Integrated river basin management (IRBM): Application of HEC-HMS and SWAT2005 for Kurau River sub-basin, Perak

NURAMIDAH HAMIDON, *PhD Student, Department of Hydraulic and Hydrology, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310, UTM Skudai, Johor, Malaysia. Email: nuramidahhamidon@gmail.com*

ZORKEFLEE ABU HASAN, *Senior Lecturer, River Engineering and Urban Drainage Research Centre (REDAC), Universiti Sains Malaysia, Engineering Campus, Seri Ampangan, 14300 Nibong Tebal, Penang, Malaysia. Email: redac04@eng.usm.my*

SOBRI HARUN, *Head Department of Hydraulic and Hydrology, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310, UTM Skudai, Johor, Malaysia. Email: sobriharun@utm.my*

ABSTRACT
Sufficient related information is also very crucial to assist and support in decision making which then lead to the right direction. Moreover, to date, the implementation of Integrated River Basin Management (IRBM) in this country is still at the initial stage and most of the programs are related to awareness, capacity building and establishment of institution. Abidin (2004) stated the four major water-related problems are water shortages, water pollution, floods and landslides. These problems disrupt economic activities and the last two can result in loss of properties and lives. Realizing the seriousness of the problems and the threat it may pose to the environment, Othman et al. (2000) said Malaysia has embarked on a journey to practise Integrated River Basin Management (IRBM) particularly to strengthen the sustainable management of the country's natural resources as IRBM looks at all the contributing factors to the river catchments in an integrated manner and provides a holistic approach to safeguard the water resources and the environment, reduce water quality, deterioration, control floods, sedimentation and pollution. In this study, Kurau River Sub-basin was selected as the case study to support the implementation IRBM using two mathematical models which is Soil and Water Assessment Tools (SWAT2005) and Hydrologic Engineering Centre -Hydrologic Modelling System (HEC-HMS). The simulated model were fit with the observed data and shows that the HEC-HMS and SWAT2005 are suitable model to predict the hydrologic changes and sediment in Kurau River Sub-Basin.

Keywords: IRBM; HEC-HMS 3.1; SWAT2005.

1 Introduction

IRBM is the coordinated use and management of land, water and other natural resources and activities within a river basin, as stated by Ramadasan et al. (2000) to optimize the use of resources and ensure its stability and productivity now and in the future. Unfortunately, whatever the title of the study might be, very likely the content and outcome of the studies will be biased to the organisation that conducted or sponsored the studies. Hence, IRBM needs comprehensive legislation, a strong institutional set up and a good database for planning, monitoring and control. Many models have been developed by many scientists and engineers to find the possible causes and hence the best solutions for numerous problems at river basin level to specific and localized area. Nowadays, many mathematical models have incorporated or integrate the GIS application to generate inputs and display output or as interface for the entire modelling processes. Their integration could be utilised towards establishing a DSS which is vital for effective river basin management. In this study, Kurau River Sub-basin was selected as the case study to support the implementation IRBM using two mathematical models which is Soil and Water Assessment Tools (SWAT2005) and Hydrologic Engineering Centre -Hydrologic Modelling System (HEC-HMS) to determine the suitability as Decision Support System Tools for IRBM. The integration of these modelling tools with Geographic Information System (GIS) will provide the information to aid decision making and finally in establishing a Decision Support System (DSS). The information and finding from the simulation results can be used to enhance the basin planning and management for the area.

2 Study Area

Kurau River Sub-basin as shown in Figure 1 lies between latitude 40 51' (N) and 50 10' (N), longitude 1000 38' (E) and 1010 01' (E). The catchment area is approximately 40,000 hectares consisting of two (2) main river tributaries namely Kurau River and Ara River. The confluence of these tributaries located near Pondok Tanjung town and flow downstream into Bukit Merah Lake.Kurau River represents the main drainage artery of the basin, draining an area of approximately 682 km^2 that is generally low lying.

A dam has been constructed at 65 km upstream of the rivermouth at the mid section of the rivers to form the Bukit Merah Reservoir. This dam operates principally to irrigate the paddy areas immediately below the Reservoir. Upstream of the Reservoir are two river subsystems, namely the Kurau River subsystem and the Merah River subsystem. Both drain through undulating to steep terrain. Areas in the former subsystem have been developed extensively for tree crop while the Pondok Tanjong Forest Reserve forms the main land use of the latter subsystem. The upper portion of Kurau River basin falls in the District of Larut, Matang and Selama while the downstream portion is in the Kerian District. Both Districts are in the State of Perak. Largely rural in nature, Kurau River basin has many riverine villages established from the mid to the lower reaches of the river.

