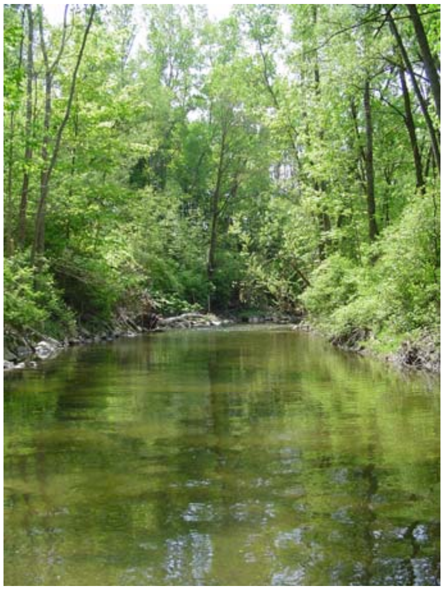
PROJECT REPORT

SEDIMENT MODELING FOR THE BUFFALO RIVER WATERSHED



Prepared by:

SHREERAM INAMDAR, PHD.
Great Lakes Center
Buffalo State College
1300 Elmwood Avenue
Buffalo, NY 14222

December 2004

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The Soil Water Assessment Tool (SWAT) model was implemented to determine annual sediment yields and critical source areas of erosion for the Buffalo River Watershed. SWAT is a public-domain, GIS-based, spatially-distributed, dynamic model that can simulate watershed-scale hydrology and water quality processes. The landuse-landcover GIS layer for the Buffalo River watershed, an important input for SWAT, was manually updated using 2002 DOQs. Core data layers required for SWAT implementation were downloaded from the EPA BASINS web site. A 10m DEM available from the NY State GIS Clearinghouse was used to characterize the watershed boundaries in SWAT. The STASGO soils database was used to describe soil parameters for the model. Drainage network for the watershed was defined using the National Hydrography Data (NHD) layer. Model simulations were performed for the period 1996-2003. Weather data for model simulations was downloaded from the online NOAA web site and was available for three weather stations located within the Buffalo River basin.

Model calibrations were performed by comparing simulated streamflow discharge and sediment concentrations against measured values. Measured discharge data was available from USGS gages located on the three primary tributaries of the Buffalo River – Cazenovia Creek, Buffalo Creek and Cayuga Creek. Sediment concentrations were measured at four locations in the Cazenovia Creek watershed using continuously-logging YSI sondes. In addition, grab suspended-sediment sampling was also performed across multiple locations across the three main subwatersheds.

Calibrations were performed by first executing the model for the Cazenovia Creek watershed. Monte-Carlo simulations were performed to identify the most sensitive parameters and the "best-fit" parameter ranges. Key parameters that were most important for hydrologic calibrations were – SFTMP, SMTMP, SMFMX, SMFMN, SNOCOVMX, SNO50COV, SURLAG, PRF, GW_DELAY, and ALPHA_BF. Discharge calibrations were best for summer and fall storm events. The model did not do a very good job in simulating streamflow during winter and early spring. The cover C and practice P factors were the most important parameters for sediment calibrations. C and P values for croplands had to be reduced considerably (from default model values) to constrain simulated sediment yields within the observed data range. Once the parameter values were identified for Cazenovia Creek, the same set of parameter values were extended for the simulating the hydrology and sediment dynamics for the complete Buffalo River watershed.

SWAT simulated annual sediment yields for the Buffalo River watershed (108,593 ha) for the years 1996-2003 were in the range of 0.5 to 1.1 tons/ha/yr with an eight-year average of 0.8 tons/ha/yr. In absolute terms the total amount of sediment averaged 86,719 tons/yr. Streamflow discharge yield for the same eight-year period averaged 0.54. The Cazenovia Creek subwatershed contributed the largest portion (45%) to the total sediment yield from the Buffalo River watershed. This was despite the fact that in terms of total acreage Cazenovia Creek had the smallest portion of cropland compared to the other two watersheds. We attribute the higher sediment yields from Cazenovia Creek to the greater proportion of steep slopes in this subwatershed. SWAT simulations indicated that headwater watersheds in Cazenovia Creek and Cayuga Creek generated some of the highest sediment concentrations.

Overall, SWAT did a fairly good job in generating annual and seasonal sediment yields at the watershed scale and thus can be used as a planning tool for watershed assessment. However, the accuracy and reliability of SWAT predictions at the finer spatial (subcatchments and stream reaches) and temporal (daily and event) scales will depend on the accuracy of input information especially - the resolution of the LULC layer, the number of rainfall stations used in simulations, and the number of internal sites against which the model has been calibrated.

1. LULC UPDATE USING 2002 DIGITAL ORTHO PHOTO QUADS (DOQS)

1.1 Introduction

The land use data that was updated for this research was a USGS land use shapefile. This file is part of the data set for HUC #04120103 that was downloaded from the BASINS 3.0 website. The land use data were compiled from satellite data collected by the USGS from the mid-1970's through the early 1980's and converted to ArcInfo format by the EPA. The map scale is 1:250,000. The land use maps were classified using Level 1 and Level 2 of the Anderson Classification system. This classification system was designed in the late 1970's by the USGS for use with remotely sensed data (Anderson et al., 1976). Level I of the classification system includes nine broad land use categories such as "Urban or Built up" and "Agricultural Land". Level II includes detailed land use types under the Level I classification such as "Residential" and "Cropland and Pasture".

1.2 Methodology

The procedure used to update the existing land use coverage for the Buffalo River watershed involved the use of Digital Orthophoto Quads (DOQ's). A DOQ is a remotely sensed image in which all distortion has been removed. The DOQ's are available for direct download via the New York State Website (www.nysgis.state.ny.us/orthoprogram). DOQs for Western New York and the Buffalo River watershed region were flown and developed in 2002.

The image tiles are in MrSid format, which is a type of wavelet compression that makes file size smaller and web accessible. Images are named according to the New York State Department of Transportation (NYSDOT) quad sheet name. The scale of the DOQ's is 1:12,000.and the ground resolution is 1 meter. The images are color-infrared. The DOQ's are projected in the UTM coordinate system based on North American Datum (NAD) 83. All DOQ's are in UTM Zone 18 to match statewide vector data compilations.

The USGS land use shapefile was used as the base map. In order to overlay this file with the image tiles of the watershed it had to be projected in to UTM zone 18 (western New York technically lies within UTM zone 17). This shapefile was directly edited to facilitate the re-incorporation of the file with the BASINS models. The resulting overlay was shifted slightly to the northeast.

Arcview 3.2 GIS was used to update the land use file. The USGS land use shapefile was draped over the DOQ's and each land use in the watershed was assigned unique transparent shading. This allowed the images to be seen underneath. The existing land use cover was put in edit mode and the Polygon Split tool was used to split polygons where changes in land use were visible. When an individual polygon is split in half, two new polygons are created both having the land use code of the original polygon. The table associated with the land use shapefile was edited simultaneously. For example, if a sub-division appears on the DOQ'S where forest appears in the existing land use, the forest polygon was split around the sub-division and the new polygon was assigned the Residential land use code in the theme table. The Anderson Level II categories used in the updating process are listed in Table 1.1. ArcView automatically recalculates the area and perimeter of split polygons.

Each of the images tiles was visually compared to the USGS land use file and all major changes in land use were made. Efforts were concentrated on areas where significant land use changes have been observed. These areas included Lancaster, East Aurora, Orchard Park, and the southern portion of Clarence.

Once the existing land use cover was completed, the shapefile was brought into ArcEdit to clean and build typology. Sliver polygons were merged with adjacent polygons and polygons with the same land use code were dissolved, using the DISSOLVE command. The dissolve process simplifies the coverage by dissolving adjacent polygons with the same land use code into one polygon (Figure 1.1).

Table 1.1: Anderson Level II categories

Land Use Name	**Code**
Residential	11
Commercial and Services	12
Industrial	13
Trans, Comm, Util	14
Industrial and Commercial	15
Mixed Urban or Built-Up	16
Other Urban or Built-Up	17
Cropland and Pasture	21
Other Agricultural Land	24
Deciduous Forest Land	41
Evergreen Forest Land	42
Reservoirs	53
Forested Wetland	61
Nonforested Wetland	62
Strip Mines	75
Transitional Areas	76

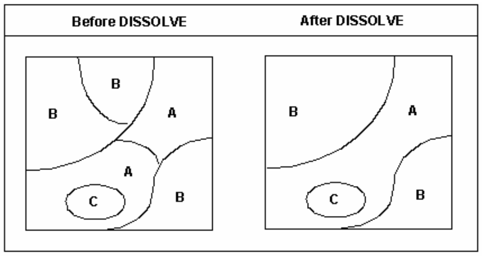


Figure 1.1: The DISSOLVE Process in ArcINFO.

1.3 Results

The old and updated LULC GIS layers are presented in Figure 1.2 and 1.3.

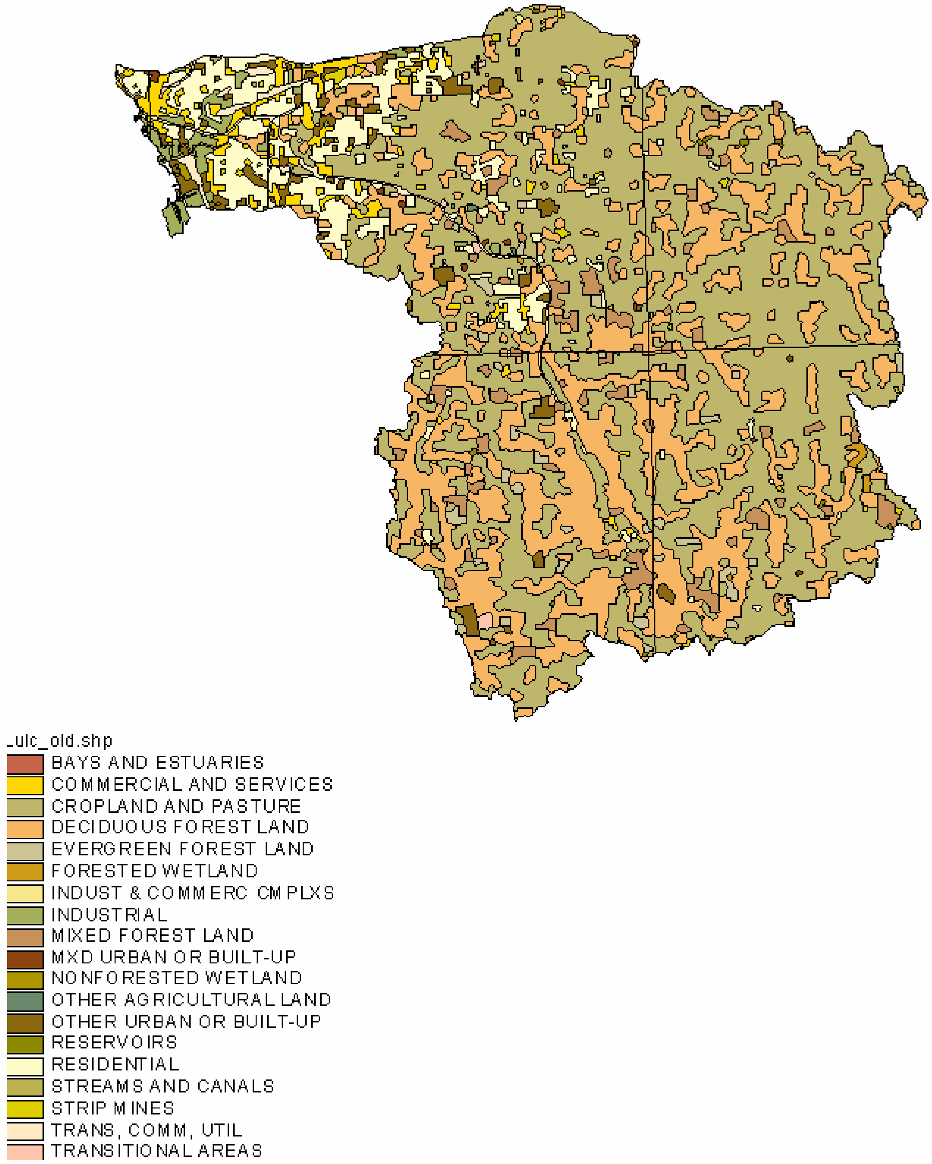


Figure 1.2: Old LULC distributed with BASINS-SWAT. LULC developed on 1970s data.

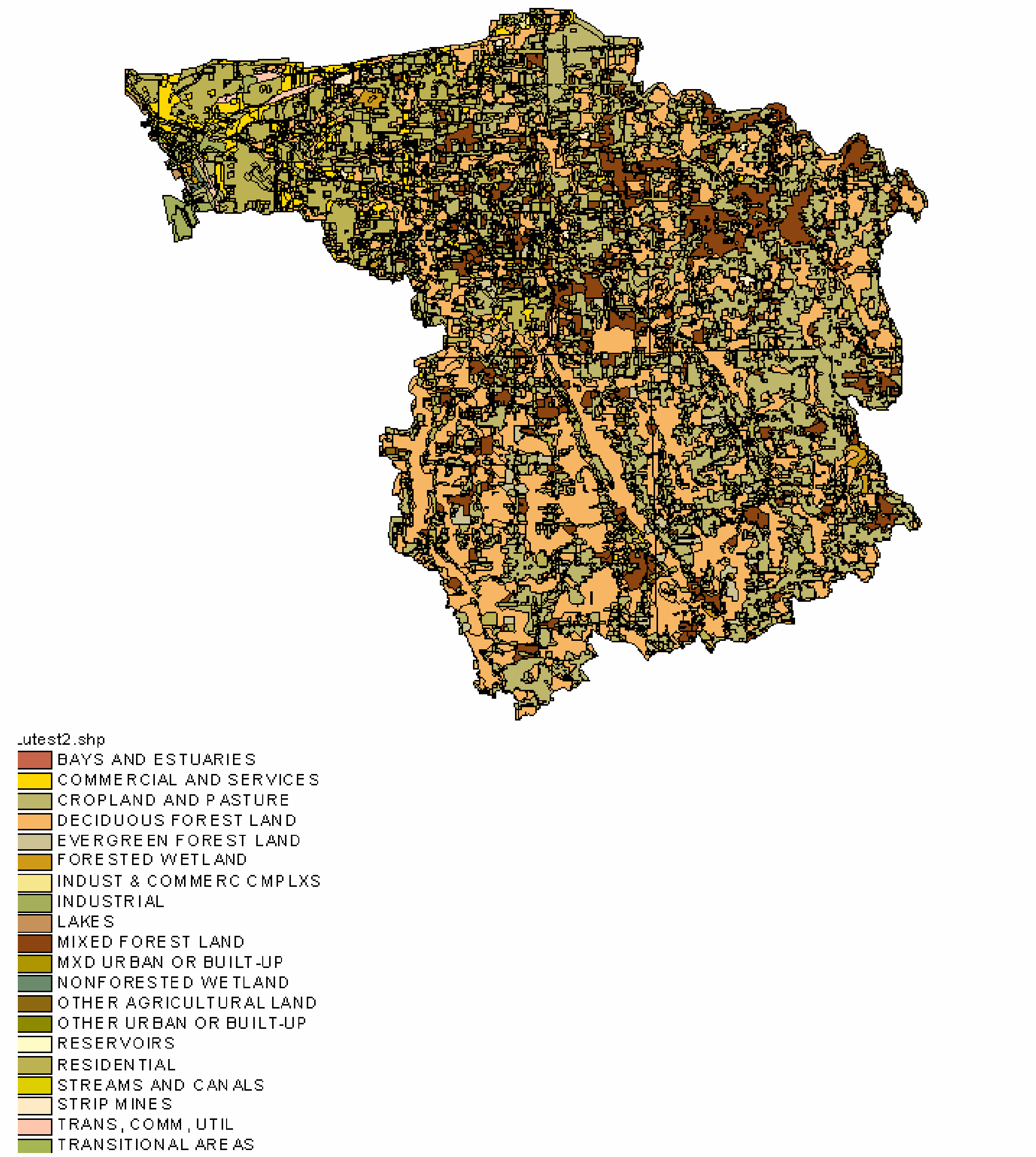


Figure 1.3: Updated LULC derived from 2002 DOQs.

2. DATA ON SEDIMENT CONCENTRATIONS

Sediment concentration data from the watershed streams was required to calibrate model simulations. Sediment concentrations in watershed streams were measured using:

- Visual assessment of the turbidity/suspended sediment
- Grab sampling to characterize suspended sediment
- Continuously-logging Hydrolab and YSI sondes

Starting August 2002 one hydrolab was installed in the Cazenovia Creek at the gage station location (Site 1A in Figure 2.1). The hydrolab recorded turbidity every 15 minutes. Grab suspended sediment sampling was performed at site to develop a regression relationship between turbidity and suspended sediment concentrations. Data from this location was available from August 2002 through December 2002 before the stream iced up. The hydrolab was reinstalled the following spring and data was available from the period of April 2003 through July 2003.

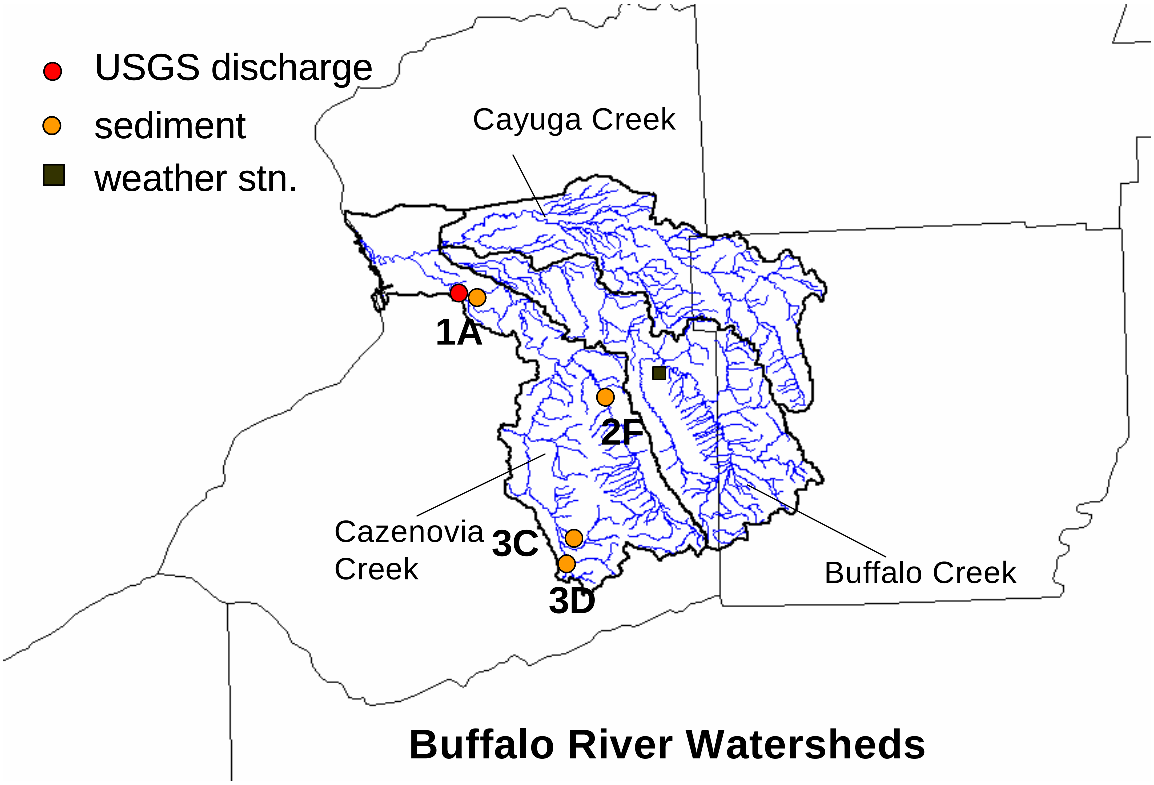


Figure 2.1: Sediment sampling locations in the Buffalo River watershed.

Starting July 2003 YSI sondes were installed at four separate locations in Cazenovia Creek to monitor turbidity (Figure 2.1 and 2.2). YSI sondes are similar to hydrolabs and record turbidity and other water quality variables. The four locations represented sediment concentrations on different stream orders and drained watersheds with different landuses.

Location 1A (Figure 2.1) situated at the USGS gage station measured the sediment concentrations at the outlet of the subwatershed. YSI sonde at 2F was located midway along the length of the east branch of Cazenovia Creek and was downstream of agricultural fields. The location at 3C was chosen to provide an estimate of sediment being generated from a subbasin which had a large forested area. Location 3D was chosen to sample a subbasin which had the most agricultural land in terms of the total fraction of the landuse. The sondes were programmed to sample at every 15 minutes. Again, grab sampling during storm events and non-storm periods was performed at each site to develop individual site-specific turbidity-suspended sediment relationships. In addition to this detailed sediment monitoring within the Cazenovia Creek subwatershed, limited grab sediment sampling was also performed at the outlets of the other two subwatersheds of the Buffalo River basin – Cayuga and Buffalo Creeks.

Figure 2.2: Photo showing the positioning of the YSI sonde at the watershed outlet of Cazenovia Creek (location 1A). The YSI sonde is encased within the white PVC pipe.

Grab samples of stream water collected at the selected sites during storm events and non-storm periods were analyzed for suspended sediment (mg/L). Suspended sediment was determined by filtering the samples through 45 µm filters and then determining the oven-dried weight of the filtered sediment. The suspended sediment values and the corresponding turbidity values recorded by the sonde were plotted to develop the suspended sediment-turbidity relationships (Figures 2.3 to 2.6). Visual assessment for sediment in the streams was performed by visiting the sampling locations (Figure 2.1) during storm events and non-storm periods.

