# FLOOD MODELLING FOR SMALL URBAN CATCHMENT OF SUNGAI RAJA, ALOR SETAR, KEDAH

**by**

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## LIST OF ABBREVIATIONS

| | |
|---|---|
| AI | Artificial Intelligence |
| ARI | Annual Return Period |
| ADID | Agriculture Drainage and Irrigation Division |
| CN | Curve Number |
| CRED | Center for Research on the Epidemiology of Disasters in Brussels |
| DEM | Digital Elevation Model |
| DTM | Digital Terrain Model |
| DID | Department of Irrigation and Drainage |
| ET | Expression Tree |
| ESRI | Environmental Systems Research Institute |
| FMS | Flood Management System |
| GIS | Geographic Information System |
| GA | Genetic Algorithms |
| GP | Genetic Programming |
| GEP | Genetic Expression Programming |
| HEC | Hydrologic Engineering Centers |
| HEC-HMS | Hydrologic Engineering Centers – Hydrologic Modeling System |
| HEC-RAS | Hydrologic Engineering Centers – River Analysis System |
| HEC-DSS | Hydrologic Engineering Centers - Data Storage System |
| HEC-DSSVue | Hydrologic Engineering Centers Data Storage System Visual Utility Engine |

| | |
|---|---|
| HSG | Hydrologic Soil Group |
| IDF | Intensity Duration Frequency |
| IS | Insertion Sequence |
| LiDAR | Light Detection and Ranging |
| LULC | Land use and land cover |
| MADA | Muda Agricultural Development Authority |
| MSMA | Manual Saliran Mesra Alam/ Urban Stormwater Management Manual |
| NRCS | Natural Resources Conservation Service |
| OFDA | United States Office for Foreign Disaster Assistance |
| RS | River Station |
| RIS | Root Insertion Sequence |
| SCS | Soil Conservation Service |
| TIN | Triangular Irregular Network |
| TR | Technical Release |
| USACE | United States Army Corps of Engineers |
| USDA | United Department of Agriculture |

## LIST OF SYMBOLS

| | |
|---|---|
| X | Magnitude of the flood |
| $\bar{x}$ | Average flood magnitude |
| S | Standard deviation of flood magnitudes |
| G | Skewness coefficient |
| $G_g$ | Generalized skew coefficient |
| P | Total storm rainfall |
| Q | Discharge |
| Q | Runoff |
| F | Infiltration |
| $I_a$ | Initial Abstraction |
| S | Potential abstraction |
| $P_e$ | Effective Storm |
| $T_r$ | Recurrence Interval |
| R | Probability |
| R | Coefficient of correlation |
| $R^2$ | Coefficient of determination |
| Ha | Hectares |
| MCM | Million cubic metre |

**PEMODELAN BANJIR DALAM TADAHAN KECIL BANDAR DI SUNGAI RAJA, ALOR SETAR, KEDAH**

**ABSTRAK**

Malaysia ialah salah satu negara yang menghadapi kemungkinan masalah banjir disebabkan pembangunan yang pesat, pengurusan sungai yang tidak mantap dan perubahan iklim. Pemodelan banjir telah dijalankan di Bandar Alor Setar iaitu Sistem Sungai Raja. Kawasan kajian adalah cenderung kepada banjir kerana berkeadaan rata dan mempunyai paras permukaan bumi yang rendah. GEP telah digunakan di dalam kajian ini dan analisis data hujan untuk setiap jam menunjukkan data dari MSMA 2 boleh digunakan untuk simulasi. Gabungan model hidrologi dan model hidraulik talah digunakan dalam kajian ini dengan bantuan perisian ArcView GIS. ArcView GIS telah digunakan untuk menyediakan data-data geometri yang diperlukan oleh HEC-RAS dan menyediakan model basin yang diperlukan oleh HEC-HMS. Pemodelan hidrologi telah digunakan untuk menghasilkan hidrograf aliran daripada hujan yang akan digunakan sebagai input di dalam pemodelan hidraulik. Dua penentukuran yang mewakili musim hujan dan keadaan selepas hujan telah dijalankan. Satu senario telah dijalankan bagi meramalkan perubahan kesan tanah terhadap kelakuan banjir iaitu 80% sub-lembangan adalah membangun dan 20% diliputi tumbuh-tumbuhan. Keputusan menunjukkan peningkatan aliran puncak sebanyak 26% (11.3 $m^3/s$) dengan membandingkan keadaan guna tanah semasa. Tempoh hujan rekabentuk 1, 6, 12 dan 24 jam disimulasikan untuk kedua-dua 10 dan 100 tahun ARI. Keputusan dari simulasi berdasarkan ARI menunjukkan paras air adalah di

bawah paras tebing sungai bagi 10 dan 100 tahun 24 jam ARI dan 10 tahun 12 jam ARI manakala selebihnya melebihi paras tebing sungai. Daripada kajian ini, adalah disarankan agar dipertimbangkan menggabungkan kedua-dua pemodelan hidrologi dan hidraulik.dalam penyediaan pelan tebatan banjir Sungai Raja.

