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THE OAK ORCHARD SOIL WATER ASSESSMENT TOOL A decision support system for watershed management Part 1: Calibration and Validation

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Part 1: Calibration and Validation

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ABSTRACT

A hydrologic model (SWAT) was developed and calibrated for the Oak Orchard watershed to evaluate sources and sinks of sediment and nutrients. The model included the most important anthropogenic features that impacted water flow and nonpoint source pollution in the watershed. These features included reservoirs at the Iroquois National Wildlife Refuge, Waterport and Medina; point sources such as the Erie Canal, US Gypsum, Allen Canning, wastewater treatment plants at Medina, Oakfield and Elba, and tiledrains at the mucklands, an intensely farmed area that was drained to combat malaria in the 19th century. The model included point sources for every subbasin so that the effects of future point sources can be evaluated. The model was calibrated for waterflow and sediment using observed loading data collected by Makarewicz and Lewis (2000, 2009). To achieve the proper water balance observed at the watershed, seasonal inputs of water had to be added from the Erie Canal and the Onondaga escarpment. This water came from outside of the watershed. The resulting calibration had a Nash-Sutcliffe (NS) prediction efficiency of 0.81 for the calibration period (1997-1999). The total cumulative sediment loading was within 2%, of observed and the monthly sediment loads fell within the uncertainty of the observed data (NS=0.31). Cumulative total phosphorous loads were within 2% of observed and the NS prediction efficiency was 0.91. The model validated very poorly in the 2008 time period primarily because of inaccurate precipitation data and incorrect groundwater fluxes from the escarpment. Further research needs to evaluate the timing and amount of groundwater flow from the escarpment because it has a significant impact on monthly flows in this watershed. It is likely that other watersheds that are nestled against the Onondaga escarpment are impacted by spring flows from this geologic feature.

INTRODUCTION

. The Oak Orchard watershed is a large contributor of nonpoint source pollution to Lake Ontario and an important harbor and navigable waterway. It is a water body that is plagued with issues of sedimentation and non point source pollution and is listed in the 1998 NYSDEC Priority Water bodies list of rivers that are impacted by sedimentation and nutrients. As it is up-gradient of several public beaches on Lake Ontario, it can also impact the health of thousands of people from the Rochester metropolitan area who use that shoreline each year for recreational use (Makarewicz and Howell, 2007; Oak Orchard River contributes to phosphorous loading of Lake Ontario which causes algal blooms that are detrimental to fish and lacustrine life (Makarewicz and Lewis, 2009). The goal of the study is to produce a model that can be used by stakeholders to manage land use development, target restoration opportunities, and identify BMPs that will maximize the reduction of dissolved and particulate nonpoint source pollution. The study will develop the model, collect necessary field data to validate it, transfer the model to stakeholders, and train personnel on its use. This report describes the how the model was developed, calibrated and validated.

BACKGROUND

Watershed characteristics

Oak Orchard River is located in Western New York in Genesee and Orleans Counties (**Fig. 1**).

The watershed covers approximately 1,173,794 acres, the majority of which is within Orleans County. Its headwaters (approximately 14% of the watershed) are located in Genesee County. The watershed lies just north of the city of Batavia; the main branch flows west and then northeast to discharge into Lake Ontario. Its southern boundary rests against the Onondaga escarpment, a steep ridge of limestone that contains numerous karst and fracture trace features (Richards et al, 2010). Many of these features flood erratically (Richards and Rhinehart, 2006; Richards and Craft, 2008) and experience dramatic water table rises in the early spring (January through April). The watershed has 28 subbasins that cover 13 townships and four villages within the two counties. The major transportation corridors through the watershed are New York Routes 104, 63, 98 and the Lake Ontario State Parkway. The Erie Canal also crosses through the northern part of the watershed and intersects the river. Out of the 28 subbasins, seven are named and include: Beardsley, Brinningstool, Fish, Marsh, Otter and Whitney Creeks. The topography of the region is mostly flat with rolling hills caused by glacial and post-glacial erosion processes. A topographic analysis of the watershed using the PCSA algorithm (Richards and Brenner, 2004) suggests that the watershed contains a significant amount of zero-sloped and internally drained topography (18% average) with individual subbasins varying from 0 to 59% (**Fig. 2**).

River gradients and sinuosity vary significantly along its length. At the headwaters, river gradients are low and flow through numerous wetlands. Flows along this stretch are probably controlled by a mix of natural and anthropogenic processes. These include: 1) a flow control structure at the downstream end of the Iroquois National Wildlife Refuge (INWR) which is used to manage water levels in various wetlands, 2) sump pumps and diversion structures designed to keep the muckland part of the watershed seasonally drained for crop production (**Fig. 1**), 3) groundwater inputs received from the Onondaga Escarpment located just to the south, and 4) groundwater inputs from glacial features within the watershed that contain thick layers of unconsolidated sediments. Acting on top of these other factors are natural-variable-source area precipitation runoff processes. Below the INWR water control feature, the river increases in gradient and has been dammed in the village of Medina and the town of Carlton for hydroelectric power (**Fig. 3**). Large reservoirs are associated with these features, and their impact on river-borne sediment fluxes and flows is probably substantial. Closer to the shore of Lake Ontario, Oak Orchard River is a national navigable waterway and has several marinas in the harbor and many docks along the main channel. Every 3 to 5 years the U.S. Army Corps of Engineers permits dredging of the harbor, channel, and lake entrance to ensure that it can be properly navigated. The cost of these dredging efforts are considerable, and this project is intended in part to manage the watershed to reduce the flux of sediment into the harbor.

The National Wetlands Inventory and the NYDEC have delineated numerous wetlands in the Oak Orchard watershed. Some of the larger ones are the INWR and the Oak Orchard Wildlife Management areas, in addition to many more that are populated around the borders of the two counties. The INWR is important not only because it contains large areas of natural diverse habitat, but also because it intercepts drainage from the heavily cropped mucklands to the east. The length of the stream corridor within this refuge is long (8.6 km -excluding the corridor in the Oak Orchard Wildlife Management Area) and it potentially benefits the chemistry of the river and acts as a net sink for river-borne sediment. There are also flood plains designated by FEMA in the watershed, most of which align with in-stream wetlands of the watershed.

The Oak Orchard watershed is primarily used for agricultural purposes. There are also several urbanized areas which include the village of Medina, Albion, Elba, and Oakfield. These areas include residential land uses along with commercial and industrial areas that have higher percentages of impervious surfaces. Also scattered throughout the watershed are areas of deciduous and coniferous forests and areas of old-field succession. Forests include species of birch, maple, oak, and beech along with the conifers of pine, firs and spruces. Land use trends since the 2000 census indicate the population is redistributing within the watershed. The watershed has seen an overall decrease in population of 5% from 2000 to 2004, and over those 4 years there has been increases in residential land use associated with villages and towns. Smaller, rural towns have decreased in population; however, their footprint of impervious landcover has not changed. Conservation practices in the watershed include the reservation of the wildlife management areas of Oak Orchard and Iroquois and several smaller wetlands protected by Ducks Unlimited.

Pollution sources

Known sources of pollution in this watershed are from State Pollution Discharge Elimination System (SPDES) permitted sites, agricultural activities and the Erie Canal. There are six SPDES sites in this watershed that discharge chemical pollutants into the river. In descending order of importance (from the perspective of flow) they are: Erie Canal, US Gypsum, Medina Wastewater Treatment Plant (WWTP), Oakfield WWTP, Elba WWTP, and Allen Canning (**Appendix A**). The Erie canal also discharges flow into Otter Creek. The sewage treatment plant in Medina has been known to overflow into the river during high storm events. Several of these point sources (US Gypsum, Oakfield and Elba WWTP and Allen Canning) drain into the river upstream of the INWR. Their inputs are forced to flow though the extensive wetlands that surround the river in the transport-limited portion of the watershed. Agricultural discharge of pollutants includes cultivated crops and animal waste. Animal waste becomes problematic when it is highly concentrated like those in Concentrated Animal Feeding Operations (CAFOs). There are seven CAFOs in Orleans County and eight in Genesee making a total of fifteen CAFOs in the watershed. A water quality study by Makarewicz and Lewis, 2009 suggests that several of these CAFO sites and agricultural production in various sites (including the Mucklands) have had a serious impact on stream segments within Oak Orchard Creek. Cultivated crops create pollutants through spraying of fertilizers and pesticides and the general increase in sediment runoff from lack of vegetation. Remedial activities by farmers such as low to no tillage planting and increased contour plowing are desperately needed. Portions of the watershed (notably the muckland in the southeastern portion of the watershed) are extensively tile-drained to allow the growth of vegetables in muck soils.

