# MODELING SYSTEMS FOR SEDIMENT MANAGEMENT AND BMP EVALUATION IN LARGE GREAT LAKES TRIBUTARY WATERSHEDS

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**Abstract:** The identification of water and sediment sources, pathways and sinks is vital to sustainable management of watersheds worldwide. Numerical modeling approaches have been implemented to evaluate water and sediment movement in several large watersheds tributary to Lake Michigan. Numerical models of watershed hydrology and sediment delivery are valuable tools to assist in the planning of Best Management Practices (BMPs) for watershed sediment issues. The models aid in developing a general understanding of the hydrologic and geomorphic behavior of watershed systems, and they allow evaluation and prediction of the effects of changing land use and BMPs such as riparian buffer zone modification.

The semi-lumped parameter Soil and Water Assessment Tool (SWAT; USDA-ARS) has been applied on several Great Lakes watersheds to assess historic land use change at the watershed scale. SWAT is particularly suited to simulations on large watersheds over long periods of time. The two-dimensional, finite-difference, Gridded Surface-Subsurface Hydrologic Analysis model (GSSHA; USACE-CHL) was used to evaluate hydrologic and sediment transport processes in detail on subwatersheds nested within the domains of the SWAT model. Because of their detail, the GSSHA model simulations were limited to smaller areas and shorter time simulations. GSSHA allowed for detailed appraisal of modification to buffer strip morphology (such as different vegetation types and strip widths) on different land uses and crop types. A key feature of these studies was the synthesis of the different modeling activities into a single methodology that may be used for watershed management initiatives.

## INTRODUCTION

Section 516(e) of the Water Resources Development Act (WRDA) of 1996 authorizes the US Army Corps of Engineers to develop sediment transport models for Great Lakes tributary watersheds contributing sediment to Federal Navigation Channels and Areas of Concern. These models and modeling systems are intended for use by local watershed managers to evaluate strategies to reduce sediment loading to the river systems, thus decreasing sediment transported to navigation areas and lessening the Corps' dredging requirements.

There are several challenging aspects of the 516(e) program. The tributary watersheds that are the greatest sediment producers are also some of the largest in the Great Lakes. To address sediment issues affecting the navigation areas, the whole watershed must be modeled, but model end-users (i.e. local watershed managers, county drain commissioners, watershed groups, etc.) are often concerned with issues on a smaller scale (i.e. locating and evaluating BMPs). Therefore, there is a large range of scale and resolution that must be addressed by these modeling systems. In addition, local entities that will use the models often have little or no modeling expertise and lack the resources to run complicated models or to buy proprietary software. These factors must be considered during model selection. While the funding authority allows for model development, it does not allow for major data collection programs, which directly affects model calibration and validation.

With these issues in mind, a sediment transport modeling system was developed for the Clinton River Watershed in Michigan. The SWAT and GSSHA models were selected as complementary models to address the issues for which they are most appropriate: SWAT for watershed-wide land use and land management issues and GSSHA for small-scale BMP evaluation.

## CLINTON RIVER WATERSHED

The Clinton River Watershed is located just north of Detroit in southeastern Michigan. The main channel travels 80 miles (128 km) from its western headwaters to Lake St. Clair near the city of Mt. Clemens. The watershed covers 760 square miles (1,968 km$^2$) of southeastern Michigan, including portions of Oakland and Macomb Counties and small areas of St. Clair and Lapeer Counties (Figure 1). The watershed is home to more than 1.6 million people in 56 municipalities. The southern portion of the watershed is dominantly urban, the middle section is undergoing rapid suburban development and the northern region is primarily agricultural and forested. The condition of the river system varies dramatically, from runoff and pollution problems in urban areas, to healthier waters with thriving trout fisheries in rural areas. A modeling system that can address both the watershed-wide issues of land use change and land management and the localized issues of specific BMP placement is required.

