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WATER QUALITY MODEL OUTPUT UNCERTAINTY AS AFFECTED BY SPATIAL RESOLUTION OF INPUT DATA[1]

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ABSTRACT: Resolution of the input GIS data used to parameterize distributed-parameter hydrologic/water quality models may affect uncertainty in model outputs and impact the subsequent application of model results in watershed management. In this study we evaluated the impact of varying spatial resolutions of DEM, land use, and soil data (30 x 30 m, 100 x 100 m, 150 x 150 m, 200 x 200 m, 300 x 300 m, 500 x 500 m, and 1,000 x 1,000 m) on the uncertainty of SWAT predicted flow, sediment, NO_3-N, and TP transport. Inputs included measured hydrologic, meteorological, and watershed characteristics as well as water quality data from the Moores Creek watershed in Washington County, Arkansas. The SWAT model output was most affected by input DEM data resolution. A coarser DEM data resolution resulted in decreased representation of watershed area and slope and increased slope length. Distribution of pasture, forest, and urban areas within the watershed was significantly affected at coarser resolution of land use and resulted in significant uncertainty in predicted sediment, NO_3-N, and TP output. Soils data resolution had no significant effect on flow and NO_3-N predictions; however, sediment was overpredicted by 26 percent, and TP was underpredicted by 26 percent at 1,000 m resolution. This may be due to change in relative distribution of various hydrologic soils groups (HSGs) in the watershed. Minimum resolution for input GIS data to achieve less than 10 percent model output error depended upon the output variable of interest. For flow, sediment, NO_3-N, and TP predictions, minimum DEM data resolution should range from 30 to 300 m, whereas minimum land use and soils data resolution should range from 300 to 500 m.

(KEY TERMS: modeling; geographic information system; SWAT model; water quality; output uncertainty.)

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INTRODUCTION

Water quality models are frequently used to estimate nonpoint source pollution (NPS) pollutant loads from watersheds and to predict stream response to various pollutant loading scenarios. Models are also used to estimate Total Maximum Daily Loads (TMDLs) from point and nonpoint sources to achieve desired water quality improvement within a watershed. Because intensive monitoring of watersheds is very expensive, it is important that minimum data requirements be identified that lead to accurate estimates of watershed response by the model. Model accuracy is necessary to avoid implementing ineffective watershed management practices.

Watershed response predictions may involve two types of errors: (1) systematic model error that occurs regardless of correct input, and (2) error due to inaccuracies of the input data (Troutman, 1983). Many of the currently available distributed parameter models require watershed data such as land use, soils, and topography or digital elevation model (DEM) in a geographic information system (GIS) format to facilitate model parameterization. Many studies have quantified the effect of the resolution of rainfall input data on model predictions (e.g., Goodrich *et al.,* 1995; Faures *et al.,* 1995; Shah *et al.,* 1996; Chaubey *et al.,* 1999). However, relatively little information is available on the effect of input spatial data resolution on model output uncertainty. Wagenet and Hutson (1996) reported that even though use of GIS has greatly enhanced the capability to simulate watershed scale water quality processes, the scale at which

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GIS data such as soil survey, elevation, and land use should be collected and used is a major concern that needs to be studied. The authors concluded that modeling results can be sensitive to the nature and quality of input variables at a given scale and that interpretation of model output is limited by the resolution and quality of input environmental data.

Studies done to assess the effect of GIS data resolution on model output uncertainty can be grouped into two categories based on model applications: (1) model uncertainty in soil media or subsurface flow predictions, and (2) surface flow and water quality response prediction uncertainty. Effects of input spatial data resolution on model predictions in soils media and subsurface flow have been relatively well documented. GIS scale, measured soil data, and meteorological data have been shown to affect model output accuracy (e.g., Wagenet and Hutson, 1996; Wilson *et al.,* 1996). In general, model predictions based on input data sets with low spatial resolution have been linked with higher uncertainty in predicting subsurface transport processes, and high resolution soil data are advocated to be used to identify areas susceptible to ground water contamination (Inskeep *et al.,* 1996).

Fewer studies have been done to quantify the effect of spatial input data resolution on uncertainty in surface flow and water quality response predictions. Most of these studies either have focused on rainfall/runoff process only, with no consideration given to water quality parameters, or have considered only a limited number of data resolutions. DEM resolution and cell aggregation have been shown to affect landscape topography and uncertainty in modeled flow (Ma, 1993; Wang *et al.,* 2000). Lower resolution DEM data (90 x 90 m) have been shown to result in less predicted flow volume and lower peak flow compared to high resolution DEM data (30 x 30 m) (Cho and Lee, 2001). Similarly, DEM data resolution has been found to affect the shape of the study area, mean water table depth, ratio of overland to total flow, and variance and skew of maximum daily flow (Wolock and Price, 1994; Zhang and Montgomery, 1994). Zhu and Mackay (2001) have demonstrated that soil data resolution affects flow and photosynthesis prediction accuracy.

