UNIVERSITI SAINS MALAYSIA

Laporan Akhir Projek Penyelidikan Jangka Pendek

Water Quality Modeling For Integrated River Basin Management In Sungai Raja, Kedah

by

Mr. Zorkeflee Abu Hasan

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2013

UNIVERSITY RESEARCH GRANT
FINAL REPORT
Geran Penyelidikan Universiti
Laporan Akhir

UNIVERSITI SAINS MALAYSIA

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A.	**PARTICULARS OF RESEARCH /** *MAKLUMAT PENYELIDIKAN:*
(i)	**Title of Research:** *Tajuk Penyelidikan:* WATER QUALITY MODELLING FOR INTEGRATED RIVER BASIN MANAGEMENT IN SUNGAI RAJA, KEDAH
(ii)	**Account Number:** *Nombor Akaun:* **1001/REDAC/8148045**
B.	**PERSONAL PARTICULARS OF RESEARCHER /** *MAKLUMAT PENYELIDIK:*
(i)	**Name of Research Leader:** *Nama Ketua Penyelidik:* **ZORKEFLEE ABU HASAN**
	Name of Co-Researcher: *Nama Penyelidik Bersama:* PROF. AMINUDDIN AB. GHANI PROF. NOR AZAZI ZAKARIA DR. H. MD AZAMATHULLA KHAIRUL RAHMAH AYUB LEOW CHENG SIANG
(ii)	**School/Institute/Centre/Unit:** *Pusat Pengajian /Institut/Pusat/Unit:* PUSAT PENYELIDIKAN KEJURUTERAAN SUNGAI DAN SALIRAN BANDAR (REDAC)
D.	**Duration of this research:** *Tempoh masa penyelidikan ini:* ***Duration :** TIGA TAHUN DAN TIGA BULAN *Tempoh :* **From** : 1 MEI 2010 **To** : 31 JULAI 2013 *Dari:* *Ke :*

E.	**ABSTRACT OF RESEARCH** (An abstract of between 100 and 200 words must be prepared in **Bahasa Malaysia and in English**. This abstract will be included in the Annual Report of the Research and Innovation Section at a later date as a means of presenting the project findings of the researcher/s to the University and the community at large) Alor Setar City is situated in a low lying and flat topography. It was prone to flooding until the completion of Alor Setar Flood Mitigation project in 1995. Sungai Raja System (SRS) comprises of Sungai Raja as the main stream and its tributaries Sungai Derga and Alor Siam is the main drainage system of the study area is much polluted. This study opted for mathematical modelling coupled with the utilization of Geographical Information System (GIS) technology to gain insight of SRS water quantity and water quality issues. The main drawback of this study is lack of available real time and continuous data required for modelling. Besides precipitation data provided by the Department of Irrigation and Drainage (DID) Malaysia, no other data is available. However, all models were calibrated and validate successfully using data collected during the study period. From the study, it can be concluded that due to complexity of urban area where the natural topography and features are modified by human, it is inevitable to utilise mathematical models and GIS technology for urban watershed management. ***Abstrak Penyelidikan*** (Perlu disediakan di antara 100 - 200 perkataan di dalam **Bahasa Malaysia dan juga Bahasa Inggeris**. Abstrak ini akan dimuatkan dalam Laporan Tahunan Bahagian Penyelidikan & Inovasi sebagai satu cara untuk menyampaikan dapatan projek tuan/puan kepada pihak Universiti & masyarakat luar). Bandaraya Alor Setar terletak di kawasan rendah dan rata. Bandaraya ini terdedah kepada banjir dan masalah in selesai apabila kerja-kerja Projek Tebatan siap dilaksanakan pada tahun 1995. Sistem Sungai Raja (SSR) meliputi Sungai Raja sebagai sungai utama dan anak-anak sungainya iaitu Sungai Derga dan Alor Siam sebagai sistem saliran utama kawasan kajian menghadapi masalah pencemaran. Kajian ini mengambil pendekatan permodelan rnematik serta penggunaan Sistem Maklumat Geografik (GIS) untuk menilai dan memahami permasalahan kuantiti dan kualiti air SSR. Tiga model metamatik digunakan , iaitu HEC-HMS, HEC-RAS dan InfoWork. Kekangan utama kajian ini ialah ketiadaan data "real time" dan data berterusan yang diperluka untuk permodelan. Selain dari data hujan yang dibekalkan oleh Jabatan Pengairan dan Saliran (JPS) Malaysia, data-data lain tidak dapat diperolehi. Walaubagaimana pun, kesemua model-model telah ditentu ukur dan validate dengan jayanya megunaan data-data yang dicerap semasa tempoh kajian. Dari kajian ini, boleh disimpulkan bahawa kawasan urban adalah komplek kerana topografi semulajadi dan ciri-ciri semulajadi yang lain telah diubahsuai oleh aktiviti manusia, memerlukan penggunaan model-model matematik dan teknolog GIS bagi tujuan pengurusan lembangan sungai urban.

F.	**SUMMARY OF RESEARCH FINDINGS** *Ringkasan dapatan Projek Penyelidikan* Impact of urbanization is very significant both in term of water quantity and water quality. The authorities that involved in urban development and those related to flood management should be able to work together to minimise the urban flood risks. Because of unpredictable future climate and human behaviour, flood management especially in highly urbanised area, flood management practitioners need to consider measures that is robust and at the same time is flexible enough to accommodate abrupt changes. Although these requirement seem very challenging but it is something possible due to the advancement of computer technology, GIS technology, and numerical models capabilities. Flood management authorities can therefore consider measures under different flooding scenarios and under different climate change condition. There are many approaches to alleviate the flooding and water quality issues in an urbanised area. This study confidently says that the numerical modelling together with GIS application are the tools to assist urban watershed management.
G.	**COMPREHENSIVE TECHNICAL REPORT** *Laporan Teknikal Lengkap* Applicants are required to prepare a comprehensive technical report explaining the project. (This report must be attached separately) Sila sediakan laporan teknikal lengkap yang menerangkan keseluruhan projek ini. [Laporan ini mesti dikepilkan] **List the key words that reflect our research:** *Senaraikan kata kunci yang mencerminkan penyelidikan anda:*

English	Bahasa Malaysia
Hydraulogic, hydraulics and water quality modelling	Permodelan hidrologi, hidrauliks, dan kualiti air
Geographical Ifgormation System	Sistem Maklumat Geografik
Urban Watershed Management	Pengurusan Kawasan Tadahan Urban

H. a) **Results/Benefits of this research**
Hasil Penyelidikan

No. *Bil:*	**Category/Number:** *Kategori/ Bilangan:*	**Promised**	**Achieved**
1.	**Research Publications (Specify target journals)** *Penerbitan Penyelidikan (Nyatakan sasaran jurnal)*	3	2 submitted and 1 under review
2.	**Human Capital Development**		
	a. Ph. D Students		
	b. Masters Students	**2**	**1 – tamat 1 – penyediaan tesis**
	c. Undergraduates (Final Year Project)		**4**
	d. Research Officers		
	e. Research Assisstants	**1**	**1**
	f. Other: Please specify		
3.	**Patents** *Paten*		
4.	**Specific / Potential Applications** *Spesifik/Potensi aplikasin*		
5.	**Networking & Linkages** *Jaringan & Jalinan*		DID Kedah
6.	**Possible External Research Grants to be Acquired** *Jangkaan Geran Penyelidikan Luar Diperoleh*		

- Kindly provide copies/evidence for Category 1 to 6.

b) **Equipment used for this research.**
Peralatan yang telah digunakan dalam penyelidikan ini.

Items *Perkara*	Approved Equipment	Approved Requested Equipment	Location
Specialized Equipment Peralatan khusus	RiverFlo-2D Notebook Workstations Low speed velocity probe		Zorkeflee – REDAC
Facility Kemudahan			
Infrastructure Infrastruktur			

- Please attach appendix if necessary.

I.	**BUDGET** / *BAJET*

Total Approved Budget : RM 170,179.00
Total Additional Budget : RM -
Grand Total of Approved Budget : RM -

Yearly Budget Distributed

Year 1 : RM 78,099.00
Year 2 : RM 65,665.00
Year 3 : RM 26,415.00

Additional Budget Approved

Year 1 : RM
Year 2 : RM
Year 3 : RM

Total Expenditure : RM
Balance : RM

- **Please attach final account statement from Treasury**

Signature of Researcher
Tandatangan Penyelidik

3/JAN/2014
Date
Tarikh

H.	**COMMENTS OF PTJ'S RESEARCH COMMITTEE** *KOMEN JAWATANKUASA PENYELIDIKAN PERINGKAT PTJ*

General Comments:
Ulasan Umum:

Kajian ini membuktikan keupayaan model HEC-RAS & InfoWORKS RS utk pengelakuan kualiti air dlm sistem saliran tepar iaitu Sg. Raja, Alor Setar.

Signature and Stamp of Chairperson of PTJ's Evaluation Committee
Tandatangan dan Cop Pengerusi Jawatankuasa Penilaian PTJ

PROFESOR DR. HAJI AMINUDDIN AB. GHANI
TIMBALAN PENGARAH REDAC

Date : 6/1/2014
Tarikh :

Signature and Stamp of Dean/ Director of PTJ
Tandatangan dan Cop Dekan/ Pengarah PTJ

Date : 07/01/2014
Tarikh :

PROFESOR NOR AZAZI ZAKARIA
PENGARAH
PUSAT PENYELIDIKAN KEJURUTERAAN SUNGAI
& SALIRAN BANDAR (REDAC)
KAMPUS KEJURUTERAAN
UNIVERSITI SAINS MALAYSIA
SERI AMPANGAN 14300 NIBONG TEBAL
PULAU PINANG.
TEL: 604-5941035 FAX: 604-5941036

WATER QUALITY MODELLING FOR INTEGRATED RIVER BASIN MANAGEMENT

IN SUNGAI RAJA, KEDAH

Research University Grant Report

(Account No: 1001/PREDAC/814085)

ZORKEFLEE BIN ABU HASAN
AMINUDDIN BIN AB. GHANI
NOR AZAZI BIN ZAKARIA
H MD AZAMATHULLA
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ABSTRAK

Bandaraya Alor Setar terletak di kawasan rendah dan rata. Bandaraya ini terdedah kepada banjir dan masalah in selesai apabila kerja-kerja Projek Tebatan siap dilaksanakan pada tahun 1995. Malangnya projek ini telah mengubah kesemua Sistem Sungai Raja (SSR) kepada parit konkrit. SSR meliputi Sungai Raja sebagai sungai utama dan anak-anak sungainya iaitu Sungai Derga dan Alor Siam. Pada masa ini SSR menghadapi pencemaran yang sebagaimana banyak sungai-sungai yang melintasi kawasan yang mempunyai penghuni yang padat dan kawasan urban.

Kajian ini mengambil pendekatan permodelan mematik serta penggunaan Sistem Maklumat Geografik (GIS) untuk menilai dan memahami permasalahan kuantiti dankualiti air SSR. HEC-HMS digunakan untuk permodelan hidrologik, HEC-RAS untuk permodelan hidraulik dan kualiti air, dan InfoWork RS menumpukan kepada permodelan kualiti air. Kekangan utama kajian ini ialah ketiadaan data "real time" dan data berterusan yang diperluka untuk permodelan. Selain dari data hujan yang dibekalkan oleh Jabatan Pengairan dan Saliran (JPS) Malaysia, data-data lain tidak dapat diperolehi.

Semua model memerlukan sesuatu untuk mengambarkan sifat-sifat fizikal seperti ciri-ciri basin (untuk HEC-HMS dan InfoWorks), data geometri (untuk HEC-RAS dan InfoWorks), dan parameter-parameter hidrauliks. Maklumat-maklumat ini diperolehi dari data spatial dan diproses atau dijana didalam persekitaran GIS; atau diisikan kedalam model secara manual. Permodelan menggunakan InfoWorks atus perisian HEC merangkumi tiga peringkat. Peringkat pertama ialah permodelan hidroloi, kedua permodelan hidrauliks, dan ketiga permodelan kualiti air. Kesemua peringkat dilaksanakan dalam InfoWorks bagi bagi permodelan menggunakan InfoWorks sebaliknya "inflow" untuk HEC-RAS dijana menggunakan HEC-HMS untuk tujuan permodelan hidrauliks sebelum permodelan kualiti air menggunakan HEC-RAS dilaksanakan.

Selain dari permodelan kualiti air mengunakan HEC-RAS, permodelan-permodelan lain baik menggunakan InfoWorks atau model-model HEC telah ditentu ukur dan validate dengan jayanya megunaan data-dat yang dicerap semasa tempoh kajian. Kesemua pelaksanaan kerja menggunakan InfoWorks dilakukan oleh Ramli (2013) dan tidak disentuh secara mendalam dalam lapuran ini. Untuk permodelan menggunakan HEC, factor utama yang mempengaruhi penghasilan hidrologik ialah "baseflow". Dari tentu ukur dan validasi, "Initial Discharge" bagi mewakili keadaan kering ialah 0.069 $m^3/s/km^2$ dan 0.125 $m^3/s/km^2$ untuk keadaan berhujan. Dua scenario dilaksanakan untuk menguji kesan perubahan gunatanah. Scenario pertama adalah keadaan 80% kawasan dibangunkan dan scenario kedua 100% kawasan dibangunkan. Hasil penyelakuan menunjukkan kadaralir puncak meningkat sebanyak 26% bagi scenario pertama dan 41% bagi scenario kedua.

Dari kajian ini, boleh disimpulkan bahawa kawasan urban adalah komplek kerana topografi semulajadi dan ciri-ciri semulajadi yang lain telah diubahsuai oleh aktiviti manusia, memerlukan penggunaan model-model matematik dan teknologi GIS bagi tujuan pengurusan lembangan sungai urban.

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WATER QUALITY MODELLING FOR INTEGRATED RIVER BASIN MANAGEMENT IN SUNGAI RAJA, KEDAH

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ABSTRACT

Alor Setar City is situated in a low lying and flat topography. It was prone to flooding until the completion of Alor Setar Flood Mitigation project in 1995. Unfortunately, this project converted the whole Sungai Raja System (SRS) into concrete drains. SRS comprises of Sungai Raja as the main stream and its tributaries Sungai Derga and Alor Siam. Currently SRS is much polluted like many other rivers that pass through highly populated and urbanised areas.

This study opted for mathematical modelling coupled with the utilization of Geographical Information System (GIS) technology to gain insight of SRS water quantity and water quality issues. HEC-HMS was used for hydrologic modelling, HEC-RAS for hydraulic and water quality modelling, and InfoWorks RS mainly used for water quality modelling. The main drawback of this study is lack of available real time and continuous data required for modelling. Besides precipitation data provided by the Department of Irrigation and Drainage (DID) Malaysia, no other data is available.

All models require representation of the physical properties such as the basin characteristics (for HEC-HMS and InfoWorks), geometric data (for HEC-RAS and InfoWorks), and hydraulic parameters. The information was either derived from spatial data and processed or generated in GIS environment; or was input into the models manually. The modelling involved three stages either it is the HECs or the InfoWorks. The first stage is hydrologic modelling, second is the hydraulics modelling, and the third is the water quality modelling. All the stages were carried out within InfoWorks environment for InfoWorks whereas inflows for HEC-RAS were produced using HEC-HMS for hydraulic modelling before carrying out the water quality modelling in HEC-RAS.

Except for water quality modelling using HEC-RAS, both InfoWorks and the HECs were calibrated and validate successfully using data collected during the study period. All works related to InfoWorks were conducted by Ramli (2013) and is not deliberated in detail in this report. For SRS, the main factor that influenced the hydrologic output is the baseflow. Form calibration and validation exercises, the Initial Discharge to represent the dry period are 0.069 $m^3/s/km^2$ and 0.125 $m^3/s/km^2$ for wet condition. Two scenarios were performed to examine the impact of land use change in SRS catchment area. First scenario is when the catchment area is 80% paved and the other is when total area is 100% impermeable. Peak discharges at the outlet of SRS increased by 26% for first scenario and 41% for the second scenario.

From the study, it can be concluded that due to complexity of urban area where the natural topography and features are modified by human, it is inevitable to utilise mathematical models and GIS technology for urban watershed management.

ABSTRAK

Bandaraya Alor Setar terletak di kawasan rendah dan rata. Bandaraya ini terdedah kepada banjir dan masalah in selesai apabila kerja-kerja Projek Tebatan siap dilaksanakan pada tahun 1995. Malangnya projek ini telah mengubah kesemua Sistem Sungai Raja (SSR) kepada parit konkrit. SSR meliputi Sungai Raja sebagai sungai utama dan anak-anak sungainya iaitu Sungai Derga dan Alor Siam. Pada masa ini SSR menghadapi pencemaran yang sebagaimana kebanyakan sungai-sungai yang melintasi kawasan yang mempunyai penghuni yang padat dan kawasan urban.

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TABLE OF CONTENTS

CHAPTER 1: INTRODUCTION

Zorkeflee Abu Hasan, REDAC, USM

1.1 BACKGROUND

Abdullah (2007) mentioned that out of 187 river basins in Malaysia, polluted river increased from 7 in 1990 to 17 in 2005. The slightly polluted river also following similar trend (Figure 1.1). Integrated River Basin Management (IRBM) was lauded as an approach that may able to resolve the water resources issues. IRBM approach considers not only water resources management but also environment management such as pollution control, development panning and biodiversity conservation.

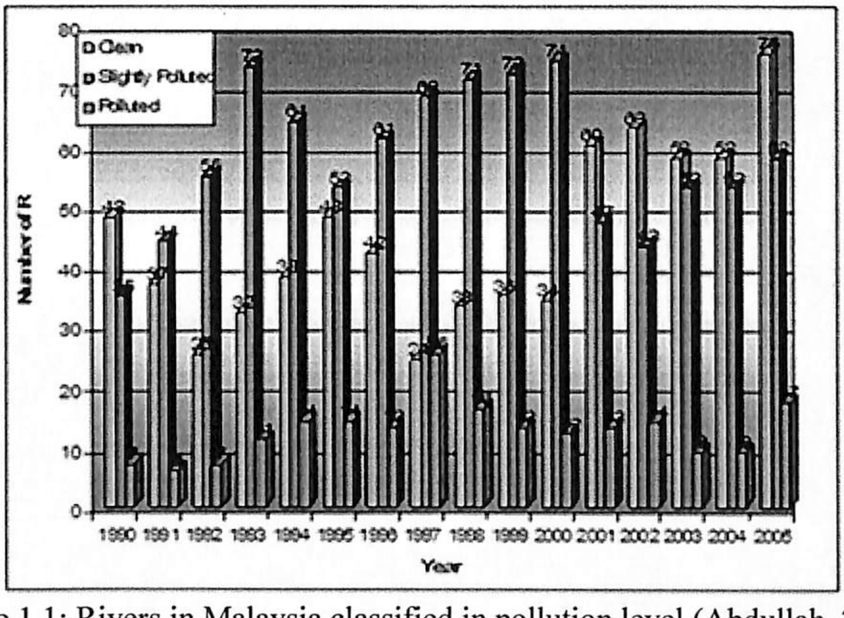


Figure 1.1: Rivers in Malaysia classified in pollution level (Abdullah, 2007)

Sungai Kedah Basin Management Plan for year 2007-2012 produces an outlay of the IRBM approach of Sungai Kedah Basin as one of the IRBM pilot project in Malaysia (DID, 2007). In view of this, Sungai Raja System (SRS) was selected to investigate the possibility of implementing an IRBM in an urbanised area. This river system was selected in due to its importance as the main drainage system for Alor Setar City.

1.2 STUDY AREA

SRS is a tributary of Sungai Kedah and made up of two main tributaries (Sungai Derga and Alor Siam) and Sungai Raja as the main river (Figure 1.2). The river system is very small with catchment area approximately 2.7 km^2 and total length of the three rivers is about 4.3 km (Sungai Derga $\approx$ 1.8 km; Alor Siam $\approx$ 1.5 km, and Sungai Raja $\approx$ 1.0 km). Before the completion of flood mitigation scheme in 1995, Alor Setar City was frequently hit by floods due to its flat and low topography. This project transformed the SRS to "concrete drains" and the SRS was cut off from the Sungai Kedah by the construction of river bund and outlet structures. Water from the SRS is discharged into Sungai Kedah by pumps installed at Sungai Raja river mouth.

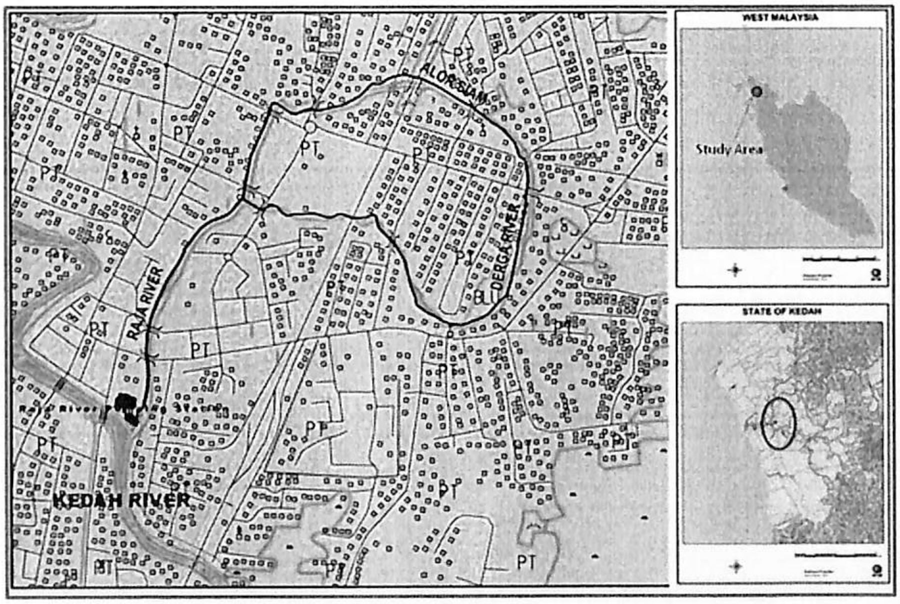


Figure 1.2: Location of Study Area.

Sungai Raja and its tributaries are urban rivers as defined by Findlay and Taylor (2006). They defined urban river as "a stream where a significant part of the contributing catchment consists of development where the combined area of roofs, roads and paved surfaces results in an impervious surface area characterising greater than 10% of the catchment" and stated that many urban rivers systems in the world are heavily degraded. SRS is no exception and currently is very polluted. Visually, the water is dark in colour and at times can be smelly. As (models, data, and assessment methods) that together form the basis for constructing a modelling system capable of simulating environmental systems relevant to a well specified problem statement (Gaber et al., 2008). While waiting for the "complete model" to become available, water quality and water quantity modelling were performed by conventional ways, i.e., using a combination of suitable mathematical models for different intended purpose. Water quality components are normally incorporated in catchment management models (e.g. SWAT and AnnAGNPS), or hydrodynamic models such as EPA-SWMM, HEC-RAS, and InfoWorks.

For this study, the modelling exercises include hydrologic modelling, hydraulic modelling and water quality modelling were using public domain and free softwares. However, a number of obstacles were met during the course of study and the most apparent is no data/records for models calibration and verification. The data/records are:-

a. No continuous and/real-time hydraulics data and records;
b. No water quality data; and
c. No pump operation records.

Due to these limitations, models calibration and validation were based on the limited data/records obtained from the site data collection activities.

1.4 OBJECTIVES

The general purpose of this study is to investigate the feasibility of applying public domain and free hydrologic, hydraulics and water quality models to assist watershed management in an urban area with limited data and records. This study area, like many urban areas in the country has very little data or no data/record that can be used for immediate flood forecasting purposes. The study focuses on the applicability and feasibility of applying these models (and not on the development of the models) in assisting the Flood Management (Stormwater Management) of Sungai Raja System.

The specific objectives are:-

a. To develop model of stormwater/flood management for Sungai Raja System,
b. To develop one-dimensional water quality model for Sungai Raja System,
c. To predict changes in hydrologic and hydraulics responses of the study area to changes in land use.

1.5 SCOPE OF RESEARCH

The study was conducted in three stages to achieve the objectives. The stages are:-

Stage 1: Establishment of data-based (inclusive of the spatial and non-spatial data/information) for the study area. Hydrologic data collection, collection of available data relevant to the study, soil sample collection, soil sample analysis and estimation of hydrologic model input parameters.

Stage 2: Carry out hydrologic modelling using HEC-HMS, hydraulic modelling using HEC-RAS, and Water Quality modelling using InfoWorks RS with appropriate methods and procedures. These include model setup preparation, sensitivity analysis, calibration and validation processes.

Stage 3: Analyze and simulate the impact of land use changes on hydrologic and hydraulics.

This research report is focussing on the hydrologic and hydraulic modelling using USACE HEC-HMS and HEC-RAS. For water quality modelling using InfoWork RS, MSc Thesis by Ramli (2013) should be referred to. Ramli (2013) managed to acquire water quality samples using REDAC's Water Quality Probe from January 2010 to December 2010 that were used for water quality modelling. Unfortunately, the water quality sampling was discontinued due to equipments malfunction and no funding (approximately RM 40,000) to fix them.

CHAPTER 2: LITERATURE REVIEW

Zorkeflee Abu Hasan, REDAC, USM

2.1 INTRODUCTION

Urbanization is a rapidly growing type of land use and the trend is continuing including in the United States of America (Bressler et al., 2009), Poland (Krauze et al., 2008) and also in Malaysia (Abdullah, 2007). This phenomenon exerted enormous pressure on water resources, river are degraded due to pollutant from various point and non-point sources from the catchment areas and dramatically alter the hydrologic responds of a watershed (Stein et al., 2007; DID, 2007). Water quality issues in urban river come from combined sewer system and effluent water from sewerage treatment plant flow to river during rainfall (Okabe et al., 2009; Durant and Abbasi, 2000). Flood problems are caused by deficient or improper land use planning; and laws and regulation to control the construction activities are not enforced properly owing to economic or political factors, or capacity or resources constraints (Jha et al., 2012).

2.2 WATER QUALITY ISSUES

Anthropogenic land use causes excessive loads of pollutants washed into rivers during rainfall runoff events. The most damaging land use practice in terms of the magnitude of pollutant load washed into rivers appears to be urban and industrial land (Simpson and Stone, 1988). Agriculture and forestry also are associated with elevated amounts of nutrient loads washed into rivers (Pegram and Gorgens, 2001; Simpson, 1991).

Significant nutrient loading from urban watershed into receiving urban rivers induced continuous deterioration and wide range of problems of environmental concerns (Fragoso et al., 2007; Chen and Adams, 2006). This situation is not confined to a particular geographic region but all areas subjected to urbanization (Findlay and Taylor, 2006) including Malaysia (DID, 2007). In Malaysia, out of 120 main rivers monitored in the country, only 44.8% is identified as clean (DOE, 2004a). Sources of the pollutant are from domestic sewage treatment plants, industries, commercial areas and urban diffuse sources are the main cause of river pollution in the country (DOE, 2004b; 2003a, 2003b).

2.3 WATER QUANTITY ISSUES

Impact of urbanization is irreversible on natural drainage pattern and past development in the flood plain did not consider the impact on hydrology (Novotny et al., 2000). Urbanization impacted the local hydrology due to the increase of the imperviousness which reduces the travel time, reduces time to peak and increases the peak flow (Rumman et al., 2005). To resolve the increase in floods, urban engineers in the past had adopted method to enlarge/increase the flow capacity of urban rivers via lining, covering and straightening the channels (Novotny et al., 2000). However, with the advent of high speed computers, more comprehensive and more conceptually realistic techniques have been developed for the study and design of urban water resources systems (Abbot, 1978). Rainfall-runoff models are common tools used to simulate stormwater runoff from urban catchments (Kennedy et al., 2007), and watershed-scale modelling has emerged as an important scientific research and management tool to understand and control water pollution (Daniel et al., 2011).

Historically most rainfall was absorbed by the surrounding landscape and became runoff during large storms after the soil became saturated. However, the hydrological function and natural water cycle of many watersheds was drastically altered as native ecosystems were replaced with streets, rooftops, driveways, sidewalks, parking lots and suburban lawns (Johnson et al., 2007). Urban land-cover / land-use change reduce infiltration rates on the land surface and runoff response times, resulting in higher flow peaks and larger total streamflow volume, shifts in subsurface flow to surface flow, and increases in flood frequency (Yang et al., 2010).

2.4 MODELLING

Computer models are very important to engineers because they can help engineers perform engineering tasks in a faster, cheaper and better way (Zhao, 2001). Models have also help to explain scientific phenomena and predicting outcomes where empirical observations are limited or unavailable (Ambrose et al., 2009). Simulation modelling can be used for operational forecasting as well as to answer WHAT-IF questions related to new projects or policies (Fedra, 1999). Three types of models commonly used in urban stormwater management, which are hydrologic, hydraulic and water quality models (Haubner et al., 2001). The modelling process involves: (1) development of study or model objectives, (2) identification of resources and constraints, and finally, (3) the selection and implementation of the model itself (Haubner et al., 2001).

Digital computers provided enormous computational opportunities and the choice of s model for a particular project depends on user needs, desired outcomes, and the project budget. Models that can simultaneously investigate hydrologic processes as well as water quality characteristics are increasingly required. Linking hydrologic and water quality modelling creates new opportunities to better understand complex processes and ex-changes in stream environments (Drake et al., 2010).

The transformation of rainfall into runoff is a critical component for flash flood analysis. Recently, distributed hydrological models became an attractive approach for the modelling of watershed hydrology. Nevertheless, limited knowledge of model inputs (initial and boundary conditions, parameters) and observations of the hydrological response make the underlying problems of calibration, sensitivity analysis and uncertainty analysis very challenging (Castaings et al., 2006).

2.4.1 Model Development

Developing a system for prediction of river flow depends on models, proper calibration–validation techniques, sound model generalization and efficient on-line system to disseminate the results publicly (Cheng et al., 2006). The reliability of model predictions depends on how well the model structure is defined and how well the model is parameterized (Bahremand and De Smedt, 2008). However, estimation of model parameter is difficult due to data adequacy (Lanyon and Melching, 2001) and large uncertainties involved in determining the parameter values (Bahremand and De Smedt, 2008). Therefore, model calibration and verification are necessary to improve the model prediction (Bahremand and De Smedt, 2008; Lanyon and Melching, 2001; Haubner et al., 2001). Daniel et al. (2011) stated that parameter estimation and calibration processes are especially challenging for ungauge basin where sparse or poor data quality often favour the use of empirical versus physically-based models.

2.4.1.1 Calibration, Verification and Validation

Calibration is the comparison of a model to field measurements, other known estimates of output (e.g. regression equations), or another model known to be accurate, and the subsequent adjustment of the model to best fit those measurements. Verification then tests the calibrated model against another set of data not used in the calibration (Haubner et al., 2001). Validation involves a determination that the model is structured and coded as intended for the range of variables to be encountered in the study. Validation tests key algorithms for accuracy. Often validation is a one-time effort, after which the modeler is comfortable with the model's "quirks" and knows how to deal with them. Validation often involves pushing parameters to the limit of reasonable extent to test an algorithm (Haubner et al., 2001).

There are two different ways to assign values to parameters: one is based on field observation and measurement of physical property and lab experiments such as soil conductivity; the other estimates the values of parameters statistically using inverse analysis approach such as regression applied to some measured inputs and known outputs (Cheng et al., 2006). The various physical parameters of the model should be adjusted until simulated values match observed values (Kemper and Wagner, 2004).

The model calibration and validation tasks are very challenging because of the number of variables and processes in play (Sayre et al., 2006). This step is not always possible due to the general shortage of data of any sort in stormwater management (Haubner et al., 2001).

2.4.1.2 Sensitivity Tests

Sensitivity is measured as the response of an output variable to a change in an input parameter, with the greater the change in output response corresponding to a greater sensitivity. Sensitivity analysis evaluates how different parameters influence a predicted output. Parameters identified in sensitivity analysis that influence predicted outputs are often used to calibrate a model (White and Chaubey, 2005).

According to Saltelli et al. (2004), sensitivity analysis is the study of how the variation in the output of a model (numerical or otherwise) can be apportioned, qualitatively or quantitatively, to different sources of variation. Sensitivity analysis is recognized as being an important aspect of the responsible use of hydraulic models (Hall et al., 2009). Sensitivity analyses are valuable tools for identifying important model parameters, testing the model conceptualization, and improving the model structure. They help to apply the model efficiently and to enable a focused planning of future research and field measurement (Sieber and Uhlenbrook, 2005).

2.4.2 Models Used In the Study

In this study the model chosen are HEC-HMS for hydrologic modelling, HEC-RAS for hydraulics and water quality modelling and InfoWorks RS for hydrologic, hydraulics and water quality modelling.

2.4.2.1 USACE Hydrologic Modelling System

Hydrologic modelling is a valuable tool in urban planning and design (Greene and Cruise, 1995). It provides a form work for conceptualizing and investigation relationships between climate, human activities and water resources (Legesse et al., 2003; Lin et al., 2008). This study uses the Hydrologic Engineering Center of the US Army Corps of Engineers, Hydrologic Modelling System (HEC-HMS). The HEC-HMS was conceived as a software-based tool for simulating the hydrologic cycle in the context of engineering problem solving (Scharffenberg et al., 2010) and have been widely used for modelling floods and impacts on land use changes (Daniel et al., 2011). It is designed to simulate the precipitation-runoff processes of dendritic watershed systems, and designed to be applicable in a wide range of geographic areas for solving a variety of water-related problems. HEC-HMS can handle large river basin water supply and flood hydrology, as well as small urban or natural watershed runoff applications (USACE, 2010a).

HEC-HMS provides a variety of options for simulating precipitation-runoff and routing processes, and is comprised of a graphical User Interface (GUI), integrated hydrologic analysis components, data storage and management capabilities, and graphics and reporting facilities (Daniel et al., 2011). To compute runoff (known as loss method), a total of twelve different loss methods are provided; seven different method are provided to simulate the process of direct runoff of excess precipitation on a watershed (transformation method); a total of four baseflow methods; and five channel routing models to compute the outflow hydrographs (USACE, 2010a; USACE, 2000).

2.4.2.2 USACE River Analysis System

River Analysis System (HEC-RAS) software, developed by the United States Army Corps of Engineers Hydrologic Engineering Center, is intended for performing one-dimensional hydraulic calculations for a full network of natural and constructed channels. The system can calculate water surface profiles for both steady and unsteady gradually varied flow. The steady flow system is designed for application in flood plain management studies. Also, capabilities are available for assessing the change in water surface profiles due to channel improvements, and levees (Kafle et al., 2010; USACE, 2010b). Main parameters needed are cross-sections for river and flood plain including left and right bank locations and flow paths, roughness coefficients (Manning's n), and contraction and expansion coefficients (Kafle et al., 2010; Cook and Merwade, 2009).

In response to the evolving needs of practitioners, HEC-RAS, a commonly used one-dimensional hydraulic river model, has been expanded to include a water quality component (Drake et al., 2010). The water quality model in HEC-RAS 4.1 is one-dimensional and simulates fate and transport of water quality parameters (USACE, 2010b, Drake et al., 2010).

2.4.2.3 HEC modelling and GIS

USACE developed HEC-geoHMS to transform required spatial data in ArcView/ArcGIS environment to develop a set of hydrologic modelling input (Basin Model) to aid the rainfall-runoff modelling of HEC-HMS (Kafle et al., 2010; Drake et al., 2010; Drake et al., 2010; Rumman et al., 2005). USACE also developed an extension known as HEC-geoRAS to be used in ArcView/ArcGIS to create input file containing geometric data from a digital terrain model (DTM) and to perform post-processing HEC-RAS simulation results (Kafle et al., 2010).

2.4.2.4 InfoWorks RS

The free version of InfoWorks RS version 10 developed by Innovyze (formerly known as MWH Soft) was used for this study. InfoWork RS is hydrodynamic modelling software to model hydrologic, channel hydraulics, water quality, and sediment transport. This software has been used in Malaysia such as by Said et al. (2009) to simulate water quality condition in Maong River, Sarawak and Hashim et al. (2011) covering Dissolve Oxygen (DO), BioChemical Oxygen Demand (BOD) and Ammonical Nitrogen (N-NH4) in the Juru River.

2.5 DATA

Data requirement is one of the driving forces for reducing model complexity to the minimum. It increases with the line of model complexity (Deksissa and Behera, 2008). It is necessary to have good knowledge of the model input in order to carry out a simulation of a real flow (Castaings et al., 2006). Most watershed models, such as hydrologic model, hydraulic model, watershed managing and planning model, drainage system model, pollution control model, landscape model, etc require watersheds and stream networks as the primary input data (Qiang et al., 1999).

The key to effective watershed characterization involves determining the physical properties that control the runoff-response characteristics of a particular sub-basin. It is necessary to combine information such as land use, soil type, watershed slope, and channel geometry in order to obtain accurate indicators of how the watershed reacts during a storm event (Kemper and Wagner, 2004). The way runoff occurs is affected by various watershed parameters. Some of these parameters are combination of various data types such as hydrologic soil groups and land use, while land slope is a product of a Geographical Information System (GIS) data set (Kemper and Wagner, 2004).

2.5.1 Geographical Information System

Geographical Information System (GIS) gives the ability to integrate different data layers in order to develop very descriptive parameters (Kemper and Wagner, 2004). The GIS has significantly changed the way spatial data are acquired and use (Greene and Cruise, 1995) and the management of spatial information has become easier (Greene and Cruise, 1996). The GIS is a powerful tool for analysis as it capability is not only to be used to visualised the flooding extend but also to produce flood damage estimation maps and flood risk maps (Werner, 2001). Another area in which GIS may be particularly helpful is the hydrologic analysis of urban watersheds (Greene and Cruise, 1996; Kemper and Wagner, 2004). For efficient and effective design, planning, and management purposes, the engineer or manager needs access to as much spatial information about the watershed as possible (Greene and Cruise, 1996).

In general, of the primary functions of GIS in modelling are to create spatial database that represents the hydrologic characteristic of a watershed, spatial data processing to produce required parameters for a particular model, and display physical characteristics of the drainage basin, and etc (Kemper and Wagner, 2004; Greene and Cruise, 1995; Fedra, 1999; Bahremand and De Smedt, 2008).

2.5.2 Digital Elevation Model

One of the main data in GIS environment to be used in hydrologic and hydraulic modelling is the Digital Elevation Model (DEM). DEMs are digital surfaces representing the area of interest with a grid of given resolution placed over the surface and elevation data assigned to each cell (Bahremand and De Smedt, 2008). DEM represented the topographic data, which to hydrodynamic model serves as a principle source to represent river terrain geometry and floodplain topography (Tarekegn, 2010). DEMs are key component for computer-based analyses of river profiles and drainage basin delineation as it provides elevation information for the land surface throughout the concerned area (Mahmood et al., 2008; Kemper and Wagner, 2004).

Delineation of watershed based on DEM worked relatively well for drainage areas where the slope of the landscape is primarily responsible for the path taken by the runoff (Kemper and Wagner, 2004). For highly urbanized and in plain areas, sometimes it is impossible to obtain correct stream networks and watershed boundaries (Qiang et al., 1999). Thus, other processing software, techniques and additional data sources (besides DEM) are needed to generate stream network and watershed boundaries (Qiang et al., 1999; Mahmood et al., 2008).

2.5.3 Land Use and Land Cover

One important parameter affecting the rainfall-runoff relationship is land use. As more homes and business are constructed within a watershed, there is generally an increase in both the volume and peak flow of storm water runoff (Kemper and Wagner, 2004). Most watershed hydrology and pollutant loading models use land use and land cover (LULC) information to generate runoff and pollutant loading estimates (Burian et al., 2002). Burian et al. (2002) refers land cover to the state or physical appearance of the land surface (e.g., grasslands, forest, bare soil, exposed rock, developed land); and land use refers to the specified purpose of land from a human perspective (e.g., high-density residential, commercial services, row crop agriculture, managed forest, rangeland). Together land use and land cover information suggest specific characteristics of the land surface (e.g., imperviousness, solar reflectivity, vegetation type, building morphology), which can be incorporated into environmental models as distributed or bulk parameterizations.

LULC datasets can be developed from a variety of sources of information including satellite imagery, aerial photographs, and site canvassing (Burian et al., 2002). With the advancements in satellite imagery, digital data, and remote sensing techniques, different land use can be classified and made available/produce in digital format using GIS technology (Burian et al., 2002; Kemper and Wagner, 2004; McLendon, 2002). The topography, soils, land use, pervious and impervious areas, storm drain system, stream channel, and street network of an urban watershed were geocoded into separate layers, and the attribute information for each layer was used to construct database attribute tables (Greene and Cruise, 1995).