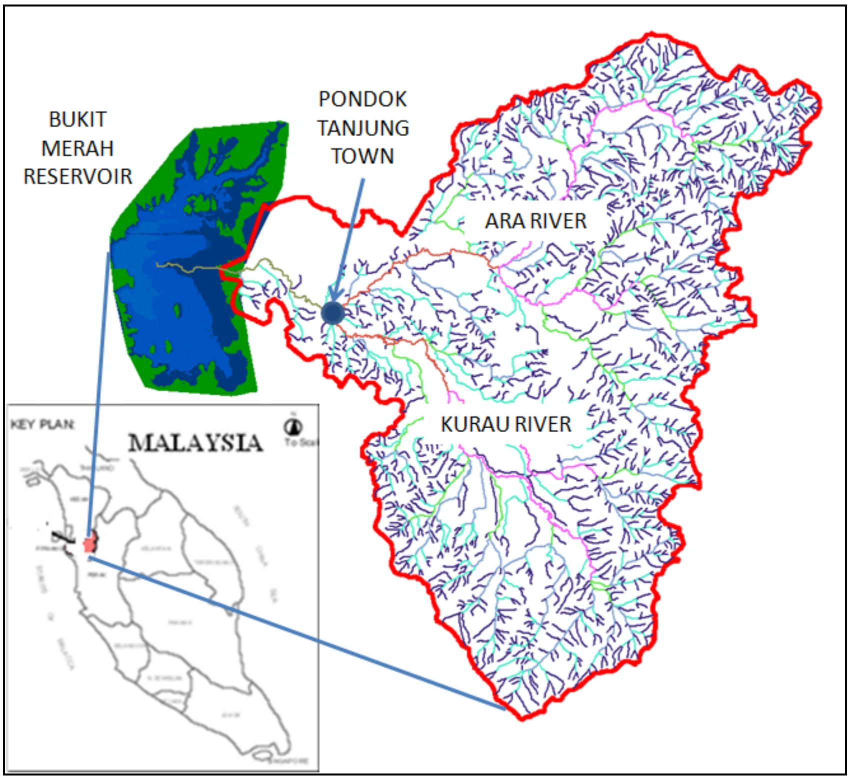

Figure 1 Kurau River sub-basin

3 Model Description

3.1 HEC-HMS3.1

The Hydrologic Modeling System (HEC-HMS) is designed to simulate the precipitation-runoff processes of dendritic watershed systems. It is designed to be applicable in a wide range of geographic areas for solving the widest possible range of problems. This includes large river basin water supply and flood hydrology, and small urban or natural watershed runoff. Hydrographs produced by the program are used directly or in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, and systems operation. The program is a generalized modeling system capable of representing many different watersheds. A model of the watershed is constructed by separating the hydrologic cycle into manageable pieces and constructing boundaries around the watershed of interest. (Scharffenberg and Fleming, 2006)

3.2 SWAT 2005

Soil and Water Assessment Tool (SWAT) is physically based, uses readily available inputs, computationally efficient, and is a continuous model that operates on a daily time step (Jha et al., 2004). SWAT was developed by the U.S. Department of Agriculture (USDA) "to predict the impact of land management practices on water, sediment and nutrient in large complex watersheds with varying soils, land use and Management conditions over long periods of time" (Neitsch et al., 2005, pg 1). SWAT interfaces with GIS software (ArcView®) using AVSWAT-X extension (AVSWAT). AVSWAT can be used to input and designate land-use, soil, weather, ground water, water use, management, pond and stream water quality data, and the simulation period (Di Luzio et al., 2002).

4 Data

Brief descriptions of the data used in the HEC-HMS and SWAT2005 modeling are as follows:-

4.1 Rainfall data

The rainfall data for this study were obtained from the Malaysia DID, covering from year 1950 to 2007. There are sixteen rainfall gauging stations in and around the study area. Some of these stations are automatic and others are manually recording type. All stations are daily rainfall stations, except one of them (Station 4908018 Pusat Kesihatan Kecil at Batu Kurau) which is an hourly data.

4.2 Streamflow data

There are three water level stations in the study area. The streamflow data for this study were also obtained from the Malaysia DID. All are hourly stations and covering from year 1961 until 2005. From the list of data acquired from the year 1950 to year 2007, only year 2004 has complete set of required data, and hence was selected for the calibration part.

4.3 Suspended Sediment data

The suspended sediment data were collected by the Hydrology Division of Malaysia Department of Irrigation and Drainage (Malaysia DID) at a regular interval from year 1977 to 2004. The data were taken daily from Batu 14 (4907422) and Pondok Tanjung stations (5007421).

4.4 Geographical Information System (GIS) Layers

GIS are combinations of hardware, software and geographically referenced data. They are very important tools for river basin management due to their ability to create, store and analyse spatially and temporally distributed data (Ruggles et al., 2001). GIS data were used as base map analysis as well as for input into watershed numerical models. The GIS layers included in the database are the Land-use/land-cover, River system, 10m x 10m Digital Elevation Model (DEM), Soil map, and hydrologic stations.

5 Model Setup

5.1 HEC-HMS Model Setup

The configuration HEC-HMS for Kurau River Sub-basin model is depicted in Figure 2. There are nine (9) nodes for the flows from every subcatchments and channel. The observed discharge data recorded at node R40 which is Pondok Tanjung station (id no. 5007421) and JR130 which is Batu 14, Batu Kurau station (id no. 4907422). There are 13 subcatchments used to represent the hydrologic model in Kurau River which is can be divided into two (2) rivers namely Kurau River and Ara River. All the subcatchments were name during the hec-geoHMS process and can be recognized depend on their location. The flow will linked from Kurau River and Ara River and finally meet at the junction call Pondok Tanjung and link through the oulet which is Bukit Merah Lake.