Watershed Stakeholders

The finished watershed model will support the activities of the following watershed stakeholders to improve the water quality of the river and its harbor. These stakeholders include the Soil Water Conservation Districts and NRCS of Genesee County and Orleans County; NYS DEC Region 8; the municipalities of Albion, Medina, Elba, and Oakfield, and the townships of Albion, Alabama, Barre, Batavia, Byron, Carlton, Clarendon, Elba, Gaines, Kendall, Oakfield, Ridgeway, and Shelby. There are three stakeholders that manage wetlands in the watershed: The National Fish and Wildlife Service which manages the Iroquois National Wildlife Refuge, NYS DEC Fish and Wildlife which manages the Oak Orchard Wildlife Management Area, and Ducks Unlimited which manages several small wetlands at the headwaters of the watershed. Other stakeholders with interests in the watershed include Brazcan which operates the hydroelectric dams at Carlton and Medina and the Oak Orchard Small Watershed Protection District, an organization of muck farmers who manage water levels (and drainage) in the mucklands. In addition, there are transportation corridors in the watershed managed by the New York State Department of Transportation (State Rtes 104, 63 and 98) and the Erie Canal which is managed by the New York State Thruway Authority. The Erie Canal is directly connected to Oak Orchard Creek and has been suggested by some stakeholders to impact Oak Orchard River by acting as a source or sink of flow and nutrients. Seven citizen stakeholders have interests in Oak Orchard's harbor and are directly impacted by sedimentation in the river. These entities are the Oak

Orchard Yacht Club, the 4c's marina, Lake Breeze Marina, Wiles Marina, Black North Inn Restaurant, Light House Restarant and the Oak Orchard Light House Committee. These stakeholders meet bimonthly in a organization called the Oak Orchard Watershed Protection Alliance (http://www.lakeplainsrcd.org/web_OakOrchardWatershed). This watershed organization is active and carries out educational programs in the watershed to improve the stewardship of the watershed's inhabitants. These activities include the construction of information signs along Oak Orchard River and yearly outreach activities on stream erosion to elementary school children. This organization also seeks funding for remediation activities within the watershed. In 2005 the Alliance commissioned and approved a State of the Basin Report for the watershed outlining pollutant issues in the watershed (Zollweg et al, 2005). In 2008, they helped fund a stress stream analysis of Oak Orchard watershed (Makarewicz and Lewis, 2009) which identified numerous stream segments possessing poor water quality conditions. The staff from the Orleans and Genesee County Soil Water Conservation Districts have completed several projects to remediate agricultural pollution by establishing zone grazing management and constructing cattle feeding structures. In addition to working with local farmers and CAFO operations, the Alliance operates a vigorous grass roots organization and sponsors yearly stream and shoreline cleanup and tire recycling programs.

PURPOSE OF THE MODEL

The model developed in this project will allow this watershed organization to make management decisions in the Oak Orchard watershed. Information gleaned from the model will also be used to reinforce the interpretations obtained from the stressed stream analysis (Makarewicz and Lewis, 2009), by evaluating more accurately the fluxes of sediment and nutrients that come from different parts of the watershed. In this study, water quality issues were identified from downstream variations in stream concentrations. Discharge data was not collected, so it is not possible to ascertain the impact that nutrient inputs in a particular stream will be to the overall flux of nutrients in the watershed. For example, one of the sites that was identified as an area of concern was runoff from the mucklands. This site was also identified by Longabucco and Rafferty (1988) as a significant source of phosphorus. There is no question the concentration of sediment and phosphorous from this area is high. However, if the discharge from the muckland is low relative to other parts of the watershed the water quality impact of the Muckland may actually be less important than other sites in the watershed which have lower sediment and phosphorus concentrations but greater discharges. The SWAT model will be able to evaluate the flux from different parts of the watershed and provide better information to stakeholders for allocating remediation resources. It will also allow the stakeholders to assess how much of the sediment and phosphorus is being sequestered at the INWR. Other issues are groundwater inputs and nutrient cycling and deposition within in-stream wetlands at the southern end of the watershed. This may improve the water quality of the river as it flows from the mucklands. Correctly ranking the flux of non-point source pollution from different parts of the watershed is essential for insuring that the watershed Alliance will allocate resources for BMPs that economically obtain the maximum benefit for the river.

METHODOLOGY

The Model

The hydrologic model chosen for this study is Soil Water Assessment Tool (SWAT, Arnold et al, 1998) calibrated for water balance and nutrients using existing flow data and waterquality data collected by Makarewicz and Lewis (2000). SWAT is a popular distributed parameter chemical load model for predicting nutrient and sediment fluxes from land use information and has been used successfully in several previous studies of watershed nutrients (Barlund et al., 2007; Easton et al., 2008; Tolson and Shoemaker, 2007; Bosch, 2008; Kliment et al., 2008). Besides traditional hydrologic paramaterizations for estimating runoff, dissolved and particulate nutrients (soil curve numbers and MUSLE), SWAT also incorporates parameterizations for instream nutrient processes, crop modeling, groundwater flow, snowmelt, and three different evapotranspiration schemes. SWAT also forms the basis of EPA-BASINS, the EPA hydrologic model used in many watershed TMDL studies. While there are other hydrologic models available that can be used to predict chemical fluxes (HSPF, SWMM, GWLF, AGNPS), these other models are either too data intensive (HSPF, SWMM), simplistic (GWLF) or obsolete (AGNPS). The latest version of SWAT is capable of simulating many of the crop and tillage practices likely to be used in the watershed and operates seemlessly within an ESRI GIS interface. The latter is important for technology transfer, as the primary stakeholder users of this model (Genesee County and Orleans County SWCD) have and use the ESRI GIS software ArcView. SWAT was implemented by simulating phosphorous and sediment loads for a range of likely precipitation scenarios and land use patterns developed from current day (2005) land use and presettlement scenarios. Climate scenarios were developed by statistically analyzing historic climate data in the study area. The scenarios included average precipitation year, wettest precipitation year, driest precipitation year, wet spring, wet summer, etc.

Channel Network Definition

The digital elevation data used to create the model are the USGS 24K 10 meter resolution DEMs, which have been appended together in Arc/Info using a bilinear interpolation scheme. The resulting grid contains significant gaps which had to be filled by successive itterations of focal averaging. These small gaps, practically invisible in the GIS, caused unreasonable watershed delineations during the early development of the model. A hydrography network digitized from the 24K topographic maps was used to modify the DEM to insure that channel elements of the model closely approximate the observed streams. This hydrography network was edited to remove wetland boundaries and reservoirs (which created triple-line streams), the Erie and Tonowanda Oak Orchard river canals, and stray topographic boundary lines. A suite of experiments were run to determine the best channel forming area thresholds. The threshold that best reproduced the observed channel network without creating spurious channels was 250 ha. However, the final model that was produced would not run properly under SWAT2005. The model ran during the computation stage of simulation but failed when writing the ascii output files. A threshold value of 700 ha was determined to be the smallest channel threshold value, which creates a model that runs properly under SWAT 2005, yet still creates a reasonable model channel network that includes many of the stream segments sampled by Makarewicz and Lewis (2009). Two shapefiles of additional gage information were used to add additional outlets in the model. These shapefiles are respectively gages.shp and sampling_sites.shp. Gages.shp contains the sites of the four validation sampling sites of the project and the gage of Makarewicz and Lewis (2000) which provides the flow calibration data. Sampling_sites.shp contain some of the sampling sites of Makarewicz and Lewis (2009). Adding these outlets to the model allows us to use another set of observed data for quality control. These outlets were added by hand prior to the final stage of watershed delineation. The resulting model has 76 subbasins and outlets (**Fig. 4**). **Table 1** details the basin-IDs of the important calibration and quality control outlets. The model closely approximates the watershed delineated by the USGS, with the exception that the model watershed includes a small area west of Gravel Road connected to the hydrography by a drainage ditch. The model watershed divide is also located slightly farther east in the vicinity of Albion with the result that it is 3% larger than the watershed for Oak Orchard mapped by the USGS.

Table 1 ***Model reach-IDs of validation and calibration sites***

Location	Basin (reach) ID
Oak Orchard at River Rd.	72
Marsh Creek at Sawyer	4
Beardsley Creek	3
Oak Orchard River at Harrison Rd.	68
INWR Water Control Structure	67
Oak Orchard River at Fisher Rd.	63

Land Use / Soil Data

Land use data was developed by digitizing and interpreting land parcels from 2005 aerial photography (**Fig. 4**). Where possible, individual crop fields were defined. Land use interpretation was checked in the field by automobile during July and August of 2009. STATSGO soil data was used to extract the soil parameters required for the model. ST-MUID codes were used to link this information. Out-of -range soil parameters had to be adjusted for three of the soil types. Multiple hydrological response units were created for each subbasin using a 10/20% overlap for land use and soil type, respectively. The resulting model has 285 individual hydrological response units for the watershed.

