and orbital paths as compared with continuous data collected by the sensor web (Rucker et al., 2004) restrict the remote sensing data. Therefore, the remote sensing measurements can also be compared with the in-situ data from the sensor web to provide the ground-truth. The deployment of sensor web in a recharge catchment is not just a function of a test for technology. It is a function of a scientific instrument in the use of hydrology (Delin et al., 2005). As shown in this research, the sensor web provides a significant spatio-temporal data, which is required to predict and monitor phenomena such as floods. Therefore, the sensor web has a major potential in changing the way in which the floods are predicted and monitored in the urban areas. Figure 30 on page 99 shows the incoming requests or notifications, which are received in the Simple Wireless Sensor Network (WSN) Consumer. Subscribers who subscribe to receive notifications when the level of water is above 769 cm from the local simplewnsconsumer of the SES, receive the above-mentioned requests. In this study, this means that if the level of water is above the mentioned threshold, there is a high possibility of floods. After the successful installation of the PostgreSQL, PostGIS, Tomcat 6.0, JRE 6.0 and the 52nSOSv3_WAR file, it has been found that the executed test.sql was successful in yielding the results (See Table 12 on page 100). This is a good indication that the properties in the table were well configured. Other SOS client was used successfully to access metadata of the time-series (Table 13 on page 100).

Table 122: Sensor data which can be accessed through the ThinSWEclient 2.0 pdf on the SOS.

Date	waterlevel (cm)
1983-04-02T03:33:15+02	347.0
1984-04-02T03:33:15+02	399.0
1985-04-02T03:33:15+02	461.1
1986-04-02T03:33:15+02	509.4
1987-04-02T03:33:15+02	595.5
1988-04-02T03:33:15+02	622.7
1989-04-02T03:33:15+02	634.1
1990-04-02T03:33:15+02	634.6
1991-04-02T03:33:15+02	704.4
1992-04-02T03:33:15+02	744.6

Table 133: Metadata of the Time-series.

Sensor Location	Jukskei-1
Sensor Phenomenon	waterlevel
Sensor Type	Jukskei-station

7. Discussion and Conclusion

The purpose of this research project was to find out if the sensor web technology helps in monitoring and prediction of floods in the Alexandra Township, particularly in the area close to the Jukskei River. The hypotheses tested in this research were “sensor web technologies help in the prediction and monitoring of floods in the urban area” and “Disaster Management officials can effectively disseminate information and data to the affected people by using sensor web technology”. Results obtained in this research confirm that the tested hypotheses must be accepted. Sensor web technologies have both the capabilities of describing the sensor that is gathering the data, capabilities of obtaining the observations and the capabilities of inserting the observations within the time the event is taking place. Sensor data is easily obtained through the server.

Three tested capabilities requests (DescribeSensor, GetCapabilities and GetObservation) all produced the expected results that were found when the GetObservation was performed. This means that the sensor system has been queried and the observations retrieved in the format that has been defined in the O and M specification by GetObservation. The DescribeSensor provides Disaster Management officials and residents with detailed information about the platforms that carry sensors that are making measurements. The GetCapabilities provide Disaster Management officials and residents with the means of accessing SOS service metadata. The GetObservation provides Disaster Management officials and residents with access to measurement data and sensor observations through spatial and temporal query which are filtered by phenomenon.

The SOS makes the access to water level data measured by the rain gauge possible. This is because the SOS is directly linked to the database or sensors, meaning that the available infrastructure transfers data from a sensor to a server (Figure 31 on page 102). The standardised interface of the SOS has been used to make the sensor data available. When the SOS receives the GetObservation request, the SOS then returns an exception or satisfies the request and in this case, the request has been satisfied. The GetObservation consists of 12 components that include offering, a feature of interest, request, service, srsName, resultModel, result, procedure, event time, version, respond format, observed property (Mckenna, 2007). What this entails is that the sensor data encoded in the O and M were successfully requested and were described in a standardised way because O and M give us concrete encoding rules on how our sensor data is described, whether as observation or measurement. This means that Disaster management officials and residents can be able to access water level data.