2.5.4 Hydrologic Soil Groups

Hydrologic Soil Groups (HSG) is grouped into four categories, A through D, based on their ability to "soak up" precipitation (Kemper and Wagner, 2004). Texas Department of Transportation (TDoF, 2011) recommended the soil group classification as follows;

Group A : Low runoff potential due to high infiltration rates even when saturated. The Basic Infiltration Rate is 7.6 mm/hr to 11.4 mm/hr and the categories of soil are deep sands, deep loess and aggregate silts.

Group B : Moderately low runoff potential due to moderate infiltration rates when saturated. The Basic Infiltration Rate is 3.8 mm/hr to 7.5 mm/hr and the categories of soil are shallow loess and sandy loam.

Group C : Moderately high runoff potential due to slow infiltration rates when saturated. The Basic Infiltration Rate is 1.3 mm/hr to 3.7 mm/hr and the categories of soil are clay loams, shallow sandy loams, soils low in organic content and soils usually high in clay.

Group D : High runoff potential due to very slow infiltration rates when saturated. The Basic Infiltration Rate is less that 1.2 mm/hr and the categories of soil are clay layer at or near the surface.

A new set of watershed parameter known as runoff Curve Number (CN) can be produced by combining the LULC with the HSG layer using the GIS software functions and procedures (CDM, 2005). This study utilizes the SCS Curve Number Loss Rate option in the HEC-HMS to compute the runoff volume.

2.6 SOIL CONSERVATIVE SERVICE METHOD

The effective rainfall was determined for each hydrologic response unit using the modified SCS method described. The Curve Number Procedure is one of the most widely used methods for calculating runoff (Mandel et al., 1997; Bhunya et al., 2011). The curve number method was originally developed by the NRCS, formerly the Soil Conservation Service (SCS), in 1954 to estimate the direct runoff from a single precipitation event on a small agricultural watershed (NRCS, 1997). The method required the curve number (CN) and initial abstraction (antecedent moisture condition, saturated hydraulic conductivity, and soil-moisture storage capacity) for each hydrologic response area (Greene and Cruise, 1995; Mandel et al., 1997; USACE, 2000). Initial abstraction is defined as losses from rainfall before runoff begins.

The main equations for the SCS-CN method are (TR55, NEH630-ch10.pdf; USACE, 2000);

The NRCS runoff equation is $Q = \frac{(P-I_a)^2}{(P-I_a)+S}$ for $P > I_a$

$$Q = 0 \text{ for } P \leq I_a$$

$$I_a = 0.2S$$

The potential maximum soil retention, S, can be obtained according to the CN value.

$$S = \frac{25400}{CN} - 254$$

Q = runoff (mm); P = rainfall (mm); S = potential maximum retention after rainfall begins (mm); and I_a = initial abstraction (mm). CN value ranges from 100 (for water bodies) to approximately 30 for permeable soil with high infiltration rates.

2.7 REMARKS

From the literatures, it can be concluded that urbanization has cause water quality and water quantity issues regardless of the status of the region or country. Numerical models has been applied to as management tool to address and improve the situations. This study utilizes HEC-HMS, HEC-RAS, and InfoWorks (free version) together with GIS softwares to investigate the applicability of these models/softwares in resolving water quality and water quantity issues in an urbanised area having very flat topography; and finally be used as management tool Sungai Kedah Basin as one of the IRBM pilot project in Malaysia (DID, 2007).

CHAPTER 3: DATA COLLECTION AND DATABASE DEVELOPMENT

Zorkeflee Abu Hasan, REDAC, USM; Mohamad Suaimi Ramli, DID Malaysia; Nor Zaimah Che Ghani, MSc REDAC, USM.

3.1 INTRODUCTION

Urban catchment management dealt with problems that are spatially distributed and dynamic. To address the dimension of these problems, combination of simulation models coupled with the Geographic Information Systems (GIS) were adapted in this study. The main activities are establishing the database (which are elaborated in this chapter) and dynamic simulation models (described in subsequent chapter).

The database comprises of spatial and non-spatial data. Spatial data will be stored using GIS softwares and the non-spatial time-series data are stored using spreadsheet and data storage software.

3.2 SPATIAL DATA

The spatial data is categorised as raster, triangular irregular network (TIN) and vector data structure. A raster is a rectangular grid of equally sized cells representing thematic or spectral data. The TIN compose of a network of triangles connected on the edges. Vector data represents map features in graphic elements known as points, lines and polygons (areas) usually accompanied with the tabular data. Tabular data are the attribute information which describes the features.

3.3 GIS DATABASE

GIS is designed to capture, manage, manipulate, analyze, and display spatially referenced data. One of the most important elements in developing GIS database is finding and utilizing the appropriate data. The data form and format are also critical to the overall GIS database development.

The identified data necessary for the study are:-

a. topographic maps,
b. aerial photos and satellite images,
c. land use,
d. river geometry,
e. drainage networks,
f. soil map, and
g. hydrologic stations

3.4 DATA AND THE PROCESSES

The data available are

a. Light Detection and Ranging (LiDAR) survey data;
b. Aerial photos;
c. As built plans for Sg Raja, Sg Derga and Alor Siam;
d. Soil map;
e. Drainage network and sub-catchment area; and
f. Stations.

3.4.1 LiDAR survey

The LiDAR survey data were obtained from the Bahagian Pengairan dan Saliran Pertanian (BPSP) of Ministry of Agriculture in ASCII *.xyz format. The files were converted and edited using GIS software into *.shp files. These data were used primarily to build terrain models.

3.4.2 Aerial Photos

Aerial photos were also provided by the BPSP together with the LiDAR survey. The aerial photos were used to assist in identifying or demarcating the land use, drainage network, and sub-catchment areas.

3.4.3 As-built plans

Scanned images of as-built plans were provided by the JPS Kedah. The plan was produced in year 1995. These plans were used to produce the river bathymetry.

3.4.4 Soil map

Soil types in a watershed are critical, as they determine infiltration rates that can occur for an area. In this study, in-situ soil analyses were conducted to estimate the minimum infiltration rates which were used to classify the soils using the values in Table 3.1. Soils are classified into four Hydrologic Soil Groups (HSG) namely group A, B, C, and D (USACE, 2000).

Table 3.1: Hydrologic soil group characteristics. The minimum infiltration rate (cm/hr) for each group is listed with its infiltration potential (adopted from USACE (2000)).

Soil Group	Description	Minimum infiltration rate (cm/hr)
A	Deep sand, deep loess, aggregated sills	0.76 - 1.14
B	Shallow loess, sandy loam	0.38 - 0.76
C	Clay loams, shallow sandy loam, soils low in organic content, and soil usually high in clay	0.13 - 0.38
D	Soils that swell significantly when wet, heavy plastic clays, and certain saline soils	0.00 - 0.13

The sites locations were recorded using the Global Positioning System (GPS) as in Figure 3.1. The generated polygon of the soil groups is shown in Figure 3.2.

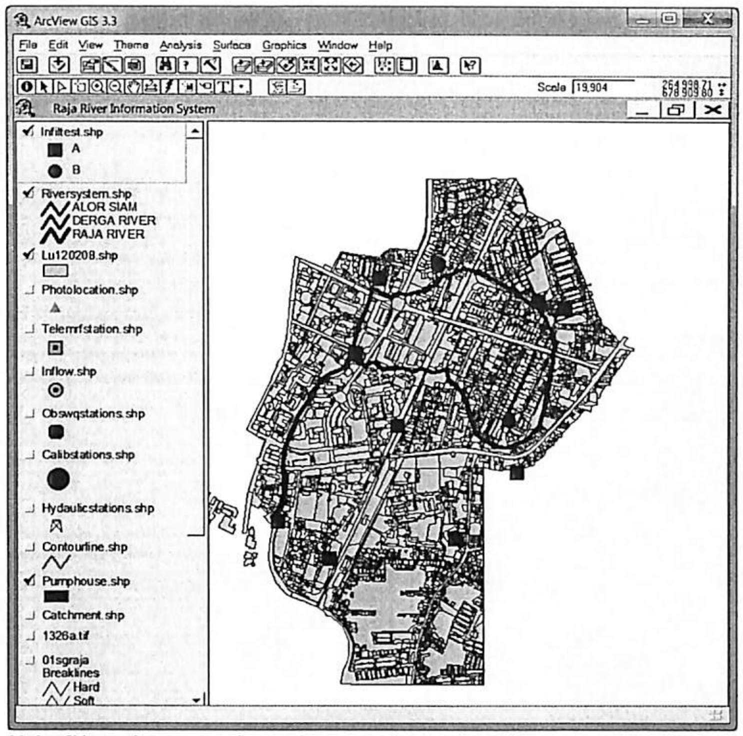


Figure 3.1: Soil infiltration test locations. The red points are HSG A and blue points are HSG B.

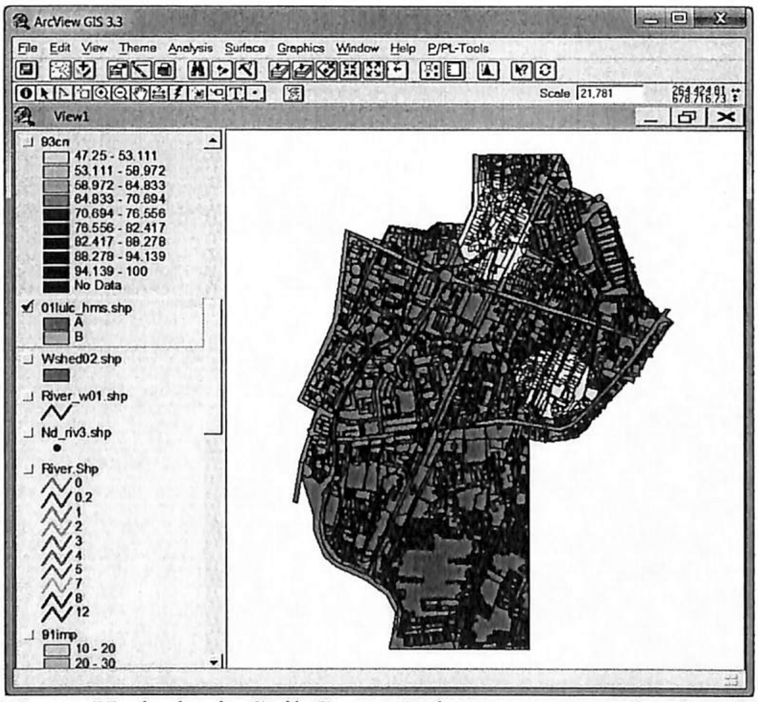


Figure 3.2: Hydrologic Soil Group Polygon generated using ArcView.

3.4.5 Drainage Network and Sub-catchments

Drainage Network and Sub-catchments information were gathered from the JPS Kedah (District of Alor Setar). A total of 129 sub-basins and 215 storm drains were identified. From the information, the drainage alignments were readjusted and regrouped to simplify the drainage system as shown in Figure 3.3.

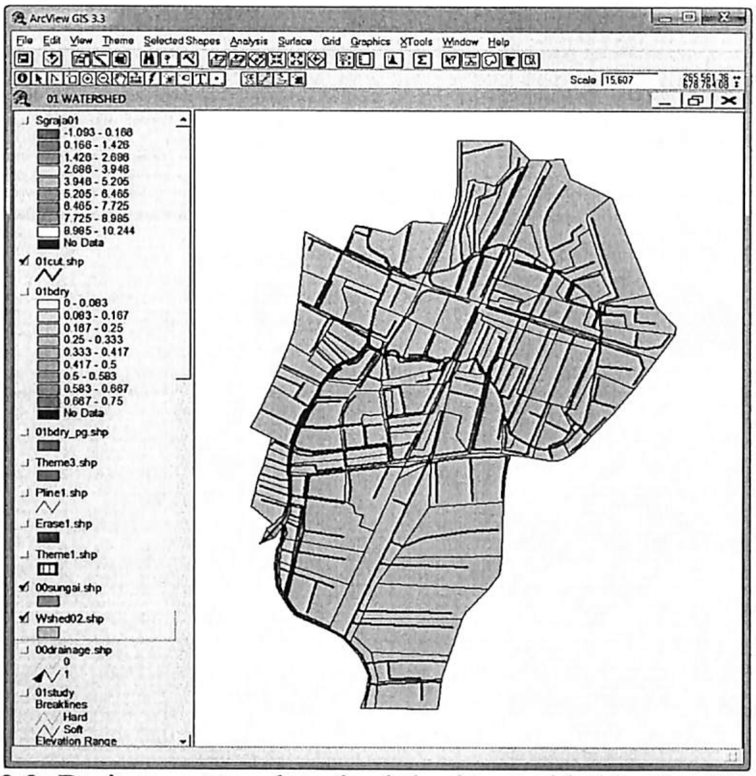


Figure 3.3: Drainage network and sub-basin provided by the JPS Kedah

3.4.6 Stations

Different type of data are required for modelling purposes but only one data type, which is precipitation is available. Other data are either limited or unavailable; hence the stations were established during the course of this study to collect the unavailable data set. The station identified to collect the data for the modelling purposes are:-

i. Precipitation stations (available)
ii. Water Quality Sampling Stations (not available)
iii. Water Quality Observation Stations (not available)
iv. Water level observation stations (not available)

3.4.6.1 Precipitation Stations

There are seven (7) precipitation stations within 10 km radius of the study area. Station maintained by the JPS is located in the study area and rests are maintained by the Muda Agricultural Development Authority (MADA) surrounding the study area (Figure 3.4). Descriptions of the stations are listed in Table 3.2.

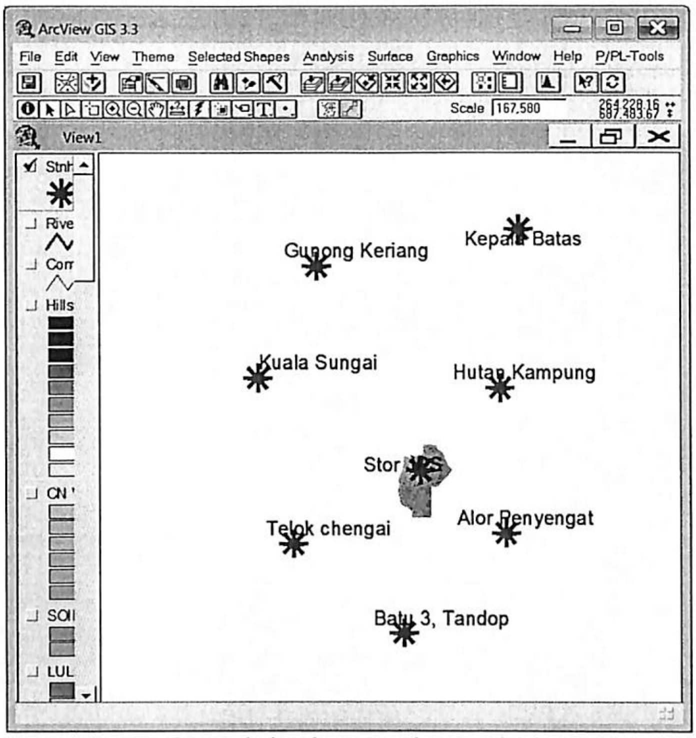


Figure 3.4: Location of Precipitation Stations within 10km of the study area

Table 3.2: List of Precipitation Stations around the Study Area.

No	Station Name		Latitude (N)	Longitude (E)	Type of Data	Duration	Source
1	Stor JPS	Stn 6103047	6.105556	100.3917	Hourly	1970-2012	JPS
					10 min, 30 min	Oct 2012 – Jun 2013	
2	Telok Chengai	Stn52	6.097806	100.3315	Daily	2001-2009	MADA
					Hourly	2011-2012	
3	Bt.3 Tandop	Stn45	6.068278	100.3676	Daily	2001-2009	MADA
					Hourly	2011-2012	
4	Alor Penyengat	Stn38	6.085	100.401	Daily	2001-2009	MADA
					Hourly	2011-2012	
5	Hutan Kampong	Stn29	6.149028	100.399	Daily	2001-2009	MADA
					Hourly	2011-2012	
6	Kepala Batas	Stn27	6.201445	100.4047	Daily	2001-2009	MADA
					Hourly	2011-2012	
7	Gunong Keriang	Stn24	6.188888	100.3388	Daily	2001-2009	MADA
					Hourly	2011-2012	

Note: Rainfall data from MADA for year 2010 only available from 1st – 3rd January, on 2nd July and from 19th – 31st December.

3.4.6.2 Water Quality Sampling Stations

Water quality (WQ) sampling was to determine the amount and/or rate of effluent entering the river system. Results of the exercise were used to establish the water quality class of SRS and for water quality modelling. Based on the identified sub-catchment by the JPS Kedah (Figure 3.5), there are 87 sub-catchments discharging directly into the river system. This makes it almost impossible to collect the amount or rate of water entering the river system at every outfall during this study period. So only some outfalls were selected for water quality modelling purpose as shown in Figure 3.6. The locations were selected based on the accessibility. These samples were used as reference for water quality classification for SRS.

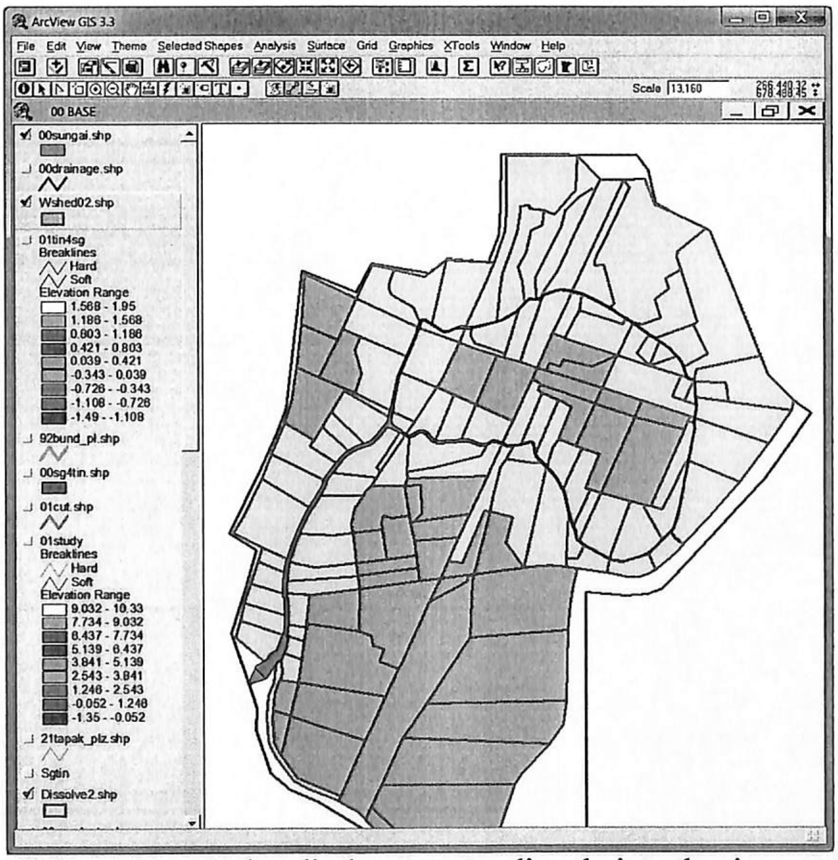


Figure 3.5: Sub-catchments that discharge water directly into the river system shown as yellow polygons.

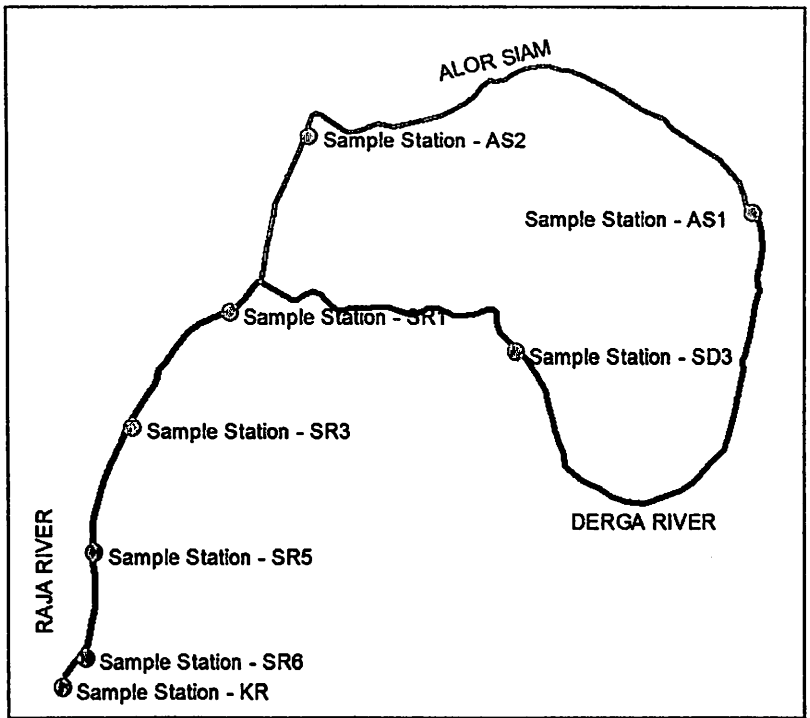


Figure 3.6: Location of Water Quality sampling stations (taken on 15th October 2010)

WQ of each location was classifies using the Water Quality Index (WQI) using the DOE (1994) classification (Table 3.3 and Table 3.4). Based on samples taken on the 15th October 2010, WQI in SRS was classified as Class III. Table 3.5 listed the result of water quality samples taken on 15th October 2010.

Table 3.3 : Relation of Water Quality Index and Pollution Degree (DOE, 1994)

Water Quality Index	Index Range	Pollution Degree
I	92.7 and more	Very clean
II	76.5 to 92.7	Clean
III	51.9 to 76.5	Moderate
IV	31.0 to 51.9	Slightly polluted
V	31.0 and less	Severely polluted

Table 3.4 : Water Quality Classification in Malaysia (DOE, 1994)

Class	I	II	III	IV	V
Ammoniacal Nitrogen	< 0.1	- 0.3	– 0.9	0.9 – 2.7	> 2.7
BioChemical Oxygen Demand	< 1	1 - 3	3 – 6	6 – 12	> 12
Chemical Oxygen Demand	< 10	10 – 25	25 – 50	50 – 100	> 100
Dissolved Oxygen	> 7	5 – 7	3 – 5	1 - 3	< 1
pH	> 7	6 – 7	5 – 6	< 5	< 5
Total Suspended Solid	< 25	25 - 50	50 - 150	150 - 300	> 300

Table 3.5: Results of Water Quality samples taken on 15th October 2010 .

No	LOCATION/ SAMPLE	pH	BOD-5 mg/l	COD mg/l	TSS mg/l	O&G mg/l	AN mg/l	DO mg/l	TN mg/l	PO4 mg/l
1	KR - PM	6.7	4	30	48	<5	<1	5.5	1	0.41
2	RO - PM	7.2	5	26	14	<5	<1	4	1	1.13
3	R245 - PM	7.1	10	28	5	<5	2	2.9	3	1.78
4	R530 - PM	7.3	4	22	10	<5	3	4.7	4	1.41
5	R840 - PM	7.1	12	32	<1	<5	5	1	6	1.94
6	AS342 - PM	7.3	11	40	6	<5	8	2.1	9	1.99
7	D634 - PM	7.2	9	36	18	<5	8	4.4	9	2
8	AS US - PM	7.3	16	50	10	<5	14	29	15	4.77
9	KR - AM	6.8	6	36	74	<5	<1	6	1	0.42
10	RO - AM	7.2	6	28	17	<5	2	4.4	3	1.03
11	R245 - AM	7	6	24	38	<5	2	4.8	3	1.17
12	R530 - AM	7	6	28	6	<5	3	5.1	4	1.51
13	R480 - AM	7	8	34	5	<5	3	5	4	1.51
14	AS342 - AM	7.1	5	28	1	<5	3	4.2	4	1.58
15	D634 - AM	6.9	5	32	12	<5	4	3	4	1.56
16	AS US - AM	7.2	15	38	8	<5	13	2.1	14	4.67

3.4.6.3 Water Quality Observation Stations

The conditions for water quality modelling (as initial conditions and for calibration) were determined by field measurements at specific date for the selected locations. The pollutants concentration for Dissolved Oxygen, pH and Ammoniacal Nitrogen measured for the dry weather condition. The location of measurement stations shown in Figure 3.7 (Ramli, 2013).

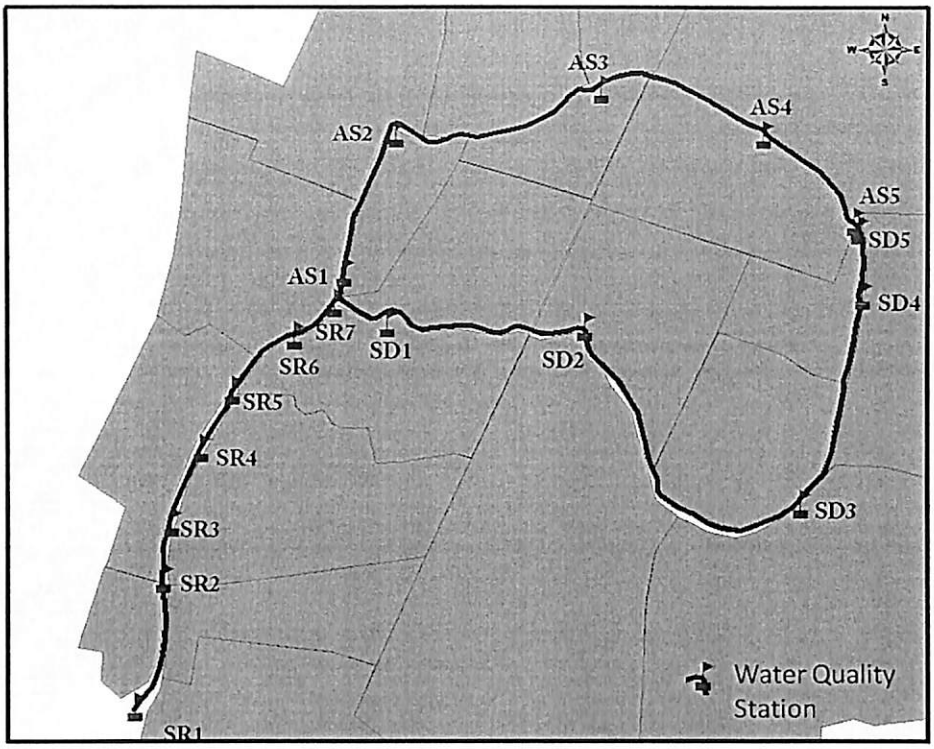


Figure 3.7 : Water Quality Stations Measurement for Initial Conditions (from Ramli, 2013)

3.4.6.4 Water level (WL) observation stations

Initially the station was set near the JPS Office but was found not suitable for calibration purposes. The WL station was transferred to immediately upstream of Pumping Station as shown in Figure 3.8. Water levels measured at this location were used for model calibrations and validation.

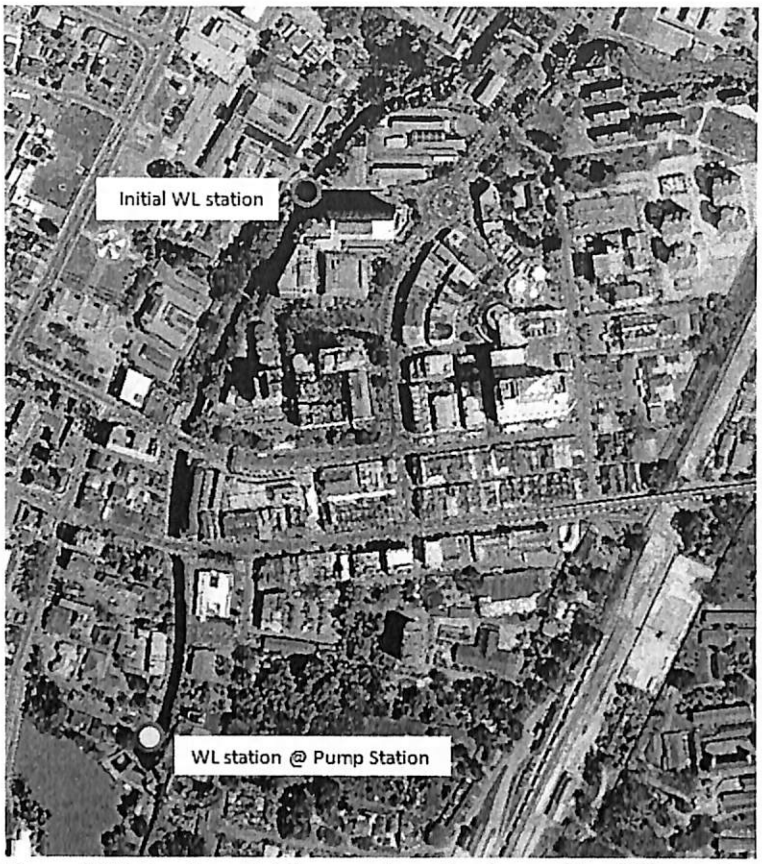


Figure 3.8: Location of Water Level Observation Stations. The WL station was transferred from the Initial WS station after it was found not suitable to just immediately upstream of the Pumping Station

3.5 NON-SPATIAL DATA

Data required to run the hydrologic and hydraulics model are precipitation and water level.

3.5.1 Precipitation

Precipitation data were obtained from the JPS and MADA as listed in Table 3.3.

3.5.2 Water level data

There was no water level and flow discharge stations in the study area. These information are necessary for calibration and validation of the models. Data were manually collected at the Initial WL Station on the 28th February 2012 from 8:30am to 4:00pm to represent the flow condition during dry period. No data was collected at night due to safety reasons. Stage hydrograph for dry condition is as shown in Figure 3.9.

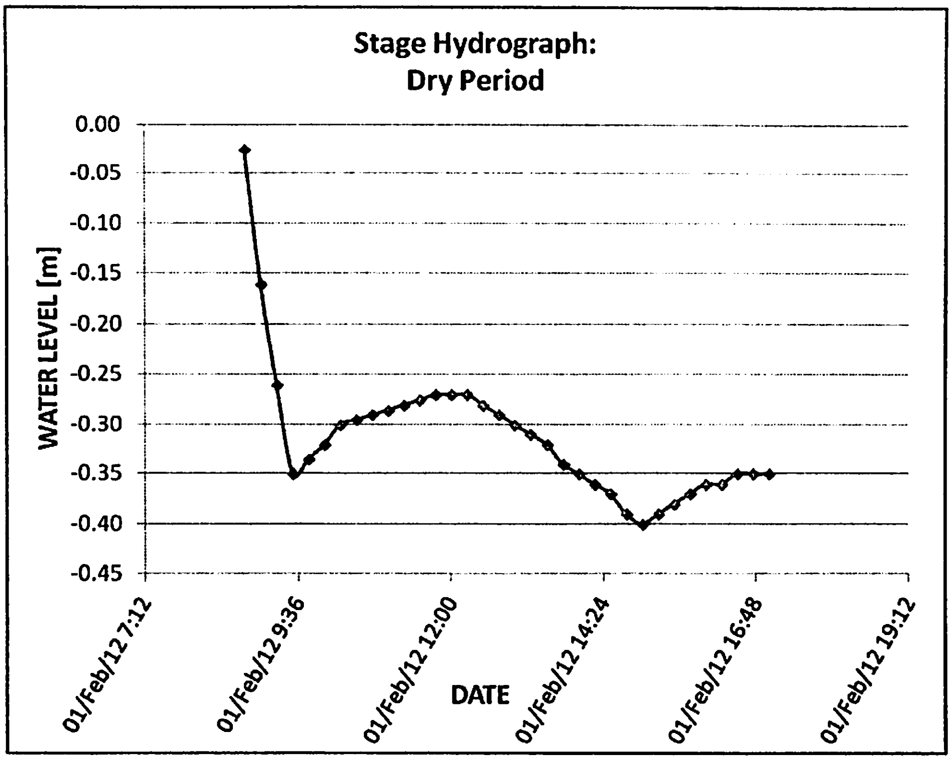


Figure 3.9: Stage Hydrograph of Sungai Raja Reach to represent dry period

To overcome the safety problem and also to obtain longer water level records, a wireless and automatic device to collect water levels (also water temperature and DO data) and transmit the information automatically was design and developed. This prototype took about a year to complete and operated successfully. The descriptions of the development of the device are as follows:-

DEVELOPMENT OF PORTABLE WIRELESS WATER QUALITY MEASUREMENT SYSTEM (WQMS)

Design, Fabrication and Test of the First Prototype

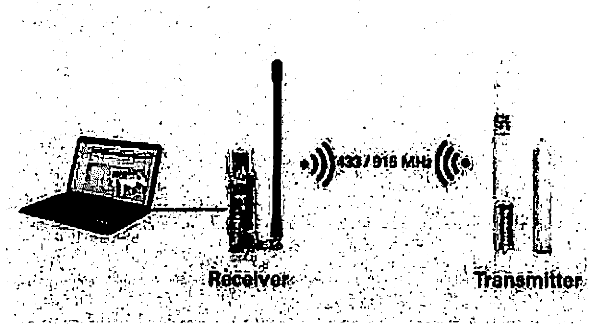


Figure 3.10: Schematic Presentation of the Wireless Water Quality Monitoring System

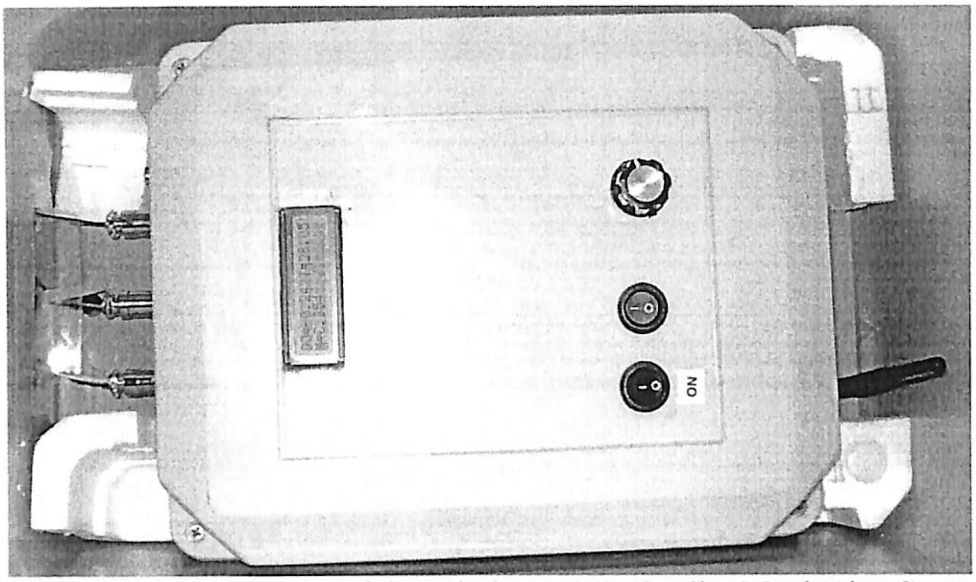


Figure 3.11: The prototype of the Wireless Water Quality Monitoring System

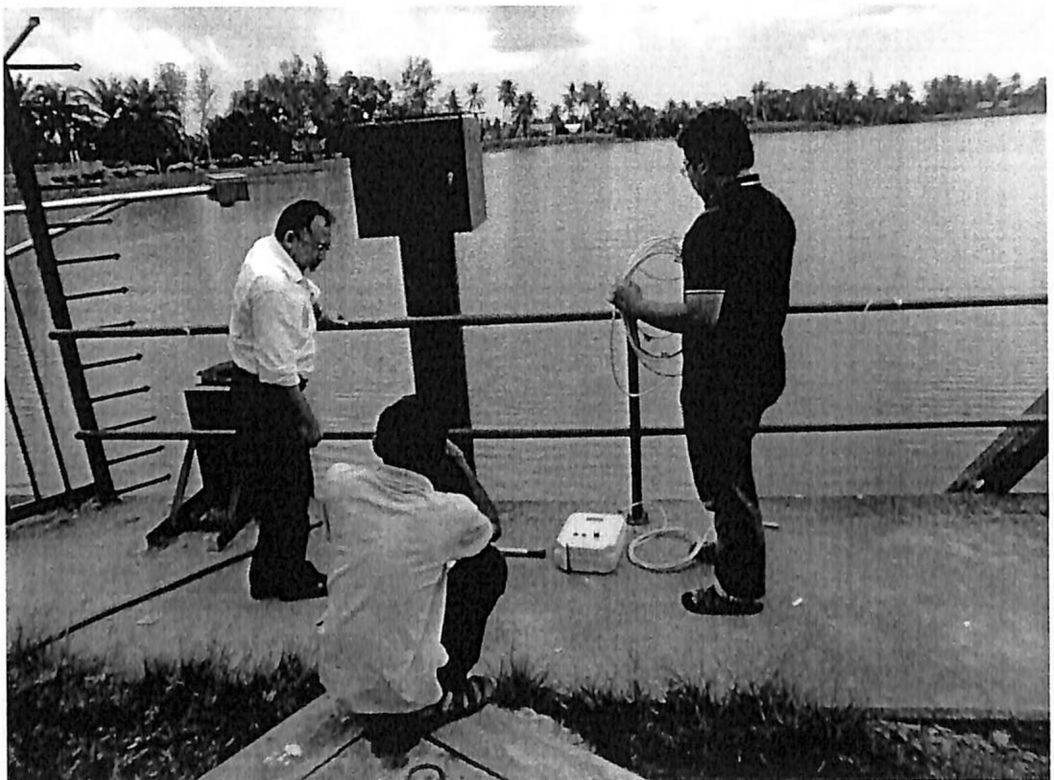


Figure 3.12: Portable wireless water environment monitoring system being tested

WQMS as shown schematically in Figure 3.10 and prototype as Figure 3.11 has successfully designed, fabricated and tested (Figure 3.12). Currently this equipment is used to measure water level, dissolve oxygen and temperature. Table 3.6 shows the specifications of the sensors used in this system.

Table 3.6: Sensors Specification used for development of WQMS.

	Sensor	Specification
1	Water level	0 - 15ft (0 – 5 m)
2	Dissolve Oxygen	0 - 100% Saturation
3	Temperature	0 - 50°C

Data measured from the sensors is displayed on the LCD at the top surface of the system and transmitted wirelessly to the server. Figure 3.13 shows the example of the data which has been transmitted from the system. The data can be logged as *.txt file. The maximum distance which the system can transmit the data to the server is about 1 km. Wireless data transmission in important because the real time data can be monitored at a location a distance away from the system without going to the system often. This equipment has solved the safety concern as well as able to obtain longer data.

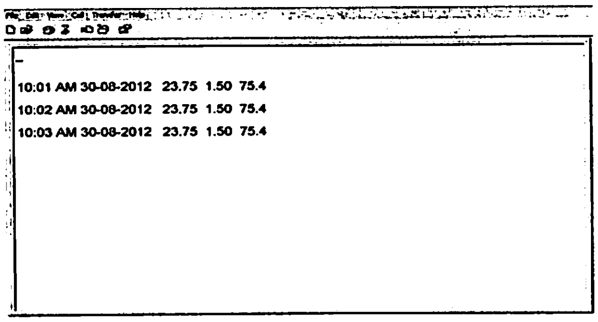

10:01 AM 30-08-2012 23.75 1.50 75.4
10:02 AM 30-08-2012 23.75 1.50 75.4
10:03 AM 30-08-2012 23.75 1.50 75.4

Figure 3.13: Example of Transmitted Data recorded in txt file

Waterproof system is important because the system will be placed on the riverbank in the outdoor environment. Currently, the system used plastic box available in the market as casing. To connect the sensors ports, power supply port, ON/OFF switch and LCD display the casing is drilled manually. Although the system is can be operated but has a number of weakness:

a. The casing is bulky;

b. Battery lasts about 4 hour and cause interruption to data transmission;

c. Battery requires a couple of hour to fully charged cause discontinuous data acquisition.

Considering the potential for this equipment, it is suggested to continue developing as follows:-

Further development: Optimization, Robustness and Reliability Enhancement

1. Upgrading Circuit Board

Currently the system circuit board (Figure 3.14) is made onto strip-board. The board requires spaces between individual components which makes the size increase. To reduce the size of the circuit board, double layer or three layers PCB can be used. However, the price for fabrication double or three layers PCB is much higher compared to the strip-board. There is trade between size and price. The PCB boards also much reliable and much easy to solder the components onto it.