**FLOOD MODELLING FOR SMALL URBAN CATCHMENT OF SUNGAI RAJA, ALOR SETAR, KEDAH**

## ABSTRACT

Malaysia is among countries that faces potential flooding problems due to rapid development, improper river management and climate change. Flood modelling was carried out within the Sungai Raja Catchment in Alor Setar City. The study area is prone to flood due to its flat and low elevation. GEP was used for statistical analysis and hourly rainfall analysis shows that design rainfall from MSMA 2 is reliable to be used in simulation. Hydrologic and hydraulic models were used in this study with the assistance of ArcView GIS. ArcView GIS was used to develop geometric data files require by HEC-RAS and preparation of Basin Model required by HEC-HMS. Hydrologic modelling was used to produce the flow hydrograph from rainfall events, as an input in hydraulic modelling. Two calibrations to represent wet and after rain condition were carried out. In order to predict the impact of land use changes to flood behaviour for Sungai Raja System, a scenario was created for the model simulation which is 80% of a sub-basin is fully developed and 20 % is vegetated land use. The result shows the increase of the peak flow by 26% (11.31$m^3$/s) as compared to the present land use. Design storm durations for 1, 6, 12, and 24 hours were simulated for both 10- and 100-year ARI. The result shows that the water level for 10 and 100 year 24 hour event and 10 year 12 hour event are below the river bank, but the rest are overtopped the channel section. It is recommended to consider both hydrologic and hydraulic in the preparation of Sungai Raja flood mitigation plan.

# CHAPTER 1

# INTRODUCTION

## 1.1 Research Background

Urbanization involves large changes of land, air, energy resources, and human populations which is leading to a major ecological effects for urban habitats (Baschak and Brown, 1995). The urban environment influence all hydrological processes which is highly heterogenous in terms of land use, subsoil characteristics and other factors (Rodriguez et al., 2008). Urbanization has affected change to natural systems that tends to happen on land use and land cover.

Land use is described as a series of operations on land, carried out by humans, with the intention to obtain products and/or benefits through the usage of land resources. Land cover is described as the vegetation (natural or planted) or man-made constructions (buildings, etc.) which occur on the earth surface (Wyatt et al., 1997). Increasingly rapid industrialization in developed countries may increase the potential for natural disaster which is an indicator of unsustainable development. Urbanization in Asia has been occurring rapidly and will continue to do so in the foreseeable future (Wan and Kahn, 2014). Flood hazard in Malaysia is worsening largely because of rapid urbanization and development (Chan and Parker, 1996). Changes of land use affects the hydrological regime of streams considerably which decrease dry period flows and significant increase flood flows.

Flooding is one of the most visible hazard which happens once a while (Banasik et al., 2008). Transformation in hydrologic response because of natural or human induced causes can affect the storage characteristics of the watershed which will increase the rates of runoff and decreases the opportunity for infiltration. Therefore, the peak runoff will increase, time to peak will decrease, and the volumes of surface runoff will increase. With less infiltration, baseflow rate will most likely decline. The increase in flow velocity that accompany the increase in the runoff rate may be the main cause of flood damage.

The usual hydrologic-hydraulic results of urbanization are an increase in the volume of direct runoff, accompanied by a corresponding decrease in the volume of the base flow, and a decrease in runoff time. When population is increasing in urban area, more and more land is converted to residential, industrial and commercial area resulting in changes to local hydrologic condition and may affect hydrologic cycle. Flash floods are one of most hazardous weather related natural disasters in the world which can increase at a very rapid rate with little or no warning. These events are described to be a flood that happens within six hours of a rainfall event and as consequences, it will create risky circumstances for people and extensive damage to property (Knocke and Kolivras, 2007). The most important characteristic of flash floods is the extremely sudden onset. Factors contributing to this type of floods are rainfall intensity, rainfall duration, surface conditions and topography and slope of the receiving basin (Barredo, 2006).

Rainfall runoff modelling and flood discharge estimations have always been essential steps in hydrologic sciences and engineering especially flood flow estimation of the precise forecasts in the management of flood related emergency program. More than other concern in hydrology, the estimation of flood discharge is to save human lives and protecting people's property (Maidment and Djokic, 2000).

## 1.2 Study Area

The study area is prone to flood due to its flat and low elevation. Figure 1.1 shows an aerial view of flooding situation occurs at the study area (The Star, 2010). It is due to heavy rainfall for two straight days caused by tropical depression that forms in South China Sea, across Peninsular Malaysia (Malaysian Meteorological Department, 2010; Today Online, 2010). The study area covers Sungai Raja catchment which runs right in the middle of the Alor Setar City. Sungai Raja system (Figure 1.2) is a tributary of Sungai Kedah with catchment area of 2.7 $km^2$ and made up of two main tributaries (Sungai Derga and Alor Siam) and Sungai Raja as the main river. The total length of the rivers is about 4.3 km where Sungai Derga length is 1.8 km, Alor Siam is 1.5 km and Sungai Raja is 1 km respectively.