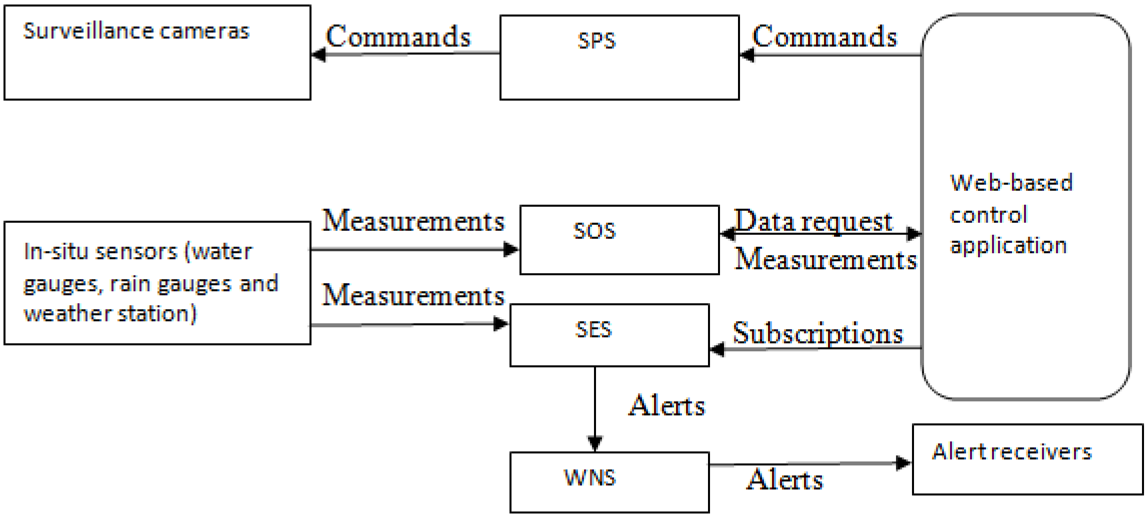


Figure 31: Conceptual sensor web concept for flood warning and monitoring system (Jirka et al., 2009).

The HEC-HMS 3.5 model was used to generate flood hydrographs. This was done by estimating the peak discharge in the Jukskei catchment. The historical rainfall data used as input in the model was acquired from SAWS. In the process of calibration, the two sets of historical rainfall data were used, including the years 1983 to 1993 and the years 1990 to 2000. After the process of calibration, the peak discharge results from the years 1983 to 1993 were 3644.8 m^3/s and for the years 1990 to 2000 the results were 3277.4 m^3/s. Through the hydrological model HEC-HMS 3.5, observed peak discharge and simulated peak discharge from the flood hydrographs were compared.

The comparison was based on three criteria that include shape of the flood hydrographs, observed and the predicted peak discharge from the flood hydrographs. It was found that from the years 1983 to 1993, the observed peak discharge of 1000 m3/s was less than the predicted discharge of 3644.8 m^3/s with the percentage error of 2.6%. The observed peak discharge obtained from 1990 to 2000, of 975.87 m^3/s, was also less than the predicted discharge of 3277.4 m^3/s with the percentage error of 235.8%. The high predicted peak discharge from the flood hydrographs can be attributed to high rainfall intensity or low rainfall intensity with long duration. As a percentage error of 2.6% the discrepancies seem quite low from the years 1983 to 1993.

The low discrepancies between the observed and predicted peak discharges from the years 1983 to 1993 can be attributed to high network of rain gauges that were available. The high discrepancies of 235.8% between the observed and predicted peak discharges from the years 1990 to 2000 can be attributed to the results of poor network of rain gauge available. The discrepancies between the observed and predicted flood hydrographs for 1983 to 1993 years and 1990 to 2000 years can be attributed to the results of poor network of rain gauge available than HEC-HMS 3.5. This is because there is no rain gauge in Alexandra Township except in the near suburb of Waterval. The network of rain gauge needs to be increased around the Jukskei River.

An effective communication system is needed to deliver notifications or warning messages to the people of Alexandra Township. The message needs to be simple and reliable to be understood by Disaster Management officials and the people in Alexandra Township. If prediction of the water level exceeds a threshold value or a certain level of the flood monitoring station, an SMS notification is sent to alert mobile phone clients in the Alexandra area where the flood is taking place. Mobile phone users send text messages to ask information about impending flood by using a unique name or station code from the monitoring station. Data, information and notifications about the flood event can be accessed by using sensor web technology

Flood is a natural hazard. It affects people around the world. Floods cause more damage to properties, displace people and result in loss of lives. In many countries, hydrological models and alert system were introduced to predict and monitor floods. However, these hydrological models and alert systems that include TV, radio and loudspeakers are not effective as preventative measures because of poor flood prediction and monitoring. They mostly support coverage of the event when it already happens. While the sensor web technology provides Disaster Management officials and residents with flood alert notifications when they are happening. This also means that historical rainfall data and other information about flood can be accessed from hydrological models by using sensor web technology. This is achieved by using the ThinSweClient 2.0 to access the historical rainfall data from the SOS server.