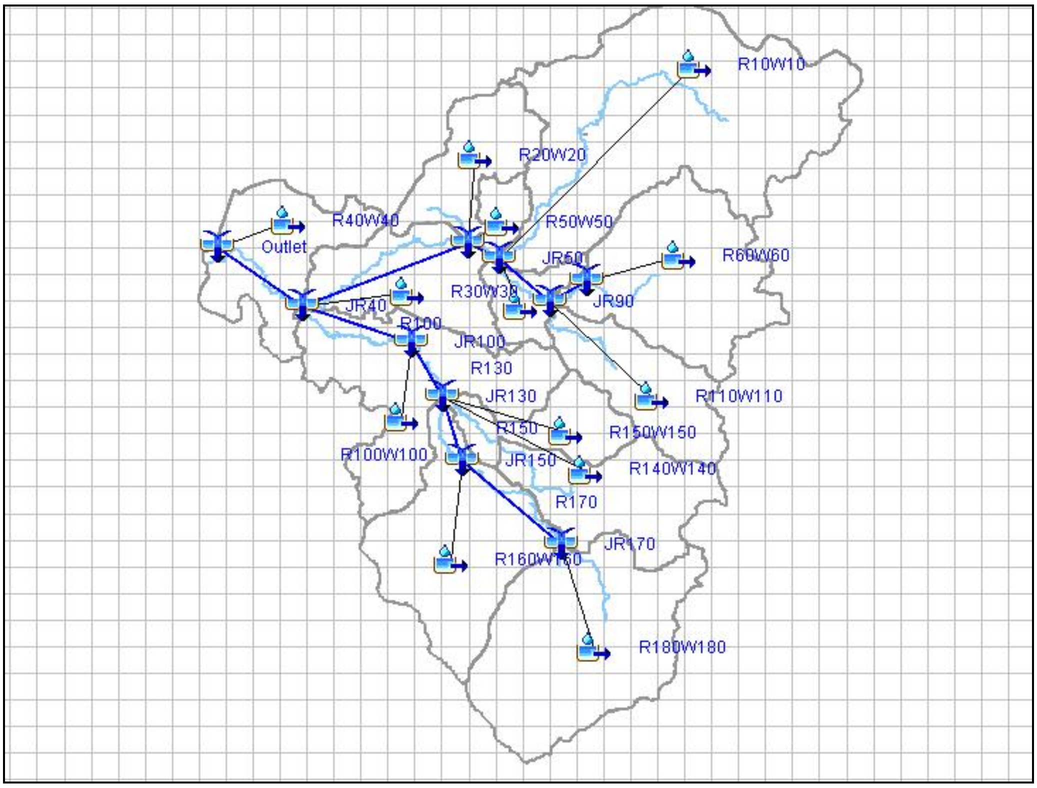

Figure 2 HEC-HMS layout model

5.2 SWAT Model Setup Process

The AVSWAT interface creates two views namely the Watershed View and the SWAT View. The Watershed View is used to process all maps while the SWAT View is used to edit input data, run the SWAT model and analyze output. The primary data needed in model preparation for the study area are DEM, Land-use Map and Soil Map. Database tables or look up tables for land-use, soil type and weather station for the study area are also needed. Precipitation data table uses six stations within the sub-basin and using data from year 1990 to 2006.

By executing all the commands in the Watershed menu all the necessary grid layers were loaded in ArcView-SWAT environment. The interface automatically overlaid those maps that were created with the same projection and resolution (RSO) against each other, divided the river basin into 31 sub-basins based on the Digital Elevation Model. Each sub-basin was further subdivided called sub-basin delineation and streams delineation. The main outlet for the whole catchment is identified and a number of HRUs based on landuse and soil type were formed. Finally extracted model inputs data from map layers and related databases for each HRUs will form a SWAT project. Figure 3 shows the schematic of SWAT Processing.

