FINAL PROJECT REPORT

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SEDIMENT MODELING FOR THE EIGHTEEN MILE CREEK WATERSHED, NIAGARA COUNTY

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TABLE OF CONTENTS

1. EXECUTIVE SUMMARY

The Soil Water Assessment Tool (SWAT) was implemented for the Eighteen Mile Creek watershed to determine annual sediment yields and critical source areas of erosion in the 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, an important input for SWAT, was manually updated using 2002 DOQQs. 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 1992-2004. Weather data for model simulations was downloaded from the online NCDC web site.

A stochastic approach was used to calibrate the hydrologic component of the model since the watershed did not have any real time USGS gages. Model simulated monthly runoff ratios for Eighteen Mile were compared against measured runoff ratios for two adjacent watersheds – the Tonawanda and Cayuga Creek watersheds. Sediment calibrations were performed by comparing model simulated daily sediment concentrations against measured suspended sediment concentrations for two sites in the watershed. Sediment monitoring was performed by continuously-recording YSI sondes and grab sampling for suspended sediment. Sediment data was collected for the period August 2004 – November 2005.

Key parameters that were most important for hydrologic and sediment calibrations included – SFTMP, SMTMP, SMFMX, SMFMN, SNOCOVMX, SNO50COV, SURLAG, ESCO, GW_REVAP, cover factor C, and practice factor P. The C and P values for croplands had to be reduced considerably (from default model values) to constrain simulated sediment concentrations within the observed data range.

Average annual streamflow discharge from the watershed was 412 mm while the annual runoff ratio was 0.45. Annual sediment yield amounted to 1.15 tons $ha^{-1}yr^{-1}$. This sediment yield is greater than that simulated by SWAT for the Buffalo River watershed (0.8 tons $ha^{-1}yr^{-1}$; Inamdar, 2004b).

There was considerable spatial variation in sediment generation within the Eighteen Mile Creek watershed with a range of 0.22-5.52 tons $ha^{-1}yr^{-1}$. A group of agricultural subbasins on the southwestern end of the watershed generated the highest sediment yields and should be targeted for implementation of best management practices.

2. INTRODUCTION

The BASINS (Better Assessment Science Integrating Point & Nonpoint Sources) suite of models is one of the tools that is being actively promoted by the Environmental Protection Agency (EPA) for developing TMDL plans for the 303(d) list of priority waters (EPA, 2001). The Soil Water Assessment Tool (SWAT) model which is provided as a part of the BASINS tools has especially been popular for developing watershed-scale budgets of water and chemicals and to identify source areas of pollution (Arnold and Fohrer, 2004). The SWAT model was implemented for the Eighteen Mile Creek watershed located in Niagara County, NY. The intent was to use SWAT to determine sediment yields at the watershed outlet and to identify subbasins and stream reaches that contributed high sediment yields. Specific tasks that were performed included:

Task 1: Determine discharge and sediment concentrations at two locations in the watershed. This data will be used to calibrate the model. Generate sediment yields.

Task 2: Implement the SWAT model for the drainage basin. Calibrate the model using discharge and sediment data. Identify the key parameters and processes.

Task 3: Using calibrated model identify watershed areas and stream reaches contributing sediment yield.

3. SITE DESCRIPTION AND METHODS

3.1 Site description

The Eighteen Mile Creek located in Western NY drains an area of 211 km^2 into Lake Ontario. A 14-year average (1990-2004) of annual precipitation for the nearest NOAA weather station (NCDC, 2005) located in Niagara Falls, NY amounted to 923 mm. Annual snowfall recorded for the same duration was 1832 mm (72 inches). Average temperature for the station was measured at 9 ^oC.

Elevations in the watershed range from 74 m at the northern edge with Lake Ontario to 202 m along the southern boundary of the watershed (Figure 3.1). The mean slope gradient for the watershed is 1.5% with a maximum of 49% along the southern edge (Figure 3.2). Predominant soil associations include: Darien-Cazenovia-Nunda (26% area), Niagara-Canadaigua-Collamer (15%), and Honeoye-Ontarioa-Lima (12%). The STASGO GIS layer showing the spatial distribution of the soil types is presented in Figure 3.3. Agriculture is the predominant landuse in the watershed covering about 50% of the watershed area, followed by forests (27%) (Figure 3.4).

3.2 Model implementation

The key GIS layers that were required by SWAT included:

1. the digital elevation model (DEM),
2. stream drainage network,
3. soils,
4. landuse-landcover (LULC).

DEMs of 10 m resolution were available for the watershed (CUGIR, 2005). The National Hydrography Drainage (NHD) network was downloaded off the USGS NHD server (USGS, 2005a). STASGO soils layers were downloaded off the USDA Natural Resource Conservation Service (NRCS) server (NRCS, 2005). The LULC layer provided with the SWAT model from the EPA BASINS web site (EPA, 2001) displayed landuse information from the 1970s. This LULC was manually updated for changes in landuse parcels by comparing the data against landuse visible in 2002 digital ortho quarter quads (DOQQs) for NY (Inamdar, 2004a). The updated LULC is presented in Figure 3.4.

A comprehensive description of the SWAT model algorithms, parameters, and execution procedures is provided in Santhi et al. (2001) and USDA-ARS (1999) and hence is not repeated here. Following Santhi et al. (2001) the watershed was subdivided into component subbasins and reaches (Figure 3.5) using default SWAT thresholds for watershed partitioning. Water and sediment budgets were determined for each of the component subbasins and stream reaches with the subbasins.

3.3 Methodology for model calibration

SWAT hydrologic calibrations are typically performed by comparing simulated streamflow discharges against measured values such as those recorded by USGS gages. Parameter values are adjusted until the fit between the simulated and measured discharges is optimum. The fit between measured and simulated discharges is quantified using various mathematical functions such as the Nash Sutcliffee efficiency, Bias, or correlation r. This approach was recently used for the Buffalo River watershed located south of the Eighteen Mile Creek watershed (Inamdar and Naumov, 2005; Inamdar, 2004b). However, unlike the Buffalo River watershed, the Eighteen Mile Creek watershed did not have any active USGS gages to record discharge. Furthermore, the two stage loggers that were installed in the watershed in 2005 did not provide data reliable enough to be used for model comparisons.

Considering that no measured discharge data was available a stochastic approach was used to calibrate the hydrologic component of the model for the Eighteen Mile Creek watershed. The approach was to compare the pattern of monthly runoff ratios (discharge divided by precipitation amounts) simulated for the Eighteen Mile Creek against those measured for two adjacent watersheds. Data on daily discharge was available for the Cayuga and Tonawanda Creek watersheds from the USGS streamflow website (USGS, 2005b). Daily precipitation data was available for the weather stations located in Niagara Falls and North Tonawanda (NCDC, 2005). Discharge and precipitation data for a 10 year period (1990-99) was collected from these locations. The daily precipitation data for Niagara Falls and North Tonawanda was averaged on a daily basis to get a daily areal average precipitation for the region. The daily discharge values were aggregated on a monthly basis for the two watersheds and then divided by the average monthly precipitation to arrive at monthly runoff ratios for the 10 year period. The 10-year monthly ratios were then further averaged for each month (e.g., grouping all Januarys ratios for the 10 year period) to determine the mean monthly runoff ratios. For model simulations, the daily averaged precipitation and temperature data (from Niagara Falls and North Tonawanda stations) was provided as an input.

Model simulations were performed for the period 1992-2004, with 1992 outputs being discarded since the first year was used as a “warm-up” period for the model. Monthly discharge data from the period 1993-2004 was then used to compute the runoff ratios which were then compared against those derived from measured data for Cayuga and Tonawanda Creeks. The fit between the measured and simulated runoff ratios was assessed using sum of squared errors ($\sum(S_i-O_i)^2$; where S_i and O_i are the simulated and observed values, respectively).

Simulated discharge that was used in the calibration was the sum of the discharges exiting subbasins 2 and 3 (Figure 3.5). Discharge from the main watershed outlet (exiting subbasin 1) was not used because a dam (Burt Dam) was located on the main stem of the Creek midway through subbasin 1.

A rigorous Monte-Carlo simulation was recently performed for the adjoining Buffalo River watershed (Inamdar and Naumov, 2005; Inamdar, 2004b) through which sensitive SWAT parameters and their optimum values were identified. These parameters and their values were used as starting points for SWAT calibrations for the Eighteen Mile Creek watershed. Parameter values were adjusted until the optimum fit between measured and simulated monthly ratios was identified.

Following the hydrologic calibrations, calibrations were performed for the sediment component of the model. For calibration of the sediment component, simulated sediment concentrations (mg/L) were compared against values measured at two selected points in the watershed. The instrumentation and sediment data collection procedures are described in the following section. Daily sediment concentrations for the two sites (described below) were available for the period August 2004 through November 2005 (with a gap in data from January 2004 through March 2004). The simulated values were compared to observed values by assessing the visual fit between the time series and by comparing the frequency distributions of the data sets. The intent was not to obtain a fit between simulated and measured values for each individual data point but rather to make sure that the simulated values were within the same order of magnitude of the measured data. A greater emphasis was placed on matching the frequency distributions of the simulated and measured sediment concentrations. Parameter values that were adjusted in the calibrations were – the cover factor C and the practice factor P.