Even though the effect of varying spatial input data resolution on model output uncertainty has been recognized, most of these studies have been limited by a small number of discrete spatial data resolutions considered. No comprehensive study has been done to assess the effect of DEM, soils, and land use resolution on output errors of hydrologic/water quality models. The objective of this study was to quantify the effect of input DEM, soils, and land use data resolution on modeled watershed hydrologic and water quality response. Knowledge of uncertainty in model output should help in determining the resolution at which GIS data should be collected in a watershed to minimize output errors when using a model for watershed response predictions.

METHODOLOGY

The effect of input data resolution on model output was tested using the Soil and Water Assessment Tool (SWAT) model (Arnold *et al.,* 1998). The model was calibrated using measured water quality and watershed characteristics data from a small agricultural watershed in the Ozark Plateau Region of Arkansas. Next, output uncertainty solely due to spatial input resolution in DEM, soils, and land use data was quantified, and acceptable resolution of input spatial data was determined based on an arbitrary 90 percent prediction accuracy.

Description of the Watershed

The study was conducted in Moores Creek watershed, a 1,890 ha agricultural watershed in western Washington County in northwest Arkansas (Figure 1). It is a subbasin of the Illinois River watershed. Major land uses within the watershed were pasture (55 percent) and mixed forests (39 percent). Animal production was prevalent in the form of numerous poultry and beef operations. Moores Creek flows to Lincoln Lake, which served as the secondary drinking water supply for the City of Lincoln in Washington County. Water quality degradation of the lake was believed to be caused by runoff of nutrients from surface-applied animal manure in the watershed. The creek has been monitored for nutrients at two sites since 1992.

Available Data

Detailed hydrology and water quality data for this watershed, collected in 1997 and 1998 by Nelson (2001), were used in this study (Table 1). Measurements included continuous stage in the stream as well as concentrations of numerous water quality parameters from stream water samples including nitrate-nitrogen (NO_3-N), ammonia-N (NH_4-N), total Kjeldahl N TKN), phosphate-phosphorus (PO_4-P), total-P (TP), and total suspended solids (TSS). Stage measurements and water samples were collected at 30-minute intervals during the rising limb of storm hydrographs, at 60-minute intervals during the