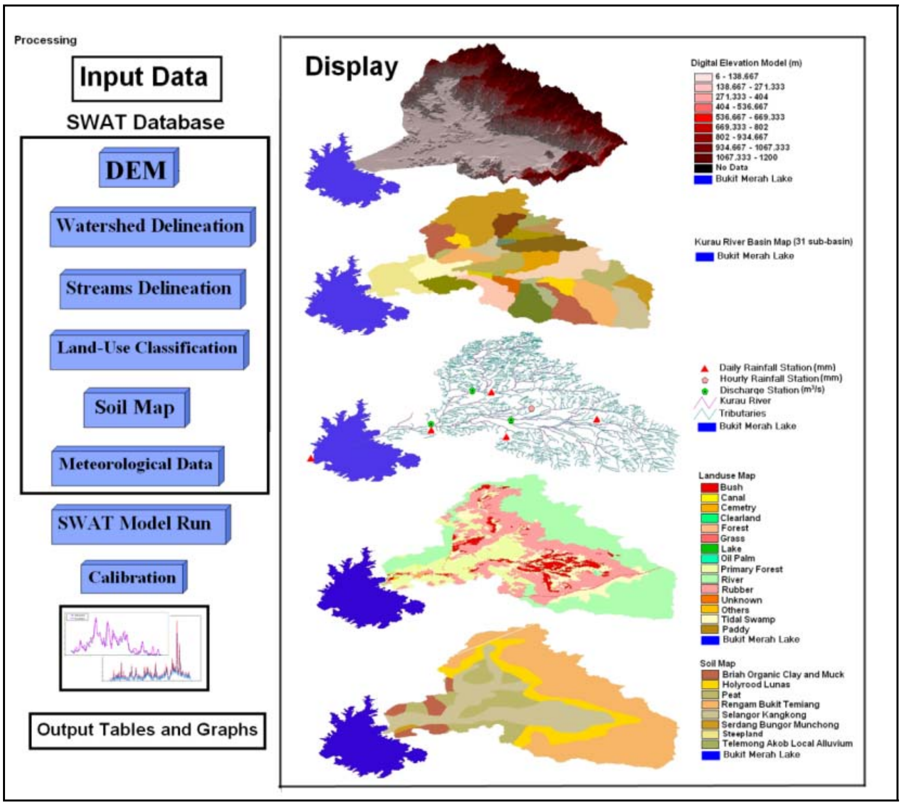

Figure 3 Schematic of SWAT processing for Kurau River

6 Results and Discussion

6.1 HEC-HMS

Calibration is a process to determine the properties or parameters which describe a system. Some parameters such as initial abstraction, curve number, imperviousness, lag time, initial discharge, recession constant and ratio are determined through calibration process where the parameters are adjusted until the observed and simulated hydrograph are almost fitted well. Some parameters such as slope, manning's n, bottom width, shape and length of river are obtained from topographic map and HEC-GeoHMS process. Validation is the process of testing the model applicability using different set of data. In validation process, the model parameters which have been applied during the calibration process are kept unchanged. The simulated and observed hydrograph comparisons will show whether there are a good agreement between them. If the validation result fails, the calibration process will be repeated. The calibration and validation process is interrelated and involves some repetitive try and error (Dinor, 2009). The hourly interval rainfall event starts from 22 October 2004 (00:00 time) to 31 October 2004 (00:00 time) are used for the calibration. The model calibration results are shown in Figure 4 for the discharge stations at Pondok Tanjung station (id no.5007421) and Figure 5 for Batu 14, Batu Kurau station (4907422). The selection of rainfall and discharge data for calibration and validation were based on the availability and the best quality of data sets at the rainfall and discharge stations. The R^2 value is used to measure the performance of the modeling. The accuracy of the hydrologic model is determined based on the coefficient of determination (R^2) value. The closer the R^2 value to 1, the better the model accuracy can be achieved, whereas the closer the R^2 value to 0, the poorer the model. Correlation is the degree of association between the elements of two samples of data, that is, between observations on two variables (McCuen,1989). From the calibration results, the peak flow at R40 Pondok Tanjung discharge station and Bt 14 were closely fit with the observed peak flow of R^2 =0.744 and R^2=0.866 respectively. However after the flow were slowly reduced and the pattern between compared and observed were not fitted well. This might due to the absence of rainfall stations within the area of sub-basin. Some observation was also made by Dinor (2009) and rainfall data for this catchment is solely depending on the recorded rainfall at the Bt 14 rainfall station. Table 1 shows comparison of peak and predicted flows for result validation.

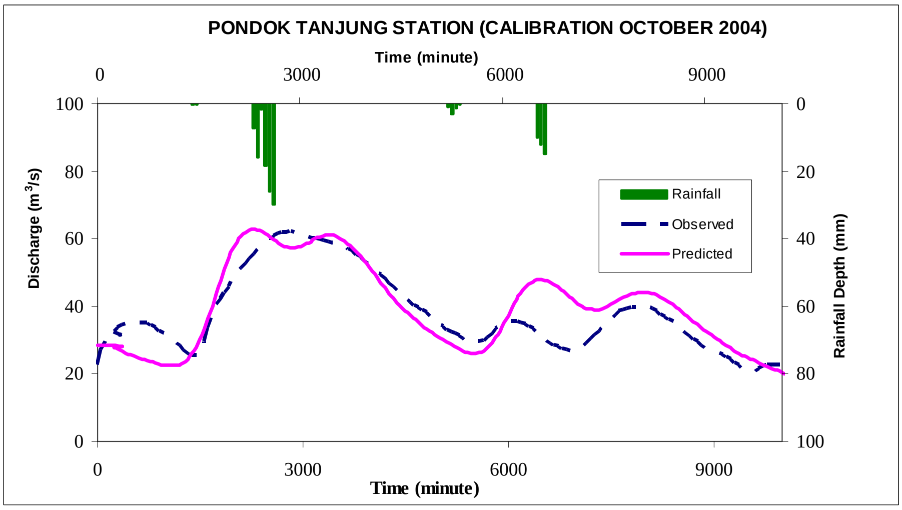

Figure 4 Runoff hydrograph for R40 at Pondok Tanjung discharge station (Calibration)

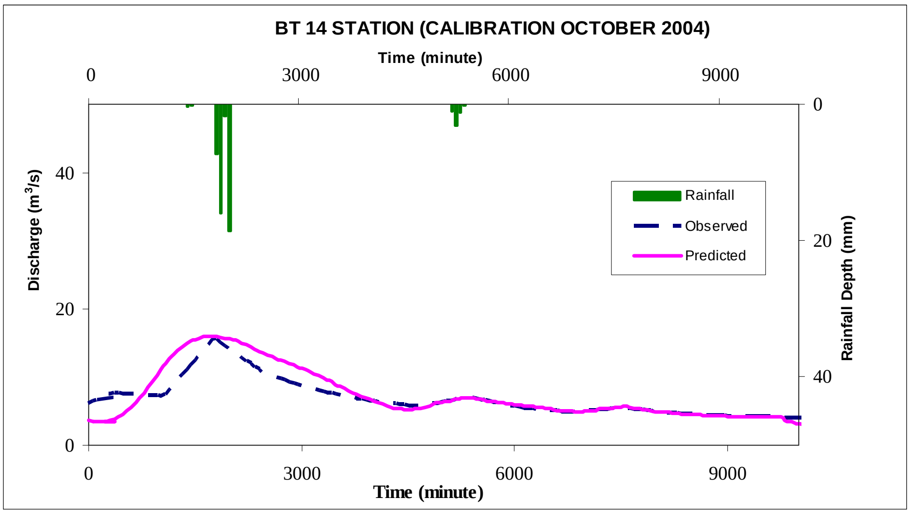

Figure 5 Runoff hydrograph for JR130 at Batu 14 discharge station (Calibration)

Table 1 Comparison of peak and predicted flows for calibration result

Station	Observed Peak Flow (m^3/s)	HEC-HMS Peak Flow (m^3/s)	Difference Peak Flow (m^3/s)	Percentage difference (%) Peak Flow
Pondok Tanjung	62.07	62.80	0.73	1.18
Bt 14	15.75	16.00	0.25	1.59

6.1.1 *Model Validation*

The calibrated model parameters were validated by using hourly interval event rainfall starts from 20 October 1999 until 30 October 1999. The validation results are shown in Figure 6 and Figure 7 for the discharge station at Pondok Tanjung station (id no. 5007421) and Batu 14, Batu Kurau station (id no. 4907422) respectively. A larger level of uncertainty was noticeable in the calibration and validation of these results. However the calibrated flow fitted well with the observed flow and the flow similarly follows the observed pattern. Validation results obtained for the R40 at Pondok Tanjung are not as good as the calibration and it may cause by the daily rainfall data distribution to hourly using Bt 14 rain gauge. Another reason might be the use of the SCS unit hydrograph method in basins where some of its assumptions, mainly basin size are not fulfilled (Kafle et al., 2008). These discrepancies can be seen from the result during validation at R40 and JR130 where there are many differences between the simulated flow and the observed. Hope in the future, more automatic rainfall stations will be installed with hourly increment data, so that the model will produce better result. Table 2 shows comparison of peak and predicted flows for result validation.