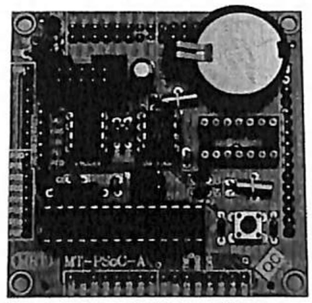


Figure 3.14: Example of Double Layer PCB Board

2. Upgrading Wireless Data Transmission Range

Currently, the system can transmit data up to 1km. We propose to use much powerful transmitter so the range of data transmission can increase up to 10 km.

3. Upgrading Data Storage Software & Real-time Graphic Creation

Currently, the transmitted data is save as *.txt file. The user needs to extract the data or plot the data inside Microsoft Excel (Figure 3.15) in order to determine the trend/graph of the measured data. The developed Real-time graphic software can automatically converts the transmitted data into graph. So, user can see the pattern of the data changing in real-time in term of graph rather than the number only. The real time pattern or graph can be directly saved to the computer.

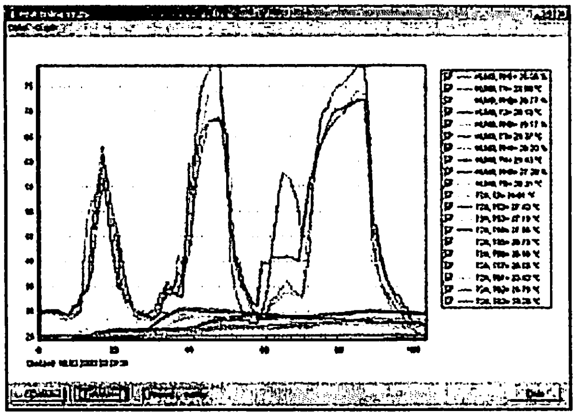


Figure 3.15: Real-time data plotting

Although this equipment also recorded the temperature and Dissolve Oxygen, only water level data were analysed. Two set of data were taken using this equipment from 11 November 2012 to 13 November 2012 (Figure 3.16 and Figure 3.17) and 28 February 2013 to 01 March 2013 (Figure 3.18).

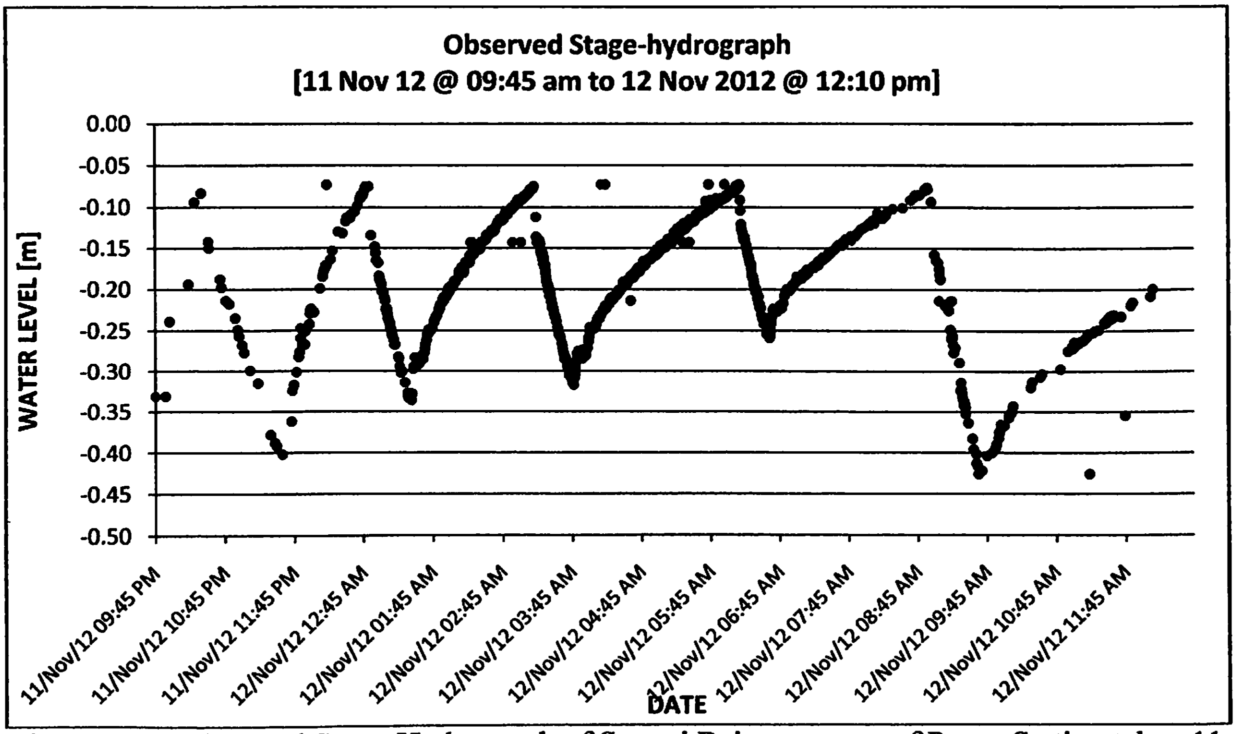


Figure 3.16: Observed Stage-Hydrograph of Sungai Raja upstream of Pump Station taken 11 Nov 12 @ 09:45 am to 12 Nov 2012 @ 12:10 pm

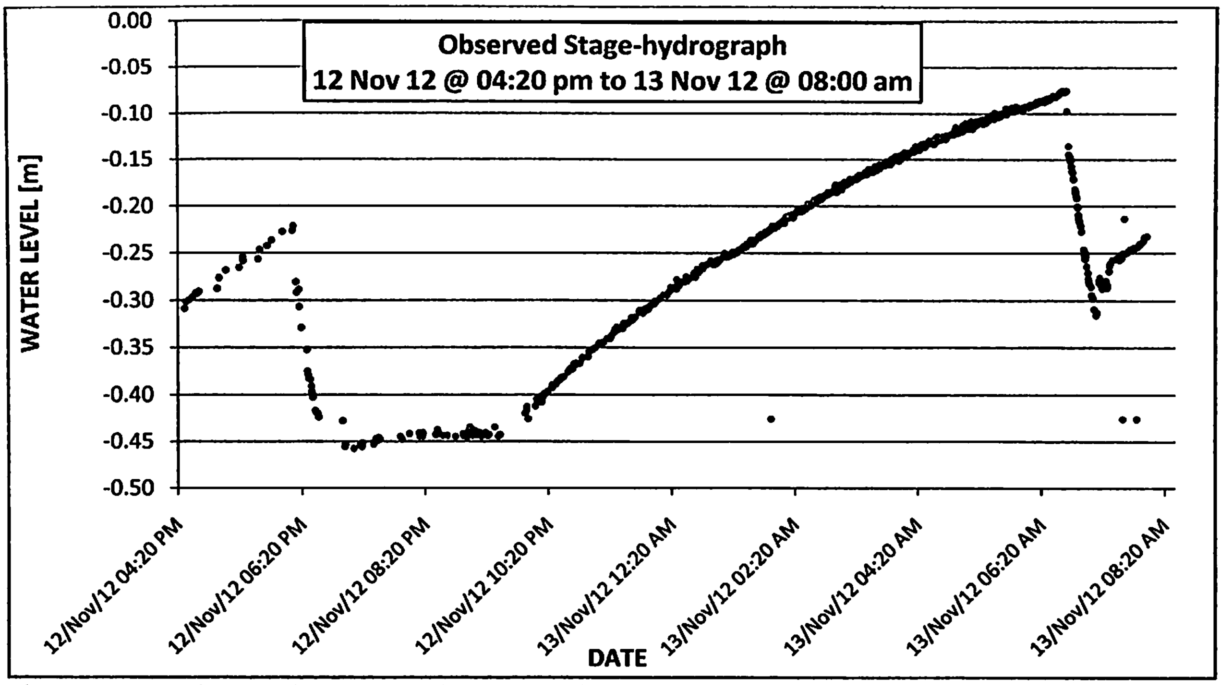


Figure 3.17: Observed Stage-Hydrograph of Sungai Raja upstream of Pump Station taken 12 Nov 12 @ 04:20 pm to 13 Nov 12 @ 08:00 am

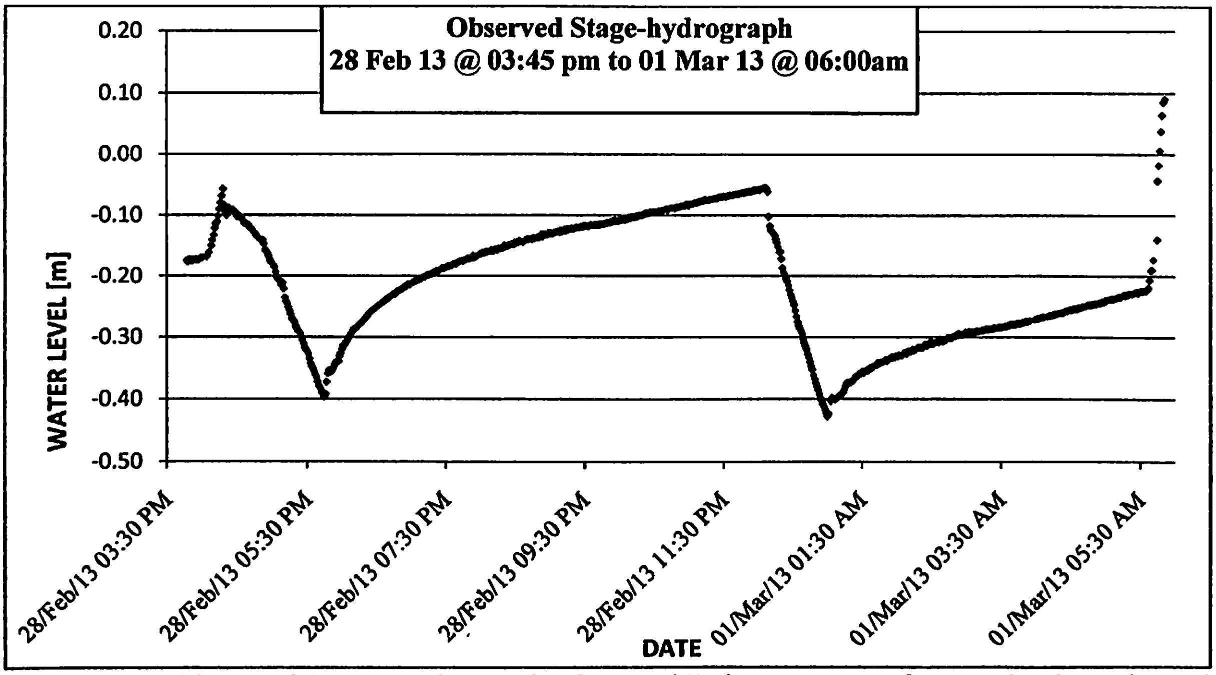


Figure 3.18: Observed Stage-Hydrograph of Sungai Raja upstream of Pump Station taken 28 Feb 13 @ 03:45 pm to 01 Mar 13 @ 06:00am

3.6 DATA PREPARATION FOR MODELLING

Data preparation involved various stages and steps. Figure 3.19 shows the flowchart of simplified models preparation in GIS environment.

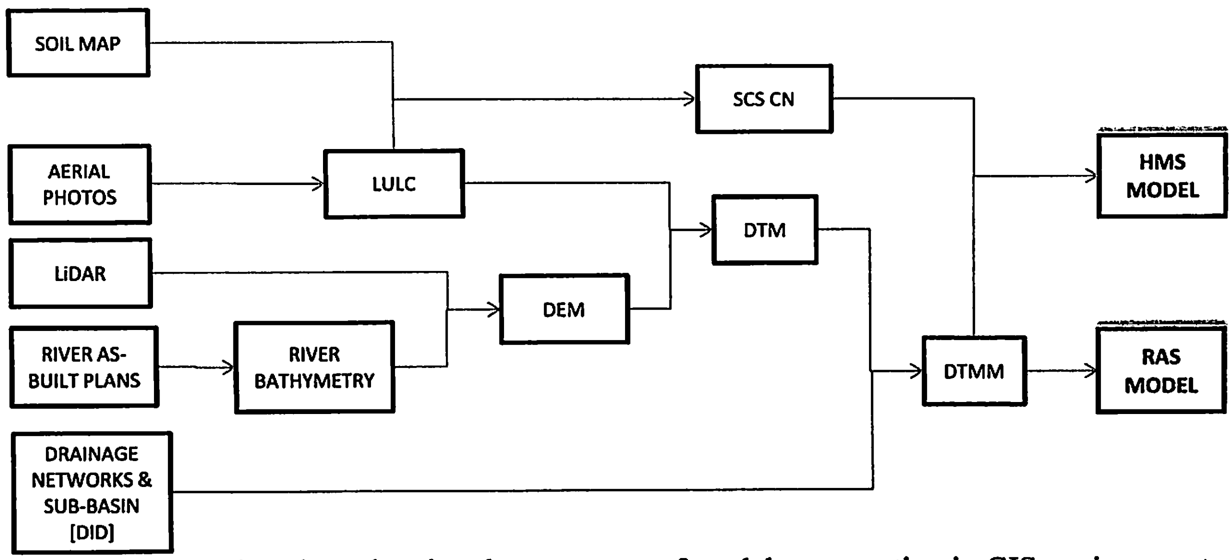


Figure 3.19: Flowchart showing the processes of models preparation in GIS environment. The leftmost boxes are the primary data that are stored in the GIS database.

Preparation of Land Use Land Cover (LULC), River Bathymetry, the Digital Elevation Model (DEM), and the Digital Terrain Model (DTM) listed below are not in sequential order.

3.6.1 Preparation of River "Bathymetry" from As-built plan

DEMs were first generated from the LiDAR and found that river details (Sungai Raja, Sg Derga and Alor Siam) were not picked up very well. The river details can be incorporated into the system by carrying out the river survey and this will consume a lot of time and financial cost. Since the river system is made of concrete and there is no modification made to the river system, then it is assumed that the as-built drawings prepared in year 1995 by the JPS are still useable. Scanned images of the as-built plans were utilised to produce the river bathymetry. The images were rescaled, reoriented, and geo-referenced using the ArcGIS geo-referencing tools. The geo-referenced images were laid under a new river theme (Figure 3.20) and the physical attributes of the rivers were "extracted" and added into the river theme attribute (Figure 3.21). The attributes are:-

a) Geometrical shape of the river;

b) Invert levels;

c) Bed slope; and

d) Structures (bridge, culvert, transition).

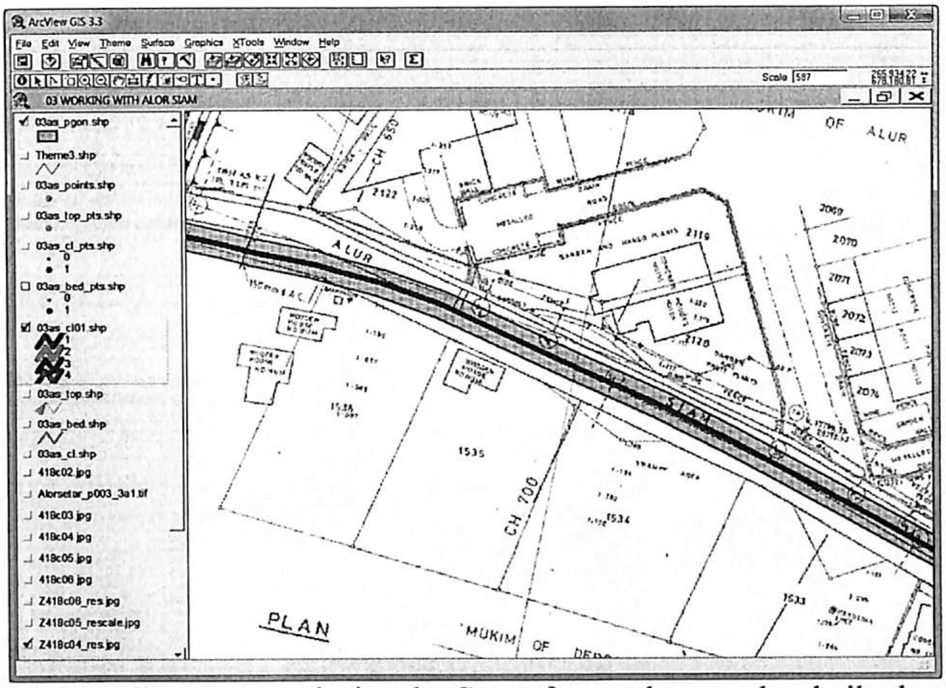


Figure 3.20: River alignment overlaying the Geo-referenced scanned as-built plans. Physical information were extracted from the images and transferred to the river theme attribute table.

Shape	Line ID	R name	Chus	Chds	Bw	Bs	Remarks	Il us	Il ds	Ls	Rs	Str	Plan no
PolyLine	1	ALOR SIAM	1268.0	1194.6	2.0	800.0	U DRAIN	0.532	0.293	1000.00	1000.00	2.0 x 1.0 x 0.3R	418c06
PolyLine	2	ALOR SIAM	1194.6	1191.6	2.0	0.0	BOX CULVERT	0.293	0.305	0.00	0.00	RC 2 X 1.2 BOX	418c06
PolyLine	3	ALOR SIAM	1191.6	1153.3	2.0	800.0	U DRAIN	0.305	0.250	1000.00	1000.00	2 M X 1 M X0.3R	418c06
PolyLine	4	ALOR SIAM	1153.3	1144.2	0.0	0.0	FILLED CULVERT	0.250	0.240	0.00	0.00	FILLED CULVERT	418c06
PolyLine	5	ALOR SIAM	1144.2	1098.0	4.0	1000.0	U DRAIN	0.240	0.215	1000.00	1000.00	4 X 1.5 X 0.3R	418c06
PolyLine	6	ALOR SIAM	1098.0	862.0	4.0	100.0	U DRAIN	0.215	0.015	1000.00	1000.00	4M X 1.5M X 0.3R	418C05
PolyLine	7	ALOR SIAM	862.0	859.6	5.0	1000.0	TRANSITION	0.015	0.015	1000.00	1000.00	5M X 1.5M X 0.3R	418C05
PolyLine	8	ALOR SIAM	859.6	847.6	5.0	0.0	BOX CULVERT	0.015	-0.020	0.00	0.00	RC 5 X 1.05M	418C05
PolyLine	9	ALOR SIAM	847.6	842.9	4.5	0.0	TRANSITION	-0.020	-0.020	1000.00	1000.00	5M X 1.5M X 0.3R	418C05
PolyLine	10	ALOR SIAM	842.9	838.0	4.5	1000.0	U DRAIN	-0.020	-0.020	1000.00	1000.00	4.5M X 1.8M X 0.3R	418C05
PolyLine	11	ALOR SIAM	838.0	564.0	4.5	1000.0	U DRAIN	-0.020	-0.295	1000.00	1000.00	4.5M X 1.8M X 0.3R	418C04
PolyLine	12	ALOR SIAM	564.0	525.0	4.5	1000.0	U DRAIN	-0.295	-0.334	1000.00	1000.00	4.5M X 1.8M X 0.3R	418C03
PolyLine	13	ALOR SIAM	525.0	508.4	8.1	1000.0	TRANSITION	-0.334	-0.339	1000.00	1000.00	8.1M X 1.8M X 0.3R	418C03
PolyLine	14	ALOR SIAM	508.4	499.4	4.5	0.0	BOX CULVERT	-0.339	-0.366	0.00	0.00	4.5M X 1.65 RC	418C03
PolyLine	15	ALOR SIAM	499.4	491.6	8.1	1000.0	TRANSITION	-0.366	-0.374	1000.00	1000.00	8.1M X 1.8M X 0.3R	418C03
PolyLine	16	ALOR SIAM	491.6	347.0	4.5	1000.0	U DRAIN	-0.374	-0.560	1000.00	1000.00	4.5M X 1.8M X 0.3R	418C03
PolyLine	17	ALOR SIAM	347.0	234.5	4.5	1000.0	U DRAIN	-0.560	-0.627	1000.00	1000.00	4.5M X 1.8M X 0.3R	418C02
PolyLine	18	ALOR SIAM	234.5	226.7	4.5	1000.0	TRANSITION	-0.627	-0.635	1000.00	1000.00	4.5M X 1.8M X 0.3R	418C02
PolyLine	19	ALOR SIAM	226.7	197.1	8.4	1000.0	BRIDGE	-0.635	-0.660	1000.00	1000.00	BRIDGE	418C02
PolyLine	20	ALOR SIAM	197.1	190.3	8.4	1000.0	TRANSITION	-0.660	-0.666	1000.00	1000.00	8.4M X 2M X 0.3R	418C02
PolyLine	21	ALOR SIAM	190.3	17.1	5.0	1000.0	U DRAIN	-0.666	-0.843	1000.00	1000.00	5 M X 2M X0.3R	418C02

Figure 3.21: Attribute of the river theme

The TIN of river bathymetry (Figure 3.22) was generated using the ArcView 3D extension. From the river bathymetry, SRS storage-curve (Figure 3.23) was produced by utilising the ArcView capability to extract volume from TIN feature.

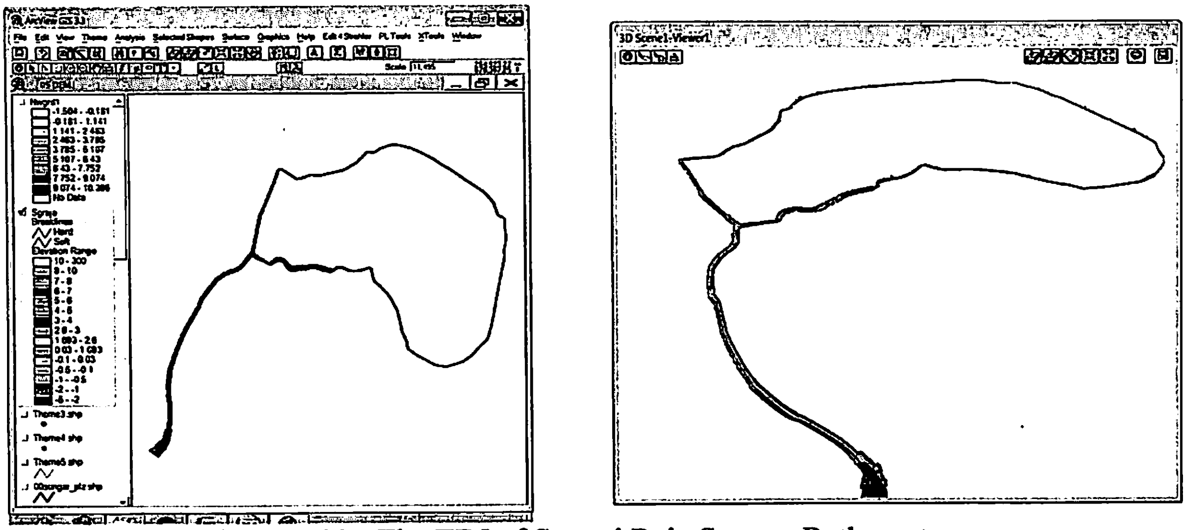


Figure 3.22: The TIN of Sungai Raja System Bathymetry.

Water Level (m)	Storage Volume (m^3)
-1.50	0.00
-1.25	100.18
-1.00	586.11
-0.75	2743.48
-0.70	3317.25
-0.60	4631.33
-0.50	6363.73
-0.40	8337.12
-0.30	10473.03
-0.20	12760.59
-0.10	15171.33
0.00	17706.46
1.10	51274.58
1.30	57859.08
1.50	69630.30

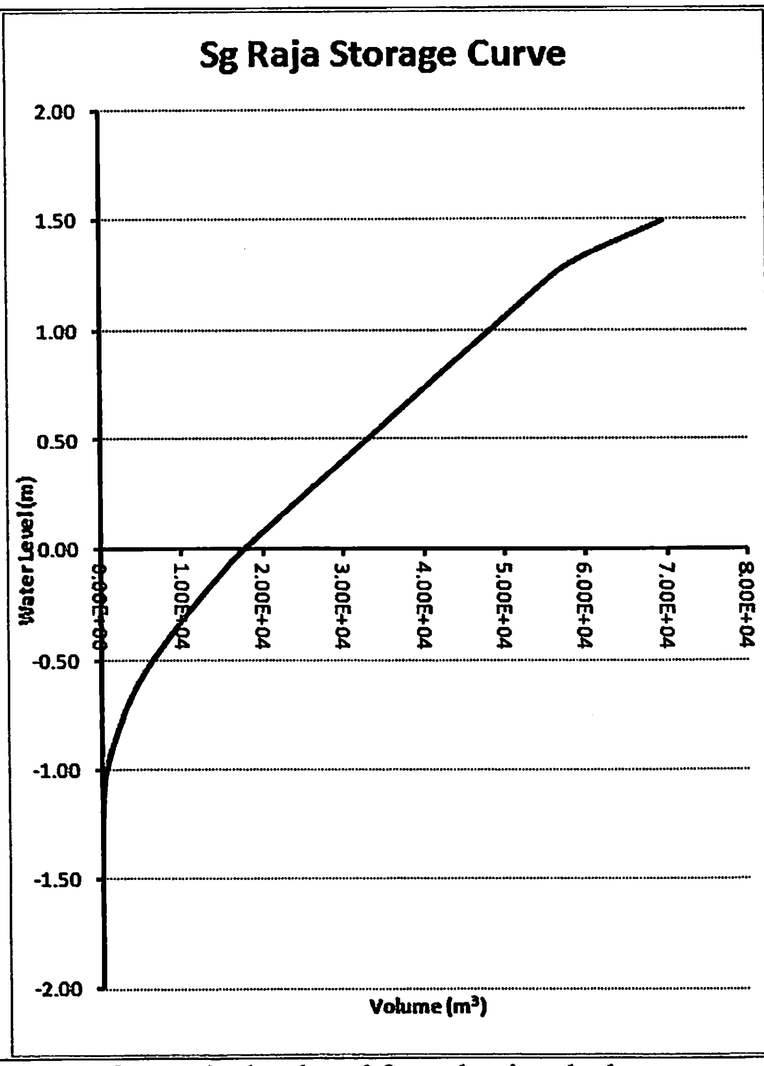


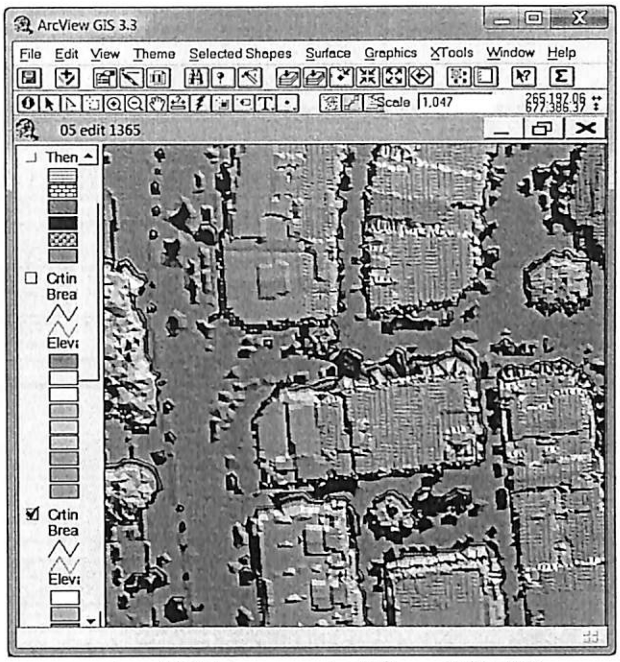
Figure 3.23: Storage curve of Sg Raja developed from the river bathymetry

3.6.2 Demarcation of Land Use and Land Cover

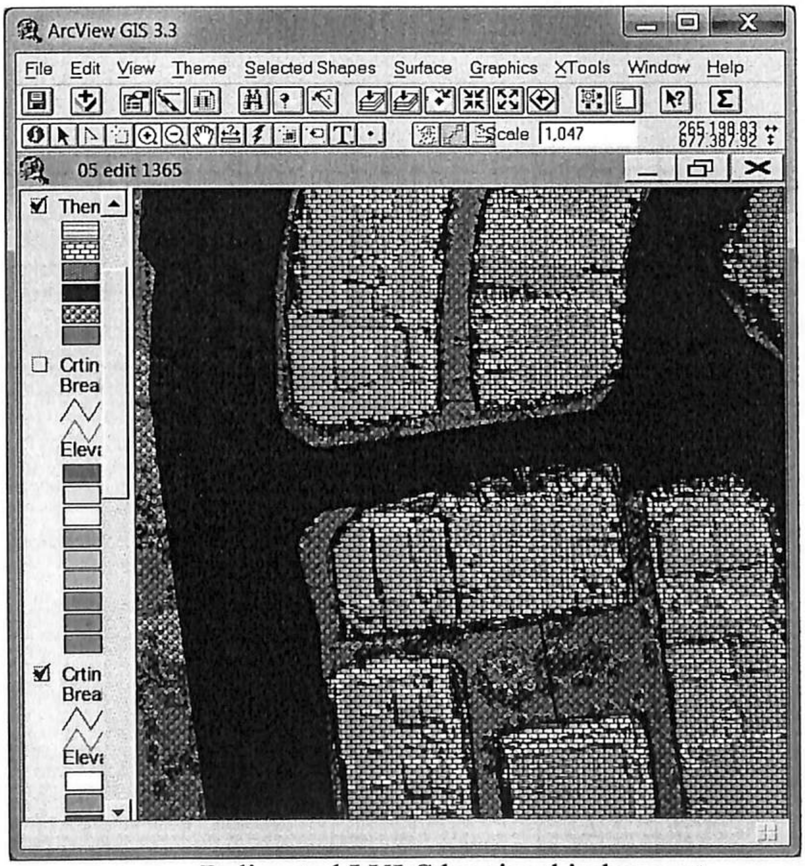
Land use is defined as the activities that take place on the land and land cover is referring to what is on the land surface. The developed areas can be easily identified from the aerial photos but not for vegetated and/or open surfaces. For modelling purposes the land use and land cover (LULC) are consider interchangeable. The LULC were categorized as barren lands, buildings, greens, roads, pavement, railways, and rivers.

LULC were extracted from aerial photos and the DEM generated from the LiDAR survey. The placement of the objects, especially tall objects cannot be judged by the aerial photos or the DEM alone. The tall objects seem to be slanting (Figure 3.24a) and the base of the buildings sometimes not clearly defined as in Figure 3.24b. Attempts were made to automatically delineate the LULC by using available features in GIS environment. One of them was trying to locate the abrupt slope change (to indicate the boundary of flatter surface (e.g. road) and steeper surface (usually building) but failed. This is due too many abrupt changes and a lot of features formed did not coincide with the buildings. Finally the LULC delineation was manually delineated by visual judgement (Figure 3.24c). Table 3.7 summarised the LULC of the study area.

a. Aerial Photo showing slanting buildings



b. DEM generated from LiDAR



c. Delienated LULC by visual judgement

Figure 3.24: Process of delineating land use. Visual judgement was found to be the most suitable technique to produce the LULC theme

Table 3.7: LULC of the study area.

LANDUSE	AREA (HA)	%AGE
Barren Land	15.176	4.78
Building	90.007	28.37
Greens	107.737	33.96
Road	52.285	16.48
Pavement	46.118	14.54
Railway	1.746	0.55
River	4.199	1.32
TOTAL	317.266	100.00

Build-up area (building, road, pavement, and railway) makes up 59.9% of the study area and lies mostly on the northern half of the study area as shown in Figure 3.25.

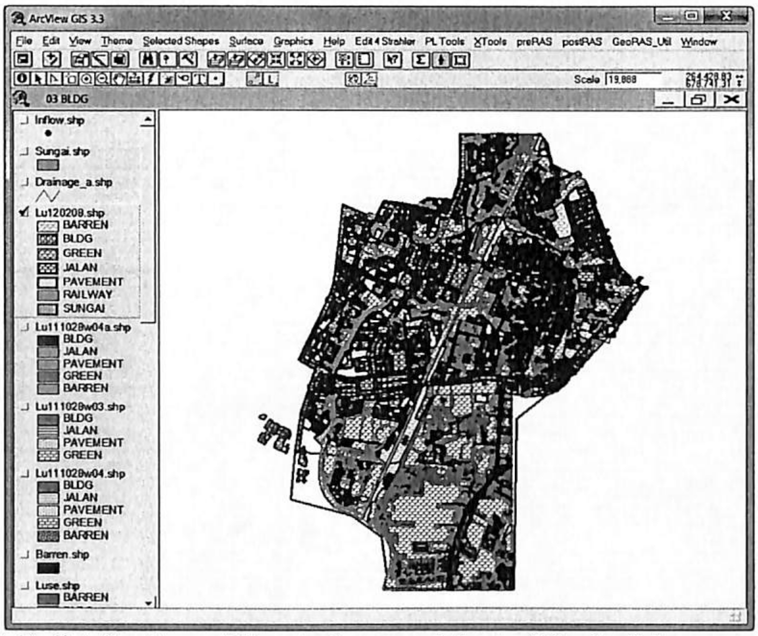


Figure 3.25: LULC distribution of the study area. Most of the build-up areas are located on the northern segment of the study area.

3.6.3 Preparation of DEM and DTM

DEM was produced by generating the LiDAR in TIN format. The generated DEM did not show the river alignment very well. This is due to areas covered by the tree canopies and LiDAR survey did not picked up waterbodies very well. There are other protruding objects such as cars, pedestrians, pillars and etc which will cause watershed delineation to be inaccurate. Removal of these objects was carried out segment by segment and requires the combination of LULC, aerial photos, LiDAR points, the DEM and most important visual judgement to clean these objects. Sequence of trees and other high objects removal is as shown in Figure 3.26 to G.32 below:-

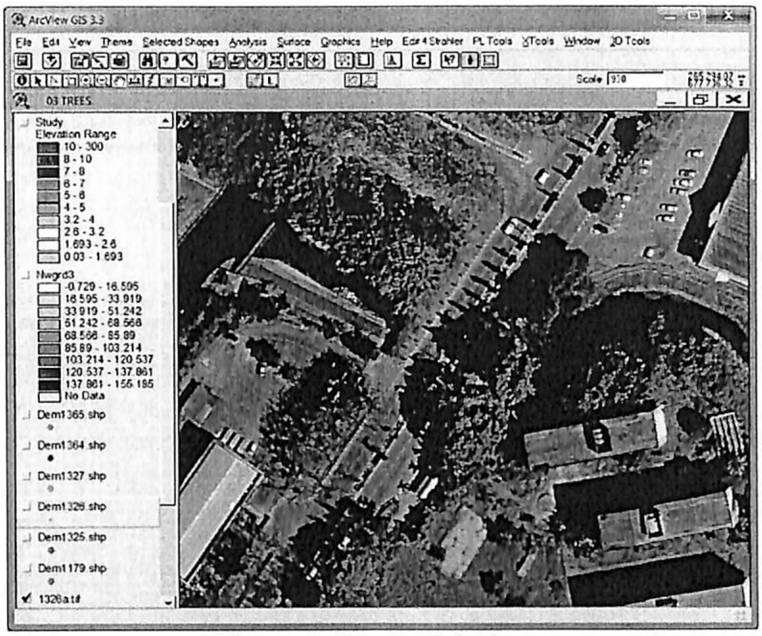


Figure 3.26: Aerial Photo

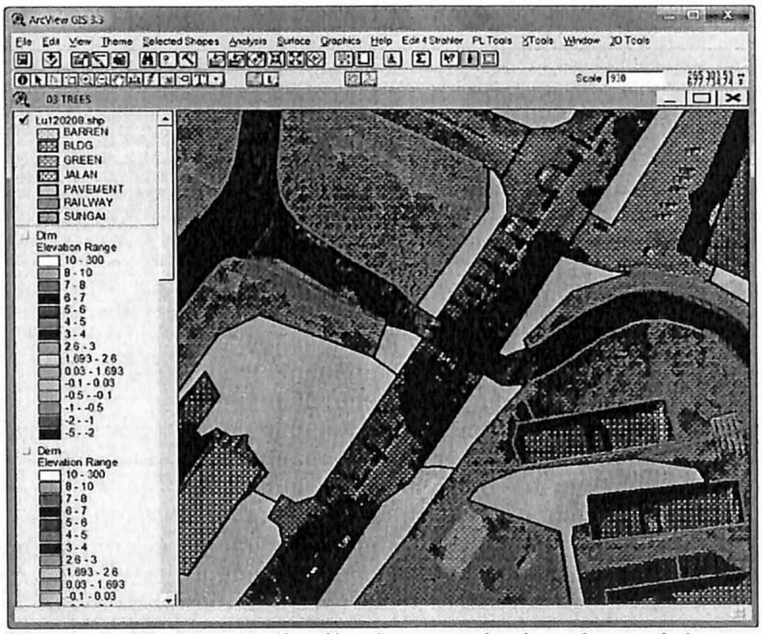


Figure 3.27: LULC distribution overlaying the aerial poto

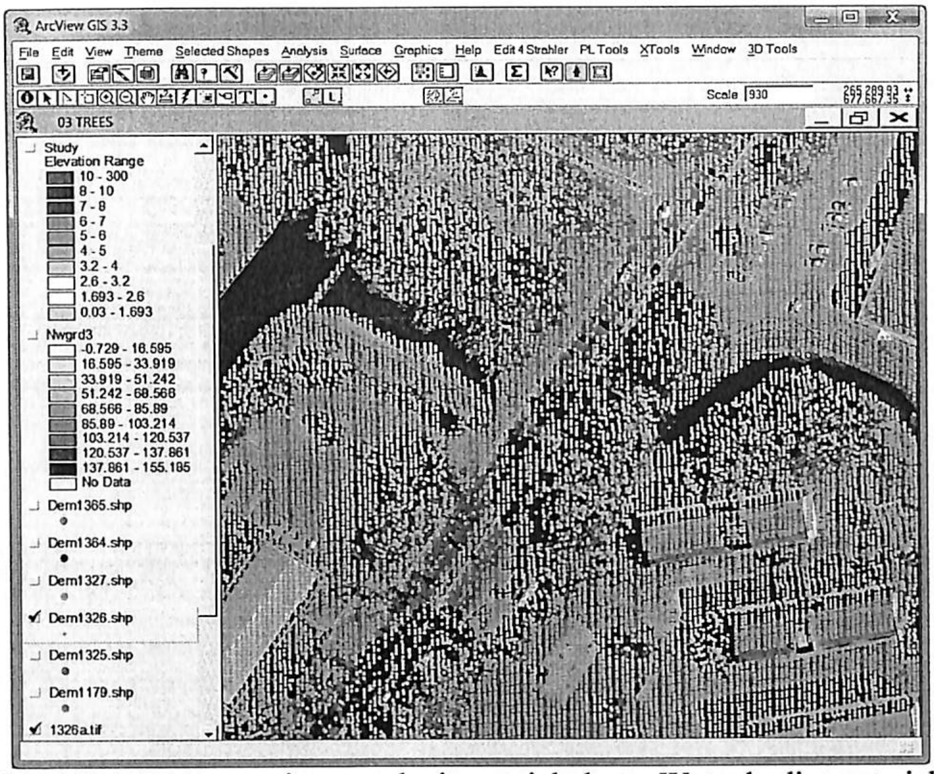


Figure 3.28: LiDAR survey points overlaying aerial photo. Water bodies not picked up by LiDAR

Figure 3.29: DEM generated using only LiDAR points.