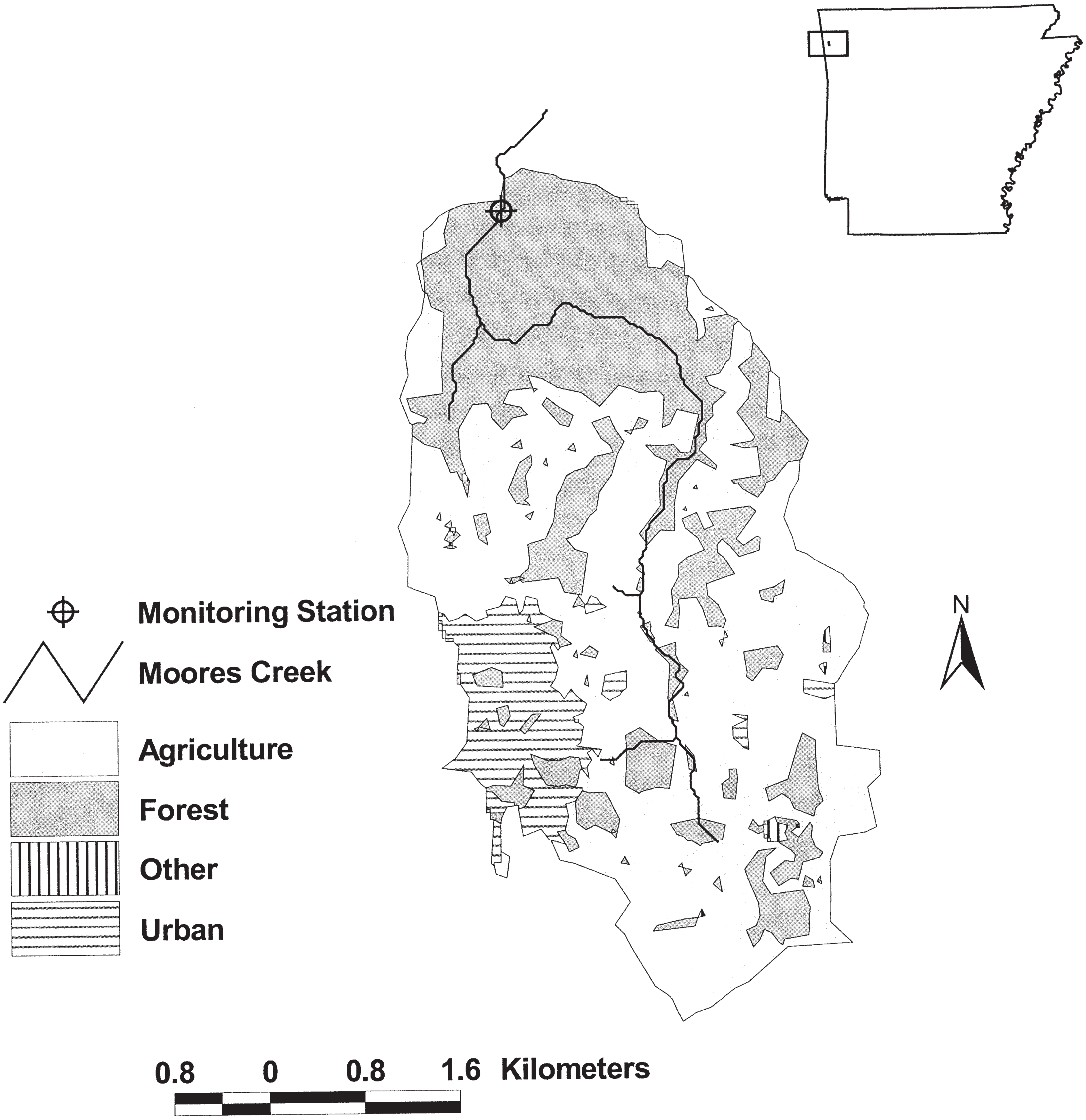


Figure 1. Location and Land Use Distribution of the Moores Creek Watershed.

falling limb, and at 14-day intervals during baseflow conditions. Flow and water quality parameter values shown in Table 1 were derived from these data.

TABLE 1. Measured Data (average annual) From the Moores Creek Watershed.

	1997	1998
Rainfall (mm)	1,114	1,122
Flow (m^3)	2,980,000	5,885,000
Sediment (mg/L)	290	139
NO_3-N (mg/L)	1.2	1.4
TP (mg/L)	0.59	0.56

A detailed watershed digital soil data set, similar to Soil Survey Geographic (SSURGO) data, was obtained from the University of Arkansas Soil Physics Lab. The DEM data for the watershed were obtained from the U.S. Geological Survey (USGS). Both of these maps were scaled 1:24,000, which was approximately 30 x 30 m in horizontal resolution. Land use and land cover data for 1999 at 30 x 30 m horizontal resolution, road network, and stream network data in GIS format were obtained from the Center for Advanced Spatial Technology (CAST) at the University of Arkansas.

Description of the SWAT Model

The SWAT model is a physically based distributed-parameter watershed scale model. It divides the study watershed into subbasins or smaller homogeneous areas (Neitsch *et al.,* 2000). SWAT considers all hydrologic processes within the subbasins of the watershed. The USEPA currently supports this model for developing TMDLs in agricultural watersheds. SWAT consists of three major components: (1) subbasin, (2) reservoir routing, and (3) channel routing. The subbasin component consists of eight major divisions. These are hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, agricultural management, and pesticides. Channel inputs include reach length, channel slope, channel depth, channel top width, channel side slope, flood plain slope, channel roughness factor, and flood plain roughness factor. GIS interfaces have been developed for the SWAT model to facilitate the aggregation of input data for simulating watersheds. The ArcView interface developed for the SWAT model was used to prepare input data files in this study (Di Luzio *et al.,* 2002). This interface requires a land cover map, soils map, and DEM as spatial inputs. A detailed description of the model can be found at the SWAT website (SWAT Model, 2000).

Model Calibration

The SWAT model was calibrated for flow, sediment, NO_3-N, and TP loads in the Moores Creek watershed. Measured hydrologic and water quality data from 1997 to 1998 were used for model evaluation (Table 1). The model was calibrated on a monthly time scale. The resolution of all input GIS data used was 30 m (our most detailed data) during model calibration. The objective function for calibration was defined as

$$\textit{Objective Function} = \min \sum (\textit{observed-predicted})^2 \quad (1)$$

where the summation included all monthly average values during the 1997 to 1998 period.

The Nash-Sutcliffe coefficient (R_{NS}^2) was used as another indication of how well model predictions matched measured stream data. R_{NS}^2 can range from $-\infty$ to 1, where 1 indicates a perfect fit. R_{NS}^2 was calculated as

$$R_{NS}^2 = 1 - \frac{\sum_{i=1}^{n} \left(O_i - P_i\right)^2}{\sum_{i=1}^{n} \left(O_i - O_{avg}\right)^2} \quad (2)$$

where O_i = monthly observed output, P_i = monthly predicted output, O_{avg} = average observed output of interest, and i = month.

