Application of BASINS for Water Quality Assessment on the Mill Creek Watershed in Louisiana

Kansheng Wu, Y. Jun Xu, W.E. Kelso, D.A. Rutherford

Abstract

GIS applications are needed to understand hydrologic processes connected with water quality assessments on a watershed scale. In this study, we applied BASINS 3.0, Better Assessment Science Integrating Point and Nonpoint Sources developed by the U.S. EPA, to a lowland terrace watershed in southern Louisiana, in order to (1) segment the watershed and streams to select monitoring locations for a new research project on forest best management practice (BMP) effectiveness, (2) create a GIS framework in a form conducive to spatial analysis on a sub-watershed scale using a customized dataset, and (3) calibrate the Soil and Water Assessment Tool (SWAT) model to obtain reliable parameter ranges. Using the data sources and GIS extensions integrated in BASINS 3.0, DEM data, and the historical USGS peak flow data, we delineated sub-watersheds, identified stream segments and sub-watershed characteristics such as areas, vegetation, soil type, and other hydrologic parameters, and simulated stream discharge for a small sub-watershed. The simulated stream flow from the SWAT model, combined with user defined precipitation and air temperature data, were compared with observed peak flow data to calibrate localized hydrologic parameters that will be used in our study site. The study shows that the BASINS 3.0 system offers efficient modules for the watershed delineation, source data integration, and hydrologic modeling. Information from BASINS and SWAT can be an effective tool for researchers and water resource managers to predict potential impacts of land management practices on water quality and other hydrologic process.

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Keywords: watershed delineation, hydrologic modeling, BASINS, SWAT, Louisiana

Introduction

Water quality has been one of the major environmental issues across the country for over 30 years (Adams et al. 2000). Although efforts to control point source pollution since the 1970s have been moderately successful, with considerable expenditures of funds and effort from federal, state, and local agencies, controlling non-point source pollution (NPS) remains a challenging task. Best Management Practices (BMPs) have been introduced to prevent NPS from agricultural and forestry activities. Coincident with state and federal legislative efforts and the nation-wide implementation of BMPs, the importance of understanding the effects of land management practices on water quality has received increased attention in watershed management during the past decade (Brooks et al. 2003).

Effective watershed management requires a detailed understanding of hydrologic and biogeochemical processes within the watershed. The relationships among land use practices, agricultural activities and water quality parameters are both spatially and temporally complex. Mathematical models and geospatial analysis tools are often employed to investigate these relationships and identify management options.

BASINS 3.0, Better Assessment Science Integrating Point and Nonpoint Sources developed by the U.S. EPA, has been reported to be a powerful tool for spatial analysis at the watershed scale. The system is embedded within a geographic information system (GIS) that integrates a variety of spatial data, including land use, soil, vegetation, climate, and elevation that are calculated with Digital Elevation Models, and a set of modeling tools, such as the Soil and Water Assessment Tool (SWAT) developed by USDA

Agricultural Research Service (Arnold et al. 1998). SWAT has been used to predict various impacts of land management on water quantity (e.g., Srinivasan and Amold 1994, Muttiah and Wurbs 2002), sediment yield and nutrient loss (e.g., Luzio et al. 2002), and pesticide fate and transport (e.g., Brown and Hollis 1996) in a wide range of watershed scales from a few dozen hectares to thousands of square kilometers. In SWAT, spatial heterogeneity in soil and land use cover in a watershed are represented by hydrological response units (HRUs), which are based on groupings of physical and hydraulic parameters. The model estimates relevant hydrologic components including evaportranspiration, surface runoff, return flow, and ground water recharge at the delineated sub-watershed.

In this study, we applied BASINS 3.0 and SWAT to quantify the stream discharge in a small Louisiana watershed from 1968 to 1980. The project watershed was chosen because of the availability of USGS data and its proximity to the location of the BMP effectiveness study. The objectives of this research are to: (1) create a GIS framework in a form conducive to spatial analysis of the proposed BMP study watershed, (2) examine applicability of BASINS and SWAT for the Louisiana's lowland terrace watersheds, and (3) calibrate the SWAT model to obtain reliable parameter ranges for our study area. This paper presents the preliminary results of this GIS and modeling study.

Methods

Site description

The study site, located in the Mill Creek watershed, Allen Parish, central Louisiana, is characterized by a humid subtropical climate, with an annual average air temperature of 20.7 ºC and annual precipitation 1558 mm. The watershed measures about 25 km long and 8.5 km wide (Figure 1), and represents a typical landscape of lowland terrace in the Gulf region. The 209.3 km^2 watershed (LDEQ, 2000) is composed primarily of commercial forest (94%) and agricultural (4%) lands. The average elevation of the northern part of the watershed is about 40-45 m, and the average elevation at the southern boundary is about 5-10 m. The dominant soils are Guyton silt loam (40.3% of total watershed) and Guyton-Messer complex (35.8%). Guyton series soils are characterized by a silt loam surface layer and a grayish loamy subsoil (USDA-SCS 1980) and poor soil drainage. The watershed was identified as impaired by LDEQ due to low dissolved oxygen concentrations.