Climate Information

Daily precipitation and temperature data required to calibrate the model was obtained from two NWS COOP stations located in Albion and Batavia. The Albion station (COOP-ID 300055) is associated with subbasins in the northern part of the watershed, while the Batavia station (COOP-ID 3004433) is associated with subbasins in the southern part of the watershed. All other meteorologic parameters were obtained from the Lockport 2NE climate station located 14 km west of the watershed. Missing data in the Albion station was replaced by data from the Batavia station (and vice-versa). The precipitation data for forcing the model in the climate scenarios comes from the climate station at the Greater Rochester Airport. This station has 80 years of continuous daily precipitation data. This data is required to evaluate a better dataset with which to develop average and wet season climate scenarios. Monthly precipitation totals were used to identify "average precipitation conditions," wet spring conditions (March-May), wet summer conditions (June-August), wet fall conditions (September-November), and wet winter conditions (December-February). For example, the wet spring scenario was the particular year of rainfall that had a yearly total precipitation that was close to the long-term average, but with a greater than average rainfall total between March and May. Based on this analysis the years used for the average and wet season climate scenarios are shown in **Table 2**: Once the year

Table 2 ***Climate scenarios (all generated from the Greater Rochester Airport climate station)***

Scenario	Year of Record	Total Yearly Precip. (in)	Precip (longterm average)
A "Typical" Year	1982	31.8	31.8 (32.2)
Wet Spring	1989	32.1	11.0 (8.2)
Wet Summer	1924	31.6	12.4 (8.1)
Wet Fall	1955	32.0	11.5 (7.5)

Wet Winter	1971	34.2	10.3 (7.3)

of record was determined, the daily data for this year was copied and appended to produce 4-year input precipitation and temperature dataset to force the model.

Reservoirs

Subbasins 67, 69, and 73 contained major impoundments. They are respectively the INWR water control structure, the Glendale Dam in Medina, and the Waterport Dam in Waterport. The INWR water control structure impounds the river to create the Oneida pond. The storage elevation associated with the spillway and emergency spillway was obtained from an original survey diagram of the pond. This was based on USGS topographic contours prior to the construction of the ponds at the refuge. The emergency spillway elevation was assumed to be the maximum operating water level at which the refuge manages the pond. This is the highest elevation at which the water can be maintained where it will not impact drainage from the muckland. Average outflow was estimated by collecting flow measurements at the water control structure during this study (2010). Spillway storage, area and elevation information for the Glendale and Waterport reservoirs was obtained from a HEC-1 analysis of the river system conducted in 1983 by Niagara Mohawk. Average flow for the Glendale dam was estimated by averaging daily flows from 1937 thru 1947. These flows were estimated by Niagara Mohawk using rating curves between power generation and flow / elevation information. Average flow from the waterport dam was estimated from 7/99 thru 6/2002. This data was provided from Brascan. **Table 3** presents the reservoir parameters that were used to force the model.

Table 3 Reservoir Parameters used in model

Impoundment	Parameter	Value	Units	Source of information
INWR Water control structure	RES_ESA	303.64	ha	INWR Planning document
	RES_EVOL	172.6	10,000 m3	
	RES_PSA	230.77	ha	
	RESPVOL	92.48	10,000 m3	
	RES_SED	32	mg/l	average of samples collected in study
	RES_K	0	mm/hr	no seepage assumed
	RES_RR	10.45	m3/sec	average of all flow measurements collected in study
Glendale Dam	RES_ESA	46.56	ha	Unpublished HEC-1 study of Oak Orchard River
	RES_EVOL	199.87	10,000 m3	
	RES_PSA	37.49	ha	
	RESPVOL	104.28	10,000 m3	
	RES_SED	default	mg/l	
	RES_K	0	mm/hr	no seepage assumed
	RES_RR	9.2	m3/sec	Median of flow data estimated from hydraulic capacity
Waterport Dam	RES_ESA	210.53	ha	Unpublished HEC-1 study of Oak Orchard River
	RES_EVOL	1147.79	10,000 m3	
	RES_PSA	135.63	ha	
	RESPVOL	671.9	10,000 m3	
	RES_SED	default	mg/l	
	RES_K	0	mm/hr	no seepage assumed
	RES_RR	6.86	m3/sec	Median of flow data estimated from

				hydraulic capacity

Point Sources

Six subbasins in the model contain active point sources (**Table 4**). A FOIA request to the NYSDEC was used to obtain discharge and chemical loading data for the wastewater treatment plants, Allen Canning and US Gypsum. Inputs from the Erie Canal were obtained from Brascan, operator of the Glendale hydroelectric power plant, as well as from the State of the Basin report (Zollweg et al., 2005). Loads were analyzed by evaluating median monthly flows and loads from the data over the entire period of record (**Appendix A**). Due to the paucity of data, a nonparametric measure of center (median) was used to force the model. Point sources of the model are all monthly loads except for the Erie Canal which had to be parameterized as daily due to the timing of input which falls during the navigable season of the canal (May 15 to November 15). Two point sources exist in subbasins 69 (the Erie Canal and the Medina WWTP) and 58 (Allen Canning, Oakfield WWTP). These point sources were summed together to provide one input file required for the model.

Table 4 Existing point sources in model

Subbasin ID	Point source	Resolution
69	Erie Canal, Medina WWTP	Daily
74	Erie Canal at Otter Creek	Daily
57	US Gypsum	Monthly
58	Allen Canning , Oakfield WWTP	Monthly
54	Elba WWTP	Monthly

Mucklands

The watershed contains a large area of drained wetlands that have been extensively tile-drained to allow muckland farming (**Fig. 1**). This portion of the watershed has very little slope. Water is conveyed to the Oak Orchard River via a series of open canals and pumps. USDA (1975) describes how this area was engineered and includes the portion-drained and farmed. Based on this work, all pasture, rangeland and agriculture HRUs in subbasins 37, 39, and 43 were considered to be tile-drained and farmed (**Fig. 4**). The total area of these HRUs falls within 4% of the area designated for crop production in this report.

Previous Observed Data

Two studies by Makarewicz and Lewis (2000, 2009) have estimated flows, sediment and nutrient loads for the watershed. The study was conducted on the river upstream of Lake Alice. This corresponds to the output of reach 72 in the model. Flow measurements were made using a USGS Bridgeboard and Price AA current meter. A rating curve was developed using continuous water level measurements obtained from the transducer of an ISCO sampler. There were issues in data quality at low flows as the stream is rocky, wide and very shallow. There were also issues with freezing conditions which tended to develop ice packs. Such ice packs make stream low measurements inaccurate. Water quality samples were obtained by collecting weekly grab samples, with several storm events being sampled using the automatic water sampler. Samples were analyzed within 24 hours at the Department of Environmental Science and Biology's water quality lab. This lab is EPA certified for phosphorous and employs rigorous quality control for all parameters that they measure. Based on the work of Harmel (2009) which provides criterion on how to judge uncertainty in observed watershed flux data, we judge this data to have cumulative uncertainties of 20% for flow, 60% for sediment and 40% for phosphorus. The high sediment load uncertainty being caused by employing grab sampling in a wide shallow river that may not be representative of sediment concentration over the entire reach, not the accuracy of the lab measurement which is excellent.

Temperature Lapse Rate

The temperature lapse rate adjusts the forcing air temperature to elevation. It is an important climate feedback in the model because air temperatures vary significantly with elevation, and air temperature is what determines whether or not precipitation in the model falls as rain or snow. It will also impact evapotranspiration calculations in the model. The climate of the Oak Orchard watershed is moderated by water due to its close proximity to Lake Ontario. The watershed also progressively increases in elevation southward from 75 m at the lake to a maximum of 300 m at its southern boundary. A thesis study by Przybyla (2010) was undertaken to evaluate temperature lapse rates in New York State. Utilizing observed monthly temperature data from climate stations, Przybyla (2010) statistically analyzed relationships between temperature and elevation. Her data suggests that there are significant differences between winter and summer lapse rates, with summer lapse rates being much higher than winter lapse rates. Her analysis suggests that lapse rates on stations thought to be moderated by the lake (as classified as "Lake climate stations" by NOAA) are not significantly different from continental climate stations located in the southern tier of the state, at least in the winter time. There were differences noted in the summer time, but they are not statistically significant with the number of data considered in the analysis. Her analysis also showed that the default model lapse rate is not statistically different than the winter observed lapse rate. Given that the model uses a single lapse rate for all seasons and that the lapse rate in the wintertime probably has a larger impact on the models hydrologic response, SWAT's default lapse rate was used in all simulations.

