IMPACT OF PRECIPITATION UNCERTAINTY ON SWAT MODEL PERFORMANCE

Milo Anderson, Environmental Engineer, USEPA-Region 5; Chicago, IL 60604; Phone: 312-886-6096 E-mail: Anderson.Milo@epa.gov
Yongping Yuan, Research Hydrologist, USEPA-Office of Research and Development; Las Vegas, NV 89119; phone: 702-798-2112; E-mail: yuan.yongping@epa.gov.
Ronald L. Bingner, Agricultural Engineer, USDA-Agriculture Research Services; Oxford, MS 38655; phone: 662-232-2966; E-mail: ron.bingner@ars.usda.gov

Abstract: The accuracy of a model output is, to a large degree, dependent upon the quality of the input data sets including their spatial and temporal resolution. Among those input data sets, precipitation is one of the most important because of its influence on the hydrological model's performance (defined as agreement between measured and simulated values) and its role in determining surface hydrologic processes. Rainfall data are often obtained from rain gage networks, which sometimes may not cover the study area. Usually, precipitation data from the nearest gage stations are used to represent the study area for model hydrological simulations. However, occasionally unusual meteorological conditions can make it necessary to consider precipitation data from gages as far away from the study watershed as the next county. The watershed south of the lake was within 10 miles of two National Oceanic and Atmospheric Administration National Climatic Data Center (NOAA NCDC) precipitation gauges on the north side of the lake, but for year 2010 the SWAT simulated flows using either of these gages as precipitation input data lacked correlation to flows observed at a United States Geology Survey (USGS) gauge on Chickasaw Creek. Due to 2010 being an unusually wet year, an assumption was that additional NOAA NCDC gauges were needed to capture the precipitation events occurred in the watershed; a particular storm occurred in the watershed may be affected by high variability of storm directional paths and variable amounts of rain/snow. By considering additional precipitation gauges within 35 miles of the watershed boundary, model performance as measured by R-squared correlation improved significantly. The nearby precipitation gauges essentially showed no correlation at a coefficient as low as 0.03 for year 2010, but using a combination of the additional gauges to capture the majority of precipitation events raised the coefficient to 0.60 for the same year.

Keywords: Precipitation; Grand Lake St. Marys Watershed; SWAT model; Runoff simulation

INTRODUCTION

The process of transformation of rainfall into runoff over a watershed is very complex, highly non-linear, and exhibits both temporal and spatial variability. Many models have been developed to simulate this process and Soil and Water Assessment Tool (SWAT) is one of these. No matter how complicated a model in simulating this process, the accurate representation of precipitation over the watershed is critical in obtaining the accurate runoff simulation and its transported pollutants.

Rainfall is commonly measured using a rain gauge, which is simply an instrument that is designed to measure the amount of rain that reaches the ground surface during a storm. Rain gauges are considered the most traditional method for measuring rainfall. They have been used historically to provide rainfall quantities and rates at a single point in space. As any measurements, errors can be induced during the measurement processes. One of the common and serious sources of errors in rain gauge measurements is wind-induced error. Another

common problem with rainfall gauge measurements is missing records. This is due to the high probability of gauge mechanical and electrical failures and is also caused by erroneous recording and publishing of rainfall measurements. As a result of measurement error and missing records, researchers and engineers often have to work with incomplete rainfall data from stations where rainfall records might be missing for a day or several days or rainfall data with measurement errors. This will limit most types of rainfall analyses such as calculation of water budgets, determining maximum rainfall intensities, and estimation of area-average rainfall intensities/rainfall amounts.

While rain gauges provide rainfall measurements at individual points, it is more of interest for hydrologic modelling to know rainfall amounts over an area, such as a small drainage basin or a watershed. Usually, the point measurements located in the watershed are assigned to the entire watershed if there is only one rainfall gauge available. The rainfall measurements from the closest rainfall gauge would be assigned to the watershed if there is no rain gauge available in the watershed. If there are more than one rain gauges available in the modelling area, techniques have been proposed to estimate area-average rainfall over an area from point measurements. The most commonly used approaches are based on weighted averaging of rainfall measurements from individual gauges that are located within or close to the area of interest. The Thiessen Polygon method is the most commonly-used method for estimating area-average from point measurements. The weight of a certain station is estimated based on its relative sub-area within the total area of interest. Are rainfall amounts over an area estimated from point measurements representative of the actual amount that happened over that area? How does one get an accurate rainfall estimate over an area based on point measurements (number of point measurements and distance of the point measurement to the interested area)? The overall objective of this study is to explore if common ways of area rainfall estimation provide representative rainfall values for a watershed through comparing SWAT model runoff simulations with field runoff observations.

