International Conference on Water Resources
(ICWR 2009)

"SWAT Application For Hydrologic and Water Quality Modeling For Suspended Sediments: A Case Study of Sungai Langat's Catchment in Selangor"

[1]Khairul Rahmah Ayub , [2]Lai Sai Hin & [3]Hamidi Abd Aziz

[1]Teacher, River Engineering & Urban Drainage Research Centre (REDAC), Engineering Campus, USM, Seri Ampangan, 14300 Nibong Tebal, Seberang Perai, Penang. Phone No. 04-5995466, Fax: 04-5941056, (corresponding author)
e-mail:redac03@eng.usm.my
[2] Senior Lecturer (PhD), River Engineering & Urban Drainage Research Centre (REDAC), Engineering Campus, USM, Seri Ampangan, 14300 Nibong Tebal, Seberang Perai, Penang. Phone No. 04-5995874, Fax: 04-5941056, e-mail:redaclai@eng.usm.my
[3] Lecturer & Dean (Professor), School of Civil Engineering, Engineering Campus, USM, Seri Ampangan, 14300 Nibong Tebal, Seberang Perai, Penang. Phone No. 04-5941008, Fax: 04-5941009, e-mail:cehamidi@eng.usm.my

Abstract

High annual rainfall in Malaysia does not solve water scarcity problems especially in urban area particularly in Sg. Langat Basin. It's due to the increases of socio-economic activities in the surrounding area and consequently, Sungai Langat water quality especially in the downstream area become deteriorate. An integrative computational methodology is developed for the management of nonpoint source pollution from catchments. The associated decision support system is based on an interface such as GIS and a comprehensive catchments simulation model such as AVSWAT-X which is formerly known as SWAT. For Sungai Langat Catchment's study, the project model was developed using AVSWAT-X to predict daily stream flow and suspended sediments (SS) in the study area. Historical data for years 1997, 2001 and 2003 is used for comparison with simulated results from the model. The results reviewed that the calibrated model is able to simulate the flow and SS for the river basin successfully.

Keywords: AVSWAT-X, Stream flow, Suspended Sediment, Modeling, Non-point source

1. Introduction

In Malaysia, there are 150 river systems with 100 of them in the Peninsular Malaysia and 50 in Sabah and Sarawak. These river systems consist of 1800 rivers with a total length of 38,000 km (Abdullah, 2007). Rapid development in Malaysia may change the natural hydrology and infiltration characteristics of the catchment areas due to the increases of impermeable area.

Urbanization and deforestation are contributing to the river pollution via the erosion and the sedimentation occurred due to the unmanaged activities. Stormwater runoff from the area for example, will flashes out all the sediments and eroded soil to the downstream area and sedimentation will be occurred in rivers. Thus, rivers become milky and shallow and it will affect rivers' capacity in order to cater more water flows from the upstream and in the worst condition, it can cause water scarceness, flash flood and other environmental problems.

Santhi *et al* (2006) discovered that nonpoint source pollution in catchment area is a serious concern. Major sources of the nonpoint source pollution are sediment erosion and nutrients. Conducting field experiments or collection of long term data is very expensive. Furthermore nonpoint sources pollution can be emerged in large catchment with multiple land uses and soil types. This scenario is difficult to associate water quality improvement and management. Thus, the application of a water quality modelling that has been developed becomes useful and crucial. Modeling approach basically can help researchers, engineers, planners and decision makers to manage the impact or effect of particular area due to development process in easier and economic ways. It also helps to predict the future impact of development to the environment particularly river water quality in specific area.

In this decade, GIS expertise has been widely explored and become a powerful tool in the research fields of environment and social sciences. Nowadays, the application of software in modeling more on hydrologic and hydraulic modeling rather than the watershed or catchment modeling involving water quality prediction. In Malaysia, modeling application has limited usage especially in order to compare it with other country. But lately, catchment or watershed modeling involving water quality prediction become decision support tools even it consider new or less implementation in Malaysia. Since Malaysian receiving high annual rainfall in which Peninsular Malaysia = 2420mm, Sabah = 2630mm and Sarawak = 3830mm (DID, 2007) due to the humid tropic climate condition but, at the same time, Malaysia also facing water shortage problems especially in urban area such as Langat Catchment area. Notable, that Sungai Langat becomes a main source of drinking water for the surrounding areas. However deterioration of the Sungai Langat water quality due to the increases of socio-economic, it leads to the mentioned problems. By using AVSWAT-X which uses GIS base interface to predict water quality for effect of suspended sediments on Sungai Langat catchment can be done.