3.4 Sediment data for calibration

Sediment monitoring was performed using continuously logging sondes and manual grab-sampling at selected locations in the watershed. Continuous monitoring was performed using YSI sondes (YSI, Inc.) which recorded turbidity at every 15 minutes. Manual grab sampling allowed us to develop regression relationships between suspended sediment concentrations and turbidity which were then used to derive the sediment concentration time-series from the sonde measurements. The high-frequency sampling by the sondes provided a detailed picture of sediment concentrations especially during storm events.

The data sondes were installed at two locations within the Eighteen Mile Creek watershed– sites E1 and E2 (Figure 3.6). At each sites the sondes were encased in 6 inch PVC pipes which were perforated along their length to allow entry of water and sediment (Figure 3.7). The sondes were downloaded every two weeks and batteries were changed as required. The sondes were calibrated prior to installation and every four months thereafter.

Grab suspended sediment sampling was performed at the two sites during low flow and storm-event periods. Suspended sediment concentrations for the samples were determined by filtering the samples through 0.45 μm Millipore (Millipore, Inc.) filters and then determining the oven-dried weight of the filtered sediment (Standard Method 2540 D as described in APHA, 1989). The suspended sediment concentrations and the corresponding turbidity values recorded by the sondes were then plotted to develop the suspended sediment-turbidity relationships. The suspended sediment-turbidity relationships for E1 and E2 along with the regression equations are presented in Figures 3.8 and 3.9. The regression equations were then used to transform the 15-minute turbidity values recorded by the sonde to suspended sediment concentrations. The 15-minute suspended sediment concentrations were then averaged to determine mean daily sediment concentrations which were evaluated against daily simulated values.

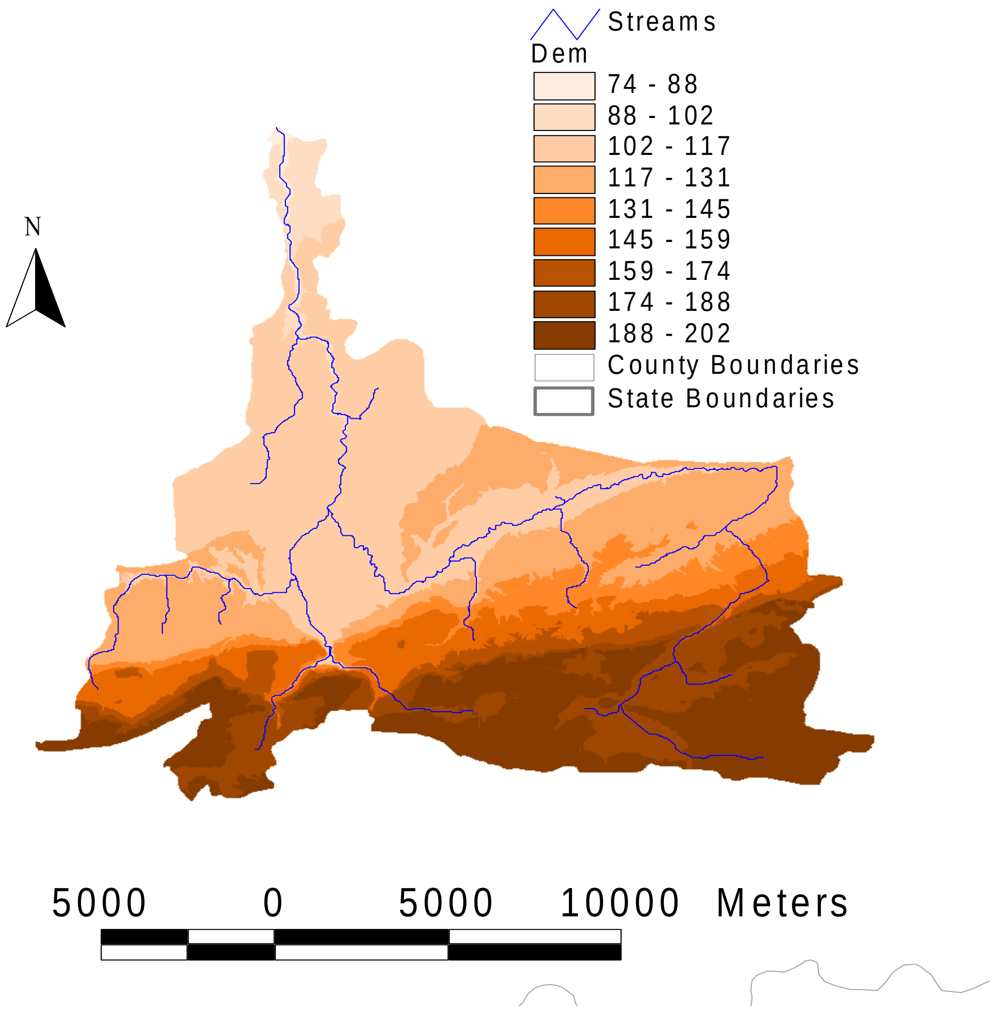

Figure 3.1: Digital elevation model (DEM) of the Eighteen Mile Creek watershed.

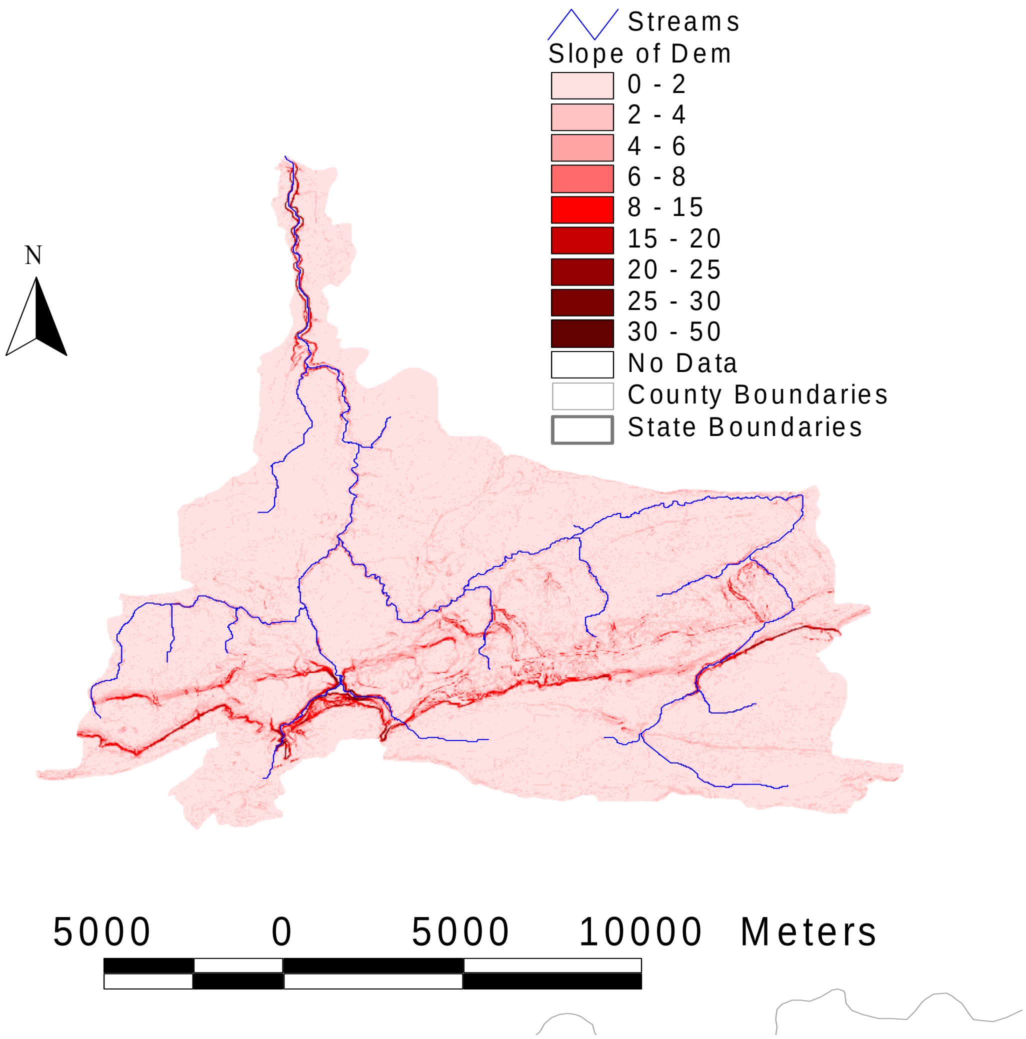

Figure 3.2: Slope gradients (%) in the Eighteen Mile Creek watershed.