METHODS AND PROCEDURES

Study Area and Its Background Information: Grand Lake St. Marys is located in Mercer and Auglaize County, northwestern Ohio (Figure 1) and is a very large size lake for its relatively small contributing watershed. The surface area of the lake comprises 17.5 percent of the overall watershed, and much of the remaining watershed is under agricultural production. There are multiple tributaries to the lake within the watershed, with the three largest tributaries making up 63% of lake's upstream drainage. Corn and soybeans are major crops. Other crops include alfalfa (8.5% of the watershed), and winter wheat/ Kentucky bluegrass (6.4% of the watershed) and hay (6.3% of the watershed). Due to the small acreage of farm land available in the watershed, many farmers own animal feeding operations to make a living and sustain local economy.

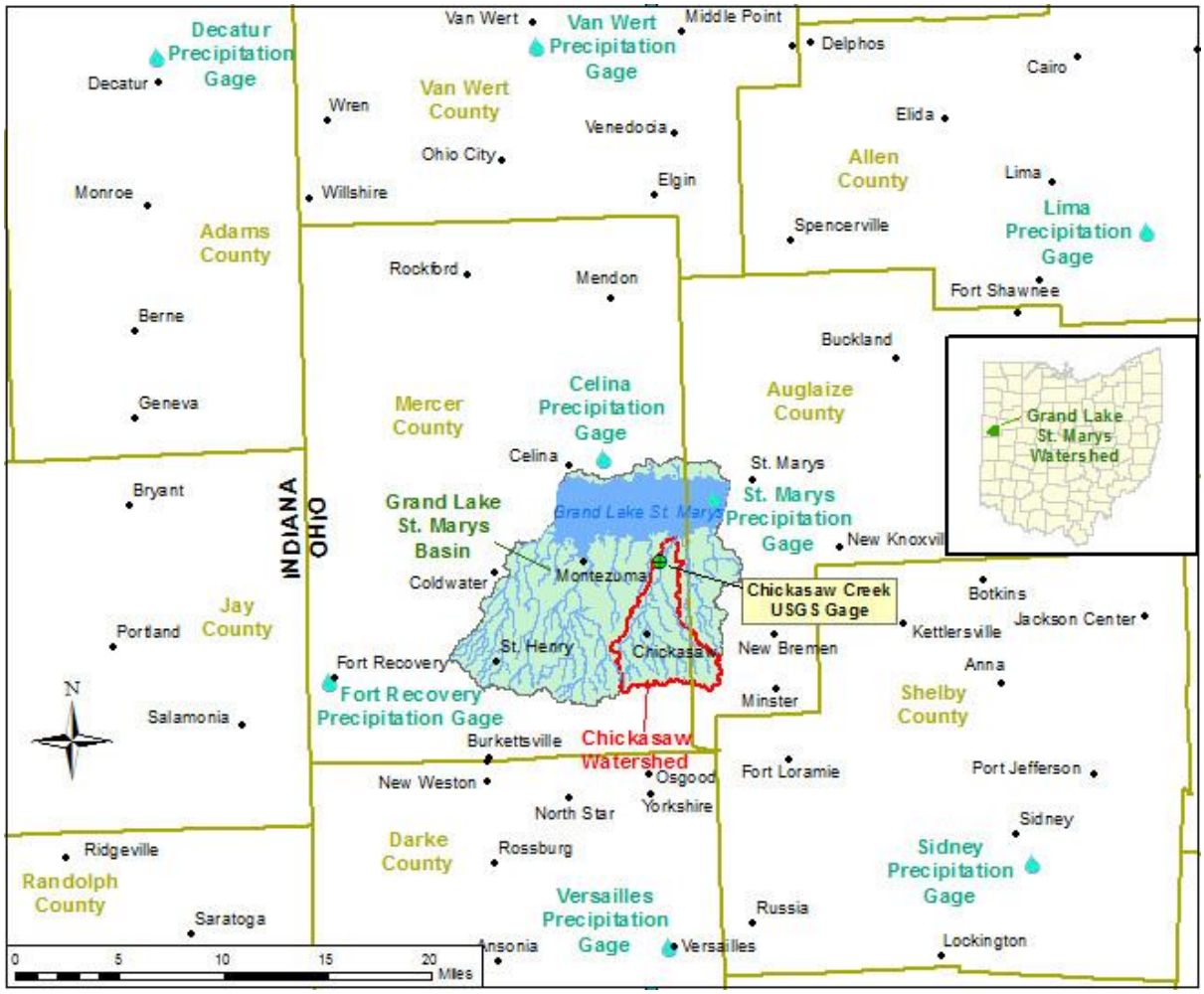

Figure 1 Locations of rural and municipal areas, USGS monitoring gages, and weather stations in the Grand Lake St. Marys Watershed, Mercer and Auglaize County, OH, USA