Additional Field Measurements

As much as possible, we utilized observed water chemistry data collected in the vicinity of the watershed to assign model water quality parameters. Model atmospheric nitrogen inputs were set to 0.72 mg/L based on observed atmospheric deposition data collected at the Ithaca and Jamestown NADPD sites. This value is the average of yearly averages over the entire calibration and validation period. Nitrate and phosphorous groundwater concentrations were determined by analyzing well water samples in nearby Leroy. Flow measurements and water quality sampling were taken at six different sites for validation purposes, as well as to estimate reservoir parameters for the INWR water control structure reservoir and to confirm that the feeder canal had an insignificant effect on the river's water budget.

Nutrient management

Crop distribution in Orleans County is 32% corn, 19.1% cabbage, 14.9% soybeans, 10.6% wheat, 17.0% hay and 6.4% fruit for the year of 2008. Although we have good information on crop distribution, we do not know the precise spatial distribution of what was grown where in the watershed. This is also likely to change from year to year from crop rotations. To overcome this issue we used a random number generator to associate each agricultural row crop HRU with a crop. The lowest random numbers were clustered together to identify cornfields. As the target percentage was approached, random numbers higher in the list were picked to insure the total % did not exceed 32%. The process was repeated for the other crops until all HRUs were assigned a crop type. HRUs associated with the

Muckland watersheds were assumed to grow onions following the suggestion of one of the stakeholders.

We developed the following 4-year crop rotations for the decision support system: corn, cabbage, onion, soybean, wheat, hay, apple and range grasses (**Appendix B**). Crop rotation sequences were developed based on consultation with the stakeholders. Management activities, harvest timing and fertilizer application rates were determined by interviewing stakeholders and farmers and by utilizing fertilizer application guidelines developed by the 2010 Cornell Guide for Integrated Field Crop Management (CCE, 2010). Moderate phosphorous soil concentrations were assumed for all soils. Harvest dates for some crops were determined from the NASS Agricultural Handbook No. 628 (USDA, 1997). Fertilizer for all hay and winter wheat crops was assumed to be dairy fresh cow manure. We assumed an early spring tillage and late fall tillage for weed control and nutrient enhancement, respectively, for some crop rotations. SWAT's PHU tool was used to estimate the plant heat units required for crop maturity. This calculation utilized the Greater Rochester Airport climate station for the estimation (**Appendix C**). Two alternative cropping management scenarios were developed from these crop rotation scenarios. They are a no phosphorus scenario, where no phosphorous was used in any fertilizer application, and a scenario where phosphorus was only used in the starter fertilizer application.

Cropping areas derived from a 2005 land coverage that we developed for this project proved to be unrepresentative of the actual areas cropped. This was determined from the unusually high organic nitrogen and phosphorous loadings which greatly exceeded the observed values after the model was calibrated for water balance. Inspection of the Agricultural Census data for 1997 revealed that in 1997, the total area of cropland in Genesee and Orleans Counties was 121,700 and 142,800 acres. The total area of farmland actually harvested was 101,700 and 128,500 acres. When these statistics were used to determine average cropping rates for the counties and then used to estimate cropland totals in the Oak Orchard watershed, the result was considerably smaller than what we determined from the land cover survey. The total cropping area in the random number generator was reduced to values predicted by this information to obtain better results. HRUs not associated to crops by the random number generator were assumed to have unmanaged range grasses as their crop.

CALIBRATION

Calibration criterion

Calibration and validation periods were June 1997 through May 1999 and January 2008 through Dec 2008 respectively. The model was run one year prior to these periods to insure it was insensitive to initial conditions. Criterion for calibration of water balance included the Nash-Sutcliffe prediction efficiency, r^2 and the visual distribution of peaks. Like all nonevent loading models, SWAT will not be able to reproduce the exact sequence of daily flow events (e.g., peak height) as it is being forced with daily averages of precipitation data and has a simple groundwater scheme. It should, however, be able to predict the size and frequency of monthly flows and fluxes which is adequate for watershed decision making and TMDL estimates. In the calibration process, emphasis was placed on reproducing the frequency of medium and large flow and sediment loads in order to assure model success. Table 5 summarizes the final value of all non-default parameters used in the model.

Table 5 Parameter values used in the final calibrated model

Surface water	Value	Groundwater parameter	

parameter			
RCN	-23.00%*	SHALLST	0.5
ESCO	0.4	DEEPST	1000
EPCO	1	GW_DELAY	10.1
SWFMN	4.0	ALPHA_BF	0.99
SWFMX	4.0	GWQMN	10
		GW_REVAP	0.02
		REVAP_MN	10
		RCHRG_DP	0
		GWHT	1
		GW_SPYLD	0.03

Water balance

Initial calibration experiments using all of the evapotranspiration schemes available in SWAT determined that the existing model was grossly underpredicting the flow of water at the calibration site. Adding the Erie Canal inputs improved the result; however, the model was still underpredicting the flow between January through March. The forcing climate data was checked and determined not to be a cause of the missing water. Seepage to the deep aquifer was also eliminated. Groundwater from outside the watershed is believed to be this missing water. The likely source of the water is the Onondaga Escarpment, where studies by Richards and students (Richards and Craft, 2008; Daniluk et al., 2008; Voortman and Simons, 2009) and hydrologic consultants (Dunn et al., 1992) have demonstrated dynamic seasonal rises in water table during the January to April time period. This time period also corresponds with the timing of karst flooding events in the Quinlan Road sinkhole (Richards and Rhinehart, 2006; Daniluk, 2009; Voortman and Simons, 2009). In addition, large areas of the Onondaga FM are thinly-soiled and contain sinkholes and fracture bedrock areas (Richards etal, 2010), which allows precipitation to enter into the escarpment and the groundwater system with little delay. Since the groundwater direction is northward , the Oak Orchard watershed is the likely destination of this water. Previous studies have also noted that the Onondaga Formation has large annual water table variations in Erie County (Kappel and Miller, 1996, Staubitz and Miller, 1987). To account for this water, reaches located in subbasins at the base of the escarpment (**Table 6**) were assumed to pick up water from outside the watershed. A set of experiments was conducted to determine how much water had to be added to these reaches in order to balance the total water flux during the calibration period. SWAT was modified to enable negative water management inputs to reaches in subbasins designated as “groundwater” subbasins (**Fig. 4**). This in effect adds water to the reaches from outside of the watershed. Water inputs were assumed to have a flux distribution that crudely follows the timing of high water table time periods observed in wells within the Onondaga Formation and karst flooding events observed east of the watershed in Leroy and Caledonia. Aggregated for monthly time periods, this produces a 0.6, 0.8, and 0.8 for January through March, respectively. A set of simulations was then conducted to determine the flow required to balance the total flow. The experiment determined that the average flows that best determined the total flow observed at the output (within 2% of observed) were 11.7, 15.6 and 15.6 cms/ha for Jan through March respectively. Uniform flow per unit area was assumed, and these fluxes were applied to reaches based on their subbasin area. Refer to the model development log (**Appendix C**) for exact values that were added to each groundwater subbasin.

Table 6 Subbasins in the model designated as receiving groundwater flow

Basin IDs		
35	47	51
36	48	52
38	49	65
46	50	63

Surface Runoff

Surface runoff was manually calibrated by modifying CN and ESCO to obtain the peak flows observed in the record. CN was modified by globally reducing the parameter by subsequent percentages. Although the study by Niezch etal., (2000) suggests that CN should not be reduced by more than 10%, inspection of previous published SWAT models demonstrates that curve numbers have to be reduced by much greater percentages in order to achieve decent results (**Table 7**). The excessive negative bias in calibrated curve numbers is odd given the long history of NRCS research that have accurately developed curve numbers for different combinations of land use and soils. Larose etal. (2006) interpreted lower CN to better drainage characteristics than what was in the database. Many of the studies that define CN were conducted at the field-plot scale. Studies have also noted that tillage and crop management practices can reduce potential abstraction requiring reductions of curve number up to 4%. This is still small relative to the curve number reductions required for model calibration in previous studies. We interpret the excessive reduction in curve numbers in these calibrated models to be due to the presence of flat and internally drained topography at watershed scales (**Fig. 2**). These features are not so prevalent at the field scale. Since the curve number approach estimates runoff by subtracting total abstraction from incoming precipitation and snowmelt, and that total abstraction includes internally drained areas, curve numbers for calibrated models of large watersheds will have to be lower than published curve numbers.