The goals of the study are (1) to establish the hydrologic and suspended sediments database for Sungai Langat (2) to predict the suspended sediments (SS) using AVSWAT-X in order to reduce the adverse affects of non point source contamination to the particular river and (3) to evaluate the effectiveness of a GIS interface physically based hydrologic and water quality model in predicting daily stream flow and suspended sediments from study catchment.

2. Material and Methods

2.1. Study area

Sungai Langat's catchment area occupies the south and south-eastern parts of Selangor and small portion of Negeri Sembilan and Wilayah Persekutuan. The main river, Sungai Langat stretches for 180 kilometres and has a total catchment area of 2350 km^2. Average annual flows and mean annual floods for this catchment is 35 cumecs and 300 cumecs respectively. The catchment is bounded on the east by Main Range (Banjaran Titiwangsa) and Straits of Malacca on the west. The main towns located within the catchment are Cheras, Kajang, Bangi, Dengkil, Banting, Sepang and Nilai. However this study only focused on the upper part of catchment area (127457.8 ha) and length of Sungai Langat involve is about 161 km as depicted in Fig. 1.

According to Idrus et al, (2004), land use types on 2001 in the study area consist of 24.11% forest, 14.94% developed area and 56.21% agricultural.

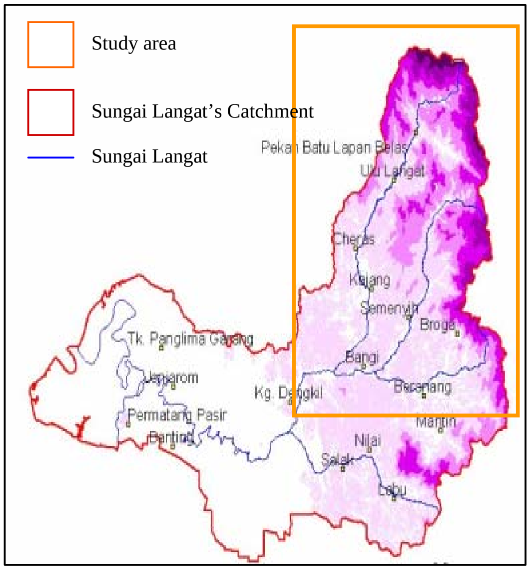

Fig. 1 Sungai Langat Catchment

2.2. Data Sets

Data sets for the year 1997, 2001 and 2003 were used in this study. Data of precipitation, flows, suspended sediments (SS), and etc. were gained from Department of Irrigation and Drainage Malaysia (DID) which is the stations are scattered in upper part of the catchment area. Daily meteorological data for the station at Kuala Lumpur International Airport, Sepang were obtained from Malaysian Meteorological Services Department (MMS). This station located in the Sungai Langat Catchment area. All the data were used as input into the SWAT hydrologic model and in model calibration and validation.

2.3 Overview of AVSWAT-X

AVSWAT-X develops as an extension of ArcView GIS entirely in avenue and is dependent on the spatial analyst and the user extensions. It allows the users to use a complete set of tools for catchments delineation and definition. Users also enable to edit the hydrological and agricultural management inputs in order to perform and calibrate the model. AVSWAT-X is a combine model to simulate hydrology and water quality with a pre-processor, interface and post-processor.

This physical based model allows a number of different physical processes to simulate in a catchment. Catchment will divided or partitioned into a number of sub-catchment purposely for modelling. This sub-catchment will help the user to differentiate the area based on soil type and land use. Hydrology impacts for every sub-catchment also ease to analyse. AVSWAT-X also has several component namely weather, hydrology, erosion/sedimentation, plant growth, nutrient, pesticides, agricultural management, stream routing and pond/reservoir routing.

Water balance is the gist or driving force for AVSWAT-X model no matter what type of study intention. Hydrologic cycle occur in sub catchment must be simulated accurately in order to predict the movement of the sediment or nutrients in the catchment. Thus, the simulation of hydrology consists of two separately major divisions called land phase of the hydrologic cycle and water or routing phase of the hydrologic cycle respectively.