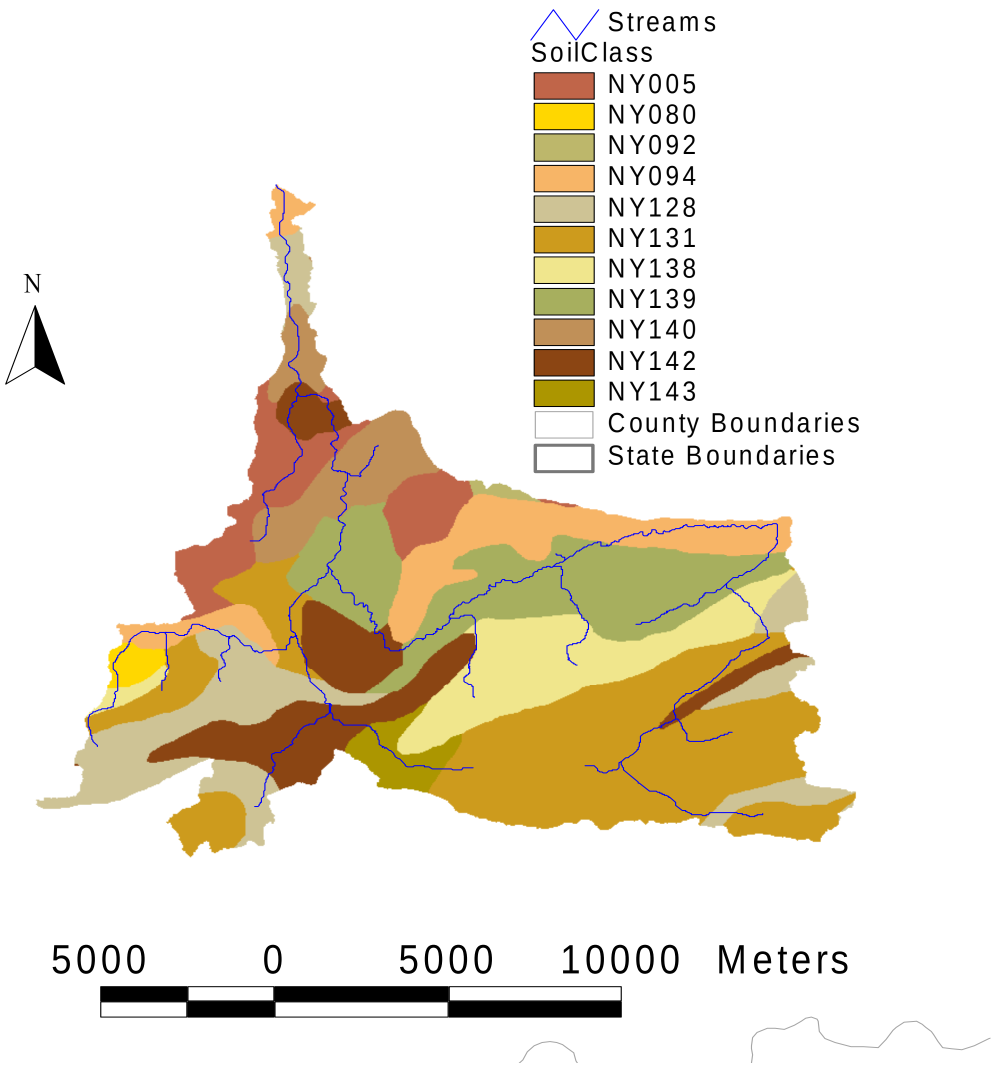

Figure 3.3: STASGO soils map for the Eighteen Mile Creek watershed.

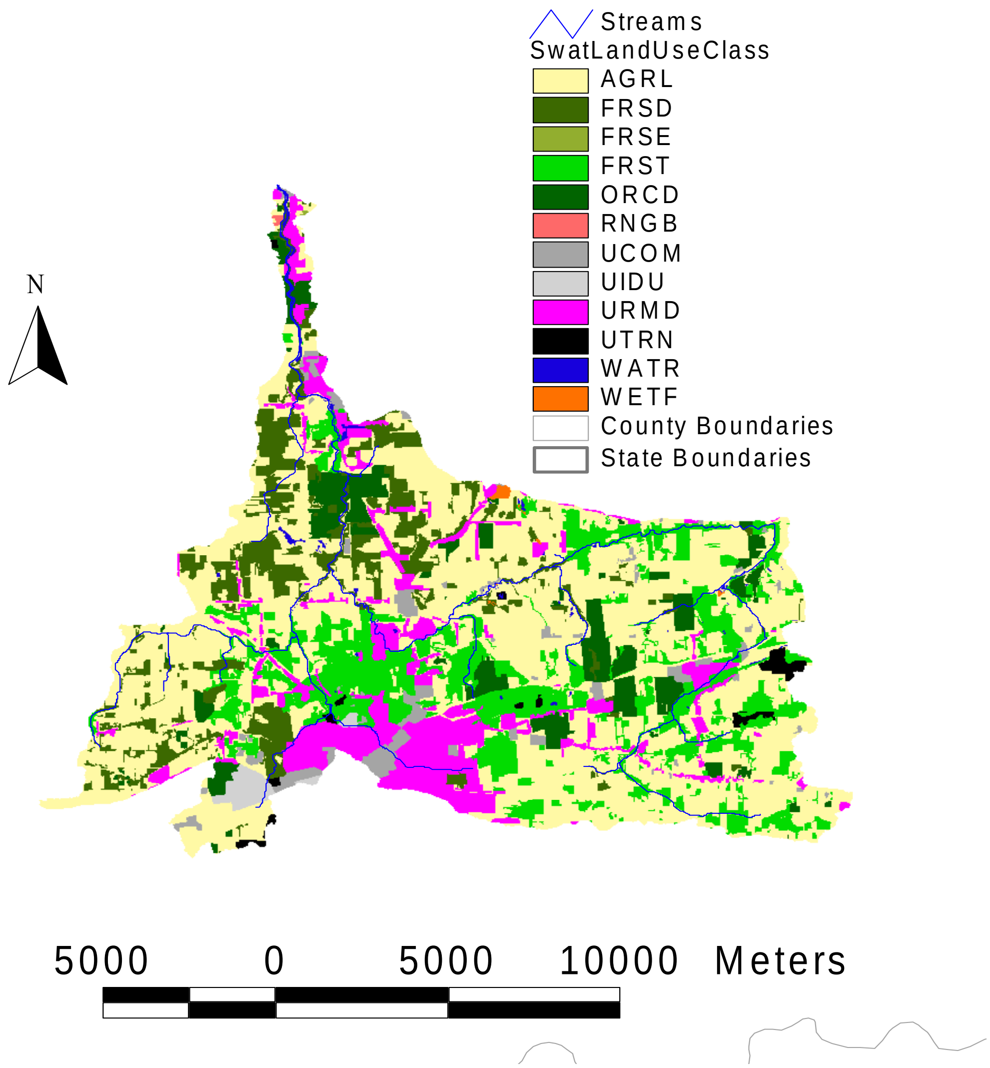

Figure 3.4: Landuse distribution in the Eighteen Mile Creek watershed.

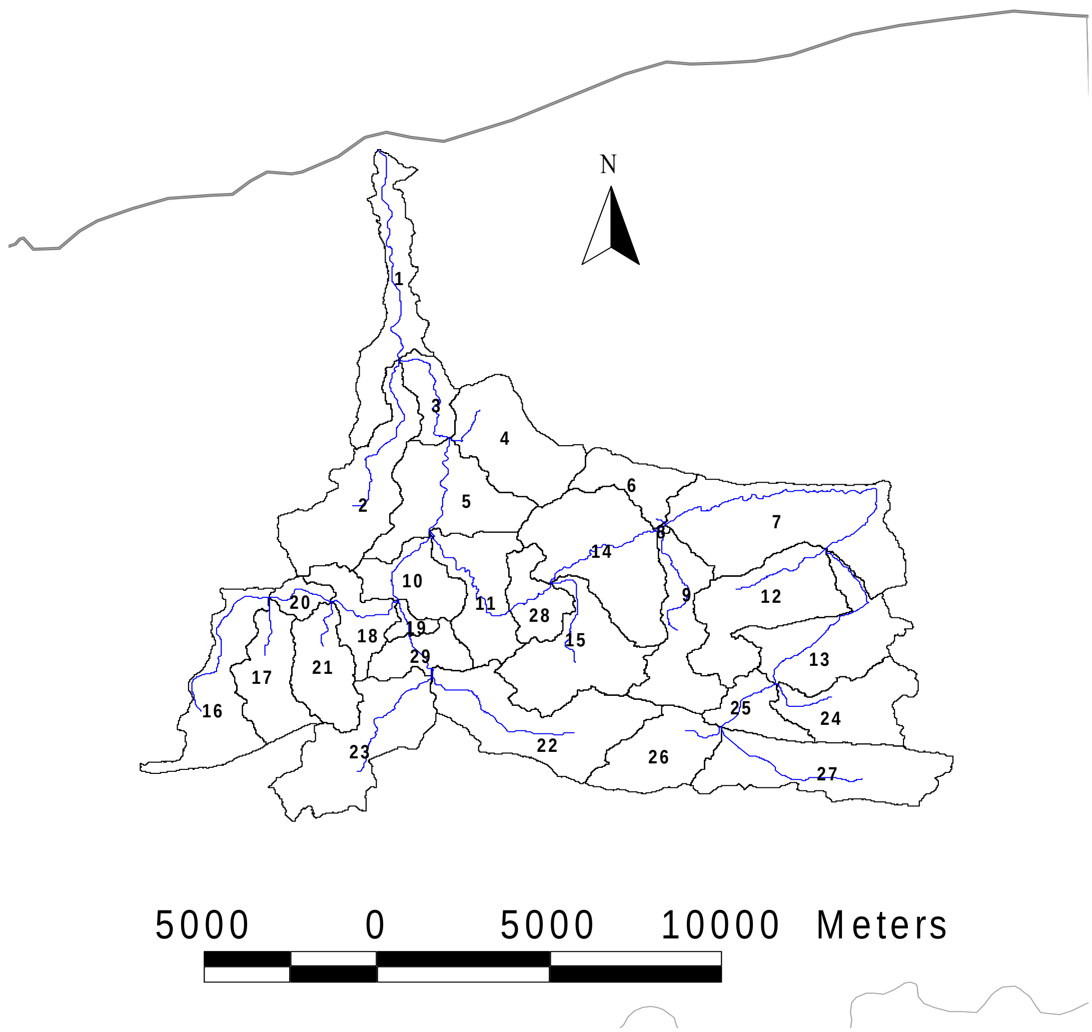

Figure 3.5: SWAT subbasin scheme for the Eighteen Mile Creek watershed.