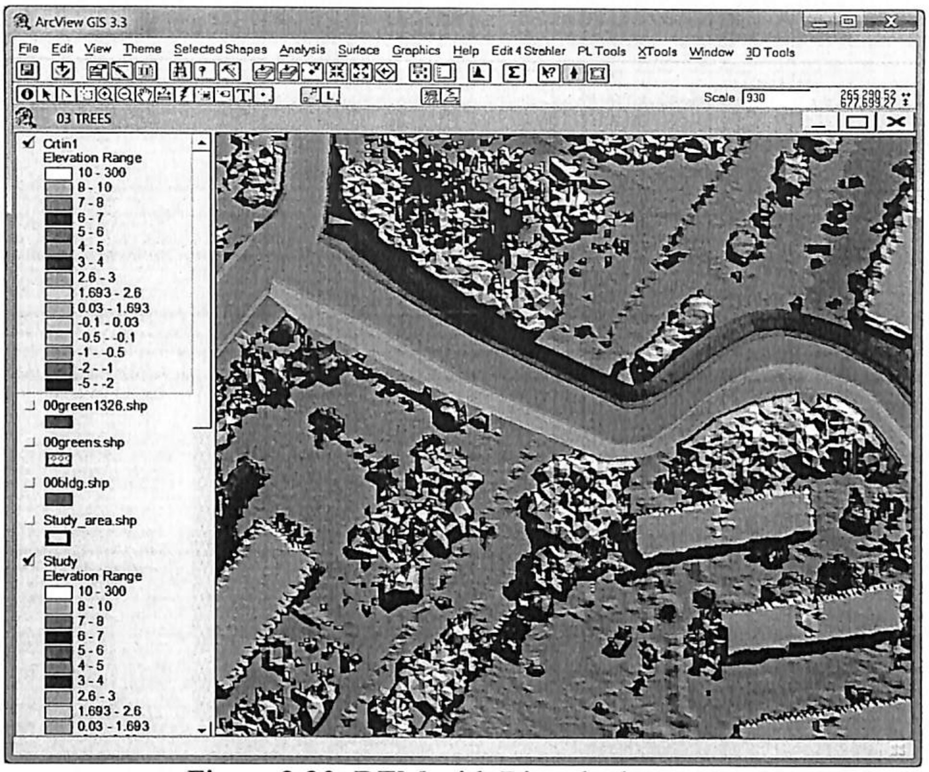


Figure 3.30: DEM with River bathymetry.

Figure 3.31: DEM with trees removed.

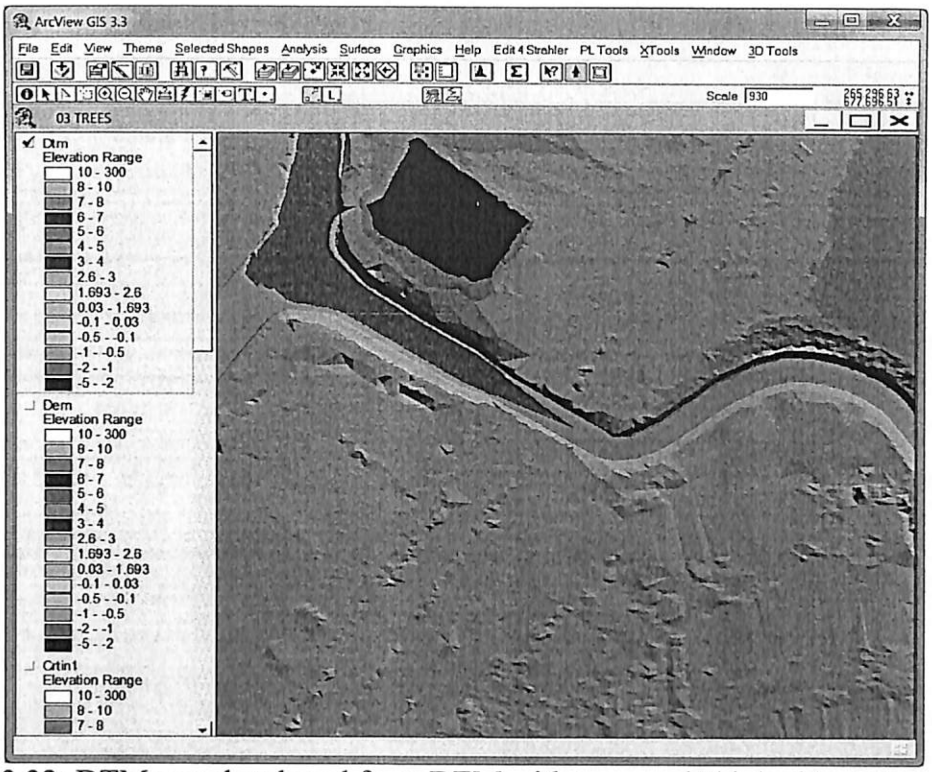


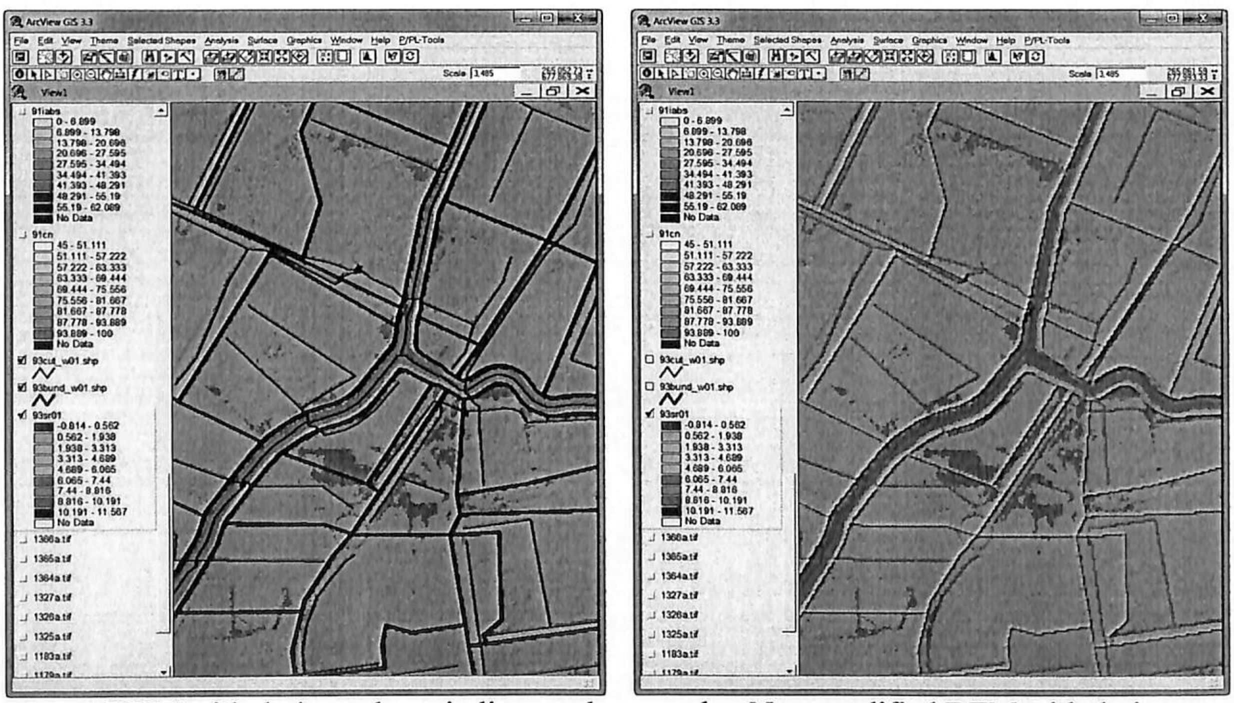
Figure 3.32: DTM was developed from DEM with trees and "high objects" removed.

3.7 PREPARING THE INPUT MAPS FOR MODELLING

3.7.1 Watershed boundaries and stream network delineation:

Accurate drainage boundaries are essential for accurate modelling studies. Prior to implementation of the hydrologic modelling watershed and stream delineation were performed. For natural terrain, the sub-basin is form based on the watershed ridges and the sub-basins can be generated automatically. Since the study area lies in a very flat area, where the elevation ranges from 2m to 3 m and mostly less than 2.5 m, automatic generating of sub-catchments will not be possible. Furthermore, the urban drainage system does not follow natural terrain. In many instances, drainage system was constructed based on the convenience, or approval from the authorities, or the new drainage alignment connectivity to existing drainage system, land availability, and etc.

Before the DTM can be used to delineate the watersheds and stream networks, the DTM produced earlier were edited and manipulated to ensure the sub-basins and drainage networks conformed to the actual condition. Two features were used for these purposes which are the watersheds and the drainage systems (obtained from the JPS). The watershed polygons were converted into polylines to represent the sub-catchments ridges or "walls". Process of 'Building Walls', involve raising the elevation of a connected watershed cells to segregated one sub-basin from the others. The digitized drainage networks were used for burning process to produce the drainage networks. Through this procedure, the DTM grid was modified to force water flow into the "drainage networks". HEC-geoHMS was used to automate the delineation processed and the resultant delineated streams and sub-basins were compared to actual condition. Further processes were carried out using the HEC-geoHMS to redistribute the sub-basin by merging or splitting the generated sub-basin until satisfactorily matched with the actual condition. Figure 3.33 shows the transformation of DTM to the modified DTM (DTMM).



a. DEM with drainage burn-in lines and ridge lines

b. New modified DTM with drainage networks and ridges

Figure 3.33: Preparation of modified DTM (or DTMM) for watershed delineation

3.7.2 Preparation of Curve Number map

Curve Number (CN) is based on soils, plant cover, % of impervious areas, interception, and surface storage. Runoff is then transformed into a hydrograph by using unit hydrograph theory and routing procedures that depend on runoff travel time through segments of the watershed (TR-55, 1986).

CN values for the study area were assigned based on the land use and the Hydrologic Soil Group. Each land use was also assigned with percent impervious. CN values and the percent imperviousness were estimated using SCS TR-55 runoff curve number for urban area as listed in Table 3.8.

Table 3.8: List of CN numbers adopted for hydrologic modelling (USDA, 2004)

LANDUSE	AREA (HA)	AREA (%)	%IMP	HSG_A	HSG_B	Equivalent Landuse of TR-55
				CN	CN	
BARREN	15.176	4.78	10	77	86	Developing urban areas: Newly graded areas (pervious areas only, no vegetation)
BLDG	90.007	28.37	98	98	98	Impervious areas: Paved parking lots, roofs, driveways, etc
GREEN	107.737	33.96	10	45	66	Woods
JALAN	52.285	16.48	98	98	98	Impervious areas: Streets and roads: Paved; curbs and storm sewers (excluding right-of-way)
PAVEMENT	46.118	14.54	98	98	98	Impervious areas: Paved parking lots, roofs, driveways, etc.
RAILWAY	1.746	0.55	90	76	85	Impervious areas: Streets and roads: Gravel (including right-of-way)
SUNGAI	4.199	1.32	100	100	100	
TOTAL	317.268	100.00				

The initial abstraction, i.e. another input required for the hydrologic modelling using SCS or NRCS Runoff Curve Number (CN) is the Initial abstraction (I_a). The calculation of I_a is following the HEC-HMS Technical Reference Manual published in year 2000.

$$I_a = 0.2\ S \quad \text{.................................} \quad (1)$$

$$S = (24500\text{-}254CN)/CN \quad \text{.................................} \quad (2)$$

Where S is the potential maximum retention which is a measure of the ability of a watershed to abstract and retain storm precipitation.

3.8 SUNGAI RAJA INFORMATION SYSTEM

All spatial information were organized and stored in the Sungai Raja Information System (SRIS) for easy access, retrieve and updating. The list of information stored n the database is as shown in Figure 3.34.

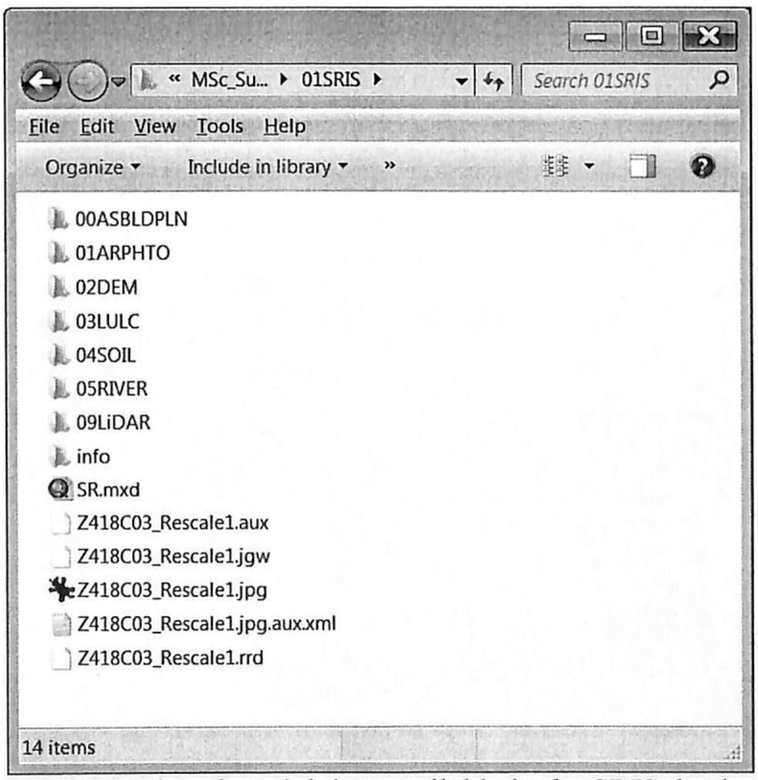


Figure 3.34: List of spatial data available in the SRIS database.

CHAPTER 4: HYDROLOGIC ADN HYDRAULIC MODELLING

Zorkeflee Abu Hasan, REDAC, USM; Nor Zaimah Che Ghani, MSc REDAC, USM.

4.1 INTRODUCTION

Reliable flow prediction is important to avoid catastrophic damage due to flood in densely populated urban area such as Alor Setar City. An event-based hydrologic modelling combined with hydraulic modelling approach was adopted to predict the water level fluctuations and pumping operation. The flow movement in the SR system is quite complicated due to the number of sub-basins that contribute flows into the river system. Although it is acknowledged that hydrodynamic model is essential tool for successful flood management, but lack of data/information posed a constraint to the modelling exercise to evaluate the applicability of the models. To overcome these drawbacks, an automatic water level recorder was design and installed as was described in Chapter 3.

The objective of this part of study was to investigate the water fluctuation in the Sungai Raja System (SRS) and pumping operation in conjunction to ascertain the applicability of combining Hydrologic Modelling System (HEC-HMS) and River Analysis System (HEC-RAS) models for SRS flood management. The modelling process is as in Figure 4.1.

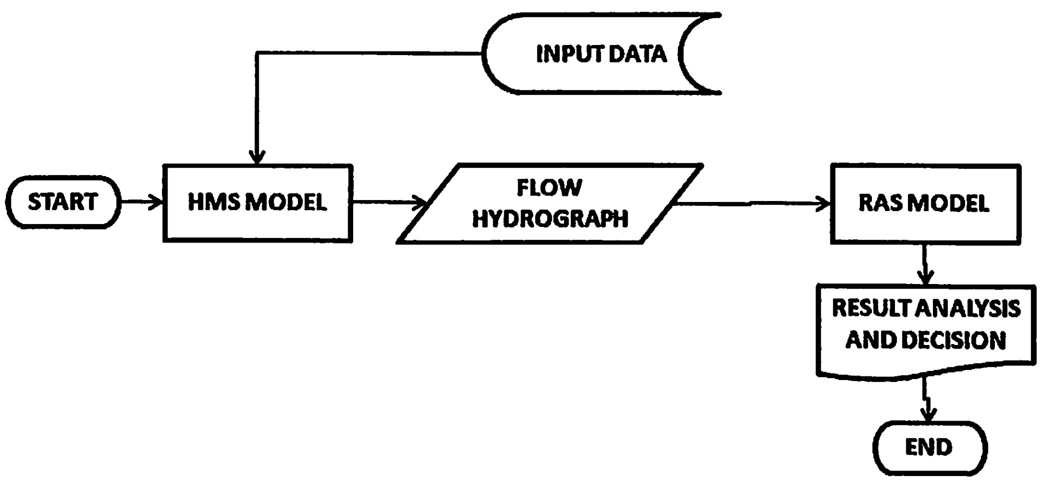


Figure 4.1: General Modelling Process for Sungai Raja System using combination of HEC-HMS and HEC-RAS models.

4.2 INTRODUCTION TO HEC-HMS

HEC-HMS is a product of the Hydrologic Engineering Center within the U.S. Army Corps of Engineers. The HEC-HMS is designed to simulate the precipitation-runoff processes of dendritic drainage basins and to be applicable in a wide range of geographic areas for solving the widest possible range of problems (USACE, 2010a). This includes large river basin water supply and flood hydrology, and small urban or natural watershed runoff. To run HEC-HMS project requires three separate models which are;

a the Basin Model

b the Meteorologic Model

c the Control Specification

4.2.1 Basin Model

The Basin Model is the representative of the actual watershed. The Basin Model contains the basin and routing parameters of the model as well as connectivity data for the basin. There are a number of elements available in the models which are the subbasins, reservoirs, junctions, diversion, sources and sinks.

The basin model provides the users with options of several methods to:-

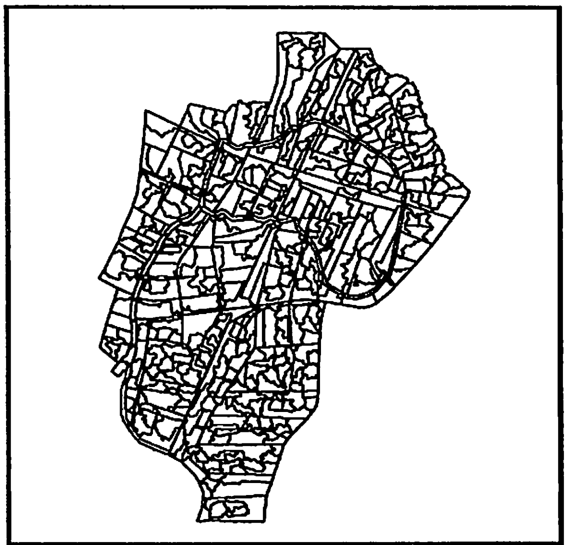
a. simulate the infiltration rate;
b. transforming excess precipitation into surface runoff;
c. represent baseflow contribution to sub-basin outflow; and
d. to simulates flows (routing) in open channels.

In this study the infiltration loss was estimated using the SCS Curve Number method. This method was selected over other methods, namely, the initial and constant-rate loss, the deficit and constant-rate, and Green and Ampt loss models due to its fewer input parameters and which can be generated automatically using the HEC-geoHMS. For the same reason, SCS unit hydrograph method was selected for the transformation and Muskingum-Cunge method for channel routing. Recession method was opted for baseflow contribution and the input were entered in HEC-HMS model environment.

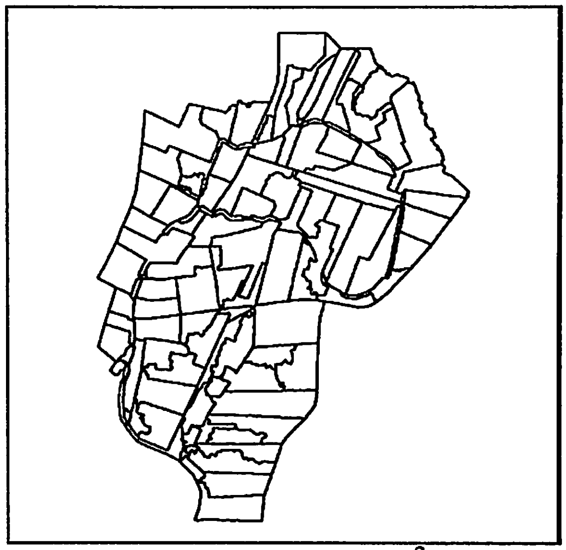
Basin model was prepared by using the HEC-geoHMS extension for ArcView 3.3 version. Although the development of basin model can be done manually, the HEC-geoHMS expedited the process. Furthermore, many of the required parameter such as the SCS CN number, initial abstraction and percentage imperviousness can be estimated within the HEC-geoHMS environment. Preparation of basin model using geoHMS involved three stages:-

a. terrain processing,
b. basin processing, and
c. hydrologic parameter estimation.

a. Terrain processing is a series of step to derive the stream network and sub-basin delineation. A number of trials were performed to automatically generate the sub-basin using various threshold values. Threshold value is the value of a contributing area which is adequate to form a stream. The smaller the value, the greater the number of sub-basin generated. Figure 4.2 shows the sub-basin generated using threshold values of $2500m^2$ and $25000m^2$. Table 4.1 listed the sub-basins distribution and minimum stream length that are automatically generated by HEC-geoHMS using different threshold values.



Threshold = 2500 m^2



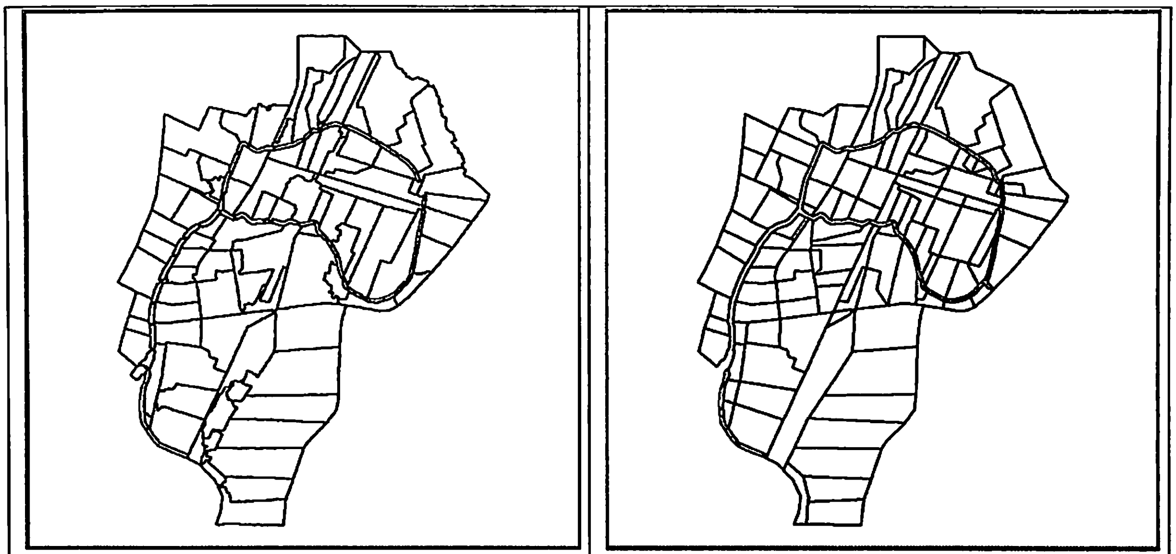
Threshold = 25000 m^2

Figure 4.2: Sub-basin generated using different threshold values. Smaller threshold value produces more sub-basins.

Table 4.1: Study area sub-basins, minimum area, and minimum river length produced by different threshold values using HEC-geoHMS.

Bil	Threshold (sq.m)	No of sub-basin	Minimum Area (sq.m)	Minimum River Length (m)
1	2500	613	8	2
2	5000	339	24	3
3	10000	195	60	5
4	15000	134	64	7
5	20000	111	624	7
6	25000	79	752	15
7	Edited	124	624	31
8	JPS	130		

b. Basin processing utilizes the 2500m^2 threshold automatically delineated sub-basins. These sub-basins were further processed using tools available in HEC-geoHMS to attain the sub-basins distribution and stream networks as close to the actual condition. Figure 4.3 shows the edited sub-basins distribution as compared to sub-basins provided by DID.



Edited Sub-basins	Sub-basins provided by DID Alor Setar

Figure 4.3: Generated sub-basins were edited to closely resemble the Sub-basins provided by DID.

c. Hydrologic parameters extraction was carried-out after the sub-basin delineation exercises were completed. The physical parameters of streams and sub-basins were extracted from the related raster data using HEC-geoHMS. The parameters are sub-basin, river length, river slope, sub-basin centroid location and elevation, longest flow path for each sub-basin, and length along the steam path from the centroid to the sub-basin outlet. Other sets of data are percent impermeable, initial abstraction, and lag time were edited using standard process in ArcView to complete the other required parameters and information.

Final process using HEC-geoHMS was generating the basin model that can be directly loaded and executed in HEC-HMS model. In this process, HEC-geoHMS developed a lumped-basin model which includes the hydrologic elements, their connectivity (as shown in Figure 4.4) and other related information. The basin model was then generated as an ASCII text file as *.basin that can be read directly by the HEC-HMS.

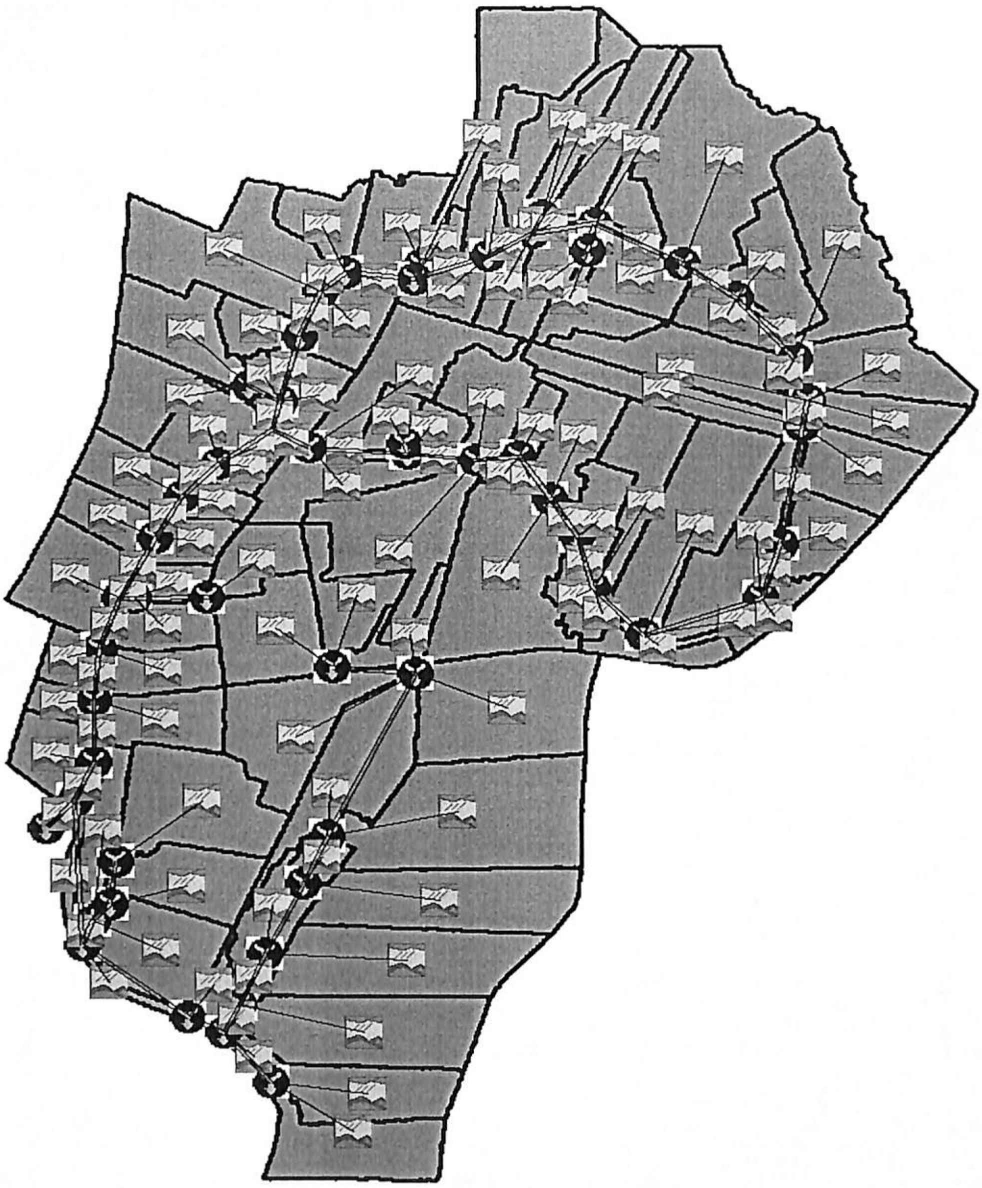


Figure 4.4: Basin Model generated using HEC-geoHMS

As mentioned earlier, Recession method was opted for baseflow estimation. The initial discharge per area method was selected to specify the initial baseflow with Ratio to Peak as the Threshold Type. The initial discharge per area during dry weather was estimated by averaging the rate of water draining into the SRS. Utilising stage hydrograph of Figure 3.9, computation was from 01/Feb/12 at 9:45am to 01/Feb/12 at 11:45 which is during no pumping period as in Table 4.2. Volumes in column [3] were extracted from the Storage Curve in Figure 3.23.

Table 4.2: Computation of initial estimate of average baseflow Discharge for dry weather

Date and Time	Water Level [m]	Volume [m³]	Δ_time [s]	Δ_vol [m³]	Q [m³/s]	av_Q @ Δ_time [m³/s/km²]	Av_Q [m³/s/km²]
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
01/Feb/12 8:45	-0.025	17072.677	0				
01/Feb/12 9:00	-0.160	13724.887	900	-3347.79	-3.720	-1.178	
01/Feb/12 9:15	-0.260	11388.056	900	-2336.83	-2.596	-0.823	
01/Feb/12 9:30	-0.350	9405.077	900	-1982.98	-2.203	-0.698	
01/Feb/12 9:45	***-0.335***	***9725.463***	***900***	***320.39***	***0.356***	***0.113***	
01/Feb/12 10:00	***-0.320***	***10045.850***	***900***	***320.39***	***0.356***	***0.113***	
01/Feb/12 10:15	***-0.300***	***10473.033***	***900***	***427.18***	***0.475***	***0.150***	
01/Feb/12 10:30	***-0.295***	***10587.411***	***900***	***114.38***	***0.127***	***0.040***	
01/Feb/12 10:45	***-0.290***	***10701.789***	***900***	***114.38***	***0.127***	***0.040***	
01/Feb/12 11:00	***-0.285***	***10816.167***	***900***	***114.38***	***0.127***	***0.040***	
01/Feb/12 11:15	***-0.280***	***10930.544***	***900***	***114.38***	***0.127***	***0.040***	
01/Feb/12 11:30	***-0.275***	***11044.922***	***900***	***114.38***	***0.127***	***0.040***	
01/Feb/12 11:45	***-0.270***	***11159.300***	***900***	***114.38***	***0.127***	***0.040***	***0.069***
01/Feb/12 12:00	-0.270	11159.300	900	0.00	0.000	0.000	
01/Feb/12 12:15	-0.270	11159.300	900	0.00	0.000	0.000	
01/Feb/12 12:30	-0.280	10930.544	900	-228.76	-0.254	-0.081	
01/Feb/12 12:45	-0.290	10701.789	900	-228.76	-0.254	-0.081	
01/Feb/12 13:00	-0.300	10473.033	900	-228.76	-0.254	-0.081	
01/Feb/12 13:15	-0.310	10259.442	900	-213.59	-0.237	-0.075	

Estimated initial average baseflow discharge is 0.069 $m^3/s/km^2$.

4.2.2 The Meteorologic Model

The meteorologic model is to prepare and calculate the meteorological boundary condition of sub-basins. HEC-HMS provides data analysis for precipitation, evapotranspiration, and snowmelt. In this study only precipitation was considered. There are seven methods available and gage weight method was selected for precipitation modelling.

HEC-HMS accepts rainfall data in a number of ways: historical data from recording and non-recording gages or design storm data. In this study, 10 minutes rainfall data from 01 October 2012 to 29 June 2013 was used.

4.2.3 Control specifications

The control specifications contains all the timing information for the model, including start time and date, stop time and date, and computational time step of the simulation.

4.2.4 Simulation Runs

From the given inputs, a simulation run calculates the precipitation-runoff response. The result are stored in the HEC Data Storage System (HEC-DSS) data format which can be read by the HEC-RAS model.

4.3 INTRODUCTION HEC-RAS

HEC-RAS simulations were performed to generate water surface profiles. HEC-RAS was designed to performed one-dimensional hydraulics computation for a full network of channels (USACE, 2010b). It requires two basic inputs for flow analyses:-

a. geometric data, and
b. flow/stage data.

4.3.1 Geometric Data

The development of HEC-RAS geometric input data was facilitated through the use of HEC-geoRAS. HEC-geoRAS is an extension to be used in ArcView environment developed by the USACE to automatically generate the HEC-RAS geometric input data. This extension facilitates not only the preprocessing of the input data but also the post-processing of HEC-RAS simulation results. To generate the geometric input file, DTM and landuse (for Manning's n values extraction) layers were used. Detail step-by-step procedures of HEC-geoRAS are not presented here and as it can be found in the respective user's manual. The geometric input data was edited in HEC-RAS environment to add pumping station and its required data. Figure 4.5 shows the HEC-RAS geometric data model. Summary of the geometric data is in Table 4.3.

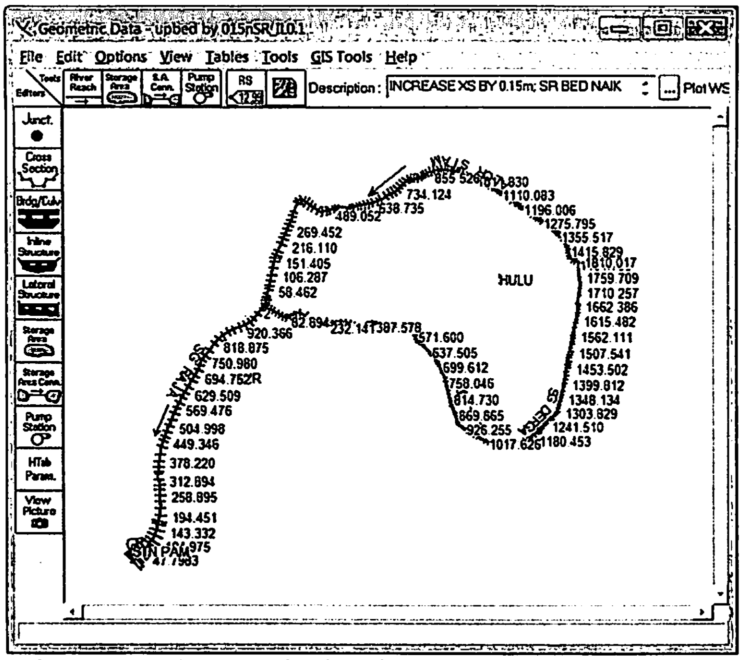


Figure 4.5: Geometric data in HEC-RAS environment

Table 4.3: Summary of Geometric Data used for modelling

River Reach	Length (m)	No. of River Sections	Structure
Sungai Derga	1810	154	
Alor Siam	1464	117	
Sungai Raja	1010	51	Weir, Pump Station

4.3.2 Flow and Stage Hydrographs

The upstream boundary conditions are the flow hydrographs entering the inlets (the most upstream river sections) of Sungai Derga and Alor Siam. The internal boundary conditions are the lateral inflow hydrographs entering the river system at river-sections that coincides or near to the outlets/outfalls of HEC-HMS sub-basins; and the downstream boundary is a stage-hydrographs at the downstream most of the Sungai Raja reach. The upstream and internal boundaries cross-sections were linked to the respective HEC-HMS DSS file to read the HEC-HMS output hydrographs. Assumed stage hydrograph was used for downstream boundary condition because it is cut-off from the main system by a weir and has no influence to the simulation results. Summary of the flow/stage input are as in Table 4.4.

Table 4.4: Summary of Flow/stage data distribution

River Reach	Upstream Boundary	Downstream Boundary	Lateral Inflow
Sungai Derga	1		31
Alor Siam	1		32
Sungai Raja		1	24

4.4 MODELS SENSITIVITY, CALIBRATION, and VALIDATION

4.4.1 Sensitivity Tests

Hydrologic and hydraulics models used in this research require numbers of input parameters. Influence of these parameters to the outputs may vary from parameter to parameter. Hence, sensitivity analyses were conducted to investigate how the output (values and behaviour) responded to changes in model input values. Not knowing the sensitivity of parameters can result in time being spent uselessly on non-sensitive one. Therefore, sensitive analysis is as an instrument for the assessment of the input parameter, for model validation and reduction of uncertainty. The parameters that were tested are as listed in Table 4.5 using rainfall from 11 November 2012 @ 12:00 to 12 November 2012 @ 00:00 as in Figure 4.6.

Table 4.5: Parameter selected for sensitivity test

Model	Parameter	Range of tested values	Initial/reference values
HEC-HMS	CN Number	-10%, -5%, 5%, 10%	CN values generated from HEC-geoHMS
	Initial Abstraction	-10%, -5%, 5%, 10%	Initial Abstraction computed in ArcView
	Percent Imperviousness	-10%, -5%, 5%, 10%	Percent Imperviousness computed in ArcView
	Baseflow discharge	-10%, -5%, 5%, 10%	0.069 $m^3/s/km^2$
	Baseflow Recession Constant	-20%, -10%, -5%, 5%, 10%, 20%	0.60
	Baseflow Ratio to Peak	0.05, 0.1, 0.5, 0.9	0.02
HEC-RAS	Computation interval	5, 10, 20, 30, 60 sec	5 sec
	Manning's n	0.015, 0.020, 0.025,0.030	0.015
	Initial Water Level (WLi)	-0.15, -0.10, -0.20, 0.00, -0.4	-0.15 m

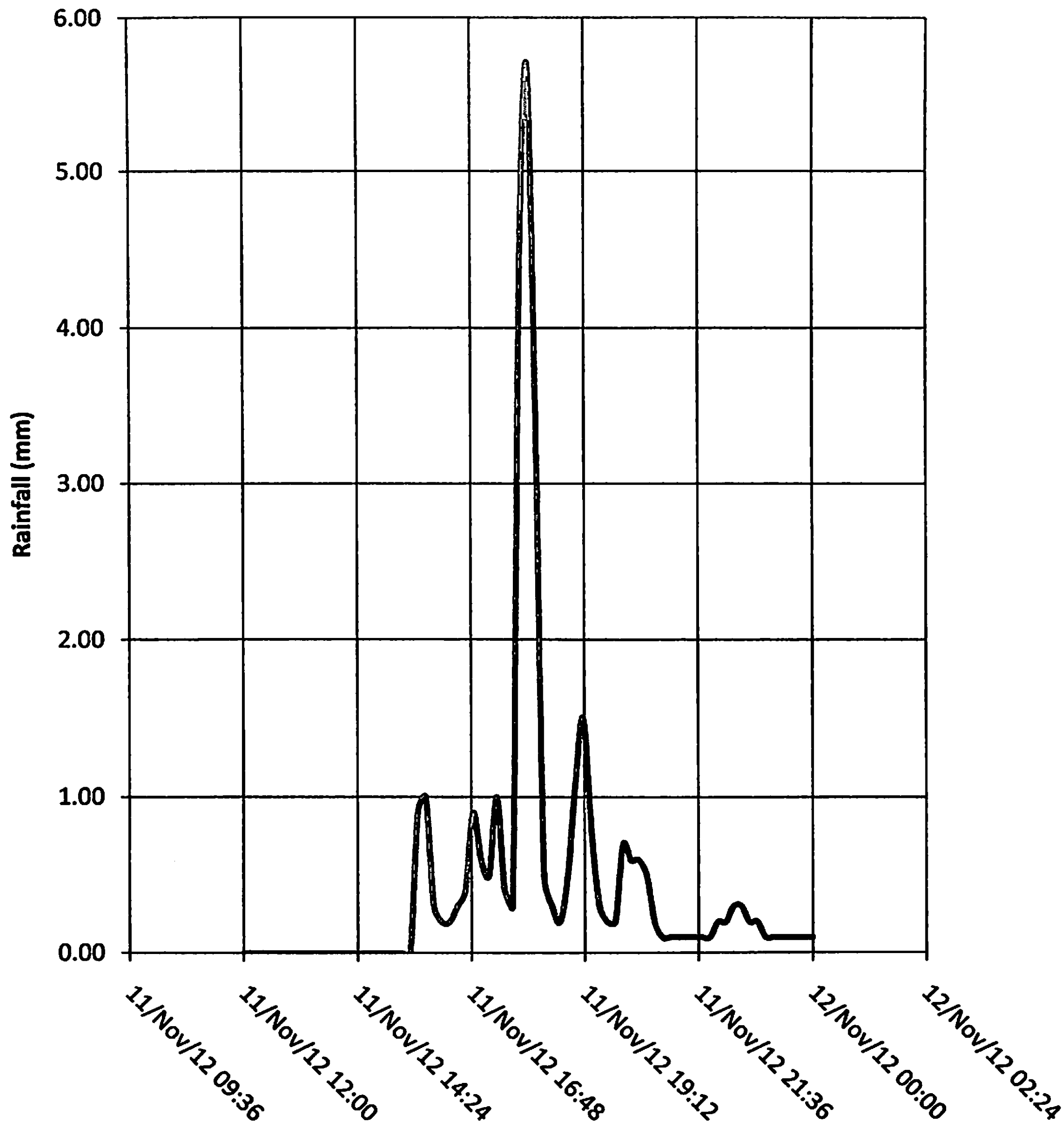


Figure 4.6: Rainfall distribution used for sensitivity tests

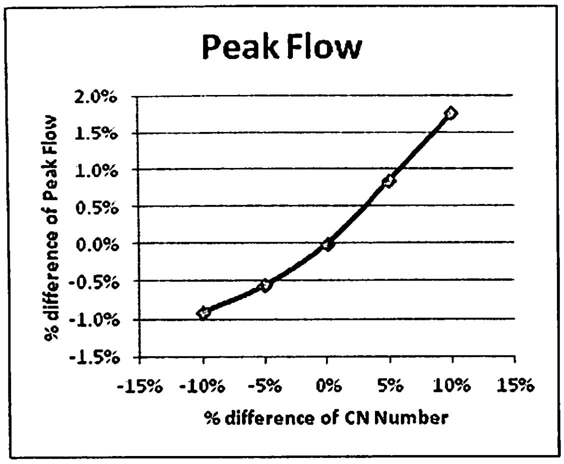
Sensitivity analyses were conducted in a systematic manner, i.e. parameter-by-parameter sequence. The each parameter value was individually varied during the sensitivity test.