The SES is used to send flood warning notifications via SMS to Disaster Management officials. SMS is a text message service, which allows mobile phone users to exchange text messages among mobile devices. The SMS text messages consist of numbers, words or a combination of alphanumeric values. Sensor web can send messages to multiple mobile phone users, the SMS messages are in English, although the most frequently spoken language in Alexandra Township is IsiZulu. The details that are provided by SMS messages include time, water level of the floods and where the people can relocate to.

Updated data and additional information about floods is easily accessible from the sensor web compared to hydrological models, which need the knowledge of experts. Updated data and additional information about floods is transferred to SES which filters incoming sensor data according to alerts criteria specified by Disaster Management officials and residents. The specification of these alerts criteria through Disaster Management officials and residents is made by using a web-based form. In this web-based form, Disaster Management officials and residents will specify the alerts conditions in which they are interested in. For example, I want to get alerts if the level of water at a certain rain gauge is above 100 cm. The web-based form allows Disaster Management officials and residents to define the channels of communication to which the alerts will be sent. For example, send an email to a certain address or SMS to mobile phones.

Therefore, if the alerts conditions that match are found by the SES, alerts are dispatched. This is done by sending notification requests to WNS which then relays to alerts to the communication end-point specified. Since Alexandra Township is a remote area, surveillance cameras are used for control mechanism. By using surveillance cameras, it is necessary to focus the cameras to the details which Disaster Management officials and residents are interested in.

In conclusion, it is important to use the sensor web to help in the prediction and monitoring of the floods in urban areas such as the Alexandra Township. The sensor web will enable Disaster Management officials and Alexandra Township residents living on the banks of the Jukskei River to receive early alerts and other essential information about natural hazards such as floods that can endanger their livelihoods. Residents from the Alexandra Township and Disaster Management officials who subscribe to get flood warning notifications when the water level of the Jukskei River reaches a certain threshold value, are able to evacuate the area before flooding occurs. This dissertation has proposed a suitable flood prediction and monitoring system by using the sensor web technology, where flood-warning notifications via SMS will be used to warn people before and during times of floods in Alexandra Township.

The local simplewnsconsumer subscribes for flood events and SES publishes their events. When the flood events match, flood-warnings are sent to Disaster Management officials and Alexandra Township residents. Officials define threshold value against observed data and if threshold value and observed data match, flood warnings are sent to residents and officials.

One advantage of using the sensor web is that, if a mobile phone is switched off, a text message would not get lost and it will be forwarded when a mobile phone is switched on again. Sending SMS text messages to a mobile phone for flood alerts to residents in the Alexandra area is based on an effective flood prediction mechanism. It becomes an efficient method for flood alerts because the mobile phone network is established and many people already own mobile phones.

8. Recommendations

The SWE services need maintenance functionality, which can be used to find sensors that are not functioning properly. The SES specification is still in the process of becoming a fully-fledged standard. Even though the SES has sufficient capabilities for flood prediction and monitoring, there are still some aspects which need extensions. The SES extensions required are only related to the capabilities of filtering. These extensions include linking and aggregating of alert conditions, supporting of all operations used in comparison such as ≤ and ≥, temporal filtering and more complex spatial filtering such as the use of complex polygons.

Further work needs to be done on the integration of different sensors in the SWE components or architecture. Currently, this is not yet well specified as to how different sensors are linked with the SWE services except via the SOS transactional profile approach. This is a very challenging and complex task because of heterogeneity of sensor network technology and sensors. This challenge can be overcome by providing guidelines on how the SWE components, sensor network and sensors are linked among and to each other. Therefore, further research on sensor network maintenance, creating profiles for SWE standards, solutions to facilitate the integration of sensors, enhancement for filtering capabilities of sensor data and solutions for sensor discovery are needed.