Land phase of hydrologic cycle is responsible to control the amount of water, sediment, nutrient and pesticide loadings in the main channel for each sub-catchment. Whereas water or routing phase is the movement of water, sediment, nutrient and etc through the stream or channel network to the outlet of the catchment. Detail of the model theory can be found in DiLuzio *et al*, 2005 and Neitsch *et al*, 2005.

2.4 Model Calibration and Validation

Since flow in model selected is a gist of an accurate prediction or simulation, it was calibrated first followed by sediment. Based on 1997 land use and weather data, simulated daily flows were compared with observed stream flows. Model calibration were carried by adjusting related parameters, particularly hydraulic conductivity for soil (SOL_K, CH_K1 and CH_K2) to obtained the requied base flow in the river, this is then followed by adjusting the parameter which control the the peak flow and lag time for surface flow. Related parameter adjusted was depicted in Table 1. Once this procedure successful, sediment calibration can be carry out based on the calibrated flow parameters. In this study, flow and sediment were calibrated from June until July 1997. In sediment calibration, 1997 observed data collected by DID were use to compare with simulated daily sediments.

In validation process, different data set which is land use and weather data of 2001 and 2003 was used, but using the same inputs parameters from the calibration process. The simulated results were again compared to observed data using the same criteria as in calibration process to confirm the result is acceptable.

Table 1. Adjusted parameters in calibration process

No	Function	Parameter	Calibrated value
1	Surface Water Response	SOL_K	100.00
2	Subsurface Water Response	GW_DELAY	1
		ALPHA_BF	0.048
3	Basins / Catchment Response	SURLAG	1
		EVLAI	3
		CH_K2	5.5
		CH_K1	0.5

3. Results and discussion

3.1. Digital elevation map

DEM is actually a gridded surface with elevation information. The DEM layer that has been created (Figure 3) from contour provided by Survey and Mapping Department of Malaysia extracted from topography map. This layer was used by the interface to delineate subbasins within the study area and estimates surfacial parameters such as area, slope, and length of flow path for each HRU. The DEM map was created with a resolution of 30 x 30 meters.

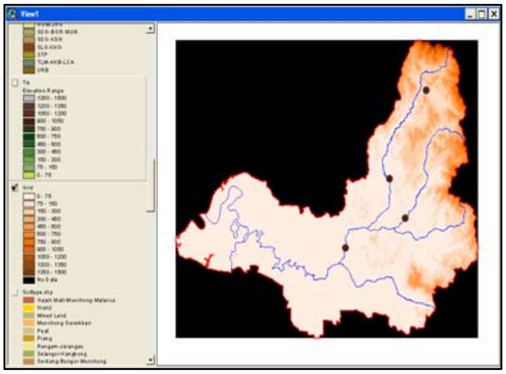

Fig. 3 Digital elevation model (DEM) for Sg Langat Catchment

3.2 Landuse

The land use gridded map derived for the study area have 7 broad classes of land cover. A sample of the map derived from landuse map (Source:DID) for year 1997 is shown in Figure 4.

3.3 Soil

Sungai Langat basin is covered by 13 soil groups, in which the hilly area at upstream border is covered by steep land, while rest of it covered by soil types belong to low land area such as Rengam-Jerengau, Selangor-Kangkong, Serdang-Bungor-Munchong, Prang and kranji as shown in Figure 5.

