ABSTRACT

Hydrologic model is a representation of the real world hydrologic processes. It is usually used for hydrologic prediction for the specified area for managing water resources. Water crisis is faced in many parts of the country due to poor water management in managing the water resources for future consumption. Among the factors affecting the water crisis is the changing weather patterns and the destruction and degradation of water catchments where these are to be addressed in managing water resources. Therefore, a watershed model representing the specified area will be produced in relating the factors for the hydrologic prediction in water resources management. In order to produce the model, spatial analysis is used using the ArcGIS Spatial Analyst Hydrology Tools in defining the stream network and the watershed boundary. The defined stream and boundary will then be overlaid with the hydrological analysis to predict the water discharge of the water catchment.

ACKNOWLEDGEMENT

Alhamdulillah. Thank you Allah SWT for granting the author opportunity, health and ability to complete this Final Year Project on ‘Watershed Delineation for a Hydrological Model using GIS Spatial Analysis’. This project is a partial fulfilment of the requirement for the Bachelor of Engineering (Hons.) in Civil Engineering for September 2012 semester.

First of all, the author would like to express her highest appreciation to Dr. A Nasir Bin Matori for his supervision throughout the completion of the project. A tremendous thanks to him upon his care, effort and commitment to make sure that any difficulties or critical situations faced during the implementation of this project can be successfully overcome.

The author would also like to seize this opportunity to thank the staff of Dr. Nik & Associates Sdn. Bhd. for the knowledge that the author gained during the internship period. It was indeed very useful in completing and facilitating the work flow of the project. Their eagerness to share the knowledge and experience were truly blissful and admirable.

Another deep appreciation goes to Pn. Husna Takaijuddin a hydrology lecturer for her willingness to assist the author in the hydrological part of the project. Many thank to Dr. Teo Wee as the coordinator of FYP I and Ir Idris Bin Othman as the coordinator of FYP II in making sure the smooth flow of the entire period of the project.

Not to forget, all lecturers and technicians who have directly and indirectly contribute towards the implementation of this project as well as friends who have given the author a never ending moral support and encouragement throughout the time. Thank you all for your support.

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CHAPTER 1

INTRODUCTION

1.1 Background Study

Water crisis is a global issue where according to World Water Vision Report, 2000 the crisis is not about the shortage of water supply to accommodate our needs but it is about how we manage water resources for the benefit of billions of people as well as the environment.

Malaysia is also facing the same crisis in some parts of the country where the relative abundance of water has become scarcity. Among the factors contributing to the increase of water demand is the growth in population, expansion in urbanisation, industrialisation, and irrigated agriculture which will also increase the water pollution, thus decreasing the availability of water resources all in all (Raja Zainal Abidin, 2004).

In accordance to WWF Malaysia, there are eleven major issues that need prior attention in sustaining water resources in Malaysia. Among those are, high rates of water wastage, changing weather patterns, destruction and degradation of water catchments, and water pollution.

As of March 2011, Malaysians statistically use an average of 226 litres of water per person daily according to Choong, 2011 where based on a study, 70% of Malaysians use more water than their necessity as said by the Water Minister Datuk Seri Peter Chin Fah Kui (Choong, 2011).

Extreme changes in weather patterns contribute to severity of water resources as for example, the 1997/98 El Nino resulted water crisis in many parts of Malaysia as stated by WWF Malaysia as water planning in Malaysia does not take into account changes in weather patterns effectively.

The enforcement of gazette water catchment areas are to be implemented strictly by the state governments to avoid damaging activities at the upstream of the water catchment areas as it affect the water supply to reservoirs as well as to the forests (Mohamed Idris, 2012).

An example of the destruction of water catchment is the encroachment incident at Bekok dam in February 2012 where it was reported that some 2000ha of forest area was encroached exposing about 500,000 people that use the water supply from the area to health threats resulting from the chemical pesticides and fertilisers that seep into the soil (Hammim, 2012).

All of the stated issues are associated closely to the water management planning and hydrological modeling is an essential tool for hydrology forecasting, and water resources planning and management (Kang and Merwade, 2011). A hydrological model is a tool used for the hydrological analysis in the particular area which is used to model the flow directions, flow accumulation, identifying the basins and sub-basins that flow to different outlet points.

1.2 Problem Statement

Water management starts with the distinct water catchment boundary for an efficient planning and development for a particular area. A watershed boundary is distinct by the highest altitude surrounding a particular stream as defined by Sewickley Creek Watershed Conservation Plan. Conventionally, this was done manually using topographic maps which is prone to error, tedious, and subject to individual judgement (Abdallah *et al.,* 2006). Therefore, automated watershed boundary delineation is used to replace the conventional method using computer-aided method such as using GIS technology.

1.3 Objectives

The objectives of this paper are identified as follows:

i. To identify watershed boundary of the selected study area
ii. To predict the water discharge of the delineated catchment based on the design rainfall

1.4 Scope of Study

The study is delimited to generate the hydrological model of the area as in this case, the preparation of the water catchment boundary, as a model or a tool for the hydrological analysis. This model is prepared for the usage of other study in managing the water resources in the particular area.

The whole process is designed to be completed in two semesters (two phases). The scope of study for the first phase is to doing research as well as gathering the required data of the study area. Besides that, the goal for the first phase is to get familiarize with the software and relating theoretical knowledge as well as the practical in doing the project. The second phase, which is the implementation part, should include the process in obtaining the hydrologic model for the study area as the output of the project.

CHAPTER 2

LITERATURE REVIEW

Several studies related to this paper are reviewed for further understanding on the hydrological modeling concept. It is observed that the model developed in each study give appropriate input used for various applications in managing water resources.

2.1 Development and application of a storage – release based distributed hydrologic model using GIS (Kang & Mewarde, 2011)

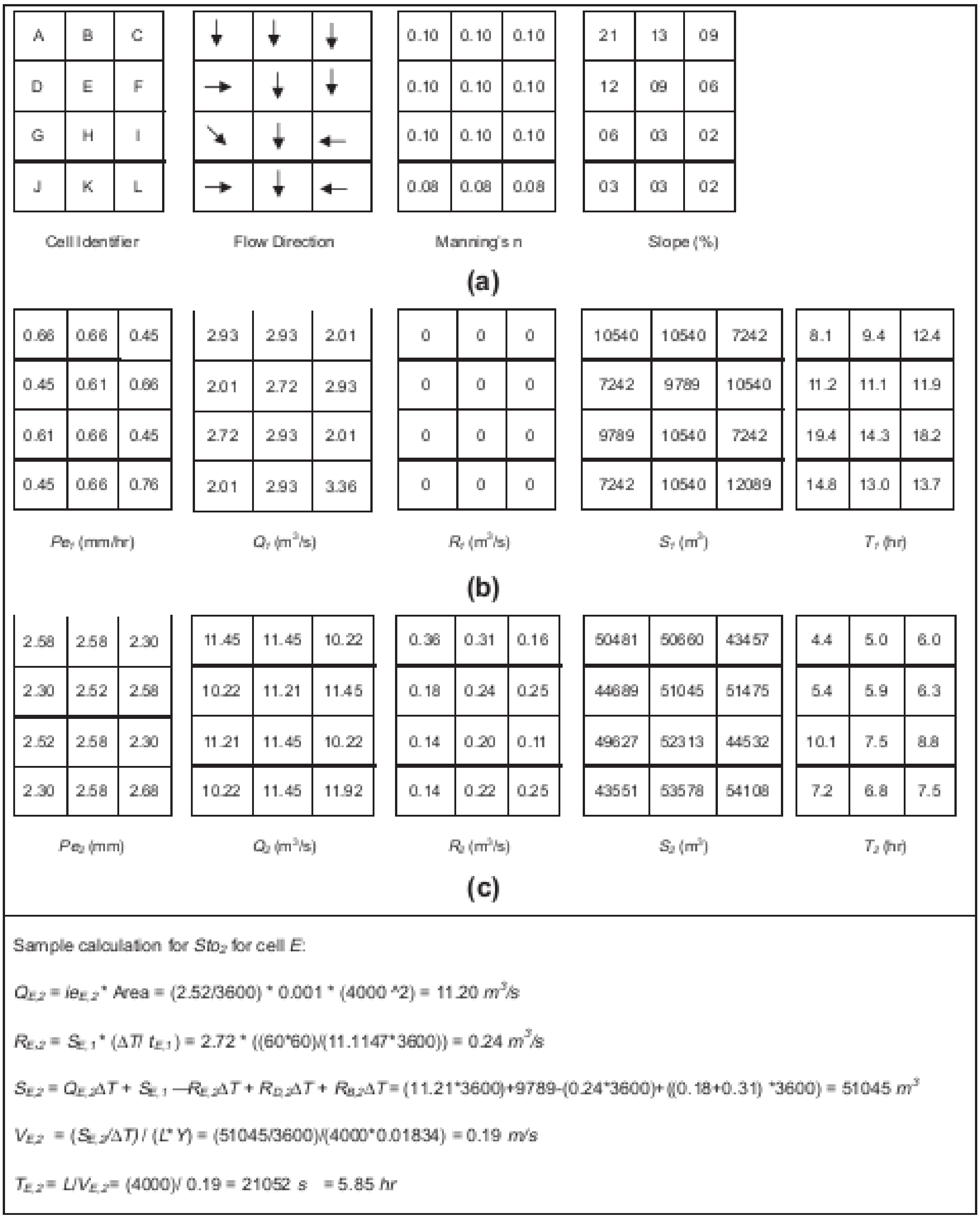
The three study areas are adopted in this study as they provide good test cases with respect to size and land use types which were derived from several geospatial data include: topographic information in the form of a DEM from the United States Geological Survey (USGS); the 2001 National Land Cover Dataset (NLCD) from USGS; and SSURGO soil data available from the National Resources Conservation Service (NRCS).

Topographic parameters such as flow direction, flow length, and slope are extracted from the DEM of these areas to be coupled with the geospatial data available for hydrological analysis. The details of the three sites are tabulated in **Table 2.1** below.

Table 2.1: Study site details

Watershed	Area (km^2)	Land use	Elevation range (m)	Ave. slope (%)	Annual precipitation (mm)
Cedar Creek	707	Agricultural (76%); forest (21%); urban (3%)	238-324	3	1100
Fish Creek	96	Agricultural (82%); urban (9%)	268-324	3.2	900
Crooked Creek	46	Urban (88%); agricultural (6%); forest (6%)	217-277	1.2	880

It is found that in the process of determining the stream network from the flow direction and flow accumulation grid, a stream area threshold of 1% of the total watershed area is used. In the model development process, as presented in this paper involves only the conceptual framework for STORE DHM. Computation of travel time to the basin outlet shows a good example of the application of the grid based distributed hydrologic model for the study. Sample calculations using a 3 x 4 hypothetical grid is shown in **Figure 2.1**.