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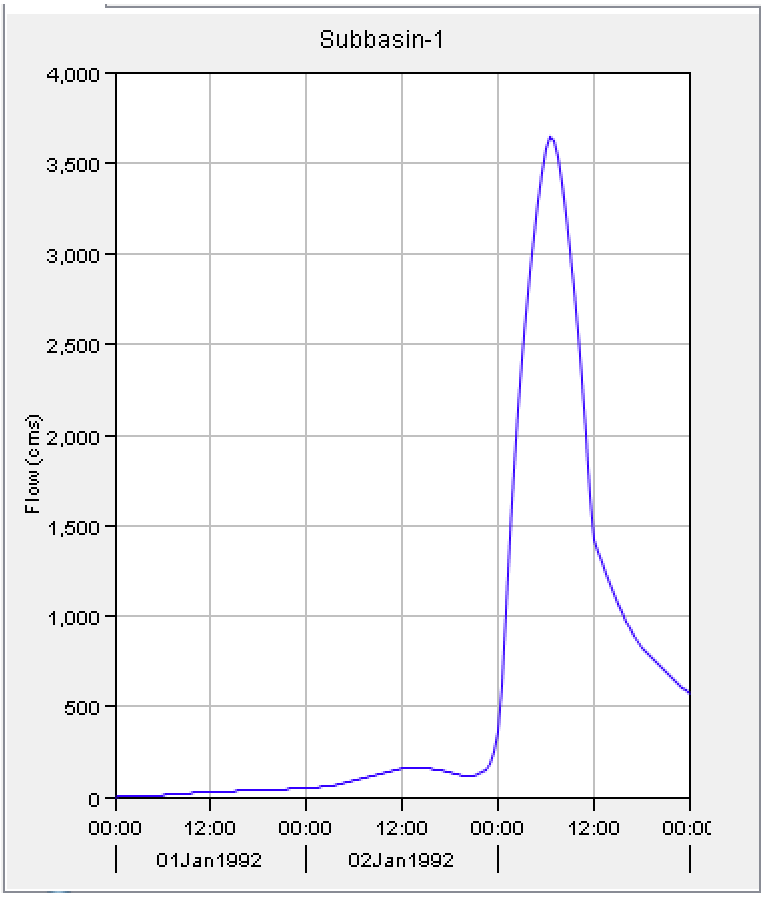