Grand Lake St. Marys (GLSM) is experiencing toxic levels of algal blooms resulting from phosphorus input from agricultural runoff. Since the outbreak of harmful algae bloom in the summer of 2010, the Ohio Environmental Protection Agency (OEPA) solicited potential short-term remedies from vendors and other interested parties. Thirty-four potential remedies were submitted in response to this solicitation. The submitted potential remedies were reviewed, evaluated and discussed by a technical committee comprised of six environmental scientists. In the absence of other information and from a strictly scientific basis, no single remedy (or proposed combination of remedies) was identified as leading to a probable effective solution. Notably, none of the proposed remedies has been tested on a scale as large as GLSM and therefore the effectiveness of those remedies when applied to GLSM cannot be predicted. The conclusion from this review is that none of the 34 remedies have a better chance for success than the application of alum alone. However, the committee did not believe that the use of alum alone, or any single management practice by itself, could improve the water quality of GLSM except perhaps only over the short term. The most important message from this committee is that the overriding need to improve the lake water quality is to improve the management of the GLSM watershed as a system. Any proposed remedies, however effective they might be in the short term, would be diminished or be completely negated by the continued input of phosphorus, other nutrients and sediment via tributaries. The goal of management of the GLSM watershed as system is implementing

management actions designed to improve the wellness and resiliency of the overall watershed. There is some urgency for the OEPA and EPA Region 5 to seek strategies on both short and long term solutions so as to improve the management of GLSM and its surrounding watershed with respect to sustainability and resilience. One of the questions concerning the longer term restoration of water quality for Grand Lake St Marys is if conservation practices can be adopted to limit nutrient loadings to the lake. The SWAT model is designed to simulate long-term impacts of land use and management on water, sediment and agricultural chemical yields at various temporal and spatial scales in a watershed (Arnold et al., 1998; Arnold and Fohrer, 2005; Gassman et al., 2007). It was chosen to evaluate the impact of conservation practices on nutrient loadings to the lake for this project. Before a model can reasonably simulate nutrient loadings, the runoff has to be reasonably simulated, which would be the first step before a model can be used to simulate nutrient loadings. The first step of the project is to evaluate SWAT runoff simulations.

Since daily flow was monitored at USGS 402913084285400 (Latitude 40°29'13" and Longitude 84°28'54") Chickasaw Creek at St. Marys Ohio (http://waterdata.usgs.gov/usa/nwis/uv?402913084285400). The Chickasaw Creek watershed with a drainage area of 16.4 square miles (42 square kilometers) was chosen as a pilot study.

SWAT Model Description: The Soil and Water Assessment Tool (SWAT) model is a continuous, long-term, physically based semi-distributed model developed to assess impacts of climate and land management on hydrological processes, sediment loading, and pollution transport in watersheds (Arnold et al. 1998). In the SWAT model, a watershed is divided into subwatersheds or subbasins, which are further partitioned into a series of hydrological response units (HRUs). HRUs are uniform units that share unique combinations of soil and land use. Hydrological components, sediment yield, and nutrient cycles are simulated for each HRU and then aggregated for the subbasins.

The hydrological cycle simulated in SWAT is based on the water balance equation:

$$SW_t = SW_0 + \sum_{i-1}^{t} (R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw})$$

where, SW_t and SW_0 are the final and initial soil water content on day i (mm H_2O), t the time steps on day i , R_{day} the rainfall that reaches the soil surface on day i (mm), Q_{surf} the surface runoff on day i (mm), E_a the evapotranspiration on day i (mm), w_{seep} the interflow on day i (mm), and Q_{gw} is the baseflow on day i (mm) (Neitsch et al. 2005).

The simulated hydrological components include evapotranspiration (ET), surface runoff, percolation, lateral flow, groundwater flow (return flow), transmission losses, ponds, and water yield (Arnold et al. 1998). Evaporation and transpiration are simulated separately in SWAT. Evaporation is computed using exponential functions of soil depth and water content and transpiration is estimated using a linear function of potential evapotranspiration (PET) and leaf area index. Three methods can be used to estimate PET: Hargreaves, Priestley-Taylor, and Penman-Monteith. The Pennman-Monteith method was used to calculate PET in this study. Surface runoff is simulated using a modification of the Soil Conservation Service (now the Natural Resources Conservation Service) Curve Number (SCS-CN) method (USDA, 2004) with daily rainfall. Curve number values used for runoff estimation are based on soil type, LULC, and land management conditions and are adjusted according to soil moisture conditions (Arnold et al. 1993). Percolation is estimated using the combination of a

storage routing technique and a crack-flow model (Arnold et al. 1998). The lateral flow is estimated simultaneously with percolation using a kinematic storage model. The groundwater flow (baseflow) into a channel is calculated based on hydraulic conductivity of shallow aquifer, distance from subbasin to main channel, and water table height. Transmission loss, amount of water removed from tributary channels by transmission, is calculated using procedures described in the SCS Hydrology Handbook. The canopy interception is estimated based on the canopy storage which is a function of vegetation type. Water yield, total amount of water leaving the HRU and entering main channel, is equal to surface runoff plus lateral flow and baseflow, and minus transmission loss and pond abstractions (Neitsch et al. 2005).