Table 7 ***Calibrated curve number adjustments in previously published SWAT studies***

Study	Location	Curve number adjustment	Comments
Abraham et al., 2007	Meki, Ethiopia	-25.00%	
Barlund et al., 2007	Lake Pyjaharvi, Finland	-21.00 to -29.00%	
Bingner et al., 1997	Goodwin Creek, MS	"slight increase"	Used TOPAZ to define watershed areas. CN obtained from observed data
Chu and Shirmohammadi, 2004	Warner Creek, MD.	Table value minus 15 and 5 for summer and winter	
Fitzugh and Mackay, 2000	Pheasant Branch, WI	No adjustments	Used TOPAZ to define watershed areas
Folle, 2010	Le Sueur River, MN	-6.00%	

Geza and McCray, 2007	Turkey Creek, CO	-5.00%	
Hu et al., 2007	Embarras River, IL	-29.00%	
Larose et al., 2006	Cedar Creek, Indiana	-10.00%	
Mulungu and Munishi, 2007	Simiyu watershed, Africa	-25.00%	
Reungsang et al., 2005	Upper Maquaoketa, IO	-6.00%	
Richards et al., 2008	Marys Creek, TX	-8.00%	
Shridhar and Nayuk, 2010	Reynolds Creek, ID	-10.00%	
Tolson and Shoemaker, 2007	Cannonsville Reservoir, NY	-20.00%	
White et al., 2010	Various watersheds, OK	No adjustments	
Wu and Johnston, 2007	Ontonogan, MI	No adjustments	Used Pond Routine

A simple calculation can be conducted to evaluate the magnitude of the impact that internally drained topography should have on curve number adjustments. If we assume that 100% of the runoff from internally-drained topography is lost to groundwater and evapotranspiration processes, runoff from the subbasin will be equal to the runoff from the unmodified curve number equation times the fraction of the watershed that is not internally drained. This adjusted runoff can then be used to estimate what the curve number should be. Once this adjusted curve number is known, the two can be subtracted and divided by the unadjusted curve number to obtain the required reduction. **Figure 6** presents the result of this analysis as a function of the percentage of internally drained topography, rainfall excess and curve number. The analysis suggests that adjustments can be significant for low rainfall excess, and for higher percentages of internally drained topography. At high levels of rainfall excess, curve number reductions from topography are important even at low percentages of internally drained topography. Since stream flow response is dominated by uncommon storm and snowmelt events that generate large inputs of rainfall excess, significant curve number reductions from internally drained topography are probably required. Note that these adjustments do not include curve number adjustments for management practices or canopy characteristics which may also be significant.

The extent of internally drained topography is high in Oak Orchard (average of 18%), with values in individual subbasins ranging from near zero (tile drained mucklands) to 58.6% (**Fig. 2**). This is probably due to the extensive areas of ground moraine in the watershed which are undulatory in nature and to anthropogenic changes in topography that tends to break up flow continuity in order to reduce flooding (Richards and Noll, 2007). Given the high values of internally drained topography for this watershed, curve numbers were adjusted systematically downward to 25% to obtain the best monthly flows over the calibration period. A 23% percent reduction in curve numbers was required to obtain an acceptable Nash-Sutcliff prediction efficiency for monthly flows. Daily peaks were still over predicted for some events in the summer and fall. The ESCO parameter was then reduced to 0.4 to increase the amount of evaporation and reduce the peak flows during these time periods. The snowmelt parameters SWMX and SWMN were then adjusted to 4.0 and 4.0 to improve monthly flow response in March and April.

Baseflow

Observed streamflow and well transducer data in the study area allowed us to determine two important baseflow parameters, GW_DELAY and ALPHA_BF. The "groundwater delay" function is a parameter that is used to control the distribution of recharge into the shallow aquifer after it leaves the base of the soil. Although it has units of time and contains the name "delay," this parameter doesn't delay significantly the arrival of the peak of recharge. It changes the center of moment of the recharge, so that at higher values of GW_DELAY the tail of the recharge distribution gets increasingly long. An analysis of water level data was conducted in four different wells to determine the GW_DELAY that best reproduces the observed water table fluctuations. Since the GW_DELAY function does not delay the arrival of the peak (even at large values of GW_DELAY the peak arrives within a day of when the water left the soil), the time of the observed peak of the water table data was assumed to be the time that the water left the soil. The observed well data was analyzed to determine the delay between the peak of the water table response and its center of moment (the time at which 50% of the water arrived at the well). The equation that SWAT uses was solved for a variety of GW_DELAYS to determine a relationship between the delay between the peak of the watertable fluctuation and its center of moment (**Fig. 7**). Based on this information, GW_DELAYS were evaluated from observed well fluctuations (**Table 8**) to determine an appropriate value for the model. Observed values had an average and standard deviation of 10.81 and 7.7, respectively. A value of 10.1 was used for all subbasins in the model.

ALPHA_BF was evaluated by solving it directly (Spruill etal, 2000) from streamflow data in Black Creek and Oatka Creek watershed for select baseflow recession periods Observed baseflow coefficients for Oatka Creek varied from 0.02 to 0.11 and 0.04 to 0.14 for Black Creek (**Table 9**). We initially chose an average value of 0.07 for the model (**Table 5**).

Table 8 GW_DELAY values derived from observed water table fluctuations

Well ID	Aquifer type	Event date	Time to center of moment (days)	GW_DELAY (days)
West Barre	sand/gravel	6/21/10	1.7	4
		5/07/10	1	2.5
		6/24/04	1.4	3.3
		8/09/08	< 0.5	1
		8/18/08	0.66	2.2
West Shelby	Lockport Dolomite	6/05/10	8	12.5
Batavia	sand/gravel	4/13/04	11.6	17.5
		3/15/06	6.8	10.5
		4/15/07	5.25	9
		4/01/08	4.66	8
		6/05/10	8.8	13.5
Caledonia	Gravel outwash	9/08/04	20.8	31
		4/06/05	4.5	8
		4/15/07	11.9	17.8
		7/03/09	0.89	2.6
		7/21/09	12	18

Table 9 **ALPHA_baseflow values derived from observed streamflow data**

USGS Gage	Start date of recession	Period (days)	ALPHA_BF
Oatka Creek at Garbutt	6/21/96	7	0.11
	7/1/96	14	0.06
	5/25/97	6	0.08
	6/11/97	9	0.04
	4/24/98	8	0.06
	5/17/98	13	0.06
	4/28/99	5	0.07
	5/30/99	14	0.03
	5/28/00	5	0.11
	6/19/00	7	0.08
	7/20/00	10	0.03
	10/9/00	8	0.09
	4/15/01	22	0.06
	6/4/01	17	0.04
	7/1/02	21	0.03
Black Creek at Churchville	7/05/96	9	0.07
	7/12/97	8	0.07
	10/9/97	8	0.11
	7/15/98	5	0.09
	8/13/98	4	0.14
	10/13/98	8	0.04
	6/4/99	9	0.09
	8/28/99	9	0.10

Once GW_DELAY and ALPHA_BF were set, an experiment was conducted to determine how the other groundwater parameters should be set. Based on these experiments, the following values were assigned to these parameters (**Table 5**). This experiment also revealed that the ALPHA_BF value was too low. A value of 0.99 turned out to produce a better result and all subbasins were re-adjusted accordingly.

Nutrient and Sediment Calibration

After flow was calibrated, the model was calibrated for sediment and total phosphorus. Previous studies have observed that sediment fluxes and total phosphorous fluxes are strongly correlated (Folle, 2010). Both are impacted by the wash off of particulates from runoff source areas, peak flows and the erosion, movement and deposition of sediment within streams (Allan and Castillo, 2007; Folle, 2010). As a consequence, sediment and phosphorous fluxes are strongly impacted by land use and agricultural management activities such as crop distribution, acreage and tillage practices. Phosphorous fluxes are also impacted by the quantities and timing of fertilizer application. Because so many of the SWAT parameters for calibrating total phosphorous and sediment are the same, we manually calibrated both simultaneously. The initial model (calibrated for water balance) strongly over-predicted phosphorous and under-predicted sediment fluxes. Our approach was to determine the total area of cropland required to obtain reasonable results for total phosphorous flux, first. This was based on the crop distribution in Orleans County for 2008. The best results were achieved with a value of total cropland estimated by utilizing the harvested land acreages obtained from the 1997 agricultural census, and subtracting from this value a portion of the cropland found in the Muckland. It was determined that two MUSLE parameters (SOL_K, SOL_LS) and the phosphorous availability index (PAI) also had to be modified. The following management conditions and SWAT parameters provided the optimum monthly flux distribution of total phosphorous in the calibration period. Total cropland in the watershed was 210 square km outside of the muckland. Cropland area in the muckland was reduced as follows. HRUs that were originally pasture and rangeland that were assumed to be cropland were set back to these land uses, and the NY41 AGRR HRU in subbasin 39 was assumed to grow soybean. All other HRUs were assumed to grow onions with no break in crop rotation. This area of cropland in the muckland is smaller than what was proposed in 1975, when the muckland drainage system was being replaced; see USDA (1975). Since this report was a proposal, it is possible that not all of the fields were put into production. Crop practice factor in the muckland was set to 0.6 which is consistent for contour plowing in low-sloped areas. SOL_K for all soil types was reduced by 10% and the topographic factor SOL_LS was reduced by 20%. Once total phosphorous was calibrated, the channel erosion parameters, cover factor and channel erodibility were adjusted to obtain the optimum fluxes for sediments. The best results were obtained with values of 0.15 and 0.09, for cover factor and erodibility, respectively.