A	B	C
D	E	F
G	H	I
J	K	L

Cell Identifier

↓	↓	↓
→	↓	↓
↘	↓	←
→	↓	←

Flow Direction

0.10	0.10	0.10
0.10	0.10	0.10
0.10	0.10	0.10
0.08	0.08	0.08

Manning's n

21	13	09
12	09	06
06	03	02
03	03	02

Slope (%)

(a)

0.66	0.66	0.45
0.45	0.61	0.66
0.61	0.66	0.45
0.45	0.66	0.76

Pe_1 (mm/hr)

2.93	2.93	2.01
2.01	2.72	2.93
2.72	2.93	2.01
2.01	2.93	3.36

Q_1 (m^3/s)

0	0	0
0	0	0
0	0	0
0	0	0

R_1 (m^3/s)

10540	10540	7242
7242	9789	10540
9789	10540	7242
7242	10540	12089

S_1 (m^3)

8.1	9.4	12.4
11.2	11.1	11.9
19.4	14.3	18.2
14.8	13.0	13.7

T_1 (hr)

(b)

2.58	2.58	2.30
2.30	2.52	2.58
2.52	2.58	2.30
2.30	2.58	2.68

Pe_2 (mm)

11.45	11.45	10.22
10.22	11.21	11.45
11.21	11.45	10.22
10.22	11.45	11.92

Q_2 (m^3/s)

0.36	0.31	0.16
0.18	0.24	0.25
0.14	0.20	0.11
0.14	0.22	0.25

R_2 (m^3/s)

50481	50660	43457
44689	51045	51475
49627	52313	44532
43551	53578	54108

S_2 (m^3)

4.4	5.0	6.0
5.4	5.9	6.3
10.1	7.5	8.8
7.2	6.8	7.5

T_2 (hr)

(c)

Sample calculation for Sto_2 for cell E:

$Q_{E,2} = ie_{E,2} * \text{Area} = (2.52/3600) * 0.001 * (4000 \wedge 2) = 11.20\ m^3/s$

$R_{E,2} = S_{E,1} * (\Delta T/\ t_{E,1}) = 2.72 * ((60*60)/(11.1147*3600)) = 0.24\ m^3/s$

$S_{E,2} = Q_{E,2}\Delta T + S_{E,1} - R_{E,2}\Delta T + R_{D,2}\Delta T + R_{B,2}\Delta T = (11.21*3600)+9789-(0.24*3600)+((0.18+0.31)\ *3600) = 51045\ m^3$

$V_{E,2} = (S_{E,2}/\Delta T) / (L * Y) = (51045/3600)/(4000*0.01834) = 0.19\ m/s$

$T_{E,2} = L/V_{E,2} = (4000)/\ 0.19 = 21052\ s\ \ = 5.85\ hr$

Figure 2.1: Sample calculations using a 3 x 4 hypothetical grid

Another finding of this paper is that the grid size (resolution) of DEM affects the travel time computation which will later affects the flow hydrograph. A higher resolution DEM produces lower peak which indicates larger time interval, whereas a lower resolution DEM produces higher peak which indicates smaller time interval. An example of the flow hydrographs with various DEM resolutions is presented in **Figure 2.2**.

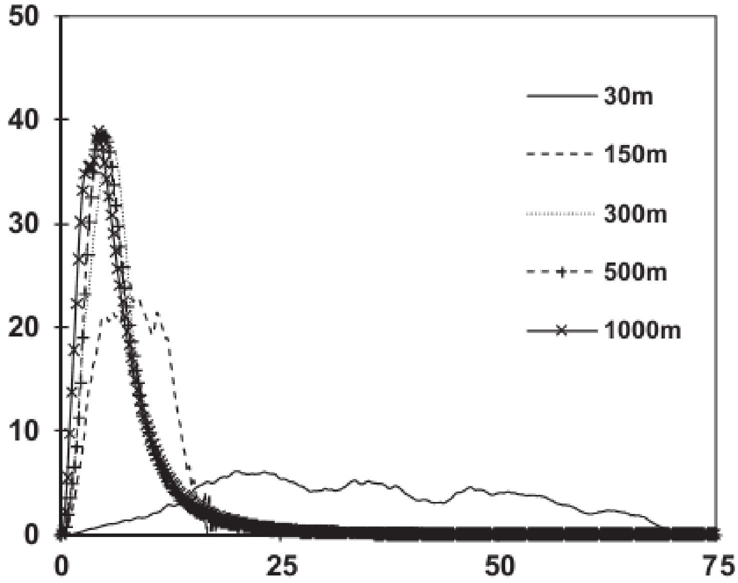


Figure 2.2: Cedar Creek model hydrographs with different DEM resolution

Four different storms at each site of hourly gauged rainfall data obtained from the National Climatic Data Center, and NEXRAD *StageIII* radar rainfall data obtained from the Ohio River Forecast Center (OHRFC) are used for model application at the three study sites. The model output is then validated against the streamflow data includes the base flow and surface runoff obtained from the USGS instantaneous Data Archive web site (http://ida.water.usgs.gov/ida/)

The results of the model application show that STORE DHM can simulate the hydrologic behaviour of a watershed presented in hydrographs that is quite similar with observed data. Different from the usual raster or grid based models, STORE DHM considers the flow contribution of neighbouring cells using the continuity equation (change in storage = input-output).

It is stated that the modeling processes is done in the ArcGIS environment.

The same method of coupling the topographic parameters with the geospatial data will be adopted in this project to carry out the hydrological analysis.

2.2 Development and application of a simple hydrologic model simulation for a Brazilian headwater basin (Mellow *et al.*, 2008)

The objectives of this work are:

i. To create a semi-physically based hydrologic model in semi-distributed to sub-basins approach and based on GIS and Remote Sensing tools
ii. To simulate the hydrologic responses of the Grande River Basin (GRB), thus creating an important tool for management and planning of water resources for region

It is observed that semi-physically based hydrologic model shown in **Figure 2.3** in semi-distributed to sub-basins approach gives out better performance in comparison with a lumped approach affecting the Nash-Sutcliffe Coefficient (C_{NS}) scores (coefficient of precision) as it depends significantly to the peak discharge of the outlet point.

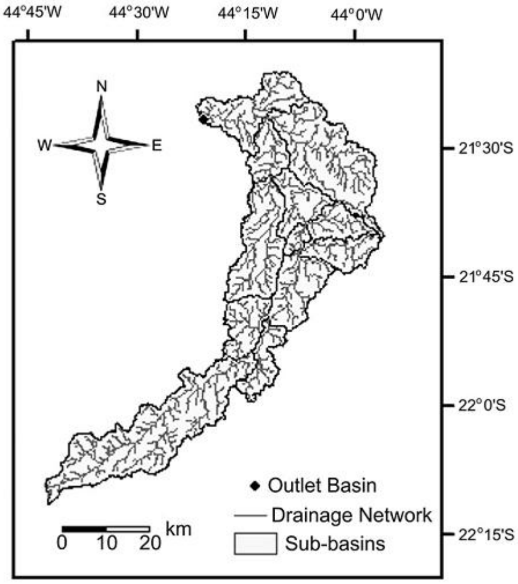


Figure 2.3: Grande River Basin subdivided into sub-basins

The topography and flow network of GRB as shown in **Figure 2.4** shows the DEM of 30m resolution with elevation point higher than 2500m above sea level which define the flow network of GRB as well as the sub-division of GRB with the assistance of GIS computational tools.

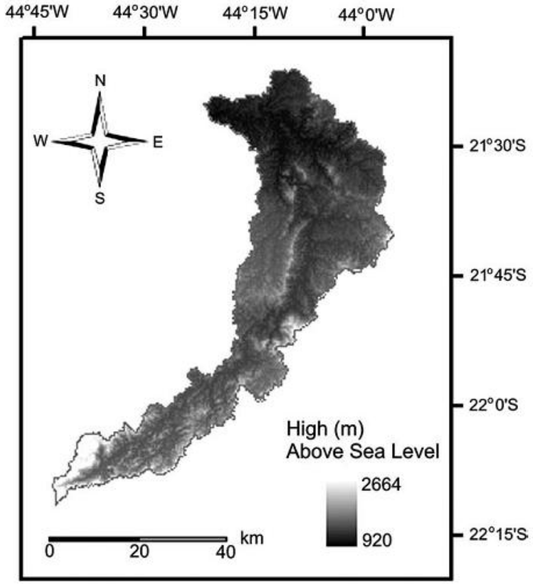


Figure 2.4: DEM of the Grande River Basin

The finding of the study is that, the semi-distributed approach is reliable as it gives better characterization of the basin topography, includes the slope steepness, roughness and time of concentration. A further explanation for that is the topography parameters as in lumped approach would give the mean values of each topographic characteristic as compared to the semi-distributed approach which will give a more precise topographic parameters as it take into account variation of the parameters since the basin itself covers a huge differential in elevation.

From the model application, the model is able to give the impact of land-use change scenarios, appropriate and adequate for the future land-use planning in the region.

The method of further divide the catchment into sub-catchment will be adopted in the project to obtain a better characterization of the basin topography, since the study area covers different elevation and land use.

2.3 Automatic extraction of watershed characteristics using spatial analysis techniques with application to groundwater mapping (Benosky & Marry, 1995)

The software used in this study is the MicroImages' PC-based map and image processing system (MIPS). The software is developed, intended to account fully the flat terrain areas within a DEM. It was developed at the US Geological Survey EROS (Earth Resources Observation System) Data Center by Jenson and Dominique (1998).

The objective of this study is to develop geometric and morphologic characteristics of watersheds using the spatial analysis techniques with a set of methodology that can be summarized in **Figure 2.5.** Each process is crucial in performing the following phase of the process where the start of the next phase is dependent to the previous process.

It started with the determining the watershed areas and perimeters, then the determining the main flow path for each watershed, determining the maximum width of each watershed, mapping the maximum watershed width, next, determining the connectivity between watersheds and lastly determining the soil types within each watershed.

In determining the watershed areas and perimeters, Watshed SML script is used. The ASCII output of the process is the watshed.dat and the image output of the process is the perimeter of the watershed.