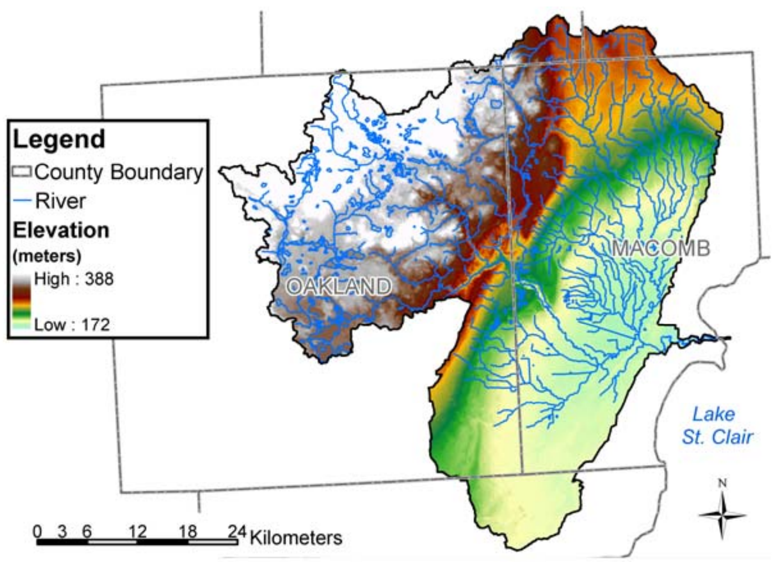


Figure 1 Clinton River Watershed topography map.

## MODEL SYSTEM

"Simple models are sometimes incapable of giving desirable detailed results, and detailed models are inefficient and could be prohibitive for large watersheds. Therefore, finding an appropriate model for an application and for a certain watershed is quite a challenging task" (Borah and Bera, 2003).

The model selection phase was a very important part of this project. Issues that require consideration include data availability, specific questions to be addressed, watershed characteristics and end-user capabilities. All of these factors are combined, resulting in the selection of the optimal modeling tools. For the Clinton River Watershed, one of the most important considerations was the ultimate use of the modeling system – for both watershed-wide issues and detailed BMPs by local watershed managers. The SWAT and GSSHA models were chosen as a result of the selection process.

The Soil and Water Assessment Tool (SWAT) is a quasi-physically based, semi-empirical, watershed-scale numerical model for the simulation of water, sediment, nutrient and pesticide movement in surface and subsurface systems. SWAT aids in prediction of the impacts of climate and vegetation changes, reservoir management, groundwater withdrawals, water transfer, land use change and watershed management practices on water, sediment and nutrient dynamics in complex watershed systems. Land use and management conditions can be varied over long time periods, making the model a particularly useful tool to aid in the implementation of watershed-scale BMPs. SWAT is a continuous-time model, intended for the prediction of long-term water and sediment yields from a watershed. While SWAT is most appropriate for agricultural watersheds, it does have the capability to model urban areas, making it well suited to model the entire Clinton River Watershed.

SWAT is a semi-lumped parameter model that discretizes an area into Hydrologic Response Units (HRUs), based on land use, soil and management areas. Because of this lumping, SWAT cannot be used to target detailed, site-specific BMPs. The lumping of the watershed into HRUs and using a daily time step allows the SWAT model to simulate long time periods for large watersheds very quickly. This is important for evaluating the long-term impacts of land use and land management scenarios in a watershed.

SWAT is non-proprietary and is freely available to the public via the SWAT website (http://www.brc.tamus.edu/swat/). This is an important characteristic of the modeling system, due to the limited funding available to local watershed managers for modeling software. The AVSWAT extension interface is also free but requires ArcView GIS software. While ArcView is not free, local watershed management entities often have GIS software for other purposes and thus do not have to purchase it specifically for watershed modeling.