4.4.1.1 HEC-HMS Sensitivity Test Results:

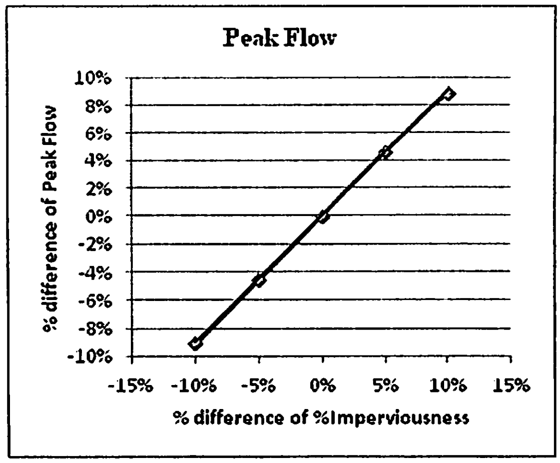
Table 4.6 summarises the sensitivity tests for HEC-HMS. The values are taken at the downstream most junction element (or the outlet of the system) of the HEC-HMS model (OB02500). Figure 4.7 shows the peak flow variations in response of each parameter adjustment.

Table 4.6: Summery of HEC-HMS Sensitivity Test Results at OB02500

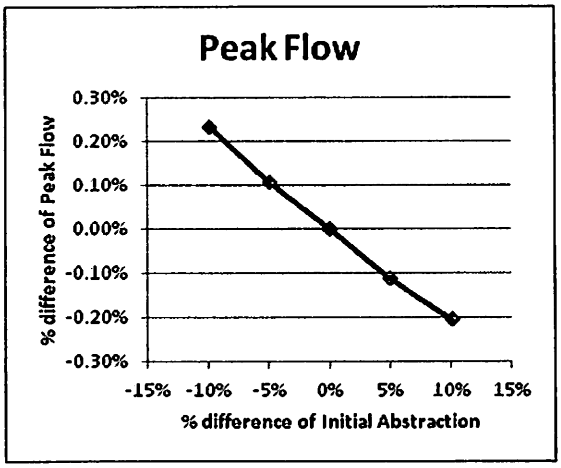
Parameter	Range of values	Peak Flow		Total Outflow	
		m^3/s	% different	mm	% different
Loss Model: CN Number	-10%	7.7592	-0.91	21.642	-0.96
	-5%	7.7872	-0.55	21.728	-0.56
	0%	7.8303	0.00	21.851	0.00
	5%	7.8966	0.85	22.023	0.79
	10%	7.9683	1.76	22.228	1.73
Loss Model: % Impervious	-10%	7.1225	-9.04	20.425	-6.53
	-5%	7.4758	-4.53	21.144	-3.24
	0%	7.8303	0.00	21.851	0.00
	5%	8.1891	4.58	22.557	3.23
	10%	8.5251	8.87	23.215	6.24
Loss Model: Initial Abstraction	-10%	7.8487	0.23	21.946	0.43
	-5%	7.8387	0.11	21.895	0.20
	0%	7.8303	0.00	21.851	0.00
	5%	7.8216	-0.11	21.811	-0.18
	10%	7.8143	-0.20	21.777	-0.34
Baseflow: Initial Discharge	-10%	7.8027	-0.35	21.561	-1.33
	-5%	7.8186	-0.15	21.727	-0.57
	0%	7.8303	0.00	21.851	0.00
	5%	7.8412	0.14	21.975	0.57
	10%	7.8567	0.34	22.141	1.33
Baseflow: Recession Constant	-20%	7.8165	-0.18	21.729	-0.56
	-10%	7.8243	-0.08	21.793	-0.27
	-5%	7.8275	-0.04	21.822	-0.13
	0%	7.8303	0.00	21.851	0.00
	5%	7.8325	0.03	21.879	0.13
	10%	7.8354	0.06	21.906	0.25
	20%	7.8410	0.14	21.958	0.49
Baseflow: Ratio to Peak	0.02	7.8303	0.00	21.851	0.00
	0.05	7.8303	0.00	22.668	3.74
	0.10	7.8303	0.00	26.246	20.11
	0.30	8.0131	2.33	44.668	104.42
	0.50	9.6032	22.64	66.518	204.42
	0.90	17.9569	129.33	126.997	481.20



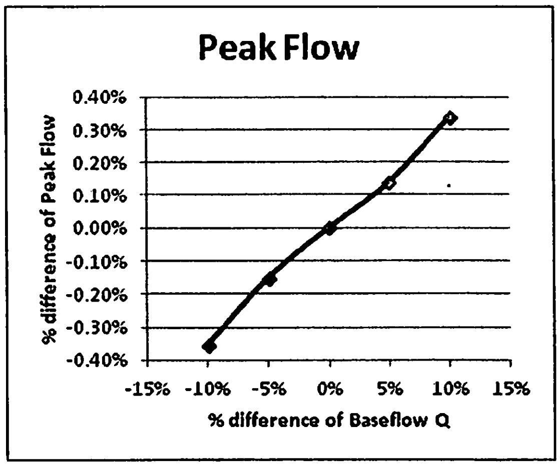
Loss Model: CN Number



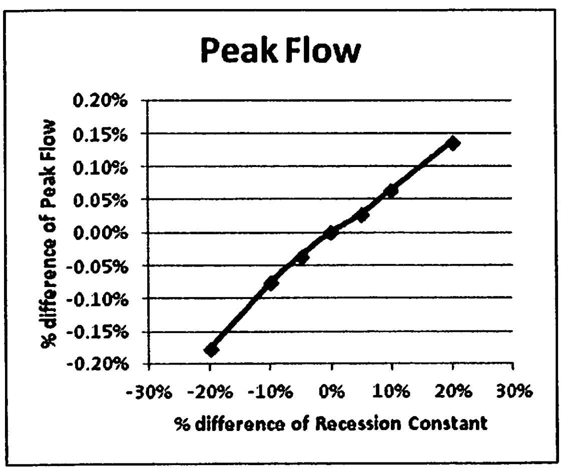
Loss Model: % imperviousness



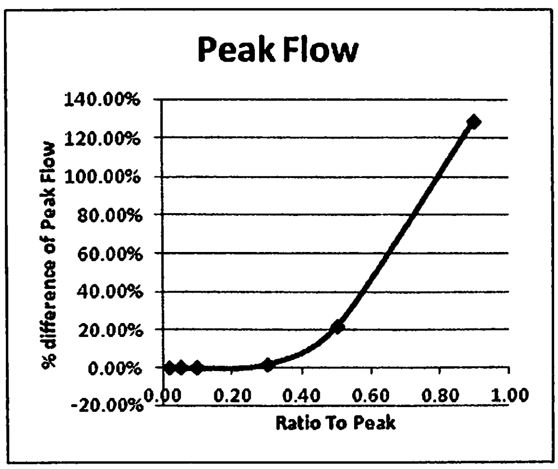
Loss Method: Initial Abstraction



Baseflow: Initial Discharge



Baseflow: Recession Constant



Baseflow: Ratio to Peak

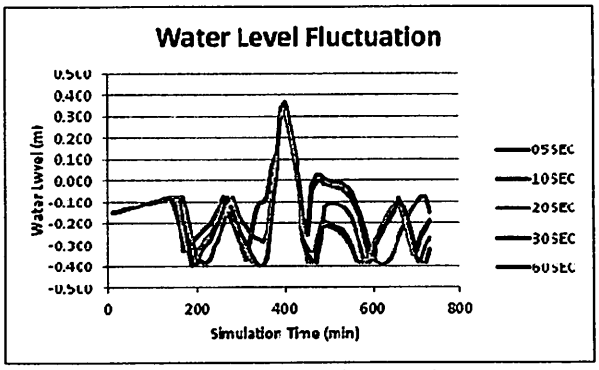
Figure 4.7: Peak Flow variation with different HEC-HMS parameters values

Results of HEC-HMS sensitivity tests show that the model is sensitive to change of values of %imperviousness. The Peak Flow increases by approximately 1% for every 1% increase of

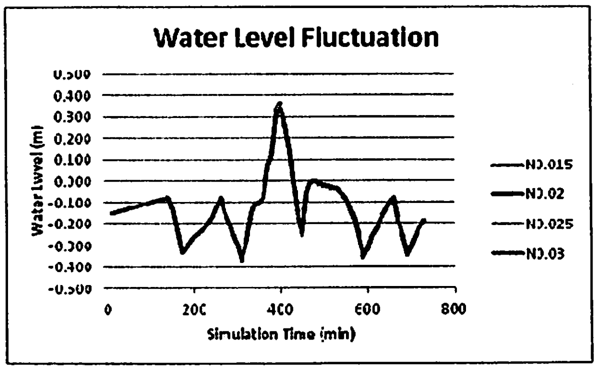
%imperviousness. The model is also sensitive to changes of CN values but at smaller extent if compared to %imperviousness. For the parameter Ratio to Peak, HEC-HMS model is very responsive for values greater than 0.3. For other parameters, the peak discharge responded to changes of values almost linearly and at much smaller rate.

4.4.1.2 HEC-RAS Sensitivity Test Results:

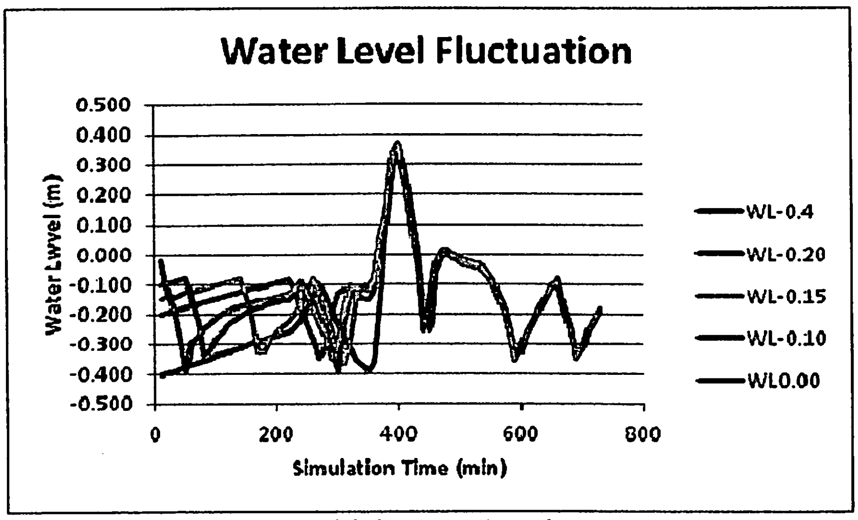
Results of HEC-RAS sensitivity test are shown in Figure 4.8. Simulation results at the RS52.464 were used for comparison.



Computation interval



Manning's n



Initial Water Level

Figure 4.8: Comparison of Water Levels variation at RS52.464 with different HEC-RAS parameters values.

From Figure 4.8, river Manning's n does not influence water level fluctuation. Computation interval has some influence on water level and does not follow specific trend. For initial water level (WLi), the difference of water level fluctuation is very obvious before the peak water level. After the peak water level, there are no significant water level differences. The reason for this is that the pumping stops at the same predetermined water level. Since the rate of inflow is the same, then the water level fluctuation are the same for all cases.

From the sensitivity tests (HEC-HMS and HEC-RAS), all parameters tested will influence the simulation result except for Manning's n.

4.4.2 Calibration

The usefulness and reliability of a model for prediction depend on the accuracy of its output. On one hand, the output of a model is dependent on the parameter values but on the other hand estimation of model parameters is complicated due to large uncertainties especially those that cannot directly measured in the field. However, the values need to be assigned to each parameter. The models were calibrated by trial-and-error parameter adjustment with the aim to satisfactorily simulate the water level fluctuation and pumping operation. After each run, the simulated stage-hydrographs were compared against measured data.

In this study, all records (stage-hydrograph, flow-hydrograph, and pumping schedule/operation) required for calibration are not available. The only option is to compare the model output with the observed stage-hydrograph. The first calibration was to represent dry period, the second to represent wet event and third calibration to represent condition after wet event. Figure 4.9 summarises the process taken for calibration.

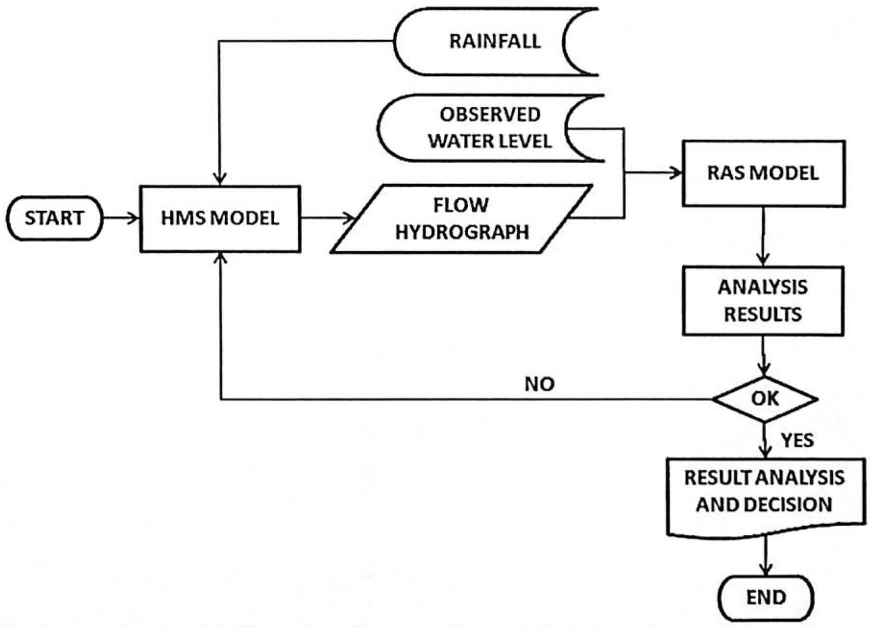


Figure 4.9: Hydrologic (HEC-HMS) – Hydraulics (HEC-RAS) models calibration process.

4.4.2.1 First Calibration

First attempt of the calibration was to compare simulated and observed water levels at DID office which is approximately located at River Station RS818.875 of Sungai Raja reach (Figure 4.10). Parameters used for the test are listed in Table 4.7.

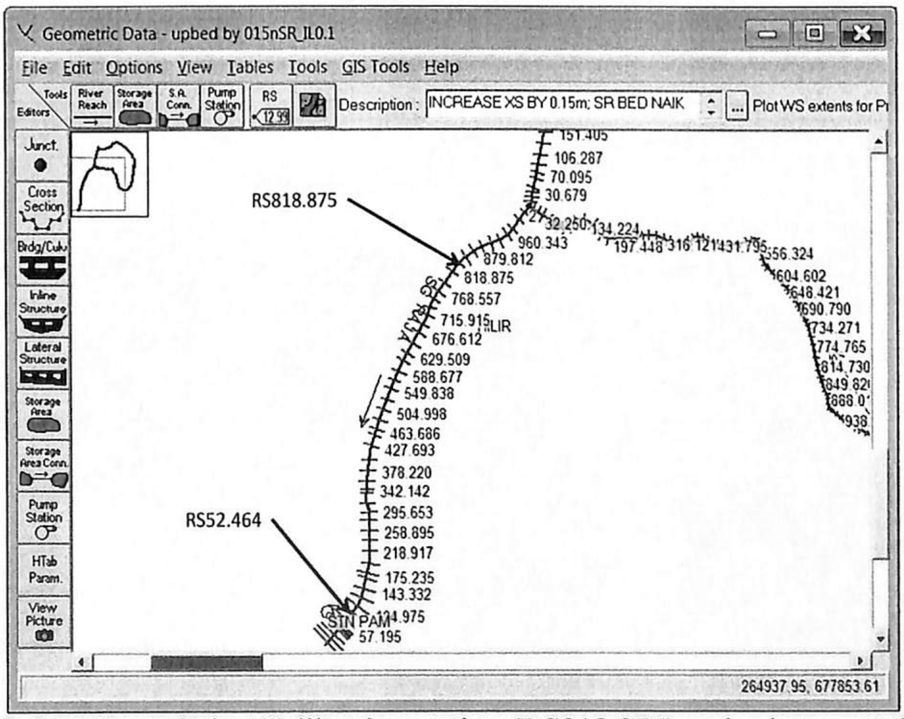


Figure 4.10: Location of First Calibration station (RS818.875) and subsequent Calibration station (RS52.464)

Table 4.7: Parameters for Calibration 1

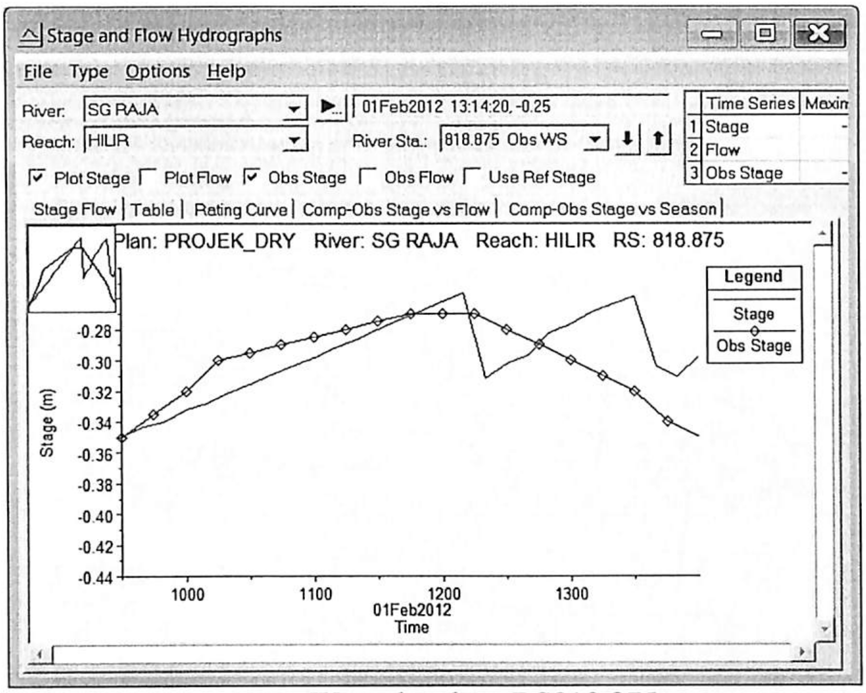
Model	Parameters	Range of values
HEC-HMS	Loss Method: SCS Curve Number	
	Initial Abstraction (I_abs)	Values as generated using HEC-geoHMS
	CN Number (CN)	Values as generated using HEC-geoHMS
	%Impervious (Iimp)	Values as generated using HEC-geoHMS
	Baseflow: Recession Model	
	Initial Type	Discharge per Area
	Initial Discharge (Qi)	0.04 to 0.07 m3/s/km2
	Recession Constant (RC)	0.55 to 0.95
	Ratio to Peak (R2P)	0.002 to 0.9
	Simulation time	30 Jan 2012 @ 00:00 to 02 Jan 2012 @ 17:00
	Time Interval	1 mim
HEC-RAS	Manning's n	0.015
	Pump Operation	3 m3/s for head = 0m and 2.5 m3/s for head = 10m
	Unsteady Flow: Initial water level	-0.35m
	Simulation time	01 Feb 2012 @ 09:30 to 01 Feb 2012 @ 14:00
	Computation Interval	5 sec

As this calibration is for dry period, only baseflow parameters were tested and the most acceptable values are as listed in Table 4.8.

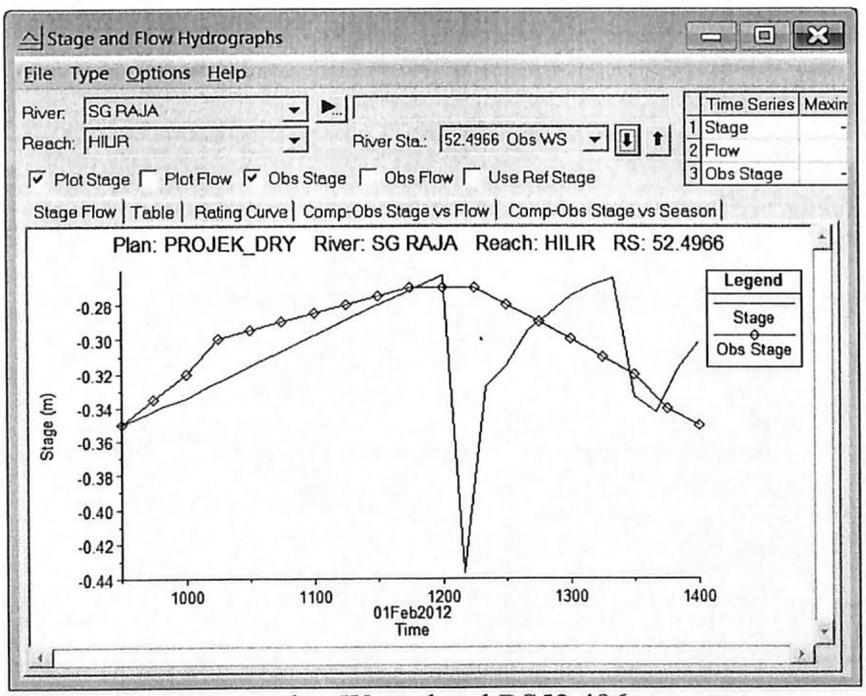
Table 4.8: Acceptable value for First Calibration.

Model	Parameters	Range of values
HEC-HMS	Loss Method: SCS Curve Number	
	Initial Abstraction (I_abs)	Values as generated using HEC-geoHMS
	CN Number (CN)	Values as generated using HEC-geoHMS
	%Impervious (Iimp)	Values as generated using HEC-geoHMS
	Baseflow: Recession Model	
	Initial Type	Discharge per Area
	Initial Discharge (Qi)	0.069 $m^3/s/km^2$ (this is in agreement with the estimated value in Table 4.2)
	Recession Constant (RC)	0.95
	Ratio to Peak (R2P)	0.002
	Simulation time	30 Jan 2012 @ 00:00 to 02 Jan 2012 @ 17:00
	Time Interval	1 min
HEC-RAS	Manning's n	0.015
	Pump Operation	3 m^3/s for head = 0m and 2.5 m^3/s for head = 10m
	Unsteady Flow: Initial water level	-0.35m
	Simulation time	01 Feb 2012 @ 09:30 to 01 Feb 2012 @ 14:00
	Computation Interval	5 sec

After the first calibration exercise, the RS818.875 was found not very suitable to compare the pumping operation interval. Figure 4.11 shows the discrepancies between water levels at RS818.875 (observation point) and RS52.464 (immediately upstream of Pumping Station)



a. Water levels at RS818.875



b. Water level RS52.496

Figure 4.11: Stage hydrograph of RS818.875 and RS52.496 of Sungai Raja showing different Water level at the start of pumping operation.

The new observation station was then sited at approximately 10m upstream of the Pumping Station (close to RS52.469, and the location as shown in Figure 4.10) to be used for the subsequent calibration exercises.

4.4.2.2 Second Calibration

This calibration exercise was to represent the wet condition. Running the HEC-HMS and HEC-RAS using the first calibrated parameters as in Table 4.8 produces result as in Figure 4.12 below. The result indicated that further parameters adjustment is required.

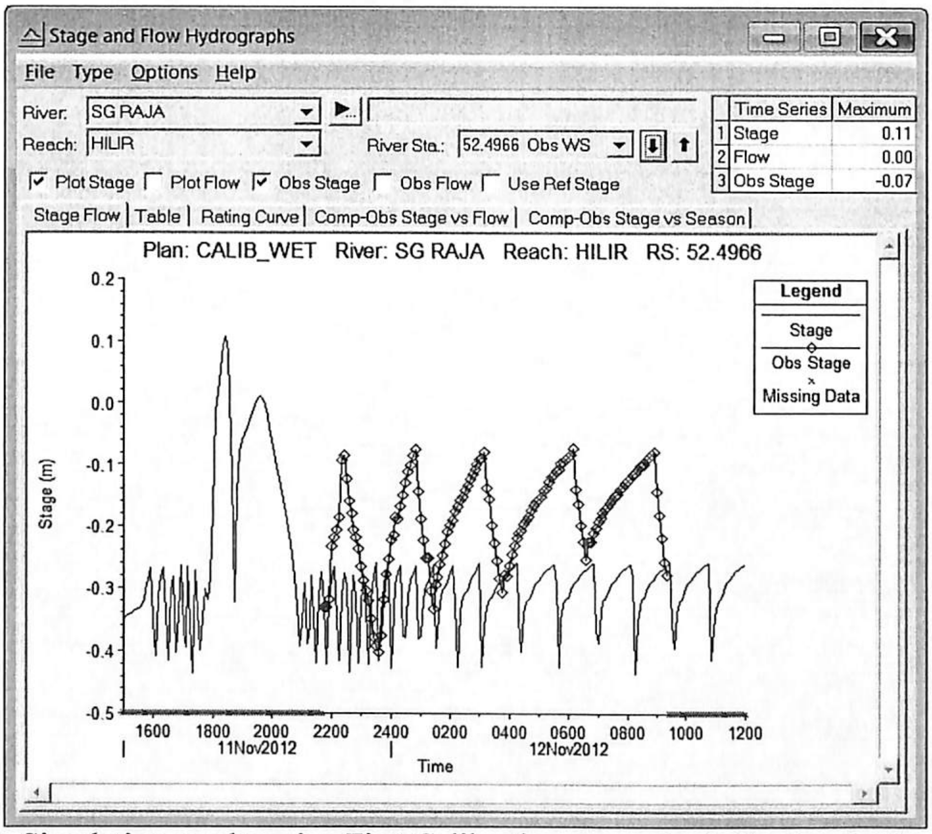


Figure 4.12: Simulation results using First Calibration parameter indicating further parameter adjustment for wet condition.

The calibration was conducted by systematically adjusting four HEC-HMS parameters (I_abs, Qi, RC and R2P) and two HEC-RAS parameters (Pump Operation and WLi) values. Step-by-step processes were carried out for this calibration and the calibrated range/values are as describe in Table 4.9.

Table 4.9: Summary of the second calibration parameters

Model	Parameters	Range of values used for calibration	Calibrated Values
HEC-HMS	Loss Method: SCS Curve Number		
	Initial Abstraction (I_abs)	Values as generated using HEC-geoHMS	For CN >= 80; I_abs = 0 mm For 60 >= CN > 80; I_abs = 2% of the initial computed values For CN < 60; I_abs = 20% of the initial computed values
	CN Number (CN)	Values as generated using HEC-geoHMS	
	%Impervious (Iimp)	Values as generated using HEC-geoHMS	
	Baseflow: Recession Model		
	Initial Type	Discharge per Area	
	Initial Discharge (Qi)	0.069 to 0.130 $m^3/s/km^2$	0.125 $m^3/s/km^2$
	Recession Constant (RC)	0.93, 0.95, 0.96,	0.95
	Ratio to Peak (R2P)	0.002 to 0.02	0.002
	Simulation time	11 November 2012 @ 00:10 am to 13 November 2012 @ 10:00	
	Time Interval	1 minute	
HEC-RAS	Manning's n	0.015	
	Pump Operation	2 to 3 m^3/s for head = 0m; 2 to 3 m^3/s for head = 10m	2.25 m^3/s for head = 0m; 2.2 m^3/s for head = 10m
	Unsteady Flow: Initial water level (WLi)	-0.4 to -0.1 m	-0.15 m
	Simulation time	11 November 2012 @ 1500 to 12 November 2012 @ 1200	
	Computation Interval	5 second	

Figure 4.13 compares the stage-hydrographs at RS52.496 using Qi=0.0.069 $m^3/s/km^2$ and Qi=0.125 $m^3/s/km^2$ during and immediately after rainfall event. Qi=0.125 $m^3/s/km^2$ produces closer agreement to the observed values. Figure 4.14 shows the two of the calibration results. Based on visual judgement parameter values used to produce stage-hydrograph as in Figure 4.14(a) were accepted as the calibrated values.

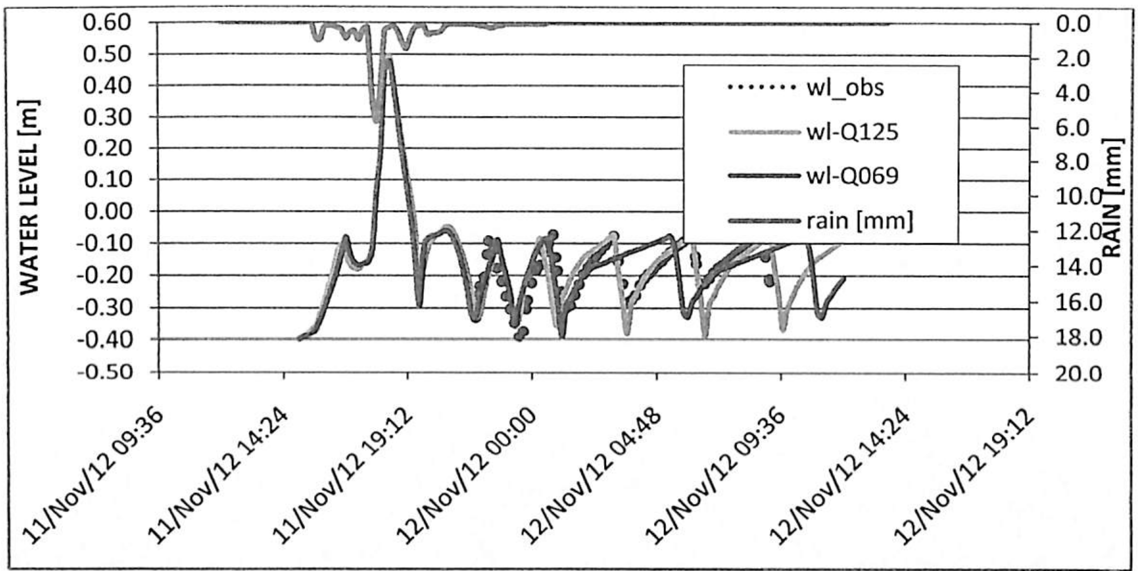
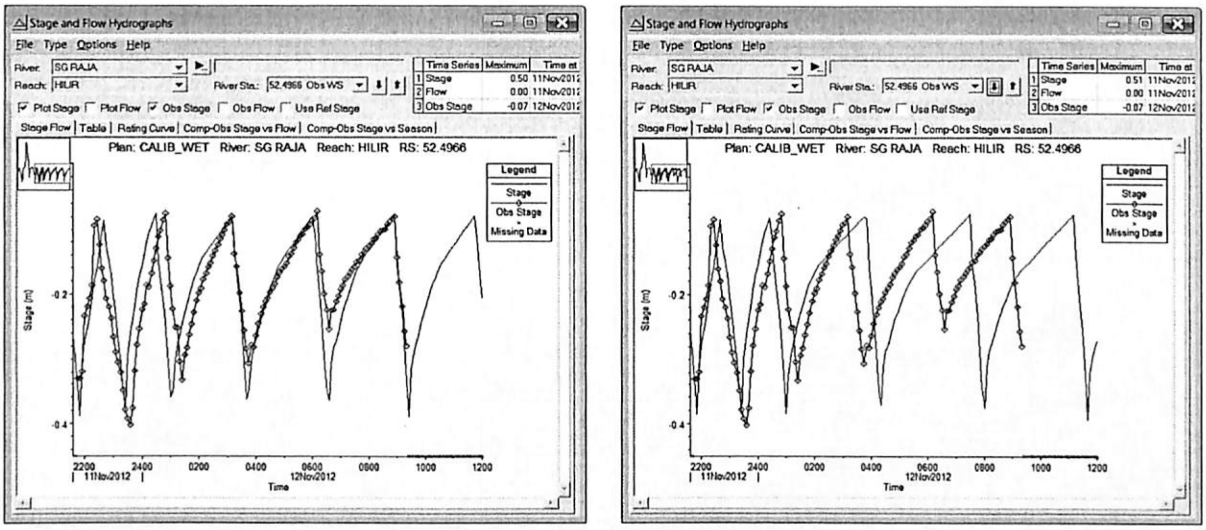


Figure 4.13: Comparison of Stage-hydrographs at RS52.496 using Qi=0.0.069 $m^3/s/km^2$ and Qi=0.125 $m^3/s/km^2$ during and immediately after rainfall event.



a. Qi=0.125, RC=0.95, R2P=0.002 and WLi=-0.15

b. Qi=0.1, RC=0.95, R2P=0.002 and WLi=-0.15

Figure 4.14: Comparison of Stage-hydrograph and Pumping operation at RS52.496 based on different Qi values.

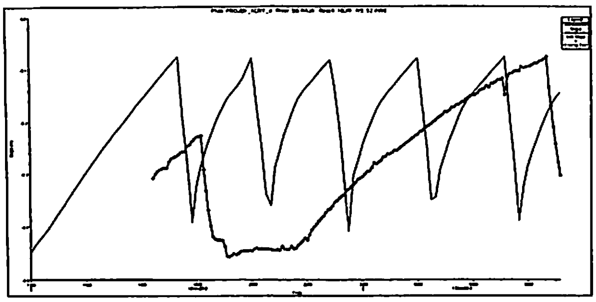
4.4.2.3 Third Calibration

This calibration was to represent the after wet (rain event) condition. Table 4.10 listed the range of values used during the calibration process. Only Qi was adjusted and Qi = 0.069 0.0125 $m^3/s/km^2$ were tested. Both Qi did not produce very good agreement compared to the observed water levels. Adjusting the simulation time (ST) did not solve the problem.

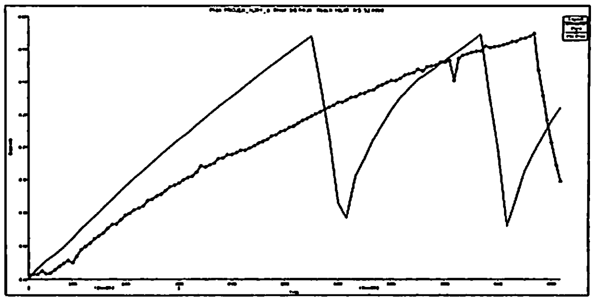
However, adjusting Qi = 0.065 $m^3/s/km^2$ and running HEC-RAS from 12 November 2012 @ 2110 to 13 November 2012 @ 0710 produces better agreement result. Figure 4.15 shows four of the simulation results and Figure 4.15(d) is the closest fit to part of the observed stage-hydrograph. The parameters values that produce Figure 4.15(d) are listed in Calibrated Values column of Table 4.10.

Table 4.10: Summary of the parameters values used for Third Calibration

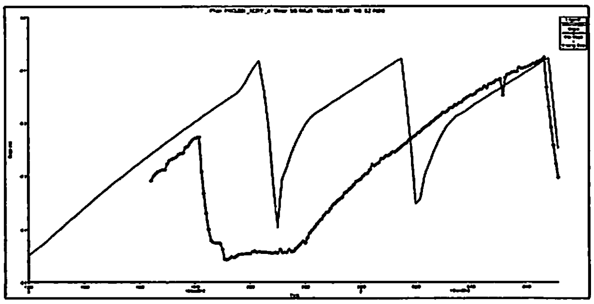
Model	Parameters	Range of values used for calibration	Calibrated Values
HEC-HMS	Loss Method: SCS Curve Number		
	Initial Abstraction (I_abs)	Result of Second Calibration: For CN >= 80; I_abs = 0 mm For 60 >= CN > 80; I_abs = 0.02 of the initial computed values For CN < 60; I_abs = 0.2 of the initial computed values	
	CN Number (CN)	Values as generated using HEC-geoHMS	
	%Impervious (Iimp)	Values as generated using HEC-geoHMS	
	Baseflow: Recession Model		
	Initial Type	Discharge per Area	
	Initial Discharge (Qi)	0.069 $m^3/s/km^2$, and 0.125 $m^3/s/km^2$	0.069 $m^3/s/km^2$
	Recession Constant (RC)	0.95	
	Ratio to Peak (R2P)	0.002	
	Simulation time (ST)	12 November 2012 @ 12:00 pm to 13 November 2012 @ 08:00	
	Time Interval	1 minute	
HEC-RAS	Manning's n	0.015	
	Pump Operation	2.25 m^3/s for head = 0m; 2.2 m^3/s for head = 10m	
	Unsteady Flow: Initial water level (WLi)	-0.15 m; -0.45 m	-0.45 m
	Simulation time (ST)	12 November 2012 @ 1200 to 13 November 2012 @ 0710 and 12 November 2012 @ 2110 to 13 November 2012 @ 0710	12 November 2012 @ 2110 to 13 November 2012 @ 0710
	Computation Interval	5 second	



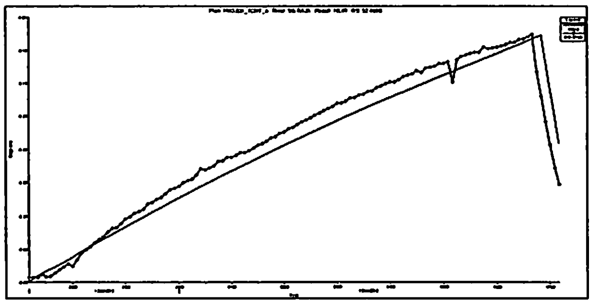
a. Qi=0.125; ST= 12NOV12 1200 – 13NOV12 0710



b. Qi=0.125; ST= 12NOV12 2110 – 13NOV12 0710



c. Qi=0.069, ST= 12NOV12 1200 – 13NOV12 0710



d. Qi=0.069, ST= 12NOV12 2110 – 13NOV12 0710

Figure 4.15: Stage-hydrographs of different Qi and initial simulation time.

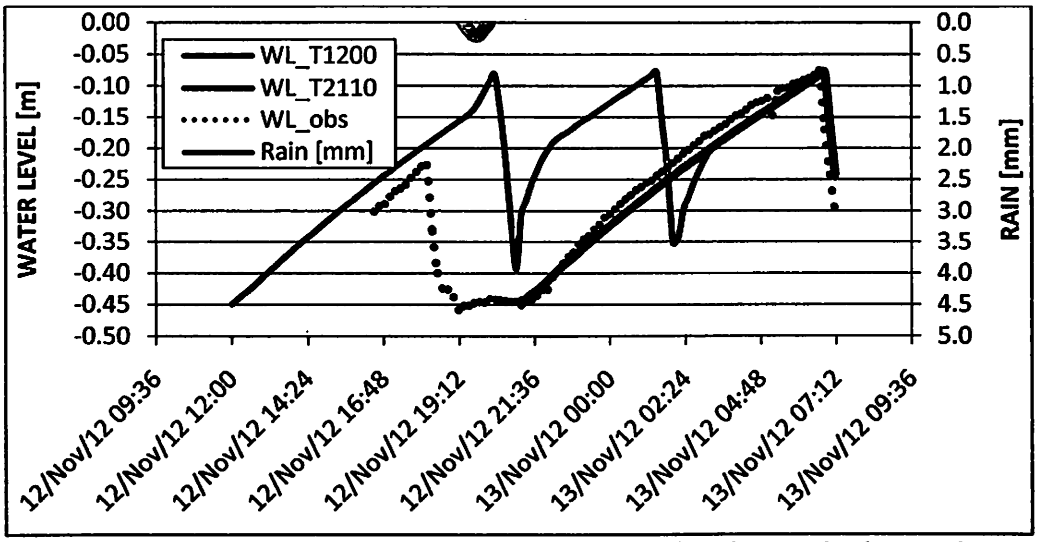


Figure 4.16: Effect of Simulation Time to simulated stage-hydrograph.