The model was calibrated first for total monthly flow by calibrating separately for storm and baseflow conditions. The procedure outlined in the SWAT model user's manual (Neitsch *et al.,* 2000) was followed to adjust model parameters during the calibration process. In summary, curve number (CN) was the most dominant parameter affecting surface runoff and was used to minimize the differences between observed and predicted storm flow. Baseflow was calibrated by adjusting the ground water revaporation coefficient and the threshold depth of water in the aquifer for revaporation.

After flow calibration, sediment and nutrient loads were calibrated. Model parameters adjusted to calibrate sediment loads were the soil erodibility factor, peak rate adjustment factors for sediment routing, and parameters affecting sediment reentrainment. Nutrient outputs were calibrated by modifying average slope length, P enrichment ratio, soil bulk density, plant uptake of P, rate factor for mineralization, N and P percolation coefficients, P availability index, and P soil partitioning coefficient. The poultry litter application rate in the watershed was estimated to be 5,600 kg/yr based on litter production rate in the watershed and was assumed to be applied on all existing pasture areas (detailed manure application records from farmers in the watershed were not available). The total manure load was partitioned into two applications at six-month intervals to reflect predominant local production practices in the watershed.

Quantification of Model Output Uncertainty Due to Input Data Spatial Resolution

The input GIS data needed by the SWAT model were topography (DEM), land use, and soils. All these data were available at a horizontal resolution of 30 x 30 m for the watershed. The uncertainty in the SWAT output due to spatial resolution of input DEM, land use, and soils data was quantified by running the model at seven spatial resolutions (30 x 30 m, 100 x 100 m, 150 x 150 m, 200 x 200 m, 300 x 300 m, 500 x 500 m, and 1,000 x 1,000 m) for all storm events and baseflow conditions for the period 1997 to 1998. Flow, sediment, NO_3-N, and TP were the model outputs of interest. Flow, sediment, and NO_3-N were directly calculated by SWAT, whereas TP was estimated as the sum of organic P and mineral P. Uncertainty in the model output due to input data resolution was quantified as relative error (RE), defined as

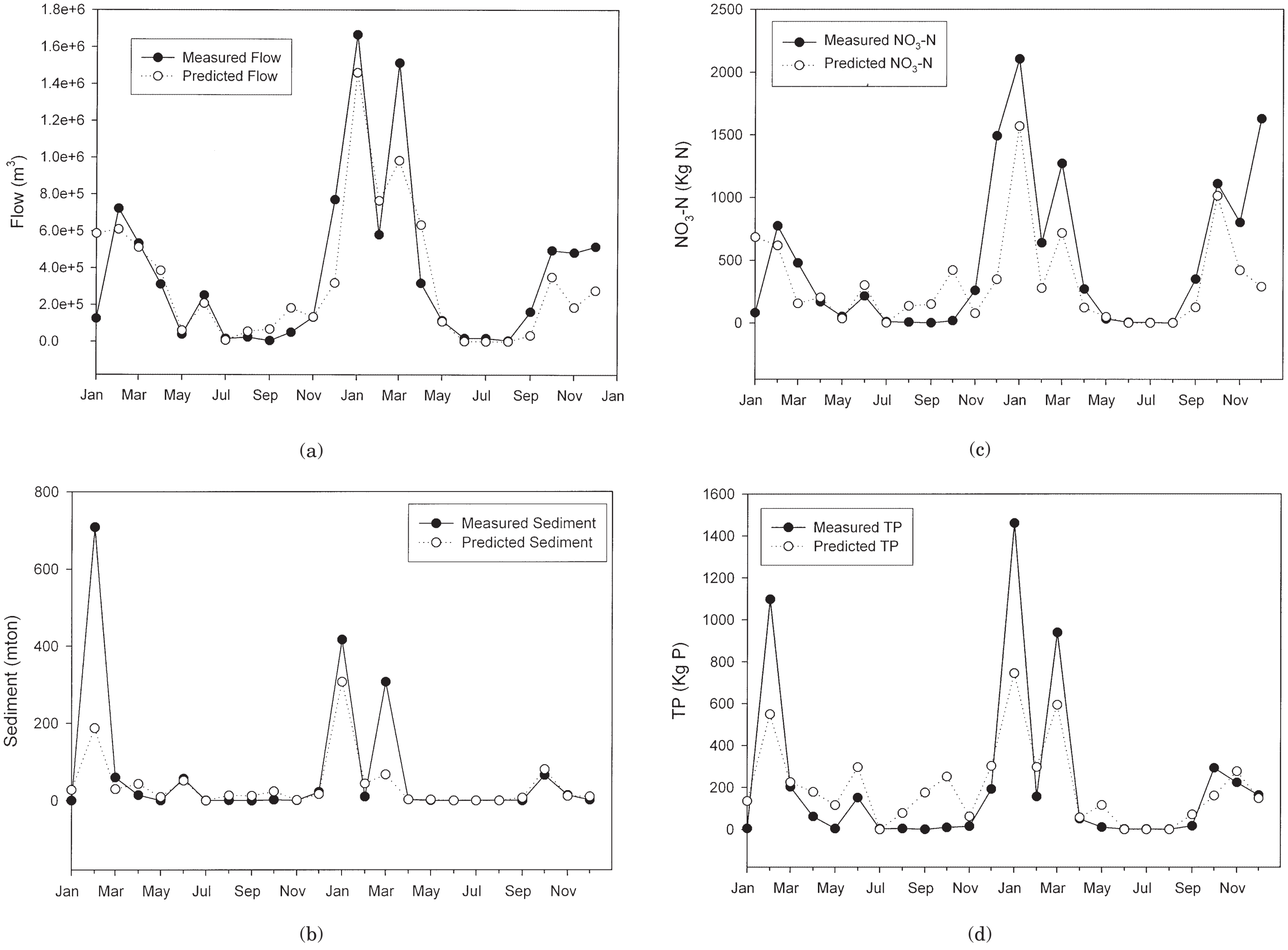
$$RE(\%) = \frac{\left(P_{30} - P_{coarse}\right)}{P_{30}} \times 100 \qquad (3)$$