Model Input Preparation

The basic SWAT model inputs include a digital elevation model (DEM), Cropland Data Layer, and the Soil Survey Geographic Database (SSURGO) data. Other inputs include daily weather data and field management practices including planting, harvesting, fertilization and tillage information. In addition, streamflow data are also needed for model calibration and validation. The different datasets and their sources are given in Table 1.

The source of the Digital Elevation Model (DEM) data used for the SWAT modeling effort on GLSM was downloaded from USDA Data Gateway. The data is part of the National Elevation Dataset (NED), of which USGS is the original data source. The best horizontal resolution available was 3 meter grid cells, or one-ninth arc second, and this resolution of NED was used in SWAT modeling of GLSM tributary watersheds. Elevation data were converted to ArcGrid format, as required for input elevation data into SWAT. More information about NED can be obtained at http://ned.usgs.gov.

Table 1 Summary of Datasets and their sources used for building the model.

Datasets	Source
Elevation	United States Geological Survey (USGS)
Precipitation	National Climatic Data Center (NCDC)
Soil Classification	Soil Survey Geographic Database (SSURGO)
Landuse	Cropland Data Layer (USDA NASS)
Streamflow	United States Geological Survey (USGS)
Water quality	United States Geological Survey (USGS)

The Cropland Data Layer (CDL) originating from the USDA National Agricultural Statistics Service was used as the input land use/land cover dataset for SWAT modeling of GLSM tributary watersheds. Although SWAT can accommodate other land cover datasets such as the National Land Cover Dataset (NLCD), the CDL was used as it is ideally suited for watersheds that are largely agricultural in land use. The CDL includes information on what crops were planted in a given year on a field level, whereas the NLCD treats cropped fields collectively as a generalized single land use type, regardless of crop type. For modeling efforts in GLSM, the 2009 (56-meter pixel resolution), 2010 (30-meter pixel resolution), and 2011 (30-meter pixel resolution) versions of CDL were used. More information about CDL can be obtained at: http://www.nass.usda.gov/research/Cropland/metadata/meta.htm. As shown in Table 2, Chickasaw watershed is dominated by agricultural crop lands, where corn and soybeans are practiced over 50% of the entire watershed. The entire area of the

watershed is 11960 acres (4840 ha.) and the area draining to the USGS gauges is 10625 acres (4300 ha.).

Table 2 Summary of land use in the Chickasaw watershed

Land use	Area (Acres)	% of watershed area
Corn	4702	39.5
Soybean	2898	24.3
Alfalfa	1010	8.5
Winter wheat/ Kentucky bluegrass	758	6.4
Hay	748	6.3
Forest	384	3.2
Pasture	66	0.6
Urban	342	2.9
Water	11	0.1
Other crops*	1041	8.7
Total	11960	100

*other crops include various crop rotations.

The dominant soil associations in the Chickasaw watershed include Blount, covering 42% of the Chickasaw watershed with 4 soil layers; Pewamo, covering 32% of the watershed with 3 soil layers; and Glynwood, covering 20% of the watershed with 3 soil layers. These 3 soil types altogether comprise 93% of the watershed. The remaining 7% of the watershed is split among 13 soil types, and none of which exceed 3% of the watershed (most are below 1%). The major soil properties are listed in Table 3. Based on the Mercer County Soil Survey, the Blount is somewhat poorly drained, Pewamo is very poorly drained and Glynwood is moderately well drained (http://soils.usda.gov/survey/online_surveys/ohio/mercerOH1979/Mercer.pdf).

Table 3 Soil physical information from SSURGO used in SWAT modeling

Soil Type	Blount				Pewamo			Glynwood		
Layer	1	2	3	4	1	2	3	1	2	3
Depth from the soil surface (mm)	254	635	813	1524	330	940	1524	229	584	1524
Organic carbon content (% soil weight)	1.45	0.29	0.15	0.15	4.36	1.45	0.48	1.16	0.39	0.13
Moist bulk density (g/m^3)	1.45	1.55	1.6	1.73	1.45	1.55	1.6	1.38	1.58	1.75

Weather Data: Daily weather data hosted by the National Oceanic and Atmospheric Administration (NOAA) National Climate Data Center (NCDC) were used to serve as input into the SWAT model. Based on interviews and recommendations from local people, the lake itself appears to have an effect on approaching storms, resulting in different precipitation patterns on the south side of the lake where the Chickasaw watershed is located and on the north side of the lake where two weather stations which are the closest to the watershed are located (in Figure 1). In addition, meteorological observations indicate that the courses that storms travel can be highly variable, especially in relatively wet years. Thus, instead of the

usual modelling approach of just going with the closest gages, precipitation information from various directional precipitation gauges within 35-mile radius from the watershed boundary were collected in the hope of capturing precipitation coming from all directions of the watershed. This was done to explore the possibility of finding the representative precipitation pattern in the watershed.