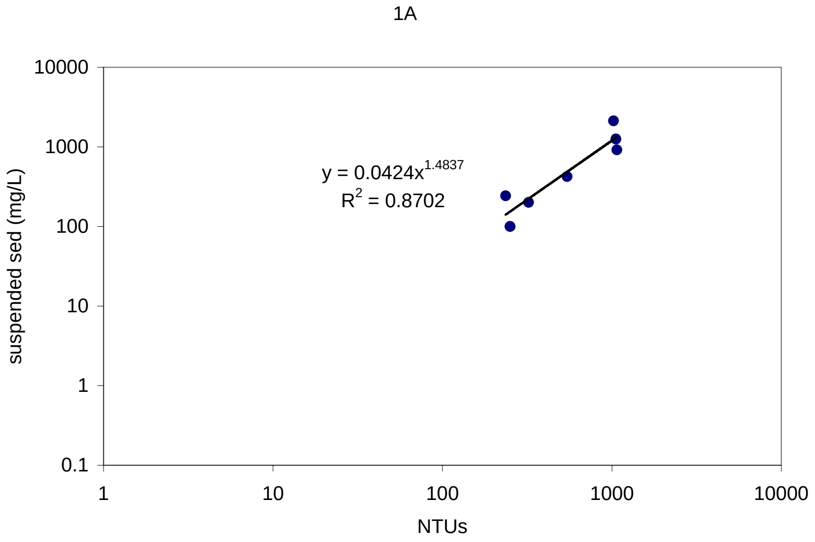


Figure 2.3: Relationship between suspended sediment and turbidity for site 1A. The regression line shows the fitted linear equation to measured data points.

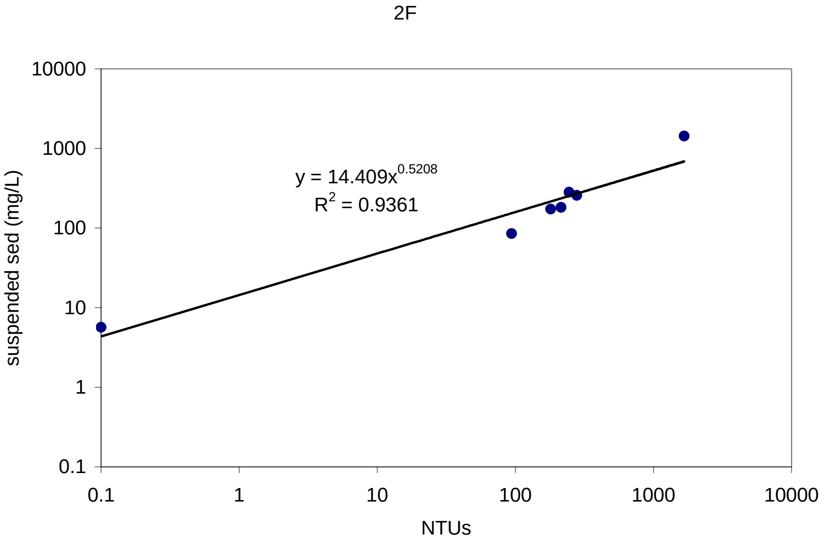


Figure 2.4: Relationship between suspended sediment and turbidity for site 2F. The regression line shows the fitted linear equation to measured data points.

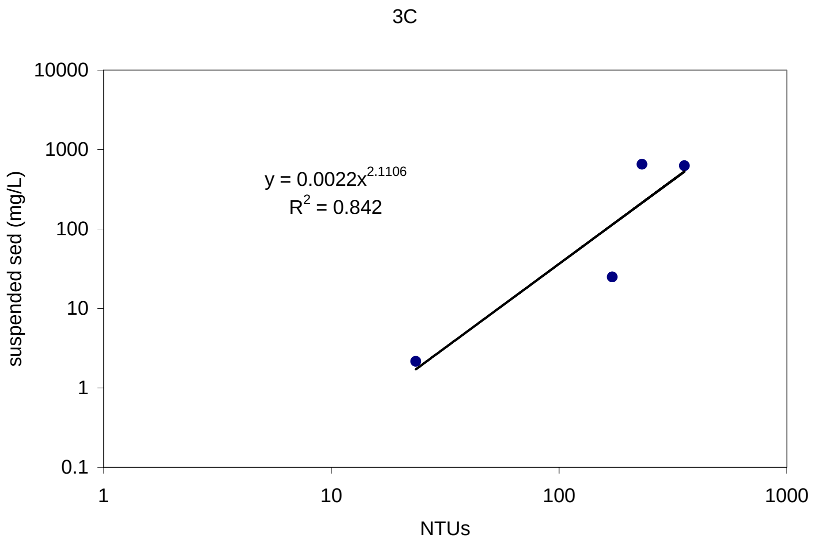


Figure 2.5: Relationship between suspended sediment and turbidity for site 3C. The regression line shows the fitted linear equation to measured data points.

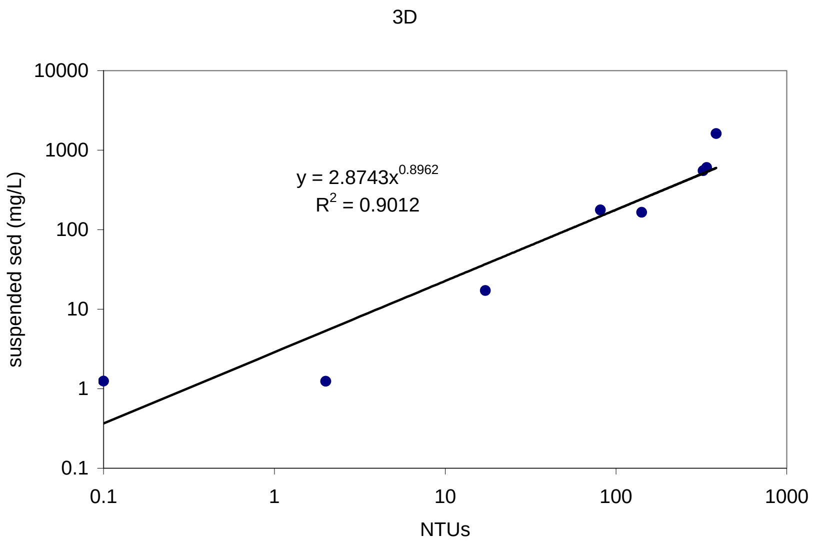


Figure 2.6: Relationship between suspended sediment and turbidity for site 3D. The regression line shows the fitted linear equation to measured data points.

In addition to the sediment grab sampling for developing regression relationships for the sonde/hydrolab locations, some limited grab sampling (of suspended sediment in streamflow) was also conducted to determine the spatial pattern of sediment concentrations across the three main subwatersheds of the Buffalo River – Cazenovia Creek, Buffalo Creek, and Cayuga Creek. The sites at which grab samples were collected are shown in Figure 2.7. The suspended sediment concentrations recorded at these sites for storm and non-storm periods are presented in Figures 2.8 and 2.9, respectively.

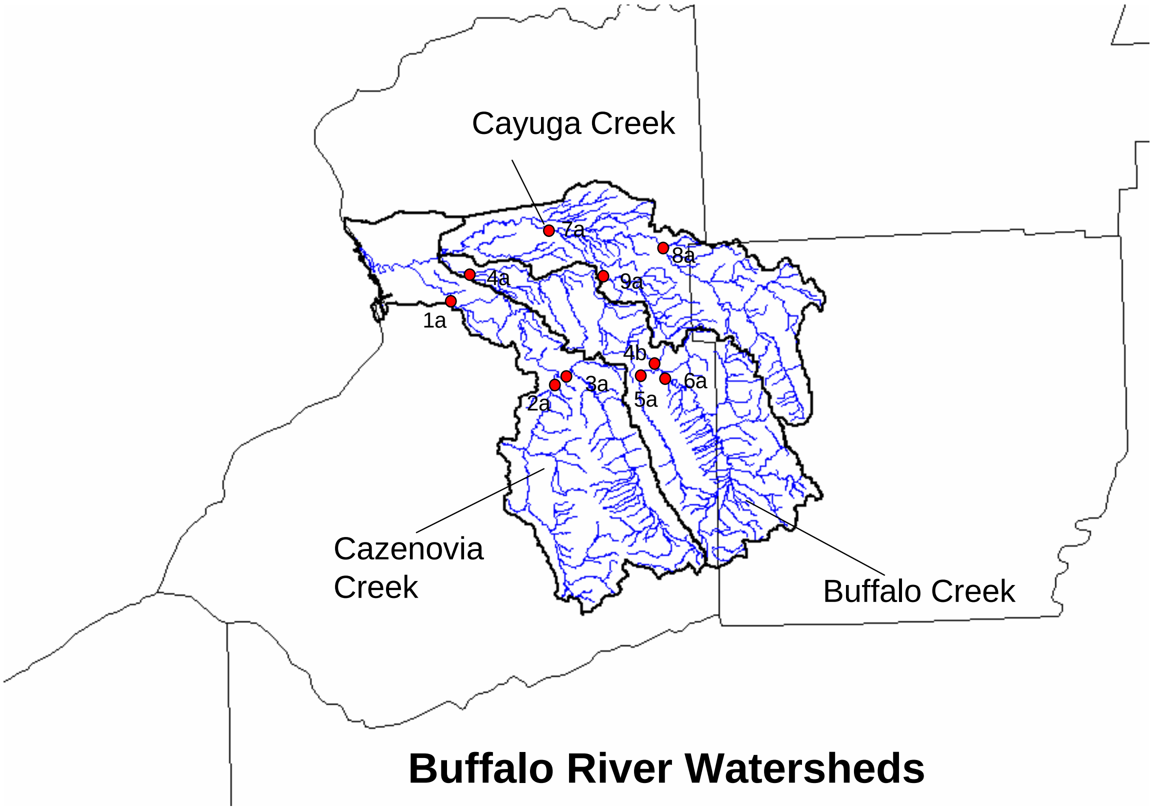


Figure 2.7: Locations for grab suspended sediment sampling performed during storm and non-storm periods.

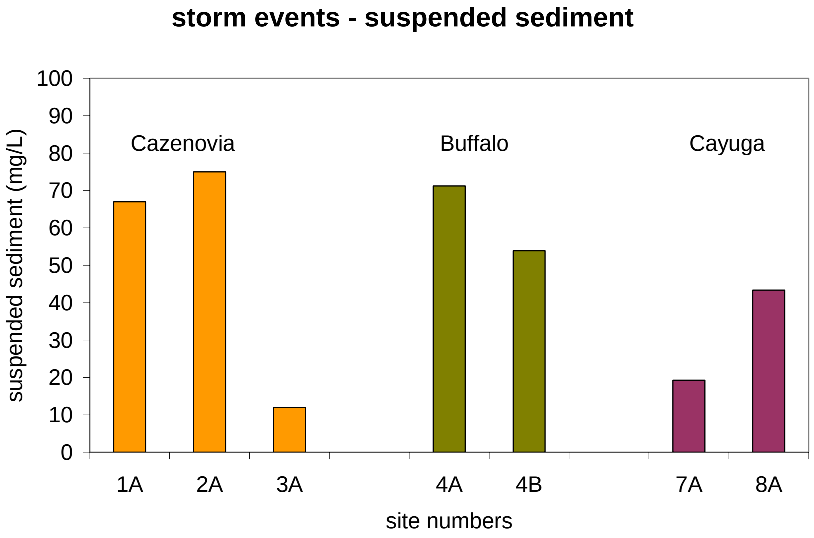


Figure 2.8: Suspended sediment concentrations recorded during storm events across the three main subwatersheds.

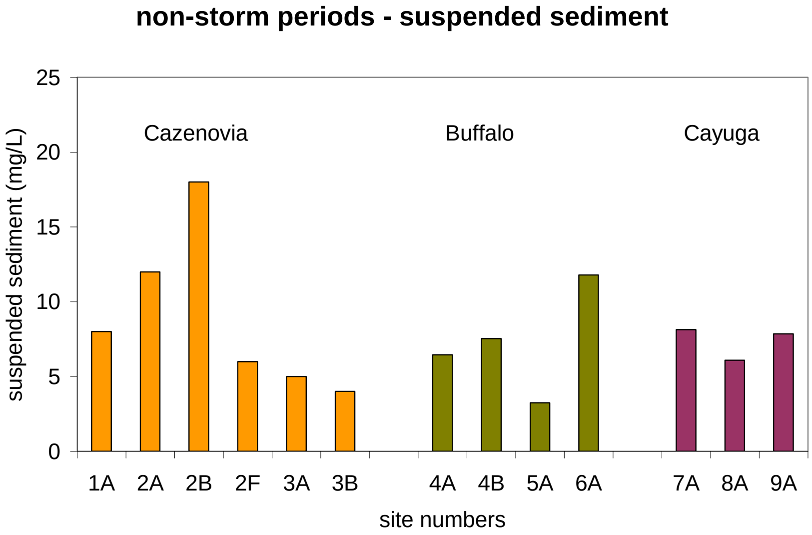


Figure 2.9: Suspended sediment concentrations during non-storm periods across the three main subwatersheds

From Figures 2.8 and 2.9, sediment concentrations were highest in the Cazenovia Creek followed by Buffalo and Cayuga Creeks across both storm and non-storm periods. The difference between sediment concentrations for Cazenovia and Buffalo Creeks was lower during storm periods. Within Cazenovia Creek, sediment concentrations measured for the east branch (2A, 2B) exceeded values recorded for the west branch (3A, 3B).

3. SWAT CALIBRATION FOR THE CAZENOVIA CREEK WATERSHED

The BASINS-SWAT (Di Luzio et al., 2002; Srinivasan and Arnold, 1994) (http://www.brc.tamus.edu/swat/) model was first implemented for the Cazenovia Creek subwatershed of the Buffalo River basin (Figure 3.1). The Cazenovia Creek watershed covers an area of 136 square miles in the 424 square miles Buffalo River watershed. The intent was to calibrate the model using detailed data from the Cazenovia Creek watershed and then extend the calibrated parameter values for the full Buffalo River watershed simulation.

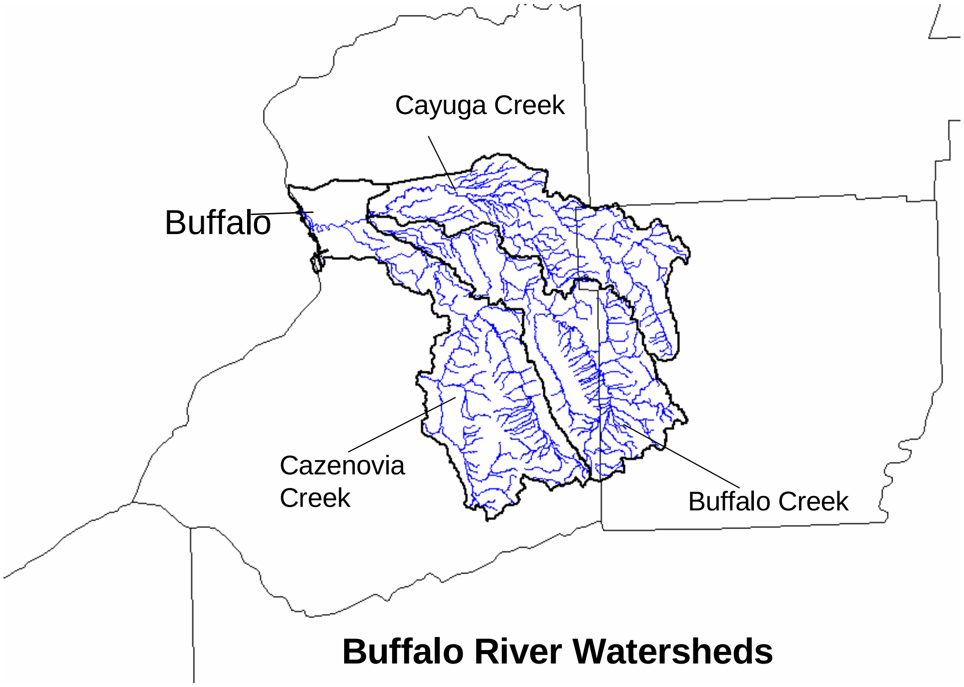


Figure 3.1: The 424 square mile Buffalo River watershed and its three main subwatersheds - Cazenovia, Buffalo, and Cayuga Creeks.

3.1 Implementation of the model

The following base GIS layers were developed to delineate the Cazenovia Creek watershed in the BASINS-SWAT model:

- 10 m DEM – developed by merging 10m DEM quads available off the internet.
- National Hydrography Data layer showing the streams – available off the internet
- Updated USGS LULC layer – described above
- STASGO soils layer – available over the internet http://www.ncgc.nrcs.usda.gov/branch/ssb/products/statsgo/

The DEM, LULC, and soils layers for the Cazenovia Creek watershed implementation are presented in Figures 3.2 through 3.4.

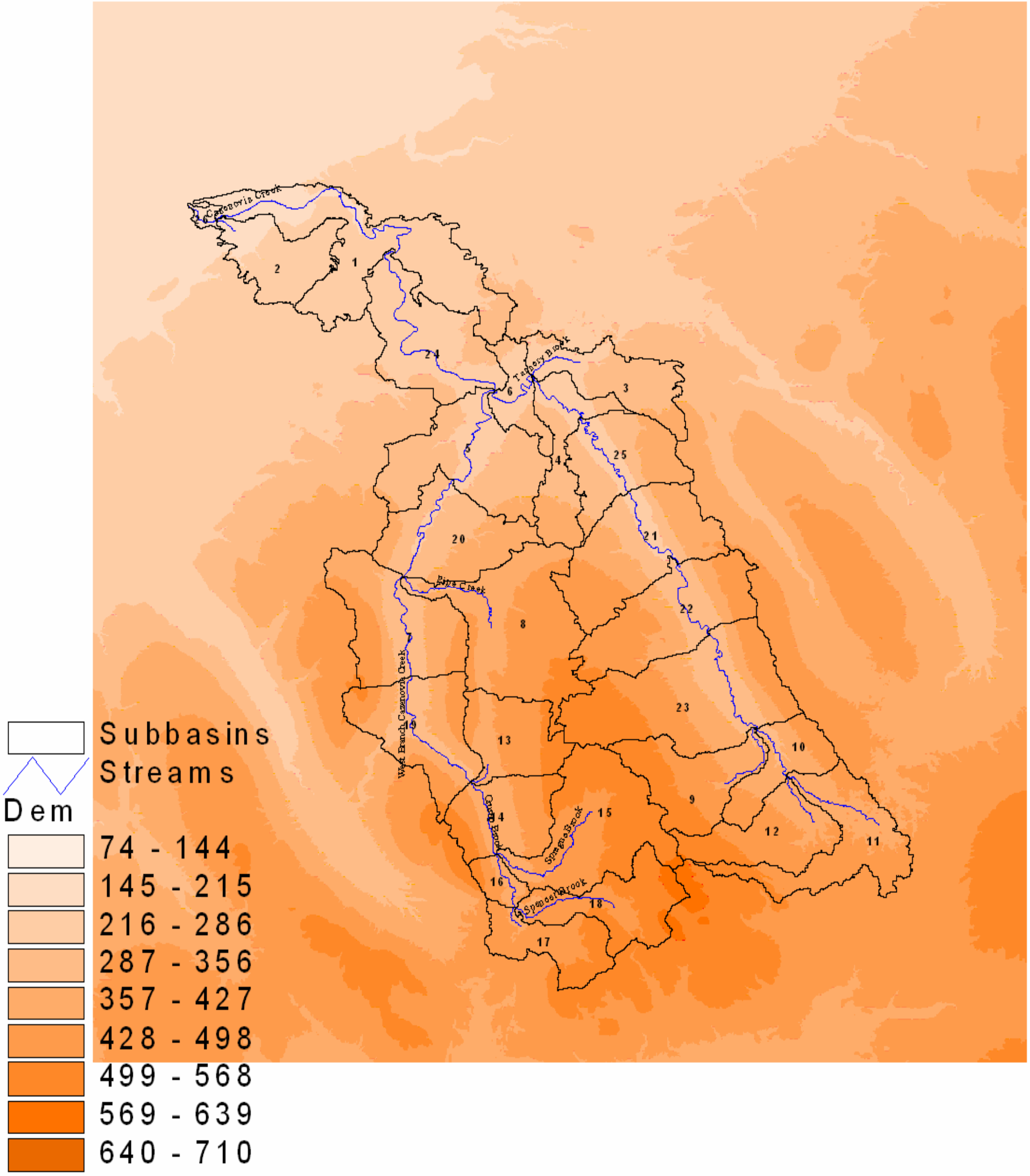


Figure 3.2: Cazenovia Creek subbasin with the 10 m grid DEM. DEM elevation is in meters.