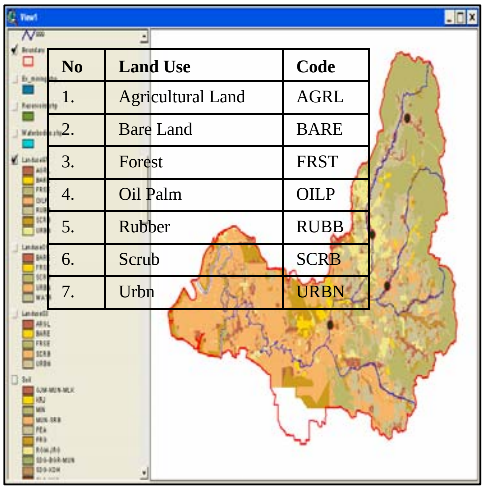

Fig. 4. Land Use Distributions in Sungai Langat Basin

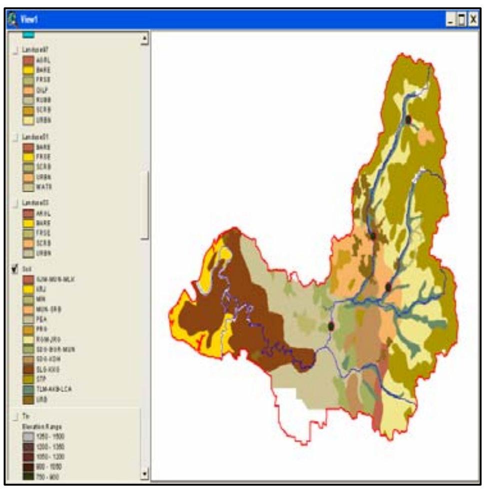

Fig. 5 Soil Types Distribution in Sungai Langat Basin

3.4. Model calibration

Calibration results were generally acceptable. The flow were considerably fit with the observed data as shown in Figure 6 (a) and cumulative flow for predicted and observed data as shown in Figure 6 (b). Prediction of flow versus observed data in Pearson correlation are considered moderately strong with value R=0.6991.

The result for suspended sediment obtained from prediction is also considerably fit with the observed data as shown in Figure 7 (a) and cumulative suspended sediment for predicted and observed data as shown in Figure 7 (b). Prediction of suspended sediment versus observed data in Pearson correlation are considered good with value R=0.6717 respectively.

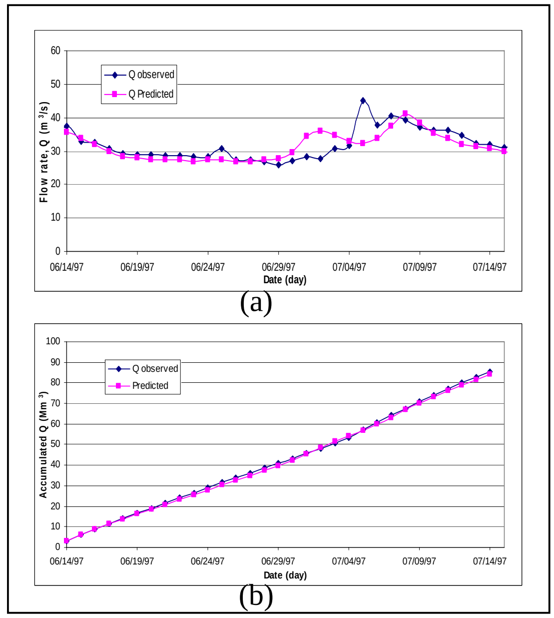

Fig. 6. Calibrated Flow in Sungai Langat: (a) Predicted and Observed Flow (b) Cumulative predicted and observed flow

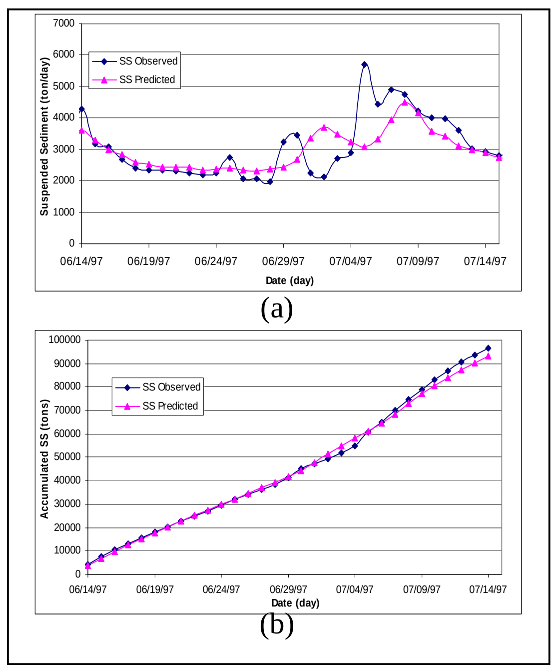

Fig. 7. Sediments calibration: (a) Predicted and Observed sediments (b) Cumulative predicted and observed flow

3.2 Model Validation

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. In this study, the results of validation are consider acceptable and applicable to the study area as shown in Figures 4 to Figure 7, in which the observed and predicted daily flows as well as suspended sediments for both years are close to each other in terms of magnitude. The flows predicted for year 2001 and 2003 were considerably fit with the observed data as shown in Figures 8(a) and 8(b).