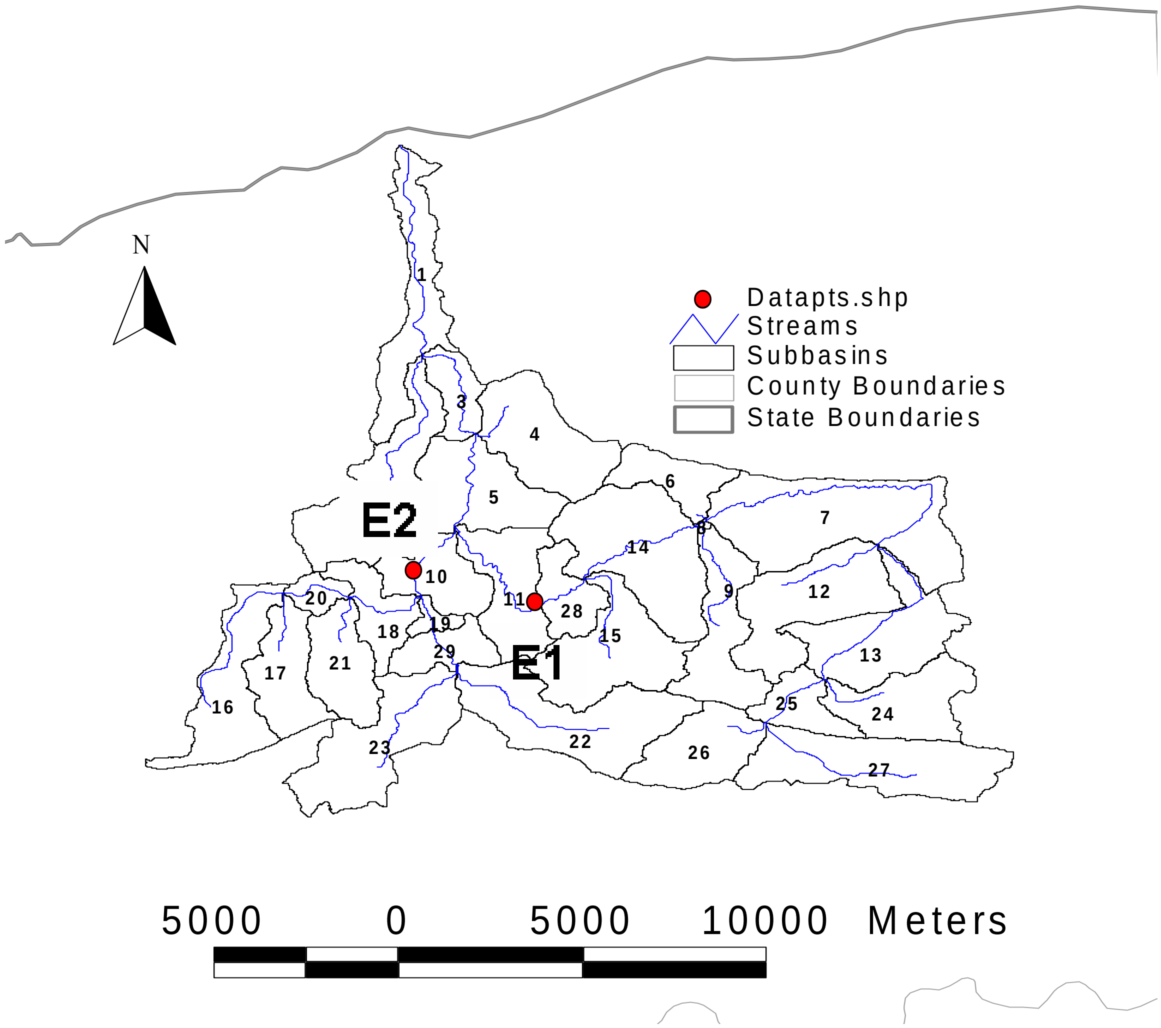

Figure 3.6: Sediment monitoring stations E1 and E2 (indicated by red dots) in the Eighteen Mile Creek watershed.

Figure 3.7: YSI sondes located within PVC pipes at stations E1 (left) and E2 (right).

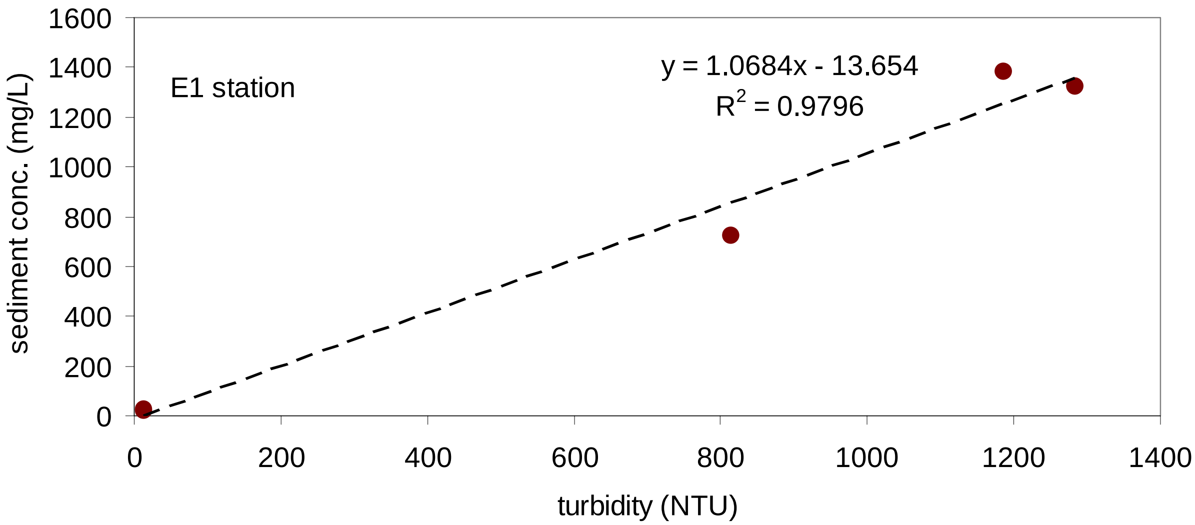

Figure 3.8: Relationship between turbidity (NTU) and suspended sediment concentrations (mg/L) for station E1.

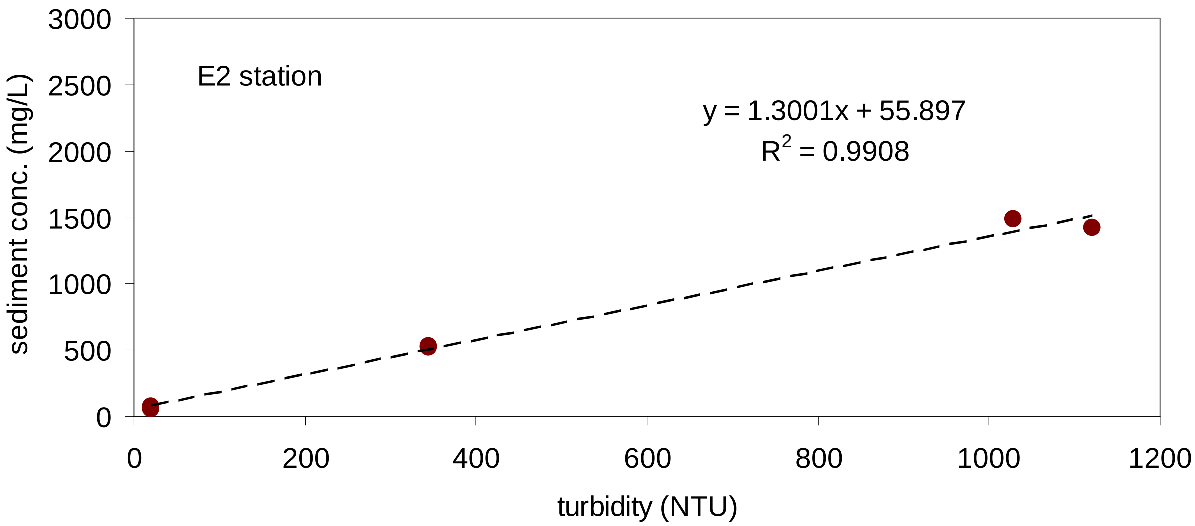

Figure 3.9: Relationship between turbidity (NTU) and suspended sediment concentrations (mg/L) for station E2.