Figure 4.16 clearly shows that selection of simulation time in the HEC-RAS model is an important aspect that needs to be considered for close river system such as Sungai Raja System. The result of simulation started at 12 November 2012 @ 1200 (symbolised as WL_T1200) responded to the rainfall event with higher rate of inflow into the SRS. The most likely reason is: the HEC-HMS model was setup to assume the whole study area receives the same amount of rainfall as the rainfall station, but in actual case the rainfall intensity may varies within the study area. This is shown by the observed water level which flattened after the rainfall event. This means that the rate of inflow is equivalent to the pumping rate for about 1 hour. Once the pump ceased operation, water level in Sungai Raja starts to rise.

From the calibration (First to Third Calibration) results, the acceptable calibrated parameter values are summarised in Table 4.11.

Table 4.11: Summary of the acceptable calibrated parameters values

Model	Parameters	Calibrated Values
HEC-HMS	Loss Method: SCS Curve Number	
	Initial Abstraction (I_abs)	Result of Second Calibration: For CN >= 80; I_abs = 0 mm For 60 >= CN > 80; I_abs = 0.02 of the initial computed values For CN < 60; I_abs = 0.2 of the initial computed values
	CN Number (CN)	Values as generated using HEC-geoHMS
	%Impervious (Iimp)	Values as generated using HEC-geoHMS
	Baseflow: Recession Model	
	Initial Type	Discharge per Area
	Initial Discharge (Qi)	Dry period: 0.069 $m^3/s/km^2$, Rainy period: 0.125 $m^3/s/km^2$
	Recession Constant (RC)	0.95
	Ratio to Peak (R2P)	0.002
	Simulation time (ST)	As required
	Time Interval	1 minute
HEC-RAS	Manning's n	0.015
	Pump Operation	2.25 m^3/s for head = 0m; 2.2 m^3/s for head = 10m
	Unsteady Flow: Initial water level (WLi)	As Required
	Simulation time (ST)	As Required
	Computation Interval	5 second

4.4.3 Model Validation

Models validation was conducted for rainfall event from 28th February 2013 to 01st March 2013 and Table 4.12 listed the rainfall distribution during this period.

Table 4.12: Rain data used for Models Validation

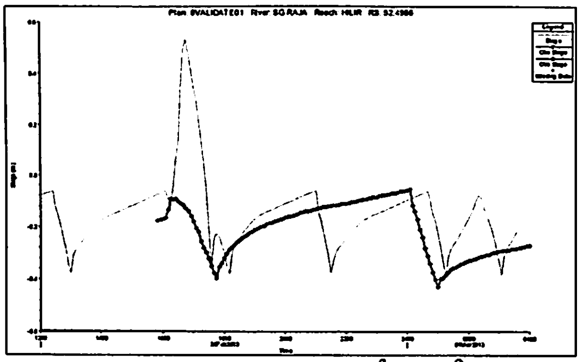
DATE	Rain [mm]
28/Feb/13 12:00	0.0
...	...
28/Feb/13 16:10	0.0
28/Feb/13 16:20	12.4
28/Feb/13 16:30	0.6
28/Feb/13 16:40	0.0
...	...
01/Mar/13 01:00	0.0
01/Mar/13 01:10	0.1
01/Mar/13 01:20	0.1
01/Mar/13 01:30	0.1
01/Mar/13 01:40	0.1
01/Mar/13 01:50	0.1
01/Mar/13 02:00	0.5
01/Mar/13 02:10	0.6
01/Mar/13 02:20	0.0

Table 4.13 listed the parameters used for the validation.

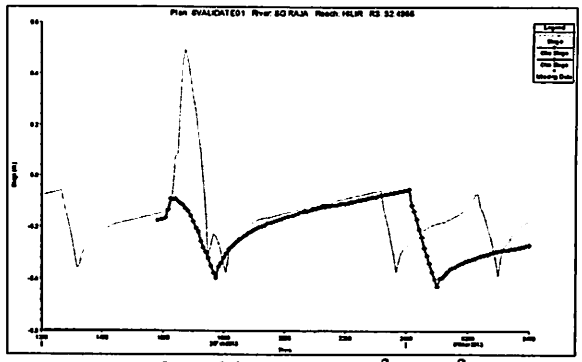
Table 4.13: Summery of the parameters values used for Models Validation

Model	Parameters	Calibrated Values	Validation Values
HEC-HMS	Loss Method: SCS Curve Number		
	Initial Abstraction (I_abs)	Result of Second Calibration: For CN >= 80; I_abs = 0 mm For 60 >= CN > 80; I_abs = 0.02 of the initial computed values For CN < 60; I_abs = 0.2 of the initial computed values	
	CN Number (CN)	Values as generated using HEC-geoHMS	
	%Impervious (Iimp)	Values as generated using HEC-geoHMS	
	Baseflow: Recession Model		
	Initial Type	Discharge per Area	
	Initial Discharge (Qi)	0.069 $m^3/s/km^2$ (Rainy); 0.125 $m^3/s/km^2$(Dry)	0.060 $m^3/s/km^2$
	Recession Constant (RC)	0.95	0.95
	Ratio to Peak (R2P)	0.002	0.002
	Simulation time	As Required	25 Feb 2013 @ 0000 to 01 Mar 2013 @ 0800
	Time Interval	1 minute	
HEC-RAS	Manning's n	0.015	
	Pump Operation	2.25 m^3/s for head = 0m; 2.2 m^3/s for head = 10m	
	Unsteady Flow: Initial water level (WLi)	0.0 m to -0.45 m	-0.08 m
	Simulation time	As Required	11 November 2012 @ 2110 to 13 November 2012 @ 0710
	Computation Interval	5 second	

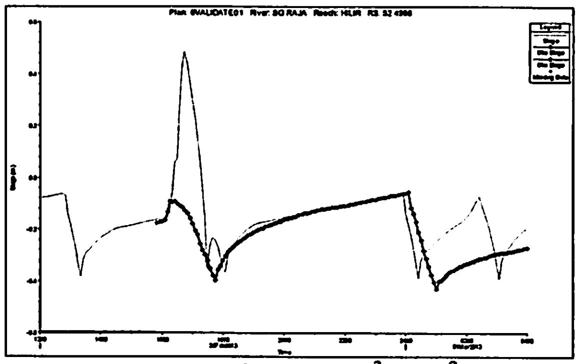
Running the models using the calibration Qi values did not produce very good fit and changing the Qi = 0.060 $m^3/s/km^2$ produces better result (Figure 4.17c and Figure 4.17d).



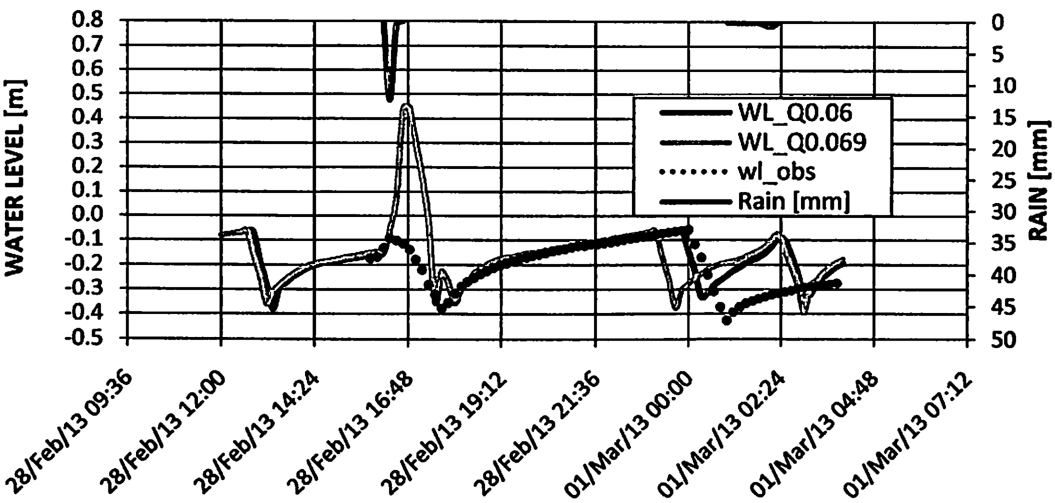
a. Qi =0.125 $m^3/s/km^2$



b. Qi = 0.069 $m^3/s/km^2$



c. Qi = 0.06 $m^3/s/km^2$



d. Observed Stage-hydrograph compared with Qi=0.06 $m^3/s/km^2$ and Qi= 0.069 $m^3/s/km^2$

Figure 4.17: Stage-hydrograph of different Qi. Qi=0.06 $m^3/s/km^2$ produces the better fit compared to Qi= 0.069 $m^3/s/km^2$.

Even though three calibrations were carried-out to represent three different cases, but there are still many possibilities that may occur in real life situation as portrayed by this validation results. For these exercises, besides uneven rainfall distribution within the study area, it can be assumed that the models' algorithm did not capture all the processes that are taking place. Nonetheless, the list of values in Table 4.11 can be used for model simulation for SRS.

4.5 MODEL SIMULATIONS

For model simulation, the rainfall event used for Second Calibration (11 November 2012 @ 00:10 am to 13 November 2012 @ 10:00) was used. Two scenarios were created for the model simulation. The first simulation is for condition when 80% of a sub-basin is fully paved (developed) and the remaining 20% is green or vegetated land use. The second simulation is when the whole study area is developed. Computation of parameters values as in Table 4.14.

Table 4.14: Parameter values for Models Simulation

SCENARIO	LANDUSE / PARAMETER	BUILD-UP AREA [1]	GREEN [2]	WEIGHTED VALUE per unit area [3]	VALUE FOR SIMULATION [4]
1	CN Number	98	40	86.4	86
	% impervious	98	10	80.4	80
	Initial Abstraction (mm)	-	-	0	0
2	CN Number	98		98	98
	% impervious	98		98	98
	Initial Abstraction (mm)	-	-	0	0

For sub-basins having values of CN and %impervious greater than column [4], those values remain unchanged. Simulation time used for Second Calibration (wet condition) was used for this model simulation (Table 4.15).

Table 4.15: Simulation time for Model Simulation.

Model	Simulation time
HEC-HMS	11 November 2012 @ 00:10 am to 13 November 2012 @ 10:00
HEC-RAS	11 November 2012 @ 1500 to 12 November 2012 @ 1200

Simulation results indicated that the study area will respond to landuse change as shown in Table 4.16 and Figure 4.18.

Table 4.16: Peak discharge comparison of Second Calibration, Scenario 1 and Scenario2.

SIMULATION	PEAK DISCHARGE (m^3/s)	% INCREASE (Referenced to 2^ND^ Calibration)	DATE AND TIME
Second Calibration	8.98		11 November 2012 @ 18:20
Scenario 1 (SIM1)	11.31	26	11 November 2012 @ 18:20
Scenario 2 (SIM2)	12.62	41	11 November 2012 @ 18:20

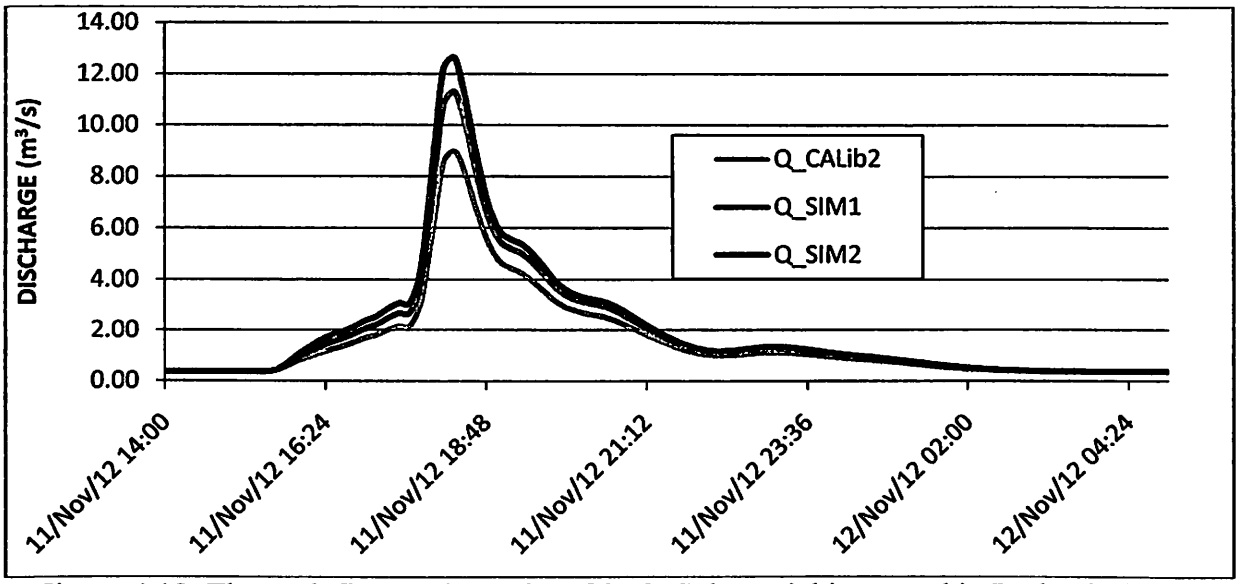


Figure 4.18: The peak flow at the outlet of SRS. Substantial increased in Peak Discharge between the present land use and the Scenarios.

However, there is not much different in the pumping operation for all simulations. All generated water levels are below 1.0 m which is will not cause flooding in Alor Setar City. The stage-hydrographs of the simulations are as in Figure 4.19. The water fluctuations and pumping operation during the rainfall event differs quite substantially for each simulation but behave almost similarly after the rainfall event.

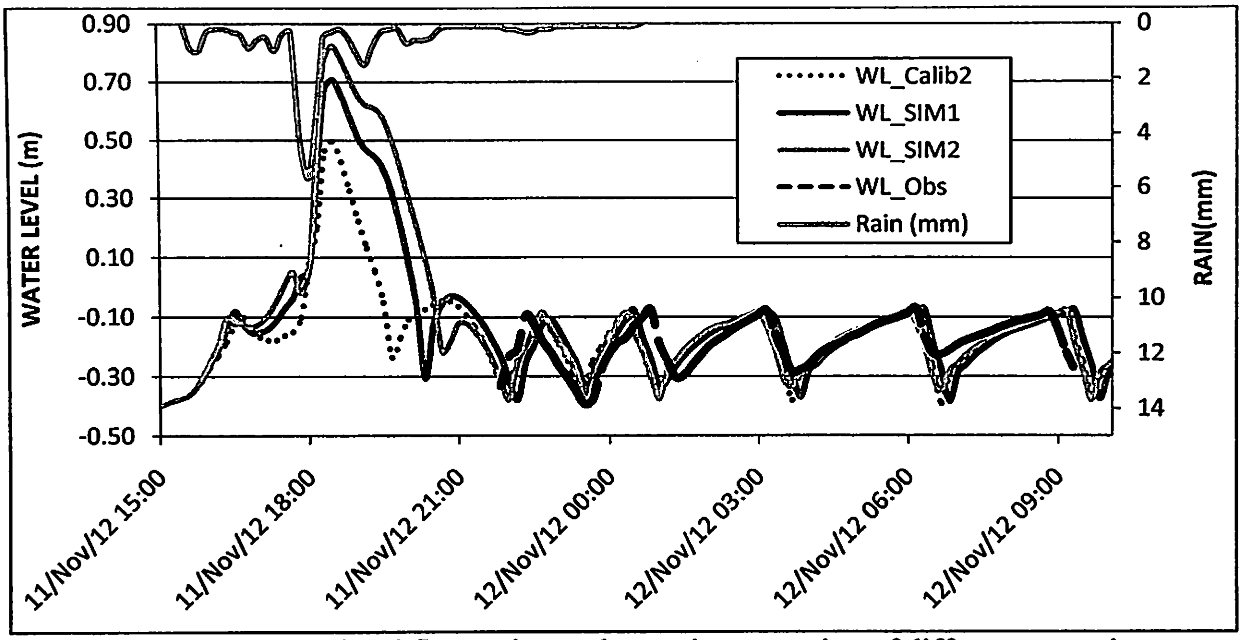


Figure 4.19: Water level fluctuation and pumping operation of different scenarios.

4.6 SUMMARY

The study area is urbanised and lies on a low and flat topography. But the availability of LiDAR DEM and GIS technology, delineation of watershed and drainage network were done quite easily and accurately. SRS model was constructed using hydrologic (HEC-HMS) and hydraulics (HEC-RAS) models together with the utilisation of GIS softwares. Model calibrations and validation results were verified with the observed values. From the analysis, the results are comparable to the observed values and within the acceptable simulation accuracy. Hence, the techniques and the mathematical models used are applicable for stormwater/flood management tool even for an area such as SRS that has very limited data and information.

CHAPTER 5: WATER QUALITY MODELLING

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5.1 INTRODUCTION

Water quality is a critical issue for the Sungai Raja System. To address the issue fully dynamic one dimensional modelling approach was utilized. Water Quality Modelling was to investigate the water quality trend and dispersion in the SRS. The InfoWorks RS and HEC-RAS softwares were tested to perform the Water Quality simulations.

5.2 Water Quality Modelling using InfoWorks RS v 10

This sub-Section 5.2 is the excerpt of work done by Ramli (2013) on water quality modelling using InfoWork RS. Ramli (2013) has intensively carried out the hydrologic, hydraulics and water quality modelling using the InfoWork RS software and by no mean is to be repeated in this report.

Figure 5.1 shows the sub-catchment configuration and Figure 5.2 shows the identified outfalls where flow and water sampling data were collected for modelling purposes. Forty outfalls were identified; 7 at Sungai Raja; 20 at Alor Siam; and 13 at Sungai Derga. Data were collected during dry season and were taken at every two hour interval for 24 hour.

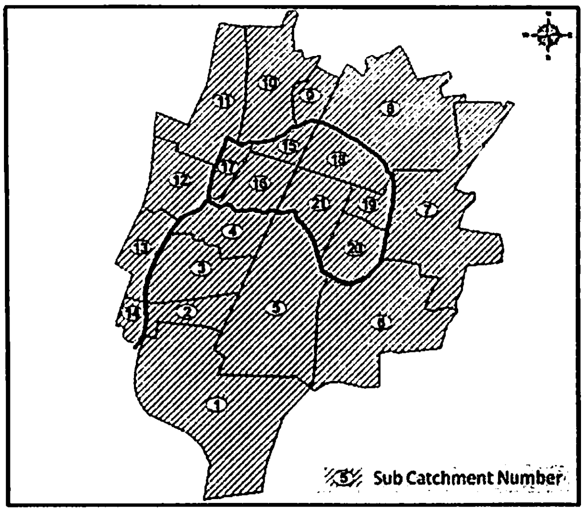


Figure QW.2: Delienated Sungai Raja System sub-catchment area used for InfoWork hydrologic modelling.

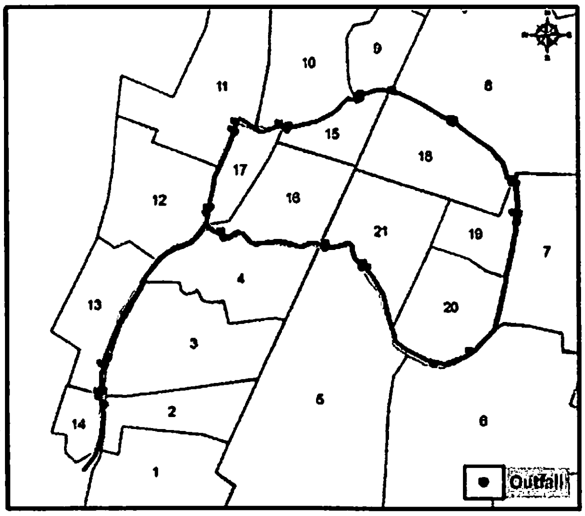


Figure QW.2: Locations of outfalls where flow and water quality samples were collected.

Ramli (2013) has intensively conducted the water quality modelling that comprises of sensitivity test, calibration, and validation of the models. Model setup and results of the sensitivity tests and model calibrations are briefly described as below.

5.2.1 Model Configuration

Model configuration involves the input of river characteristics that is, cross sections, roughness coefficient, bed slope, alignment of the river system, hydraulics and water quality boundary condition and initial conditions.

5.2.2 Boundary Conditions

Boundary condition of hydraulic model is flow from outfalls at dry and wet weather conditions. The hydrograph plots at outfalls used for dry weather condition module as a boundary condition. Water quality model required additional data such as pollutants concentration at each outfall. Since the real time data not available for this Sungai Raja System, the boundary type discharge versus pollutant concentration applied in this study. The average value for three subsequence measurement was taken as a pollutants concentration at particular discharge.

5.2.3 Initial Conditions

For this study, the initial conditions for hydraulic model were defined using result from a steady state simulation. The initial conditions for water quality model were determined by field measurements at specific date for the selected locations. The pollutants concentration for Dissolved Oxygen, pH and Ammoniacal Nitrogen measured for the dry weather condition. The instruments and method used for water quality data collection discussed in the Section 3.5.3. The location of measurement stations shown Figure 5.3.

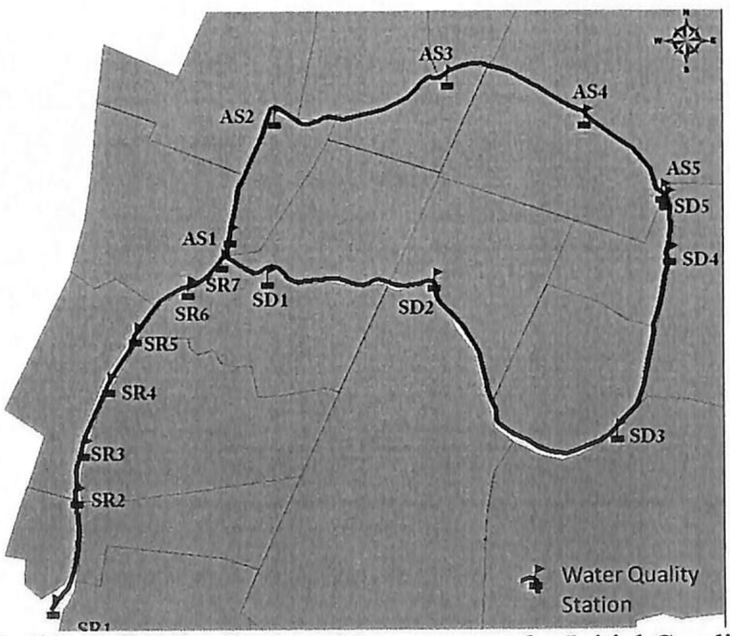


Figure 5.3: Water Quality Stations Measurement for Initial Conditions

5.2.4 Sensitivity Test

The sensitivity analyses for water quality model were for reaeration factor, diffusion rate, heat exchange coefficient, temperature and decay rate. The input values for the parameters are listed in Table 5.1.

Table 5.1: Initial Values of Sensitivity Analysis for Water Quality Model

Analysis	Reaeration Factor	Diffusion Rate	Heat Exchange Factor	Ambient Temperature	Decay Rate
Initial Value	1.0	0.0064	0.04	25°C	0.20

Table 5.2: Conclusions of the Water Quality Sensitivity Test

Sensitivity Test	Conclusions
Sensitivity of DO, AN and pH to Reaeration Factor	reaeration factor is not sensitive for the water quality model. The default value was used for further simulation
Sensitivity of DO, AN and pH to Diffusion Rate	Effect of dispersion rate to Dissolved Oxygen patterns is not too critical which is the range of concentration vary from 0.50 mg/L to 0.60 mg/L or 0.1 mg/L different for dispersion range 0.07 ft^2/s to 19.39 ft^2/s.
	The Ammoniacal Nitrogen (AN) trends indicated uniform pattern at pumping operation in river system. The largest dispersion rate shows the lowest concentration of AN in the channel.
	pH value is sensitive to changes of dispersion rate in the river system.
Sensitivity of DO, AN and pH to Heat Exchange	Degradation of Dissolved Oxygen occurs for increasing of heat exchange rate. Faster heat transfer into water body will effected concentration of Dissolved Oxygen in the river system. Hence, magnitude of heat exchange in the water column is important parameter to evaluate concentration of Dissolved Oxygen in the water body.
Sensitivity of DO, AN and pH to Water Column Temperature	Dissolved Oxygen is sensitive to magnitude of temperature in the river system.
	Others pollutant shown uniformed trend with different temperature

5.2.5 Calibration

Calibration process is to "fine tune" the model to fit a data set by adjusting the relevant parameters. The calibration station is SR-719 as shown in Figure 5.4.

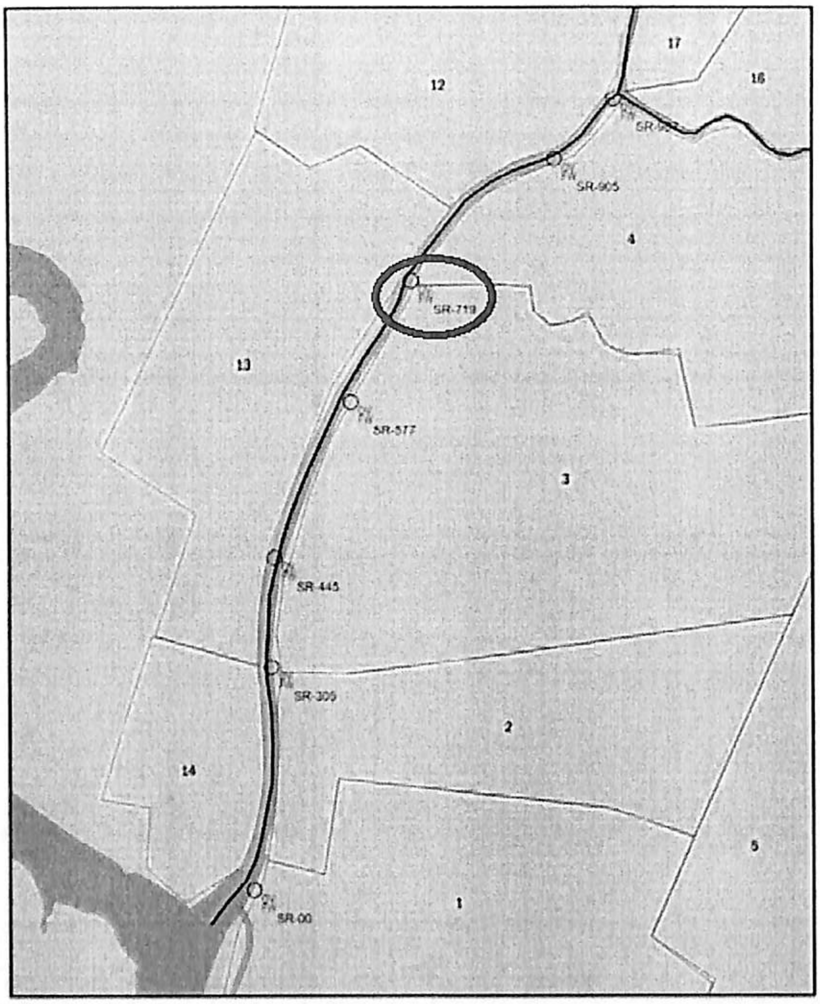


Figure 5.4: Model Calibration Stations Located at Sungai Raja

The calibration of water quality model figured out by several values of dispersion rate. The values tested and simulated results of the DO are as shown in Figure 5.5. The statistical analysis for simulated results and field measurement at CH719 of Sungai Raja carried out and result of regression analysis displayed in Table 5.3. The coefficient of determination, R^2 is 0.836, which is good fit value for the periods of data measurement. The standard error for Dissolved Oxygen is -0.0322mg/L to +0.0322 mg/L.

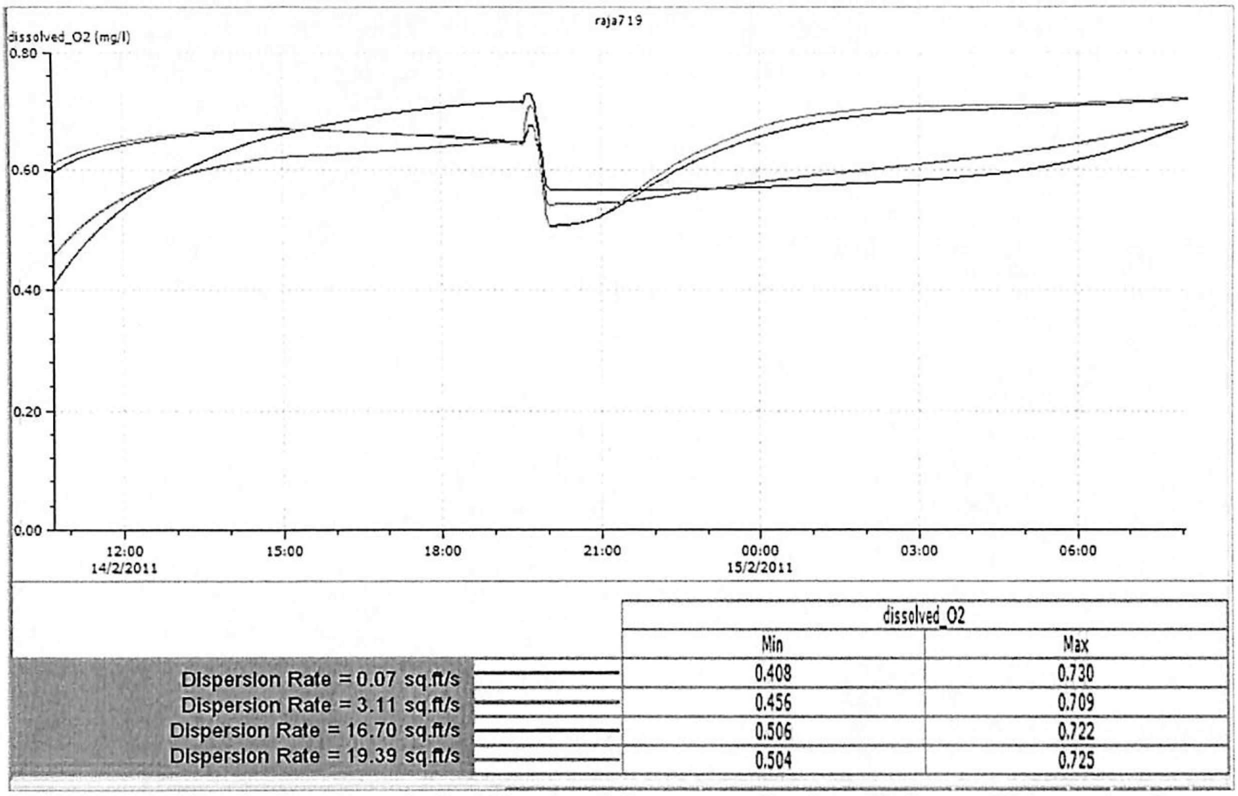


Figure 5.5: Simulations Result for Dissolved Oxygen at Various Values of Dispersion Rate

Table 5.3 : Regression Analysis of Dispersion Coefficient 19.39 ft2/s for Dissolved Oxygen at CH719 of Sungai Raja

Data	R	R^2	Std. Error
Observed v/s Simulated	0.915	0.836	0.0322

Table 5.4 shows the R^2 values for various dispersion rate and pollutants concentration.

Table 5.4: Regression Analysis for Dispersion Coefficients at CH719 of Sungai Raja

Dispersion (sq.ft/s)	Coefficient of Determination, R^2		
	DO	AN	pH
Default Value	0.158	0.000	0.000
0.070	0.858	0.138	0.452
3.110	0.88	0.162	0.446
16.700	0.846	0.271	0.459
19.390	0.836	0.773	0.461
50.000	0.706	0.731	0.459

The Ammoniacal Nitrogen (AN) simulations analysis for 19.39 ft^2/s shows the best agreement compared to other dispersion rate values. The changes of pH value throughout simulation result for dispersions rate show very small variances and influenced coefficient of determination value. The best fits value of coefficient of determination examined was 0.461 for dispersion rate of 19.390.

5.2.6 Water Quality Simulations

Model simulation for humid or wet weather condition have shown that better quality of DO and AN compared with dry season. DO concentration increases after rainfall is from 60% to 80% better than the concentration during the dry season. Increasing volume of water in the river can decreased AN concentration from 15 mg/L to 0.1 mg/L. Thus, the presence of rainfall in the catchment area can help improve the water quality of the river system.

Conservation methods studied further by flowing water containing high dissolved oxygen content in certain areas. Dissolved Oxygen concentrations in the Class I passes from upstream of Sungai Derga and Alor Siam. Significant changes of DO shown before approaching the junction of the three rivers. After the junction of these rivers, the water quality back to the original pattern which is in Class IV. This proves that the DO concentration in the Sungai Raja not affected by the concentration in the Sungai Derga and Alor Siam. Therefore, rehabilitation methods need to develop to ensure the success of the conservation program.

The next method of conservation is to increase the velocity of water to the river system. With the increasing speed by 40% of water has helped increase the DO level up to 75% of the original condition. However, concentrations of AN and pH is not changed according to water velocity, and this proves that the water velocity does not influence the concentrations of AN and pH.

5.3 WATER QUALITY MODELLING USING HEC-RAS

Water quality module was added to the current HEC-RAS version 4.1. The water quality module uses the QUICKEST-ULTIMATE explicit numerical scheme to solve the one-dimensional advection-dispersion equation (USACE, 2012). This model simulates fate and transport of water temperature, arbitrary conservative and non-conservative constituents, dissolved nitrogen (NO3-N, NO2-N, NH4-N and Org-N), dissolved phosphorus (PO4-P, OrgP), algae, CBOD, and dissolved oxygen. The details of the HEC-RAS water quality model can be seen in its user's manual.

The inputs requirements for Water Quality module include the hydrodynamic information, water temperature, meteorological data and water quality (nutrient parameters) data. The hydrodynamic data were read from the earlier unsteady flow run prior to execution of the water quality model. The water temperature model requires a time series for water temperature and meteorological data. The nutrient modelling requires all the aforesaid data input. The meteorological data needed (for the temperature and nutrient modelling) and Nutrient Parameter as listed in Table 5.5.

Table 5.5: List of Meteorological Data and Nutrient Parameter required by HEC-RAS for Temperature and Nutrient Modelling

Meteorological Data	Nutrient Parameter
• Atmospheric pressure; • Air temperature; • Humidity (vapour pressure, relative humidity, wet bulb or dew point); • Solar radiation; • Wind speed; and • cloudiness	• Dissolved Nitrite Nitrogen (NO2); • Dissolved Nitrate Nitrogen (NO3); • Dissolved Organic Nitrogen (OrgN); • Dissolved Ammonium Nitrogen (NH4); • Dissolved Organic Phosphorus (OrgP); • Dissolved Orthophosphate (PO4); • Algae; • Carbonaceous Biological Oxygen Demand (CBOD); and • Dissolved Oxygen (DO)

Due to intensive data requirement and also unavailability of those data to run the water quality modelling using HEC-RAS, this study conducted only model testing for water temperature modelling. This was done due to the importance of temperature in nutrient modelling. USACE (2012) stated that most of the rate constants in the nutrient model are temperature dependent; nutrients may not be modelled unless water temperature is also simulated or set to a fixed value.

5.3.1 Water Temperature Modelling

Water temperature predictions are performed using the water quality module within HEC-RAS. Temperature modelling requires hydrodynamic input and meteorological input. The hydrodynamic modelling was deliberated in Chapter M. This sub-section will introduce the steps required to construct a functioning water temperature model.

5.3.1.1 Hydrodynamic Model

Flow and stage information are main inputs for water temperature modelling besides the meteorological information. These information were provided by the hydrodynamic model used for hydrologic and hydraulics Third Calibration described in Chapter M.

5.3.1.2 Water Temperature Data Entry

To compute temperatures in the Sungai Raja System, HEC-RAS model requires temperature boundary conditions. These information are required for every discharge/inflow location used for hydrodynamic modelling. Since no water temperature time series is available, assumed time series water temperature data were used as water temperature system boundaries. Figure 5.6 shows the assumed Water Temperature time series used in the modelling. These time series data were organised using the spreadsheet type data editor provided by the HEC-RAS. This editor facilitates cut and paste, auto fill, basic mathematic functions, search and replace, and linear interpolation of series information.

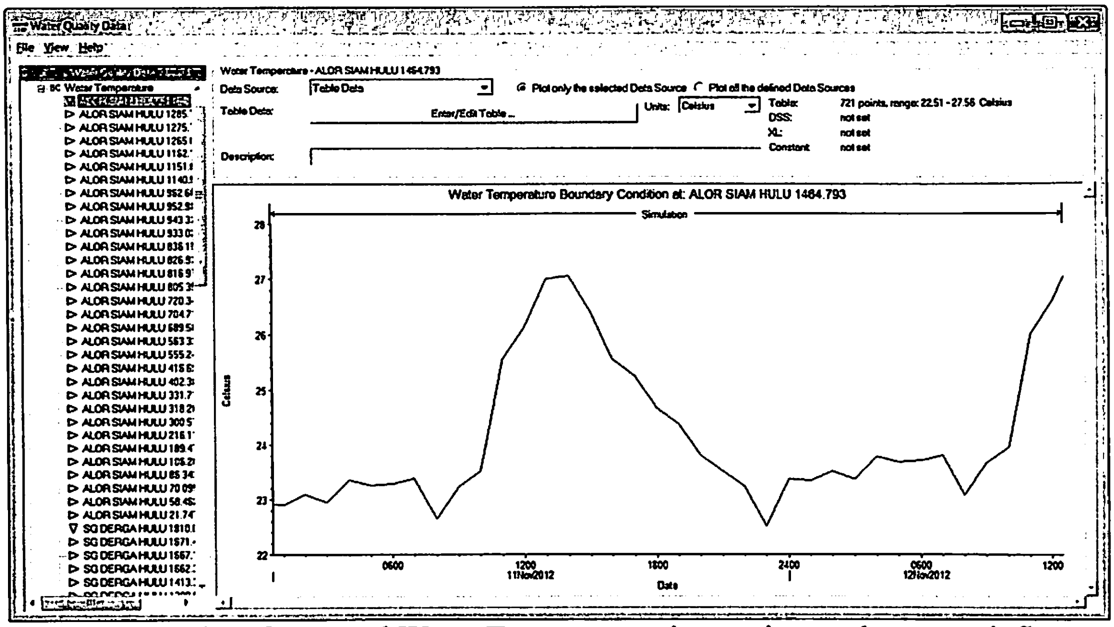
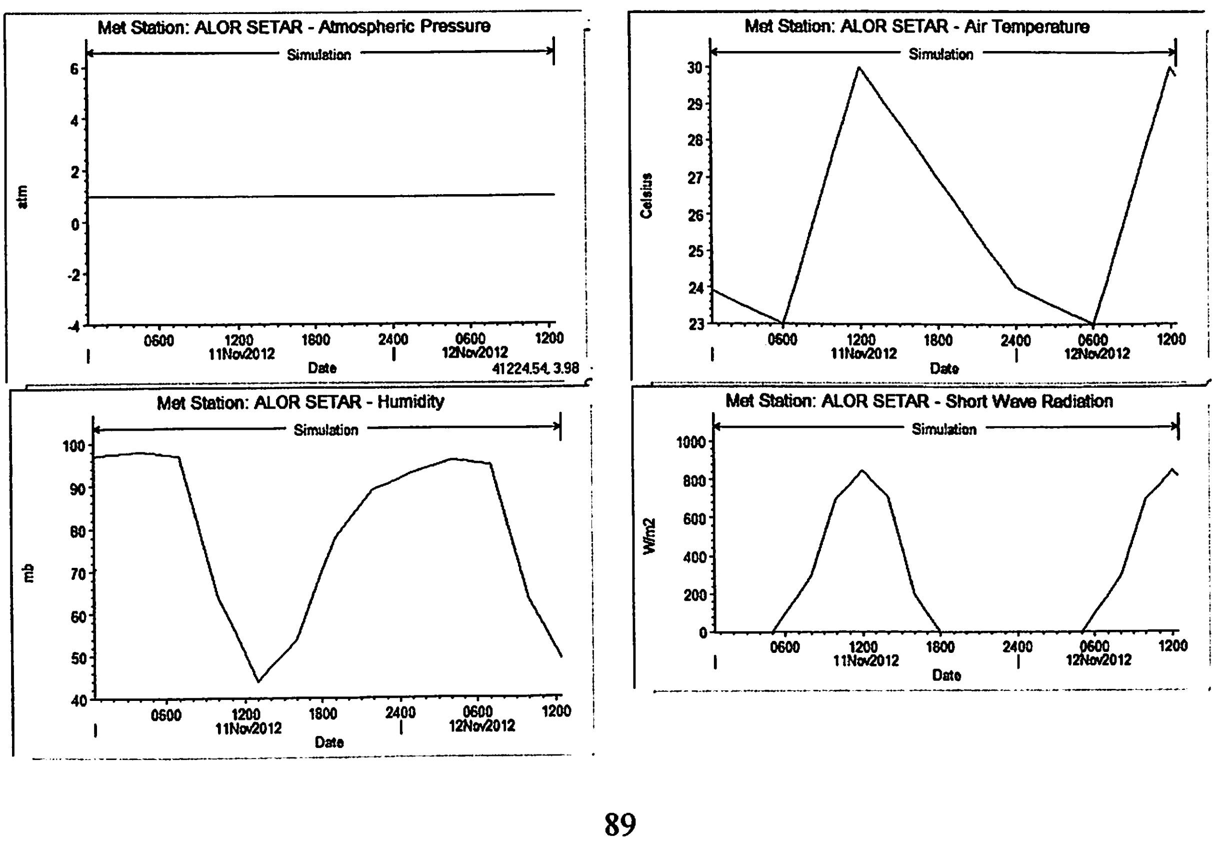
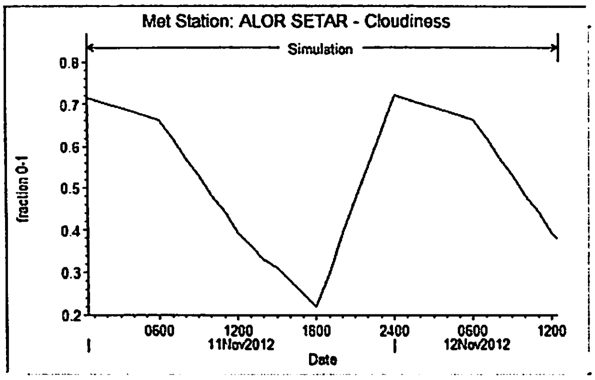


Figure 5.6: Plot of assumed Water Temperature time series used at every inflow and outfall location.