The GIS data layers necessary to create SWAT input files are a DEM, land use and soils coverages. The DEM was obtained from the National Elevation Dataset and was preprocessed using ArcHydro Tools, a non-proprietary package. Land use was taken from the 1992 National Land Cover Dataset (NLCD); each NLCD land use category was assigned a SWAT land cover/plant type. SWAT also requires climate data for the simulation period. For the Clinton

River Watershed SWAT model, daily rainfall data were obtained from Michigan's SEMCOG stations, and daily maximum and minimum temperature data were obtained from the Selfridge Air National Guard Base in Mt. Clemens.

Preliminary calibration of model hydrologic performance was undertaken using USGS streamflow measurements at USGS Gage # 04165500, the same location as the SWAT model outlet. A baseflow filter (Arnold and Allen, 1999) was used on the USGS streamflow data to determine the average annual ratio of baseflow to surface runoff for comparison to SWAT simulated baseflow. The Clinton River SWAT model was roughly calibrated to annual water yield and baseflow values and further calibrated to monthly water yields and daily values for particular events (Figure 2).

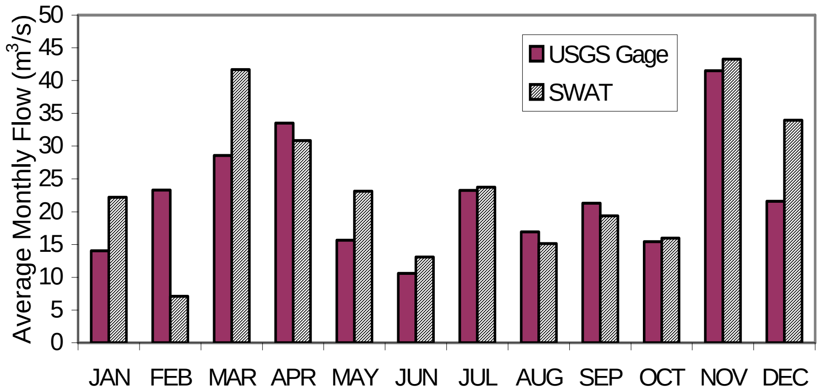


Figure 2 1992 measured and predicted discharge at model outlet.

The largest discrepancies between observed and predicted flows occurred in the winter and spring months. The Clinton River SWAT model does not replicate snowmelt events accurately; to improve these results, more detailed local temperature and precipitation data are required and modification to the frozen soil infiltration routines in SWAT may be necessary. Due to the lack of measured sediment transport data, the sediment component of SWAT was not calibrated. While this limits the model use for quantitative sediment loading estimates, the model can still be used in a relativistic manner, such as determining percent reduction in sediment yield or delivery between scenarios.

The SWAT model hydrology was also calibrated using the 1978 land use data and climate data from 1976 to 1980. With the calibrated model, climate data from 1990 to 1994 was run through the model with 1978 land use to determine the relative difference the change in land use from 1978 to 1992 had on sediment delivery. The 1978 and 1992 land use data sets had different resolutions, so the relative changes in specific land use types are approximate. There was little change from 1978 to 1992 in the percentage of urban/developed areas, the portion of the watershed used for agriculture increased by 10 %, and the percentages of forest and rangeland areas decreased (Figure 3).