where P_{30} was the best model output using 30 x 30 m data resolution for DEM, soils, and land use and P_{coarse} was the model output using the coarser data resolution. We did not use the measured watershed response data to calculate RE because even with the best possible model calibration, there is some residual error present in model predictions. It was not possible to isolate model errors solely due to input data resolution if measured watershed response data were used. However, using the best possible model predicted value (P_{30}) to calculate RE at coarser resolutions enabled us to isolate the model uncertainty solely due to input data resolution.

RESULTS AND DISCUSSION

Model Calibration

Results of flow calibration are shown in Figure 2a. The calibrated annual flow was overpredicted by 11 percent in 1997 and underpredicted by 13 percent in 1998. The monthly flow calibration yielded R_{NS}^2 value of 0.76 and was comparable to other reported values for SWAT calibration. Monthly SWAT flow calibrations by Peterson and Hamlett (1997) yielded R_{NS}^2 of 0.55 if snow events were neglected, while Chu *et al.* (2000) had R_{NS}^2 value of 0.51. Results of the sediment, NO_3-N, and TP calibrations are shown in Figures 2b, 2c, and 2d, respectively. The calibration yielded R_{NS}^2 values of 0.48, 0.44, and 0.66 for sediment, NO_3-N, and TP, respectively. In general, the model performance to simulate flow and water quality



(a)

(c)

(b)

(d)

Figure 2. Calibration Results for (a) Monthly Flow, (b) Sediment, (c) NO_3-N, and (d) TP (calibration period January 1997 to December 1998).

response of the Moores Creek watershed was similar to other published reports (e.g., Santhi *et al.,* 2001, VanLiew and Garbrecht, 2002).

Model Uncertainty Due to Input Data Resolution

The average predicted streamflow and mass losses of sediment, NO_3-N, and TP for 1997 and 1998 are shown in Tables 2, 3, and 4 as a function of input data resolution for DEM, land use, and soils, respectively. Results showed that in general, the SWAT output was more sensitive to input DEM data resolution than to soil and land use resolution. Decreases in land use and soil resolution resulted in smaller predicted flow and water quality parameter uncertainty than did decreases in DEM resolution. Maximum RE in flow, sediment, NO_3-N, and TP due to resolution of land use data was 7, 19, 11, and 41 percent, respectively, and due to soils data was 2, 26, 11, and 16 percent, respectively.

TABLE 2. Average Annual SWAT Model Predictions at Varying DEM Resolutions (1997 to 1998).

	Flow		**Sediment**		**NO_3-N**		**TP**	
Scale	**Volume (m^3)**	**RE (percent)**	**Mass Loss (Mg)**	**RE (percent)**	**Mass Loss (kg)**	**RE (percent)**	**Mass Loss (kg)**	**RE (percent)**
30 x 30m	3,751,000		445		3,790		2,390	
100 x 100m	3,683,000	2	370	17	3,760	1	2,810	-18
150 x 150m	3,606,000	4	310	31	3,680	3	2,610	-9
200 x 200m	3,508,000	6	280	37	3,520	7	2,100	12
300 x 300m	3,407,000	9	230	48	3,010	21	710	70
500 x 500m	2,774,000	26	230	48	2,830	25	670	72
1,000 x 1,000m	2,722,000	27	83	81	1,880	50	290	88

TABLE 3. Average Annual SWAT Model Predictions at Varying Land Use Resolutions (1997 to 1998).