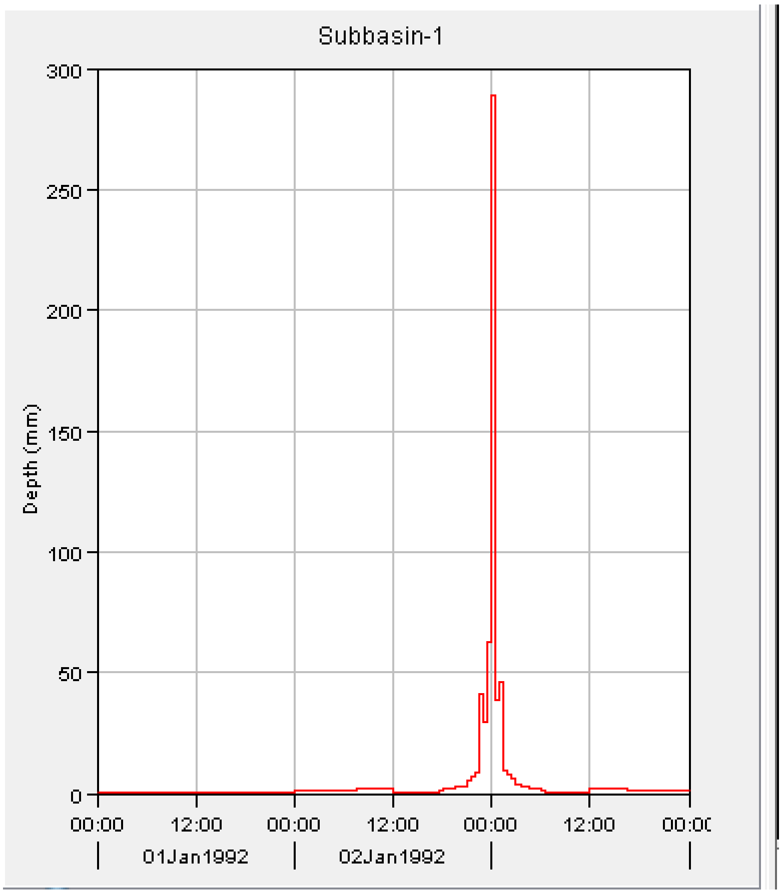
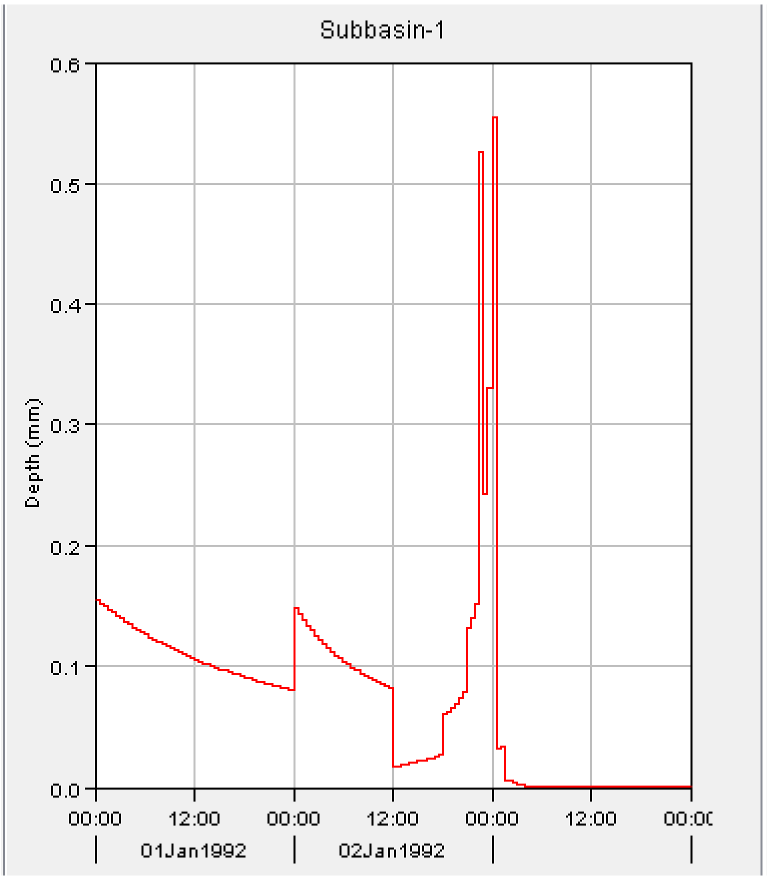
APPENDICES