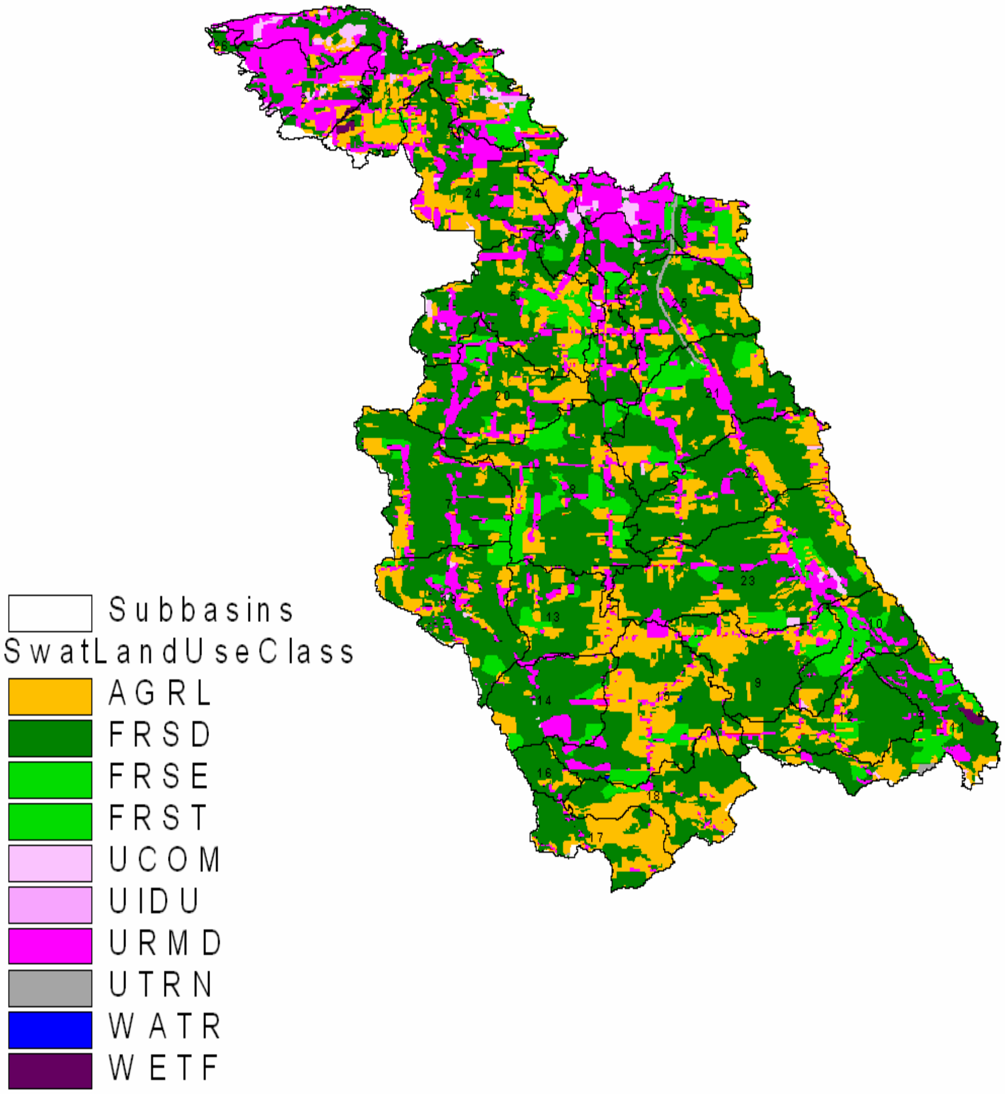


Figure 3.3: LULC for the Cazenovia Creek subwatershed developed from the 2002 DOQs.

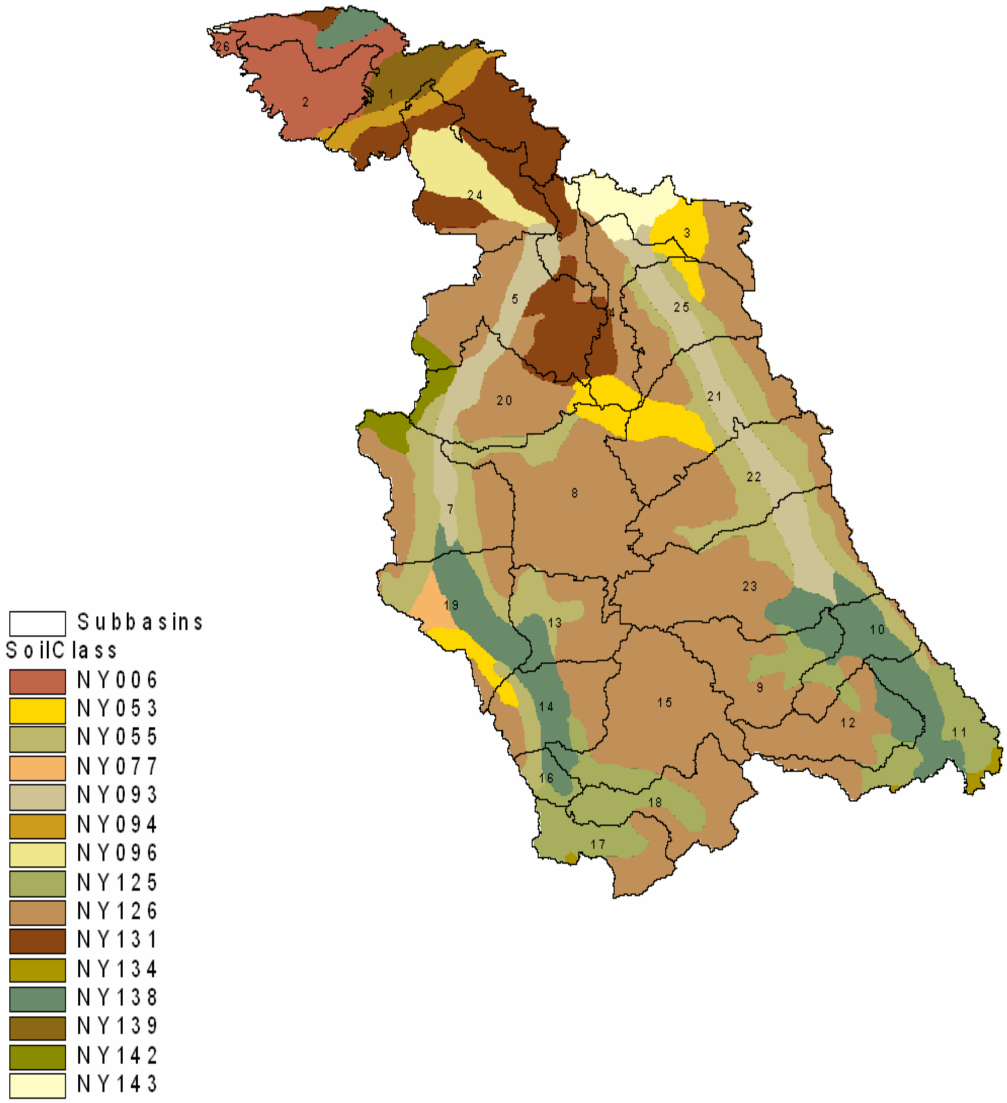


Figure 3.4: STASGO soils distribution for the Cazenovia Creek subwatershed.

3.2 Climate data and streamflow discharge

Daily weather data was available for three climate stations in the Buffalo River watershed. The data was downloaded off the NOAA web site: http://www.ncdc.noaa.gov/oa/climate/stationlocator.html. The three stations were – Buffalo Airport, Wales and Bennington. Data for the period 1990 through 2004 was downloaded and used in model simulations. Cazenovia Creek simulations were performed using only Wales station data since it was the closest station to the subwatershed.

Daily streamflow discharge measured at three USGS gage stations in the Buffalo river watershed was obtained for the USGS web site: http://waterdata.usgs.gov/ny/nwis/current/?type=flow. The three gage stations were: Cazenovia Creek at Ebenezer, Buffalo Creek at Gardenville, and Cayuga Creek at Lancaster. Discharge data for the period 1990 through 2004 was downloaded.

3.3 Methodology for model calibration:

The following steps were taken for calibrating the SWAT model for the Cazenovia Creek watershed:

1. The streamflow discharge data for USGS gage on Cazenovia Creek for the period 1997 to 2002 was selected. This data was then decomposed in baseflow and stormflow values using the baseflow filter algorithm (http://www.brc.tamus.edu/swat/soft_baseflow.html).

2. Model calibrations were then performed by adjusting selected parameter values till the simulated values of total streamflow, baseflow and stormflow matched the observed values. Similar to observed values, total simulated streamflow was partitioned into baseflow and stormflow using the filter algorithm. Model calibrations were performed by executing the SWAT model in a Monte-Carlo simulation mode outside the ArcView framework. For Monte-Carlo simulations chosen parameter values were varied within predetermined parameter bounds. The parameter bounds were decided based on measured values and literature data on our watershed. Specific objective tests were used to quantify the fit between discrete observed and simulated values. The details on the Monte-Carlo tests are provided in the following section. Monte-Carlo simulations allowed us to identify the most sensitive parameters for our watershed and climate conditions and also provided the optimal parameter bounds.

3. For streamflow, the intent during calibrations was to fit the model as closely as possible to the observed data. Discrete point discharge values of observed and simulated data were compared and the difference between the two was minimized. In comparison for sediment data the intent was to first bring the simulated values within an order of magnitude of the observed data and subsequently fine-tune the calibrations if possible.

4. After optimal parameter bounds were identified using Monte-Carlo simulations, the model was executed within the single-run ArcView framework using the optimal parameter values. Simulations were performed for the period 1997-2002.

5. Model simulations for sediment concentrations were further evaluated using data from the years 2003-2004. Spatial pattern of sediment generation in the watershed was evaluated by comparing model predictions against sediment data from multiple points.

3.4 Monte Carlo Simulations

The fact that SWAT is a process-based, distributed model means that it has a multitude of parameters. SWAT parameters control different aspects of model behavior, from discharge to sediment and pollutant transport, and are likely not equally important for any specific simulation goal. For the model calibration to be successful, and especially if automated calibration methods are to be employed, we need to know how sensitive is SWAT to different parameters. Model sensitivity is usually studied through the use of Monte Carlo method, whereby the model is run many times each time varying the values of parameters. Here is a brief outline of Monte Carlo method used in this study:

1. Select physically meaningful bounds (minimum and maximum values) for each parameter
2. Run the model many times, during each of the runs: (a) Select a random value for each parameter from the corresponding bounds, usually using the uniform distribution; (b) Run model with these parameter values; (c) Measure model performance by calculating one or more objective functions.
3. Analyze data from all runs – look at the relation between parameter value and model performance. More or less sophisticated methods (e.g., Generalized Sensitivity Analysis) may be used to achieve this purpose. In this study we use a simple approach: Pearson's correlation between parameter value and an objective function.

An objective function is a numeric measure of model performance, i.e. of how well the model corresponds to the observed system. We use the following four objective functions calculated from daily observed and predicted values:

<u>Nash-Sutcliffe measure (NS) (Nash and Sutcliffe, 1970)</u>:

$$NS = 1 - \frac{\sum_{t=1}^{n} (O_t - Z_t)^2}{\sum_{t=1}^{n} (O_t - \overline{O})^2}$$

where O_t and Z_t are respectively observed and predicted values at time t, and O is the mean of observed values. NS varies from 1 (for a perfect model fit) to 0 (model is no better than simple average of observed discharge) to negative values (model performs worse than the observed average discharge). Generally, NS values in the range 0 - 0.33 are considered to indicate poor model performance, 0.33 - 0.75 – acceptable, and 0.75 - 1 – good performance.

<u>Model Bias (Yapo et al., 1996):</u>

$$Bias = \frac{\sum_{t=1}^{n}(Z_t - O_t)}{\sum_{t=1}^{n} O_t}$$

Bias measures the tendency of the model-simulated values to be larger or smaller than their observed counterpart (Beldring, 2002).

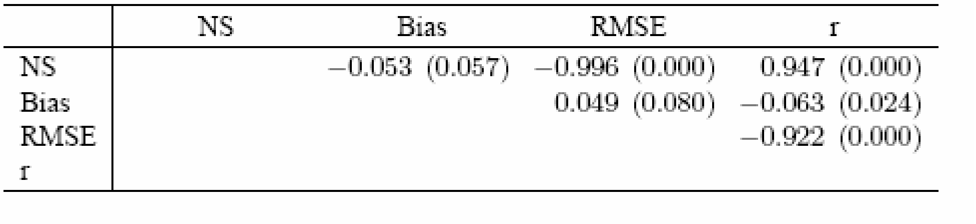
<u>Root Mean Square Error (RMSE):</u>

$$RMSE = \sqrt{\frac{1}{n}\sum_{t=1}^{n}(O_t - Z_t)^2}$$

Correlation (r) is the usual Pearson product-moment correlation.

When using multiple criteria of model performance care should be taken to avoid measures that are closely related, i.e.” measure similar characteristics of the discrepancy between a model and the modeled quantity” (Beldring, 2002, p. 192). Closely related measures duplicate each other and thus have low cumulative information content, while ”orthogonal” or noncommensurable (Gupta et al., 1998) criteria quantify relatively independent aspects of modeled system and therefore have high total information content. The idea of noncommensurable measures of information is illustrated in Table 2.2. We used simple Pearson’s correlation to estimate the degree of duplication of the four objective functions defined above. Three out of four objective functions – NS, RMSE, r – are highly correlated: correlation coefficient is close to 1 or -1 and p-value is low. Bias, on the other hand, is not significantly correlated with any other functions. Based on this assessment only two objective functions are selected for further use in this sensitivity study: NS (we could have selected RMSE or r, but NS is more customarily used), and Bias.

Table 3.1: Correlation of objective functions, based on 1300 SWAT model runs. Pearson’s correlation coefficient between the four objective functions. Number in parentheses is p-value associated with the correlation test.



	NS	Bias	RMSE	r
NS		−0.053 (0.057)	−0.996 (0.000)	0.947 (0.000)
Bias			0.049 (0.080)	−0.063 (0.024)
RMSE				−0.922 (0.000)
r				

Table 2.3 summarizes results of sensitivity analysis based on a Monte Carlo experiment which consisted of 2,400 SWAT runs. Each run was a daily simulation from 1997 to 2002 (6 years). The objective functions were calculated for measured and simulated discharge at Cazenovia watershed outlet. Parameters included in this analysis were selected on the basis of preliminary sensitivity experiments, each focusing on a specific type of parameters (basin wide, soil, groundwater, etc.) and having 300 SWAT runs. The two “Sensitivity” columns, “NS” and

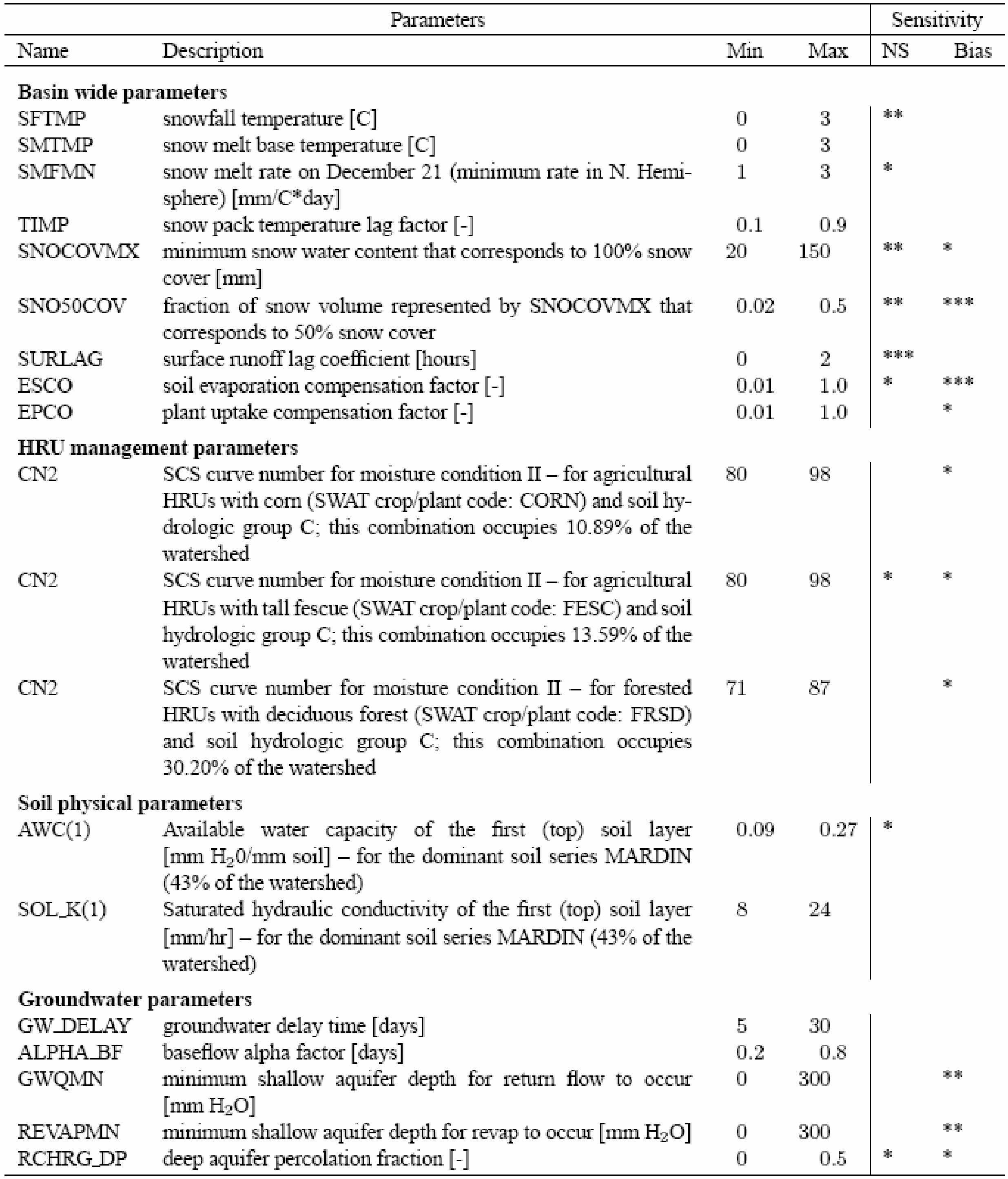
“Bias” provide qualitative assessment of SWAT sensitivity to these parameters using the two selected objective functions. A blank entry means that SWAT is not sensitive to the parameter in question (according to the chosen objective function), while “*”, “**”, and “***” denote some, medium, and high sensitivity. Several conclusions can be made from the table:

- SWAT exhibits sensitivity to different parameters and to a different degree according to NS versus Bias. This is to be expected, since these two objective functions provide non-overlapping information on model error: Bias looks for the overall tendency of the model to underestimate or overestimate discharge, while NS focuses on the closeness of daily discharge fit.
- Basin wide parameters are very important, especially those related to snow distribution, snowfall, and to a lesser degree, snowmelt.
- As was found during manual calibration, the surface lag coefficient, SURLAG, is extremely important for achieving good fit to daily hydrograph. This observation is confirmed by high sensitivity of NS to SURLAG.
- Soil evaporation compensation parameter, ESCO, is particularly significant for the overall water budget, as measured by Bias.
- In a similar way, groundwater parameters mostly affect the overall water balance, and are thus “noticed” by Bias. Groundwater is too slow to affect daily hydrograph fit emphasized by NS.

Figures 3.5 - 3.8 show dotty plots resulting from the 2,400-run Monte Carlo experiment. On each plot gray vertical lines show parameter values that correspond to the best 2% of simulations (i.e. best 48 simulations). SWAT is said to be sensitive to a parameter when one or more of these statements are true:

- There is a significant correlation between the parameter and an objective function.
- The relationship between the parameter and the objective function is non-linear (as indicated by the superimposed trend line)
- The majority of best SWAT runs concentrate in one area of the parameter space – gray lines congregate together.

Table 3.2: SWAT parameters used in sensitivity analysis for discharge simulations.



Parameters				Sensitivity	
Name	Description	Min	Max	NS	Bias
Basin wide parameters					
SFTMP	snowfall temperature [C]	0	3	**	
SMTMP	snow melt base temperature [C]	0	3		
SMFMN	snow melt rate on December 21 (minimum rate in N. Hemisphere) [mm/C*day]	1	3	*	
TIMP	snow pack temperature lag factor [-]	0.1	0.9		
SNOCOVMX	minimum snow water content that corresponds to 100% snow cover [mm]	20	150	**	*
SNO50COV	fraction of snow volume represented by SNOCOVMX that corresponds to 50% snow cover	0.02	0.5	**	***
SURLAG	surface runoff lag coefficient [hours]	0	2	***	
ESCO	soil evaporation compensation factor [-]	0.01	1.0	*	***
EPCO	plant uptake compensation factor [-]	0.01	1.0		*
HRU management parameters					
CN2	SCS curve number for moisture condition II – for agricultural HRUs with corn (SWAT crop/plant code: CORN) and soil hydrologic group C; this combination occupies 10.89% of the watershed	80	98		*
CN2	SCS curve number for moisture condition II – for agricultural HRUs with tall fescue (SWAT crop/plant code: FESC) and soil hydrologic group C; this combination occupies 13.59% of the watershed	80	98	*	*
CN2	SCS curve number for moisture condition II – for forested HRUs with deciduous forest (SWAT crop/plant code: FRSD) and soil hydrologic group C; this combination occupies 30.20% of the watershed	71	87		*
Soil physical parameters					
AWC(1)	Available water capacity of the first (top) soil layer [mm H_20/mm soil] – for the dominant soil series MARDIN (43% of the watershed)	0.09	0.27	*	
SOL_K(1)	Saturated hydraulic conductivity of the first (top) soil layer [mm/hr] – for the dominant soil series MARDIN (43% of the watershed)	8	24		
Groundwater parameters					
GW_DELAY	groundwater delay time [days]	5	30		
ALPHA_BF	baseflow alpha factor [days]	0.2	0.8		
GWQMN	minimum shallow aquifer depth for return flow to occur [mm H_2O]	0	300		**
REVAPMN	minimum shallow aquifer depth for revap to occur [mm H_2O]	0	300		**
RCHRG_DP	deep aquifer percolation fraction [-]	0	0.5	*	*

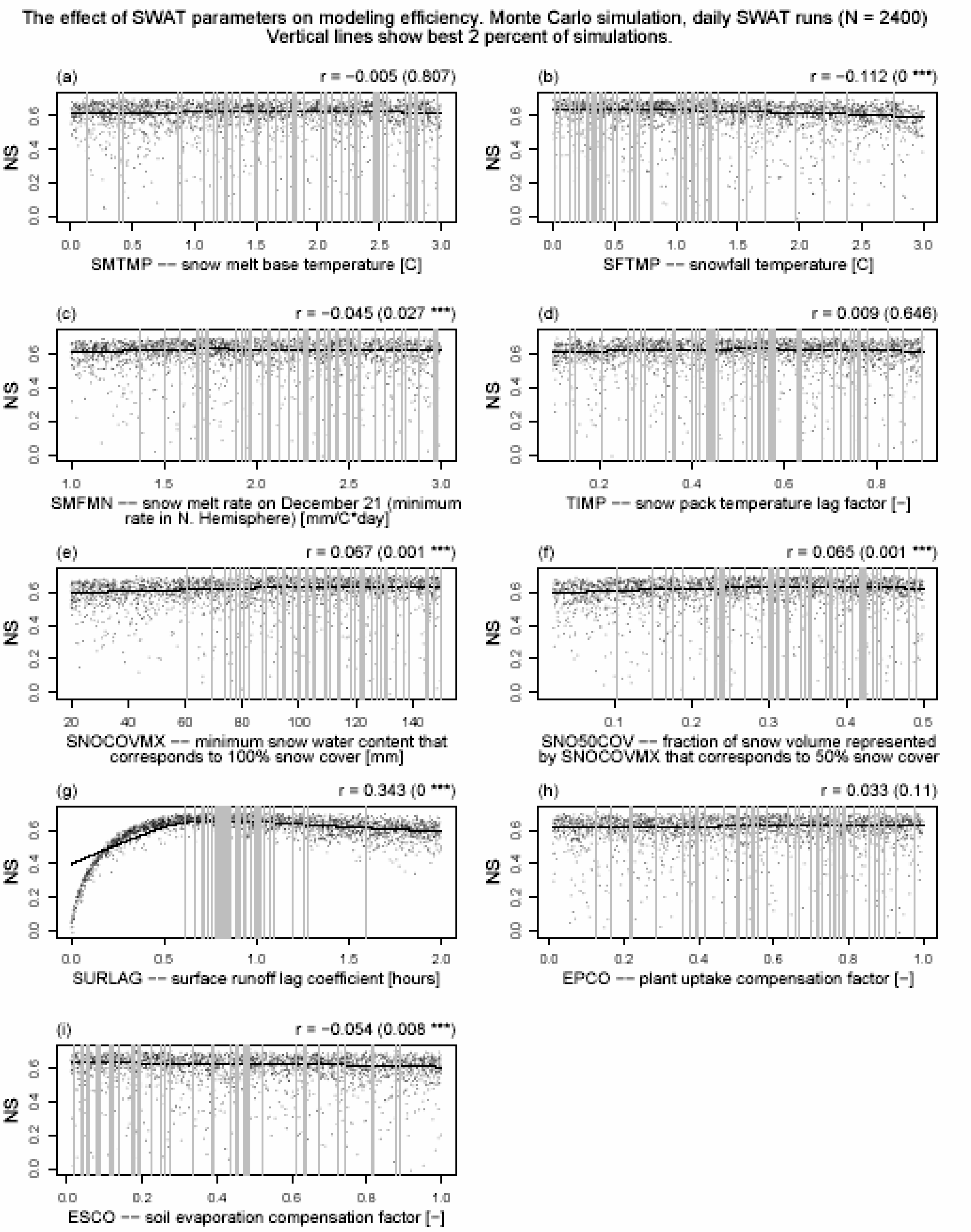


Figure 3.5: Sensitivity of SWAT discharge simulations to basin-wide parameters as measured by Nash Sutcliffe efficiency. Numbers at the top right corner of every plot are correlation between parameter value and Nash Sutcliffe efficiency and its p value.