	Flow		**Sediment**		**NO_3-N**		**TP**	
Scale	**Volume (m^3)**	**RE (percent)**	**Mass (Mg)**	**RE (percent)**	**Mass (kg)**	**RE (percent)**	**Mass (kg)**	**RE (percent)**
30 x 30m	3,751,000		445		3,790		2,390	
100 x 100m	3,790,000	-1	496	-12	3,790	0	2,440	-2
150 x 150m	3,803,000	-1	486	-9	3,730	2	2,510	-5
200 x 200m	3,788,000	-1	475	-7	3,830	-1	2,300	3
300 x 300m	3,744,000	0	470	-6	3,730	1	2,380	0
500 x 500m	3,774,000	-1	475	-7	3,720	2	2,060	14
1,000 x 1,000m	3,498,000	7	360	19	3,390	11	1,400	41

TABLE 4. Average Annual SWAT Model Predictions at Varying Soil Resolutions (1997 to 1998).

	Flow		**Sediment**		**NO_3-N**		**TP**	
Scale	**Volume (m^3)**	**RE (percent)**	**Mass (Mg)**	**RE (percent)**	**Mass (kg)**	**RE (percent)**	**Mass (kg)**	**RE (percent)**
30 x 30m	3,751,000		445		3,790		2,390	
100 x 100m	3,808,000	-2	484	-9	3,830	-1	2,450	-3
150 x 150m	3,818,000	-2	487	-9	3,880	-2	2,540	-6
200 x 200m	3,844,000	-2	431	3	4,090	-8	2,460	-3
300 x 300m	3,787,000	-1	472	-6	4,070	-7	2,440	-2
500 x 500m	3,802,000	-1	405	9	3,950	-4	2,430	-2
1,000 x 1,000m	3,783,000	-1	558	-26	4,200	-11	1,770	26

DEM Resolution

DEM resolution affected the watershed delineation, stream network, and subbasin classification in the SWAT model (Table 5). The 30 x 30 m DEM resulted in eight subbasins and a total watershed area of 1,893 ha. As the DEM resolution decreased, total computed watershed area and average watershed slope also decreased, while average slope length increased. The modeled stream network became consistently less accurate at coarser resolutions. These impacts were a direct consequence of losing topographic details at the coarser DEM resolutions. Since the coarsest-input DEM poorly represented the true topology of the watershed, the model was not able to correctly predict the watershed characteristics or stream network. A study done by Zhang and Montgomery (1994) using TOPMODEL also found that watershed area decreased as DEM resolution decreased.

TABLE 5. DEM Resolutions Effects on Watershed Area, Subbasins, and Topography.

DEM Resolution	Watershed Area (ha)	No. of Subbasins	Average Slope	Average Slope Length (m)
30 m	1,893	8	0.060	95
100 m	1,871	10	0.050	107
150 m	1,879	10	0.044	117
200 m	1,840	8	0.039	114
300 m	1,827	4	0.032	126
500 m	1,700	6	0.022	134
1,000 m	1,400	2	0.015	128

The model predictions for flow, sediment, NO_3-N, and TP loads at coarser resolutions were compared to the predictions at the calibrated DEM resolution (30 x 30 m). Table 2 shows the average annual predicted values for selected outputs. The variance in RE in each annual model output for 1997 as affected by DEM data resolution is illustrated in Figure 3. The sediment prediction was affected most by the input DEM data resolution, followed by NO_3-N, flow, and TP up to 200 m data resolution. However, at DEM coarseness of 300 m and less, TP was the most sensitive model output, followed by sediment, NO_3-N, and flow (Figure 3). In general, the results indicate that as the DEM resolution became coarser, the predicted flow volume decreased. Coarser resolutions also reduced the average slope of the modeled watershed (Table 5). The average slope of the watershed was reduced from 6 percent at the 30 m DEM to 1.5 percent at the 1,000 m DEM, which resulted in less flow. Furthermore, average slope length was increased 35 percent from the 30 m DEM to the 1,000 m DEM. Sediment and NO_3-N predictions followed the same trend, decreasing as DEM resolution became coarser, also due to the combination of decreased slope and increased slope length at coarser DEM resolutions. TP predictions also decreased with decreasing DEM resolution; however, the model initially overestimated TP, then the predicted load decreased at coarser DEM resolutions. These results are consistent with the results reported by Cho and Lee (2001) in which the authors found that the SWAT simulated flow was higher for 30 x 30 m DEM data resolution compared to flow predicted using 90 x 90 m DEM. The authors surmised that a finer data resolution resulted in a higher slope and hence the higher simulated flow volume. In a study using 71 watersheds and TOPMODEL, Wolock and Price (1994) found that increasing DEM coarseness from 30 x 30 m to 90 x 90 m increased the ratio of overland flow to total flow and the variance and skew of daily flow but did not affect mean daily flow predictions.