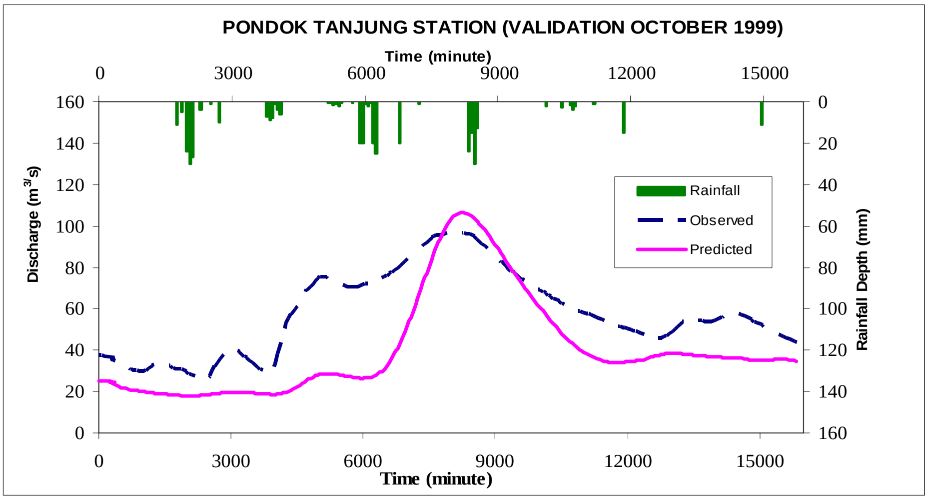

Figure 6 Runoff hydrograph for R40 at Pondok Tanjung discharge station (Validation)

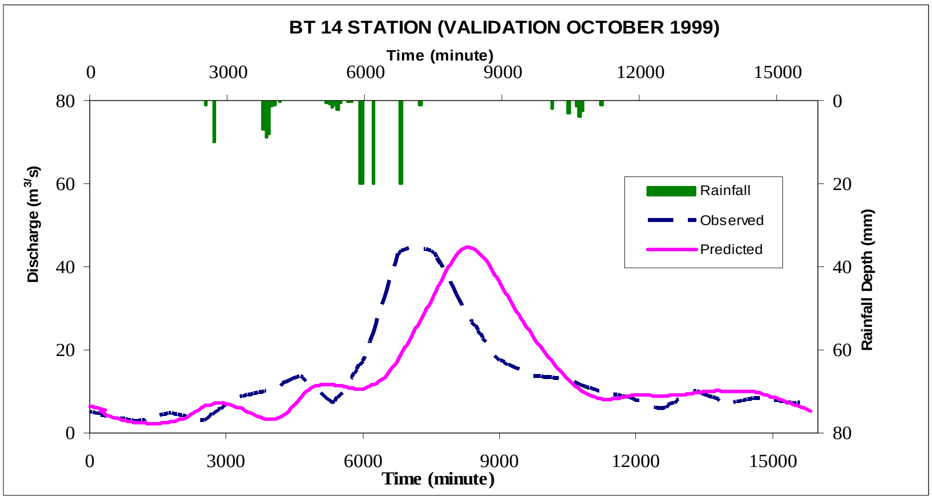

Figure 7 Runoff Hydrograph for JR130 at Batu 14 discharge station (Validation)

Table 2 Comparison of peak and predicted flows for result validation

Station	Observed Peak Flow (m^3/s)	HEC-HMS Peak Flow (m^3/s)	Difference Peak Flow (m^3/s)	Percentage difference (%) Peak Flow
Pondok Tanjung	96.73	106.50	9.78	10.11
Bt 14	44.76	44.70	0.06	0.13

6.2 WAT2005

The calibration tool incorporated in AVSWAT-X allows the user to perform global changes on input parameters that are commonly modified during the calibration process. Calibration and validation process carried out after the AVSWAT-X project model of study basin was successfully developed.
Model calibration and validation are indispensable for simulation, which are used to assess model prediction results. Calibration was performed by comparing the simulated and observed surface runoff. After achieving a reasonable runoff data, the same parameters were used for calibration of the sediment yield and further for validation (Neitsch et al., 2002).

Upon completion of SWAT modeling and simulation, the outputs from SWAT are contained in 3 outputs files namely HRU output files, the Reach (.rch) output files and the Sub-basin (.bsb) output file. The Reach output file and the Sub-basin Output File contain information of predicted result such as stream flow and sediment load at each outlet. These data can be used to analyze the stream flow and water quality such as suspended sediment in the study area.

6.2 1 Low and Suspended Sediment Calibration

Calibration of SWAT was performed using October to December 2004 flow and suspended sediments data on daily conditions basis. In order to calibrate flow, several surface and subsurface runoff parameters are adjusted to replicate daily observe flow data, meanwhile for suspended sediment calibration, parameter for suspended sediment response need to be adjusted to be fit with the observed suspended sediments data. The simulated or predicted flows were than compared with observed data as shown in Figure 8 and 9.