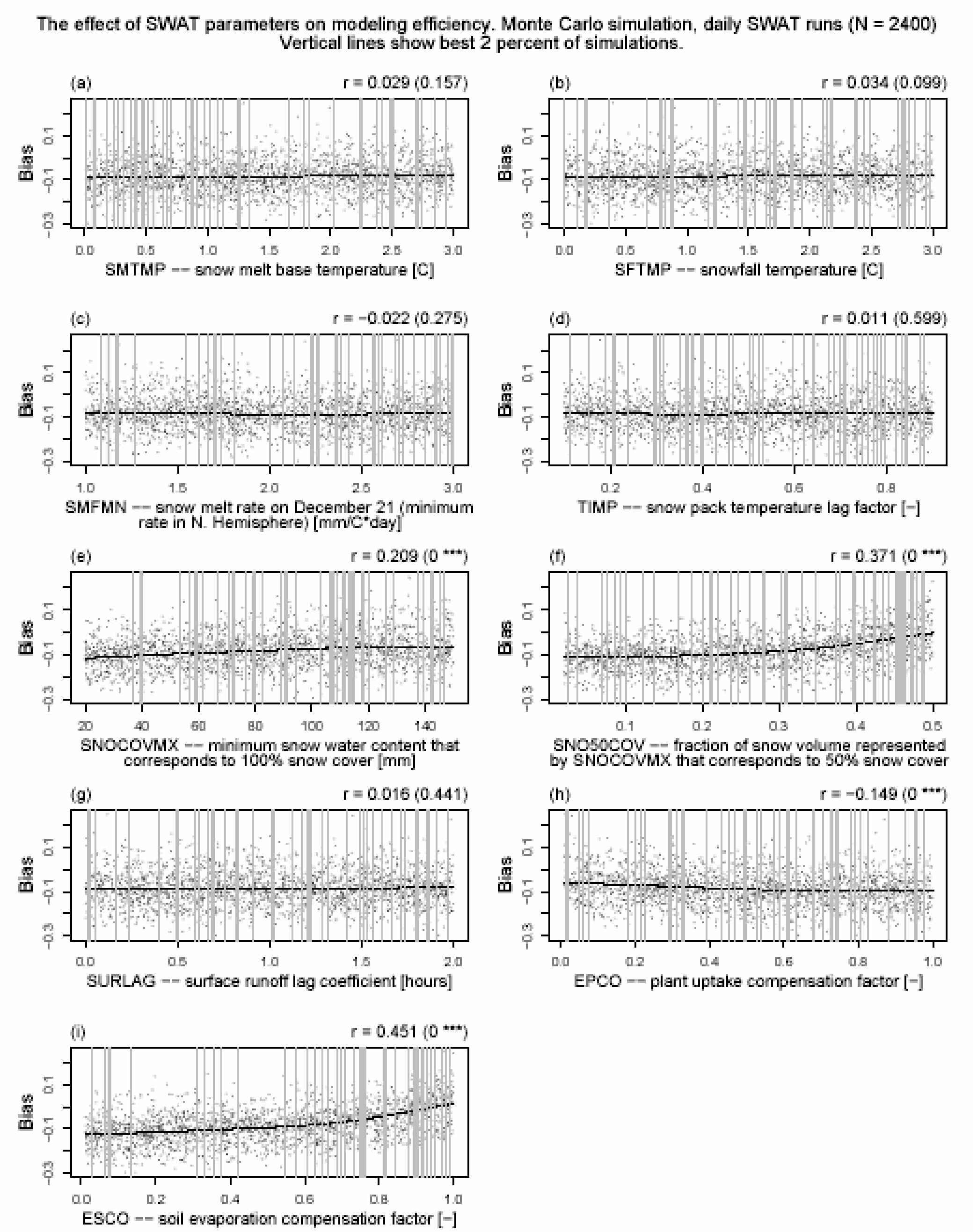


Figure 3.6: Sensitivity of SWAT discharge simulations to basin wide parameters as measured by Bias. Numbers at the top right corner of every plot are correlation between the parameter value and Bias and its p value.

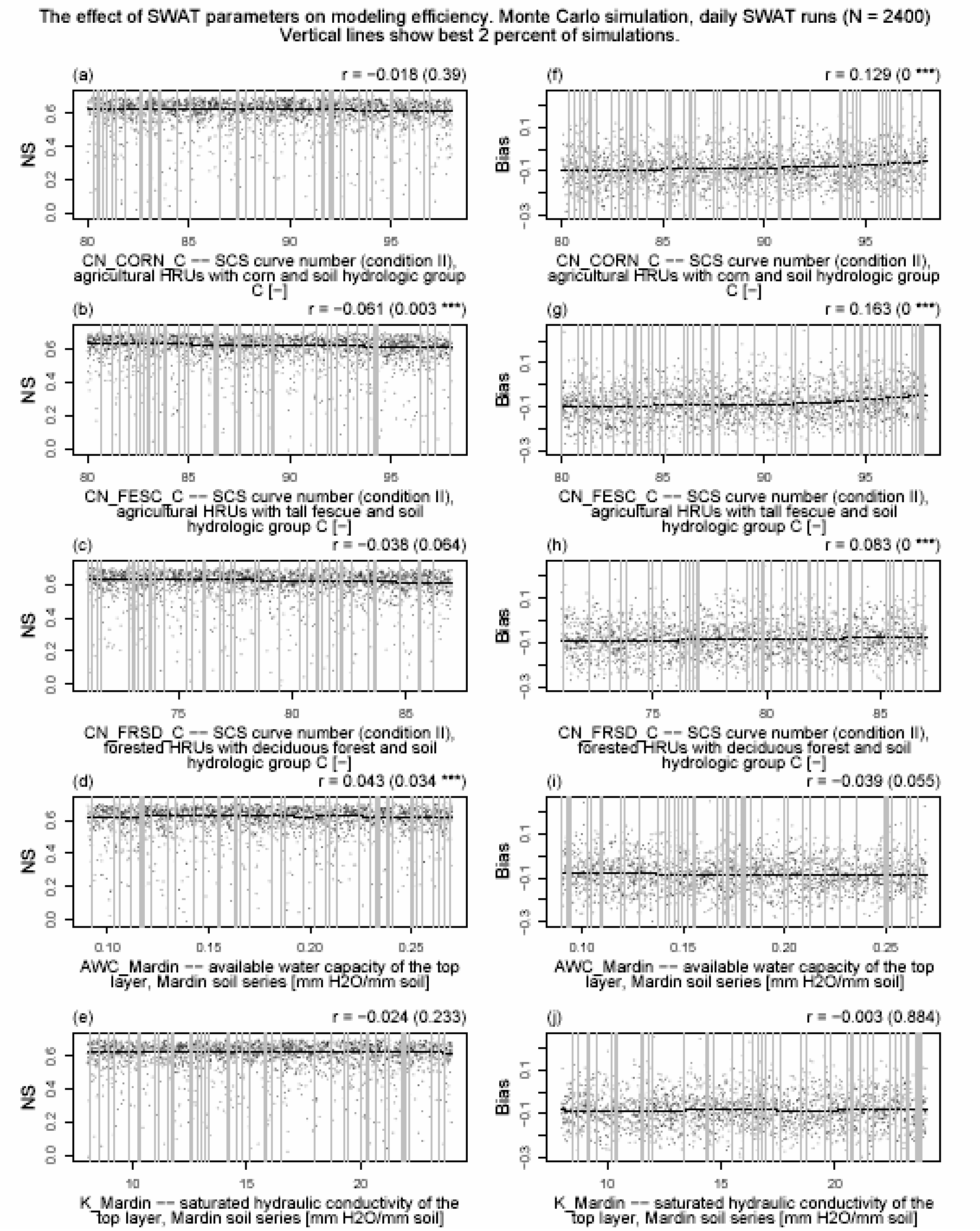


Figure 3.7: Sensitivity of SWAT discharge simulations to HRU management parameters – curve numbers, and soil physical parameters as measured by Nash Sutcliffe efficiency and Bias.

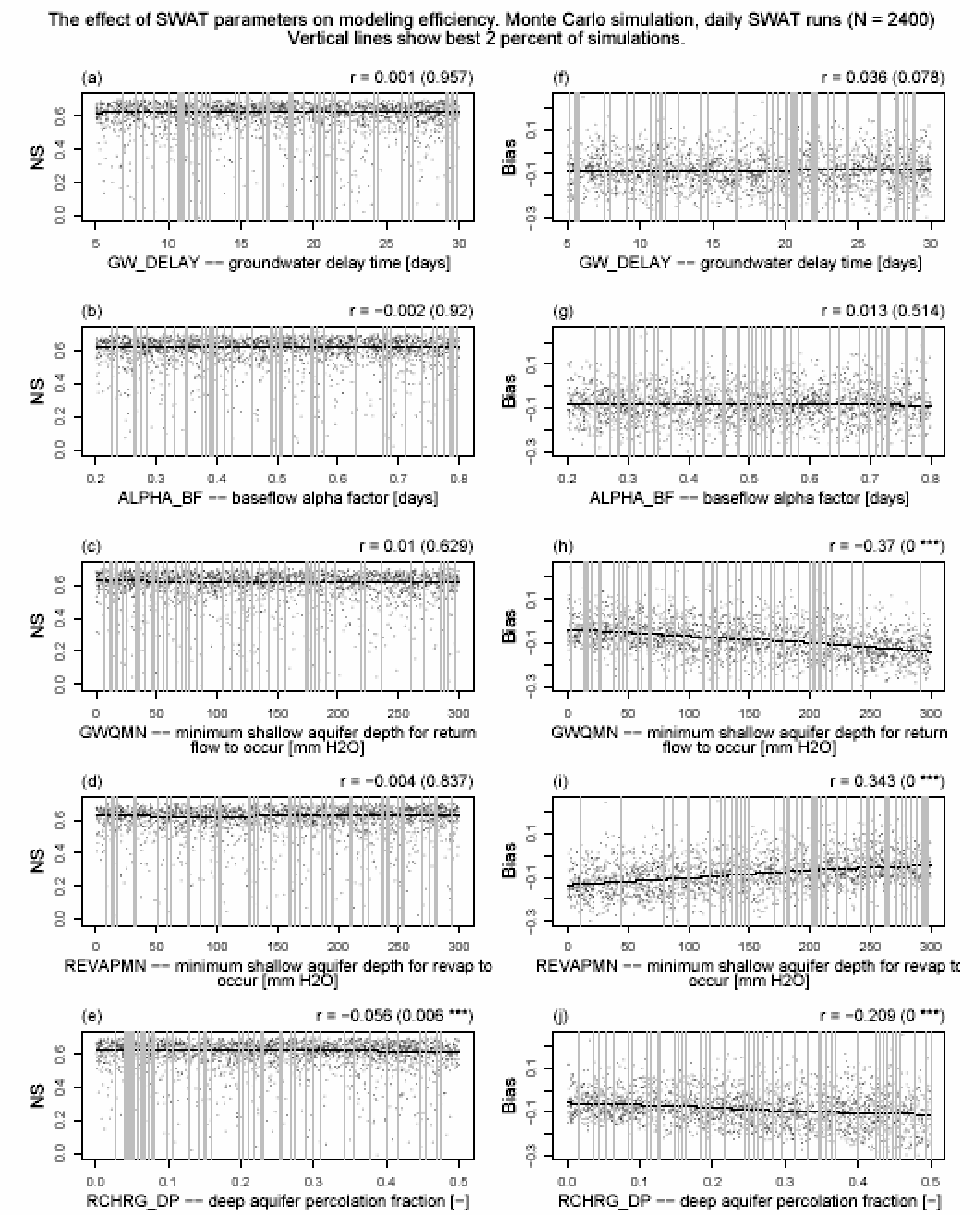


Figure 3.8: Sensitivity of SWAT discharge simulations to groundwater parameters measured by the Nash Sutcliffe efficiency and Bias

3.5 Calibration for streamflow discharge

Once the optimum parameter values were identified (Table 3.3) from Monte Carlo analysis, these values were then used in ArcView-based SWAT simulations. Streamflow comparisons were first performed at the annual scale. A plot of the simulated and measured annual streamflows for the period of 1998-2003 is presented in Figure 3.9. Simulations were performed for the years 1997-2003, but data for 1997 was not considered since this was used as a "warm-up" period for the model simulations (so that model results could stabilize). Except for the year 2001, all simulated annual streamflow discharge values were within 10% of the observed totals. The average deviation across the six year period was -7.9%. Except for the year 1999, the model under-predicted the annual streamflow discharge.

A plot of the daily simulated and observed streamflow comparisons for two separate years are presented in Figures 3.10 and 3.11. The model did a better job in simulating the summer and fall periods but was not able to represent the streamflow dynamics for winter and spring seasons very accurately. During winter (January-March) the observed streamflows were greater than that predicted by the model. Whereas, the simulated values exceeded the observed data during spring (April-May). This indicates a problem with the snow storage and release (melt) parameters in the model. It appears that a greater amount of melting is occurring during winter than what the model is simulating. It is also likely that the observed streamflow data may be higher than what occurs at the site. The gage station at Cazenovia is often subject to ice jams and backing-up of the water during the winter periods. Ice jams and freezing of the stream surface cause water levels to rise and during this time the gage indicates an "ice" condition rather than providing a stage and discharge value. The USGS "adjusts" these periods and estimates the possible discharge that may have occurred based on stage elevations for ice-free conditions. It is likely that this estimation procedure might produce slight overestimation of streamflow discharge.

The daily plots also indicate that there are some summer and fall storms events for which the model either under or over-predicts the streamflow discharge. We attribute this to variability in rainfall distribution across the watershed. Since we are using only one rainfall station to represent the rainfall pattern over an area of 136 mi^2 it is very likely that we may not be representing the natural variability in rainfall distribution. Inclusion of additional meteorological stations will most likely improve model fits.

A frequency analysis of daily streamflows for the period 1998-2003 (Figure 3.12) indicated that the model overpredicts the occurrence of the low streamflows (< 5 m^3/s) and underpredicts the occurrence of flows in the range of 5-15 m^3/s. This essentially indicates that model simulated baseflows (especially during winter) are lower than observed values.

Table 3.3: Selected values of SWAT parameters used for ArcView-based SWAT simulations.

Parameter	Description	Value	How value was obtained
Bain input file (*.bsn)			
SFTMP	Snowfall temperature [C]	0.7	Monte Carlo calibration
SMTMP	Snowmelt base temperature [C]	0.5	Monte Carlo calibration
SMFMX	Maximum snow melt rate [mm/C*day]	3.7	Monte Carlo calibration
SMFMN	Minimum snow melt rate [mm/C*day]	1.9	Monte Carlo calibration
TIMP	Snow pack temperature lag factor [-]	0.5	Monte Carlo calibration
SNOCOVMX	Minimum snow water content that corresponds to 100% snow cover [mm]	25.0	Monte Carlo calibration
SNO50COV	Fraction of snow volume represented by SNOCOVMX that corresponds to 50% snow cover [-]	0.5	Monte Carlo calibration
SURLAG	Surface runoff lag coefficient [days]	1.0	Monte Carlo calibration
PRF	Peak rate adjustment factor for sediment routing [-]	1.58	Based on measured storm events
SPCON	Linear parameter for sediment re-entrainment	0.001	Monte Carlo calibration
SPEXP	Exponent parameter for sediment re-entrainment	1.00	Monte Carlo calibration
Groundwater Input file (*.gw)			
GW_DELAY	Groundwater delay time [days]	20.0	Monte Carlo calibration
ALPHA_BF	Baseflow alpha factor [days]	0.4	Monte Carlo calibration

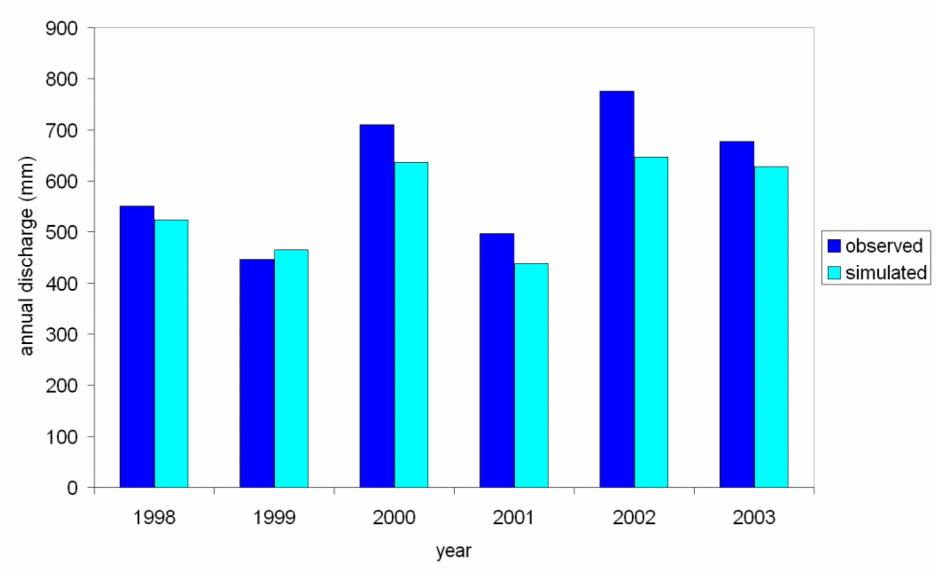


Figure 3.9: Comparison of simulated and observed annual streamflow totals.

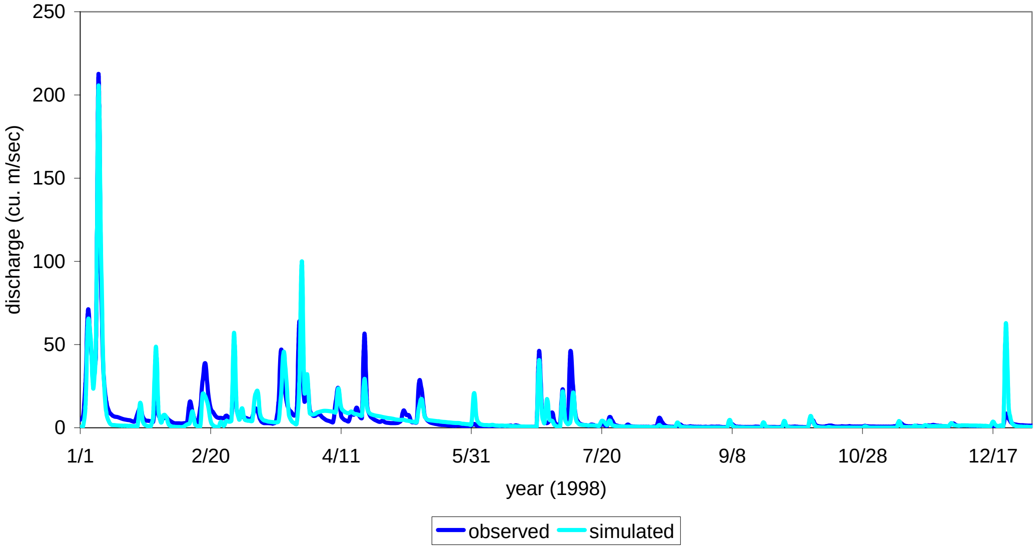


Figure 3.10: Simulated and observed daily streamflow discharge for the year 1998.