Suspended sediment predicted for year 2001 and 2003 were also considerably fit with the observed data as shown in Figures 9(a) and 9(b). It is believed that the wide range occurred for the suspended sediment in the cumulative graph for the both year are due to the different land use in the study area compared with the calibrated land use data set. Notable that Sungai Langat's Catchment facing a rapid growth due to the federal government decision in order to develop Kuala Lumpur International Airport (KLIA), Putrajaya, Multimedia Super Corridor (MSC) and others.

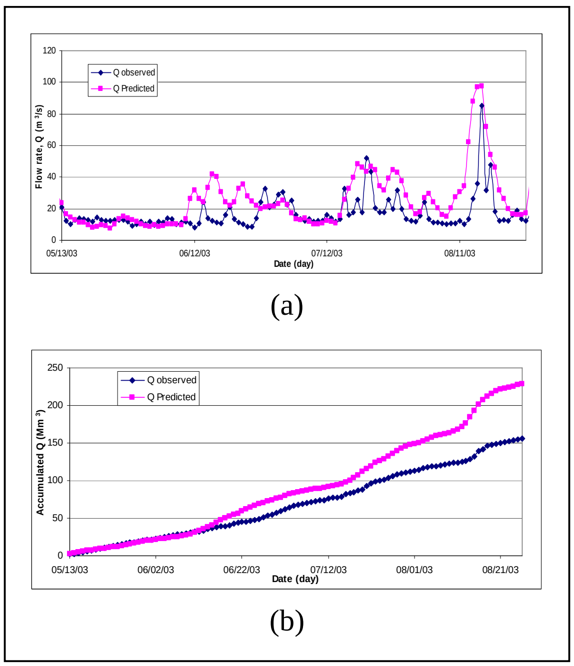

Figure 8. Sample of results for a) Predicted and Observed Flow (b) Cumulative predicted and observed flow for year 2003

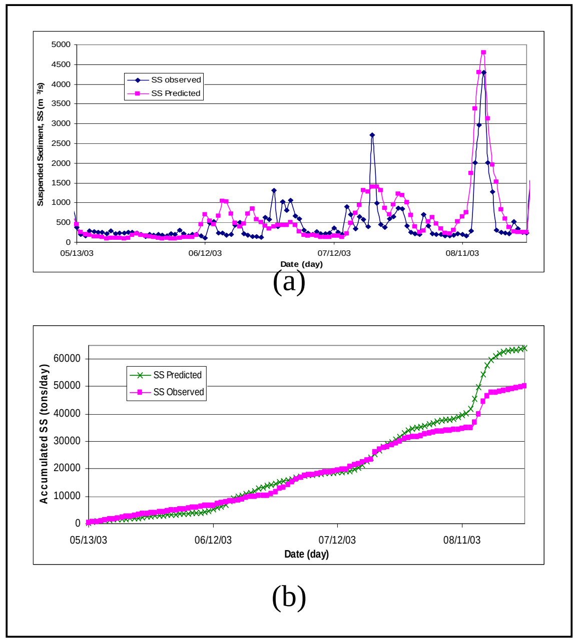

Figure 9. Samples of results for a) Predicted and Observed suspended sediment (b) Cumulative predicted and observed suspended sediment for year 2003

Based on the statistical analysis carried out, the results are considered moderately strong and acceptable as depicted in Table 2 for flow and Table 3 for sediments.

Table 2. Statistical analysis (Pearson correlation, R and Deviation, D)

	FLOW (m^3/sec)		
	Calibration (1997)	Validation (2001)	Simulation (2003)
Pearson Correlation (R)	0.70	0.49	0.63
Average Error, (%)	-1.8 to 29.6	-12.0 to 58.7	-0.37 to 356.7

Table 3. Statistical analysis (Pearson correlation, R and Deviation, D)

	SEDIMENTS (mg/L)		
	Calibration (1997)	Validation (2001)	Simulation (2003)
Pearson Correlation (R)	0.67	0.46	0.82
Average Error, (%)	-11 to 73	-15.76 to 965.78	-66.5 to 519.00

4. Conclusion

In this study, water quality of Sungai Langat's Catchment Area was modeled by using latest version of Soil Water Assessment Tool namely Arc View Soil Water Assessment Tool – X (AVSWAT-X) version 2005. Daily observed data was used to compare with the daily simulation results for flow and suspended sediments.