Appendix A: The generated hydrographs which indicate precipitation loss, precipitation and runoff.




Subbasin-1
Depth (mm)
300
250
200
150
100
50
0
00:00
12:00
00:00
12:00
00:00
12:00
00:00
01Jan1992
02Jan1992


Subbasin-1
Depth (mm)
0.6
0.5
0.4
0.3
0.2
0.1
0.0
00:00
12:00
00:00
12:00
00:00
12:00
00:00
01Jan1992
02Jan1992

Appendix B: Three core-capabilities of the Sensor Observation Service of the sensor web.

The functionalities and operations of the SOS are divided into extensions and core. The core consists of its mandatory operations that include DescribeSensor, which is used in the querying of the sensor description (Figure 1). GetObservation is used in the accessing of observations or measurements (Figure 3). GetCapabilities is used in the retrieving of metadata service together with its content (Figure 2).

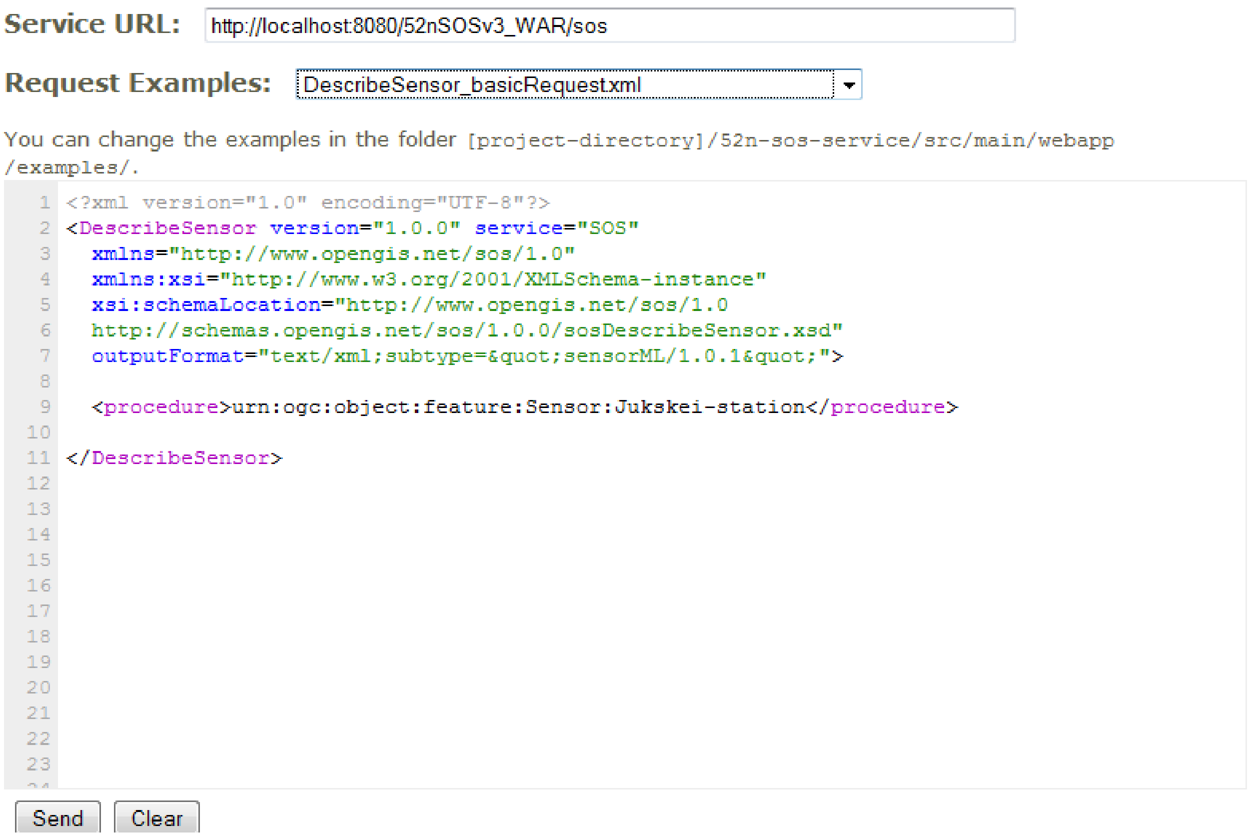


Figure 1 The DescribeSensor Capability.