Figure 1.1 Flood situation at Bulatan Maal Hijrah, Alor Setar on 2010 (The Star, 2010)

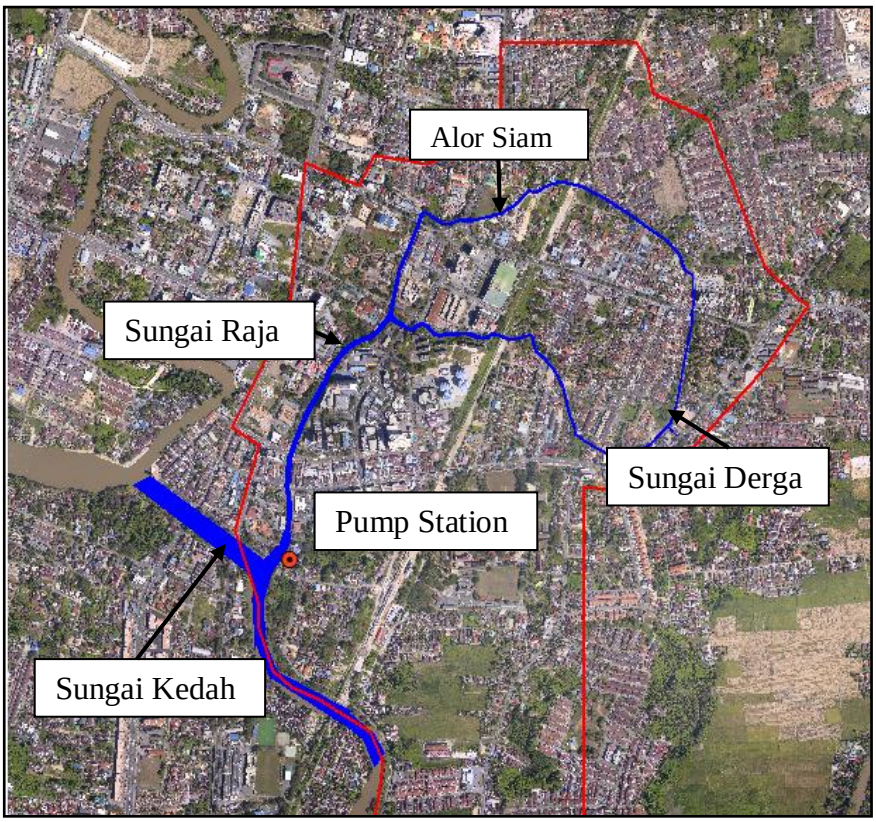


Figure 1.2 Catchment area of Sungai Raja where Sungai Raja System passes through the centre of Alor Setar City

In 1992, Department of Irrigation and Drainage (DID) carried out the Flood Mitigation Project to solve the flooding problems of Alor Setar City where the whole Sungai Raja system was converted to concrete lined channel. It was separated from Sungai Kedah by gated structure and pumping station (Ramli et al., 2011). Flows from the Sungai Raja catchment area are drained by gravity to a pump station (Figure 1.3) before being discharged to the Sungai Kedah.

(a)

(b)

Figure 1.3 (a) Pump station at Sungai Raja and (b) The weir and gates separate Sungai Raja System from the Sungai Kedah

## 1.3 Problem Statement

One of the reasons for water related problems in urban areas is the dynamic change of the land use due to rapid urbanization affecting the local hydrological processes. In developed areas, peak flows can be several times higher than they were in previous undeveloped condition (Desa, 1997). In urban areas, the impact can be very significant because the areas affected are densely populated and contain vital infrastructure. Water resources and urban flood management require hydrologic and hydraulic modelling.

## 1.4 Objectives

The aim of the research is to predict the impact of land use change on flood management by using hydrologic and hydraulics modelling. The specific objectives are:

(1) To construct a flood modelling system for Sungai Raja.

(2) To predict the impact of land use changes to flood behaviour for Sungai Raja system.

## 1.5 Scope of Work

The scope of work for this study consists of four stages. These stages are:

Stage 1: Establishment of GIS database for Sungai Raja catchment.

Stage 2: Hydrologic data collection, rainfall precipitation from MADA and DID Alor Setar, collection of available data relevant to the study and analysis of rainfall. It required input with data collected and field data information including cross section, geometry data, flow, rainfall data, and land use.

Stage 3: Execution of hydrologic modelling using HEC-HMS and hydraulic modelling using HEC-RAS with appropriate methods and procedures. These include model setup preparation, sensitivity analysis, calibration and validation processes. Calibrated parameter is used to simulate the impact of land use change to flood magnitude.