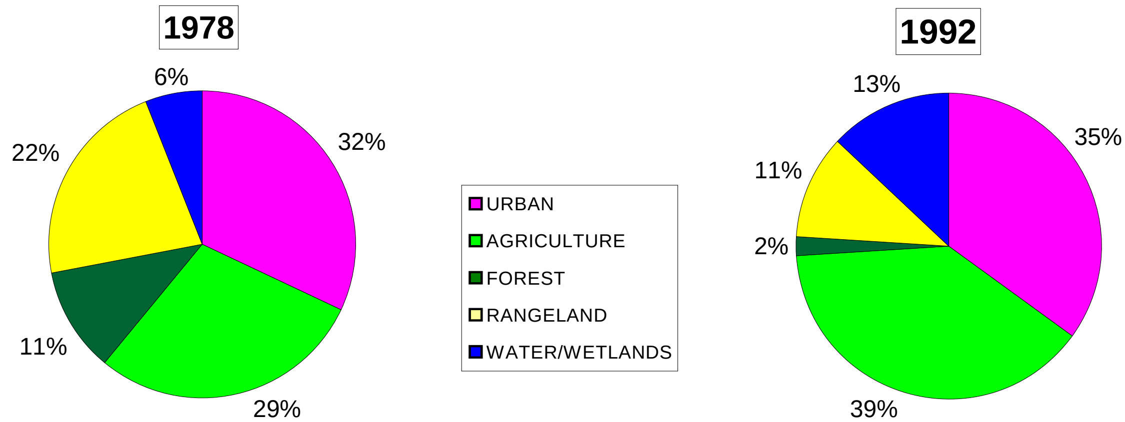


Figure 3 1978 and 1992 land use breakdown for the Clinton River Watershed.

Results for the average annual net soil erosion per unit area ($t/km^2.yr^{-1}$) for the 1978 and 1992 land use scenarios are shown in Figure 4. The annual values increased, on average, by 32%, resulting from only a 10% increase in agricultural land area. Scenario exercises such as this demonstrate how the SWAT model can be used to quickly evaluate the impact of land use change on watershed soil erosion.

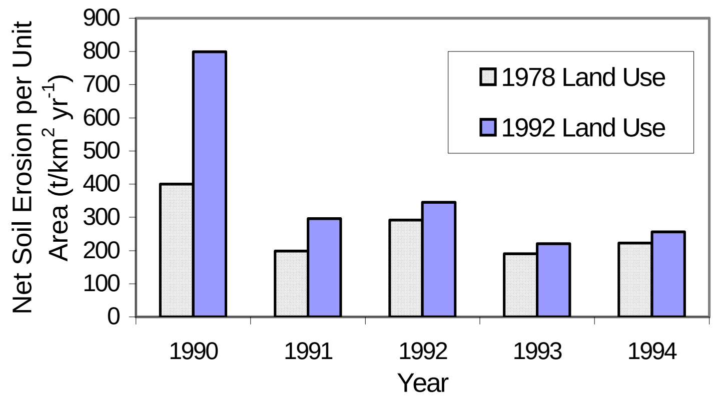


Figure 4 SWAT soil erosion results comparing different land use datasets.

SWAT can be used to model the entire Clinton River Watershed over long time periods, but it is not designed to simulate small-scale BMPs that were of interest to local watershed managers, so the GSSHA model was used to construct a detailed representation of small-scale BMPs. GSSHA (Gridded Surface Subsurface Hydrologic Analysis) is a physically based, distributed-parameter model that simulates the hydrologic response of small watersheds. Features include 2-D overland flow, 1-D streamflow, 1-D infiltration, 2-D groundwater, and full coupling between the groundwater, vadose zone, streams, and overland flow. The fully coupled groundwater to surface water interaction allows GSSHA to model both Hortonian (infiltration-excess) and Non-Hortonian (saturation-excess) areas. The model employs mass-conserving solutions of partial differential equations and closely links the hydrologic compartments to ensure an overall mass balance and correct feedback. GSSHA is a reformulation and enhancement of CASC2D (Ogden and Julien, 2002) and is supported by the US Army Corps of Engineers Engineer Research and Development Center (ERDC).

GSSHA is a fully distributed model so there is no requirement to lump areas according to their hydrologic characteristics. The watershed is divided into cells and water and sediment are routed from cell to cell according to topography. This feature makes GSSHA appropriate for simulating detailed BMPs on a subwatershed and smaller scale, providing the input data resolutions are appropriate to the processes being modeled. GSSHA can run in both single event and long-term modes but long-term simulations are often computationally impractical. For example, when using the full Richard's Equations in GSSHA, the time step needs to be less than one minute if the grid mesh size is less than 30 meters (Kalin and Hantush, 2003). The modeling for the Clinton River Watershed was therefore run for single events only.