The next process, determining the main flow path for each watershed, Flowpath SML script is used. The raster output of the process is the Flowpath.dat each watershed main flow path. Two distinct types of resulting basins from two different types of flow path termination were identified. Type 1 flow path (**Figure 2.6(a)**) also known as 'convergent' basin is when the flow accumulation values approach zero at the headwaters of the watershed's main flow path. While Type 2 flow path (**Figure 2.6(b)**) is known as 'plane slope' basins is when the flow path is a part of a larger channel system within the quadrangle.

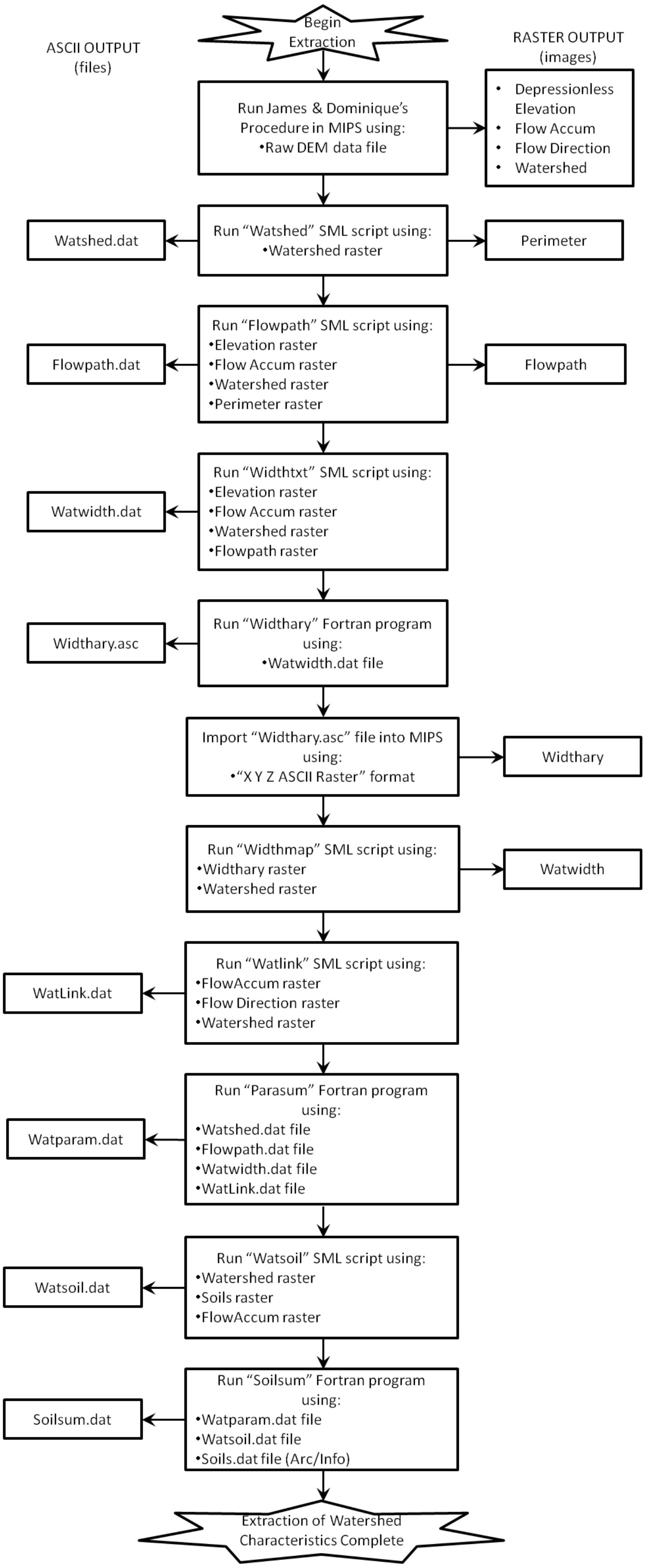


Figure 2.5: Flow chart for extracting watershed characteristics

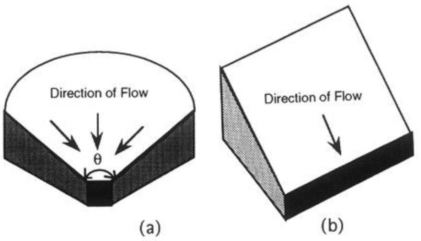


Figure 2.6: (a) Type 1 ‘convergent’ basin and (b) Type 2 ‘plane slope’ basin

These two types of basins are then assigned accordingly to the Flowpath.dat output raster at the pour points of the watershed. In this process, both the length is established and the average gradient is calculated.

Moving on to the next phase, in determining the maximum width of each watershed, Widthtxt SML script is used. Watwidth.dat as the ASCII output is obtained containing the maximum width of the watershed perpendicular to the general direction of the main flow path. Maximum width 1 and 2 and slopes 1 and 2 are reported as to take into account the different basin types.

The Watwidth.dat file is run using the Widthary Fortran program in order to convert it to a raster format. Only then, the process of mapping the maximum watershed width can be done by using the Widthmap SML script where the output would be the Watwidth. **Figure 2.7** shows a raster file including all the maximum width, main flow path of each watershed, and the perimeter of each watershed produced earlier.

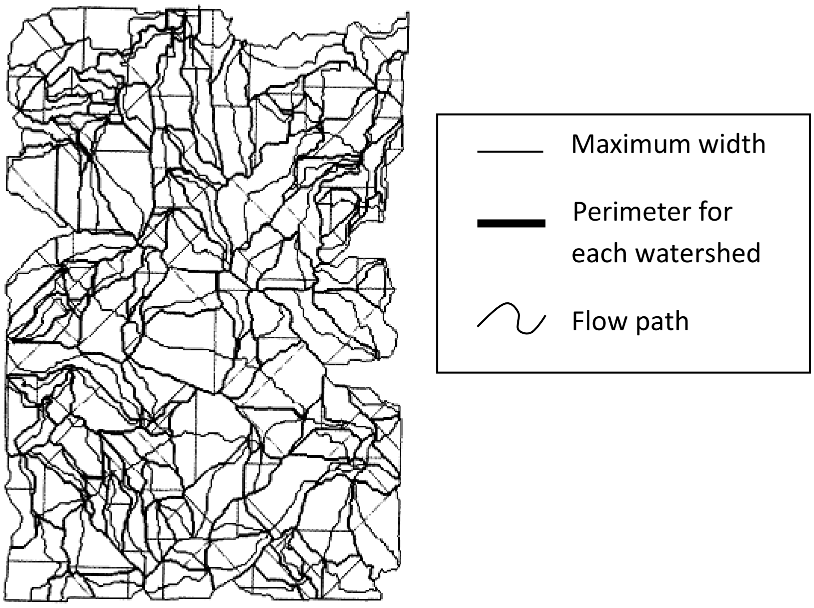


Figure 2.7: A quadrangle of Glenoma, Washington

The last phase of the process is determining the soil types within each watershed. The soil data used in this study is obtained from the Washington Department of Natural Resources (WDNR) in Arc/Info format. The data is converted into raster format using the ‘Polygrid’ command in Arc/Info.

The type of soil is determined using the Watsoil SML script whereas the Soilsum Fortran program is used in the assignment of watershed’s soil types and its associated soil properties:

- Designate the soil at the watershed’s pour point
- Designate the soil that occupies the greatest amount of area within the watershed
- Compute an area-weighted average of the soil properties within the watershed

With the completion of the last process, the characteristics extracted can be used for further hydrological modeling process. Applications of the output can be summarized as follows:

- Groundwater level prediction
- Groundwater level distribution within a watershed
- Mapping the groundwater ratios
- Creating groundwater level zones

The applications output can then be used in managing the hill slopes within the quadrangles and forecast potentially hazardous landslides.

The objective of the study is somewhat similar to the objective of the project where watershed is delineated and the characteristics of each sub-catchment is determined in order to produce an output that is able to be used in management process of the area.

CHAPTER 3

METHODOLOGY

3.1 Key Milestone and Study Plan

The project is divided into two phases, namely FYP I conducted in the first semester and FYP II in the following semester. Activities done in FYP I are mostly covering the researches made related to the topic, understanding in great extent of the topic as well as the gathering of the data and information. Familiarization of the software that is going to be used in the project is also done in the first semester in order to ease the work flow during the FYP II.

The approach of this project is based on examination and understanding of the scope of work and the timing for the completion of the project. In accordance with the milestones provided in the guideline for final year project, several have been identified and summarized for FYP I and FYP II in **Table 3.1a** and **Table 3.1b** respectively.

Table 3.1a: Key Milestone for FYP I

Key Milestone	**Proposed Week**
Submission of Extended Proposal Defence	Week 6
Proposal Defence	Week 10
Submission of Interim Draft Report	Week 13
Submission of Interim Report	Week 14

Table 3.1b: Key Milestone for FYP II

Key Milestone	**Proposed Week**
Submission of Progress Report	Week 8
Pre-EDX	Week 11
Submission of Draft Report	Week 12
Submission of Dissertation (soft bound)	Week 13
Submission of Technical Paper	Week 13
VIVA	Week 14
Submission of Project Dissertation (hard bound)	Week 15

A detailed activity and work processes flow for FYP I and FYP II can be explained in **Figure 3.1a** and **Figure 3.1b** respectively.

No.	Detail/Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	**Selection of Project Title**	🟩	🟩						Mid-Semester Break							
2	**Preliminary Research Work**			🟩	🟩	🟩	🟩	🟩								
	• Research on the project topic			🟩	🟩	🟩	🟩									
	• Submit draft of literature review to supervisor					🟩	🟩									
	• Familiarization of the software					🟩	🟩	🟩		🟩	🟩					
3	**Submission of Extended Proposal Defence**									🟩	🟥					
4	**Proposal Defence**									🟩	🟩	🟥				
5	**Continuation of Project Work**											🟩	🟩	🟩		
	• Data gathering											🟩				
	• Start-off activities											🟩	🟩	🟩		
6	**Submission of Interim Draft Report**														🟥	
7	**Submission of Interim Report**															🟥

Figure 3.1a: Gantt Chart representing the process flow for FYP I

No.	Detail/Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	**Continuation of Project work**	🟩	🟩	🟩	🟩	🟩	🟩	🟩	Mid-Semester Break							
	• Detailed Study Area	🟩	🟩													
	• Determine the location of the map			🟩												
	• Delineation of watershed			🟩	🟩	🟩										
	• Data gathering for relevant hydrological data of the study					🟩	🟩	🟩								
2	**Submission of Progress Report**									🟥						
3	**Continuation of Project work**										🟩	🟩	🟩			
	• Hydrological Analysis										🟩	🟩	🟩			
4	**Poster Presentation**													🟥		
5	**Submission of Dissertation**														🟥	
6	**Submission of Technical Paper**														🟥	
7	**VIVA**															🟥
8	**Submission of Project Dissertation (Hard Bound)**															🟥

Figure 3.1b: Gantt Chart representing the process flow for FYP II

3.2 Project Methodology

For the first objective, the software used in the project is the ArcGIS software developed by Environmental System Research Institute (ESRI) currently in version 9.3 since it provides a complete system in designing and managing the GIS data.