SWAT Model Simulations and Performance Evaluation: Based on the DEM and selected outlets, the watershed was delineated into subbasins. Subsequently, the subbasins were partitioned into homogeneous units (HRUs), which shared the same land use, soil type, and slope range. In this study, a total of 30 subbasins were delineated, among which 27 subbasins drain to the USGS flow gauge station. HRUs were defined by applying a 10% threshold for land use, soil type, and slope range so any of these components that had a use/type/range less than 10% of a particular subbasin got eliminated from influencing the model result. The net effect of eliminating these minor influences was to significantly improve the efficiency of the model while not significantly affecting the result. Each HRU represents a unique combination of land use, soil type, and slope range, and collectively they provide much of the information needed by the SWAT model to characterize the watershed.

Model simulations were first performed using SWAT default values with precipitation data from the closest gauge (St. Marys). Next, model simulations were performed using SWAT default values with one precipitation gauge at a time for the remaining precipitation gauges from Figure 1. Finally, a hybrid precipitation file was developed to capture precipitation pattern of the watershed by using data from a single gauge to cover a range of consecutive dates based on which gauge best simulated actual precipitation events in term of timing and magnitude within that particular date range. To evaluate the model performance, four statistical measurements were used (Moriasi et al., 2007) including the coefficient of determination (R^2), Nash-Sutcliffe efficiency (NSE), RMSE-observations standard deviation ratio (RSR) and percent bias (PBIAS).

RESULTS AND DISCUSSION

Results from the Closest Precipitation Gauge: The first model simulation was performed using the SWAT default values and precipitation from the closest weather station, St. Marys precipitation gauge in which the missing records were substituted with the precipitation records from the Celina Precipitation gauge (Figure 1). For those two years of the model simulation for which observed flow data were available (2009 and 2010), the R^2 is 0.37 and 0.03 for 2009 and 2010, respectively (Figure 2). The R^2 of 0.37 for 2009 is within the acceptable range for an uncalibrated model simulation, but the R^2 of 0.03 for 2010 is unacceptable. Furthermore, the hydrographs in Figure 2 below show that the simulation did a fairly good job aligning with observed flow peaks for 2009, whereas the simulated peaks essentially aligned very poorly with observed peaks for 2010.