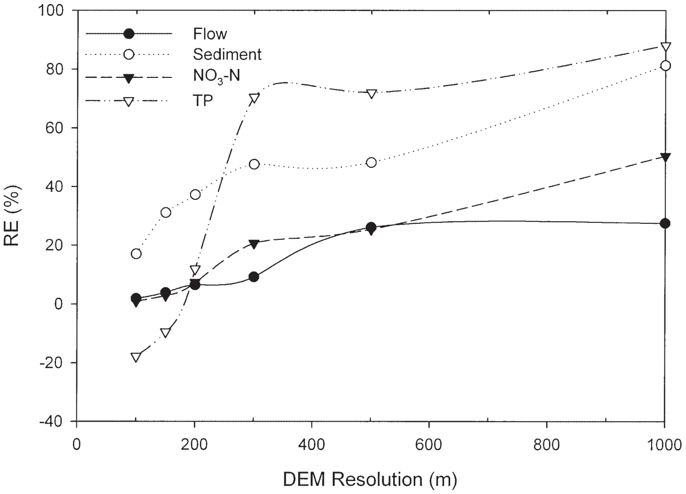


Figure 3. Average Relative Error (RE) for Flow, Sediment, NO_3-N, and TP for All Model Outputs.

Land Use Input Resolution

The model predictions for flow, sediment, NO_3-N, and TP loads at various spatial resolutions for land use were compared, as above, to the predictions at the calibrated land use resolution of 30 x 30 m (Table 3). The RE in predicted flow was less than 10 percent at all resolutions, indicating that predicted flow was not substantially affected by land use data resolution.

Sediment predictions initially increased at the 100 m scale but then gradually decreased at the coarser resolutions. A 1,000 m land use resolution yielded significantly greater RE (19 percent) in predicted sediment transport. Predicted NO_3-N was also similar to the calibrated NO_3-N values up to 500 m resolution and was significantly smaller (RE = 12 percent) at 1,000 m resolution. RE in TP predictions was less than 5 percent up to 300 m land use resolution but increased considerably at 500 m and 1,000 m data resolutions.

Relative distribution of agricultural, urban, and forest areas within a watershed can affect prediction of flow and water quality response when land use characteristics are used to derive model parameters. The fraction of pasture, forest, and urban areas represented by the model within the watershed as affected by land use data resolution is given in Table 6. Land use distribution did not change significantly up to 500 m resolution. However, at 1,000 m resolution, the fraction of pasture and urban areas was reduced from 70.5 percent to 43.8 percent, while fraction of forest land increased by a corresponding amount. When land use was redistributed from pasture and urban to forest, the average CN for watershed decreased, resulting in more predicted infiltration and less surface runoff. This led to decreased predicted flow, nutrient, and sediment transport from the watershed. Decreased NO_3-N loads would be expected with decrease in flow, and decreased TP loads would be expected with a decrease in sediment loads.

Land use data resolution had a smaller effect on model output uncertainty compared to DEM data resolution. REs in flow, sediment, NO_3-N, and TP at all land use data resolutions were less than REs at corresponding DEM data resolutions.

TABLE 6. Land Use Redistribution as a Function of Resolution.

Land Use Resolution	Percent of Total Watershed Area		
	Pasture	Forest	Urban
30 m	58.6	33.4	8.0
100 m	59.9	32.4	7.7
150 m	58.4	33.1	8.5
200 m	57.9	34.3	7.9
300 m	54.5	38.0	7.5
500 m	64.0	29.6	6.5
1,000 m	42.5	56.2	1.3

Soil Input Resolution

The average SWAT model predictions at varying soil data resolutions are given in Table 4. Flow predictions were relatively unimpacted by decrease in soil resolution. Predicted sediment load fluctuated between overprediction and underprediction. The RE in sediment load prediction was within 10 percent up to 500 m soil resolution. NO_3-N was overpredicted at all soil resolutions and followed the trend of flow predictions. The RE in NO_3-N prediction was less than 11 percent for all soil data resolutions. TP was slightly overpredicted at all resolutions, except at 1,000 m, where it was underpredicted by 26 percent.