5.3.1.3 Meteorological Data Entry

Similar to the Water Temperature data input, the meteorological time series data (as listed in Table 5.5) used for the modelling are assumed data. The time series information for the meteorological inputs is as in Figure 5.7.





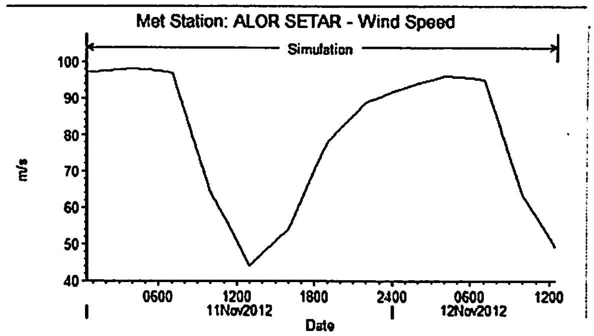
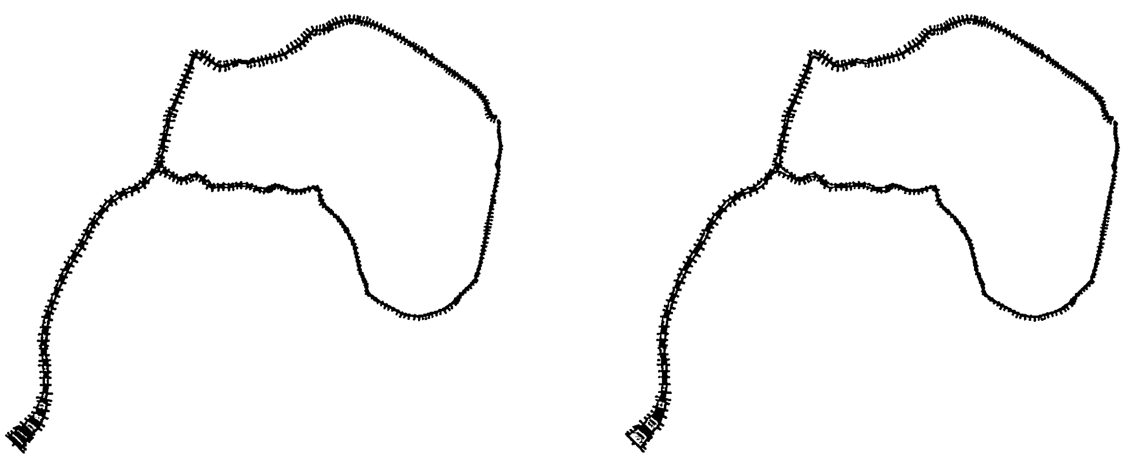


Figure 5.7: Assumed meteorological time series data used for the Water Temperature modelling

5.3.1.4 Water Quality Cell

Water temperature calculations within HEC-RAS occur at water quality cells. The water quality cell is an area between two neighbouring cross sections. However, HEC-RAS also allow the modeller to configure the water quality cells to span over multiple cross sections usually for areas where the cross sections have been placed very closed together (such as around bridges or other hydraulic structures (USACE, 2010). For this study, the minimum water quality cell lengths were set at 1m which corresponds to the minimum reach length in the system geometry, i.e., area between two neighbouring cross sections; and 20m to test the model sensitivity to the minimum reach length (Figure 5.8).



a. Water quality cell set at 1m b. Water quality cell set at 20m

Figure 5.8: Water quality cell configuration using minimum length reach length of 1m and 20m.

5.3.1.5 Dispersion Coefficient

Dispersion coefficient can be assign to as few as one or as many as all cross section. For this modelling exercise, tests were conducted for dispersion coefficient of 1 m^2/s, 10 m^2/s, 100 m^2/s, and 500 m^2/s.

5.3.2 Running the Simulation

The hydrodynamic model was simulated from 11 November 2012 at 0030 hrs to 12 November 2012 at 0930 hrs using 10 seconds computational interval. Water quality was simulated from 11 November 2012 at 0030 hrs to 12 November 2012 at 1230 hrs. The simulations were to investigate the model sensitivity to minimum water quality cell length and dispersion coefficient. Two sets of test were conducted as listed in Table 5.6.

Table 5.6: Sensitivity Tests carried-out for Water Temperature Modelling.

Test	Water Quality Cell Length	Dispersion Coefficient (m^2/s)			
1	1 m	1	10	100	500
2	20 m	1	10	100	500

5.3.3 Simulation Results

Results of the simulated time series water temperature were taken at the Sungai Raja last water quality cell of every run. These outputs were compared to input water temperature for each test set. Simulation results for Test 1 are shown in Figure 5.9 and for Test 2 are shown in Figure 5.10. The simulated water temperature profiles are higher than the input water temperature for both test series. At this juncture, no adjustment was made to the parameter or input of this water quality model as this model was not using actual data.

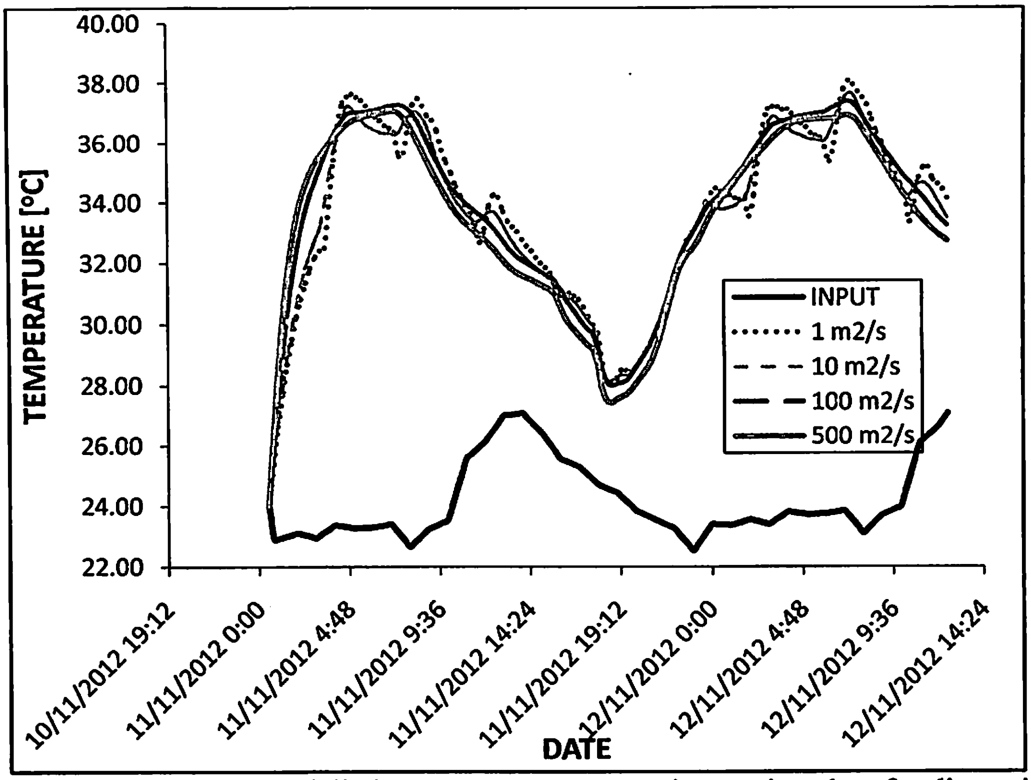


Figure 5.9: Test 1 modelled Water Temperature Time series plots for dispersion coefficient of 1 m^2/s, 10 m^2/s, 100 m^2/s, 500 m^2/s and Input Water Temperature.

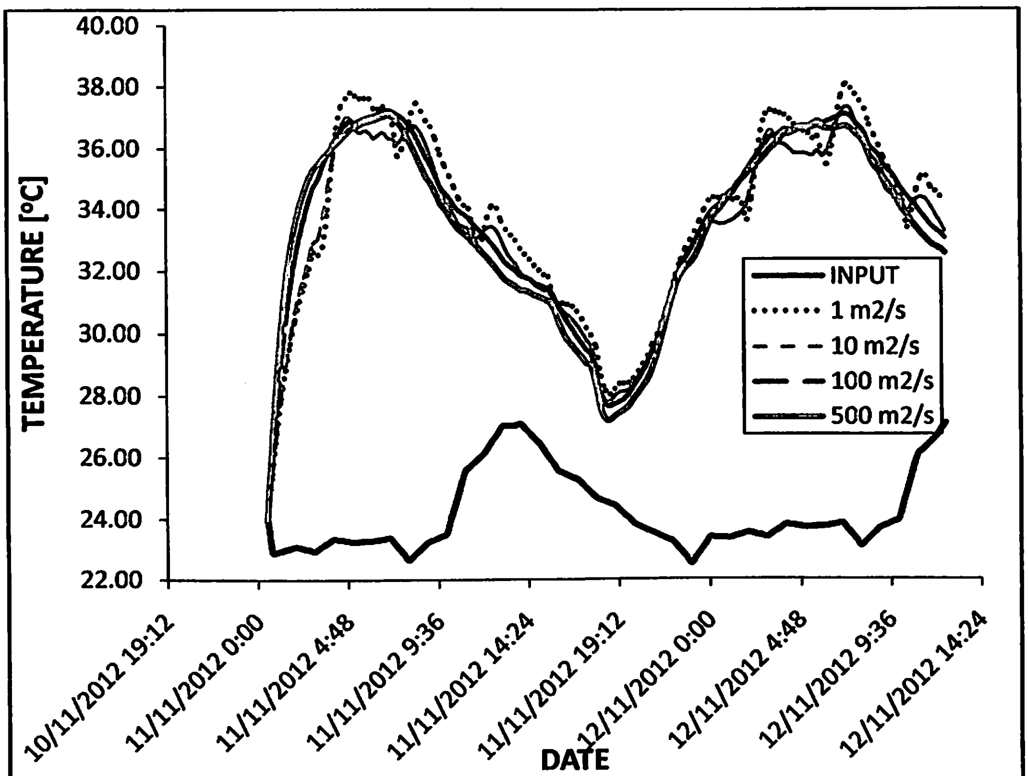
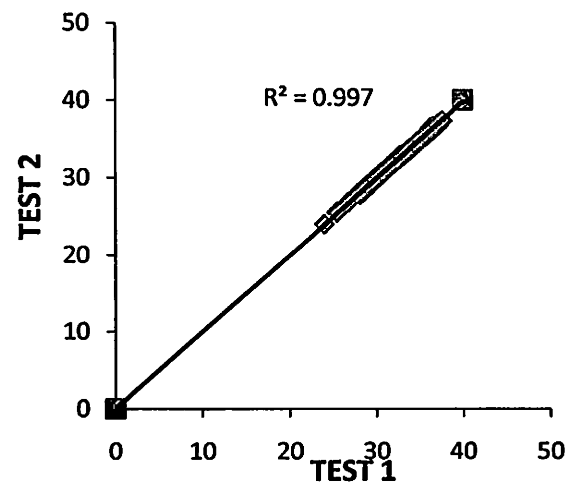
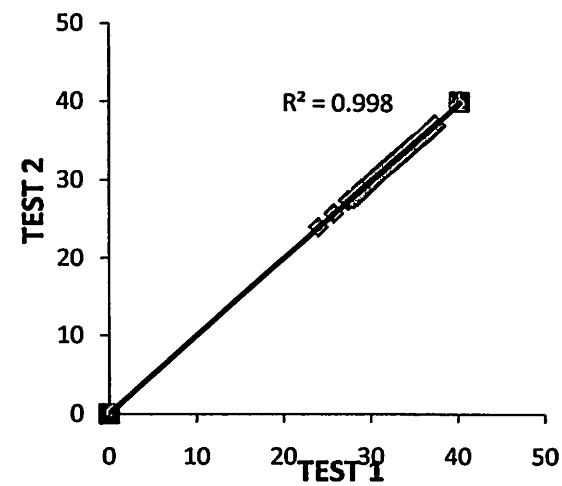


Figure 5.10: Test 2 modelled Time series plots of water temperature for dispersion coefficient of 1 m^2/s, 10 m^2/s, 100 m^2/s, 500 m^2/s and Water Temperature input.

Figure 5.11 demonstrate that the SRS temperature model is not very sensitive to the dispersion coefficient where R^2 for Test 1 is 0.9979 and 0.9988 for Test 2.



Test 1 versus Test 2 for dispersion coefficient of 10m2/s



Test 1 and Test 2 for dispersion coefficient of $100m^2/s$

Figure 5.11: Water temperature correlation (at end of Sungai Raja) between Test 1 and Test 2 for Dispersion Coefficient of $10m^2/s$ and $100m^2/s$.

Stream flow is an important factor affecting water temperature as illustrated in Figure 5.12. The water temperature is at the lowest when the inflow rate is the highest.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

Zorkeflee Bin Abu Hasan, REDAC, USM

6.1 CONCLUSIONS

Impact of urbanization is very significant both in term o water quantity and water quality. The authorities that involved in urban development and those related to flood management should be able to work together to minimise the urban flood risks. Because of unpredictable future climate and human behaviour, flood management especially in highly urbanised area, flood management practitioners need to consider measures that is robust and at the same time is flexible enough to accommodate abrupt changes. Although these requirement seem very challenging but it is something possible due to the advancement of computer technology, GIS technology, and numerical models capabilities. Flood management authorities can therefore consider measures under different flooding scenarios and under different climate change condition.

This study opted to apply HEC-HMS and HEC-RAS numerical models coupled with the utilization of GIS software to review the current Alor Setar Flood mitigation operation. From the model calibration for various rainfall condition, validation, and simulations based on 80% and 100% paved catchment area, it can be concluded that the Flood Mitigation Project and its current operation is still appropriate and applicable.

As per water quality issues, this study focussed on the in-stream water quality characteristic and behaviour. Two numerical modelling softwares were used, which are InfoWorks RS and HEC-RAS. The application of InfoWorks RS for water quality modelling was deliberated in detail by Ramli (2013) whilst the usage of HEC-RAS was briefly mentioned in Chapter 5 of this report due to insufficient data (especially the observed water quality parameters).

There are many approaches to elevate the flooding and water quality issues in an urbanised area. This study can confidently said that the numerical modelling together with GIS application are the tools to assist urban watershed management.

6.2 RECOMENDATIONS

The limitations and constraints of the study lead to the following recommendations:-

a. To install real time water level and water quality stations at appropriate locations. Hydrologic and hydraulics modelling can be improved with the availability of better estimate "baseflow" and amount of nutrient entering the SRS.

b. To carry-out water quality modelling at watershed level (since pollutant entering a river system came from point and non-point sources) in addition to this study in-steam water quality modelling.

c. To look into possibilities of applying the capabilities of HEC-HMS HEC-RAS and also the InfoWorks in designing Best Management Practice options for urbanised area such as the study area. This will lead to the Integrated River Basin Management practice as intended by the DID (2007).

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APPENDIX

UNIVEI SAINS MALAYSIA
UNIT KULAN WANG PENYELIDIKAN/RU
JABATENDAHARI KAMPUS KEJURUTERAAN
PENYKUMPULAN WANG
TEMPERAKHIR 12/2013

12/20/2013

Status Projek : AKTIF

Tajuk P : WATER QUALITY MODELING FOR INTEGRATED RIVER BASIN MANAGEMENT IN SUNGAI RAJA, KEDAH
ENCIK ZORKEFLEE ABU HASAN

No Projek (Agensi) : KEJURUTERAAN & TEKNOLC

Pusat Pian : Pusat Penyelidikan Sungai dan Saliran

Tempoh Projek : 2010 / 4 - 2013 / 10

No Akaun : 1001 / 814085

Penyeli : ZORKEFLEE ABU HASAN

Vot	teranqan	Peruntukan Asal (a)	Perbelanjaan Tahun Lalu (b)	Peruntukan Semasa (c)	Tanggungan (d)	Belanja (e)	Jumlah Belanja (f) = (d) + (e)	Baki (a) - (f)	% ((b)+(f)) / (a)
11000		59,145.00	$35,490.42	$0.00	$0.00	$5,200.00	$5,200.00	$18,454.58	0.00
		$59,145.00	**$35,490.42**	**0.00**	**$0.00**	**$5,200.00**	**$5,200.00**	**$18,454.58**	0.00
21000	JALANAN DAN \ HIDUP	9,100.00	$3,875.50	$0.00	$0.00	$1,082.90	$1,082.90	$4,141.60	0.00
23000	HUBUNGAN UTILITI	600.00	$0.00	$0.00	$0.00	$0.00	$0.00	$600.00	0.00
24000	AAN	2,000.00	$0.00	$0.00	$0.00	$0.00	$0.00	$2,000.00	0.00
27000	\LAN DAN ' PAKAI HABIS	44,000.00	$36,106.90	$0.00	$0.00	$41,847.30	$41,847.30	($33,954.20)	0.00
28000	YELENGGARA AN 3AIKAN KECIL	15,000.00	$0.00	$0.00	$0.00	$396.00	$396.00	$14,604.00	0.00
29000	KHIDMATAN iAS DAN PITALITI	6,000.00	$8,651.00	$0.00	$0.00	$1,090.00	$1,090.00	($3,741.00)	0.00
		$76,700.00	**$48,633.40**	**0.00**	**$0.00**	**$44,416.20**	**$44,416.20**	**($16,349.60)**	0.00
35000	TA-HARTA AL LAIN	34,334.00	$34,229.00	$0.00	$0.00	$0.00	$0.00	$105.00	0.00
		$34,334.00	**$34,229.00**	**0.00**	**$0.00**	**$0.00**	**$0.00**	**$105.00**	0.00
		$170,179.00	**$118,352.82**	**$0.00**	**$0.00**	**$49,616.20**	**$49,616.20**	**$2,209.98**	0.00

Application of one-dimensional water quality modelling for in stream dissolved oxygen

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ABSTRACT
Located at Alor Setar the Capital City of Kedah, Raja River is a minor stream with a catchment of about 360 hectare. The stream is heavily stressed by domestic and commercial waste loads and has shown significant degradation in water quality since 1994. Currently, the stream reaches show critically low Dissolved Oxygen (DO) level through much of its length during dry weather condition with high temperature. The software package of InfoWorks RS 10.0 model was applied to simulate the DO level at dry weather condition (low flow) periods. The results were used to determine DO level according to Malaysia Water Quality Standard and to identify stream portions that indicate the worst value of DO.

Keywords: Dissolved Oxygen; urban river; water quality; InfoWorks RS model.

1 Introduction

In recent years, rapid development and urbanisation within the river catchment and along the river corridors, including Alor Setar City (ASC) have resulted in deteriorating river water quality, threatening the once pristine conditions of the upper tributaries in the river system. The Government has spent a lot of allocation and efforts to maintain and upgrade the river water quality. One of the strategies to ensure clean water as highlighted in the Sungai Kedah Basin Management Plan 2007-2012 (Department of Irrigation and Drainage Malaysia, 2007) is to reduce pollution from urban sources. The river system involved in the urban source for ASC is the Raja River System.

Raja River System (RRS) is an urban river which is located in the heart of Alor Setar the Capital City of Kedah. The main river for the system is Raja River which passes through the heart of the city and ultimately discharges into Kedah River. It was reported that the level of Dissolved Oxygen in the Kedah River was 2.6 % of saturation, hence is classified as Class V (DID, 2007).

Stream water quality study was carried out by David A. Todd and Philip B.B. (1985) for Buffalo Bayou, Texas. They found that stream conditions are important factor in stream quality, a contention that is supported by the seasonal variation of stream DO with stream flow and temperature. A study of water quality problem of RSS was conducted for 24 months, beginning in July 2009 and ending in June 2011.

The contention of the study was that Raja River is an important stream that should be protected and rehabilitated as a clean river due its location at the centre of Capital City. From evidence collected in the study, it is clear that the stream's DO level has reached critical condition and rehabilitation programme must be planned by the related authorities to maintain cleanness of the Capital City.

2 Study area

RSS is a tributary of Kedah River and is located at the heart of Alor Setar city. The river system consists of two main tributaries which are Alor Siam (1,475 m) and Derga River (1,813 m). These tributaries meet Raja River at 984 m upstream outlet of Kedah River (Figure 1).

In 1992, Department of Irrigation and Drainage (DID) carried out the Flood Mitigation Project to solve the flooding problems of Alor Setar City. The whole river system was converted to concrete lined channel and RRS was separated from the Kedah River by gated structure and pumping station.

Landuse of RRS catchment is made up of approximately 65% build-up areas, 30% undeveloped area (vegetated and barren lands) and 5% waterbodies. This landuse distribution may have contributed to the

poor water quality of RRS. Unfortunately, there is no water quality data/information available at the onset of this study to ascertain the water quality status.
RSS is enclosed system and disconnected from Kedah River which leads to these uncertainty:

(a) Is the present pumping operation able to remove the pollutant from RRS?
(b) Can we predict/determine how the pollutants "move" within the system?

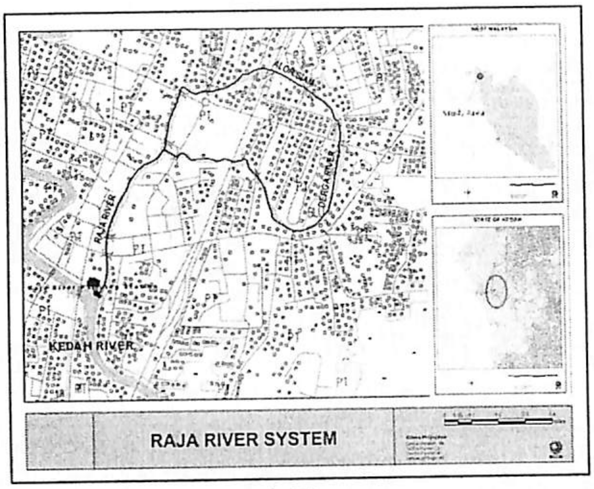


Figure 1 Raja River system

The original river system was a natural river that drains out the surplus water from the city. The capacity of the river system is insufficient to accommodate the run off due to rapid development at the surrounding areas. Since the current and expected future development will result in increase in the surface run-off of the river, The Drainage and Irrigation Department (DID) decided to carry out the Flood Mitigation Project in 1992 where by the river system were widened and concrete lined. The result of this transformation may increase pressures on the water quality of the river, which is expected to get worst in the future.

3 Methods

With the aforementioned concept in mind, the study focused on three major goals. The first purpose was to establish instream water quality model for Raja River System for DO analysis. The second purpose was to determine current DO level according to Interim National Water Quality Standard (INWQS) by the Malaysian International Hydrological Programme (2007). The last goal was to identify the location or sub catchment that contributed the worst DO level.

Also the study followed by two basic techniques that are sampling and analysis and another is model setup.

3.1 Data collection and analysis

(a) Sub-catchment delineation
The area of each sub catchments were processed and calculated using Arc-GIS software packages as illustrated in Figure 2. The total catchment area is about 361 hectares, consisting of various types of developments. Generally, most of the landuse for Alor Siam sub-catchment consists of medium-cost housing schemes and village area. The worst expected pollution contributions originate from the village area. Part of the Derga River sub-catchment is covered by medium scheme housing area and small portion of agriculture activities.

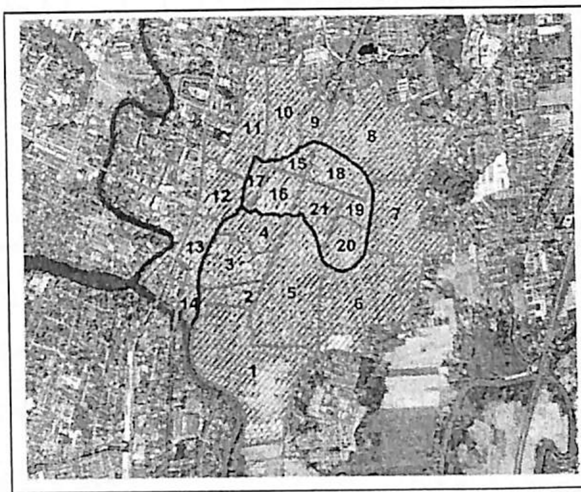


Figure 2 Sub-catchments for entire river system

(b) Inflow hydrographs

Continues data collection was conducted from November 2009 to February 2011 for the entire river system. To feed data requirement for the hydraulic model, the main pipes and drains that are connected to the river were identified from the as-built drawing and confirmed with GPS equipment during site visit. There were 40 sources of outfalls of various sizes: seven into Raja River, 20 into Alor Siam and 13 into Derga River.

The hydrographs for the 21 sub-catchments inflow were tabulated and plotted accordingly. The site measurement for flow in each pipe and drain was conducted every Saturday and Sunday in the month of January and February of 2011. The water in the river was collected by 4 litres container and the time was noted. The average of three flows was used to calculate flow rate in m^3/s.

According to Emre & Charles (2009), the duration of the wet weather period that can influence in-stream water quality varies between 2 days and 2 weeks in similar rivers studied. They had studied the duration of storm effect on in-stream water quality for Chicago Waterway System.

There was no heavy rain during the sampling period; hence these flow data can be represented as normal dry condition and will be used for Boundary

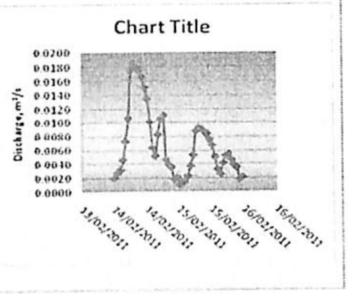
Condition to the model. Table 1 shows an example of hydrograph for one of the sub-catchments.

Table 1 Hydrograph at Dry Weather Condition for Sub-Catchment 8

OBSERVED HYDROGRAPH

Sub Catchment - 8
Area in sqm - 367,906.40

Date-Time	Average Flow, m³/s	Time - Flow Hydrograph
14/02/2011	0.0020	
14/02/2011 01:00	0.0028	
14/02/2011 02:00	0.0031	As measured on every Saturday and Sunday for the month of January to early February.
14/02/2011 03:00	0.0046	
14/02/2011 04:00	0.0074	
14/02/2011 05:00	0.0107	
14/02/2011 06:00	0.0175	
14/02/2011 07:00	0.0184	
14/02/2011 08:00	0.0180	
14/02/2011 09:00	0.0175	
14/02/2011 10:00	0.0166	
14/02/2011 11:00	0.0151	
14/02/2011 12:00	0.0134	
14/02/2011 13:00	0.0101	
14/02/2011 14:00	0.0064	
14/02/2011 15:00	0.0052	
⋮	⋮	
15/02/2011 17:00	0.0052	
15/02/2011 18:00	0.0055	
15/02/2011 19:00	0.0046	
15/02/2011 20:00	0.0039	
15/02/2011 21:00	0.0035	
15/02/2011 22:00	0.0018	
15/02/2011 23:00	0.0021	



(c) Pumping operation

Site visits were conducted with DID Kedah representatives, confirming that under normal condition (without rain) pumping operation occurs once a day with only one pump running. Site investigations were executed on February 2011 to measure the flow velocities and water surface levels at selected locations. Field measurements show that the velocity is almost zero before pumping operation and the water surface level rising slowly (about 6mm / hour). Hence, velocity profile cannot be used for calibration before pumping procedure. Instead, the recorded water surface level (WSL) as shown in Figure 3 will be used for hydraulic model calibration.

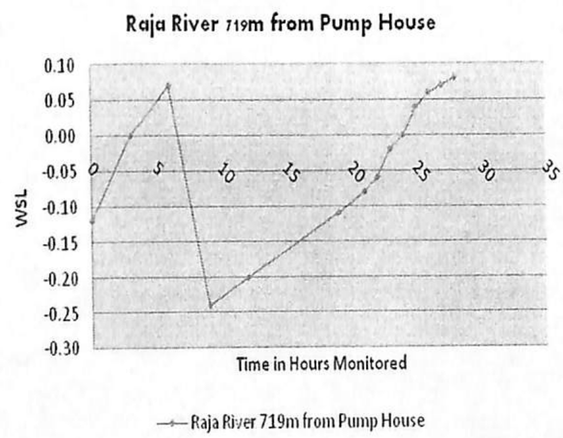


Figure 3 Water Surface Level at CH 719: Raja River

(d) Water quality sampling

Water quality sampling involved collecting samples of in-stream river water using Multi Parameter Sonde 6600v2 water quality probe to measure concentration of DO in the stream as shown in Figure 4.

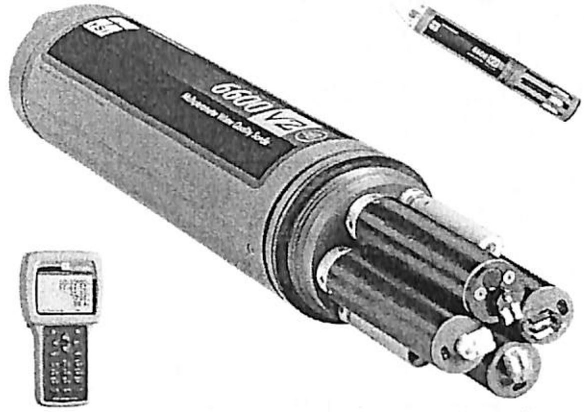


Figure 4 Multi Parameter Sonde water quality probe

The field measurement was undertaken at certain distance from the pumping station along Raja River, Derga River and Alor Siam River. The sample was collected in the container and the probe was inserted into the river for 5 to 15 minutes or till reading shown steady values.

With collaboration with Kedah DID, the samples were sent for the laboratory test for basic six index of water quality, that are Dissolved Oxygen, BioChemical Oxygen Demand, Chemical Oxygen Demand, Ammoniacal Nitrogen, Suspended Solid and pH. The result of laboratory test was illustrated in Table 2 to Table 4.

Table 2 Laboratory Test Result at Raja River Pumping Station

Pollutant	Laboratory Test Result At Sungai Raja Pump Station						
	12.11.09	13.4.10	22.4.10	30.4.10	18.6.10	7.2.10	15.7.10
DO	0.4	< 0.1	< 0.1	4.1	1.8	0.9	2.1
BOD	13	7	7	4	14	10	3
COD	30	40	17.2	17	44	49	23
AN	4	-	-	2	5	4	2
TSS	15	6	108	18	28	5	62
pH	6.8	6.8	6.2	7.1	6.8	6.9	6.8
Temp.	36.7	-	-	29.0	29.0	28.5	-
WQI	45.9	-	-	70.2	45.1	46.7	58.9
CLASS	IV	-	-	III	IV	IV	III

Table 3 Laboratory Test Result at one third of Alor Siam

Pollutant	Laboratory Test Result At Alor Siam 342 m from Junction						
	12.11.09	13.4.10	22.4.10	30.4.10	18.6.10	7.2.10	15.7.10
DO	0.1	-	-	0.5	2.2	1.2	<0.1
BOD	14	2	<2	12	15	13	15
COD	28	46	9.5	21	26	56	54
AN	6	-	-	3	6	5	3
TSS	15	9	9	33	<1	38	47
pH	7.0	7.0	6.4	7.3	6.7	7.1	6.7
Temp.	36.6	-	-	29.0	29.0	28.5	-
WQI	45.8	-	-	48.4	51	41.8	40.7
CLASS	IV	-	-	IV	IV	IV	IV

Table 4 Laboratory Test Result at middle of Derga River

Pollutant	Laboratory Test Result At Sungai Derga 634 m from Junction						
	12.11.09	13.4.10	22.4.10	30.4.10	18.6.10	7.2.10	15.7.10
DO	1.1	-	-	1.7	2.2	0.3	2.1
BOD	16	12	<2	9	13	8	7
COD	28	77	19	50	44	65	23
AN	5	-	-	3	4	3	1
TSS	8	9	11	87	14	9	134
pH	7.0	7.2	6.4	7.2	6.8	7.1	7.0
Temp	36.7	-	-	29.0	29.0	28.5	-
WQI	46.9	-	-	45.1	48.1	47	56.9
CLASS	IV	-	-	IV	IV	IV	III

The results show that the Water Quality Index (WQI) for the entire river system belong to Class IV and indicate that the contribution for the low WQI was low DO level and high BOD. Indeed the average DO level falls below Class V during the study periods. The fluctuations or trends of DO level are the main interest in this study.

Dissolved Oxygen concentration data was collected at selected river cross sections as shown in Figure 5. There were seven stations for the entire Raja River, five stations for Derga River and Alor Siam (as illustrated in Figure 6) were established.

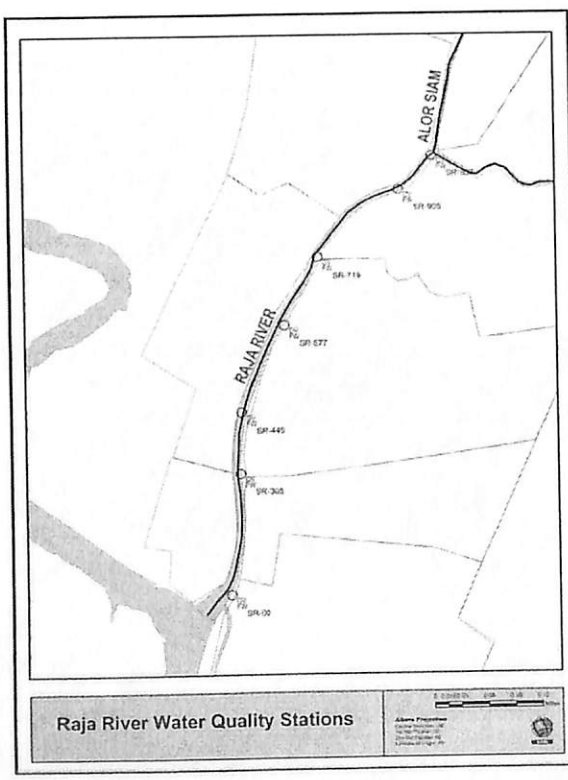


Figure 5 Raja River observation station for DO concentration

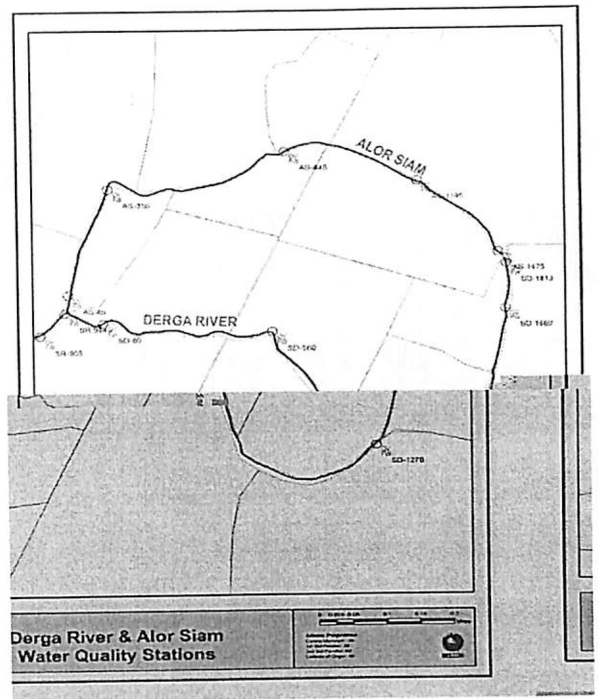


Figure 6 Derga River and Alor Siam observation station for DO concentration

Trends of in stream DO quality before pumping operation as shown in Figure 7 indicated that the concentration of DO varies along the length of the river. The value of DO concentration for entire Raja River ranges from 1.4 mg/L and 0.4 mg/L, indicating water quality of Class IV and V during the study periods.

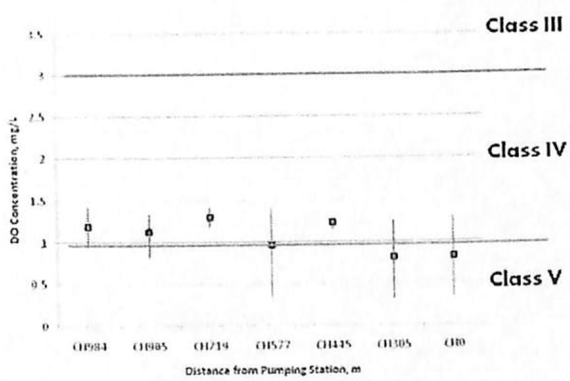


Figure 7 Profile of DO at Raja River

Degradation of DO concentration at upstream down to downstream indicate that DO level becomes low density in term of increasing in water volume. The concentrations measurement at selected location for the entire river system was done from February 2010 to October 2010 as shown in Figure 8. The results indicated that DO concentration varied through location that is from 0.10 mg/L to 3.0 mg/L.