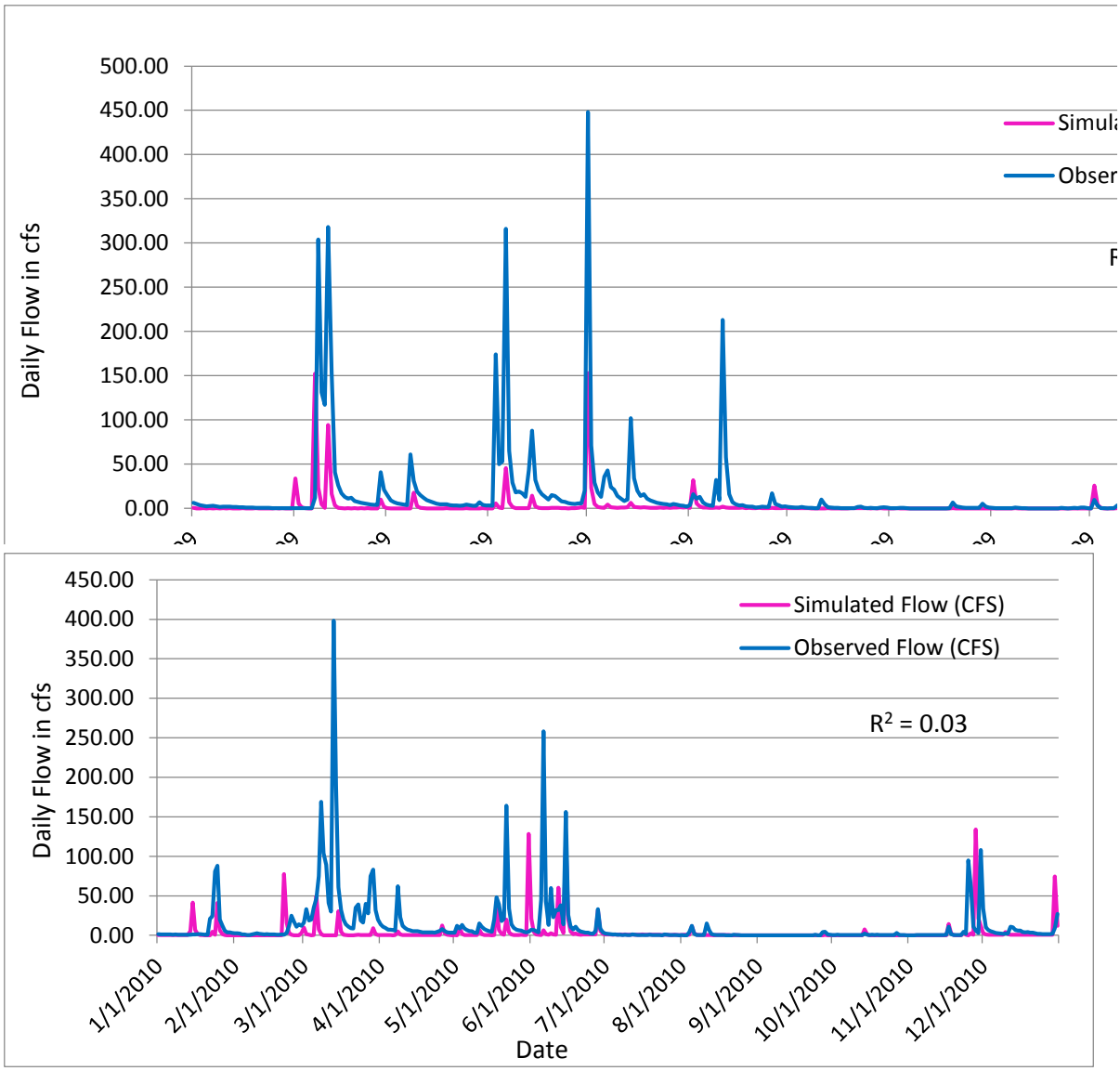

Figure 2 Flow hydrographs for initial uncalibrated model run with SWAT default values using precipitation data from St. Marys precipitation gauge.

The very poor correlation for Year 2010 of the model suggests that improvements to the model might be very difficult. After having tried model developers' recommendations for applying seasonal adjustments to the curve number for the Chickasaw watershed, it was found, unfortunately, very little improvement was achieved on model's performance. The poor correlation between simulated flow and observed flow led us to question the credibility of climate data. How well did the input precipitation dataset at the St. Marys weather station represent actual precipitation conditions in the watershed? The flow correlation coefficients were so low, especially for year 2010 (Figure 2), it seemed that the NOAA precipitation gage used did not match up with actual precipitation in the Chickasaw watershed based on the near-zero correlation of the simulated hydrograph comparing with the observed hydrograph for 2010 (Figure 2). Although the St. Marys precipitation gauge is only a few miles away from the Chickasaw watershed, the zero correlation of the hydrograph indicates that the precipitation gage is totally irrelevant to the flow generated in the watershed.

Results from other Precipitation Gauges: Additional SWAT simulations were performed using the SWAT default values and precipitation data from each of the weather gauges displayed in Figure 1. Table 4 shows the R^2 (correlation coefficients) for each gauge:

Table 4 SWAT model simulations with precipitation data from different precipitation gauges

R-squared	St. Marys	Celina	Decatur	Van Wert	Lima	Sidney	Versailles	Ft. Recov
Year 2009	0.37	0.50	0.17	0.37	0.17	0.14	0.02	0.06
Year 2010	0.03	0.07	0.03	0.07	0.02	0.23	0.04	0.06

As shown in Table 4, using precipitation data from the Sidney precipitation gauge to the southeast of the Grand Lake St. Marys watershed in neighboring Shelby County showed great improvements in correlating daily simulated and observed flows for the year of 2010. Further comparisons on a monthly basis gained more insights on weather patterns of the watershed; for example, in June of 2010, an R^2 of 0.59 was obtained using precipitation data from the Sidney precipitation gauge comparing an R^2 of 0.19 from the St. Marys precipitation gauge (Figure 3). It may be concluded that the first flow peak in this month was caused by a shared precipitation event occurring at both the watershed and the Sidney gauge.

The increased R^2 for June 2010 using precipitation data from the Sidney precipitation gauge is very encouraging, demonstrating that considering a more distant precipitation gauge from the modeled watershed can be promising in capturing the precipitation pattern of the watershed. The hydrograph above demonstrates that the more distant Sidney precipitation gauge might better represent precipitation of the watershed, at least for the first half of June in 2010. However, how well St. Marys precipitation gauge represents the second half of the month can't be overlooked, suggesting that weather experienced at the St. Marys precipitation gauge might better represent the precipitation pattern of the watershed for this time period.

This raised the question: what would be the best way to construct a precipitation file to represent the precipitation happened over the modeled watershed? A precipitation file covering the years 2009 and 2010 was constructed using observed precipitation from all 8 precipitation gauges (Figure 1). For the month of June 2010, it seemed that the Sidney precipitation gauge best represented most of the first half of June, and the St. Mary's precipitation gage represented the second half. Figure 4 illustrates the result of SWAT simulation with such a hybrid precipitation input file.