RESULTS

Following the suggested protocols of Moriasi etal (2007), we have adapted a variety of graphical and error indexes to calibrate and validate the model (**Figure 8** though **11**, **Table 10**). **Fig. 8** shows the predicted monthly flow discharges over the calibration period. The resulting calibration has a Nash-Sutcliffe model prediction efficiency of 0.81 and an R square of 0.83 for monthly discharge. The mean and standard deviation of observed and model flows were (10.6, 6.6) and (10.5, 6.4) cms respectively. **Fig. 9** shows the sediment and phosphorous loads over the calibration period. The model predicts total phosphorous and total sediment flux within 2% of observed. Mean and standard deviation of sediment fluxes were (349, 315) and (355, 305) tons per month for observed and modeled, respectively. Observed and modeled phosphorous had a mean and standard deviation of (7.5, 12.9) and (7.8, 15.4) tons/month, respectively. Modeled fluxes follow approximately the monthly pattern of fluxes observed during the calibration period within the level of uncertainty of the data. R squares for modeled and observed fluxes were 0.32 and 0.90 for sediment and phosphorous respectively (**Fig. 10**). These results should be considered excellent for water balance and total phosphorus, and fair for sediments. Monthly sediment flux errors were greatest in January and March, the time period when Onondaga groundwater flow was added to the model to balance the water budget. These discrepancies, as well as the following validation analysis, demonstrates how much uncertainty in the model is caused by these groundwater flows.

Validation performance using the calibrated model was poor, with a Nash-Sutcliffe efficiency close to 0. This implies that the mean of the observed flow data is as good as a predictor as the model. Although the flows follow the basic monthly pattern of observed flows, the magnitudes were off for the peaks. The R square for the model was 0.21. It should be noted that with such a short period of validation (12 data points total) the weight of one month will strongly impact the results. Three issues contributed to the poor performance of the model in the validation period. Model discharge was greater than the total observed flow, suggesting that groundwater flows from the Onondaga escarpment

Table 10 *Calibration results (monthly)*

	Mean observed	Mean model	Standard deviation observed	Standard deviation model	Cumulative error
Flow	10.6	10.5	6.6	6.4	5.00%
Sediment	349	355	315	305	2.00%
Total Phosphorus	7.5	7.8	12.9	15.4	2.00%

were smaller than they were during the 1997 through 1999 period. The model underpredicted flow in the month of May which may have been caused by groundwater contributions from the escarpment coming later in the year (in April). Note that the observed well data do show occasional water table rises as late as April. The model also grossly over predicted discharge during the months of January-March and December 2008. Inspection of the forcing climate data reviewed a large discrepancy in precipitation between the Albion and Batavia stations in the early spring. The Batavia station had more than double the amount of precipitation than Albion during the month of January 2008. Spatial variability in precipitation that leads to inaccurate climate inputs is a well known contributor to model inaccuracy. Oak Orchard watershed is influenced by lake effect precipitation which can cause southward variations in precipitation. It is possible that the climate station in Batavia was not representative of the precipitation being received by the subbasins in the southern part of the watershed. To explore these issues we kept the surface water and groundwater calibration parameters the same as the calibration model, but ran the model using only the Albion climate data without Onondaga Escarpment groundwater inputs. **Figures 11 and 12** shows the result. These results should be considered in the light that there is only one year of validation data. The error in one individual month will have a significant impact in NS prediction efficiency and R square calculations.

These results emphasize the importance of understanding the magnitude and timing of groundwater inputs from the Onondaga escarpment. Since these vary from year to year it will be a major source of uncertainty in the model. Chu and Shirmohammadi (2004) also had to parameterize groundwater from outside of the model watershed in order to develop reasonable baseflow values for a SWAT model in the Piedmont. It is interesting to note that the steeper topography of the Piedmont is likely to have considerably less internally-drained and zero-sloped topography than Oak Orchard watershed, implying the baseflow issue here is more problematic than what was encountered in that study. Tolson and Shoemaker interpreted baseflow underprediction in their model of the Cannonsville Reservoir to be due to SWAT's infiltration scheme where movement of water downward is not permitted in frozen soils. They modified their model to allow some movement of water between soil layers and were able to obtain a better representation of base flow in the late spring. Our model does not include this change in SWAT's code and therefore is impacted by this issue. We do not doubt that it contributes to the excessive daily peakiness of runoff seen during during the winter months and the lack of baseflow predicted by the model (particularly in the month of May). However, the magnitude of flow underpresentation in the model, combined with its timing coincident with the water table fluctuations and karst flooding observed in the Onondaga FM, seems to imply an outside source of groundwater for the missing water during the calibration period. This is supported circumstantially by geological characteristics of the Onondaga escarpment. It is considerably higher in elevation than Oak Orchard watershed, it contains areas of thinly-soiled fractured bedrock where precipitation and snowmelt is likely to recharge rapidly into the groundwater table, and the regional groundwater flow direction is north toward the watershed. These groundwater inputs did not seem to occur during the validation period. .

The Erie Canal was a critical point source to include in this model. Without it, summer flows would have been much lower than observed. Inputs from the Erie canal, although regulated to be 225 cfs every day of the navigable season, are sometimes higher due to lake seche from Lake Erie. This will contribute another source of uncertainty to the model. Given the importance and relative unpredictability of the Onondaga Escarpment inputs, we suggest that managers should run the model with and without Onondaga Inputs before making management decisions.

CONCLUSIONS

The results demonstrate the importance of the Erie Canal and groundwater inputs from outside of the watershed in controlling the hydrology of Oak Orchard river. Both water sources had to be incorporated into the model in order to achieve a satisfactory calibration. The resulting calibration was excellent for flow and total phosphorous and fair for sediment fluxes during the calibration period. Model performance in the validation period was much weaker, a result attributed to climate and groundwater contribution differences in 2008, as well as to the limited amount of validation data. The validation result suggests that the groundwater inputs were not as significant in 2008. These results stress the need for a better understanding of the timing and magnitude of the groundwater inputs that come from the Onondaga Escarpment. Groundwater level data in this geologic unit over a long period of time is needed to better design a probability function for simulating groundwater flows in the model. Based on these results, we suggest that the model be run in two scenarios: with groundwater inputs and without groundwater inputs in order to evaluate the full range of possible fluxes in a climate and nutrient management scenarios. The model development log provides in **Appendix D** provides a blueprint in how this model can be developed from start to finish using the AVSWATX interface. The model will be available at the College of Brockport, and the Genesee and Orleans County Soil and Water Conservation Districts. Interested stakeholders are encouraged to contact the principal author if you would like to have this model installed in your computer.

REFERENCES CITED

Allan, J. D. and Castillo, M. (2007) *Stream Ecology: Structure and Function of Running Waters*, 2nd ED, Springer, AA. Dorchdrecht, The Netherlands, 436pp.

Arnold, J.G., Shrinivasan, R.,Muttiah, R.S. And Williams, J.R. (1998) Large Area Hydrologic Modeling and Assessment, Part 1:Model development, *JAWRA* **34(1)** 73-89.

Abraham, L.Z., Roehrig, J., Chekol, D.A. (2007) Calibration and Validation of SWAT Hydrologic Model for Meki Watershed, Ethiopia, Conference on International Agricultural Research for Development, University of Kassel-Witzenhausen and University of Gottingen, October 9-11, 2007, 5pp.

Barlund, I., Kirkkala, T., Malve, O. and Kamiri, J. (2007) Assessing SWAT model performance in the evolution of management actionsfor the implementation of the Water Framework Directive in a Finish Catchment, *Environmental Modelling & Software* **22,** 719-734.

Bingner, R.L., Garbrecht, J., Arnold, J.G., Srinivasan, R. (1997) Effect of Watershed Subdivision on Simulation Runoff and Fine Sediment Yield, *Transactions ASAE*, **40**, 1329-1335.

Bosch, N. (2008) The influence of impoundments on riverine nutrient transport: An evaluation using the Soil Water Assessment Tool, *J. of Hydrology* **355,** 131-147.

Chu, T.W. And Shirmohammadi (2004) Evaluation of the SWAT Model's Hydrology Component in the Piedmont Phyiographic Region of Maryland, *Transactions ASAE*, **47,** 1057-1073.

Cornell Cooperative Extension (2010) *2010 Cornell Guide for Integrated Field Crop Management*: downloaded 6/2010 from http://ipmguidelines.org/FieldCrops/default.asp.

Daniluk, T. L., Libby, J. L., Richards, P.L., Craft, J.H., and Noll, M. (2008) *Seasonal Water Table Variations in the Onondaga FM, Western NY*, 2008 Annual Meeting, GSA, Houston, TX.