Stage 4: Result analysis and discussion

## 1.6 Thesis Outline

The thesis comprises of five chapters. Chapter 1 provides a brief of research background, problem statement, objectives of study and scope of work. Chapter 2 contains literatures that are relevant with research study includes flooding and urbanization, precipitation analysis, hydrologic and hydraulic models, GIS application in flood assessment and example of flood management system. Chapter 3 provides the method applied in order to complete the research study which is preparation of data and modeling using HEC-HMS and HEC-RAS. Chapter 4 explains the detail of the precipitation analysis annually, monthly, daily and hourly using GEP and linear regression and describes the process of sensitivity test, calibration, validation and model simulation. Chapter 5 summarizes the conclusions of study and suggestions for future study. References and appendices are enclosed at the end of the thesis.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

Floods are the most familiar natural disasters affecting many people across the world than all other natural disasters. It is also are the most costly in terms of human hardship and economic loss (Huang et al., 2008). Floods cause great damage around the world every year. Jonkman, (2005) reviewed from OFDA/CRED International Disaster Database, maintained by the Centre for Research on the Epidemiology of Disasters in Brussels (CRED) in cooperation with United States Office for Foreign Disaster Assistance (OFDA), in the last decade of the 20th century floods killed about 100,000 persons and affected over 1.4 billion people. The statistics prove that floods have huge impact on human well-being around the world and it may lead to economic damage and harms to eco-systems and historical and cultural values.

Flooding is described as a "temporary covering of land by water because of surface water escaping from their normal confines or due to overflowing of a body of water especially onto normally dry land. Floods vary in their duration, area, water-level, which is closely connected both with meteorological conditions and with local conditions of runoff formation (Kukharchyk, 2006; Whitfield, 2012). The major dissimilarity between types of flood is established by considering the size of the area involved and the length of the triggering precipitation event (Bronstert, 2003). The results produce extensive long lasting floods and local sudden floods (Barredo, 2006).

Flash floods express flooding in small catchments that is mainly caused by short and highly intensive precipitation such as thunderstorms. The warning time for these events is short and the length of the flood event is also short, but this type of flood is also often connected with severe harms where they have high velocities and tremendous erosive forces, and only extremely solid structures can endure their destructive force (Plate, 2002; Bronstert, 2003; Knocke and Kolivras, 2007).

### 2.1.1 Urbanization and Floods

Urbanization is one of the extreme cases of land use change. Although currently only 1.2% of the Earth's land is considered urban, the spatial coverage and density of cities are expected to rapidly increase in the future. It is expected to increase from 75% of people in developed countries in 2000 to 83% in 2030, while over the same period it will increase from 40% to 56% in less developed countries (Cohen, 2003; Shepherd, 2005; Jacobson, 2011).

Alterations in land use associated with urban development affect flooding in many ways. Removing vegetation and soil, grading the land surface, and constructing drainage networks increase runoff to streams from rainfall. Hence, the peak discharge, volume, and frequency of floods increase in streams. Changes to stream channels during urban development can limit their capacity to convey floodwaters. Roads and buildings constructed in flood-prone areas are exposed to increase flood risks, as well as inundation

and erosion, as new development continues can put local population at risk (Bronstert, 2003; Konrad, 2003; Banasik et al, 2008; Han and Burian, 2009; Nunes et al., 2009). Urbanization can contribute significant changes to the hydrological regimes of small catchments, bringing to flash floods. It can cause major damage and put local population at risk (Nunes et al., 2009; Doytsher et al., 2010). Therefore, urban problems associated with the hydrologic aspects of water management should become increasingly more sensitive.

Flood damage related to all types of harm because of flooding. It covers a wide range of harmful effects on humans. Effects of flood damage can be further classified into direct and indirect effects. Direct flood damage cover up all types of damage which relate to the immediate physical contact of flood water to humans, belongings and the surroundings. Indirect or consequential effects include damage, which happens as consequences of the flood and disruptions of economic and social activities. This harm can affect areas quite a bit larger than those actually inundated. Meanwhile the damage potential of flash floods is confined to the direct neighborhood of the river, the total damage usually is not very extensive even though due to the high velocities, the individual damage to structures or persons caught in such floods is very high ( Plate, 2002; Messner and Meyer, 2006).

Flood hazard mitigation can be divided broadly into structural and non-structural approaches according to whether engineering or administrative methods are used. Structural approaches are based on the keenness of humans

to control floods or protect human settlements meanwhile non-structural approaches are based on adjustment of human activities and human society to mitigate flood damage. These structural and non-structural strategies have been used together to form a flood mitigation program. Depending on a community's capacity, commitment and existing conditions, each community has adopted a different combination of mitigation policies (Plate, 2002; Schanze et al., 2006; Kang, 2009; Ab Ghani et al., 2012). An important step in this direction would be to overcome the existing lack of knowledge and lack of support of flood-prone households regarding their increased responsibility to contribute to private flood damage reduction (Bubeck, 2013).

### 2.1.2 Example of Case Study of Flood Modelling

A study by Martin et al. (2012) states that most floods in Uganda are due to torrential storms that result in bursting of river banks and thereby cause floods. In 2011, Sironko and the neighbouring Eastern districts, experienced floods from torrential rains and bursting of river banks that left many homeless and damaged property. Flood modeling can easily be accomplished using the readily available tools such as HEC-HMS/RAS and GIS tools. The study is to perform hydrologic and hydraulic analysis for river Sironko and prepare flood hazard maps for Sironko district.