Detailed analyses of the simulated and observed values were performed in order to confirm the significance and correlation of the results among daily simulated and observed data. The accuracy of the watershed model is determined based on the coefficient of determination (R^2) value. The R^2 value measures how well the simulated versus observed regression line approaches an ideal match and ranges from 0 to 1, with a value of 0 indicating no correlation and a value of 1 representing that the predicted dispersion equals the measured dispersion (Krause et al., 2005).

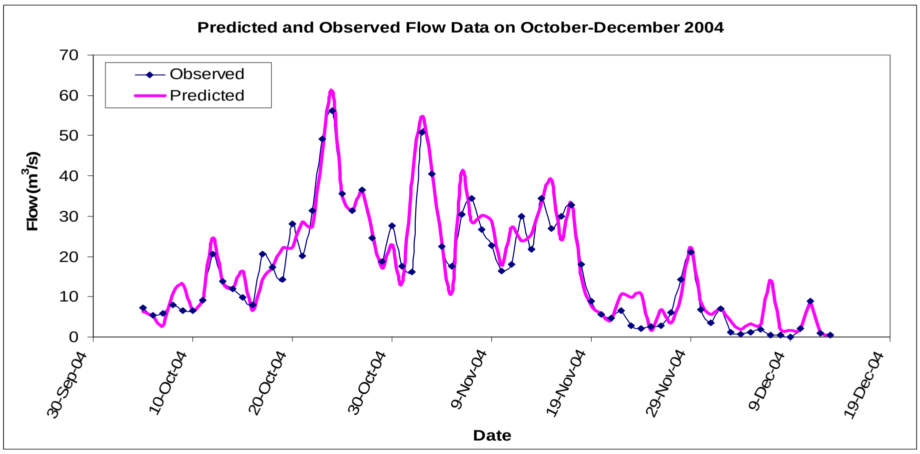

Figure 8 Predicted and observed flow data on October to December 2004

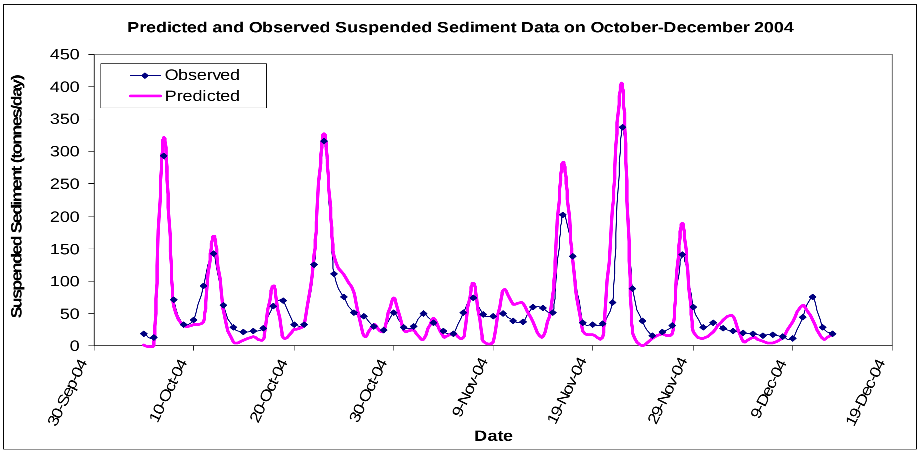

Figure 9 Predicted and observed suspended sediment data on October to December 2004

6.2 2 Flow and Suspended Sediments Validation

The period of model validation are selected on October 1993 and October-December 1991 with daily conditions. The applicability of calibrated project model in order to predict future flow and suspended sediment in the study area is evaluate or determine via validation process. Results of the validation are acceptable and applicable based on the Figure 10 until Figure 13 respectively. Observed, predicted daily flows and suspended sediments are close to each other in terms of magnitude and timing. Table 3 shows comparisons of peak for predicted flow and suspended sediment in validation result.

Flow on the validation October 1993 and October to December 1991 were considerably fit with the observed data as shown in Figure 10 and 12, Prediction of flow versus observed data in R^2 value are considered moderately strong with value R^2=0.694 and R^2= 0.554. Suspended sediment on October to December 1991 were also considerably fit with the observed data as shown in Figure 11 and 13 even there is a slight difference value between observed and predicted. Prediction of suspended sediment versus observed data in Pearson correlation are considered acceptable with value R^2=0.643 and R^2=0.650. Higher suspended sediment by observation data set is believed due to the combination of suspended sediments come from point sources due to the human activities such as sand mining, construction and non-point source.

Table 3 Comparisons of peak for predicted flow and suspended sediment in validation result

Period of Validation	Data	Observed	SWAT	Difference	Percentage difference (%)
October 1993	Flow (m^3/s)	91.3925	84.7600	6.6325	7.3
	Suspended Sediment (tonnes/day)	762.2000	984.3000	222.1000	29.1
October-December 1991	Flow (m^3/s)	97.9577	90.87000	7.0877	7.2
	Suspended Sediment (tonnes/day)	529.000	607.1000	78.1000	14.8