For the second objective, the hydrological analysis is done using *Manual Saliran Mesra Alam* 2nd Edition and Hydrological Procedure No. 1 (2010) developed by Department of Irrigation and Drainage (DID) Malaysia.

The process flow of the project is illustrated in **Figure 3.2** below and the detailed process methodology is explained in details in achieving the objectives.

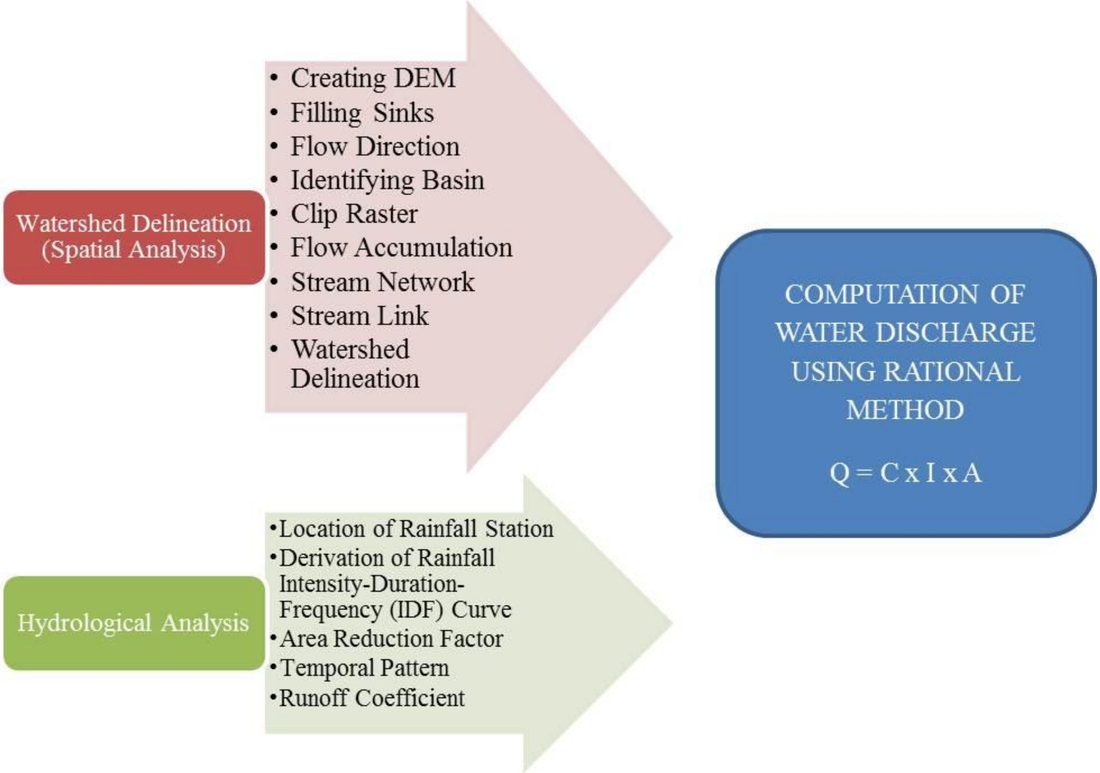


Figure 3.2: The process flow of the whole project

3.2.1 Watershed Delineation (Spatial Analysis)

Creating DEM

The raw data is obtained in the form of drawing format (.dwg) which consists of contours. It is first converted into shapefile (polylines) then imported into the ArcGIS software to be converted into raster format.

It is very important to set the projection of the map in the first step by using the *Define Projection* tool. The Projected Coordinate System is used where the unit of measurement is typically in feet or meters different from the Geographical Coordinated System where the unit of measurement is in decimal degrees for latitude and longitude.

The projection used for the study area is the Kertau_RSO_Malaya in meters. The Kertau datum is used since the study area is located in the Peninsular Malaysia. Malaysia uses two datums which is the Kertau datum for Peninsular Malaysia and Timbalai datum for Sabah and Sarawak.

Once the projection is set up, the *Topo to Raster* tool is selected and the shapefile is used as the input feature and is saved as *DEM30*. A cellsize of 30m is chosen as accordance to the Mapping Center Answer (ESRI, 2008) as shown in **Figure 3.3.**

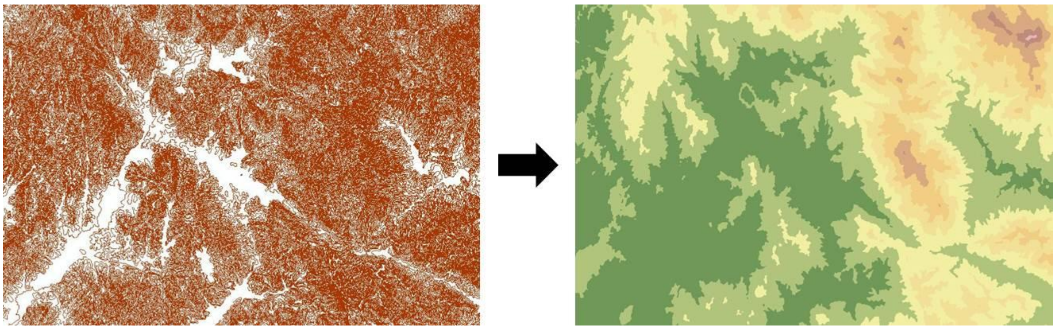


Figure 3.3: Topo to Raster process

Filling Sinks

This function is used in creating a depressionless DEM. The grid created earlier contains cells with different elevation and when a cell is surrounded by cells with higher elevation, water will trap in that particular cell and will not flow (Merwade, 2011). It is crucial to fill the sinks because the network should be that of the continuation of flow path of each cell that will finally flow to the edge of the grid and when this fails, the trapped cell may drain into each other causing endless processing loop (Surface hydrologic modeling, 2010).

Figure 3.4a and **Figure 3.4b** below show the illustration of what filling does, either chopping off tall cells or filling in sinks:

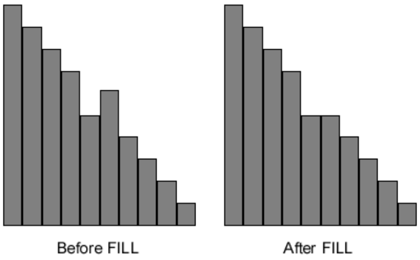


Figure 3.4a: Chopping off tall cells

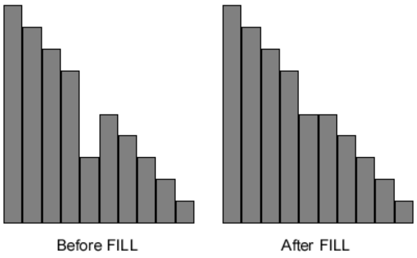


Figure 3.4b: Filing in sinks

Source: Surface Hydrology Modeling, 2010

The *Fill* tool is used and the *DEM30* is used as the input surface raster and the output is saved as *Fill_DEM30.* (**Figure 3.5**)

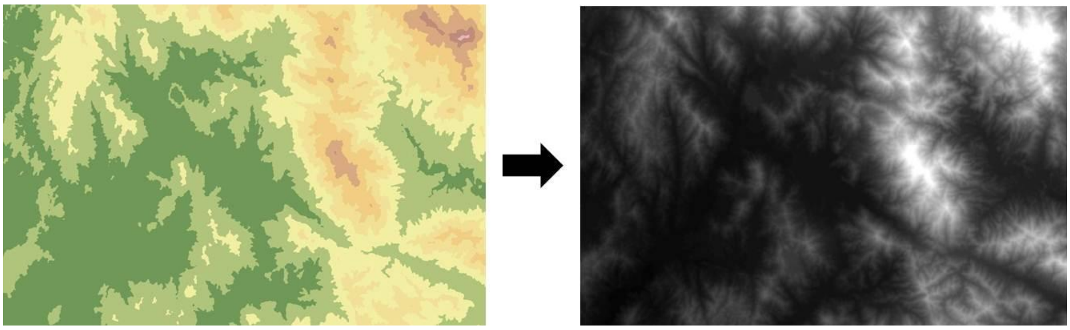
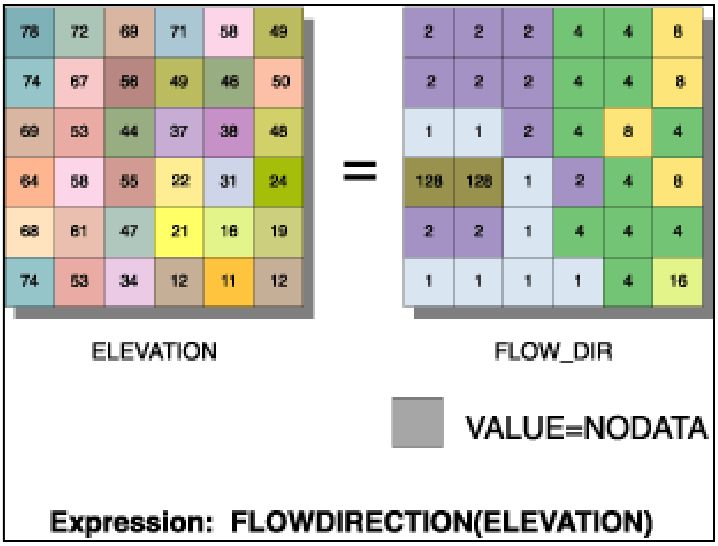


Figure 3.5: Fill process

Flow Direction

Flow direction is needed to determine where the landscape will drain by implying coded cells representing the direction of the flow. Note that the coding numbers “do not have any absolute, relative, or ratio meaning, they are just used as numeric place holders for nominal direction data values (since grid values are always numeric).” as stated in the Surface Hydrology Modeling (2010). An example of the input and output of the data can be shown in **Figure 3.6** where the coding of each direction is shown in **Figure 3.7.**

For example, Figure 3.6 shows that if the flow is directed due to South, the centre cell will be coded as number 4.