4. RESULTS AND DISCUSSION

4.1 Discharge calibrations

The comparison of observed and simulated monthly runoff ratios corresponding to the optimal fit is presented in Figure 4.1. The runoff ratios for Cayuga and Tonawanda creeks were closely bunched across the months indicating a similar hydrologic response pattern for these watersheds. The sum of squared errors corresponding to the optimal fit between observed and simulated values was 0.39. Model simulated values for Eighteen Mile Creek were closest to observed data points for the period July-December. Simulated runoff ratios did not match as well with the observed values during the winter and spring months, with the greatest discrepancy for the month of June (Figure 4.1). The optimal parameter values are presented in Table 4.1. Parameters that were especially important in constraining simulated discharge volumes were SMFMX, SMFMN, ESCO, and REVAP_C.

It is important to note here that the influence of Erie Canal and the water discharges from the canal to the stream network was not simulated. Water is occasionally released from the canal to the Eighteen Mile tributaries, but since there was no record of these releases we were not able to account for this in the model simulations.

4.2 Sediment calibrations

Similar to the observations made for the Buffalo River watershed (Inamdar and Naumov, 2005; Inamdar, 2004b), model simulations performed for Eighteen Mile Creek with default cover (C) and practice (P) factors produced sediment concentrations much higher than the measured values. To constrain the sediment concentrations, all C values for agricultural (AGRL) parcels were reduced from the default value of 0.2 (associated with corn crop) to a value of 0.1. Only AGRL parcels were adjusted since this landuse was responsible for most of the sediment generation in the watershed. A reduction in the corn C value from 0.2 to 0.1 constrained the simulated sediment concentrations at E2 within the range of the observed, however the simulated values for E1 still exceeded the corresponding observed data (Figure 4.2 and 4.3). This result suggests that either the cropland in E2 was not actively cultivated or that there were sediment sinks in the drainage system (above E2) which the model did not simulate. Our previous analysis for the Buffalo River watershed indicated that only a fraction of the cropland identified from DOQQs was actively cultivated (Inamdar and Naumov, 2005). To further constrain the sediment concentrations for E1, the P values for all catchments draining to E1 were reduced from the default of 1.0 to 0.1. This large reduction in the P value produced sediment concentrations which were much closer to the observed values at E1 (Figure 4.4). These calibration results highlight the importance of and need for multiple measurements within the watershed. These results also suggest that SWAT predictions of sediment cannot be taken at face value and that considerable fine-tuning of parameters is required for realistic sediment predictions.

In addition to the visual comparison of time series data, a comparison of the frequency distributions of simulated and observed concentrations were also performed (Figure 4.5 and 4.6). The frequency distribution for E1 indicates that the model over-predicted the high sediment concentrations. For E2, the model did a good job in predicting the higher sediment concentrations (400-2000 mg/L) but under-predicted the occurrence of intermediate sediment concentrations (75-200 mg/L).

While performing the sediment calibrations the "channel degradation" component of the SWAT model was deactivated. The component was deactivated because we did not have the appropriate measured data to constrain parameter values. Our visual observations in the watershed indicate that some streambank erosion does occur along some stream reaches especially during periods of elevated streamflow (winter and spring).

4.3 Discharge and sediment yields

Once discharge and sediment calibrations were performed, discharge and sediment yields were generated for the Eighteen Mile Creek watershed. The yields were generated for a location upslope of the Burt Dam (flow exiting subbasins 2 and 3 – Figure 3.5). This was because the dam was not included in model simulations. Over the 10 year simulation period (1993-2004) annual streamflow discharge ranged between 268-568 mm (Figure 4.7) with a mean of 412 mm. The mean annual runoff ratio for this simulation period was 0.45.

Annual sediment yield for the same location and simulation period ranged between 0.67-1.87 tons/ha/yr (Figure 4.8) with mean of 1.15 tons $ha^{-1}yr^{-1}$. SWAT simulations for the Buffalo River watershed (Inamdar and Naumov, 2005; Inamdar, 2004b) indicated a mean annual sediment yield of 0.8 tons $ha^{-1}yr^{-1}$. For comparison, the USGS measured sediment yield for the Big Darby Creek in Ohio (138,306 ha) for 1993 was 1.0 tons $ha^{-1}yr^{-1}$ (USGS, 2004). Similarly, the annual sediment yield for Juniata River near Newport (868686 ha), PA for the period 1985-1993 was measured at 1.24 tons $ha^{-1}yr^{-1}$.

To get an estimate of the seasonal pattern in sediment generation, the mean monthly sediment yields (tons) were computed for subbasins 10 and 28 (which corresponded with the stations E2 and E1, respectively). For both locations sediment yields were high during winter and early spring with highest values recorded for the month of March (Figure 4.9). Winter and spring are periods of high runoff and consequently result in a greater delivery of sediment from the watershed.

4.4 Spatial pattern of water and sediment yields

The spatial pattern of runoff generation is presented in Figure 4.10. Subbasins that generated the highest runoff included - 6, 20, and 22; while least runoff was produced from 11, 15, and 29. The elevated runoff from subbasin 22 was not unexpected since this basin had the greatest proportion of urban development (URMD, refer to Figure 3.4) as a proportion of the subbasin area. Conversely, the large proportion of forested areas (FRST) in subbasins 11, 15, and 29 were likely responsible for the low runoff from these subbasins.

There was considerable spatial variation in sediment generation in the watershed. Sediment yields varied from 0.22 to 5.52 tons $ha^{-1}yr^{-1}$ (Figure 4.11). Highest sediment yields were generated from a cluster of subbasins (16, 17, and 20) located on the southwestern edge of the watershed. Lowest values of sediment were recorded for subbasins 3, 5, 11, and 28. Subbasins that generated the highest sediment yields (16, 17, and 20) also appeared to have the greatest proportion of AGRL parcels (Figure 3.4). Clearly, these subbasins should be targeted if best management practices for reducing sediment yield are to be implemented in this watershed.

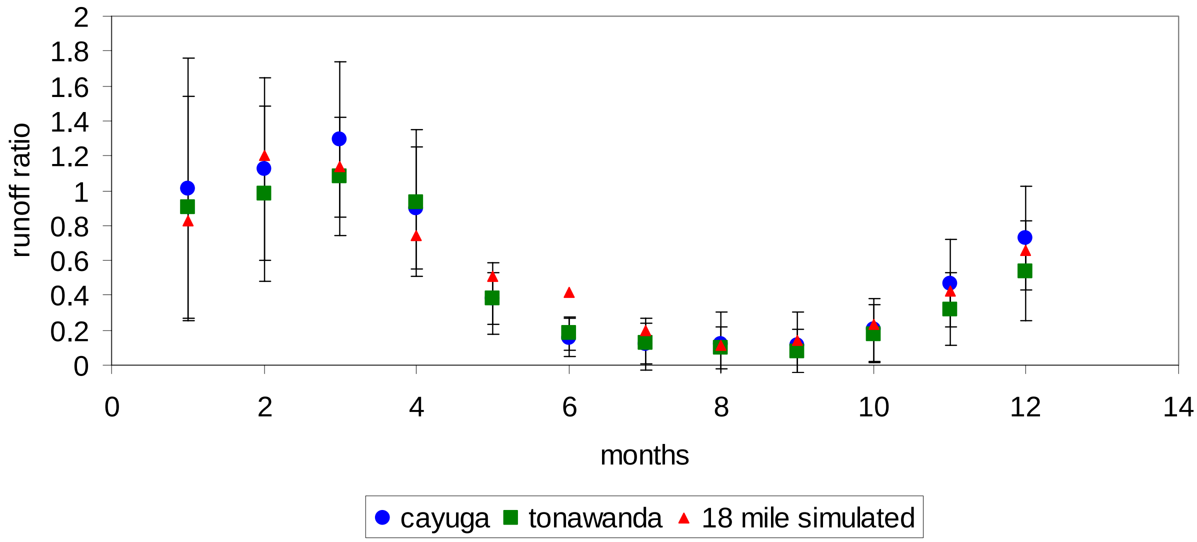

Figure 4.1: Comparison of monthly runoff ratios from measured discharges for Cayuga and Tonawanda Creeks against simulated values for Eighteen Mile Creek watershed.

Table 4.1: Optimum parameter values used for SWAT executions.