Three HUC14 subbasins in the Clinton River Watershed were modeled with GSSHA. Choice of these basins was based on discharge data availability and identification of significant sources of watershed sediment according to anecdotal information. No sediment data were available for any of the subbasins, thus the sediment loads predicted by the model could not be considered as absolute values.

The Paint Creek subwatershed was one of the three areas modeled with GSSHA. Paint Creek covers an area of approximately 96 $km^2$ (37 $mi^2$), where approximately 23% is urban/developed, 32% agricultural, 33% forested and 11% wetlands, and the soil varies from loamy sand to sandy loam. The model was calibrated against flow discharge from USGS Gage #04161540 at Rochester, which has a temporal coverage from 1954 to present. Flow data from 1996 were utilized for the basin calibration (Figure 5).

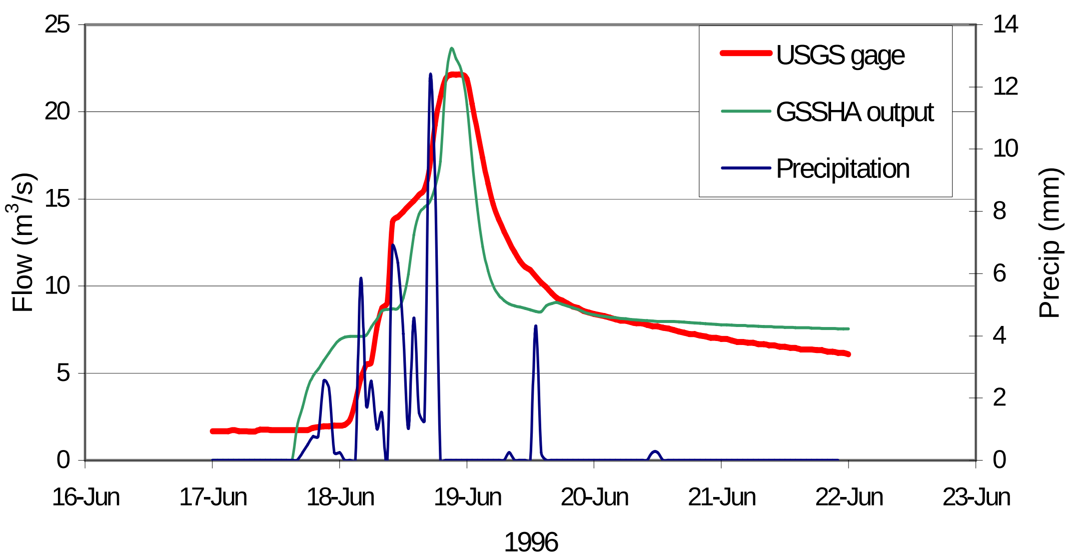


Figure 5 GSSHA flow calibration results.

The calibrated GSSHA model was used to simulate the hydrologic response of riparian buffer strips of varying width and vegetation type on a small area within Paint Creek. Buffer strips are areas of permanent vegetation that help control delivery of sediment and other pollutants to streams by reducing overland flow, velocity and discharge, causing sediment to drop out of suspension. This type of BMP could not be simulated with SWAT because it requires grid-to-grid routing at a fine spatial resolution (a 5 m grid size was used in GSSHA). While the detailed physical processes simulated in GSSHA make it ideal for evaluating small-scale BMPs, the model is not specifically designed to facilitate BMP analysis and there are no built-in BMPs in GSSHA. In order to represent riparian buffers in GSSHA, land use and management characteristics in riparian grid cells were adjusted to represent buffer characteristics.