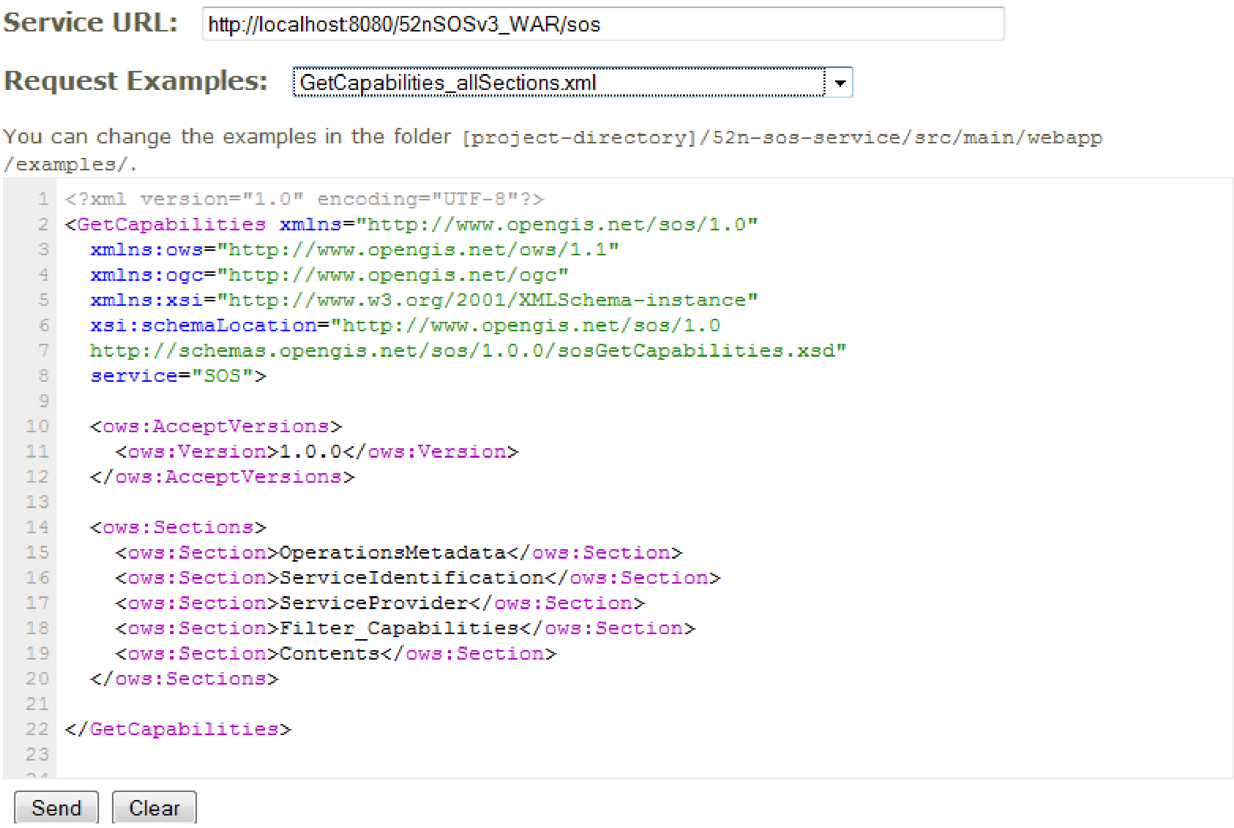


Figure 2 The GetCapability.

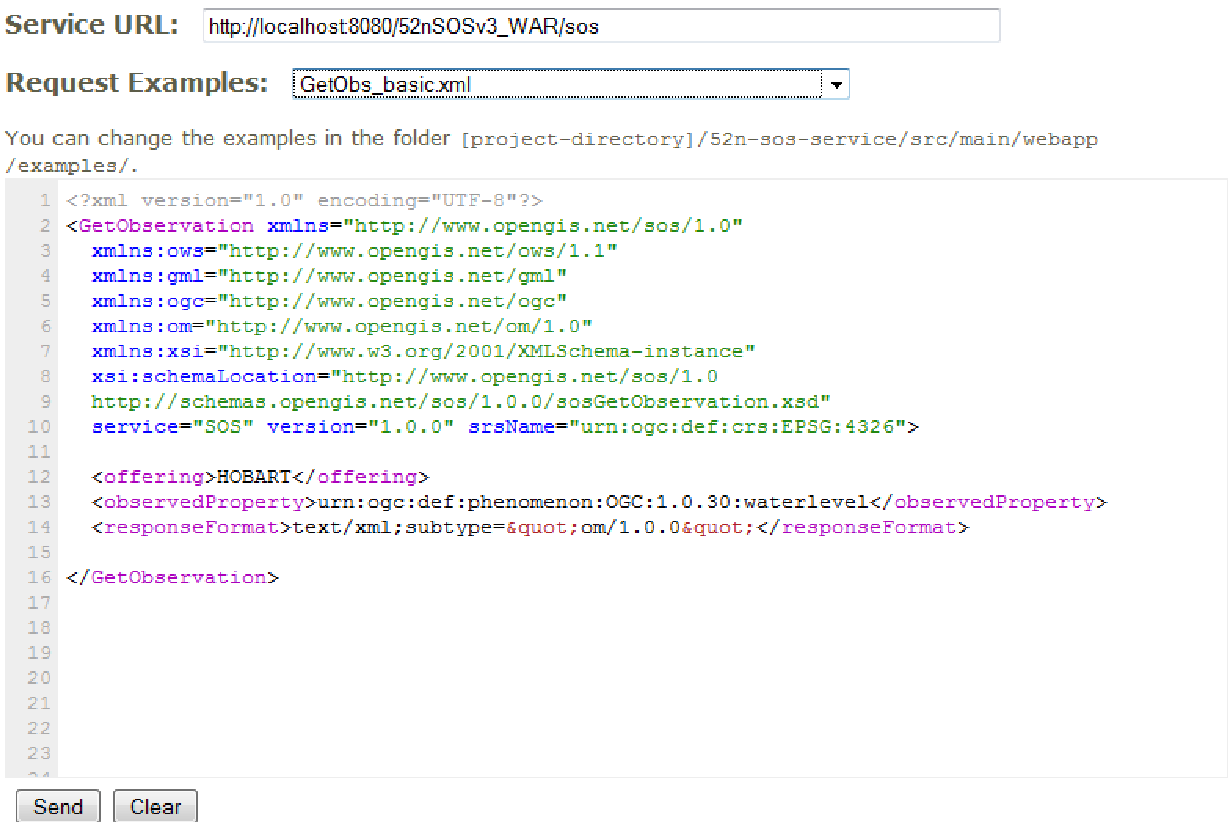


Figure 3 The GetObservation Capability.