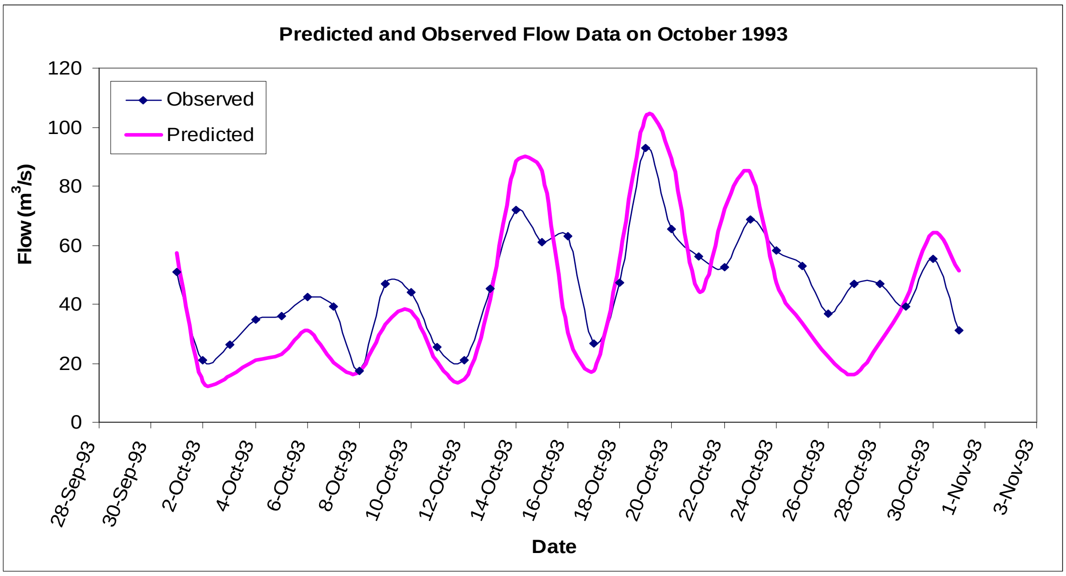

Figure 10 Predicted and observed flow data on October 1993

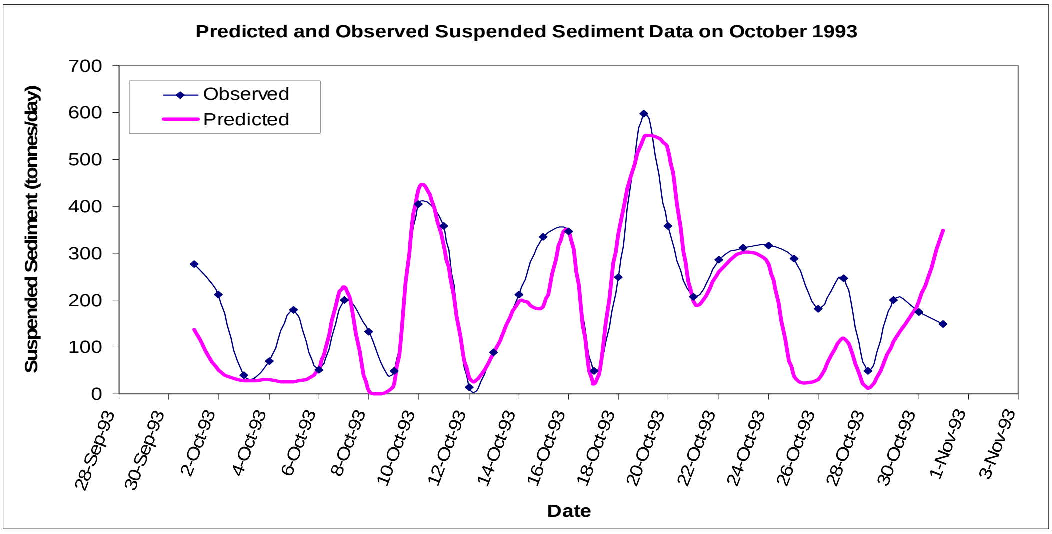

Figure 11 Predicted and observed suspended sediment data on October 1993

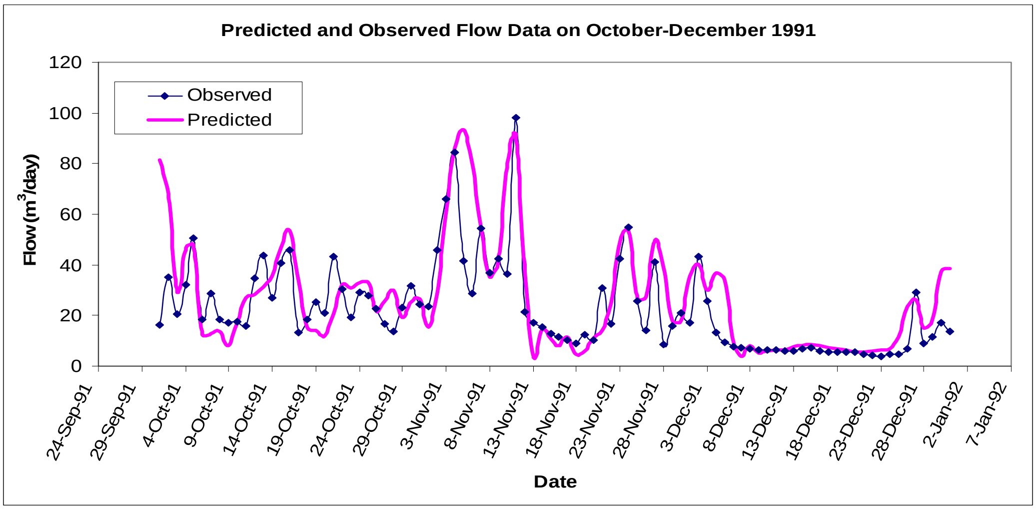

Figure 12 Predicted and observed flow data on October to December 1991

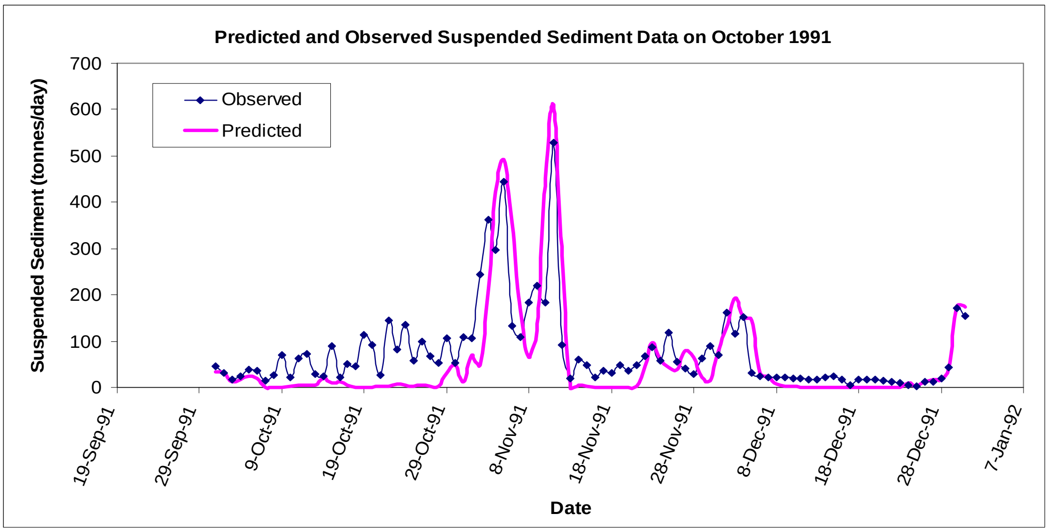

Figure 13 Predicted and observed suspended sediment data on October to December 1999

7 Conclusion

Result of the studies indicates that GIS and other modeling software are effective environment for river basin analysis and its integration with hydraulic model and will play a valuable role trying to make decision making process more practical. GIS also can be utilize from a small scale modelling up to as large as a river basin scale. This study also hope can assist the river basin manager and relevant agencies the ability to make predictions and evaluate management options for future river basin studies especially at localized area, planning and implementing IRBM in Malaysia.

References

1. Abidin, R.Z. (2004). *IWRM Implementation Realities in Malaysia*, Director General, Economic Planning Unit, Prime Minister's Department, Malaysia.Keynote address presented on 9 June 2004 at the Malaysian Water Forum, 8-10 June 2004, held in conjunction with the First Malaysian Water Week, 6-14 June 2004, Kuala Lumpur, Malaysia.
2. Abdullah, (2000), *Towards realising Integrated River Basin Management in Malaysia*, Proceedings: National Conference of Sustainable River Basin Management in Malaysia, 13 -14 November 2000, Kuala Lumpur.
3. Chen-Fa, Verburg and Peter H, (2007). *Impacts of land use change scenarios on hydrology and land use patterns in the Wu-Tu watershed in Northern Taiwan.*
4. Di Luzio M, R. Srinivasan, J.G. Arnold, S.L. Neitsch, (2002) *in User Guide for ArcView Interface for SWAT2000*, Grassland, Soil And Water Research Laboratory – Agricultural Research Service, and Blackland Research Center – Texas Agricultural Experiment Station.
5. Dinor, J (2009), *The Effect of Deforestation on Catchment Response in the Tropical Climate Region: Case Study for Sungai Padas Catchment*. Master Thesis, River Engineering and Urban Drainage Centre, USM Engineering, Penang.