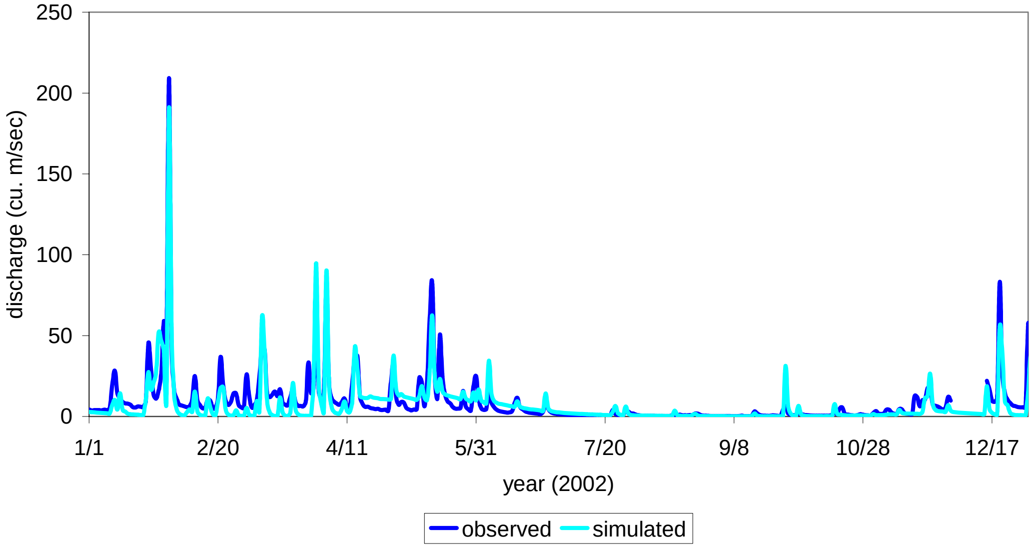


Figure 3.11: Simulated and observed daily streamflow discharge for the year 2002.

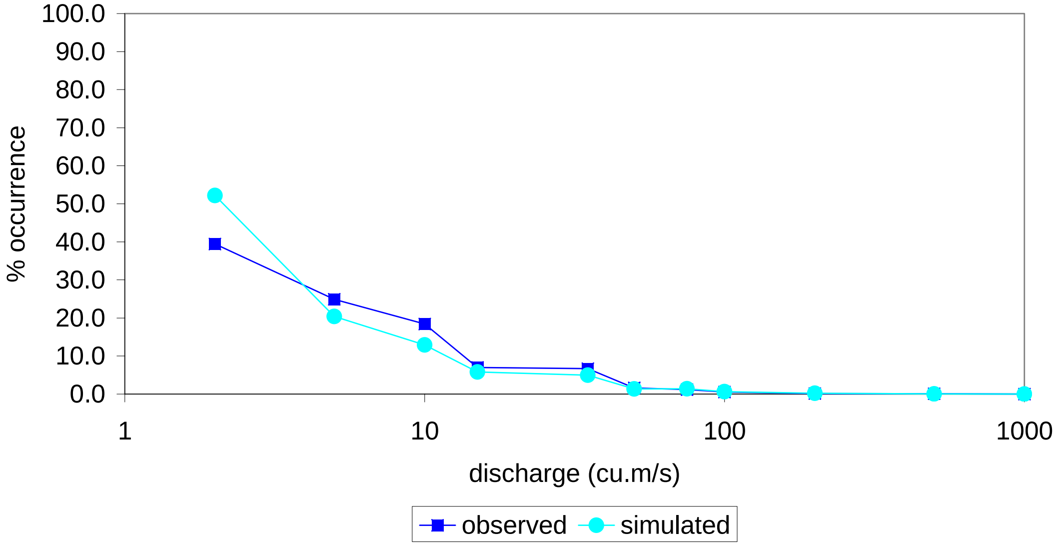


Figure 3.12: Frequency comparisons of simulated and observed daily streamflow for the 1998-2003 period.

3.6 Calibrations for sediment concentrations

The SWAT model was calibrated for sediment by comparing model simulated stream sediment concentrations (mg/L) against measured sediment concentrations from hydrolab/YSI sondes. Due to the large variability in temporal pattern of measured values of sediment concentrations the intent was to constrain the simulated values within the same order of magnitude as the observed values. We did not attempt to fit the simulated exactly to the measured values. Sediment parameters were adjusted till the simulated concentrations were within the same order of magnitude as the observed values. Comparisons were performed by comparing the sediment concentrations measured at the watershed outlet (USGS gage location) with the simulated values for storm events during fall 2002 and spring 2003 (site 1A in Figure 2.1). During these calibrations the channel erosion component was set to zero, i.e., the model did not simulate channel degradation. The channel component was "inactivated" to reduce the amount of parameters that we had to vary to calibrate the model.

As can be seen in the plots (Figure 3.13) model simulated values exceeded the observed sediment concentrations for fall storm events but under-predicted the sediment concentrations during high flows associated with spring storm events (post 5/9/2003 in Figure). However, all simulated sediment concentrations were within the same order of magnitude as the observed values. The large spike in sediment concentrations after 12/10/2002 was associated with an ice-scour event. SWAT cannot simulate sediment dynamics associated with ice-scours and hence did not simulate this response. The comparisons also show that under the current calibration set-up the model does not do a very good job in simulating high sediment yields associated with large spring events.

Parameters that were adjusted for sediment calibration included the USLE cover factor C and the practice factor P. The C factor (USLE_C) was adjusted for generic agricultural land (AGRL) only. All agricultural land in the Cazenovia Creek watersheds was classified in the generic AGRL category. This classification was chosen since a variety of practices were being employed on agricultural fields ranging from corn cultivation to fields that had been “retired” into pasture. Default C and P values for AGRL yielded very high sediment loads. Without calibration (and with default parameter values) simulated values were one order (10 times) of magnitude greater than the observed concentrations. To reduce the simulated sediment concentrations to within the observed range the C factor was reduced from the default value of 0.20 (in the User Database) to a value of 0.10. Similarly, the P factor was changed for AGRL landuse only. This was done by changing the default P value (1.0) to a value of 0.10 in the subbasin data files. By adjusting these parameters sediment yields at the watershed outlet were constrained to the same order of magnitude as the observed values.

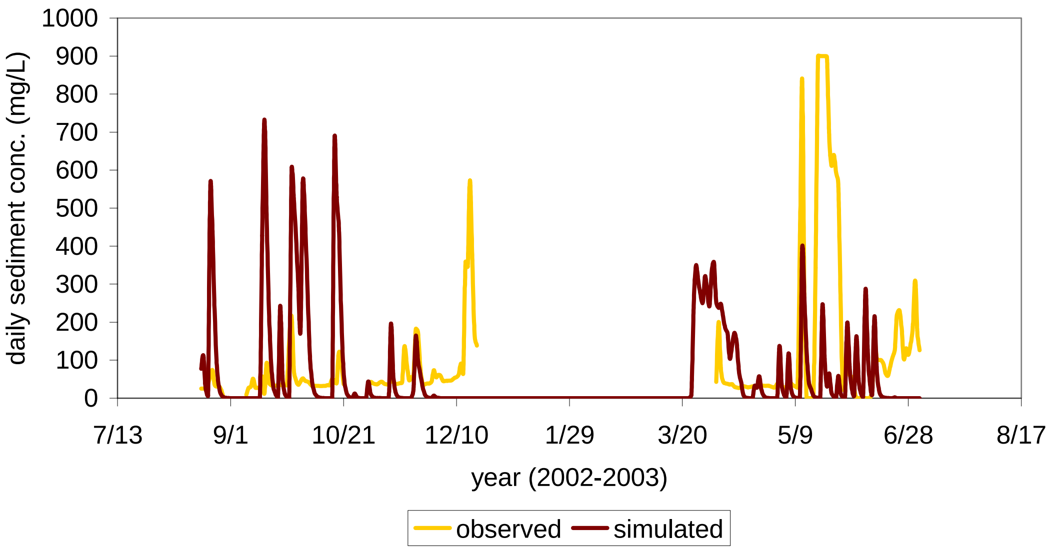


Figure 3.13: Observed versus simulated sediment concentrations (mg/L) for the Fall 2002 through Spring 2003 period.

Figure 3.14: Photograph showing the impact of ice-jams on channel banks. This picture was taken after the ice-jam breakup of December 10, 2001. The ice slabs scoured the channel banks to a height in excess of 7 feet from the channel bottom.

3.7 Evaluation of sediment simulations

Once the model was calibrated using for sediment using the 2002-2003 data, model predictions were further evaluated using additional data. Although this step is sometimes referred to as the model "validation", we prefer to refer to it as model evaluation.

Model simulations were compared to sediment concentrations measured at 1A for the period 2003-2004. Measured data was available for the latter part of November and December 2003 and then for the period March through May 2004. Again, high sediment concentrations observed in December 2003 were associated with ice scour which the model could not simulate. Simulated sediment concentrations for large spring events were underestimated by the model.

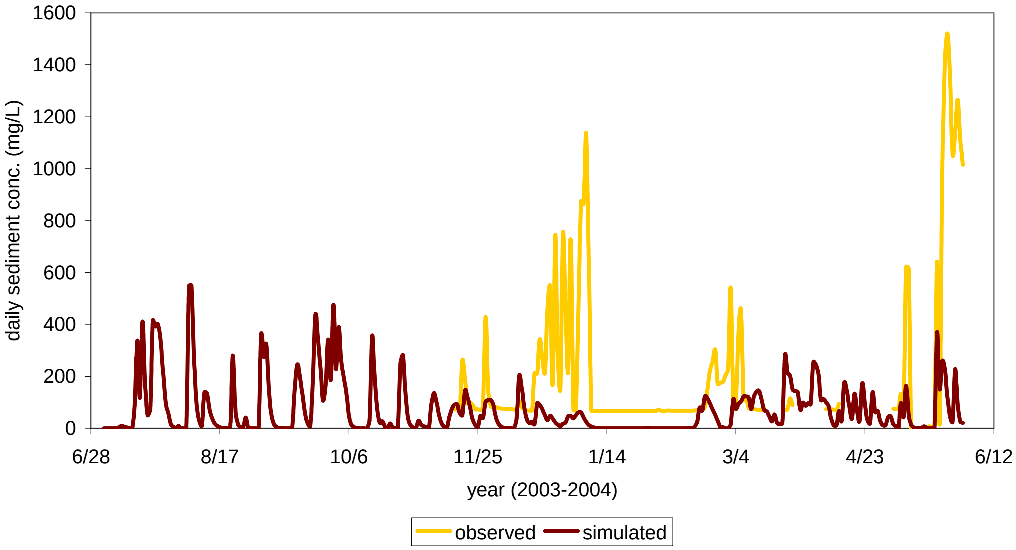


Figure 3.15: Comparison of observed versus simulated sediment concentrations for site 1A.

In addition to the outlet (1A) comparisons, simulated sediment concentrations were also compared against measured values recorded for the other three sites in the Cazenovia Creek watershed – sites 2F, 3C, and 3D. The intention here was to determine if the model calibrated against outlet data could replicate the spatial pattern of sediment generation for internal subcatchment nodes. The comparisons were performed using both time-series and frequency-distribution (% exceedance) plots. The benefit of using frequency plots is that the statistical distributions of observed and distributed data can be compared for a site. Use of frequency distribution plots has been recommended and is considered a stronger test for model evaluations since statistical patterns of observed and simulated data are compared as opposed to point comparisons (as in time-series comparisons of observed and simulated data).

Frequency distribution for observed sediment concentrations for the four sites is presented in Figure 3.16. As can be seen from the figure sites 1A and 2F show more elevated sediment concentrations compared to site 3C and 3D. Site 1A sediment concentrations ranged from less than 20 to greater than 1500 mg/L. Site 2F show higher number of exceedances in the 200-400 mg/L range. More than 80% of the sediment concentrations recorded for 3C were lower than 20 mg/L, whereas site 3D recorded higher concentrations than 3C. Our visual observations indicated that Site 3C drained a subwatershed which was mostly forested (with a forested county park) whereas subwatershed 3D had greater fraction of agricultural fields. The observed trends in sediment concentrations for 3C and 3D tend to agree with the landuse within the watersheds.

Frequency distributions of simulated concentrations for the four sites are presented in Figure 3.17. If the observed and simulated frequency distributions are compared it appears that the model is not doing a good job of replicating the statistical patterns of sediment generation across the four sites. The time-series plots show that simulated concentrations are generally within the same order of magnitude as observed values for 2F and 3D but the model is not able to replicate the individual event responses. We believe one of the reasons for this is the use of just one rain gage for the model simulations. Multiple rain gages would have allowed the model to better represent individual storms and would have improved the fit. Simulated concentrations for 3C were much greater than the observed values. We attribute this to the larger proportion of agricultural land (as compared to our onsite visual assessment) in the GIS LULC layer for this subwatrershed. The GIS LULC layer was developed based on DOQQS and it appears that the agricultural land within this watershed was incorrectly identified and overestimated. This indicates some of the limitations associated with mapping landuse parcels from DOQs.

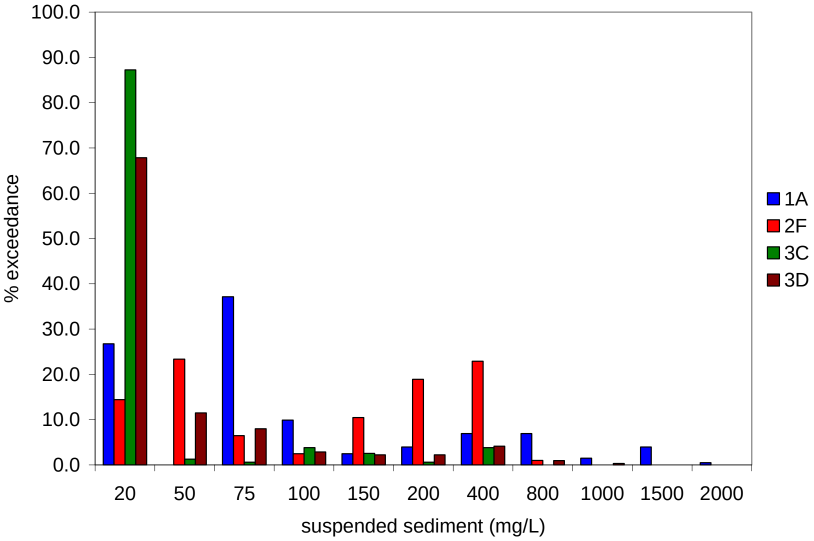


Figure 3.16: Percent exceedance plot showing the pattern of measured suspended sediment across the four sampled sites in Cazenovia Creek subwatershed. Sites 1A and 2F show greater exceedances of higher sediment concentrations followed by 3D and 3C.

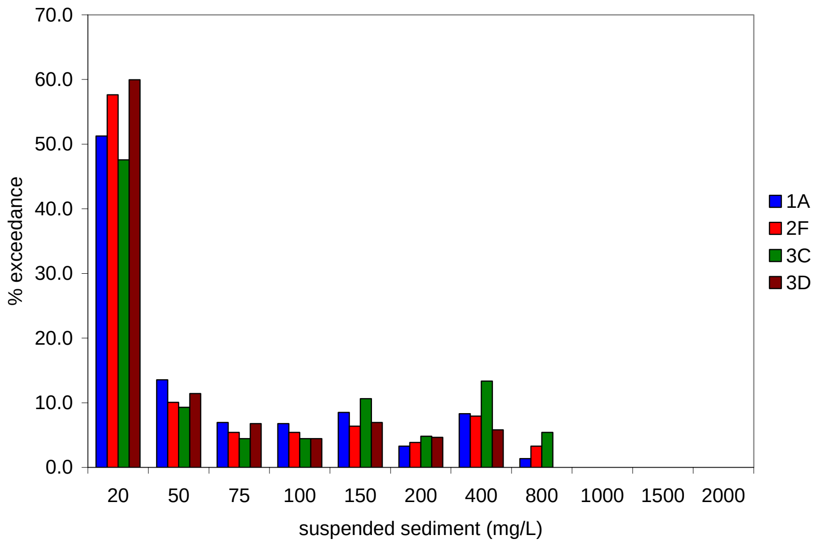


Figure 3.17: Percent exceedance plot showing the pattern of simulated suspended sediment across the four sampled sites in Cazenovia Creek subwatershed.

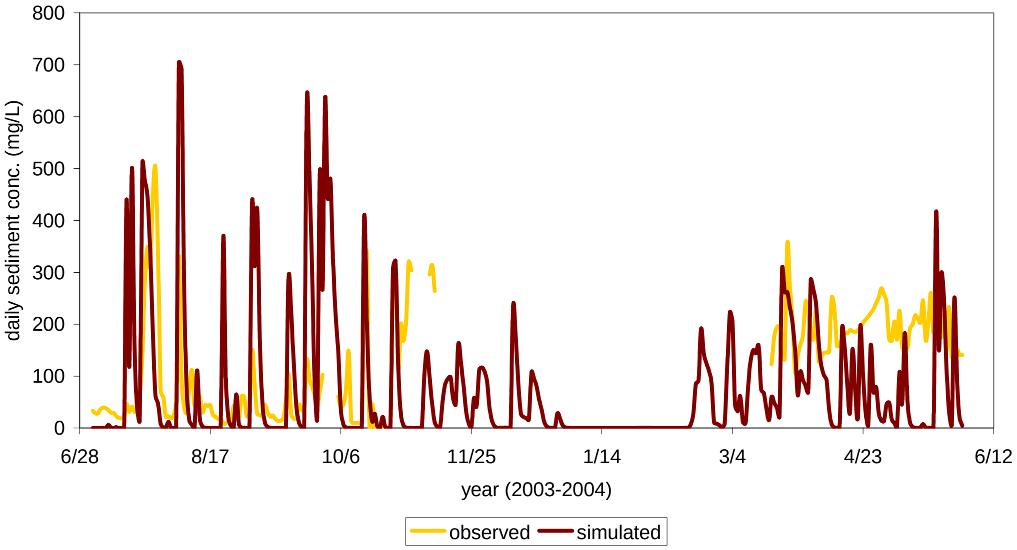


Figure 3.18: Comparison of observed versus simulated sediment concentrations for site 2F. Simulated values were with the same order of magnitude as observed, but the model could not replicate the individual storm event responses.

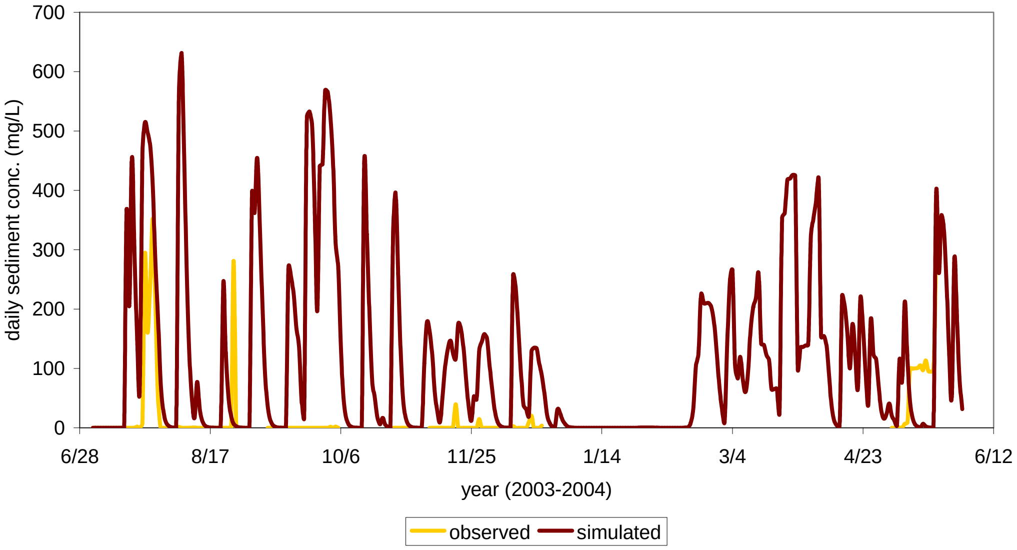


Figure 3.19: Comparison of observed versus simulated sediment concentrations for site 3C. Simulated values were much higher than observed sediment concentrations.

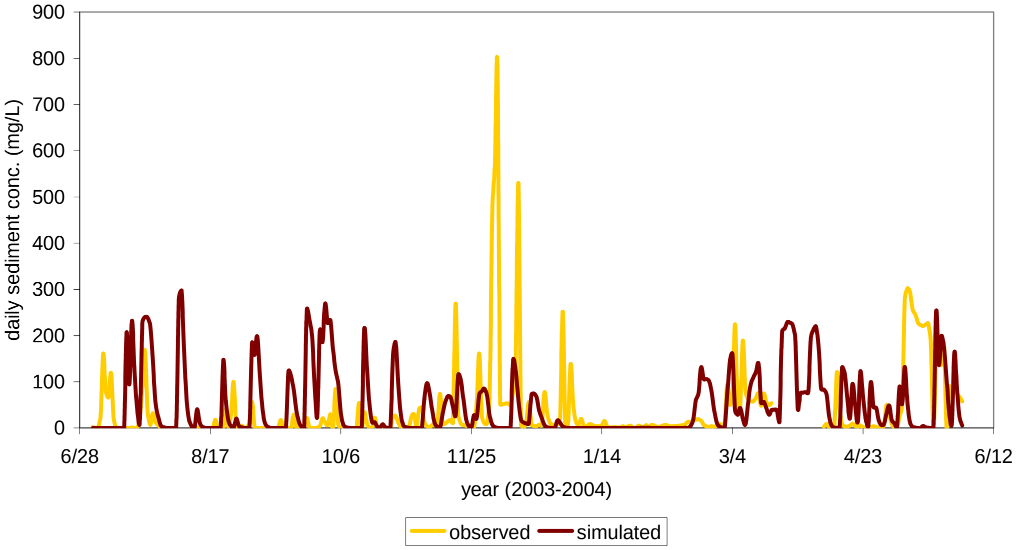


Figure 3.20: Comparison of observed versus simulated sediment concentrations for site 3D. Simulated values were with the same order of magnitude as observed, but the model could not replicate the individual storm event responses.