Based on this study, AVSWAT-X model are found very well established GIS interface physically based model. The model not only use for long term basis prediction but also allow application or simulation in the short period. The capability of the model as water quality modeling in predicting the condition of the suspended sediment in the study area by using different data set also proven. Beside that surface runoff occurred during the rainfall event also contribute to the high suspended sediments loading at the outlet of study area also shows in the prediction results.

From this study, the results obtained in the range of moderate to good results which is R values for calibration and validation period in the range of 0.46 to 0.82 for both parameters (flow and suspended sediments). Beside, the effectiveness of a GIS interface physically based hydrologic and water quality model in predicting daily stream flow and suspended sediments for the study area also proven due to the percent of the average error obtain for flow and suspended sediments in this study in the range of -66.5% to 965.78%. Thus, without any doubt this support that the model is capable to use as one of the water quality management tools due to the effectiveness of the model. By using water quality modeling, future environmental management especially any activities involve water can be easily predict. Thus, environmental sustainable development can be achieved easily.

Acknowledgements

The authors would like to gratefully acknowledge Department of Irrigation and Drainage, Malaysia for grant this study. The authors would also like to express appreciation to the Vice Chancellor of the Universiti Sains Malaysia (USM) for the support in this study.

References

1. Abbaspour, K. C., Yang, J., Maximov, I., Siber, R., Bogner, K., Mieleitner, J., Zobrist, J. & Srinivasan, R. (2006). Modelling Hydrology and Water Quality in the Pre-Alpine/Alpine Thur Watershed using SWAT. *Journal of Hydrology.* Elsevier. pp 413-430.
2. Abdullah, K. (2007). Bring Nature Back to Our Rivers. "*Abstract of* 2nd *International Conference on Managing Rivers in the 21st Century: Solution Towards Sustainable River Basins*". Kuching, Sarawak, Malaysia. 6th June – 8th June , 2007. Penang: River Engineering and Urban Drainage Research Centre (REDAC), USM. ISBN: 978-983-3067-18-3. pp A-4.
3. Benaman, J. A., Shoemaker, C. A. & Haith, D. A. (2005). Calibration and Validation of Soil and Water Assessment Tool on an Agricultural watershed in Upstate New York. *Journal of Hydrologic Engineering.* ASCE. Vol. 10. pp 363-374.
4. Borah, D. K., Arnold J. G., Bera, M., Krug, E. C. & Liang, X. Z. (2007). Storm Event and Continuous Hydrologic Modeling for Comprehensive and Efficient Watershed Simulations. *Journal of Hydrologic Engineering.* ASCE. Vol. 12. pp 605-616
5. Department of Irrigation and Drainage. (2007) Kompendium Data dan Maklumat Asas Jabatan Pengairan dan Saliran Malaysia, 2007. (unpublished)
6. DiLuzio, M., Mitchell, G. & Sammons, N. (2005). AVSWAT-X Short Tutorial. Watershed Modeling Using SWAT 2003. *3rd Conference on Watershed management to Meet Water Quality Standards and Emerging TMDL (Total Maximum Daily Load).* Atlanta, Georgia. 5th March – 9th March, 2005. (unpublished)
7. Muleta, M. K. & Nicklow, J. W. (2005). Decision Support for Watershed Management Using Evolutionary Algorithms. *Journal of Water resources Planning and Management.* ASCE. Vol. 131. pp 35-44
8. Neitsch, S.L., Arnold, J.G., Kiniry, J.R. & Williams, J.R. (2005). Soil and Water Assessment Tool Theoretical Documentation Version 2005. Texas Water Resources Institue. Texas.
9. Santhi, C., Srinivasan, R., Arnold, J. G. & Williams, J. R. (2006). A Modelling Approach To Evaluate the Impacts of Water Quality Management Plans Implemented in a Watershed in Texas. *Environmental Modelling and Software.* Vol. 21. pp 1141-1157.
10. Vazquez-Amabile, G. G. & Engel, B. A. (2008). Fitting of Time series Models to Forecast Streamflow and Groundwater Using Simulated Data from SWAT. *Journal of Hydrologic Engineering.* Vol. 13. pp 554-562.