Parameter	Description	Calibrated Values	Default values
Basin parameters (*.bsn)			
SFTMP	Snowfall temperature [C]	0.7	1.0
SMTMP	Snowmelt base temperature [C]	0.5	0.5
SMFMX	Maximum snow melt rate [mm/C*day]	4.0	4.5
SMFMN	Minimum snow melt rate [mm/C*day]	3.0	4.5
TIMP	Snow pack temperature lag factor [-]	0.5	1.0
SNOCOVMX	Minimum snow water content that corresponds to 100% snow cover [mm]	25.0	1.0
SNO50COV	Fraction of snow volume represented by SNOCOVMX that corresponds to 50% snow cover [-]	0.5	1.0
SURLAG	Surface runoff lag coefficient [days]	1.0	4.0
PRF	Peak rate adjustment factor for sediment routing [-]	1.58	1.0
SPCON	Linear parameter for sediment re-entrainment	0.001	0.001
SPEXP	Exponent parameter for sediment re-entrainment	1.00	1.5
Groundwater parameters (*.gw)			
GW_REVAP	Groundwater evaporation coefficient	0.10	0.0
HRU parameters			
ESCO	Soil evaporation compensation factor	0.5	0.0

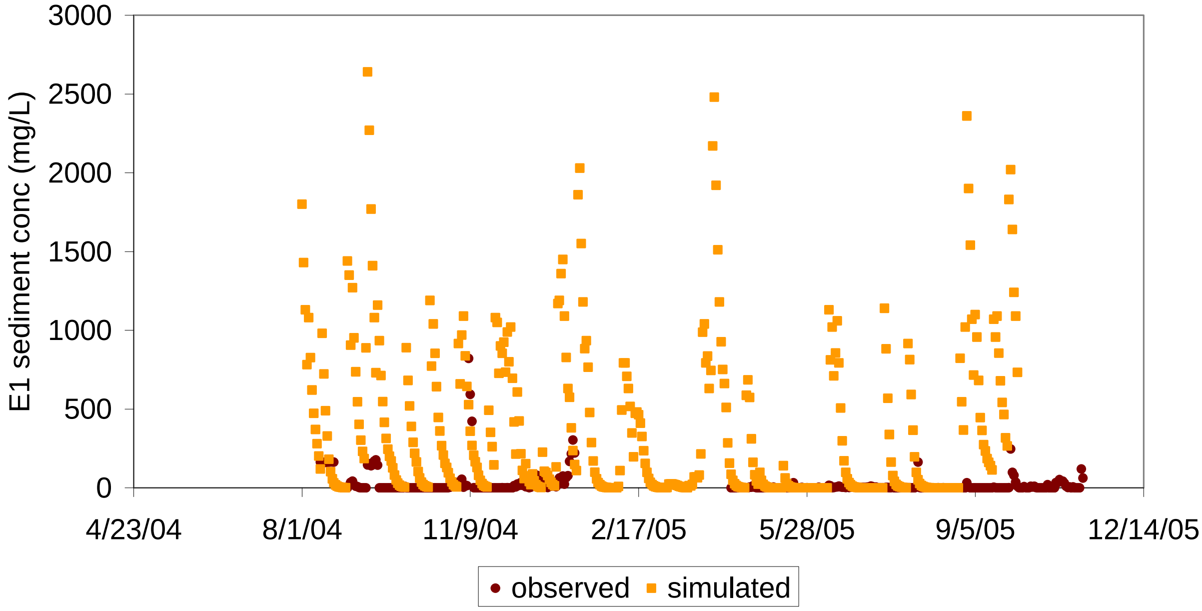

Figure 4.2: Comparison of measured and simulated sediment concentrations (mg/L) for station E1.

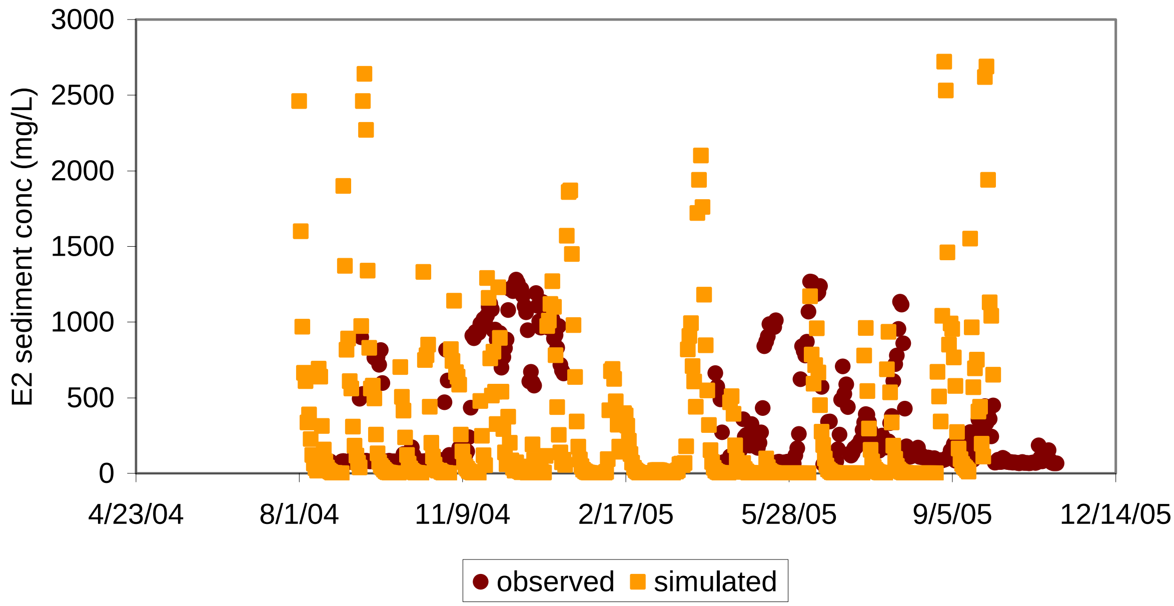

Figure 4.3: Comparison of measured and simulated sediment concentrations (mg/L) for station E2.

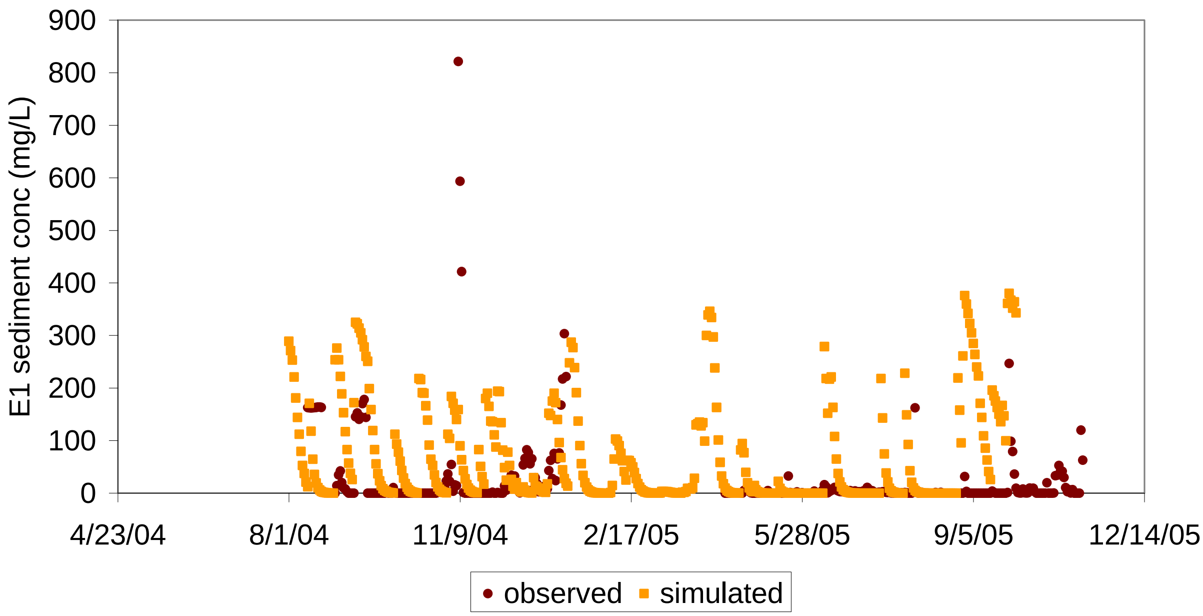

Figure 4.4: Comparison of measured and simulated sediment concentrations (mg/L) for station E1.

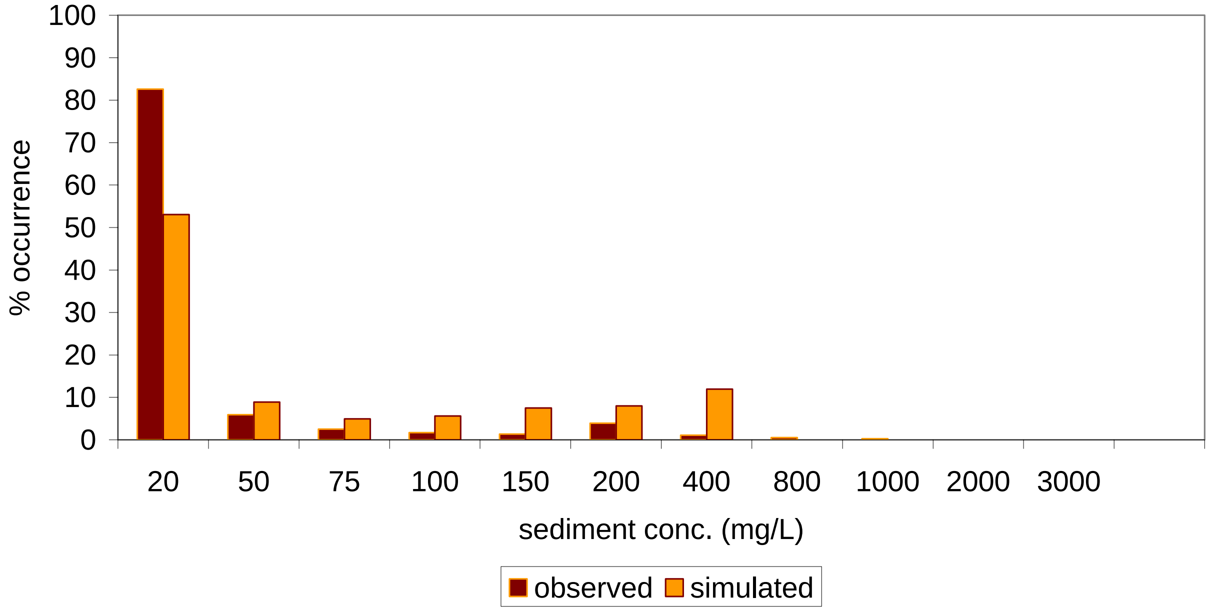

Figure 4.5: Comparison of frequency distributions of measured and simulated sediment concentrations (mg/L) for E1.