78	72	69	71	58	49
74	67	56	49	46	50
69	53	44	37	38	48
64	58	55	22	31	24
68	61	47	21	16	19
74	53	34	12	11	12

ELEVATION

=

2	2	2	4	4	8
2	2	2	4	4	8
1	1	2	4	8	4
128	128	1	2	4	8
2	2	1	4	4	4
1	1	1	1	4	16

FLOW_DIR

▨ VALUE=NODATA

Expression: FLOWDIRECTION(ELEVATION)

Figure 3.6: An illustration for the elevation input and flow direction output

32	64	128
16		1
8	4	2

Figure 3.7: The code number representation of each direction from the centre cell.

Source: ArcGIS Desktop Help 9.3 Manual >>Flow Direction

The *Flow Direction* tool (**Figure 3.8**) is used and the *Fill_DEM30* is used as the input surface raster and saved as *FlowDir30*

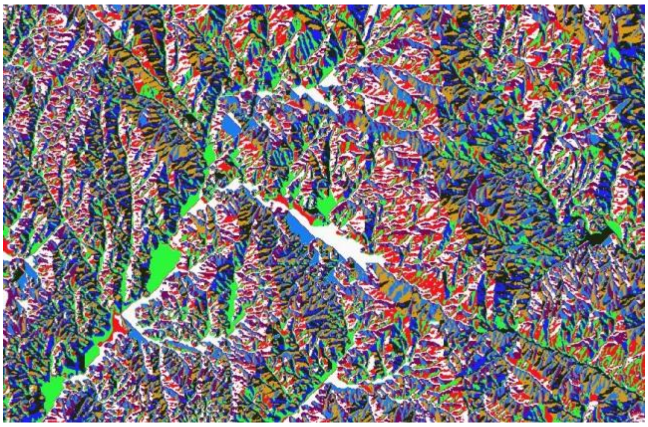


Figure 3.8: Flow Direction

Identifying Basins

The *Basin* tool is used to identify the basins that flow to each outlet point on the map edge and the *FlowDir30* is used as the input flow direction raster and saved as *Basin30.* The desired basin is then selected as shown in **Figure 3.9**.

Figure 3.9: Basin highlighted

The purpose of this step is to extract the desired basin and process only that particular basin. The selected basin is then converted into vector format to provide as a boundary for clipping raster in the next step.

Clip Raster

The *FlowDir30* is used as the input raster for clipping process with the identified basin, *Basin30* polygon as the output extent using the *Clip* tool. The output raster is saved as *Clip_FD30*. Note that the 'Use Input Features for Clipping Geometry' box is ticked in order to obtain a clipped geometry exactly as the input features perimeter and the output can be shown in **Figure 3.10.**

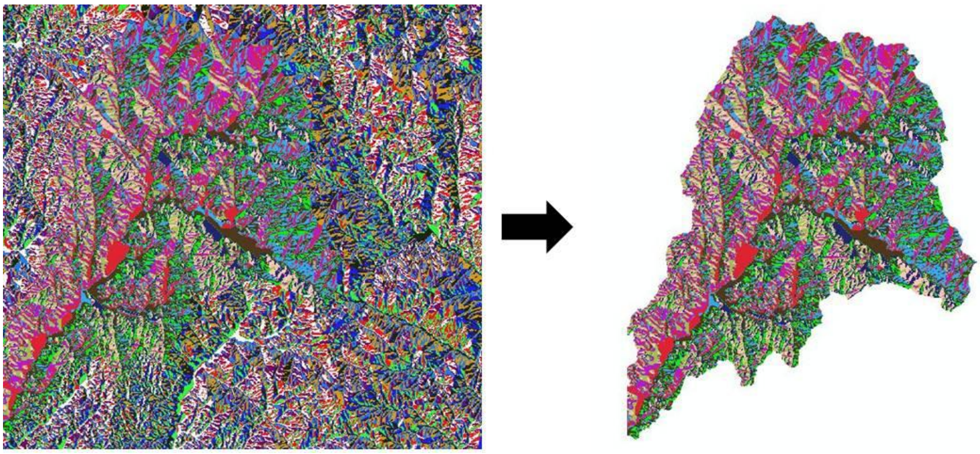


Figure 3.10: Clip process

Flow Accumulation

This function accumulates the number of cells that are draining to any particular cell in the DEM taking the flow direction grid as the input as illustrated in **Figure 3.11.** The centre of the magnified cells chosen in the red box shows the value of "3" since it accumulates three cells flows. The output of the function is shown in **Figure 3.12** where it shows the full illustration of a grid.

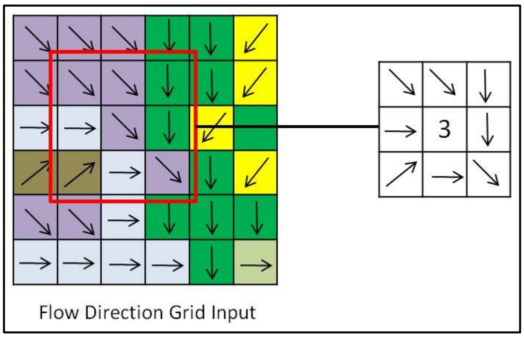
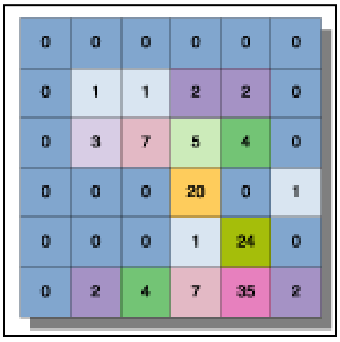


Figure 3.11: The input of Flow Accumulation and the accumulation process



0	0	0	0	0	0
0	1	1	2	2	0
0	3	7	5	4	0
0	0	0	20	0	1
0	0	0	1	24	0
0	2	4	7	35	2

Figure 3.12: The output of the Flow Accumulation

Source: ArcGIS Desktop Help 9.3 Manual > >Flow Accumulation

The end result of this activity is to generate a network of high-flow cells (Surface hydrology modeling, 2010) as shown in **Figure 3.13**.

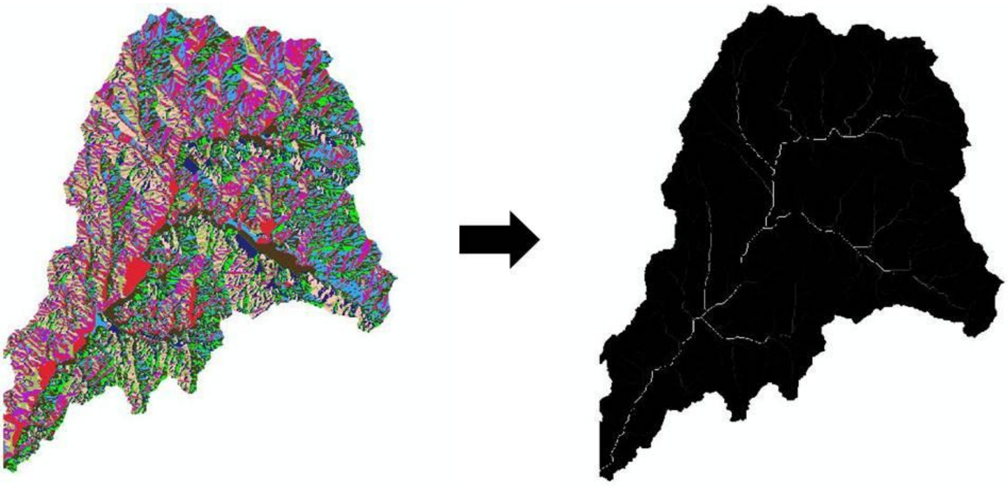
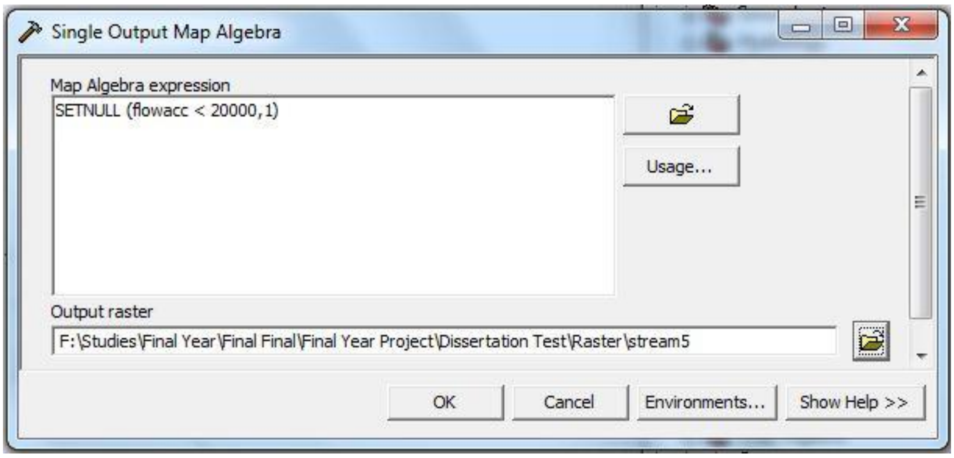


Figure 3.13: Flow Accumulation process

Stream Network

Flow accumulation generated earlier will be the input to create a stream network as it shows the high-flow cells that will define a network (Merwade, 2011). An assumption is made by Merwade (2011) is that a stream is defined when a certain area (threshold) drains to a point. Assuming an area of 18km² to be the threshold, the number of cells corresponding to the area is 20,000 (18000000/(30*30)) where 18000000 is the threshold area and 30 is the number of the DEM resolution used in the study. The indication of the number is that any cells with flow accumulated greater than 20,000 cells will have a value of 1 and displayed as a stream network.

The *Raster Calculator* tool is used using the *FlowAcc30* as the input and saved as *Stream5* as shown in **Figure 3.14**. The stream raster is then converted into vector format using the *Stream to Feature* tool.



Map Algebra expression

SETNULL (flowacc < 20000,1)

Output raster

F:\Studies\Final Year\Final Final\Final Year Project\Dissertation Test\Raster\stream5

Figure 3.14: Raster Calculator

Stream Link

Stream link is the line that connects two successive junctions, a junction and the outlet, or a junction and the drainage divide. An illustration of the said elements is shown in **Figure 3.15.** Stream link functions to give unique Ids to each stream links available in the network.