The sub-watershed used for the hydrologic simulation in this study measured 4.7 km^2. It encompassed a first-order stream located about 8 km southeast from the proposed Mill Creek BMP study site (Figure 1). The site was similar in geomorphology, soils, and land use activities, and was the closest location that provided streamflow measurements.

Data sources

Spatial data sources used in this research include DEM, soil, land use, reach file, climate, and USGS stream flow data (gage station 08013350). Five USGS 24K DEM quads (3009202, 3009210, 3009211, 3009218, and 3009219) were used to create a single coverage for the entire study area. Soil data were obtained from the State Soil Geographic Database (STATSGO) (http://www.ftw.nrcs.usda.gov/stat_data.html). Land use cover data were obtained from USGS Land Use and Land Cover (LULC) Database (http://edc.usgs.gov/products/landcover/lulc.html), that was based primarily on manual interpretation of 1970s and 1980s aerial photography.

Climate data, including daily precipitation and daily maximum and minimum air temperature were obtained from the Southern Regional Climate Center. Precipitation data were obtained from four nearby weather stations, while air temperature data were gathered from two stations (Figure 1). Daily wind speed, humidity, and solar radiation data used for the hydrologic modeling were provided by SWAT.

Peak flow data from 1968 to 1980 from the USGS gauge station 08013350 were used to evaluate the hydrologic model. Unfortunately, no daily streamflow data was available at this station, and SWAT did not provide peak flow estimates. Despite the discrepancy between the USGS peak flow and the SWAT-simulated daily average flow, it is acceptable to compare these two datasets to obtain general ranges of SWAT model parameters, which will be used as initial values for our future BMP effectiveness study site.

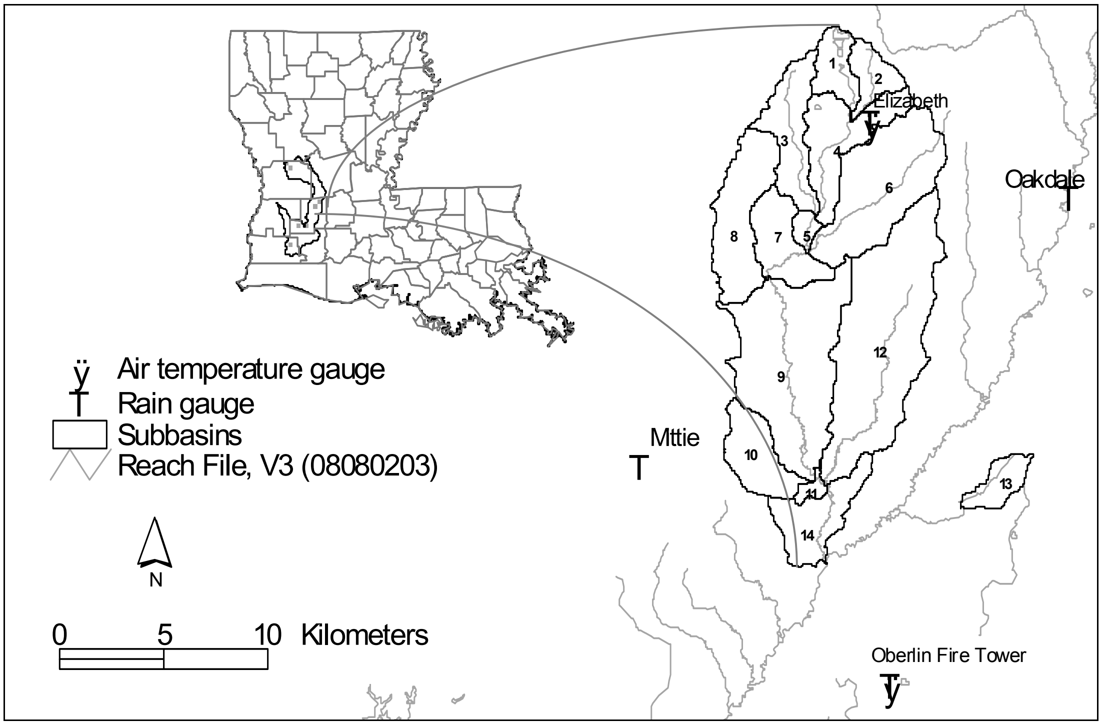

Figure 1. Delineated sub-watersheds and weather station locations

Data analysis

The Universal Transverse Mercator (UTM) projection was used for all spatial coverages in this study. Sub-watersheds were delineated with the Automatical Procedure provided by BASINS 3.0, which was used to delineate the BMP study watershed and the USGS 08013350 gauge station watershed with 24K DEM data.