Hydrological modeling was performed using HEC-HMS. The model output results were the quantified runoff floods that resulted from input

rainfall data. The 10, 50, 100, 250, and 500 year design storms (rainfall) of 96.93mm, 130.90mm, 145.54mm, 164.88mm, and 179.51mm data input into Sironko HMS models generated runoff (flood discharges) of 71.8$m^3$/s, 123$m^3$/s, 138.5$m^3$/s, 163.9$m^3$/s, and 183.4$m^3$/s magnitude respectively. Sironko RAS hydraulic model simulate the 10, 50, 100, 250 and 500 year floods of 71.8$m^3$/s, 123$m^3$/s,138.5$m^3$/s, 163.9$m^3$/s and 183.4$m^3$/s magnitudes respectively to determine the maximum channel flood depths for all river cross sections. The maximum channel flood depths were 5.21m, 6.53m, 6.84m, 7.31m and 7.65m for the simulated 10, 50, 100, 250, and 500 year design flood respectively.

The flood hazard maps for the 10, 50, 100, 250, and 500 year floods were generated as shown in Figure 2.1. From the flood hazard maps developed, the most prone area is Sironko river middle reach. Also some villages located in the flood plain would be affected more especially with 50, 100, 250 and 500 year floods.

## 2.2 Precipitation Analysis

Engineering studies of water resources development and management depend a lot on hydrological data. These data should be stationary, consistent, and homogeneous when they are used for frequency analyses or to simulate a hydrological system (Dahmen and Hall, 1990).

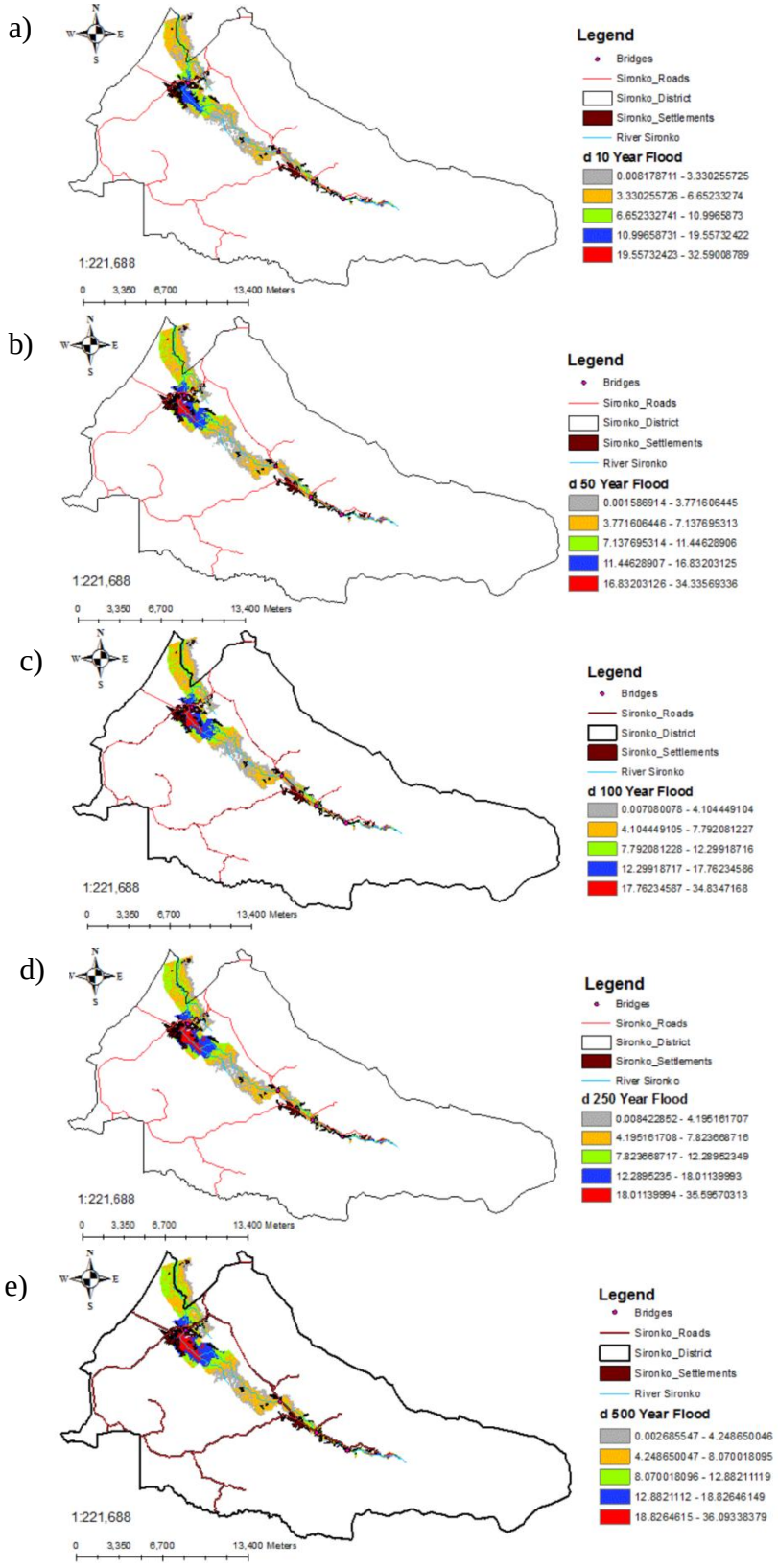


Figure 2.1 Sironko district flood hazard maps for a) 10 year flood b) 50 year flood c) 100 year flood d) 250 year flood e) 500 year flood

### 2.2.1 Checking the Consistency of Data

Hydrologic data generally consist of a sequence of observations of some phase of the hydrologic cycle made at a particular site. The data may be a record of the discharge of a stream at a particular rain gauge. Although most hydrologic preferred a long record to a short one but the longer the greater (DID, 2011).