Daniluk, T.L. (2009) *Source of Flood Water at the Quinlan Road Sinkhole Leroy, New York,* Undergraduate Thesis, Dept. of Earth Sciences, The College at Brockport., Brockport, NY, USA.

Dunn Geo. Eng. (1992) Task 2, Phase A Report State Superfund Standby Program Lehigh Valley Railroad Derailment Site RI/FS, Town of Leroy County of Genesee, New York, published by Dunn Geocience Engineering Co., P.C. Albany, NY 12205 80pp.

Easton, Z.M., Fuka D.R., Walter, T. Cowan, D.M., Schneiderman, E.M. And Steenhuis, T.S. (2008) Re-conceptualizing the soil and water assessment tool (SWAT) to predict runoff from variable source areas, *J. Hydrology* **348,** 279-291.

Folle, S.M. (2010) *SWAT Modeling of Sediment, Nutrients and Pesticides in the Le-sueur River Watershed, South-Central Minnesota*, Ph.D Dissertation, The University of Minnesota, 233pp.

Fitzugh, T.W. And Mackay, D.S. (2000) Impact of input parameter spatial aggregation on an agricultural nonpoint source pollution model, *J. Hydrology,* **236,** 35-53.

Geza, M. and McCray, J.E. (2007) Effects of soil data resolution on SWAT model stream flow and water quality predictions, *J. Environmental Management*, **88,** 393-406.

Harmel, R.D., Cooper, R.J., Slade, R.M., Haney, R.L. and Arnold, J.G. (2006) Cumulative Uncertainty in Measured Streamflow and Water Quality Data for Small Watersheds, *Transactions ASABE*, **49,** 689-701.

Hu, X., McIsaac, G.F., David, M.B., Louwers, C.A.L. (2007) Modeling Riverine Nitrate Export from an East-Central Illinois Watershed Using SWAT, *J. Environmental Quality* **36**, 996-1005.

Kappel, W.M. and Miller, T.S. (1996) Geology, Hydrology and Ground-Water Flow near the Akron Municipal well, Erie County, New York, *USGS Water-Resources Investigation Report* **96-4193**, 22pp.

Kliment, Z., Kadlec, J. and Langhammer, J. Evaluation of suspended load changes using AnnAGNPS and SWATsemi-empirical erosion models, *Catena* **73,** 286-299.

Larose, M., Heathman, G.C., Norton, L.D. and Engel, B. (2006) Hydrologic and Atrazine Simulation of the Cedar Creek Watershed Using the SWAT Model, *J of Environmental Quality,* **36,** 521-531.

Longabucco, P. And Rafferty, M.R. (1988) *Delivery of Phosphorous to Lake Ontario from Cultivated Mucklands in the Oak Orchard Creek Watershed.*, Paper R005725, NYS DEC Bureau of Technical Services and Research Division of Water, 68pp.

Makarewicz, J.C. And Howell, T. (2007) Lake Ontario Intensive Year – 2008, The Lake Ontario Coastal Zone -Status Assessment IN Developing Cooperative Monitoring Strategy for Lake Ontario, White paper, LOLA Workshop, International Joint Commission, Kingston, Ontario.

Makarewicz, J.C. and Lewis, T.W. (1998) Phosphorus and Sediment Loss from Watershed of Orleans County: Johnson, Oak Orchard, and Sand Creek Watersheds. Available from Drake Library, The College at Brockport, Brockport, NY.

Makarewicz, J.C. and Lewis, T.W. (1999) Phosphorus and Sediment Loss from Watershed of Orleans County-Year 2: Johnson, Oak Orchard, and Sand Creek Watersheds. Available from Drake Library, The College at Brockport, Brockport, NY.

Makarewicz, J.C. and Lewis, T.W (2009) Oak Orchard Creek Watershed: The Location of Sources of Pollution, Annul Loss of Nutrients and Soil to Lake Ontario, and a Test of Effectiveness of Zone Tillage as a Best Management Practice, Dept. Environmental Science and Biology, The College at Brockport, 66pp.

Moriasi, D.N., Arnold, J.G., Van Liew, M.W., Bingner, R.L., Harmel, R.D. And Veith, T.L. (2007) Model Evaluation Guidelines for Systematic Quantification of Accuracy in Watershed Simulations, *Transactions ASABE,* **50,** 885-900.

Mulungu, D.M.M. And Munishi, S.E. (2007) Simiyu River catchment parameterization using SWAT model, *Physics and Chemistry of the Earth*, **32,** 1032-1039.

Przybyla, S. (2010) Variations of Near- Surface Air Temperature Lapse Rates in New York State: Implications for Hydrologic Processes, Undergraduate Thesis, Dept. of Earth Sciences, The College at Brockport., Brockport, NY, USA.

Reungsang, P., Kanwar, R.S., Jha, M., Gassman, P.W., Ahmad, K. and Saleh, A. (2005) Calibration and Validation of SWAT for the Upper Maquoketa River Watershed, Working Paper 05-WP 396, Center for Agricultural and Rural Development, Iowa State University, Ames Iowa 19pp.

Richards, C.E., Munster, C.L., Vietor, D.M., Arnold, J.G. And White, R. (2008) Assessment of Turfgrass sod best management practice on water quality in a Suburban watershed, *J. Environmental Management* **86,** 229-245.

Richards, P.L. (2007) Karst Related Flooding between Leroy and Caledonia, 2007 Annual conference of the Finger Lakes Institute, p32-35.

Richards, P.L. and Brenner, A. (2004) Delineating Source Areas for Runoff in Depressional Landscapes; Implications for Hydrologic Modeling, *Journal of Great Lakes Research,* **30,** 9-21.

Richards, P.L. And Craft, J.H. (2008) Karst-Related flooding in the Onondaga FM, Western, NY. 2008 Annual Meeting, NE Section, Geological Society of America.

Richards, P.L. and Noll, M. (2007) *GIS-based Buffer Management Optimization for Phosphorous: A Field Test of Whether a Topographically-Based Phosphorous Model Can be Used to Locate Best Management Practices, FINAL REPORT,* New York State Water Resources Institute http://wri.eas.cornell.edu/grants.html 30pp.

Richards, P.L. and Rhinehart, S. (2006) *Rapid and Anomalous Flooding from a Western NY Sinkhole*, Proceedings of the annual conference of the Finger Lakes Institute, Hobart William Smith College, Geneva, NY. 4pp.

Richards, P., Libby, J. L., Kuhl, A., Daniluk, T., Lyzwa, M. (2010) *Prediction of Areas Sensitive to Fertilizer in Thinly-soiled Karst, FINAL REPORT* , New York State Water Resources Institute http://wri.eas.cornell.edu/grants.html 29pp.

Shridhar, V. and Nayak, A. (2010) Implications of climate driven variability and trends for the Hydrologic assessment of the Reynolds Creek Experimental Watershed, Idaho, *J. Hydrology* **385,** 183-202.

Spruill, C.A., Workman, S.R., Taraba, J.L. (2000) Simulation of Daily and Monthly Stream Discharge from Small Watersheds using the SWAT Model, *Transactions ASAE*, **43,** 1431-1439.

Staubitz, W.W. And Miller, T.S. (1987) Geology and Hydrology of the Onondaga Aquifer in Eastern Erie County, New York, with emphasis on Ground-water-level declines since 1982, *USGS Water-Resources Investigation Report* **86-4317** 44pp.

Stypa, A. (2009) Impact of Precipitation Events on Phosphorus Fluxes from the Oak Orchard Watershed using SWAT, Undergraduate Thesis, Dept. of Earth Sciences, The College at Brockport. 20pp.

Tolson, B.A. And Shoemaker, C.A. (2007) Cannonsville Reservoir Watershed SWAT 2000 model development, calibration, and validation, *J. Hydrology* **337,** 68-86.

USDA (1975) Plan & Environmental Impact Statement: Oak Orchard Creek Watershed, Genesee and Orleans Counties, New York, Unpublished report, Orleans and Genesee County Soil Water Conservation Districts 153pp.

USDA (1997) *Usual Planting and Harvesting Dates for US. Field Crops, December 1997*, NASS Agricultural Handbook No. **628**, 51pp.

Voortman, B. and Simons, G. (2009) Surface Water – Groundwater Interaction at the of the Allegheny Plateau, Joint Master's Thesis, Utrecht University, Holland, The College at Brockport, Brockport, NY, USA.

White, M.J., Storm, D.E., Busteed, P.R. Smolen, M.D. And Zhang, H. (2010) A quantitative loss assessment tool for agricultural fields, *Environmental Modeling and Software*, **25,** 1121-1129.

Wu, K. and Johnston, C.A. (2007) Hydrologic response to climactic variability in a Great Lakes Watershed: A case study with the SWAT Model, *J. Hydrology* **337,** 187-199.