Three buffer widths were simulated (10, 20 and 30 m) along with five vegetation types and four land uses adjacent to the buffer strip. The objective of this exercise was to evaluate the potential of GSSHA for simulating buffer strips and to provide a buffer analysis tool and methodology that can be applied in different areas and circumstances within the Paint Creek watershed. The percentage reduction values were determined from scenarios without buffers for each land use type (Table 1).

Table 1 GSSHA percentage reduction in erosion results for riparian buffer scenarios.

| **Buffer Land Use** | Buffer Width | Percent Reduction in Sediment | | | |
|---|---|---|---|---|---|
| | | **Land Use Adjacent to Buffer Strip** | | | |
| | | Bare ground | Row Crops | Small Grain | Residential |
| Short Grass | 10 m | 15.3 % | 3.9 % | 9.8 % | 29.4 % |
| | 20 m | 26.9 % | 6.6 % | 16.4 % | 36.2 % |
| | 30 m | 33.9 % | 8.0 % | 22.0 % | 40.2 % |
| Long Grass | 10 m | 15.4 % | 3.6 % | 9.4 % | 14.6 % |
| | 20 m | 26.4 % | 5.7 % | 13.0 % | 17.1 % |
| | 30 m | 33.0 % | 6.3 % | 16.5 % | 21.9 % |
| Forest | 10 m | 15.3 % | 3.7 % | 9.5 % | 14.8 % |
| | 20 m | 26.4 % | 5.7 % | 13.2 % | 17.6 % |
| | 30 m | 33.1 % | 6.5 % | 17.0 % | 22.6 % |
| Bermuda Grass | 10 m | 15.7 % | 3.6 % | 9.7 % | 30.3 % |
| | 20 m | 26.9 % | 6.4 % | 16.1 % | 35.3 % |
| | 30 m | 33.6 % | 7.2 % | 21.3 % | 39.0 % |
| Brush | 10 m | 15.3 % | 4.0 % | 9.8 % | 27.5 % |
| | 20 m | 26.8 % | 6.5 % | 15.6 % | 31.5 % |
| | 30 m | 33.8 % | 7.7 % | 20.5 % | 34.1 % |

## CONCLUSIONS

The US Army Corps of Engineers has been authorized to develop sediment transport modeling systems for Great Lakes tributary watersheds to be delivered to local watershed managers to better manage sediment on the land, thus reducing Corps dredging costs in Federal Navigation Channels and Areas of Concern. The challenges posed by funding stipulations (multiple scales of application; complex processes yet the need for ease of use of the end product) were met by using multiple models. The models were set up and calibrated using readily available data, which did not include watershed sediment load data. While this limited model application for absolute quantitative assessments of watershed sediment loadings, the models were still useful to determine the relative effects of different BMPs on sediment yield and delivery.

The SWAT and GSSHA models together can address many challenges faced by watershed managers. Each model is applied at the appropriate scale to investigate both watershed issues and small-scale BMPs for sediment management. The models are non-proprietary and available to the public, though additional software is required for graphical pre- and post-processing. A user manual and custom ArcView extension facilitated use of these models by watershed managers. Table 2 summarizes the types of modeling activities most appropriate for the GSSHA and SWAT models.

Table 2 SWAT and GSSHA appropriate modeling scenarios.

| **SWAT** | **GSSHA** |
|---|---|
| Long period simulations; climate change | Detailed (event) modeling |
| Large watersheds | Detailed erosion/sedimentation |
| Basin-wide management practices | Subbasin & small-scale BMP evaluation |

In general, SWAT is more suited for long-term, large-scale modeling, while GSSHA is better for short-term, small-scale simulations. SWAT is useful in determining impacts of past and future land use/land management decisions in a watershed, and GSSHA is valuable in determining impacts of detailed small-scale BMPs such as buffer strips and rain gardens. SWAT has the ability to simulate both point and non-point sources of pollution as well as nutrient transport. Together SWAT and GSSHA cover the range of time and space scales required for watershed management.

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