All hydrological observations, including precipitation measurements contains errors and uncertainties (Aghakouchak et al., 2010). The continuity of a record may be broken with missing data because of many reasons for example damage or fault in rain gauge during a period. Missing data is the main problem happens in hydrological studies where precipitation record from a certain rain gauge is not complete throughout the year. This can be due to breakdown of a gauge, or the elimination of artefacts, such as brightband in radar rainfall images. The missing data can be estimated by using the data of the neighbouring stations (Shaw et al., 2011).

The double-mass analysis is a consistency check used to detect whether the data at a site have been subjected to significant change in magnitude due to external factors such as tampering of the instrument, change in the recording conditions, or shift in observation practices. The change due to meteorological factors will equally affect all stations involved in the test and thus will not cause a lack of consistency created by the external effects.

The analysis also provides a means of adjusting the inconsistent data (Ram, 1989).

### 2.2.2 Intensity Duration Frequency (IDF) Curves

The intensity duration frequency (IDF) curves of rainfall are a very important tool for hydrological planning. It has been used in design and construction of different structures in water management such as flood protection, sanitation networks and so on. The most common form of design rainfall data are IDF curves. IDF curves summarize conditional probabilities (frequencies) of rainfall depths or average intensities. Specifically, IDF curves are graphical representations of the probability that a certain average rainfall intensity will occur. The return period is the reciprocal of the probability that an event will be equaled or exceeded in any one year or other time unit (Bedient et al., 2008; Gaál and Hlavčová, 2010).

A critical features of IDF curves is that the intensities are indeed averages over the specified duration and do not represent actual time histories of rainfall. The contour for a given return period could represent the smoothed results of several different storms. To reiterate, IDF curves do not represent time histories of real storms where the intensities are averaged over the indicated duration; a single curve represents data from several different storms; the duration is not the duration of an actual storm and most likely represents a shorter period of a longer storm; and it is incorrect to use IDF

curves to obtain a storm event volume because the duration must be arbitrarily assigned. The preponderance of IDF information in the hydrologic literature is primarily a result of the need for IDF curves for use in the rational method (Bedient et al., 2008).

Empirical Equation 2.1 can be used to minimize error in estimating the rainfall intensity values from the IDF curves (DID, 2011).

$$i = \frac{\lambda T^{K}}{\left(d + \theta\right)^{\eta}} \tag{2.1}$$

where,

$i$ = average rainfall intensity (mm/hr)

$T$ = Average recurrence interval – ARI ($0.5 \leq T \leq 12$ month and $2 \leq T \leq 100$ year);

$d$= storm duration (hours), $0.0833 \leq d \leq 72$; and

$\lambda, \kappa, \Theta$ *and* $\eta$ = Fitting constants dependent on the rain gauge location

## 2.3 Statistical Method - Gene Expression Programming (GEP)

Since the early 1950s, Artificial Intelligence (AI) technology has developed from the interest of a few researchers to a valuable tool to support humans making decisions. The development of expert systems produced knowledge engineering, the process of building intelligent systems. AI is the field of computer science that deals with making machines behave in a way

that would generally be accepted as requiring human intelligence (Wurbs, 1994; Negnevitsky, 2011).

Genetic programming (GP), a branch of genetic algorithms (GA), is a method for determining the most "fit" computer program by artificial evolution. GP initializes a population consist of chromosomes, and the fitness of each chromosome is estimated regarding a target value. The individuals in the new generation are, in their turn, through a few developmental processes, such as expression of the genomes, confrontation of the selection environment, and reproduction with modification. The reproduction includes not only replication but also the action of genetic operators capable of creating genetic diversity. During replication, the genome is copied and transmitted to the next generation. So, in GEP, a chromosome might be modified by one or several operators at a time or not be modified at all (Holland, 1975; Ferreira, 2001 and 2006; Mohammad et al., 2011; Azamathulla and Ahmad, 2012;).

## 2.4 Hydrologic Modelling

Hydrologic modelling mostly involved the development of concepts, theories and models of individual components of the hydrologic cycle, such as overland flow, channel flow, infiltration, depression storage, evaporation, interception, subsurface flow, and base flow (Singh and Woolhiser, 2002; Nelson et al., 2004). A selected number of the most popular event, continuous, and urban runoff models for hydrologic simulation are listed in Table 2.1.