6. Jha, M., P.W. Gassman, S. Secchi, R. Gu, and J. Arnold. (2004). "*Hydrologic Simulations of the Maquoketa River Watershed with SWAT.*" In AWRA'S 2003 Spring Specialty Conference.
7. Proceedings. Edited by D. Kolpin and J.D. Williams. Middleburg, VA: American Water Resources Association.
8. Krause, P., Boyle D. P., and Base F.. (2005). *Comparison of different efficiency criteria for hydrological model assessment. Adv. Geosci*. 5: 89-97.
9. Lin, Yu-Pin (Department of Bioenvironmental Systems Engineering, National Taiwan University, No.1 Sec.), Hong, Nien-Ming, Wu, Pei-Jung, Wu, Chen-Fa, Verburg and Peter H, (2007). *Impacts of land use change scenarios on hydrology and land use patterns in the Wu-Tu watershed in Northern Taiwan.*
10. McCuen, H. R. (1989), *Hydrologic Analysis and Design (2nd Edition).* Prentice Hall Inc.
11. Neitsch S.L, J.G. Arnold, J.R. Kiniry, J.R. Williams. (2005*), Soil and Water Assessment Tool Theoretical Documentation*, Grassland Soil and Water Research Laboratory – Agricultural Research Service, and Blackland Research Center – Texas Agricultural Experiment Station.
12. Othman, F, Shaaban M. G, Akib, S, (2000), *Integrated River Basin Management- Concept and Practice.*
13. Ramadasan K, M.N.A. Salam, S. Kumaran and B. Perumal (2000) *Integrated River Basin Management: Conservation and Ecological Strategies*, Proceeding Paper for National Conference on Sustainable River Basin Management in Malaysia, Kuala Lumpur on 13 & 14 Nov 2000 Organised by DID, MANCID and MWP.
14. Ruggles, R., Brandes, D., and Kney, A.D. (2001). *Development of a Geographical Information System for Watershed Research, Information and Education. Bridging the Gap: Meeting the World's Water and Environmental Resources Challenges*, Proceedings of World Water and Environmental Resources Congress 2001. Available Online: http://www.ascelibrary.org.
15. USACE-HEC, (2003), "*Geospatial Hydrologic Modeling Extension, HEC-GeoHMS v1.1. User's Manual"*, US Army Corps of Engineers, Hydrologic Engineering Center, December.
16. William A. Scharffenberg and matthew J. Fleming, (2006), *Hydrologic Modeling System HEC-HMS User's Manual*, US Army Corps of Engineers.