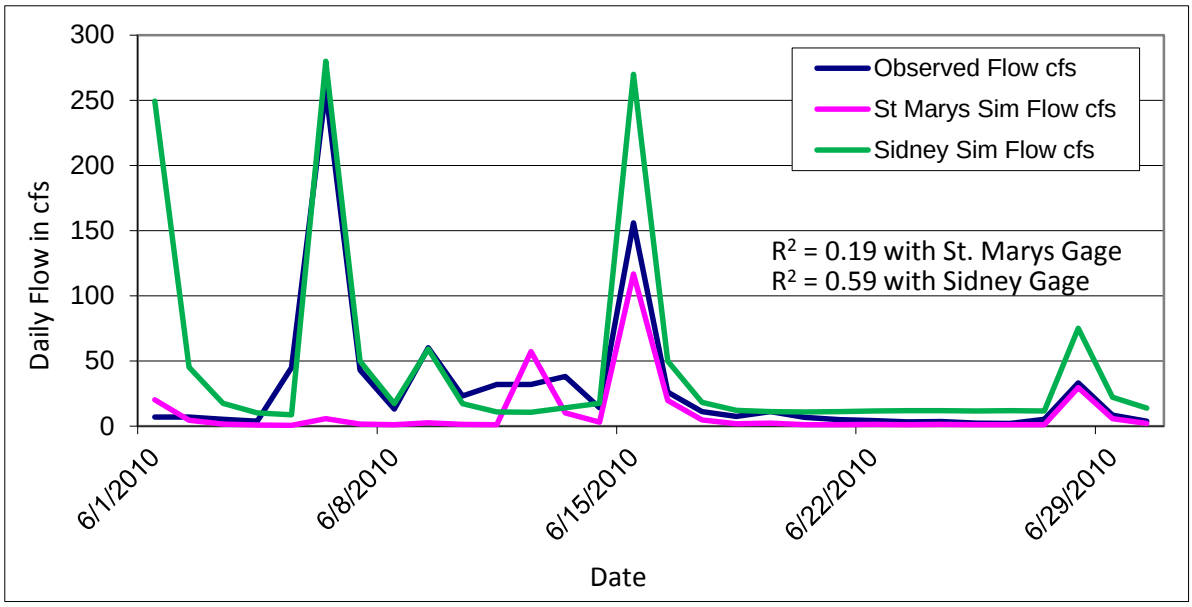

Figure 3 Simulated flow hydrographs using precipitation data from the Sidney precipitation and the St. Marys precipitation gauge vs observed flow hydrograph for June of 2010.

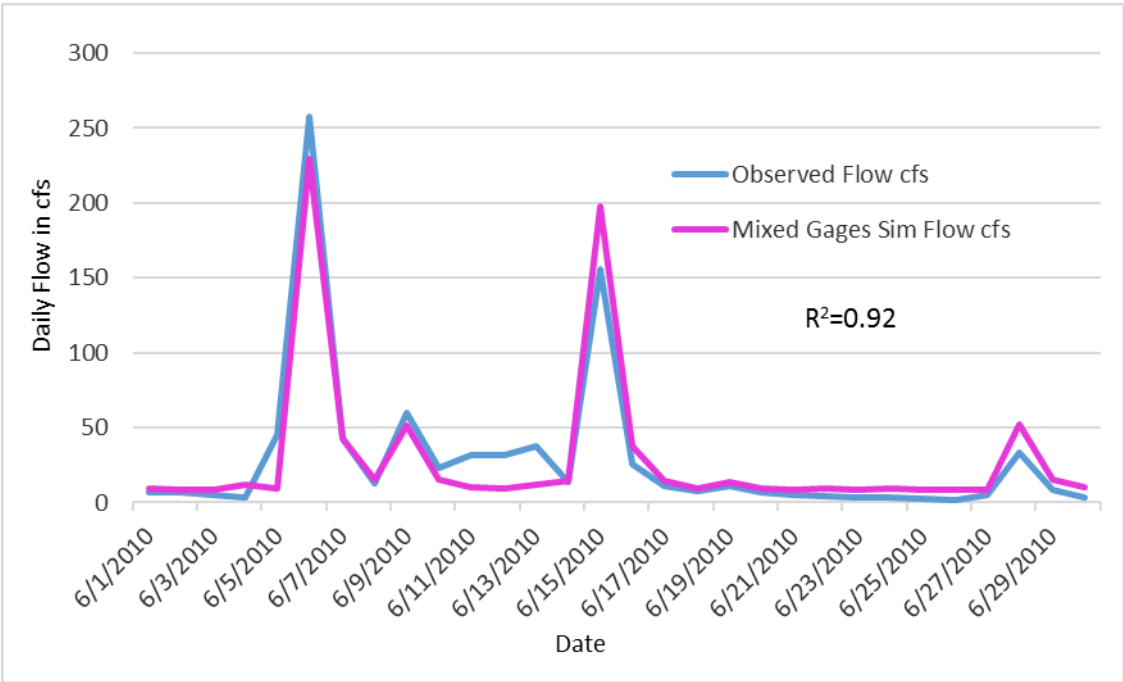

Figure 4 Simulated flow using a hybrid precipitation data from the Sidney precipitation and the St. Marys precipitation gauge vs observed flow for June of 2010.