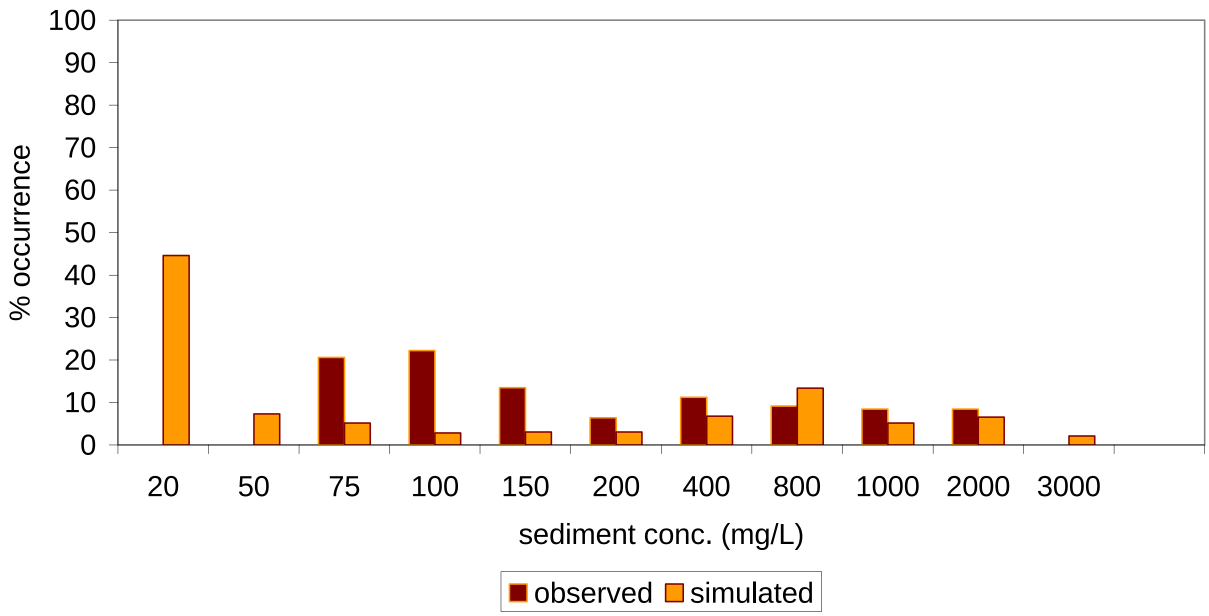

Figure 4.6: Comparison of frequency distributions of measured and simulated sediment concentrations (mg/L) for E2.

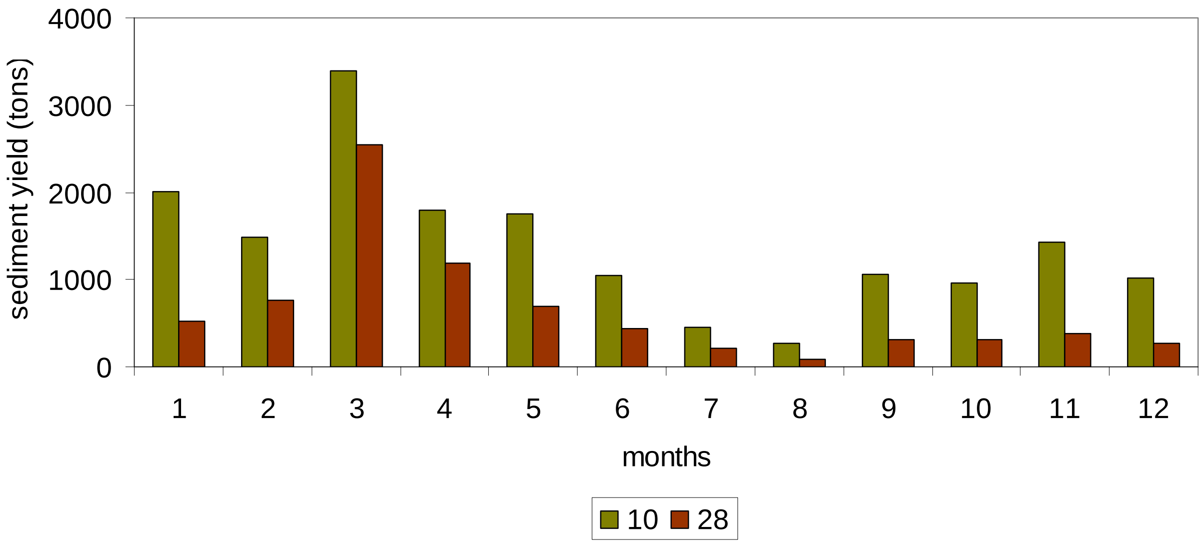

Figure 4.7: The pattern in monthly sediment yields (tons) for subbasins 10 (E2) and 28 (E1). The monthly values are an average over the simulation period 1993-2004.

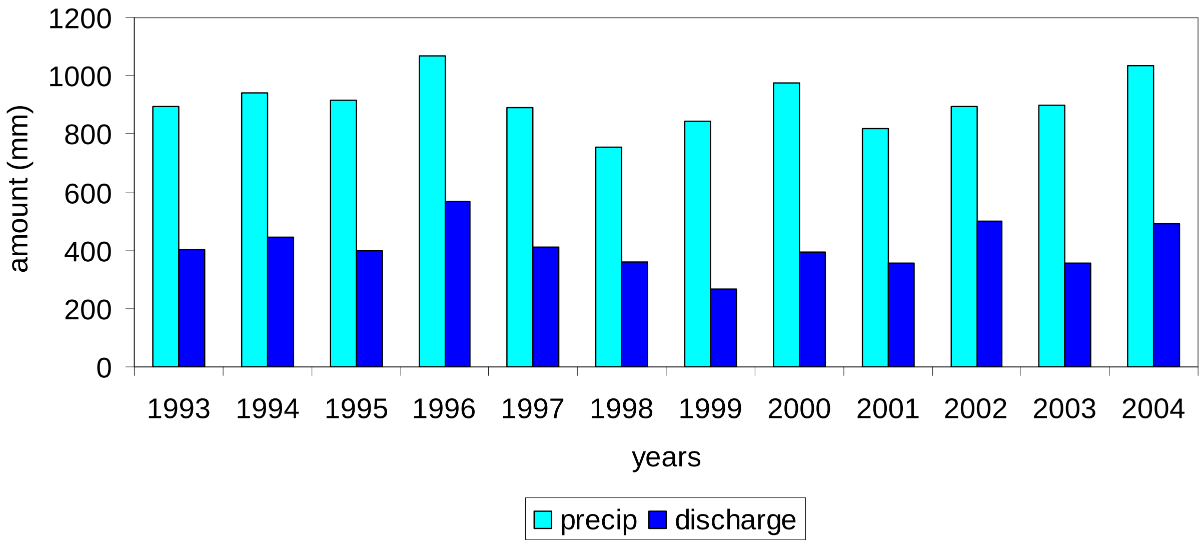

Figure 4.8: Annual precipitation and discharge (mm) values for the Eighteen Mile Creek watershed over the 1993-2004 simulation period.

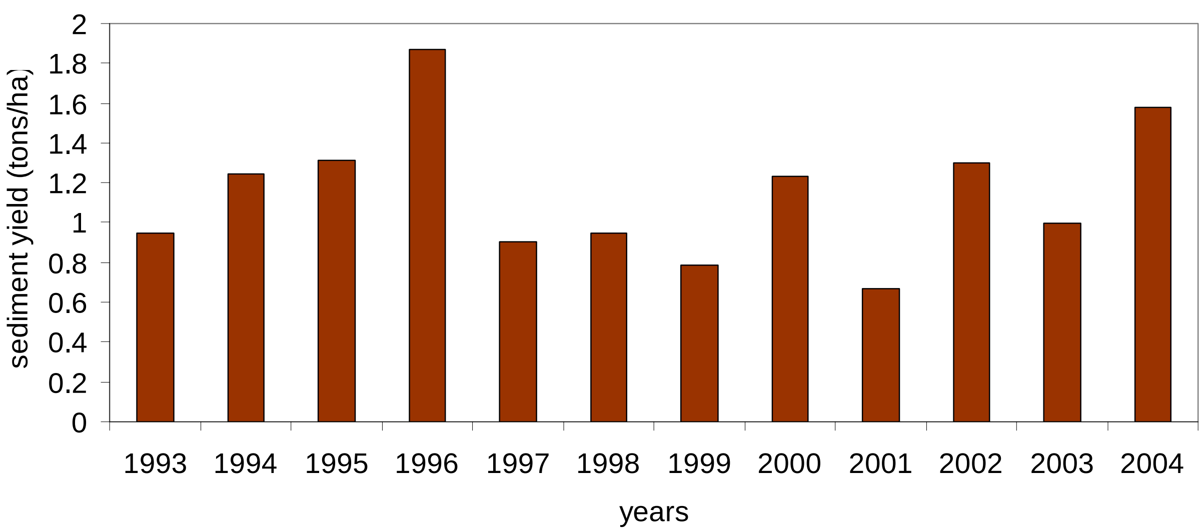

Figure 4.9: Annual sediment yields (tons $ha^{-1}yr^{-1}$) for the Eighteen Mile Creek watershed over the 1993-2004 simulation period. Average annual sediment yield was 1.15 tons $ha^{-1}yr^{-1}$.