The resulting distribution between hydrologic soil groups (HSG) in the watershed at various soil data resolutions is shown in Table 7. Soils in the watershed were classified as HSG-B (moderate infiltration rates), HSG-C (slow infiltration rates and moderately fine to fine texture), and HSG-D (high runoff potential and very fine texture). Percentage of HSG-B in the watershed did not change significantly up to 300 m soil resolution. At 500 m resolution, the fraction of HSG-B increased by almost 10 percent, and at 1,000 m resolution, it decreased by more than 10 percent. The fraction of HSG-C decreased by almost 12 percent at 500 m resolution, most of which was assigned to HSG-B. The HSG-D did not change significantly, except at 1,000 m resolution, where it increased by 4 percent. Decreased predicted sediment load at the 500 m resolution was probably due to increased percentage of HSG-B, which was less erodible than the other groups. Increased predicted sediment load at the 1,000 m resolution was due to increased percentage of both HSG-C and HSG-D, which had more erosion potential than HSG-B. SWAT predictions of TP were decreased by 26 percent at the 1,000 m soil resolution.

TABLE 7. Hydrologic Soil Group Redistribution as a Function of Resolution.

Soil Resolution	Percent of Total Watershed Area		
	HSG-B	HSG-C	HSG-D
30 m	32.4	53.3	14.2
100 m	33.3	52.3	14.3
150 m	32.5	52.7	14.8
200 m	32.4	54.1	13.4
300 m	32.0	54.7	13.0
500 m	42.4	42.8	14.9
1,000 m	21.8	59.8	18.4

The minimum resolutions of the input data required to obtain less than 10 percent error in the SWAT model predictions for the study watershed are indicated in Table 8. The model outputs were most sensitive to the DEM data resolution. In order to have less than 10 percent model error, DEM data resolutions finer than 300 m should be used for flow predictions, less than 200 m for NO_3-N, and less than 30 m for sediment and TP predictions. Flow was not affected significantly by land use data resolution. However, land use data resolution should be less than 30, 500, and 300 m to accurately predict sediment, NO_3-N, and TP, respectively. Additionally, soil data resolution had no significant effect on flow predictions. However, resolution should be less than 500 m for sediment, NO_3-N, and TP predictions.

TABLE 8. Minimum GIS Input Data Resolution Needed to Achieve Less Than 10 Percent Output Error.

	Minimum Input Data Resolution (m)		
Output	**DEM**	**Land Use**	**Soils**
Flow	300	1,000	1,000
Sediment	30	30	500
NO_3-N	200	500	500
TP	30	300	500

SUMMARY AND CONCLUSIONS

When a hydrologic/water quality model is used to evaluate flow/water quality response of a watershed, every effort must be taken to minimize model uncertainties associated with input data. Results of this study indicated that GIS data resolution has significant impact on model output uncertainty. While it is desirable to have as much detailed GIS data as possible, often the cost of the data collection determines the resolution of the GIS data used in model applications. A comparison of the absolute values of relative error in the SWAT model predictions induced by various resolutions of DEM, land use, and soils indicated that DEM was the most sensitive input variable that affected flow, sediment, NO_3-N, and TP predictions. Both soil and land use resolution induced similar REs in model predictions up to 300 m data resolutions. For flow predictions, land use and soil resolution had similar impacts up to 500 m resolution. The RE in flow prediction was higher for soils as compared to land use at 1,000 m resolution. Land use induced larger RE in sediment predictions at 1,000 m resolution. However, soils resolution had larger impact on predicted TP at 500 and 1,000 m resolutions. The RE in NO_3-N prediction was not significantly different for soils and land use data resolutions.

The following conclusions are supported by the results of this study.

1. SWAT model output was most sensitive to input DEM data resolution. A decrease in DEM data resolution resulted in decreased watershed area and slope and increased slope length and significantly affected flow and water quality response predictions.

2. Flow predictions were not significantly affected by land use data resolutions. However, RE in sediment prediction was greater than 10 percent at 100 and 1,000 m resolutions. NO_3-N prediction was significantly affected at 1,000 m and TP prediction at 500 m, respectively. This was due to change in distribution of pasture, forest, and urban areas within the watershed at coarser resolutions.

3. Soils data resolution had no significant effect on sediment, NO_3-N, and TP predictions up to 500 m data resolution. However, sediment and NO_3-N were overpredicted by 26 and 11 percent, respectively, and TP was underpredicted by 26 percent at 1,000 m soil resolution. This was due to reduction in the total area under HSG-B and increase in watershed area under HSG-C and HSG-D at this resolution. RE in flow prediction was less than 2 percent at all soil resolutions.

4. Minimum resolution for input GIS data to achieve less than 10 percent model output error depended upon the output of interest. For flow, sediment, NO_3-N, and TP predictions, minimum DEM data resolution ranged from 30 to 300 m. Similarly, land use and soils data resolution needed ranged from 30 to 500 m.

Use of models in making watershed response predictions can be expected to increase in the future. This is especially true for the SWAT model, as it is now a part of the Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) modeling framework and is supported by the U.S. Environmental Protection Agency (USEPA) to be used for TMDL development (Di Luzio *et al.,* 2002). Results from this study indicate that every effort must be made to collect and input GIS data at a finer resolution to minimize uncertainties in the model predictions.

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