The SCS Curve Number (CN) method was chosen for hydrologic simulation. A default CN2 of 35-95 was defined for the initial simulation. To calibrate CN2 the following four scenarios were used: Scenario 0: default from SWAT, 35-98; Scenario 1: 60-73; Scenario 2, an increase of 10% based on scenario 1; and Scenario 3: a decrease 10% based on scenario 1. The simulated discharge was compared with the USGS peak flow data. Regression coefficients and root mean square errors from a linear regression model were used to evaluate the modeling results. All statistical analyses were done with the SAS statistical software package (SAS 1999).

Results and Discussion

Watershed delineation and characteristics

BASINS' Automated Delineation tool delineated 14 sub-watersheds in the Mill Creek watershed (Figure 1, Table 1) with a total area of 200.4 km^2, which was about 9 km^2 larger than that (209.3 km^2) reported by the Louisiana Department of Environmental Quality (LDEQ 2000). The small watershed that was used for SWAT hydrologic modeling was also delineated with the BASINS' Automated Delineation tool. The delineated area was 4.9 km^2, which was slightly larger than the USGS-defined drainage area (4.7 km^2). The difference in the delineated areas in both cases was small (4.25% and 5.4%, respectively), suggesting that BASINS is a reliable tool for digital watershed delineation.

BASINS' automated watershed delineation provided not only sub-watershed boundaries and area, but also basic information on watershed characteristics, such as slope, stream reach length, area percentages of land use and soil types, and hydrologic response unit (HRUs). However, the size and topographic relief of a watershed appeared to affect accuracy of delineation.

Table 1. Relevant characteristics of delineated sub-watersheds in the Mill Creek watershed.

Su	Ar	Str	Sub(%)	El (m)	Lum	Apm(%)	Som*	Ars(%)	Hrus
1	6.1	5144.9	1.31	45	FRSE	30.6	LA112	79.5	12
2	5.3	4859.7	0.65	43	FRSE	60.8	LA123	74.7	6
3	12.3	9881.6	1.22	45	FRSE	85.8	LA112	57.8	8
4	14.1	9747.4	0.82	34	FRSE	85.8	LA123	65.4	7
5	1.9	2863.7	0.46	30	FEST	78.4	LA186	63.3	4
6	26.6	13747.1	0.32	34	FEST	79.8	LA186	88.8	5
7	10.5	5374.7	0.51	31	FRSE	76.5	LA123	84.1	4
8	16.7	9818.8	1.14	35	FRSE	92.3	LA112	69.3	5
9	38.8	14560.3	0.65	26	FRSE	76.6	LA123	53.2	9
10	10.2	6719.9	0.55	27	FRSE	89.1	LA123	90.4	4
11	1.4	2376.6	1.11	20	FRSE	67.8	LA114	70.8	3
12	45.3	18222.1	0.42	30	FRSE	50.3	LA186	76.2	8
13	4.9	4798.9	0.32	27	FEST	85.9	LA123	72.5	3
14	11.2	7517.4	1.02	20	FRSE	54.4	LA123	57.6	8

Notes:
Su: Sub-watershed — Ar: Areas in km^2
Str: Stream reach (m) — Sub: Sub-watershed slope (%)
El: Elevation (m) — Lum: Land use of maximum area in sub-watershed
Apm: Area percentage of maximum land use
Som*: Soil type of maximum areas in sub-watershed, see the STATSGO for detailed soil type
Ars: Area percentage of maximum soil type (%) — Hrus: Hydrologic response units
FRSE: Evergreen Forest Land — FRST: Mixed Forest Land

When a watershed is small and flat, the USGS reach file may not be appropriate for automatic delineation due to a possible large difference between DEM and reach data.

Simulation and calibration

Four scenarios with varying CN2 values were simulated. Compared to the other three scenarios, Scenario 2 with 60-73 achieved the highest R^2 (0.71) and smallest root MSE (55.5). Table 2 summarizes parameters used in the Scenario 2 simulation. A comparison of the simulated daily average streamflow with the measured peak flow showed a similar temporal pattern over the period from 1968 to 1980 (Figure 2).

For localized and site-specific application, calibrating SWAT input parameters and performance of global changes with observed data are necessary (Luzio et al. 2002). Although SWAT has 27 input parameters that can be user-adjusted, the sensitivity of each parameter is different for a specific output. When water balance components are considered, adjustment of runoff curve numbers and revap coefficients would give good correspondence (Srinivasan et al. 1998). Manoj et al. (2003) reported that curve number (CN), evaporation compensation factor (ESCO), groundwater delay time (DELAY), plant uptake factor (EPCO), revap coefficient (REVAP), and soils available water capacity (AWC) were most sensitive to stream flow. In our study, both the R^2 and root MSE changed dramatically when CN was changed from its default range of 35-98 to a more preferable range 60-73. However, an increase or decrease outside this CN range did not result in substantial changes in the model.