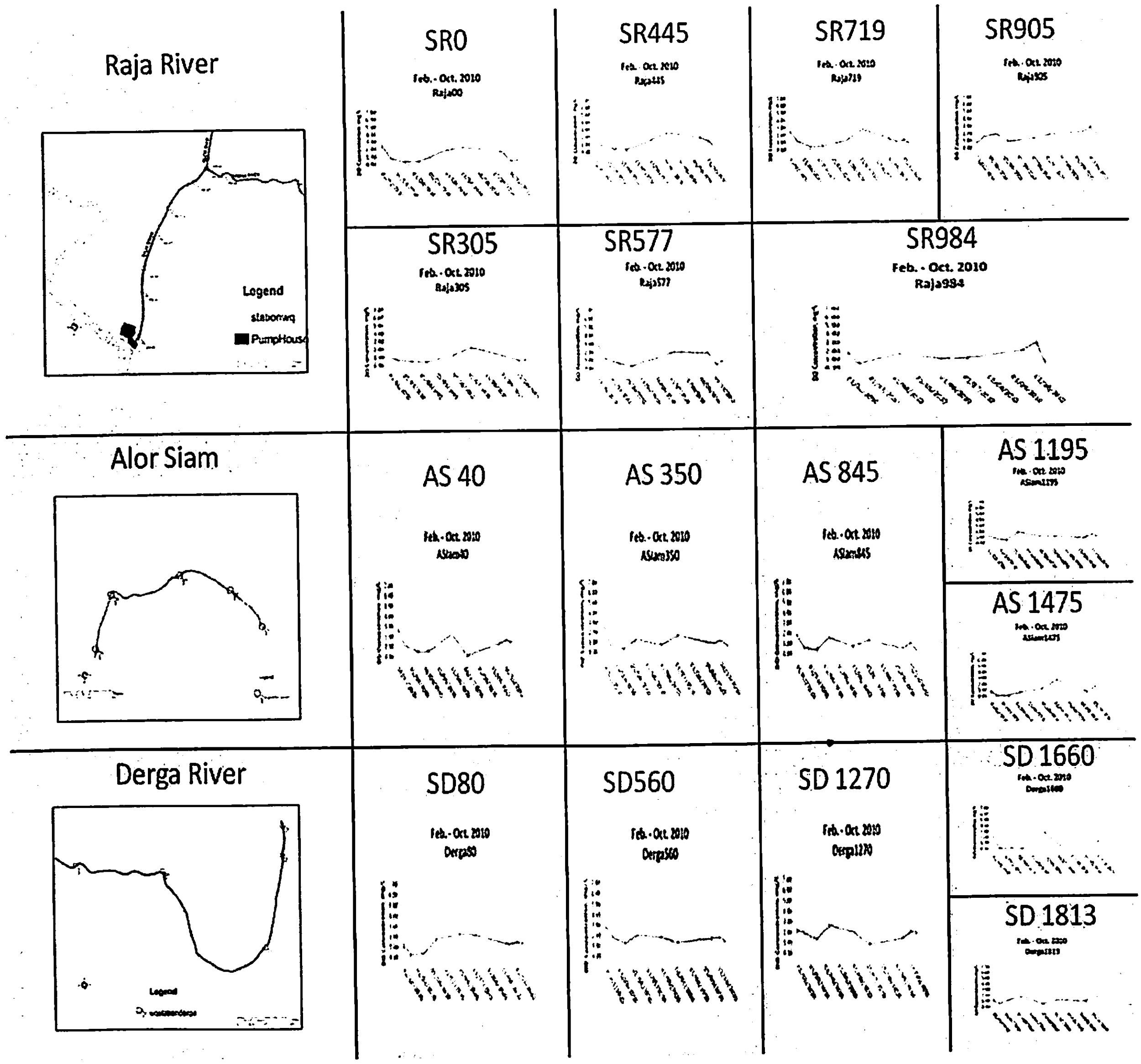


Figure 8 Dissolved Oxygen pattern at observation stations

3.2 Model configuration

Water Quality Modelling has evolved appreciably since its innovation in the early years of the twentieth century (Chapra, 1997). Significant improvements have been made to the original computer models, therefore, improving the quality of model outputs. Today's computer models allow us to simulate in one, two, and even three dimensions. In addition, they enable users to model water bodies that are either in steady state or dynamic systems. Model solution techniques have also been improved and the two most commonly employed are finite differences or finite elements. As a result of these improvements, users are now applying computer models to larger and larger river systems, in order to estimate hydrodynamics and more importantly, water quality.

With regard to rivers and given specific input, such as stream flows, the hydrodynamic models can be used to predict outputs, such as water surface elevations and velocities. In addition, given hydraulic and contaminant concentration value, the water quality models also can be used to predict contaminant loading rate. The hydraulic and water quality models utilization consist of a detailed set of equations that serve to represent complex physical processes. However, as the number of required equations to describe the processes in question increases, the computational time and model complexity also increases. As a result, numerical models have been developed to aid in the solution of complex process equations.

The first step begins with hydraulic and water quality model setup or configurations. At this stage, one dimensional software packages of InfoWorks RS version 10.0 was used. This software package also has free version up to 250 nodes (the study has less than 250 nodes) and it contains hydraulic and water quality model. The models configuration involved hydraulic model, which is need to be established in order to run water quality modelling. However, the reliability of water quality model is dependent on the accuracy of the hydraulic models, including the quality of the calibration data (Vasconcelos et al, 1997). A well-calibrated hydraulic model provides the basis for answering critical questions on facility operation, sizing, method and so forth.

Since the scope of study was dry weather condition, the configuration data setup were roughness coefficient and pump characteristic. However water quality model is more complex than hydraulic model due to more parameters that must be configured such as decay rate, diffusion coefficient, reaeration and so forth (Speight, 2008). The similar software package was used for the study of water quality Maong River, Sarawak by S.Said et al. (2009). The satisfaction decay rate of organic matter was found 0.1 per day.

There are several formulas to estimate longitudinal dispersion coefficient for streams and rivers. Fischer et al. (1979) have developed the equation with 0.43 is a coefficient of determination. For the local study, generic programming to predict longitudinal dispersion was carried out by H.M. Azamatullah and A.A. Ghani (2010). A genetic programming approach was used to derive a new expression for the prediction of the longitudinal dispersion coefficient (K_x) in natural rivers.

The basic equation used by the software to compute flows, depths and discharges is a method based on the equations for shallow water waves in open channels - the Saint-Venant equations as follows:

For 1-D continuity,

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = 0 \text{, 1-D} \quad (1)$$

And for 1-D momentum,

$$\frac{1}{A}\frac{\partial Q}{\partial t} + \frac{1}{A}\frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right) + g\frac{\partial y}{\partial x} - g\left(S_o - S_f\right) = 0 \quad (2)$$

Water Quality Model initial condition and boundary condition parameter was determined during data collection from February to October 2010. However, the hydraulic model initial condition was determined from the steady simulation and boundary condition as measured flow for dry weather condition.

Reaeration coefficient for dissolved oxygen can be determined by using standard formulae of Owens et al. (1964) and O'Conner-Dobbin as follow:

For $d \leq 2.12$ m,

$$k_a = 5.32\frac{u^{0.67}}{d^{1.85}} \quad (3)$$

For $d > 2.12$ and $u < 1.68d^{0.3689} - 1.433$,

$$k_a = 3.93\frac{u^{0.5}}{d^{1.5}} \quad (4)$$

Where u is mean of velocity and d is the flow depth. Further, temperature factor for reaeration rate for dissolved oxygen can be calculated as follows:

$$k_{a,T} = k_{a,20}\theta^{T-20} \quad (5)$$

Equation 3 to 5 was used to determine coefficient of oxygen reaeration in the model.

4 Simulation result analysis

In this study, the boundary condition for the hydraulic model was observed flow hydrographs, calibration parameter was carried out for roughness coefficient only. Figure 9 to 13 show the bivariate plot for various roughness coefficients, n for Raja River at location distance 719 m from pumping station for the calibration date 14th February 2011.

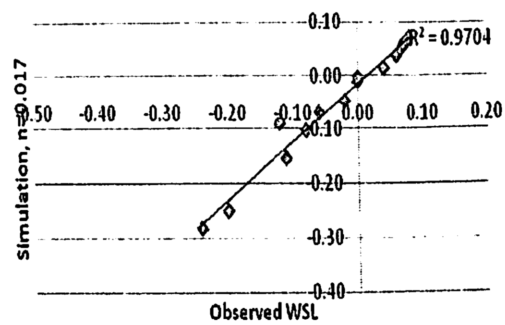


Figure 9 Coefficient of Determination, R^2 for n = 0.017

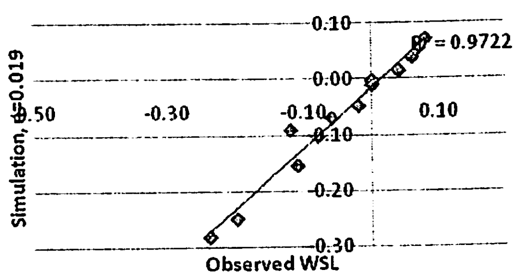


Figure 10 Coefficient of determination, R^2 for n = 0.019

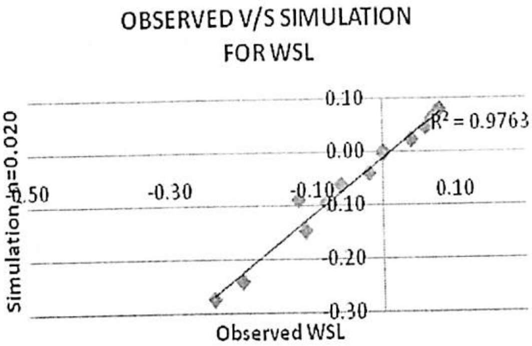


Figure 11 Coefficient of determination,R^2 for n = 0.020

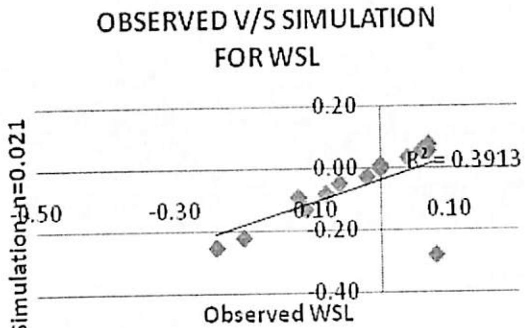


Figure 12 Coefficient of determination,R^2 for n = 0.021

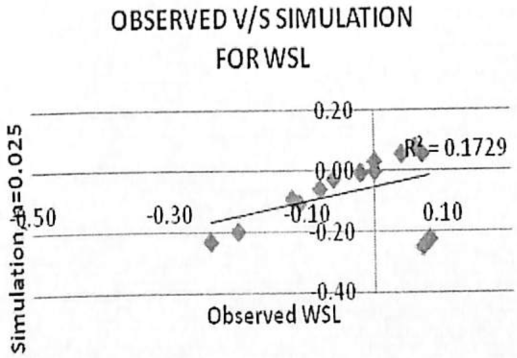


Figure 13 Coefficient of determination,R^2 for n = 0.025

From the results, 97.63% of the variation in water surface level at roughness coefficient of n =0.020 is significant with observed WSL at location Raja River 719 m from pumping station. Hence, hydraulic model with roughness coefficient of n = 0.020 will be used to simulate water quality model.

Due to unavailability of automatic monitoring water quality station at the river, the type of boundary condition for water quality model used was flow-concentration. The calibration station was decided at Raja River that was 719 m from pumping station. Result of calibration shows that the parameters involved were diffusion coefficient, reaeration temperature factor, and decay rate. However, the best fit simulation result with observation was i) Diffusion Coefficient = 19.39 sq.ft/sec; ii) Reaeration temperature factor = 1.024; and iii) Decay Rate = 0.2/day. The coefficient of determination at calibration station was 0.6545 or 65.5% (Figure 14).

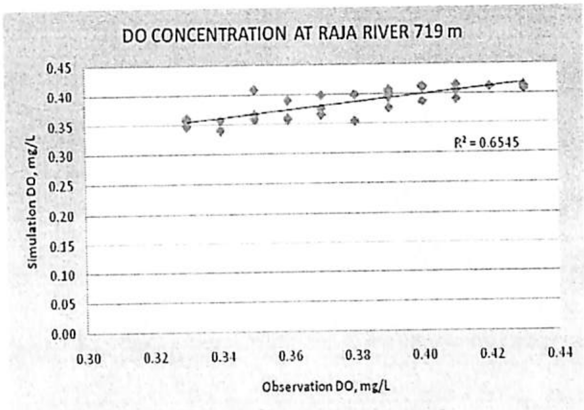


Figure 14 R^2 at calibration station

The simulation was carried out at 14th to 15th February 2011 for dry weather condition for the whole Raja River system. The results of DO concentration for the selected location were illustrated in Figure 15 and Figure 16.

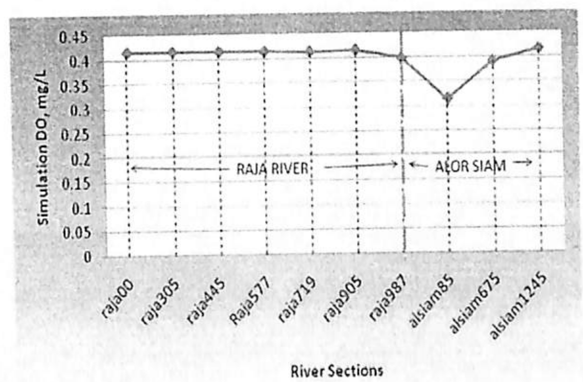


Figure 15 Trends of DO concentration from Alor Siam to downstream Raja River

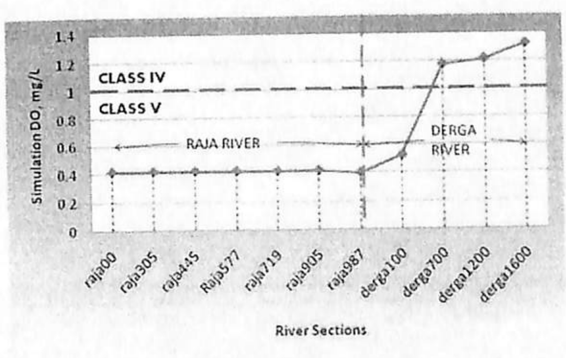


Figure 16 Trends of DO concentration from Derga River to downstream Raja River

Refering to Interim National Water Quality Standard (MIHP, 2007), the water quality standard for

Raja River and Alor Siam belong to Class V during the dry weather condition on 14th and 15th February 2011.

However, water quality standard for Derga River at the second half of river length, indicating Class IV, is better than that in Alor Siam. Inflow from the sub catchments of Alor Siam and Derga River contributed to low concentration of DO for Raja River.

5 Model predictions

Yang et al. (2010) used calibrated model to predict future water quality conditions under two different wastewater management scenarios for the study of water quality modelling of a Hypoxic Stream.

Analysis from the simulation results found that degradation of DO concentration in Raja River is due to the low DO concentration originating from Alor Siam and Derga River. The sub catchments suspected of contributing low level of DO concentration were catchments 5, 10, 11, 15 and 17. The adjustment for the model was done by adding Class II to Class IV of DO concentration at all sub catchments for Alor Siam and Derga River. This procedure was implemented to clarify the earlier judgement. The simulation results as shown in Figure 17.

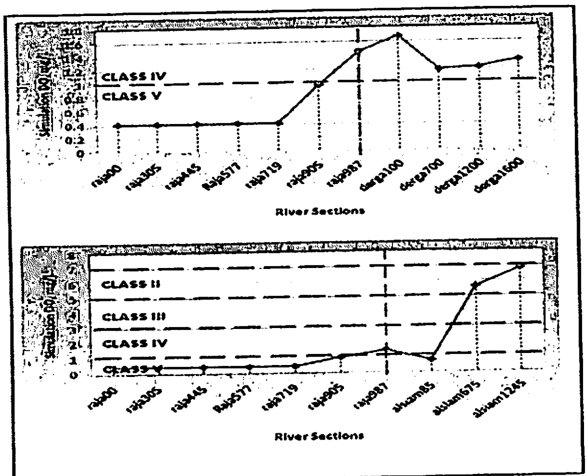


Figure 17 Prediction of DO concentration for River System.

Simulation result shows that DO concentration for Raja River is almost the same before and after DO alteration for sub-catchments Alor Siam and Derga River. Hence, low DO concentrations from tributaries do not significantly reduce DO in the main river that is Raja River.

6 Conclusion

The paper presents a water quality modelling study of a Raja River System (RRS) receiving effluents from urban source of Alor Setar City (ASC). Saturation of DO is about 2.6% or 0.2 mg/L was reported by DID in year 2007. The modelling framework is configured to simulate the profile of DO concentrations during dry weather condition. Unavailability of gauge station for flow and water quality in the RRS was forced us to conduct field data collection from November 2009 to February 2011 in order to fill model boundary condition. From the laboratory test results, the WQI for selected locations for RRS belong to Class III and IV. The low concentration of DO at entire RRS was contributed low WQI index. The model was well calibrated using measured data on 14th and 15th February 2011. The coefficient of determination for hydraulic model was 97.63% and water quality model 65.5%.

Results of simulation show the critical low concentration of DO occur in the entire RRS unless at location up stream of Derga River and Alor Siam. Low concentration of DO at Raja River suspected has been influenced by Derga River and Alor Siam. However, model prediction simulation analysis proofs that low concentration of DO at both tributaries is not significant for low DO at Raja River and current pumping procedure inadequate to remove pollutant from RRS. Finally, some effort would need to be made to upgrade water quality in the RRS to ensure compliance with WQI standard and to provide for ongoing study to identify future river protection strategies.

Acknowledgements

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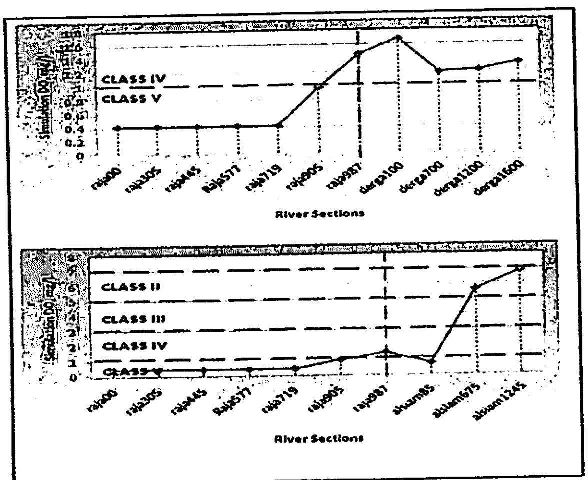

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Water Science and Technology

Estimation of missing rainfall data using GEP: Case Study of Raja River, Alor Setar, Kedah.

--Manuscript Draft--

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Abstract:

Water resources and urban flood management require hydrologic and hydraulic modeling. However, incomplete precipitation data is often the issue during hydrological modeling exercise. In this study, gene expression programming (GEP) and linear regression model was utilised to correlate monthly precipitation data from a principal station to its neighbouring station located in Alor Setar, Kedah, Malaysia. The study illustrates the applications of GEP and linear regression to determine the most fitted rainfall station to the principal rainfall station. This is to ensure reliable estimate of missing rainfall can be made should the principal station malfunctioned. These were done by comparing principal station data with each individual neighbouring station. Result of the analysis reveals that the stn38 is the most compatible to the principal station. Stn38 has highest coefficient of correlation for both methods. GEP technique is more efficient as having the highest value of R^2 which is 0.886.

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Estimation of missing rainfall data using GEP: Case Study of Raja River, Alor Setar, Kedah

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Abstract

Water resources and urban flood management require hydrologic and hydraulic modeling. However, incomplete precipitation data is often the issue during hydrological modeling exercise. In this study, gene expression programming (GEP) and linear regression model was utilised to correlate monthly precipitation data from a principal station to its neighbouring station located in Alor Setar, Kedah, Malaysia. The study illustrates the applications of GEP and linear regression to determine the most fitted rainfall station to the principal rainfall station. This is to ensure reliable estimate of missing rainfall can be made should the principal station malfunctioned. These were done by comparing principal station data with each individual neighbouring station. Result of the analysis reveals that the stn38 is the most compatible to the principal station. Stn38 has highest coefficient of correlation for both methods. GEP technique is more efficient as having the highest value of R^2 which is 0.886.

Keywords: GEP; hydrology; missing precipitation data; regression analysis

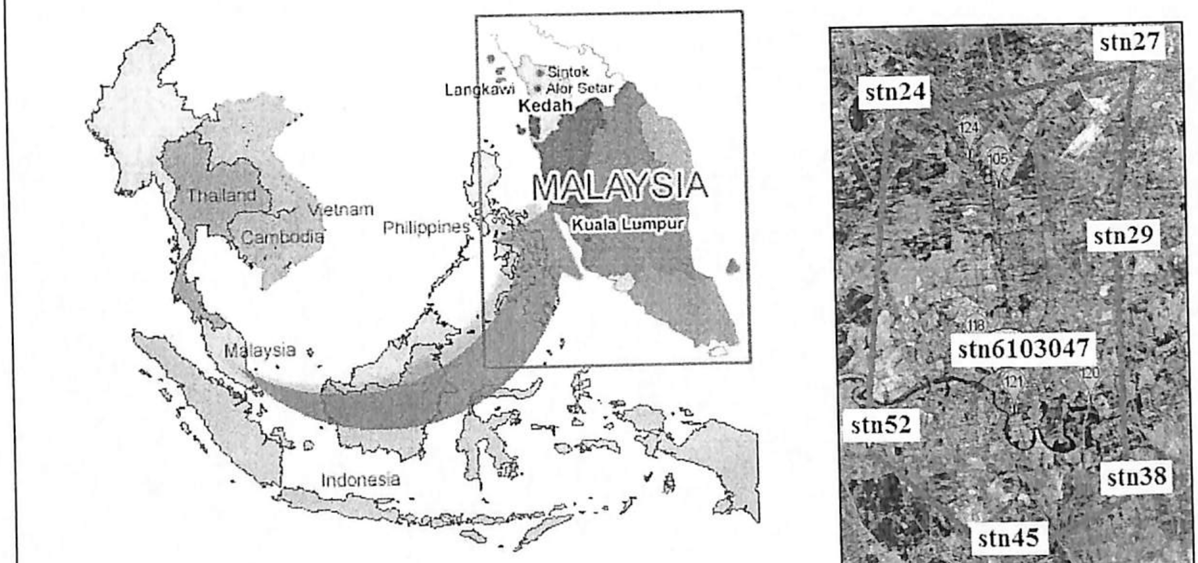
Introduction

The importance of precipitation are: (1) identifying precipitation characteristics; occurrence and temporal and spatial variability, (2) statistical modeling and forecasting of precipitation and (3) resolving the problems such as floods, droughts and landslides as stated by De Silva et al., (2007). But, in some cases, a large number of stations could be down simultaneously, thus creating many inaccurate readings or missing data (Kajornrit et al., 2011; Teegavarapu et al., 2009). In Malaysia, the number of rain gauge stations with complete records for a long duration is very scarce. Rainfall records often contain missing data values due to malfunctioning of equipment and severe environmental conditions. Thus, the estimation of rainfall amount is needed if missing data happened at the principal rainfall station. This study was to investigate the possibilities of correlating monthly rainfall of principal rainfall station to its six neighbouring stations. This was done to ensure reliable estimate of missing precipitation data can be done before proceed with water resources management and flood management modelling.

Description of the study area

The study area was carried out in Alor Setar City the capital of Kedah state in Malaysia. It is located within the Raja River Catchment. The study stands in the range of two meters above sea level and ten kilometres from the sea. It is prone to flood due to its flat and low elevation. 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 Raja river system was converted to concrete lined channel. It was separated from Kedah River by gated structure and pumping station (Ramli et al., 2011).

A study is being conducted to investigate how Raja River system responds to the land use change by carry out hydrologic and hydraulic modeling. One of the main input of the modeling is precipitation data but missing precipitation data has always been an issue for hydrologic modelling as states earlier. There are seven rainfall stations in this study area, stn6103047 as principal station is surrounded by six Muda Agricultural Development Authority (MADA) rainfall station as shown in Figure 1 and Table 1. The minimum densities recommended of precipitation stations by the WMO are 1 station for 250 km^2 for the mountainous area, 1 for 900 km^2 for the coastal area and 1 for 10 km^2 for urban areas (WMO, 2008). In the study area, there are seven stations within 200km^2 for the study area (approximately 1 station for 30 km^2).



(a) (b)

Figure 1 Location map of a study area (a) Alor Setar is provincial capital of Kedah, located in the western part of Peninsular Malaysia in the northern city of Malaysia (b) Close up view of the study area in Alor Setar, Kedah

Table 1 Details of the rainfall stations

Station Name		Custodian	Coordinate		Distance Stn6103047 – MADA station (km)
			Latitude	Longitude	
Stor JPS	Stn6103047	DID	6.105556 N	100.3917 E	-
Telok Chengai	Stn52	MADA	6.097806 N	100.3315 E	4.3
Bt. 3 Tandop	Stn45	MADA	6.068278 N	100.3676 E	5
Alor Penyengat	Stn38	MADA	6.085 N	100.401 E	5
Hutan Kampong	Stn29	MADA	6.149028 N	100.399 E	5.3
Kepala Batas	Stn27	MADA	6.201445 N	100.4047 E	10.6
Gunong Keriang	Stn24	MADA	6.188888 N	100.3388 E	8.8

Data and Methodology

In order for hydrologic modelling be conducted smoothly, data consistency of a principal station was compared to its neighbouring rainfall station by applying gene expression programming (GEP) technique and regression analysis method. Monthly rainfall series data have been obtained from DID and MADA for 9 years periods from 2001 until 2009. For this study, MADA stations were selected based on closest distance with stn6103047 as shown in Table 1.

For the training set in GEP, the data is selected from 2001 until 2006 and the rest is used as the testing test. The functional set and operational parameters used in the present GEP modelling are listed in Table 2 and Table 3 respectively. GEP is an extension to genetic programming (GP). It is a search technique that evolves computer programs (Ab and Azamathulla, 2012; Azamathulla et al., 2013). It was developed by Ferreira (2001) using basic principles of the genetic algorithms (GA) and genetic programming.

Hashmi et al., (2011) shows simple example of a GEP model having two genes (terms), which are linked by an addition function, is presented here to clarify the working of the GEP system. This GEP chromosome is given by:

$$(a*b)+(\frac{c}{d}) \quad (1)$$

where 'a', 'b', 'c' and 'd' are predictor variables and +, * and / represent addition, multiplication and division respectively. The above equation can also be expressed by the following expression tree (ET) which is usually produced by GEP software packages. Meanwhile, the fitted regression line can be written in the following form:

$$y_i = \beta_0 + \beta_1 x + e_i \quad (2)$$

where e_i is called residual which represent the error in the fit of the model to the actual data.

Table 2 Functional set for the GEP model

Function Set	Symbol	Weight	Arity
Addition	+	2	2
Subtraction	-	2	2
Multiplication	*	2	2
Division	/	1	2
Square root	Sqrt	1	1
Exponential	Exp	1	1
Natural logarithm	Ln	1	1
X to the power of 2	X2	1	1
X to the power of 3	X3	1	1
Sine	Sin	1	1
Cosine	Cos	1	1
Tangent	Tan	1	1

Table 3 Genetic operators used in GEP modeling

Parameters	Definition	value
P_1	Mutation rate	0.044
P_2	Inversion rate	0.1
P_3	IS transposition rate	0.1
P_4	RIS transposition rate	0.1
P_5	One-point recombination rate	0.3

P_6	Two-point recombination rate	0.3
P_7	Gene recombination rate	0.1
P_8	Gene transposition rate	0.1

Results and Discussion

GEP and linear regression method was used to predict precipitation of stn6103047 using 9 years of monthly rainfall data to select the most suitable rainfall station. Regression equation in Table 3 shows relationship between stn6103047 with each MADA rainfall stations. From the equation, x refers to MADA rainfall stations respectively. The equation using GEP and simple linear regression (x = stn38) is now defined by the following Equation 3 and Equation 4 respectively. The equation for GEP also can be expressed by Expression Tree (ET) as shown in

Figure 2. Figure 2 shows an ET for the relationship between stn38 and stn6103047.

$$
\begin{aligned}
stn6103047 = {} & \tan\left[\left(\sin x - x^2\right)\left(x^2 - 0.840185\right)\right] \\
& + \\
& (\ln)(\exp)(\sin)\left[\sqrt{x} - \sqrt{(x+8.399719)-x}\right] \\
& + \\
& \left[(x+0.154083)-(-2.685944)^2\left(\exp x^2\right)\right]+\sin\left(\cos-5.893769\right) \\
& + \\
& (10.101483\tan x)^2\left[\exp\left(-232.026432+\cos x\right)\right] \\
& + \\
& \exp\left(\left(\left(\cos\left(x-0.103241\right)^3\right)^2\right)^3\right) \\
& + \\
& \tan\left[\frac{\sin x}{6.750244}-\left(\cos\left(9.078826x\right)\right)\right]^2
\end{aligned}
\tag{3}
$$

and

$$Stn6103047 = -1.6 + 0.871 Stn38 \tag{4}$$

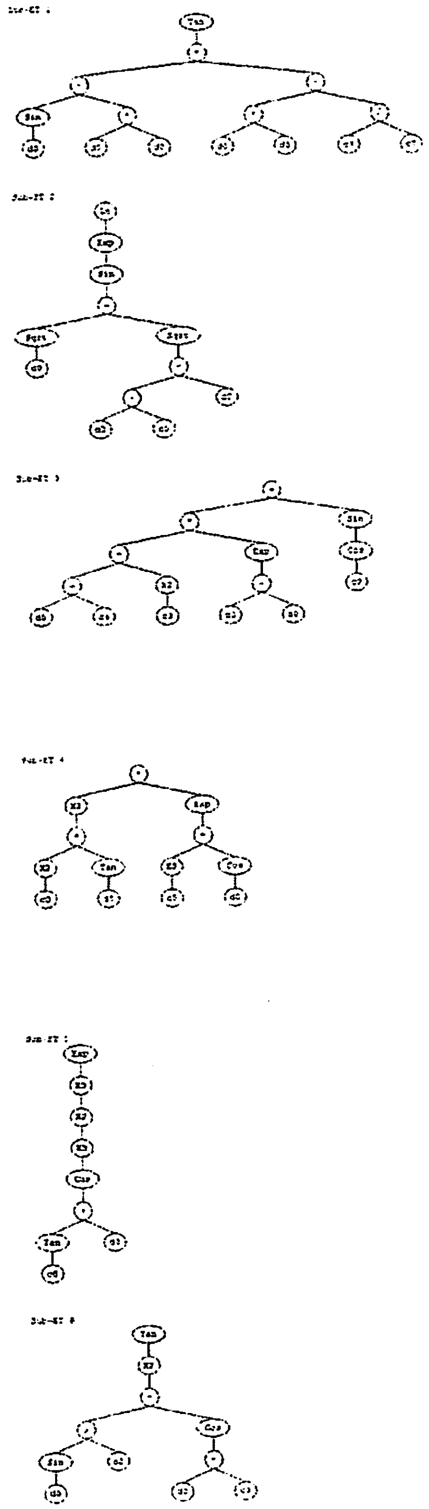


Figure 2 Expression Tree of the equation

Table 4 Summary of the analysis from 2001-2009

Station	Simple linear regression			GEP technique		
	R	R^2	RMSE	R	R^2	RMSE
Stn6103047-Stn52	0.825	0.680	72.24	0.895	0.802	15.81
Stn6103047-Stn45	0.844	0.712	68.85	0.931	0.867	20.08
Stn6103047-Stn38	0.867	0.752	63.86	0.941	0.886	21.70
Stn6103047-Stn29	0.841	0.707	69.37	0.926	0.857	19.67
Stn6103047-Stn27	0.711	0.505	93.89	0.864	0.747	14.54
Stn6103047-Stn24	0.772	0.596	81.40	0.840	0.706	13.88

The coefficient of determination (R^2) and the root mean square error (RMSE) are used in the current study. The RMSE describes the average difference between predicted values and measured values as shown in Equation 5. The R^2 represents the degree of association between predicted and the measured values as shown in Equation 6.

$$RMSE = \left[\frac{\sum (X-Y)^2}{n} \right]^{\frac{1}{2}} \quad (5)$$

$$R^2 = \left[\frac{\sum xy}{\sum x^2 \sum y^2} \right]^2 \quad (6)$$

where,

$$x = (X - X)$$

The R^2 of GEP technique (0.886) for stn38 in Table 3 is highest compared to the simple linear regression (0.752. The R^2 value is indicator of systematically the model fits the data. If R^2 close to 1 indicates that we have accounted for almost all the variability with the variables specified in the model. Whether obtained equation adequately represents the relationship shown by the correlation coefficient.

The values of R for GEP technique of stn38 is 0.941.Its value of 1 represents a perfect relation, and 0 indicates no relationship between the variables. The degree to which two or more predictors are related to the dependent variable is expressed in R. The function has a determination coefficient as a measure of the goodness of fit of the model, and this represents the proportion of the variation of the dependent variable (stn6103047 rainfall depth) explained by the regression model (Marquinez et al., 2003).

The graph in Figure 3 shows the predicted stn6103047 against the observed stn6103047 which achieve acceptable R^2=0.879 for GEP technique and graph in Figure 4 shows R^2=0.751 for simple linear regression. So, stn38 for GEP technique is reasonably close to the observed stn6103047 as the (R value is 0.941). The larger R value the stronger the association between the two variables and the more accurately to predict the values of stn6103047.

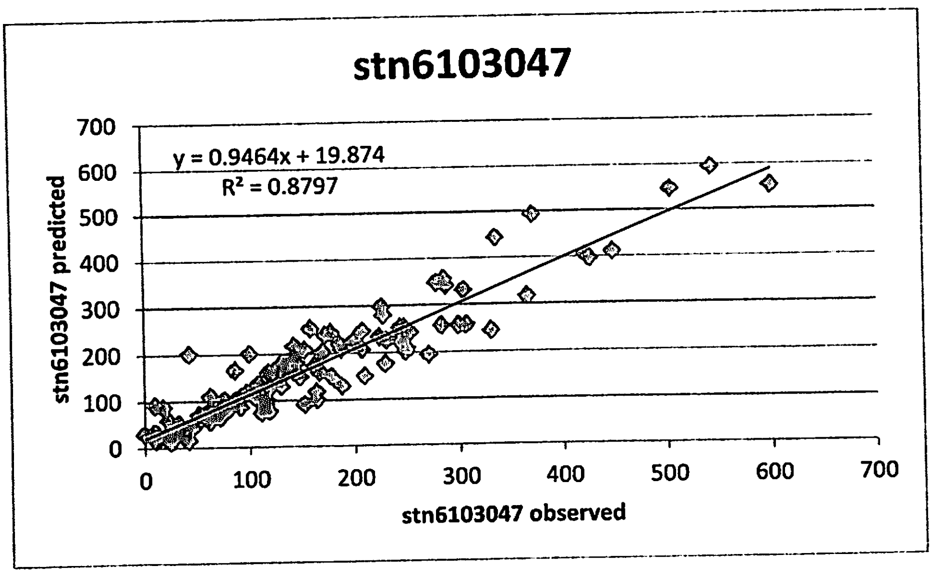


Figure 3 Observed and predicted graph for Stn6103047 using GEP technique

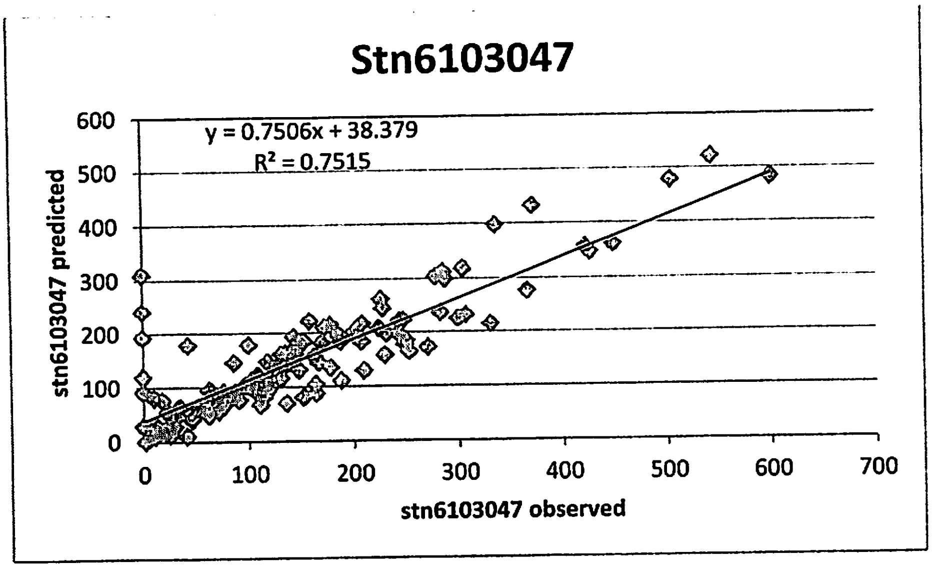


Figure 4 Observed and predicted graph for Stn6103047 using simple linear regression

Conclusions

This study has using GEP technique and simple linear regression to determine the most fitted rainfall station to the principal rainfall station. As GEP technique provides more efficient results, it will be used to estimate the missing rainfall. It will be used to correlate monthly precipitation data from the principal station to stn38. From the analysis, stn38 is the most fitted rainfall to the principal station as having the highest R^2 from both methods. The R^2 for GEP technique is 0.886 and R^2 for simple regression is 0.751.

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1	MOHAMAD SUAIMI BIN RAMLI (P-REM012)	Pemodelan Kualiti Air untuk Sungai Bandar: Kajian Kes Sungai Raja, dan Tributeri (Sungai Derga dan Alor Siam) Alor Setar, Kedah	
2.	NOR ZAIMAH BINTI CHE GHANI (P-REM0025)	Pemodelan Hidrologi untuk Kawasan Kecil Taadahan Bandar: Kajian Kes di Sungai Raja, Kedah	

WATER QUALITY MODELLING FOR URBAN RIVER : A CASE STUDY OF SUNGAI RAJA AND ITS TRIBUTARIES (SUNGAI DERGA AND ALOR SIAM) OF ALOR SETAR, KEDAH

by

MOHAMAD SUAIMI BIN RAMLI

Thesis submitted in fulfillment of the requirement for the Degree of Master of Science

NOVEMBER 2013

ACKNOWLEDGEMENT

In the name of Allah, Most Gracious, Most Merciful

Praise to Allah for giving me health, strength and knowledge to finally complete this research.

I would like to convey my thanks and appreciation to my main Supervisor En. Zorkeflee bin Abu Hasan, for his guidance, advice and cooperation for the whole period which enable me to finally complete this research. I will always treasure his guidance and help to this research. Greatest thanks to Professor Koh Hock Lye, my co-supervisor for his help and advice throughout this research.

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Thank you and may God bless you all always.

WATER QUALITY MODELING FOR SUNGAI RAJA, ALOR SETAR, KEDAH.

By

LIM CHEE KENG

This dissertation is submitted to

UNIVERSITI SAINS MALAYSIA

as partial fulfillment of requirements for the degree of

BACHELOR OF ENGINEERING (CIVIL ENGINEERING)

School of Civil Engineering,
Universiti Sains Malaysia (USM)

March 2010

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URBAN RUNOFF MODELING OF SUNGAI RAJA, ALOR STAR, KEDAH USING EPA SWMM 5.0

By

SYAMSUL AZLAN BIN SALEH

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June 2012

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Thank you.

Dedicated to my beloved,

Ayahanda Saleh bin Osman

Bonda Che Mariah bt. Saad

Khairon Misa

Syamsul Annuar

Marziatul Akhtar

Marziatul Akmar

Muhammad Azmin

Muhammad Aiman

HYDROLOGIC MODELLING OF SUNGAI RAJA CATCHMENT USING HEC-HMS

NUR HASYIMAH BINTI HASHIM

SCHOOL OF CIVIL ENGINEERING

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2012

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Last but not least, I hope that this thesis will be a good reference and give benefit to the mankind all over the world in the future.

FLOOD SIMULATION OF SUNGAI RAJA CATCHMENT USING HEC-RAS

SITI RAFIDAH BINTI OTHMAN

SCHOOL OF CIVIL ENGINEERING

UNIVERSITI SAINS MALAYSIA

2012

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Dear Sir/Madam,

LETTER OF OFFER – GRADUATE RESEARCH ASSISTANT (GRA)

The Research Creativity & Management Office (RCMO), of Universiti Sains Malaysia is pleased to offer you an appointment as Graduate Research Assistant **(GRA)** in the **RIVER ENGINEERING & URBAN DRAINAGE RESEARCH CENTRE (REDAC).** You will be given a financial assistance of Ringgit Malaysia **(RM) 1,300.00 per month** to be paid from the project **WATER QUALITY MODELING FOR INTEGRATED RIVER BASIN MANAGEMENT IN SUNGAI RAJA, KEDAH (1001/REDAC/814085).** Your appointment begins **1 SEPTEMBER 2011** and ends **28 FEBRUARY 2013.**

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3. As a Graduate Research Assistant, you are required to serve under the supervision of **Encik Zorkeflee Abu Hasan** and perform all the duties to assist him in his research project as well as through research undertaken studies under the Scheme. You are also not eligible for any other remuneration.

4. Either party may terminate the service by giving written notice of **not less than 30 days** or failing this you are expected to pay one month of the financial assistance in lieu of notice. Your service can also be terminated if the provisions of the emoluments of the project are insufficient.

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Yours sincerely,

(HASAN AB HAMID)
Executive Officer
Research Creativity & Management Office
Division Of Research & Innovation

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Tuan,

PER : Perbincangan Permodelan Sg. Raja

Dengan hormatnya perkara di atas adalah dirujuk.

Adalah dimaklumkan bahawa Ibu Pejabat JPS Negeri Kedah akan menganjurkan taklimat mengenai Permodelan Sg. Raja untuk mengenalpasti altenatif yang sesuai bagi meningkatkan kualiti air sungai. Sehubungan dengan itu, pihak tuan dijemput memberikan taklimat dan berkongsi hasil kajian berkaitan pada tarikh dan tempat seperti berikut :

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Pembentang	:	**En. Zorkeflee b. Abu Hasan, Redac, USM.**

Sekian, terima kasih.

"BERKHIDMAT UNTUK NEGARA"
"CINTALAH SUNGAI KITA"

Saya yang menurut perintah,

(HJ. AB. QAHAR B. OSMAN)
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