The excellent result and correlation displayed in Figure 4 provided evidence that constructing a hybrid file from additional precipitation gauges nearby the watershed is necessary to represent the precipitation pattern of the watershed. St. Marys weather data would do a good job at picking up on weather systems coming out of the north, but adding other gages from all directions might pick up weather from all directions.

The result of using a hybrid precipitation input file constructed using a mix of observed daily precipitation data from all 8 precipitation gauges are shown in Table 5. The R^2 of 0.60 between model simulation and field observation displayed in Table 5 can be considered as excellent for an uncalibrated model simulation. The 2010 overall correlation using hybrid precipitation file increased to 0.60 from the dismal 0.03 using just the St. Mary precipitation data and 0.23 using just the Sidney precipitation data.

Table 5 Comparison of model performance using a hybrid precipitation data from all 8 precipitation gauges vs using only St. Marys Weather Station for water year of 2009 and 2010.

Simulated vs. Observed Flow R-squared Correlation	Using St. Marys Weather Station Precipitation Data	Using Hybrid Precipitation Data from All 8 Stations
2009	0.37	0.51
2010	0.03	0.60

Because the results speak so strongly for themselves, a meteorological perspective was sought out. The question of considering precipitation events from multiple gages as far away from the modeled watershed as the next county was posed to someone with a background in meteorology. The meteorologist considered it perhaps a trick question because from a meteorology perspective, it's absolutely appropriate to consider weather data from multiple gages when considering weather for a multi-county area commensurate in size to a major metropolitan area. It's what happens every evening in weather broadcasts in metro areas, or to quote the meteorologist above, "of course it's okay to consider precipitation gages in the next county!"

CONCLUSIONS

Accurate estimation of rainfall amount over a watershed is critical for getting accurate runoff simulation. The common practice of assigning the point measurements located in the watershed to the entire watershed may not represent the precipitation pattern over the watershed. This study shows that a watershed precipitation pattern could be influenced by precipitations from all directions. The closest precipitation gauge, the St. Marys on the north shore of Grand Lake St. Marys experienced a quite different weather pattern than the modeled Chickasaw Creek watershed, which is on the south side of the lake. Thus, it is important to construct a hybrid precipitation file from all 8 precipitation gauges within 35-mile radius from the boundary of the watershed.

ACKNOWLEDGEMENTS

The United States Environmental Protection Agency through its Office of Research and Development funded the research described here. It has been subjected to Agency review and approved for publication. The authors are grateful for the valuable comments and suggestions provided by reviewers.

Notice: Although this work was reviewed by the USEPA, and approved for publication, it may not necessarily reflect official Agency policy. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

REFERENCES

Arnold, J.G., Allen, P.M., and Bernhardt, G. (1993). "A comprehensive surface-groundwater flow model," Journal of Hydrology, 142(1-4), pp 47-69.

Arnold J.G., and Fohrer, N. (2005). "SWAT2000: current capabilities and research opportunities in applied watershed modelling," Hydrological Processes 19, pp 563-572.

Arnold, J.G., Srinivasan, R., Muttiah, R.S., and Williams, J.R. (1998). "Large area hydrologic modeling and assessment - Part 1: Model development," Journal of American Water Resour. Association, 34(1), pp 73-89.

Gassman P.W., Reyes M.R., Green C.H., and Arnold J.G. (2007). "The Soil and Water Assessment Tool: Historical Development, Applications, and Future Research Directions," Transactions of the ASABE, 50, 1211-1250.

Neitsch S.L., Arnold J.G., Kiniry J.R., Williams J.R. (2005). "Soil and Water Assessment Tool Theoretical Documentation," Temple, TX.

Moriasi D.N., Arnold J.G., Van Liew M.W., Bingner R.L., Harmel R.D., Veith T.L. (2007). "Model evaluation guidelines for systematic quantification of accuracy in watershed simulations," Transactions of the Asabe, 50(3), 885-900.

USDA, NRCS, (2004). National Engineering Handbook, Part 630, Hydrology. Chapter 8, Land Use and Treatment Classes.

USDA, NRCS, (2004). National Engineering Handbook, Part 630, Hydrology. Chapter 9, Hydrologic Soil-Cover Complexes.

USDA, NRCS, (2004). National Engineering Handbook, Part 630, Hydrology. Chapter 10, Estimation of Direct Runoff from Storm Rainfall.