3.8 Key deductions from the calibration process

The following important deductions can be made from the hydrologic and sediment calibrations of the SWAT model for the Cazenovia Creek subwatershed:

- SWAT was able to do a fairly good job in simulating streamflow at the annual and monthly time scales considering that a single weather station was used represent the precipitation distribution across a 136 square mile subwatershed.

- SWAT clearly was unable to simulate the high baseflow conditions observed during the winter. Apparently the slow but continuous snow melt that was occurring through the winter and which sustained the base flow in the stream was not simulated by the model.

- SWAT simulated spring snowmelt streamflows were greater than those observed. Clearly, the model is maintaining a larger snowpack for longer periods and releasing it during the spring snow melt season. If the parameters can be adjusted that some of the snow pack is slowly released through the winter, the high spring flows which are simulated in the spring could be reduced.

- Simulated sediment concentrations were calibrated within the same order of magnitude as the observed values but the model did not do a very good job in replicating concentrations for individual storm events.

- To constrain simulated sediment concentrations with the same order of magnitude as the observed values - the default C and P values for agricultural land (AGRL) had to be reduced considerably. The C value was reduced by 50% (from 0.2 to 0.1) and P the value by 90% (from 1.0 to 0.1). The total effect of reducing these parameters is 95% reduction in sediment load. This reduction could also have also been achieved by reducing any one of the two parameters.

- The large reductions in the C and P values factors for model calibrations were needed because the parcels of land identified as “cropland” were not necessarily completely in cultivation. Many of these parcels had some filter strips or bands of vegetation on their edges or in interior locations. The C and P values used in the USLE equation for agricultural fields are representative of conditions where the land parcel is completely in agriculture (crop cultivation). For situations where a narrow width of vegetation might be located downslope of the field the C and P values have to be reduced to account for the sediment being trapped or deposited in the vegetative buffer. In the Cazenovia Creek subwatershed most agricultural land had vegetated areas adjoining streams and drainageways. These vegetated areas did not show up separately as buffer strips on the GIS layers but got included as agricultural land in the landuse delineation in the model. Furthermore, although land parcels in the watershed were classified as “agricultural”, many of these land parcels were not being actively cultivated, but rather “retired” into pasture.

- While calibration, the large changes (reductions) in C and P values could be avoided if: (a) the buffer strips adjacent or downslope of the fields can be delineated as such in the GIS layers; and (b) if “active”, “inactive”, or “retired” agricultural fields can be clearly identified and these distinctions can be made in the GIS LULC layer. However, some adjustments in the C and P values will always be needed since there are limits to which you can represent small vegetated strips in the model – especially if one is simulating a large watershed.

- YSI sonde and hydrolab data from winter showed extremely high sediment concentrations during channel scouring caused by ice-jams and ice-jam breakup. The high streamflow and high sediment concentrations recorded during ice-jam breakups suggest that ice-jams may contribute to a large portion of sediment load to the annual sediment budget. SWAT cannot simulate the formation of ice jams and ice-jam breakup and hence may underestimate the annual sediment export from watersheds where ice-jams occur.

- Comparisons of SWAT simulated sediment concentrations against observed data from multiple points within a watershed suggest that SWAT calibration against outlet data does not guarantee that simulations at internal catchment nodes will be accurate. SWAT simulated values for the outlet were of the same order as observed, but for subwatershed 3C the simulated values were much higher than observed. We attributed the high sediment concentrations at 3C to the incorrect representation of cropland in the GIS LULC layer that was used in the model. This highlights some of the limitations associated with characterizing LULC from DOQs and the importance of measured data from multiple internal points to verify model simulations.

3.9 Spatial pattern in sediment generation

The SWAT generated spatial pattern of sediment concentrations (Figure 3.21) shows that high sediment concentrations are generated in headwater basins. The basins that produce the highest concentrations are 18, 16, 9, and 13. The least amount of sediment is generated from subbasins that have the largest fraction of suburban landuse (2 and 3). To investigate the likely factors influencing sediment generation at the catchment scale, the percent cropland and average slope gradient was determined for each of the subcatchments (Figures 3.22 and 3.23). From Figures 3.21, 3.22, and 3.23 it is apparent that subbasins that produce high sediment concentrations also have a greater percent of agricultural land and steeper slope gradients.

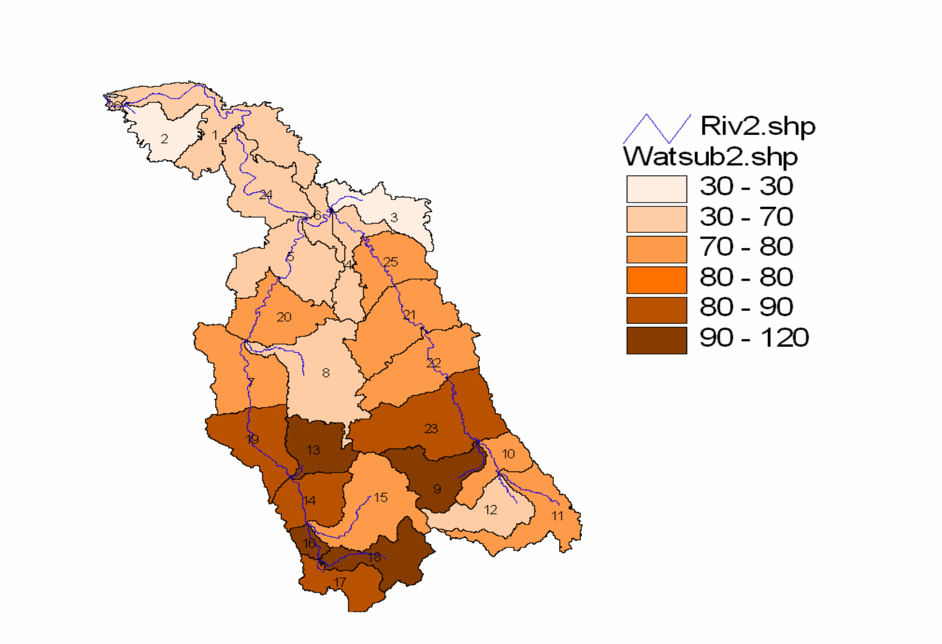


Figure 3.21: A spatial map of the watershed showing SWAT simulated sediment concentrations in streamflow for individual subbasins. Sediment concentrations are in mg/L.

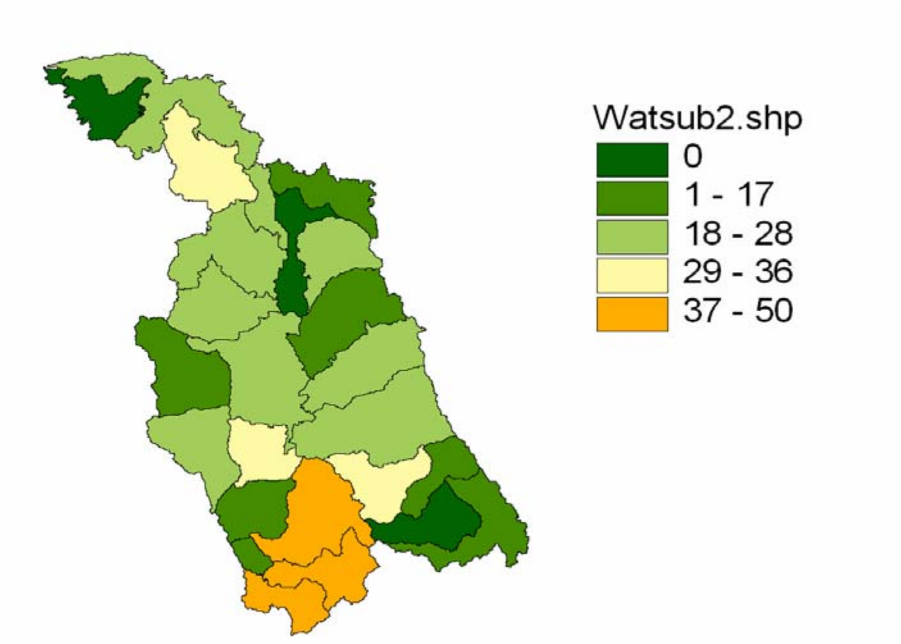


Figure 3.22: A spatial map of the watershed showing the distribution of agricultural land in individual subbasins (as a percent of the subbasin total landuse).

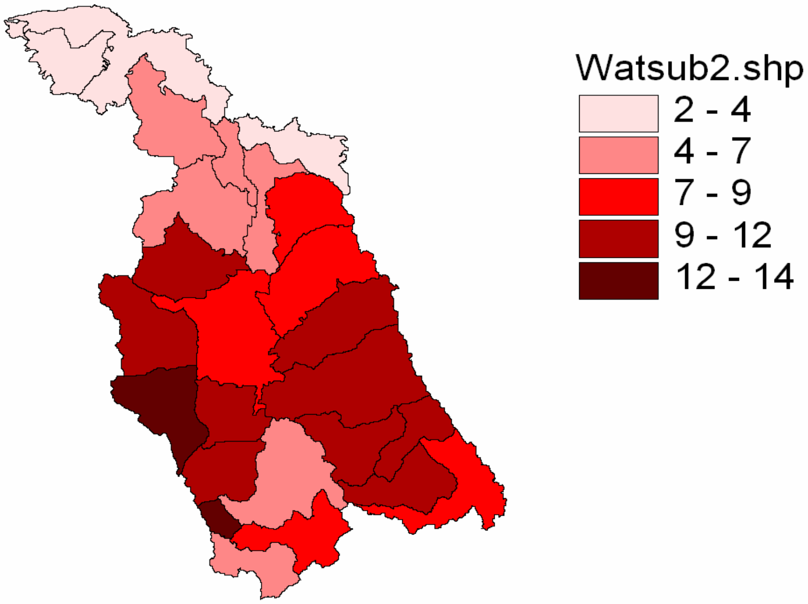


Figure 3.23: A spatial map of the watershed showing the average slope gradient for subbasins (in percent).

4. CALIBRATION OF SWAT MODEL WITH “ACTIVE” CROPLANDS

Data on “active” croplands in Cazenovia Creek subwatershed was available in the form of a GIS layer from the Erie County office of the USDA-NRCS office (Mr. John Whitney). This data layers indicated cropland parcels that were being currently cultivated (Figure 4.1). This data extended to only the Erie County portion of the Buffalo River watershed (complete Cazenovia Creek subwatershed and a part of the Buffalo Creek subwatershed).

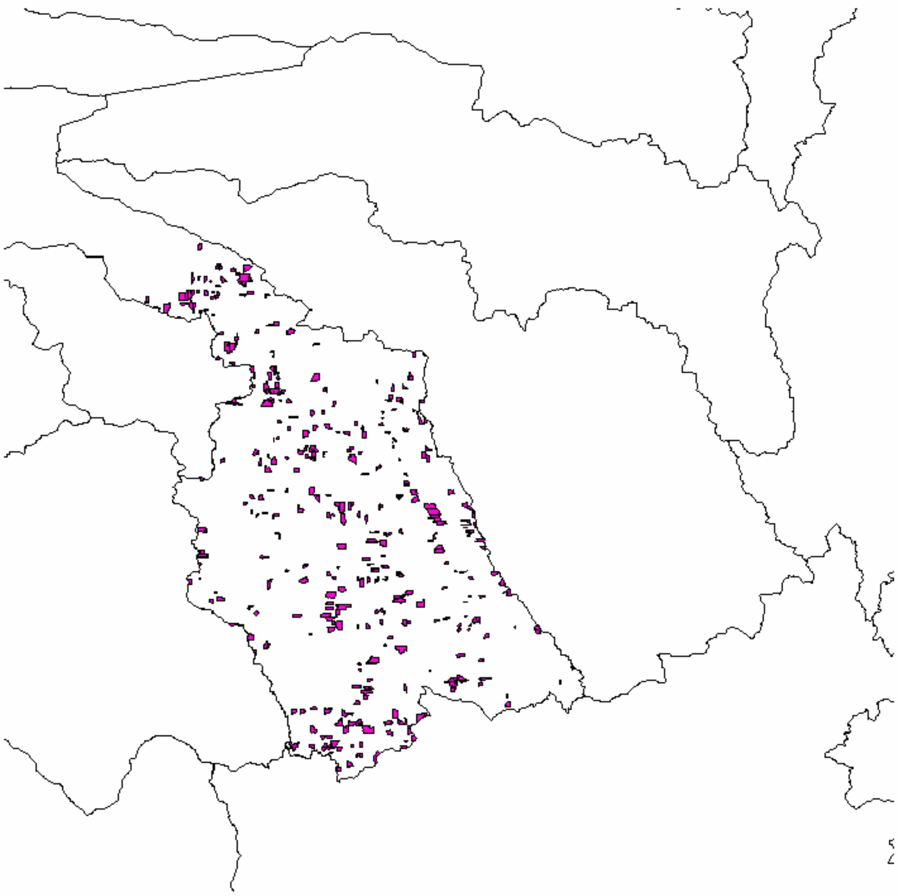


Figure 4.1: Actively cultivated cropland parcels (in pink) in the Cazenovia Creek subwatershed.

In the sediment calibration described above we had found that C and P values associated with cropland had to be reduced considerably since the actual extent of “actively” cultivated fields was much less than the cropland area displayed in the LULC GIS layer. Since the “actively” cultivated field info was now available, we performed simulations with this layer to check if the use of only the "active" cropland along with default C and P values would produce more acceptable results.

Cropland area from the original LULC that matched the active fields was classified as cropland with default AGRL C and P values of 0.2 and 1.0, respectively. All other cropland was treated as "retired" agricultural land with very low C and P values (similar to forest). All other landuse parcels were maintained as per the original LULC theme.

A comparison of observed and simulated sediment concentrations over the period 2002-2004 for the watershed outlet (1A) is presented in Figure 4.2. Although use of active cropland does not necessarily improve model fits with observed, sediment concentrations simulated with active cropland and default C and P values are of the same magnitude as those produced with the original LULC and reduced C and P values. Both simulated results are within the same order of magnitude as the observed values. These simulations suggest that if the default (and recommended) values of C and P for cropland have to be used we will have to clearly identify the active cropland fields within the watershed. If the cropland extent in the LULC is greater than the actively cultivated fields, default values of C and P will likely produce sediment concentrations higher than observed.

For site 2F (Figure 4.3) the use of active cropland produced lower sediment concentrations than those generated by the original LULC and the observed levels. Clearly the model is underestimating the sediment yields with the active cropland for this internal node. For 3C however, the simulated values with active cropland were much closer to observed data and much lower than sediment concentrations simulated by the original LULC (Figure 4.4). This was expected since the cropland area in the active cropland GIS layer was much less than that in the original LULC GIS layer. In contrast to 3C, use of active cropland layer resulted in very high sediment concentrations for 3D (Figure 4.5), much higher than those simulated by original LULC and also much higher than the observed values. The simulation results for 3D using active cropland layer are clearly not realistic. There are two likely explanations for these results – 1. that the active cropland parcels do not match ground reality (i.e., there could be vegetative strips or other sediment sinks in the fields that have not been represented in the active cropland GIS layer; or 2. that the rate of sediment generation of cropland fields is much lower than that being simulated via the use of default C and P values. It is likely that both these factors may be responsible for the high sediment concentrations simulated for 3D.

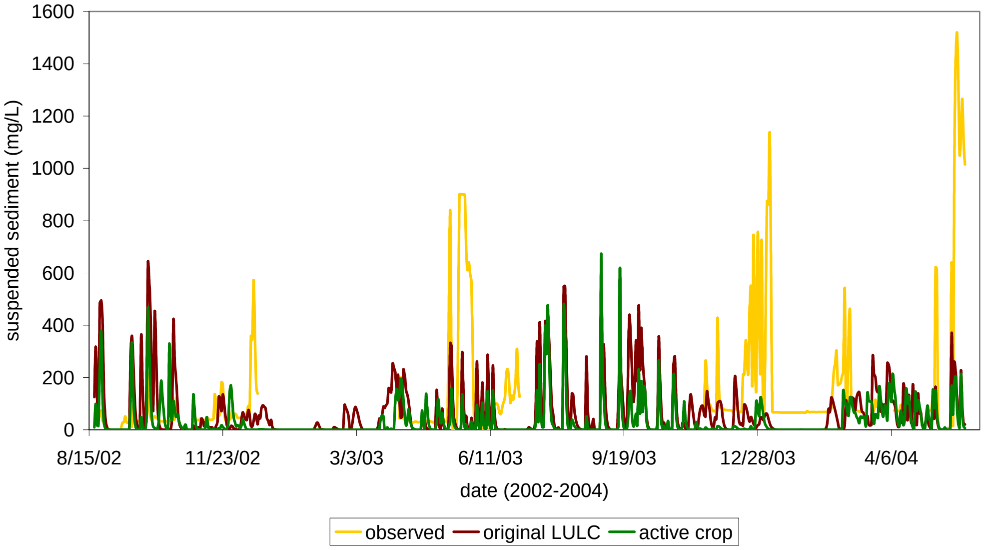


Figure 4.2: Simulated sediment concentrations for 1A using "active" LULC compared against observed values and simulated values from original LULC.

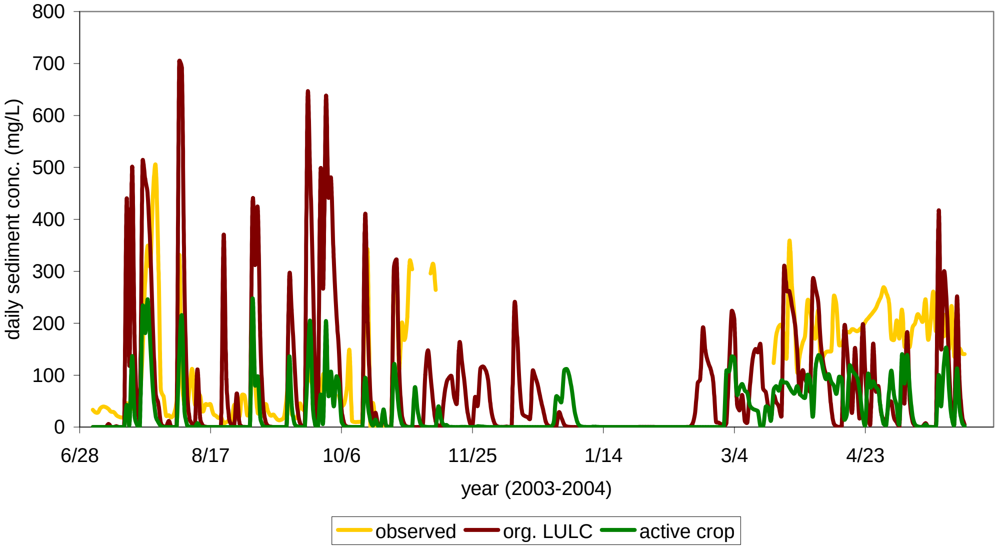


Figure 4.3: Simulated sediment concentrations for 2F using "active" LULC compared against observed values and simulated values from original LULC.

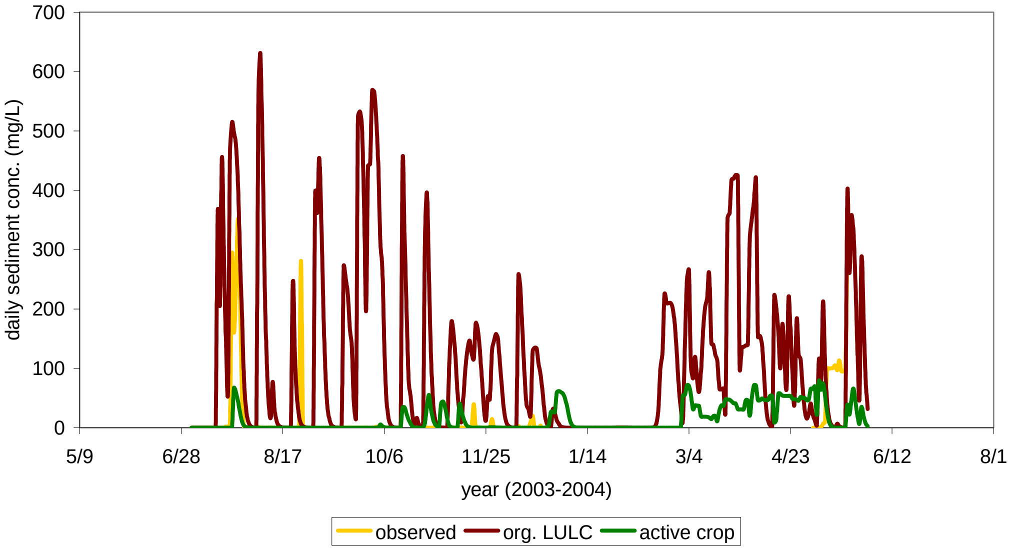


Figure 4.4: Simulated sediment concentrations for 3C using "active" LULC compared against observed values and simulated values from original LULC.

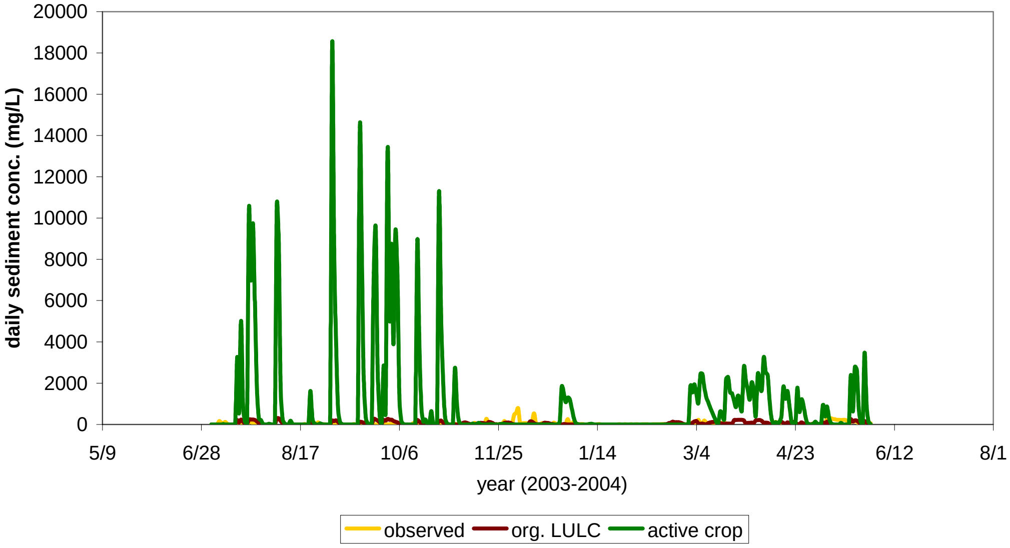


Figure 4.5: Simulated sediment concentrations for 3D using "active" LULC compared against observed values and simulated values from original LULC.