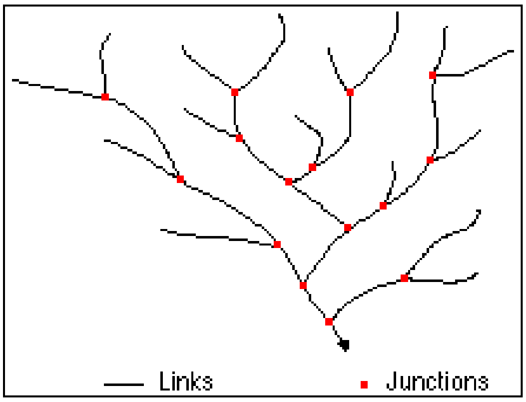


Figure 3.15: An illustration of links and junctions

Source: ArcGIS Desktop Help 9.3 Manual > >Stream Link

Use the *Stream Link* tool and provide *Stream5* and *Clip_FD30* as the input stream raster and input flow direction raster respectively to obtain the stream link as shown in **Figure 3.16.**

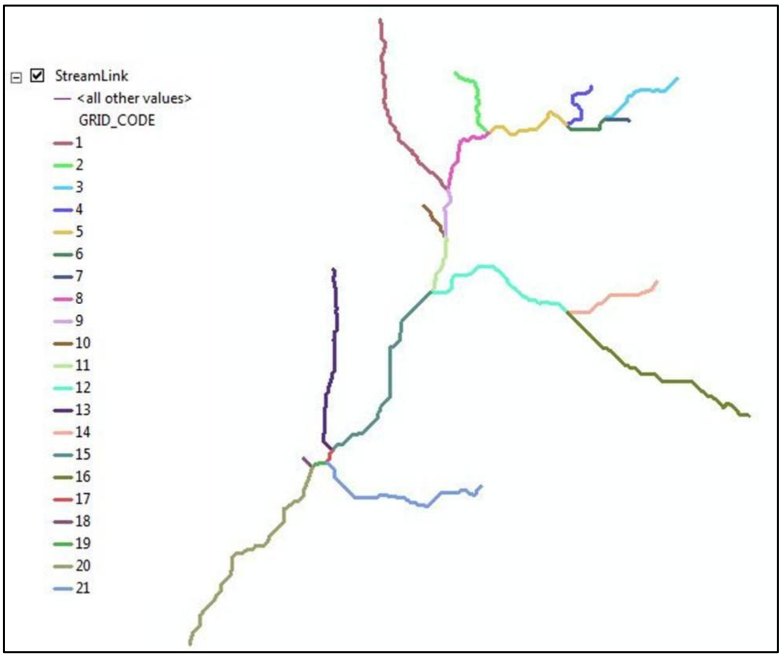


Figure 3.16: Stream Link output

Watershed Delineation

This process gives out the sub-basin delineation of *Basin30* within the *Basin30* (shp.) perimeter. The *StreamL* computed before will be the input feature pour point data for the *Watershed* tool in dividing the sub catchment. Each Grid_Code will have its own area.

The delineated watershed raster is then converted into vector format using *Raster to Polygon* tool. The final output of the delineated watershed and the stream network is shown in **Figure 3.17**. Each sub-catchment is renamed and the property of each sub-catchment will be explained in the next chapter.

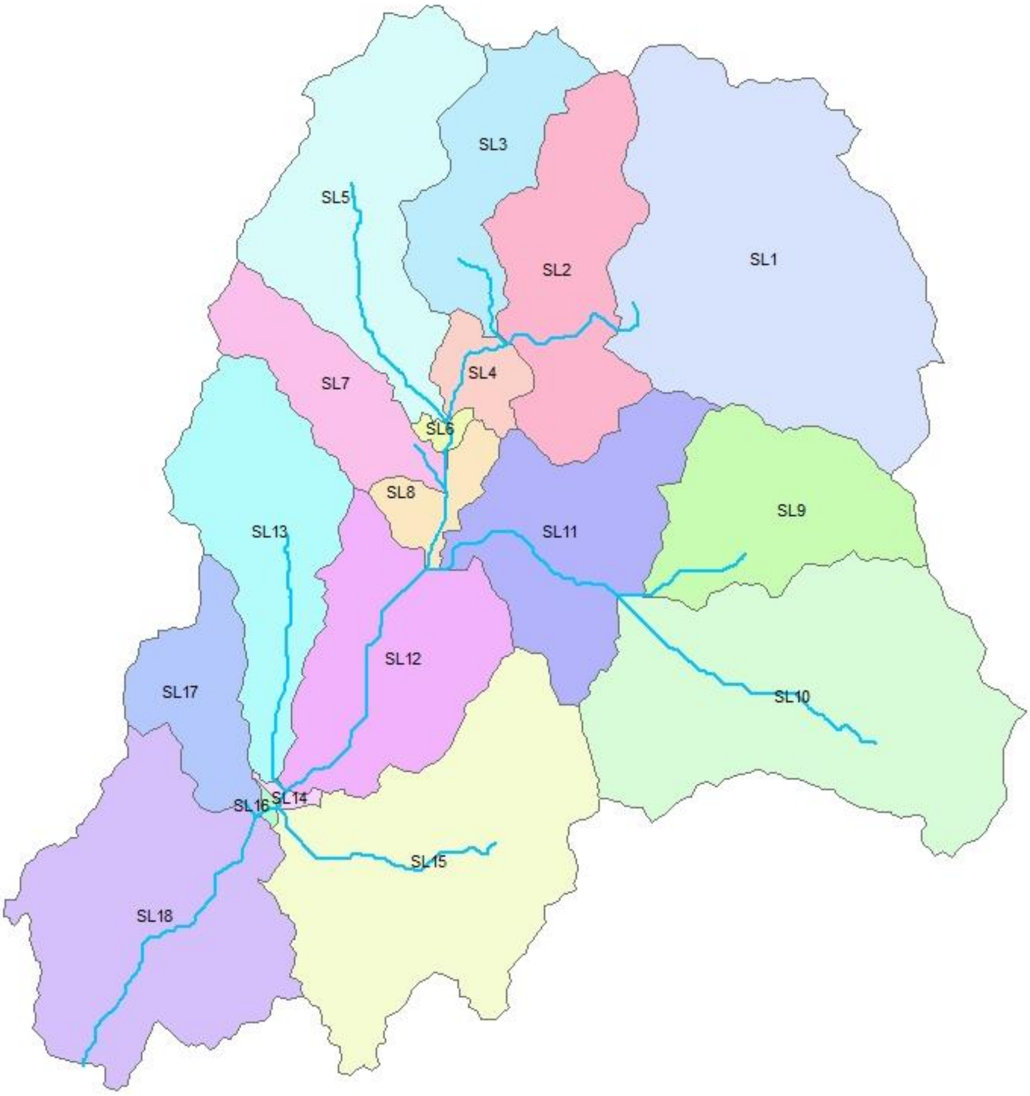


Figure 3.17: Watershed delineated

3.2.2 Hydrological Analysis

Location of Rainfall Station

The location of the rainfall station can be obtained from the rainfall inventory prepared by *Jabatan Pengairan dan Saliran* (JPS). The coordinate obtained for the location will then be inserted into the map layer as shown in **Figure 3.18.**

Figure 3.18: Rainfall Station located within the delineated watershed

Derivation of Rainfall Intensity-Duration-Frequency (IDF) Curve

The next step in the analysis is to obtain the IDF Curve for the desired station. The parameters of the IDF Curve are obtained from Hydrological Procedure No. 1 (2010) (HP1).

For this project, the only available data provided in HP1 is the IDF parameters for Station Sek. Keb. Kg. Sg. Lui (Station ID: 3118102). Therefore, it is assumed that the whole catchment will use the rainfall intensity of this station.

The rainfall intensity is computed using the formula given below:

$$I = \frac{\lambda T^{k}}{(d+\theta)^{\eta}}$$

Where I – The rainfall intensity (mm/hr)
T – Annual recurrence interval, ARI (years), $2 \leq T \leq 100$
d – Storm duration (hours)
λ, κ, θ and η – Fitting constants dependent on the rainfall station

The fitting constants for the selected rainfall station are shown in **Table 3.2** below and the IDF Curve generated is shown in **Figure 3.19.**

Table 3.2: Derived parameters for Station Sek. Keb. Kg. Sg. Lui

State	*Station ID*	*Derived Parameters*			
		λ	ҡ	θ	η
Selangor	3118102	**63.155**	**0.177**	**0.122**	**0.842**

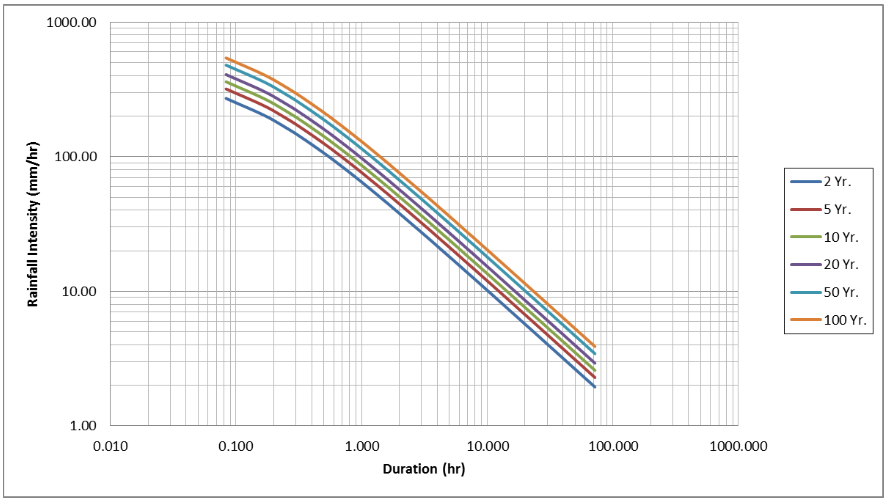


Figure 3.19: IDF Curve generated for Station Sek. Keb. Kg. Sg. Lui

Area Reduction Factor (ARF)

It is very important to note that the rainfall intensity obtained earlier is the point rainfall.

The area of the whole catchment in this study is 290 km² and the ARF computed for the area is tabulated in **Table 3.3.**

ARF is obtained from HP1 (2010) for different storm duration using the formula below:

$$ARF = a \cdot A^b$$

Where a and b – derived coefficient
A – Area of catchment (km²)

Table 3.3: The ARF computed using the catchment area of 290 km² for various storm duration of different return period

Storm Duration (hr)	RETURN PERIOD (years)					
	2	5	10	20	50	100
0.25	0.98	0.96	0.93	0.90	0.86	0.83
0.5	0.98	0.96	0.93	0.90	0.85	0.82
1	0.97	0.96	0.93	0.89	0.85	0.82
3	0.96	0.95	0.92	0.89	0.84	0.81
6	0.96	0.95	0.92	0.88	0.84	0.80
12	0.96	0.95	0.91	0.88	0.83	0.79
24	0.95	0.95	0.91	0.87	0.83	0.79
48	0.95	0.94	0.91	0.87	0.82	0.78
72	0.95	0.93	0.91	0.87	0.82	0.77

Temporal Pattern

The temporal pattern of rainfall is used to represent the typical variation of rainfall intensities during a typical storm. HP1 (2010) gives recommendations on temporal patterns to be adopted for the design storm in Peninsular Malaysia. The patterns prepared are for nine standard storm duration: 0.25, 0.5, 1, 3, 6, 12, 24, 48, and 72 hours.