Table 2. Parameterization in the hydrologic modeling with SWAT.

Parameters *	Symbol	Ranges
Curve number	CN2	60-73
Groundwater revap coefficient	REVAP	0.02-0.2
Evaporation compensation factor	ESCO	0-1
Plant uptake factor	EPCO	0.01-1
Groundwater delay time(day)	DELAY	0-500

* Refer to SWAT user manual (Neitsch et al 2002).

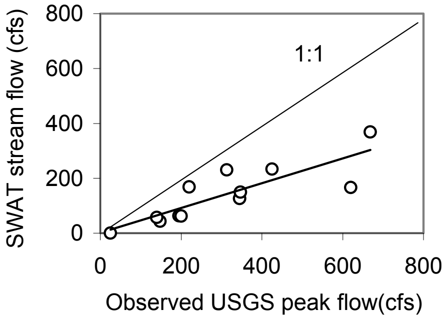

Figure 2. Comparison between simulated daily average stream flow and USGS-observed peak flow during 1968 to 1980.

Use of the SWAT model in this study required the assumption that land use and land cover did not change during the simulation period. Because land use in rural Louisiana has not changed substantially in the last few decades, this assumption is probably valid for the modeled watersheds in rural Louisiana; land use and land cover data were collected around 1978-1980. However, integration of dynamic land use data into the SWAT model could provide more reliable information, especially in those watersheds undergoing significant changes in land management practices.

Simulated hydrologic components

The simulated water balance components for 08013350 watershed (number 13 in Table 1 and Figure 1), such as precipitation, actual evapotranspiration (ET), and discharge are shown in Figure 3. Actual ET showed a clear seasonal fluctuation with the highest value (147.5 mm) in July and the lowest in December (14.9 mm), while precipitation was relatively evenly distributed over the year with a monthly range between 102 and 180 mm. Similar to actual ET, discharge showed a distinctive temporal trend, with the highest value in May (107.8 mm) and the lowest value in August (18.8 mm). Based on precipitation and temperature data from nearby weather stations, annual average precipitation for the study period in this watershed was 1676 mm, slightly higher than the longer-term average. Annual actual ET and annual discharge were estimated to be 868 mm and 784 mm, respectively. The 24 mm difference between the input (precipitation) and output (evapotranspirtion + discharge) may indicate a small groundwater recharge in the area.

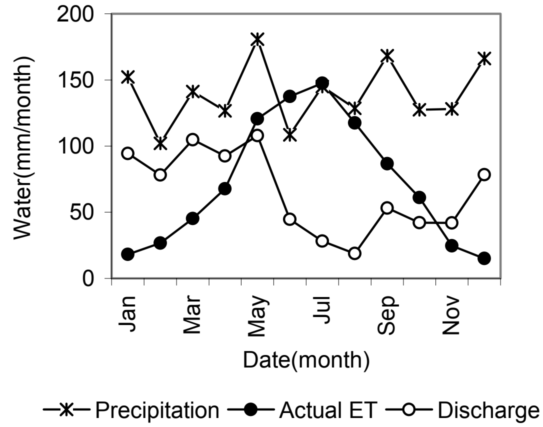

Figure 3. Seasonal trend of simulated hydrologic components.

Srinivasan et al. (1998) reported that the SWAT model may overestimate monthly streamflow during spring and summer when high spatial variability of precipitation is present, or underestimate streamflow when extreme precipitation events occur (Rosenthal et al 1995). In this study, we found a significant seasonal pattern of monthly streamflow (Figure 3) that decreased with increasing actual ET. The monthly discharge dropped rapidly in June and remained low throughout November, mainly due to the higher forest transpiration rates. The monthly average actual ET and discharge were both high in May (120.7 mm, 107.8 mm) and both low in November (24.5 mm, 41.8 mm), indicating that removal of the forests would have the greatest impacts on site hydrology during this period of time.

Summary

A GIS framework for our future BMP effectiveness study has been created with BASINS 3.0. This framework integrates all critical datasets for spatial analyses of the relationships among soil, land use, and hydrology. BASINS with the embedded hydrologic model SWAT has proven to be an effective tool for watershed delineation in the studied lowland terrace of Louisiana. In addition to watershed delineation, it provides basic information on watershed characteristics, such as area, slope, stream reach length, land use and soil types, and the corresponding percentages. However, the size and relief of a watershed appeared to affect accuracy of delineation, and cautions should be exercised when delineating a watershed that is small and with a very flat topography. The SWAT model and the calibration of CN2 have provided reasonable estimates of the hydrologic components for the studied watershed, the initial parameterization of which will be useful for the future application in our prospective BMP effectiveness assessment.

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