Appendix C: Scripts which were used to analyse SRTM DEM in order to find the Jukskei catchment.

```
> v.to.rast input="jukskei@PERMANENT" layer=1 type="point,line,area" o\
  utput="jukskei" use="attr" column="area" value=1 rows=4096
```

```
> d.rast MASK
```

```
> r.mapcalc ''MASK=if(srtmgdem>0,1, null())''
```

Calculating the area of the watershed

```
> d.what.vect
```

Converting watershed map to watershed divide

```
> r.to.vect input=jukskei1_dem output=basin_jukskei
```

Watershed creation

```
> r.water.outlet drainage=basin_jukskei

basin=basin_outlet easting=27.5558 northing=25.5046
```

Visual rendering of output maps

```
> d.rast basin_jukskei
```

Choosing a point on the stream over which the watershed area will be estimated.

```
r.watershed elevation="jukskei1_dem" drainage="drainage_jukskei" bas\   |

|    in="basin_jukskei" stream="stream_jukskei" visual="visual_jukskei" t\   |
```

Appendix D: The two xml scripts which were obtained by running the sensor web technology.

```xml
<om:result>
 <swe:DataArray>
  <swe:elementCount>
   <swe:Count>
    <swe:value>2</swe:value>
   </swe:Count>
  </swe:elementCount>
  <swe:elementType name="Components">
   <swe:SimpleDataRecord>
    <swe:field name="Time">
     <swe:Time definition="urn:ogc:data:time:iso8601" />
    </swe:field>
    <swe:field name="feature">
     <swe:Text definition="urn:ogc:data:feature" />
    </swe:field>
    <swe:field name="waterlevel">
     <swe:Quantity definition="urn:ogc:def:phenomenon:OGC:1.0.30:waterlevel">
      <swe:uom code="cm" />
     </swe:Quantity>
    </swe:field>
    <swe:field name="temperature">
     <swe:Quantity definition="urn:ogc:def:phenomenon:OGC:1.0.30:temperature">
      <swe:uom code="Cel" />
     </swe:Quantity>
    </swe:field>
   </swe:SimpleDataRecord>
  </swe:elementType>
  <swe:encoding>
   <swe:TextBlock decimalSeparator="." tokenSeparator="," blockSeparator=";" />
  </swe:encoding>
  <swe:values>
  1991-09-09T19:40:16-09,Jukskei-1,72.57,12;
  </swe:values>
 </swe:DataArray>
</om:result>
```

```xml
 -<om:Measurement gml:id="o_3">
  -<om:samplingTime>
   -<gml:TimeInstant xsi:type="gml:TimeInstantType">
      <gml:timePosition>2008-04-01T17:46:00.000+02:00</gml:timePosition>
    </gml:TimeInstant>
   </om:samplingTime>
   <om:procedure xlink:href="urn:ogc:object:feature:Sensor:IFGI:ifgi-sensor-1"/>
   <om:observedProperty xlink:href="urn:ogc:def:phenomenon:OGC:1.0.30:waterlevel"/>
  -<om:featureOfInterest>
   -<sa:SamplingPoint gml:id="foi_1001">
      <gml:name>ALBER</gml:name>
     -<sa:position>
      -<gml:Point>
         <gml:pos srsName="urn:ogc:def:crs:EPSG:4326">52.9 7.52</gml:pos>
       </gml:Point>
      </sa:position>
    </sa:SamplingPoint>
   </om:featureOfInterest>
   <om:result uom="cm">70.4</om:result>
  </om:Measurement>
 </om:member>
-<om:member>
 -<om:Measurement gml:id="o_2">
```

Appendix E: The script used to determine the low-lying area which is vulnerable to floods.

```
GRASS 6.4.1 (jukskei_River):~ > ps.map out=mepp7<<EOF

> raster jukskei1_dem

> vlines rast_vect

> color blue

> label jukskei_stream

> end

> vareas basin_jukskei1

> color red

> fcolor red

> width 2

> label catchment area vulnurable to floods

> end

> vlegend

> end

> text 45% 75% Jukskei River

> font Helvetica-BoldOblique

> fontsize 14

> ref right

> end

> EOF

Scale set to 1 : 427655.

Reading raster map <jukskei1_dem in PERMANENT> ...

Reading vector map <basin_jukskei1 in PERMANENT> ...

Reading vector map <rast_vect in PERMANENT> ...

Reading text file ...
```

PostScript file [mepp7] successfully written