The whole of Peninsular Malaysia is further divided into 5 regions to give better representation of the rainfall distribution for different areas. The list of region and the state/areas within the region is tabulated in **Table 3.4.**

Table 3.4: Different Region for different temporal pattern

Region	State/Area
Region 1	Terengganu, Kelantan
Region 2	Johor, Negeri Sembilan, Melaka, Selangor, Pahang
Region 3	Perak, Kedah, Pulau Pinang, Perlis
Region 4	Mountainous Areas
Region 5	Urban Area (Kuala Lumpur)

Based on the table above, the study area is located in Region 2, therefore, the normalized temporal pattern for Region 2 is shown in **Table 3.5**.

Table 3.5: Normalized Temporal Pattern for Region 2 from HP1 (2010)

15-min	30-min	60-min	180-min	6-hr	12-hr	24-hr	48-hr	72-hr
0.255	0.124	0.053	0.053	0.044	0.045	0.022	0.027	0.016
0.376	0.130	0.059	0.061	0.081	0.048	0.024	0.028	0.023
0.370	0.365	0.063	0.063	0.083	0.064	0.029	0.029	0.027
	0.152	0.087	0.080	0.090	0.106	0.031	0.033	0.033
	0.126	0.103	0.128	0.106	0.124	0.032	0.037	0.036
	0.103	0.153	0.151	0.115	0.146	0.035	0.040	0.043
		0.110	0.129	0.114	0.127	0.039	0.046	0.047
		0.088	0.097	0.090	0.116	0.042	0.048	0.049
		0.069	0.079	0.085	0.081	0.050	0.049	0.049
		0.060	0.062	0.081	0.056	0.054	0.054	0.051
		0.057	0.054	0.074	0.046	0.065	0.058	0.067
		0.046	0.042	0.037	0.041	0.093	0.065	0.079
						0.083	0.060	0.068
						0.057	0.055	0.057
						0.052	0.053	0.050
						0.047	0.048	0.049
						0.040	0.046	0.048
						0.039	0.044	0.043
						0.033	0.038	0.038
						0.031	0.034	0.035
						0.029	0.030	0.030
						0.028	0.029	0.024
						0.024	0.028	0.022
						0.020	0.019	0.016

An example of the distributed rainfall pattern computed for this study is shown for the 1-hr storm duration. The steps taken are as follows:

- Multiply the rainfall depth obtained from the IDF Curve with the normalized temporal pattern above.
- The distributed rainfall is further multiplied by the ARF obtained earlier to obtain the average rainfall depth of the whole catchment
- The average rainfall depth (mm) is then converted into average rainfall intensity (mm/hr)

The final average rainfall intensity for the catchment area is tabulated in **Table 3.6.**

Table 3.6: Averaged Rainfall Intensity (mm/hr)

Storm Duration (hr)	Averaged Rainfall Intensity (mm/hr)					
	2 Yr.	5 Yr.	10 Yr.	20 Yr.	50 Yr.	100 Yr.
0.25	161.03	185.01	202.66	222.75	249.85	272.87
0.5	104.21	119.73	131.92	143.66	160.83	174.81
1	59.70	69.02	75.77	82.23	92.22	100.32
3	26.37	30.59	33.43	36.40	40.84	44.09
6	14.95	17.29	18.92	20.57	22.96	24.81
12	8.35	9.75	10.62	11.53	12.87	13.84
24	4.78	5.57	6.07	6.58	7.31	7.87
72	1.84	2.12	2.35	2.54	2.83	3.00

Runoff Coefficient, C

The runoff coefficient, c value will vary according to different land use as well as the soil type. The recommended Runoff Coefficients for various land uses is prepared by JPS in MSMA 2nd Edition, 2012.

The selected C for the sub catchments in this study is tabulated in **Table 3.7**

Table 3.7: Runoff Coefficient, C for different sub catchments

Catch_ID	Area (m^2)	Runoff Coefficient, C	
		≤ 10 years ARI	> 10 years ARI
SL1	41.59	0.37	0.46
SL2	17.51	0.40	0.50
SL3	11.58	0.30	0.40
SL4	3.47	0.47	0.57
SL5	22.27	0.31	0.41
SL6	0.69	0.42	0.52
SL7	9.34	0.32	0.42
SL8	3.51	0.35	0.45
SL9	15.79	0.30	0.40
SL10	38.52	0.33	0.43
SL11	18.22	0.33	0.43
SL12	18.66	0.50	0.60
SL13	17.93	0.40	0.48
SL14	0.43	0.43	0.53
SL15	33.37	0.37	0.47
SL16	0.22	0.49	0.59
SL17	8.47	0.32	0.42
SL18	28.27	0.54	0.64

3.3.3 Water Discharge, Q

The computation was done following the steps stated:

- Calculate the water discharge of each sub catchment using all the parameters obtained earlier for various storm duration and different ARI
    - Area, A from the delineation of the watershed
    - Rainfall Intensity, I and Runoff Coefficient, C from the Hydrological Analysis
- Accumulate the discharge from upstream to downstream accordingly

CHAPTER 4

RESULT AND DISCUSSION

4.1 Study Area

The study area for this project is Sungai Langat as shown in **Figure 4.1**. Empangan Sungai Langat is located at the upstream of the catchment and it is one of the sources of water intake that will serve the area of Hulu Langat through the Loji Pembersih Air Sg Langat. The downstream of the catchment is limited to the water treatment plant as the end result will give the estimated water discharge at that point.

The contours obtained earlier that cover the study area are from the 3857 grid and 3858 grid. Therefore, these grids are used for the project and processed for further analysis.

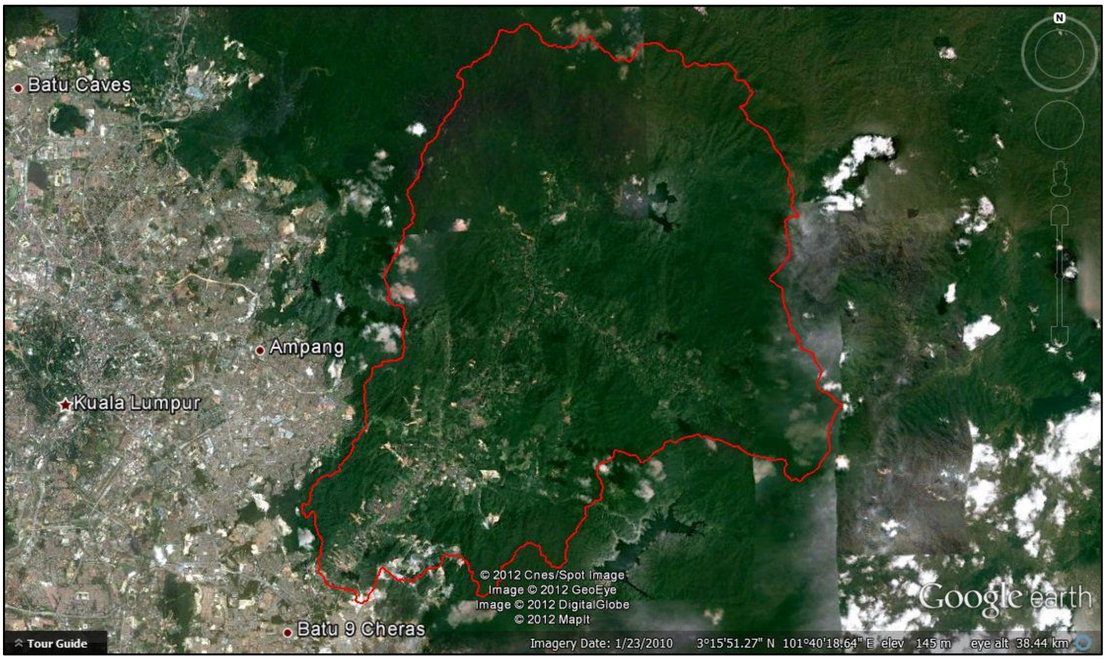


Figure 4.1: The study area delineated in red line

4.2 Watershed Delineation

4.2.1 Cell Size of DEM

According to Mapping Center Answer provided by ESRI (2008) tabulated in **Table 4.1,** the most suitable cell size for the desired map scale is the 30m DEM.

Table 4.1: The suggested pixel size for different scale provided by ESRI (2008)

Print Media, e.g, ~300 DPI		
Pixel Size	**Largest Scale**	**Smallest Scale**
~2m	1:2,000	1:10,000
~5m	1:9,000	1:24,000
~10m	1:24,000	1:100,000
~30m	1:100,000	1:250,000
~90m	1:250,000	1:500,000

A comparison was made between a 30m DEM and 120m DEM and the result can be shown in **Figure 4.2** below. Based on the figure, it clearly shows that the DEM with higher resolution (30m) gives out a finer impression of the land while on the other hand; the 120m DEM gives out a courser impression of the land.

Thus, the 30m DEM is used for further analysis and processing.