Table 2.1 Selected simulation models in hydrology (After Bedient et al., 2008)

| Model | Author | Date | Description |
|---|---|---|---|
| HEC-HMS | HEC | 1998,2006 | Hydrologic modelling system (replacing HEC-1) |
| HEC-RAS | HEC | 1995, 2006 | River analysis system (replacing HEC-2) |
| SCS-TR55 | USDA SCS | 1975 | Hydrologic simulation model |
| SWMM | Huber and Dickinson | 1971, 1988, 2005 | Storm water management model |

### 2.4.1 Hydrologic Engineering Centre - Hydrologic Modelling System (HEC-HMS)

The Hydrologic Modelling System (HMS) is intended to simulate the precipitation-runoff processes of dendritic watershed system and its design allows applicability in a wide range of geographic areas for solving diverse problems including large river basin water supply and flood hydrology, and small urban or natural watershed runoff. HEC developed several computer programs and methods to analyze and compute urban flood damage. One of the models is HEC-HMS. In HEC-HMS model, the hydrologic element objects are the main building blocks.

A watershed may be comprised of any number of Subbasins, Reaches, Junctions, or other components. Each hydrologic component object is linked to its associated neighbors to form a dendritic network (USACE, 1994 and 2010). Hydrographs produced by the program are used directly in conjunction with other software for studies water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood

damage reduction, floodplain regulation, and systems operation (USACE-HEC, 2010). The model consists of a rainfall-runoff module (SCS-CN method), a surface runoff routing module (Unit Hydrograph Method), a baseflow module (linear reservoir method), and a channel routing module (Muskingum-Cunge method).

Watershed hydrologic modelling and the associated model calibration and verification require a large set of spatial and temporal data (e.g, topography, land use/covers, soils, rainfall, and flow monitoring data) (Chu and Steinman, 2009). HEC-HMS program features a completely integrated work environment including a database, data entry utilities, computation engine, and results reporting tools. Time series, paired, and gridded data are stored in the Data Storage System (DSS) (Chu and Steinman, 2009; USACE, 2010).

HEC-GeoHMS extension and ArcView GIS were used to facilitate the tasks (USACE-HEC, 2003). By using HEC-GeoHMS, it is easier to create hydrologic inputs that can be used directly with HEC-HMS software. HEC-GeoHMS is a geospatial hydrologic modelling extension software package that uses a graphical user interface and is linked to the ArcView and Spatial Analyst GIS. HEC-GeoHMS uses DEM data to determine drainage paths and watershed boundaries and transforms them into hydrologic data structures representing the watershed response to rainfall events. The current version of HEC-GeoHMS creates a background map file, lumped basin model, grid-cell parameter file for use in running the HEC-HMS hydrologic model (Ogden et

al., 2001). Using GIS as a preprocessor can accelerate the building of an HMS model. The GIS's ability can extend beyond processing the terrain model to performing spatially intensive analysis for development of grid-based parameters. The result produced by GIS for HMS can be controlled somewhat by focusing on the GIS's description of the landscape characteristics and stream networks (Maidment and Djokic, 2000).

### 2.4.2 Application of HEC-HMS Model

Al-Abed et al. (2004) state that Jordan is part of the arid and semi arid region of the Middle East, where water resources are recognized to be limited. Hydrological simulation models interfaced with Geographical Information Systems (GIS) were used as a water management tool to study the Zarqa River basin, the largest river basin in Jordan.

The hydrological modelling system is to simulate the rainfall-runoff process of watershed systems. It is a continuous, distributed parameter, watershed scale model that stimulates large river basin water supply and flood hydrology and small urban or agricultural watershed runoff. In this model, there were three main types of needed input:

a) Loss rate method which is SCS Curve Number was selected
b) Transform method, Synder Transform selected
c) Baseflow of which recession method was selected

The results of calibration indicated that the coefficient determination between observed and simulated monthly stream flow is 0.9. The validation years were the four years 1993-1996. The coefficient of determination between the simulated and measured monthly stream flow during the validation years was 0.8. Table 2.2 shows a summary of HEC-HMS calibration and validation results and other statistical coefficients.

Table 2.2 Summary of HEC-HMS results and some statistical coefficients

| Item | Calibration | | Validation | |
|---|---|---|---|---|
| | Observed | Simulated | Observed | Simulated |
| Mean annual flow (MCM) | 100.60 | 93.40 | 103.2 | 97.20 |
| Mean annual flow (mm) | 27.40 | 25.44 | 28.1 | 26.48 |
| Standard deviation | 40.50 | 33.50 | 22.9 | 22.00 |
| Coefficient of determination, $R^2$ | - | 0.90 | - | 0.80 |
| Root mean square error | - | 12.00 | - | 6.00 |
| Yearly relative error | - | 7.00 | - | 6.00 |

Another study demonstrates by Hammouri and El-naqa (2007) used HEC-HMS rainfall-runoff model to estimate direct runoff volume, peak discharge and to construct synthetic hydrographs for an ungaged basin in Wadi Madoneh. The study was focused in Wadi Madoneh site to explore the surface water potential for groundwater artificial recharge using GIS and HEC-HMS. The sub-basin parameters (area, lag-time and average curve number) were calculated with CRWR-PrePro utility.

Table 2.3 shows the attribute table for the sub-basins with the calculated hydrologic parameters. The hydrologic parameters for each sub-basin were entered using HEC-HMS sub-basin editor; required data consist of

sub-basin area, loss rate method (SCS-CN method was used, transform method (SCS Unit Hydrograph was used), and baseflow method (baseflow was set to zero for Wadi Madoneh).