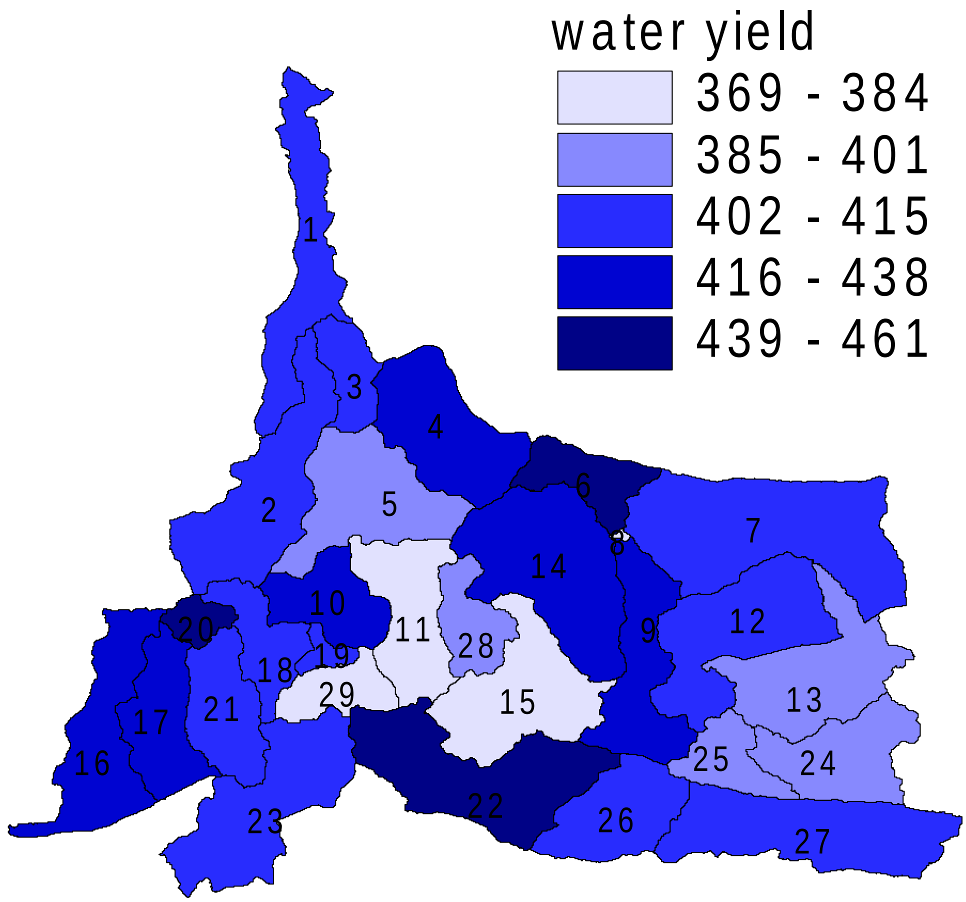

Figure 4.10: Spatial pattern of runoff generation (mm) in the Eighteen Mile Creek watershed.

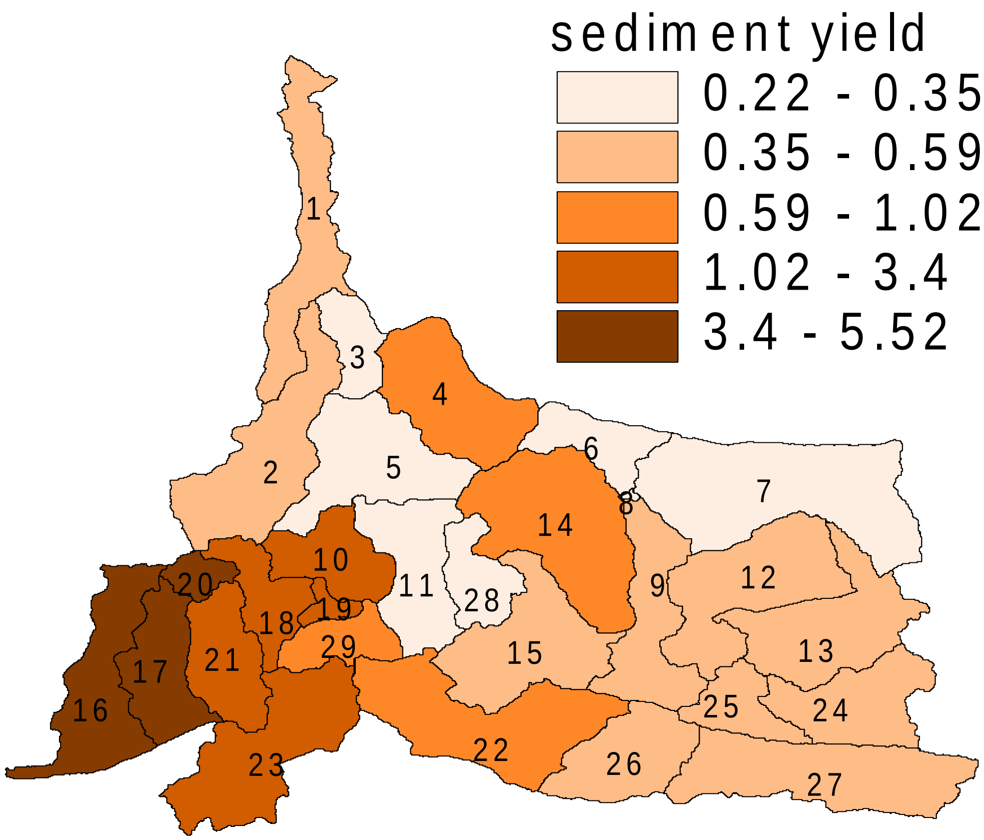

Figure 4.11: Spatial pattern of sediment generation (tons $ha^{-1}yr^{-1}$) in the Eighteen Mile Creek watershed.

5. CONCLUSIONS AND RECOMMENDATIONS

- Measured sediment concentrations were very important for constraining model simulated sediment concentrations. With default C and P parameters the model-simulated sediment concentrations were much higher than the observed values. Furthermore, measured data indicated that subbasins in the eastern portion of the watershed were not generating as much sediment as the model was predicting. This meant that the P values for the agricultural parcels for the eastern subbasins had to be further reduced so that model simulated concentrations matched the observed data.

- For hydrologic calibrations, model simulated runoff ratios were compared to measured runoff ratios for Tonawanda and Cayuga Creeks. The fit between model simulations and observations was much better for summer and fall periods compared to the winter and spring months. Hydrologic calibrations were performed using a stochastic approach. Future model evaluations should include measured streamflow discharges for the watershed.

- Key parameters that were most important for hydrologic and sediment calibrations included – SFTMP, SMTMP, SMFMX, SMFMN, SNOCOVMX, SNO50COV, SURLAG, ESCO, GW_REVAP, cover factor C, and practice factor P.

- Average annual streamflow discharge from the watershed was 412 mm while the annual runoff ratio was 0.45. Annual sediment yield amounted to 1.15 tons $ha^{-1}yr^{-1}$. This sediment yield is greater than that simulated by SWAT for the Buffalo River watershed (0.8 tons $ha^{-1}yr^{-1}$; Inamdar, 2004b).

- There was considerable spatial variation in sediment generation within the Eighteen Mile Creek watershed with a range of 0.22-5.52 tons $ha^{-1}yr^{-1}$. A group of subbasins on the southwestern end of the watershed generated the highest sediment yields and should be targeted for implementation of best management practices.

- As expected, subbasins with the largest proportion of urban development produced the greatest amounts of runoff. Across all subbasins annual average runoff varied from 369-461 mm.

- Future model evaluations should include: (a) additional sediment monitoring stations to further constrain sediment predictions; (b) evaluation of the contribution of streambank erosion to the annual sediment budget; and (c) installation of discharge gages on tributaries so that model predictions can be compared against actual measured discharges in the watershed. Future modeling should also include identification of "actively" cultivated agricultural parcels. Data available for the Buffalo River watershed (Inamdar, 2004b) showed that a large fraction of the agricultural parcels were not in "active" cultivation. Sediment generation in the watershed is strongly linked to the areal extent of cultivated fields.

6. REFERENCES

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