5. SWAT IMPLEMENTATION FOR THE COMPLETE BUFFALO RIVER WATERSHED

5.1 Implementation of the model

Using the parameter values selected during Cazenovia creek calibration the model was then extended to the full Buffalo River watershed. A new SWAT project was implemented with subbasins (Figure 5.1), soils (Figure 5.2) and LULC layers (Figure 5.3). The area of the simulated watershed was 418 square miles (or 108593 ha). Climate data was provided from three stations – Wales, Bennington, and Buffalo Airport.

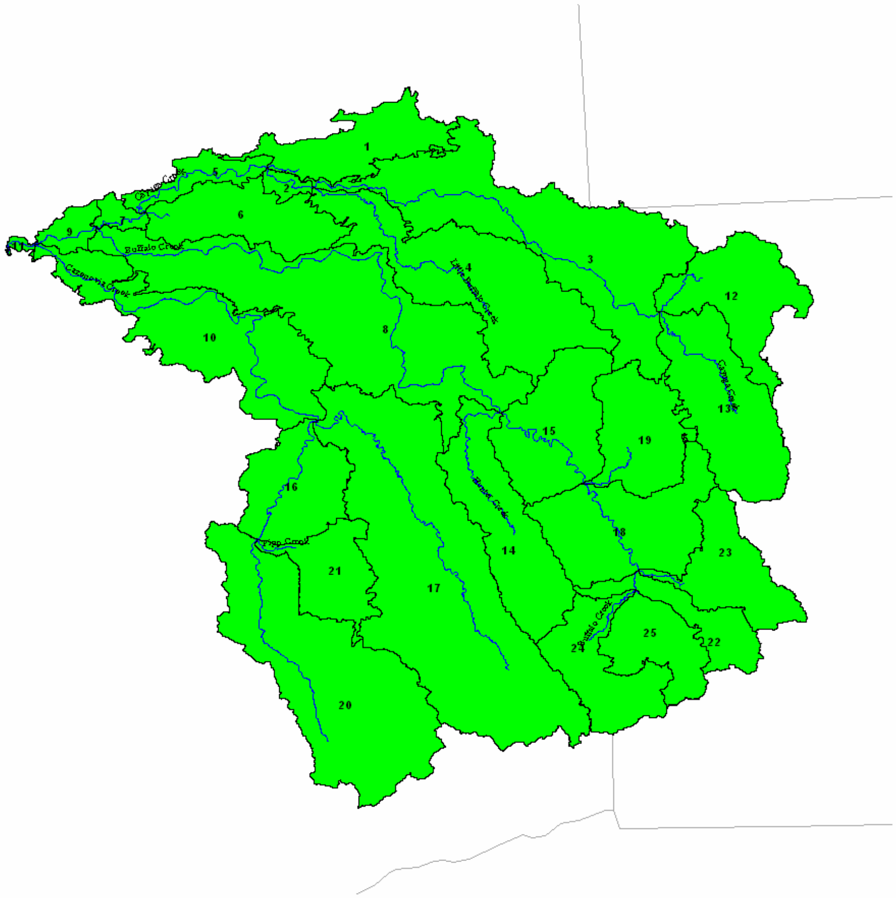


Figure 5.1: Subbasin scheme for the complete Buffalo River watershed simulation.

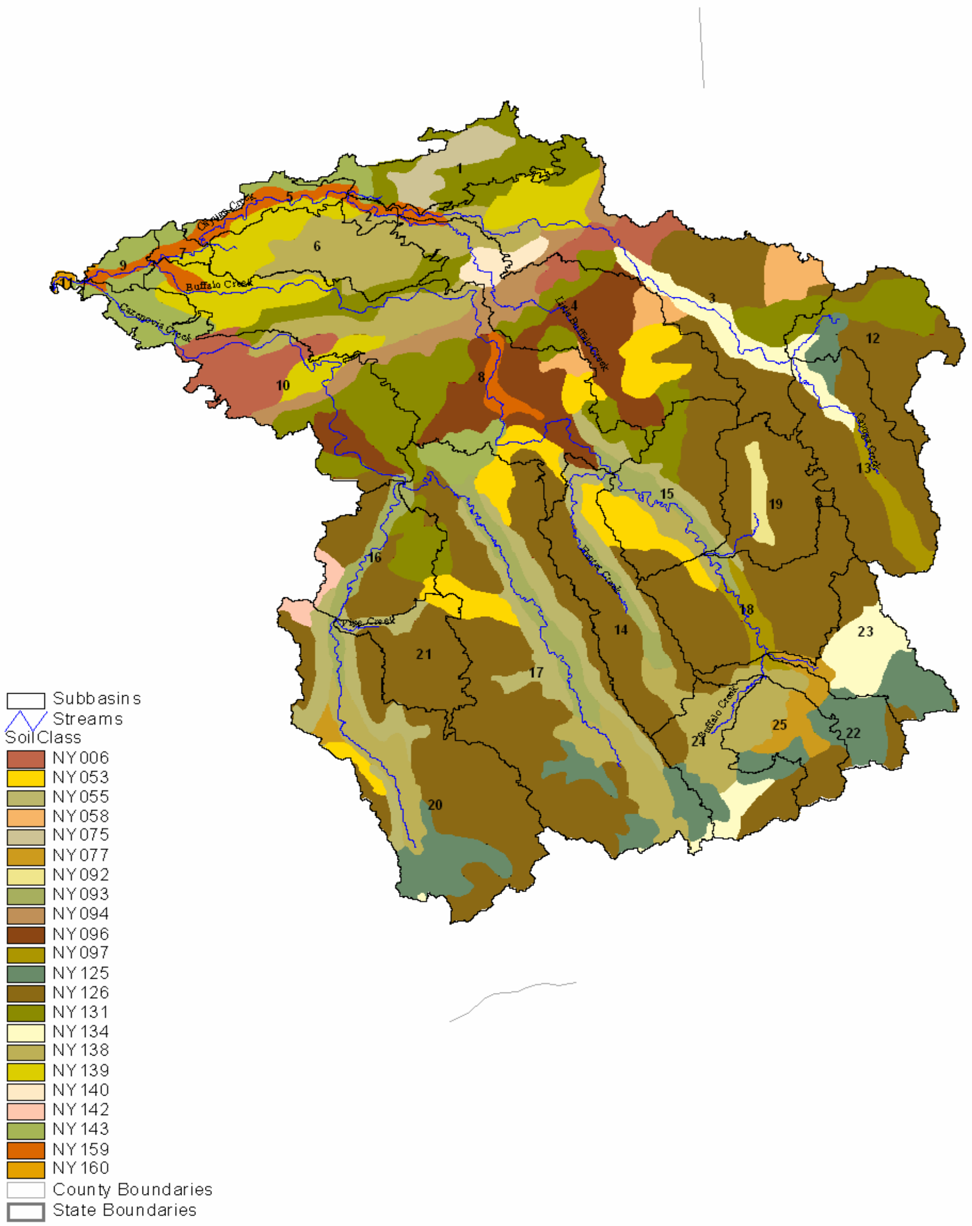


Figure 5.2: STASGO Soils distribution in the Buffalo River watershed.

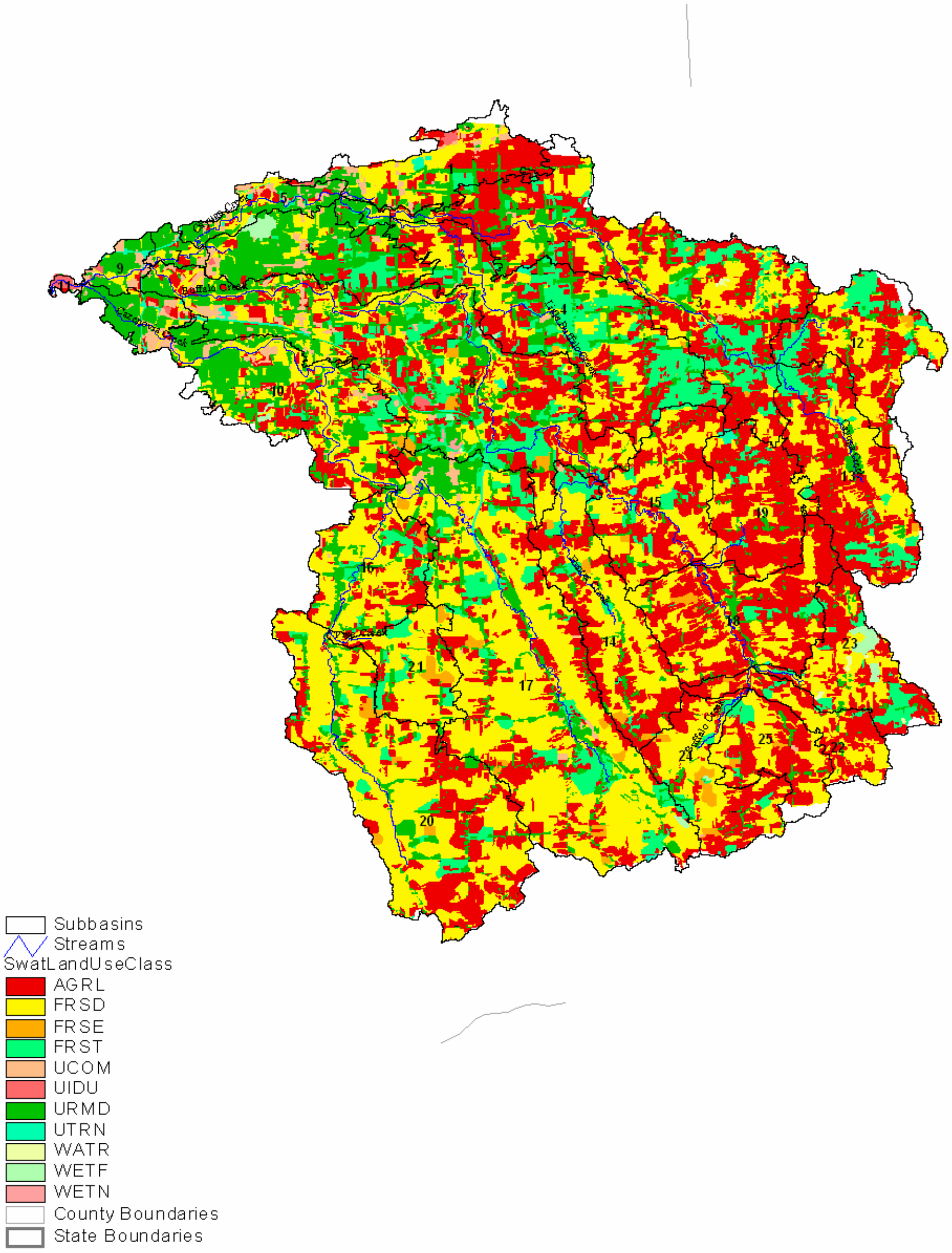


Figure 5.3: LULC (generated from DOQs) distribution for the Buffalo River watershed.

5.2 Results from model simulations

Simulated annual streamflow yields (ratio of simulated streamflow and precipitation) for the Buffalo River watershed during the period 1996-2003 are presented in Figure 5.4. The yield over the eight-year varied from 0.46 to 0.62 with an average of 0.54. Precipitation during this period ranged between 893 and 1166 mm, and streamflow discharge varied between 439 and 720 mm.

Simulated sediment yields at the watershed outlet for the period 1996-2003 are presented in Figure 5.5. Sediment yields varied from a minimum of 0.5 to a maximum of 1.13 tons/ha/yr with an eight-year average of 0.8 tons/ha/yr. Total sediment yield for the 108593 ha watershed amounted to 86,719 tons/yr (average over the eight-year simulation period). For comparison, the USGS measured sediment yield for the Big Darby Creek in Ohio (138,306 ha) for 1993 was 1.0 tons/ha/yr (http://webserver.cr.usgs.gov/sediment/stnbyTimePer.cfm). Similarly, the annual sediment yield for Juniata River near Newport (868686 ha), PA for the period 1985-1993 was measured at 1.24 tons/ha/yr. These numbers indicate that SWAT simulated sediment yields for the Buffalo River watershed are generally within the range observed for the region.

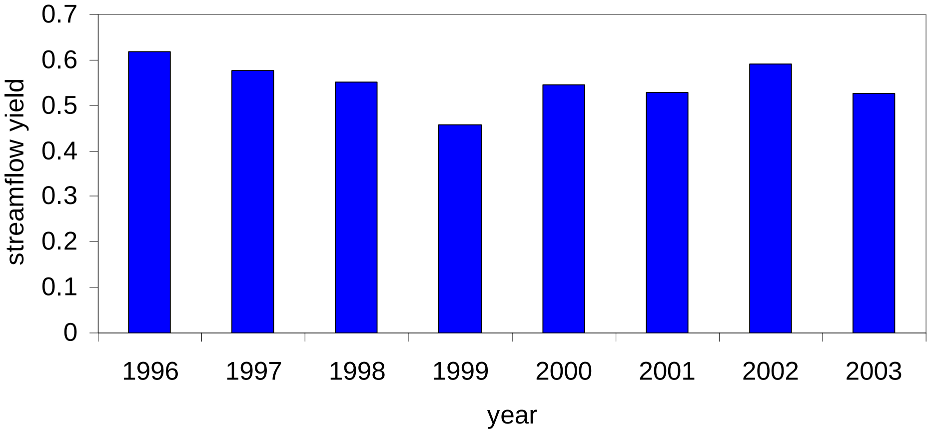


Figure 5.4: Simulated streamflow yields at the outlet of the Buffalo River watershed over the simulation period 1996 - 2003.

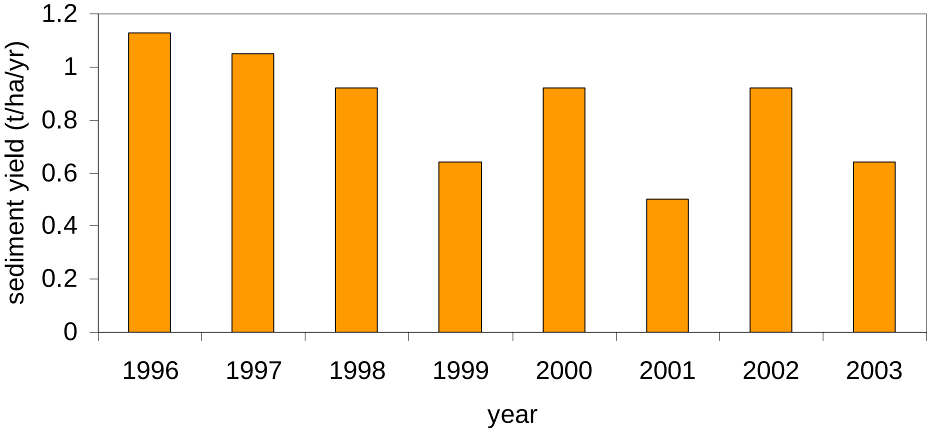


Figure 5.5: Simulated sediment yields (tons/ha/yr) from the Buffalo River watershed over the period 1996 - 2003. Yields varied from 0.5 to greater than 1.13 tons/ha/year with an eight-year average of 0.8 tons/ha/yr.

Observed and simulated contributions of streamflow (Figures 5.6 and 5.7) and sediment yields (Figure 5.8) from the three contributing watersheds were also generated and were compared against each other for model verification. Cazenovia Creek was the largest contributor of discharge to the Buffalo river watershed at 38% with Buffalo Creek and Cayuga subwatersheds having equal contributions at 31%. In comparison, the model simulated the Buffalo Creek watershed as the largest runoff contributor at 38%, followed by Cazenovia Creek at 34% and Cayuga Creek at 28% (Figure 5.7). These results suggest that calibrated parameter values based on any one of the subwatersheds (in our case the Cazenovia Creek subwatershed) cannot be simply extended to the larger parent watershed. It appears that SWAT will require further fine-tuning when the model is extended to from a subwatershed to the larger parent watershed.

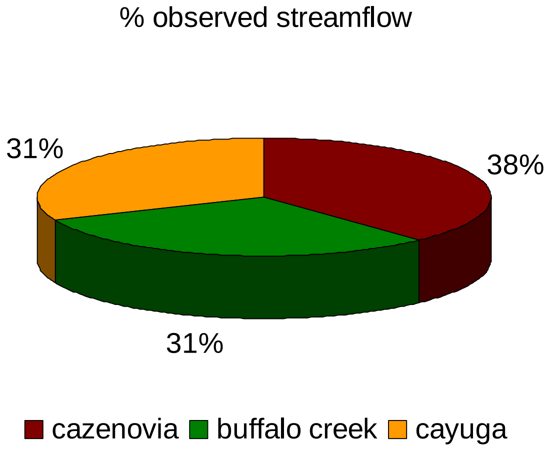


Figure 5.6: Percent streamflow contributions from each of the three major subwatersheds based on USGS gage data.

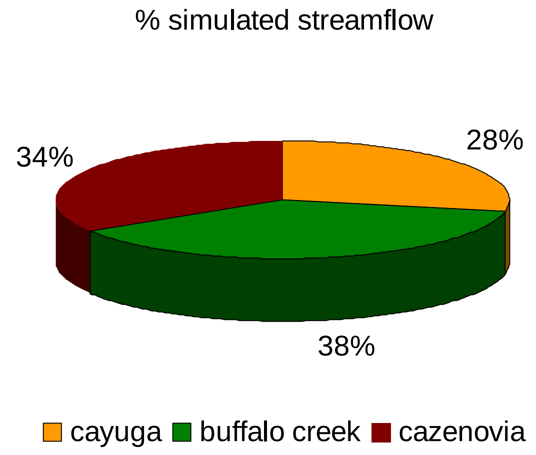


Figure 5.7: Percent streamflow contributions from the three contributing subwatersheds from model simulations.

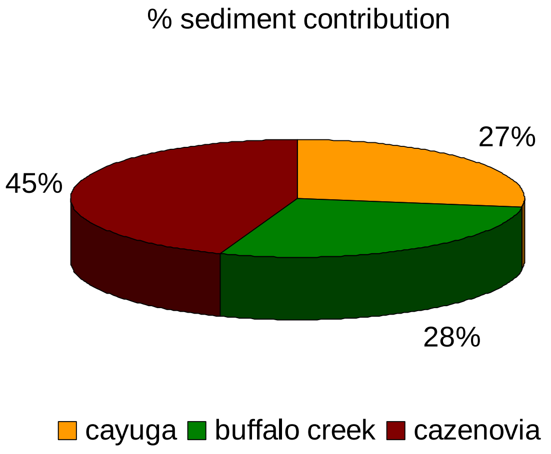


Figure 5.8: Simulated sediment contributions from the three major subwatersheds to the total sediment yield for the Buffalo River watershed.

The percent contributions of sediment from the three subwatersheds were simulated and are presented in Figure 5.8. Cazenovia Creek is the largest contributor of sediment to the Buffalo River watershed at 45% of the total yield with Buffalo Creek and Cayuga Creek watersheds following at 28 and 27%, respectively.

Simulated daily sediment concentrations for the Buffalo River watershed outlet for the period 2000-2003 are presented in Figure 5.9. Sediment concentrations varied from 0 to values in excess of 900 mg/L. Simulations show that highest sediment concentrations are typically associated with summer storm events. However, highest sediment loads are generated during spring when streamflow discharges are at their highest. Simulated daily sediment contributions from the three main subwatersheds are presented in Figure 5.10. Cazenovia Creek sediment concentrations exceeded the values recorded for the other two subwatersheds. This trend matches the pattern of sediment concentrations we observed in grab sampling of suspended sediment (Figures 2.8 and 2.9).

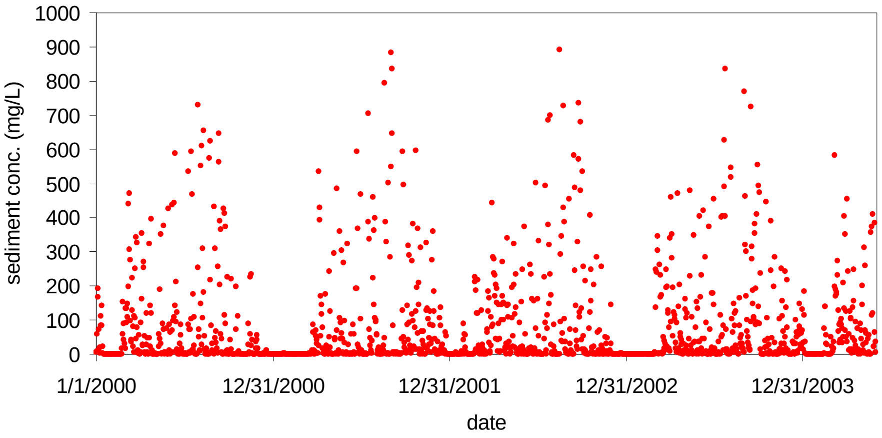


Figure 5.9: Simulated sediment concentrations (mg/L) at the Buffalo River watershed outlet for the period 2000-2003.