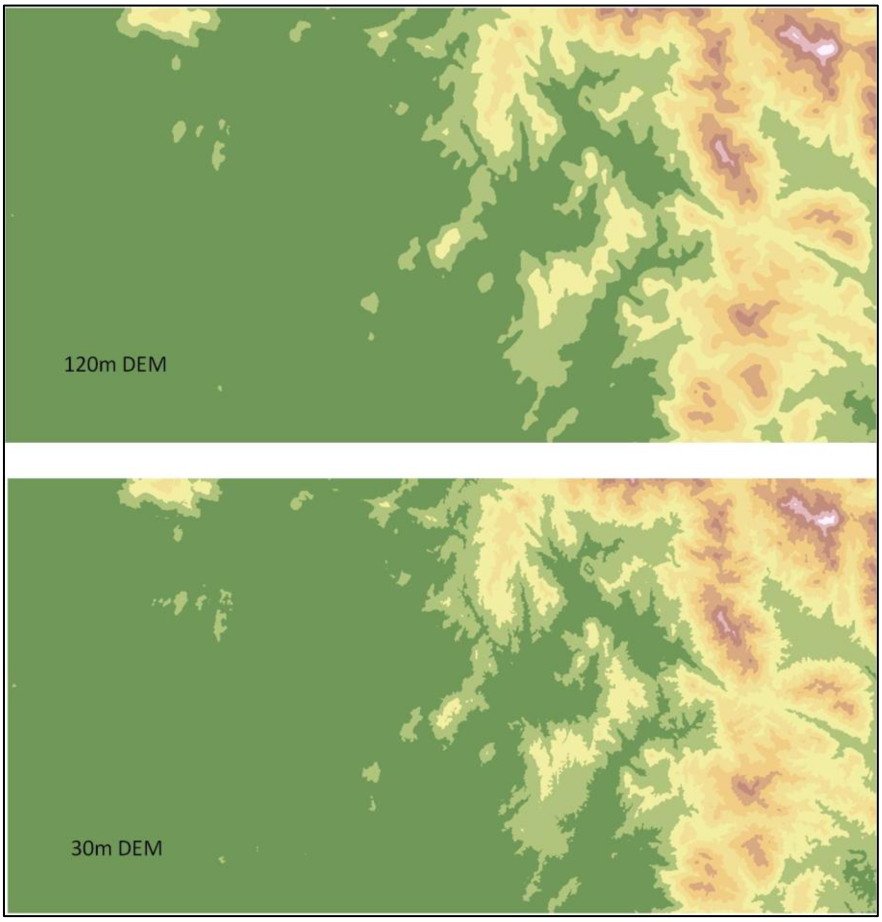


Figure 4.2: The comparison between a low resolution DEM (120m) and high resolution DEM (30m)

4.2.2 Threshold Area for Stream Network

A few other assumptions on the threshold area were made and the results obtained are shown in **Figure 4.3** below.

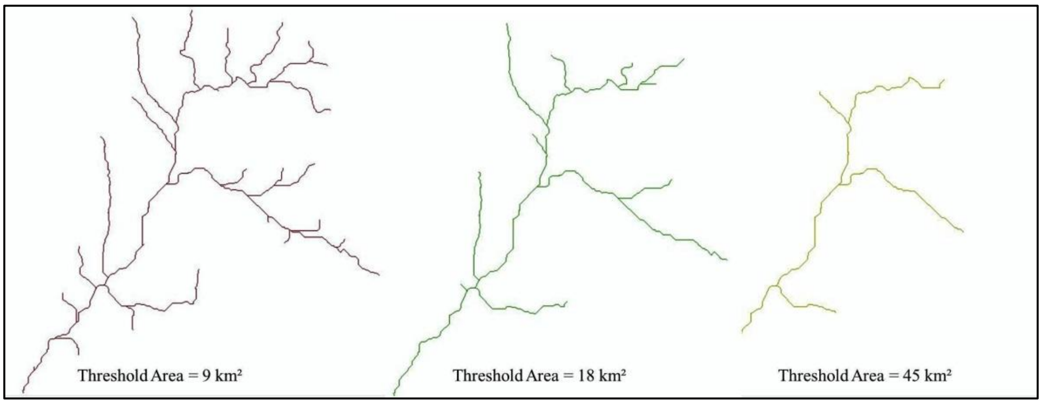


Figure 4.3: The comparison of different threshold areas

Based on the figure above, it can be observed that larger threshold area gives less dense stream whereas a smaller threshold area gives denser stream network. Depending on the necessity of the study, an appropriate threshold area is determined and in this case, a threshold area of 18km² is chosen.

4.3 Hydrological Analysis

The purpose of the hydrological analysis carried out in this study is to feed all the parameters in the Rational Method equation in finding the water discharge of the catchment.

$$\boldsymbol{Q = \frac{C \cdot I \cdot A}{3.6}}$$

Where Q - Water Discharge (m^3/s)
C - Dimensionless Runoff Coefficient
I – Rainfall Intensity (mm/hr)
A - Area of Water Catchment (km^2)

4.3.1 Rainfall Intensity

The rainfall intensity used in this study is assumed to be the same throughout the catchment. This is due to the limitation of data available for the study where out of all the stations determined within the perimeter of the catchment, only one station is provided in the HP1.

4.3.2 Runoff Coefficient

The runoff coefficient assumed for the catchment is based on the judgement made from the Google Satellite Image provided in Google Earth. For sub catchment that has multiple type of land use, the average coefficient is computed using the equation below:

$$\boldsymbol{C_{avg} = \frac{\sum_{j=1}^{m} C_j A_j}{\sum_{j=1}^{m} A_j}}$$

Where C_{avg} – Average Runoff Coefficient
C_j – Runoff Coefficient of Segment
A_j – Area of Segment *j*, (km^2)
m – Total Number of Segments

The fraction of the different land use segment is tabulated in **Table 4.2.**

The limitation faced in determining the runoff coefficient accurately is because of the absence of the land use data for the study area. The land use data, if provided, will be overlaid with the water catchment delineated and the area of different land use can be calculated accurately.

Therefore, the determination of the percentage area of different land use in each sub catchment was done manually by observation of the Google Satellite Image. Another limitation of this method is the recentness of the satellite image.

Table 4.2: The fraction of the different land use segment for each sub catchment

Catch_ID	Area (km²)	Percentage Area of Different Landuse
SL1	41.59	10% of Detention Pond (with outlet), 90% of Forest Cover
SL2	17.51	2% of Link and Terrace House, 98% of Forest Cover
SL3	11.58	1% of Retention Pond (no outlet), 7% of Sport Fields, Park and Agriculture, 92% of Forest Cover
SL4	3.47	10% of Link and Terrace House, 90% of Forest Cover
SL5	22.27	5% of Bare Soil (No Cover), 95% of Forest Cover
SL6	0.69	20% of Link and Terrace House, 30% of Bush Cover, 50% of Forest Cover
SL7	9.34	3% of Link and Terrace House, 97% of Forest Cover
SL8	3.51	1% of Sport Fields, Park and Agriculture, 10% of Link and Terrace House, 89% of Forest Cover
SL9	15.79	100% of Forest Cover
SL10	38.52	5% of Link and Terrace House, 95% of Forest Cover
SL11	18.22	5% of Link and Terrace House, 95% of Forest Cover
SL12	18.66	20% of Sport Fields, Park and Agriculture, 40% of Link and Terrace Houes, 40% of Forest Cover
SL13	17.93	15% of Roads and Highways, 85% of Forest Cover
SL14	0.43	20% of Link and Terrace House, 20% of Forest Cover, 60% of Bush Cover
SL15	33.37	5% of Bare Soil (No Cover), 10% of Link and Terrace House, 10% of Sport Fields, Park and Agriculture, 75% of Forest Cover
SL16	0.22	30% of Link and Terrace House, 70% of Bush Cover
SL17	8.47	10% of Bare Soil (No Cover), 90% of Forest Cover
SL18	28.27	20% of Bare Soil (No Cover), 40% of Link and Terrace House, 40% of Forest Cover

4.4 Water Discharge

The computation of water discharge is done cumulatively as according to the stream order as shown in **Figure 4.4.**

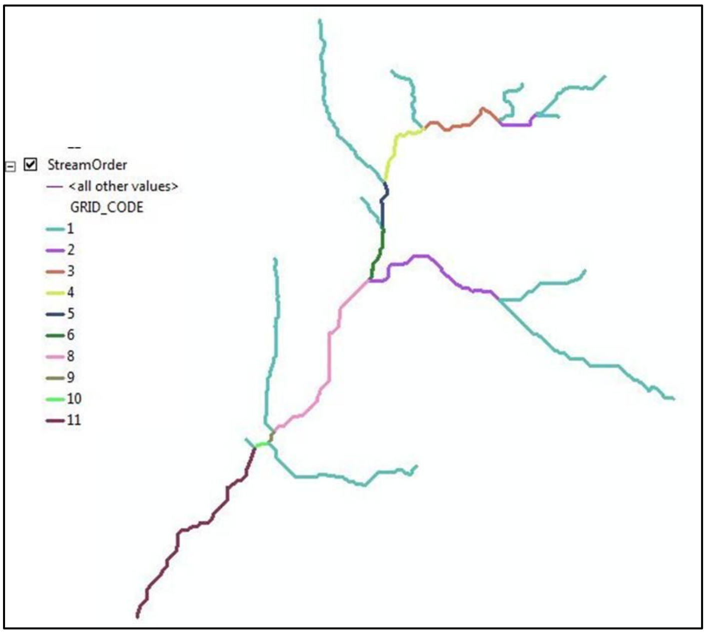


Figure 4.4: The Stream Order in computing the cumulative water discharge

Based on the figure above, the stream with Grid_Code 1 will give the water discharge into stream with Grid_Code 2. Therefore, if two streams of the same Grid_Code, the water discharge from these two streams will be added into the next stream of the subsequent Grid_Code.

The summary of cumulative water discharge at the end point of the catchment (total discharge of the whole catchment), is tabulated in **Table 4.3.**

Table 4.3: Summary of Cumulative Water Discharge at outlet point of the whole catchment

Duration (hr)	Cumulative Water Discharge, Q (m^3/s)					
	2 years ARI	5 years ARI	10 years ARI	20 years ARI	50 years ARI	100 years ARI
0.25	4861.89	5585.60	6118.49	6725.08	7543.39	8238.33
0.5	3146.30	3614.69	3982.89	4337.25	4855.60	5277.74
1	1802.30	2083.81	2287.58	2482.61	2784.19	3028.87
3	796.09	923.44	1009.45	1099.08	1232.92	1331.13
6	451.43	522.07	571.27	621.12	693.09	749.00
12	252.21	294.35	320.51	348.01	388.58	417.74
24	144.33	168.25	183.25	198.73	220.82	237.68
72	55.68	63.95	70.86	76.71	85.38	90.68

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Both of the objectives were achieved upon the completion of the project where the automated watershed is obtained as well as the water discharge predicted for the catchment.

The delineated watershed including the sub catchments were successfully delineated using the Hydrology Spatial Analysis Tool in ArcGIS 9.3. The position of the stream is checked on the Google Satellite Image and it fits accordingly with the tolerance of several meters.

The hydrological analysis was carried out as accordance to MSMA and Hydrological Procedure No. 1 and the parameters for the water discharge using Rational Method were successfully computed.

The predicted water discharge was calculated using all the prepared parameters. The output can be used in further analysis for water demand of the served area of Loji Pembersih Air Sungai Langat for efficient water source management.

For a better usage of GIS in the delineation of automated watershed, the process of computation the water discharge of each catchment can also be done using the Spatial Analysis. The method can be advanced with the addition of more understanding in GIS Spatial Analysis and practices of the software.

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