Table 2.3 Attribute table for the sub-basins with the calculated hydrologic parameters

| Sub-basin no | Area ($km^2$) | L (km) | $t_c$ (min) | $CN_i$ | Initial loss (min) | $t_L$ (min) |
|---|---|---|---|---|---|---|
| 1 | 7.2 | 4.6 | 160.89 | 78 | 14.33 | 119.39 |
| 2 | 3.5 | 2.7 | 83.84 | 78 | 14.33 | 62.21 |
| 3 | 3.7 | 3.8 | 107.13 | 78 | 14.33 | 79.49 |
| 4 | 4.5 | 2.6 | 92.50 | 78 | 14.33 | 68.64 |

Notes: L: length of the longest watercourse; $t_c$: times of concentration; $CN_i$: initial curve number; $t_L$: lag time

The intensity of rainfall was obtained from the Intensity-Duration-Frequency (IDF) curve of Zarqa rainfall station for two selected return periods: 10 years and 50 years. The control specifications for a three-day simulation period (from the $2^{nd}$ to the $4^{th}$ of April, 2006) were selected with 1 hour time interval.

Table 2.4 shows a summary of the computed direct runoff volume and peak discharge for each sub-basin in the simulated model. The peak discharge for 24-hour design storm with a 10 years return period was 5.43 $m^3/s$. Furthermore, the hydrographs for each sub-basin and for the basin outlet are shown in Figure 2.2 and Figure 2.3 respectively. The amount of runoff that would have been suitable for feasible artificial recharge practices for the simulated periods ranged from 150,970 $m^3$ to 279,700 $m^3$.

Table 2.4 Computation of direct runoff volume and peak discharge for each sub-basin

| Hydrologic element | Drainage area ($km^2$) | IDF curve for a 10 years return period | | IDF curve for a 50 years return period | |
|---|---|---|---|---|---|
| | | Peak discharge ($m^3/s$) | Direct runoff (1000 $m^3$) | Peak discharge ($m^3/s$) | Direct runoff (1000 $m^3$) |
| Sub-basin 1 | 7.2 | 1.92 | 57.51 | 4.05 | 106.54 |
| Sub-basin 2 | 3.5 | 1.26 | 27.96 | 2.67 | 51.8 |
| Sub-basin 3 | 3.7 | 1.21 | 29.55 | 2.66 | 54.76 |
| Sub-basin 4 | 4.5 | 1.58 | 35.94 | 3.39 | 66.60 |
| Outlet | 18.9 | 5.43 | 150.97 | 12.77 | 279.70 |
| Total precipitation | | 42.85 mm | | 59.41 mm | |
| Total loss | | 34.59 mm | | 42.00 mm | |
| Total excess | | 7.99 mm | | 17.41 mm | |

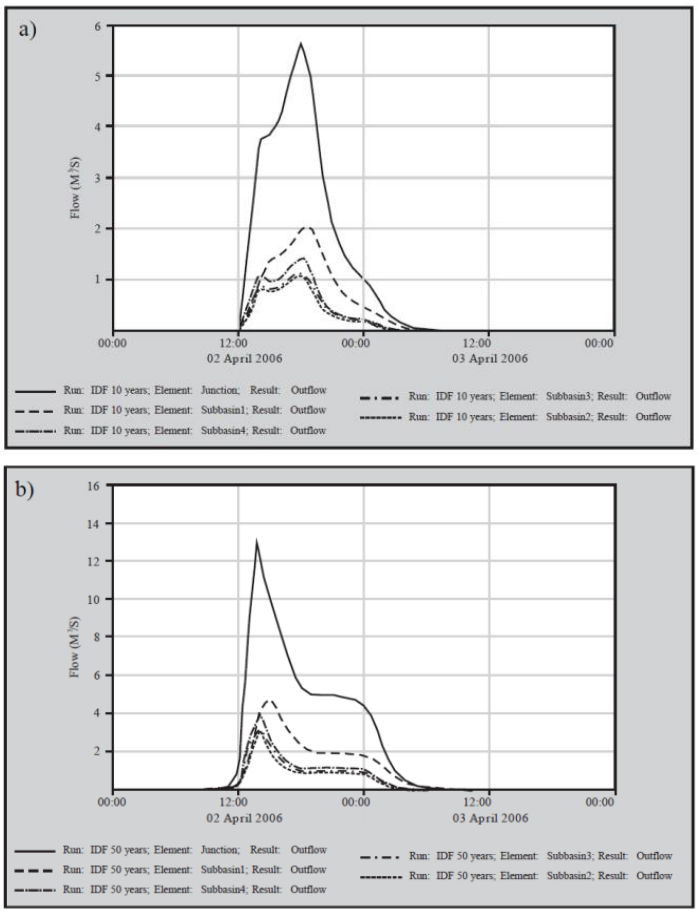


Figure 2.2 Hydrographs for each sub-basin and for the junction of the four sub-basins for a 24-hour storm event a) 10 years return period; b) 50 years return period