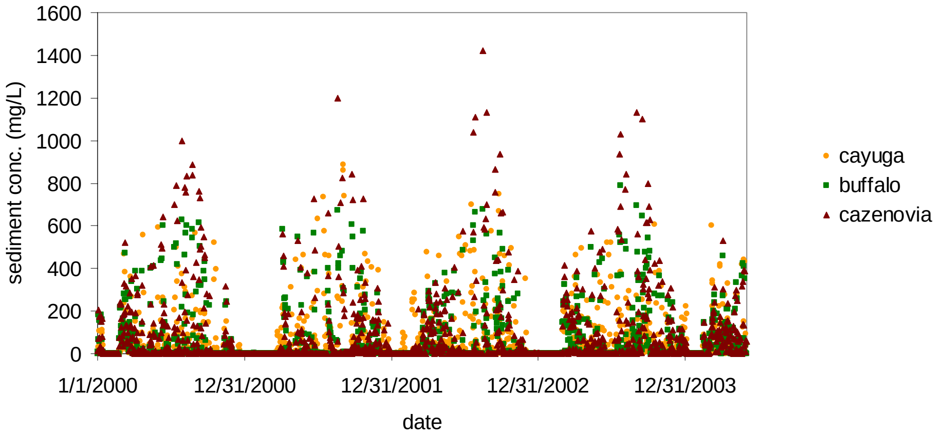


Figure 5.10: Simulated sediment contributions from the three main subwatersheds of the Buffalo River.

The spatial pattern of sediment generation for the Buffalo River watershed as simulated by the model is presented in Figure 5.11. This figure allows us to identify subcatchments which are producing high sediment concentrations. From Figure 5.11 it can be seen that some of the headwater catchments in Cazenovia Creek and Cayuga Creek are producing highest sediment concentrations. In contrast, most of the Buffalo Creek watershed appears to generate much lower sediment. One interesting result that this sediment map indicates is that – sediment generation in the Buffalo River watershed is not directly related to the distribution of croplands in the watershed (cropland are one of the sediment sources). The LULC map shows a higher proportion of cropland in Cayuga and Buffalo Creek watersheds compared to the Cazenovia Creek subwatershed. So, despite having a lower proportion of agricultural land, Cazenovia Creek generates much more sediment that the two other subwatersheds. As mentioned before, we believe one of the reasons behind the higher sediment yields is the steeper slope gradients in Cazenovia Creek. This suggests that landuse in combination with other factors (slope gradient) is regulating the sediment generation in the Buffalo River watershed.

Another interesting result that we found was that sediment concentrations for Cazenovia Creek subwatershed appear to be higher in Figure 5.10 compared to the values in Figures 3.13 and 3.15 (calibrations). This despite the fact that same set of parameter values were used in both simulations. The big difference between the two simulations is the size of subwatersheds. The scheme used during model calibrations had smaller watershed sizes since the simulation was limited to Cazenovia Creek subwatershed only. In comparison the scheme used for the full Buffalo River watershed used larger watershed sizes. This indicates that SWAT results are affected by the watershed partitioning scheme. Similar results on the influence of watershed size on sediment generation have been previously reported by Fitzhugh and Mackay (2001).

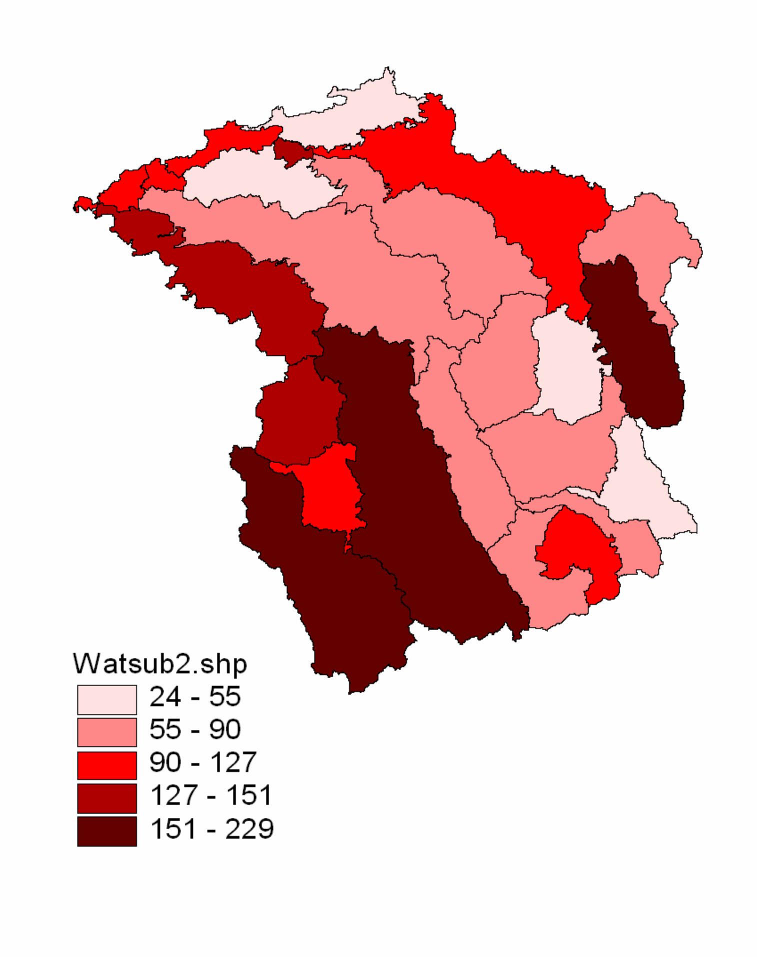


Figure 5.11: Spatial pattern of sediment generation (mg/L) in the Buffalo River watershed. As can be seen from the figure, the Cazenovia creek subwatershed appears to be the larger contributor of sediment.

6. SCENARIO ANALYSIS – IMPACT OF FILTER STRIPS

Impact of the use of filter strips was investigated for the Cazenovia Creek watershed. Two management "scenarios" were simulated: (a) Filter strip 5 m wide on all HRUs (hydrologic response units) in selected subbasins; and (b) Filter strips 10 m wide on all HRUs in selected subbasins

The selected subbasins included 9, 13, 14, 16, 17, 18, 19, 23 (refer to Figure 3.2). The reductions in average annual sediment yield due to implementation of filter strips are presented in Table 6.1. Sediment yields were reduced by 17 and 22% for 5m and 10m buffer strips, respectively. A plot of average sediment concentrations in subbasin streamflow for the base case (no filter strips) and for the two scenarios is presented in Figure 6.1. The percent reductions achieved for each subbasin corresponding to the two scenarios is presented in Figure 6.2. The following key observations can be made from the two plots.

Considerable reductions in sediment concentrations occur when 5m wide filter strips are simulated. However, increasing the filter strips by an additional 5m (total 10 m) does not produce the same level of reductions as was observed for the 0 to 5m filter condition. This suggests that benefits from implementing filter strips will taper off for further increases in filter width.

Reductions were slightly higher for subbasins with moderate slope gradient compared to subbasins with steep slopes (refer to Figure 3.4 for slope gradients). Also headwater subbasins recorded greater reductions in sediment exports (e.g., 17, 13) compared to subbasins located downstream (e.g., 23 and 19). Clearly greater improvements in water quality could be achieved by targeting headwater subbasins.

Table 6.1: Average annual change in sediment load at the watershed outlet due to implementation of filter strips of varying widths in selected subbasins in Cazenovia Creek.

Condition	**Average annual sediment load (tons/ha) Over 1998-2003**	**% reduction**
Base case	0.8	
Buffer 5m	0.65	-17%
Buffer 10m	0.62	-22%

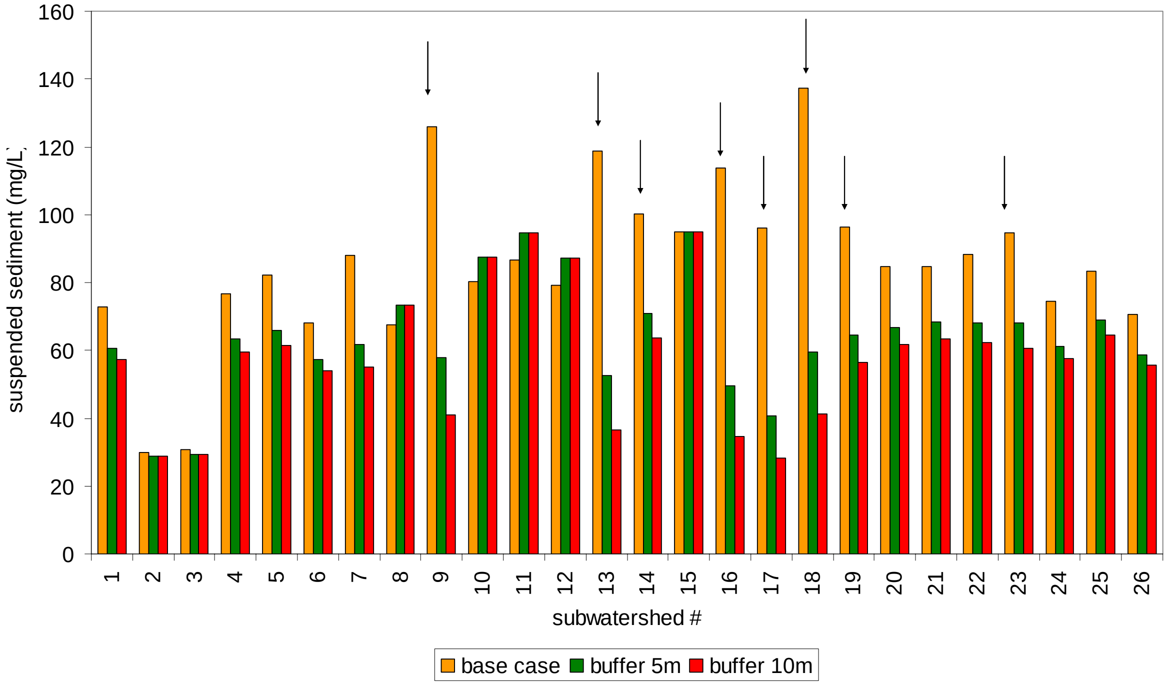


Figure 6.1: Change in suspended sediment concentrations (mg/L) due to implementation of filter strips of varying widths in selected subbasins. Arrows indicate subbasins for which filter strips or buffers are simulated.

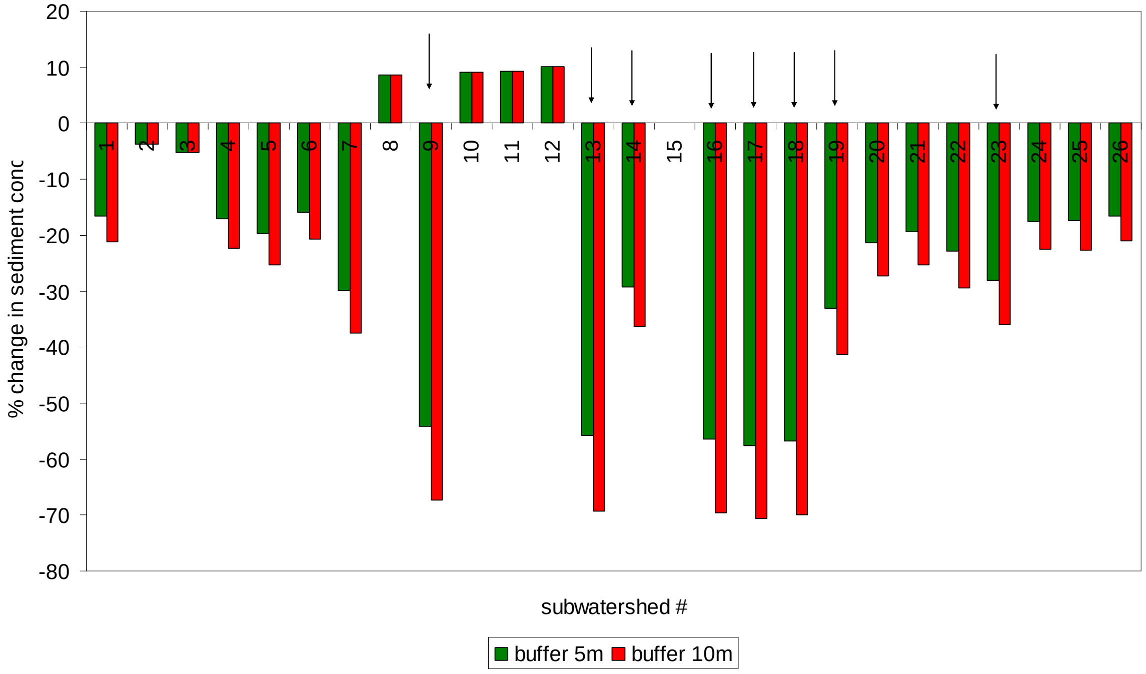


Figure 6.2: Percent reduction in suspended sediment concentrations (mg/L) due to implementation of filter strips of varying widths in selected subbasins. Arrows indicate subbasins for which filter strips or buffers are simulated.

7. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations can be derived from this study:

7.1 Model implementation

- SWAT is a user-friendly model that was successfully implemented to model the sediment dynamics and assess sediment yields for the Buffalo River watershed. Most of the data and the GIS layers required to implement the model are available off the internet. However, the GIS data layers require varying levels of modifications before they can be used in the SWAT model.

- The LULC layer is the most important input GIS layer required for SWAT model simulations. The accuracy of model predictions is very much dependent on the resolution of this layer. Specifically, the areal extent and resolution of the cropland parcels can have significant impact on sediment yields. If the areal extent of croplands as mapped in the GIS layers exceeds the extent on the ground, the use of default values for sediment parameters C and P will produce high sediment yields. Narrow vegetative buffers located along the edges of croplands can significantly reduce the sediment yield. If these narrow buffers are not mapped on the GIS layers, model predictions of sediment yield will exceed field observations.

- Although DOQs allow for a relatively quick and cheap way to update the LULC (via visual correction) layers the accuracy of the update is dependent on the resolution of the DOQs, and the interpretation of the GIS technician. DOQs allow us to only discriminate and differentiate between broad landuse categories, e.g., forests, agriculture, urban landuse, etc. Subtle differences between landuses such as actively cultivated fields versus barren agricultural parcels cannot be differentiated via visual interpretation of DOQs. Such subtle differences in landuse can however have a significant impact on sediment yields since the sediment parameter values (C and P) are considerably different for these landuses.

- The coarser soils GIS layer - STASGO was implemented in this modeling project. The more detailed soils layer – SSURGO was only available for the Erie County portion of the Buffalo River watershed. Currently the SWAT model cannot automatically use the SSURGO soils layer. The model is set up for the STASGO soils. Use of SSURGO in the SWAT Arc-View framework is possible by going through a sequence of steps. Our limited model runs with SSURGO (in the Monte-Carlo framework) suggest that use of SSURGO does change the sediment output values.

- Model recommended default threshold area values were used while partitioning the watershed into component subbasins. Our simulations (for Cazenovia Creek subwatershed followed by the full Buffalo River watershed) show that the areas of the component subbasins have an influence on the sediment yield simulated at the outlet. Similar results have also been observed by other researchers. A detailed analysis of the partitioning scheme was beyond the scope of this project.

7.2 Model calibrations

- In this project one weather station was used for the Cazenovia Creek subwatershed calibration and three weather stations were used for the full Buffalo River watershed simulations (424 sq. miles). We believe that a larger number of weather stations would have improved model fits. This is especially true for a watershed like Buffalo River where lake (Erie) influences lead to considerable spatial variability of precipitation (e.g., lake effect snow bands).

- Measured data on sediment concentrations is extremely important for model testing and calibrations. With default parameter settings (without calibration) SWAT model predictions of sediment yields for the Buffalo River watershed were orders of magnitude greater than the observed sediment values.

- Furthermore, measured data on discharge and sediment at multiple points in the watershed is important for SWAT calibrations. Calibration of the model against sediment concentrations measured at the watershed outlet alone does not guarantee that the model predictions for component subbasins and stream reaches will be accurate. Our experience from this project suggest that if the SWAT model is to be used for detailed assessment of the sediment source areas or to determine the impact of the BMPs, the model should be calibrated against multiple points in the watershed.

- Monte-Carlo simulations performed in this study were immensely valuable in identifying sensitive parameters and “optimal” parameter ranges. This was especially true for parameters such as snowmelt rates for which default values were not applicable (default values were developed for Texas!). Single model runs do not provide much insight into the uncertainty associated with parameter values.

- Continuously-recording YSI sonde and hydrolabs were immensely valuable in determining the spatial and temporal pattern sediment generation in the watershed. The sondes were able to capture the complete temporal trajectory of sediment generation during storm events at the instrumented sites. In contrast, grab sediment samples provide only a “snapshot” and do not provide the full picture of storm-event associated sediment. Hence, model comparisons should not solely be based on grab sample sediment data. However, grab sampling is helpful in generating the turbidity-suspended sediment relationship, and a combination on of sonde turbidity and grab sampling can provi9de a more comprehensive picture.

- YSI sondes and hydrolabs only record turbidity values to an upper limit of 1000 NTU. This suggests that for watersheds with high sediment generation the sondes will be unable to provide the full sediment picture. Buffalo river watershed generated sediment at the “moderate” level however for a few events the 1000 NTU limit was exceeded. This suggests that additional sampling (grab sampling or use of automatic ISCO samplers) need to be introduced where sediment concentrations are expected to exceed the sonde upper limit.

- Turbidity-suspended relationship varied across the four sites in the Buffalo River watershed. This result emphasizes the need for developing site-specific turbidity-suspended sediment relationships.

- Key parameters that were most important for hydrologic calibrations for the Buffalo River watershed included – SFTMP, SMTMP, SMFMX, SMFMN, SNOCOVMX, SNO50COV, SURLAG, PRF, GW_DELAY, and ALPHA_BF.

- Discharge calibrations were best for summer and fall storm events. The model did not do a very good job in simulating streamflow during winter and early spring.

- The cover C and practice P factors were the most important parameters for sediment calibrations. C and P values were adjusted to fit model predictions to observed data. C and P values for croplands had to be reduced considerably (from default model values) to constrain simulated sediment yields within the observed data range.

- Initial sediment calibrations were performed by “switching off” the channel erosion component. This was done so that number of parameters that had to be calibrated could be reduced. Once the initial calibrations were completed, the channel erosion component was activated, but the model crashed and model runs could not be completed. These observations indicate a bug in the Arc-View SWAT channel erosion component. Limited channel erosion simulations were performed in the Monte-Carlo framework outside Arc-View and the simulations indicated that channel erosion parameters when activated do significantly impact the watershed sediment yield.

- Use of LULC GIS layer with “active” cropland parcels along with default cropland C and P (which affect sediment predictions) values produced the same order of sediment yields as the DOQQ-derived LULC where cropland C and P values were reduced considerably. This suggests that the areal extent of active croplands has to be accurately identified else the default values of C and P will have to be reduced.

7.3 Buffalo River watershed sediment results

- SWAT simulated annual sediment yields for the Buffalo River watershed (108,593 ha) for the years 1996-2003 were in the range of 0.5 to 1.1 tons/ha/yr with an eight-year average of 0.8 tons/ha/yr. In terms of total sediment yield the average amounts to 86,719 tons/yr. For comparison, the USGS measured sediment yield for the Big Darby Creek in Ohio (138,306 ha) for 1993 was 1.0 tons/ha/yr (http://webserver.cr.usgs.gov/sediment/stnbyTimePer.cfm). Similarly, the annual sediment yield for Juniata River near Newport (868686 ha), PA for the period 1985-1993 was measured at 1.24 tons/ha/yr. These numbers indicate that SWAT simulated sediment yields for the Buffalo River watershed are generally within the range observed for the region. Overall, sediment yields from the Buffalo River watershed can be categorized as "moderate".

- The Cazenovia Creek subwatershed contributed the largest portion (45%) to the total sediment yield from the Buffalo River watershed. This was despite the fact that in terms of total acreage (as identified from DOQs) Cazenovia Creek had the smallest portion of cropland compared to the other two watersheds. We attribute the higher sediment yields from Cazenovia Creek to the greater proportion of steep slopes in this subwatershed.

- SWAT simulations indicated that headwater watersheds in Cazenovia Creek and Cayuga Creek generated some of the highest sediment concentrations. Simulations also indicate that some of the headwater sediment gets deposited in the mid reaches of the Buffalo River on its way to the watershed outlet. However, our field measurements showed high sediment concentrations for headwater catchments as well as high sediment values at the subwatershed outlet. Based on this measured data, it appears that considerable amount of sediment is also being generated by channel erosion along major tributaries. We were not able to thoroughly assess the channel erosion component for the Buffalo River watershed using SWAT.

- YSI sonde data from the winter showed extremely high sediment concentrations in streams during ice-jams and ice-jam breakup. The high streamflow and high sediment concentrations recorded during ice-jam breakup suggest that ice-jams may contribute to a significant portion of sediment load to the annual sediment budget. SWAT cannot simulate the formation of ice jams and ice-jam breakup and hence may underestimate the annual sediment export from watersheds where ice-jams occur.

- "Scenario analysis" using vegetated filter strips indicated that filter strips had the greatest impact on sediment yield when they were implemented in headwater watersheds with moderate slope gradients. Filter strips as small as 5m in width were able to reduce watershed sediment loads by 17%.

- Overall, SWAT did a fairly good job in generating annual and seasonal sediment yields at the watershed scale and thus can be used as a planning tool for watershed assessment. However, the accuracy and reliability of SWAT predictions at the finer spatial (subcatchments and stream reaches) and temporal (daily and event) scales will depend on the accuracy of input information especially - the resolution of the LULC layer, the number of rainfall stations used in simulations, and the number of internal sites against which the model has been calibrated.

8. REFERENCES

Di Luzio, M., R. Srinivasan, and J. G. Arnold. 2002. Integration of watershed tools and SWAT Model into BASINS. Journal of American Water Resources Association, 38(4): 1127-1141.

Srinivasan, R. and J. G. Arnold. 1994. Integration of basin-scale water quality model with GIS. Water Resources Bulletin 30(3): 453-462.

FitzHugh, T. W. and D. S. Mackay. 2000. Impacts of input parameter spatial aggregation on agricultural nonpoint source model. Journal of Hydrology 236: 35-53.