Zollweg, J., M. Noll, T.W. Lewis, P. Richards, S. Wells, and E. Kridel. (2005) Oak Orchard Watershed State of the Basin Report. Finger Lakes-Lake Ontario Watershed Protection Alliance and Genesee and Orleans County Soil and Water Conservation Districts.

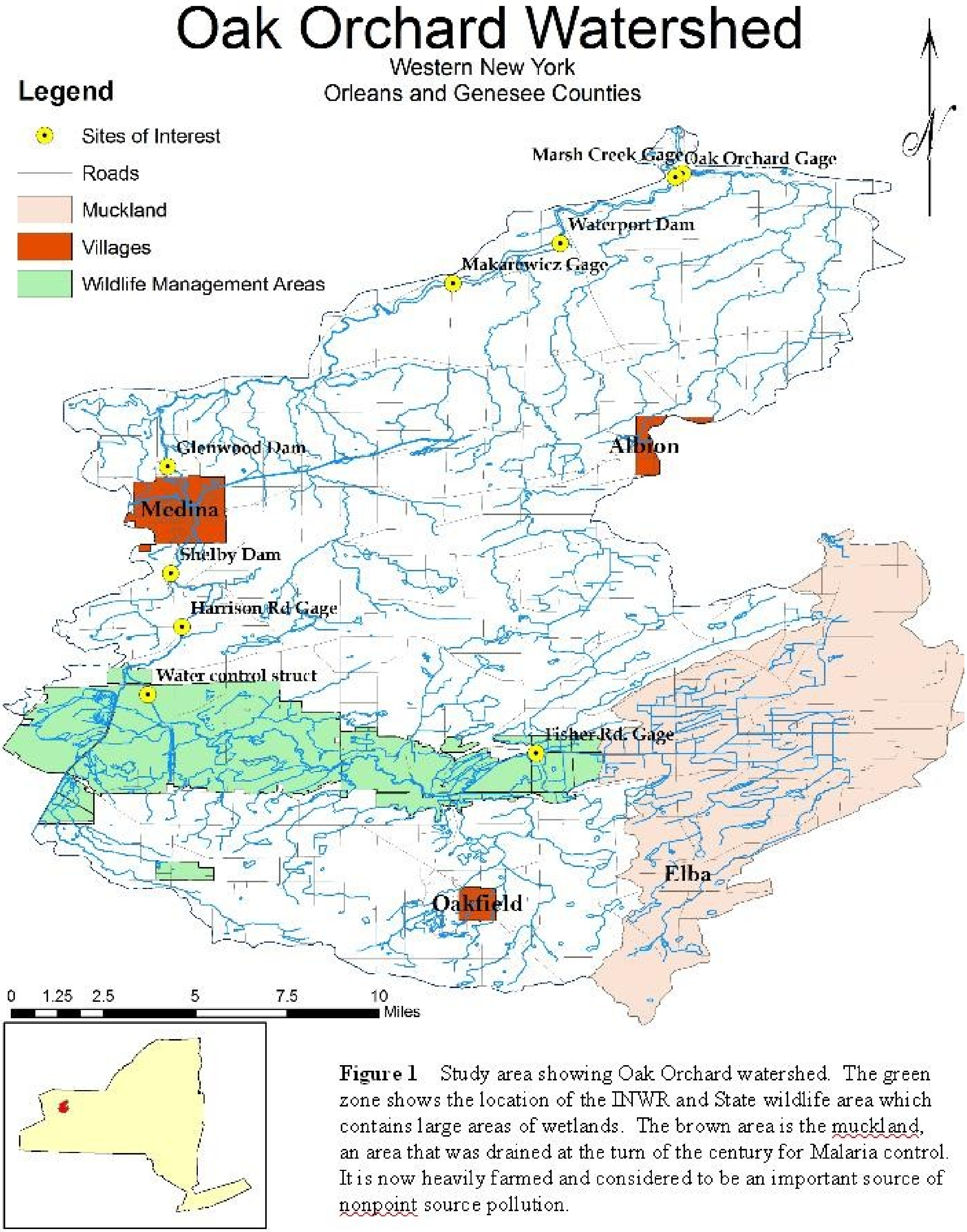


Figure 1 Study area showing Oak Orchard watershed. The green zone shows the location of the INWR and State wildlife area which contains large areas of wetlands. The brown area is the muckland, an area that was drained at the turn of the century for Malaria control. It is now heavily farmed and considered to be an important source of nonpoint source pollution.

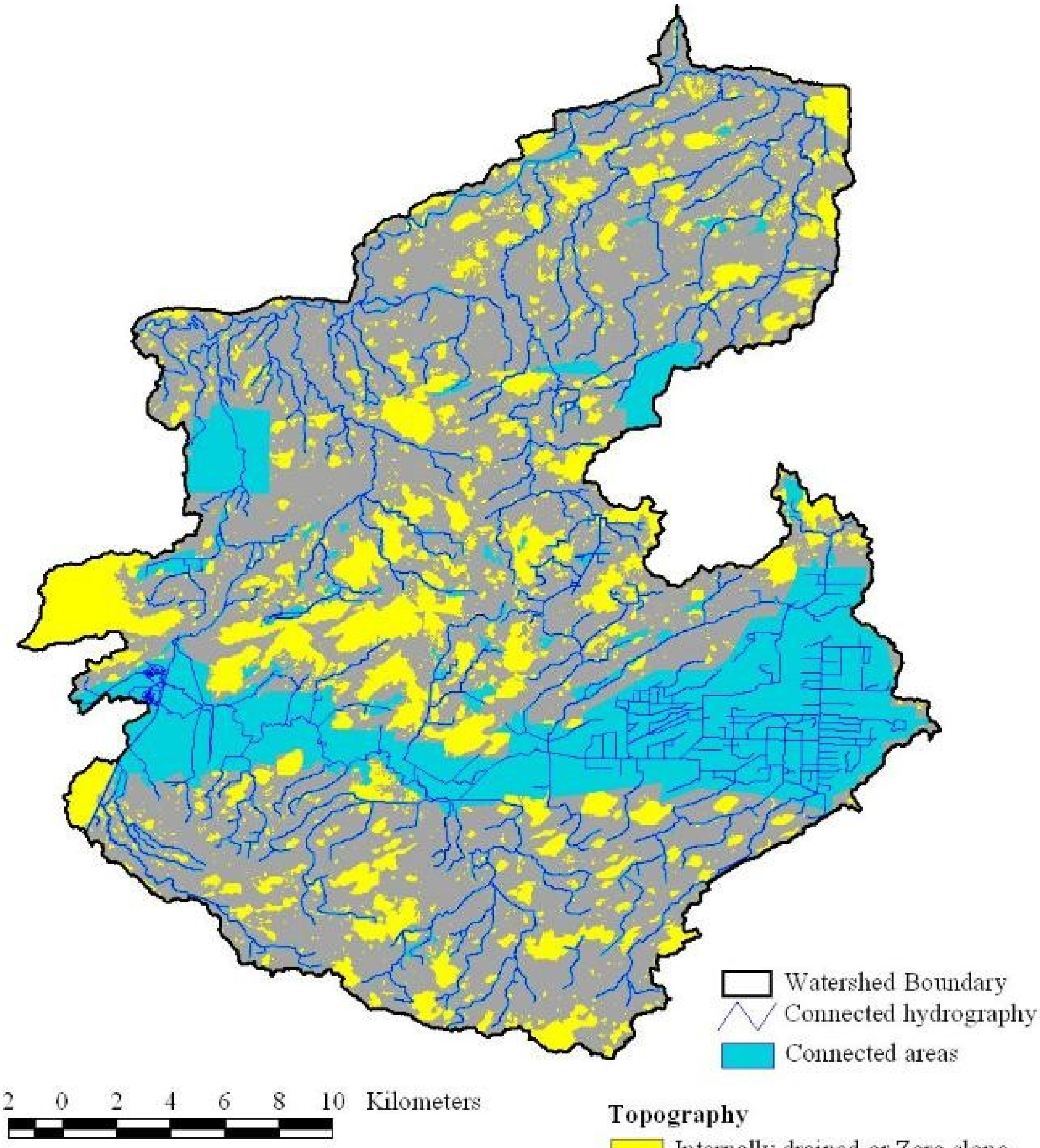


Figure 2 Connected and internally drained areas in the watershed mapped using the PCSA algorithm (Richards and Brenner, 2004). Connected areas included all of the FEMA floodplains, and hydrography (wetlands, streams and lakes) that intersects the river. All areas in the vicinity of the Mucklands were assumed to be connected because of their extensive network of tile drains. The Village of Albion and the city of Medina were also assumed to be connected because of their road networks and storm sewers. Subbasins had % internally drained areas that varied from near 0 (mucklands) to 59%. The extent of these features required the model to have curve numbers adjusted significantly below their default value.

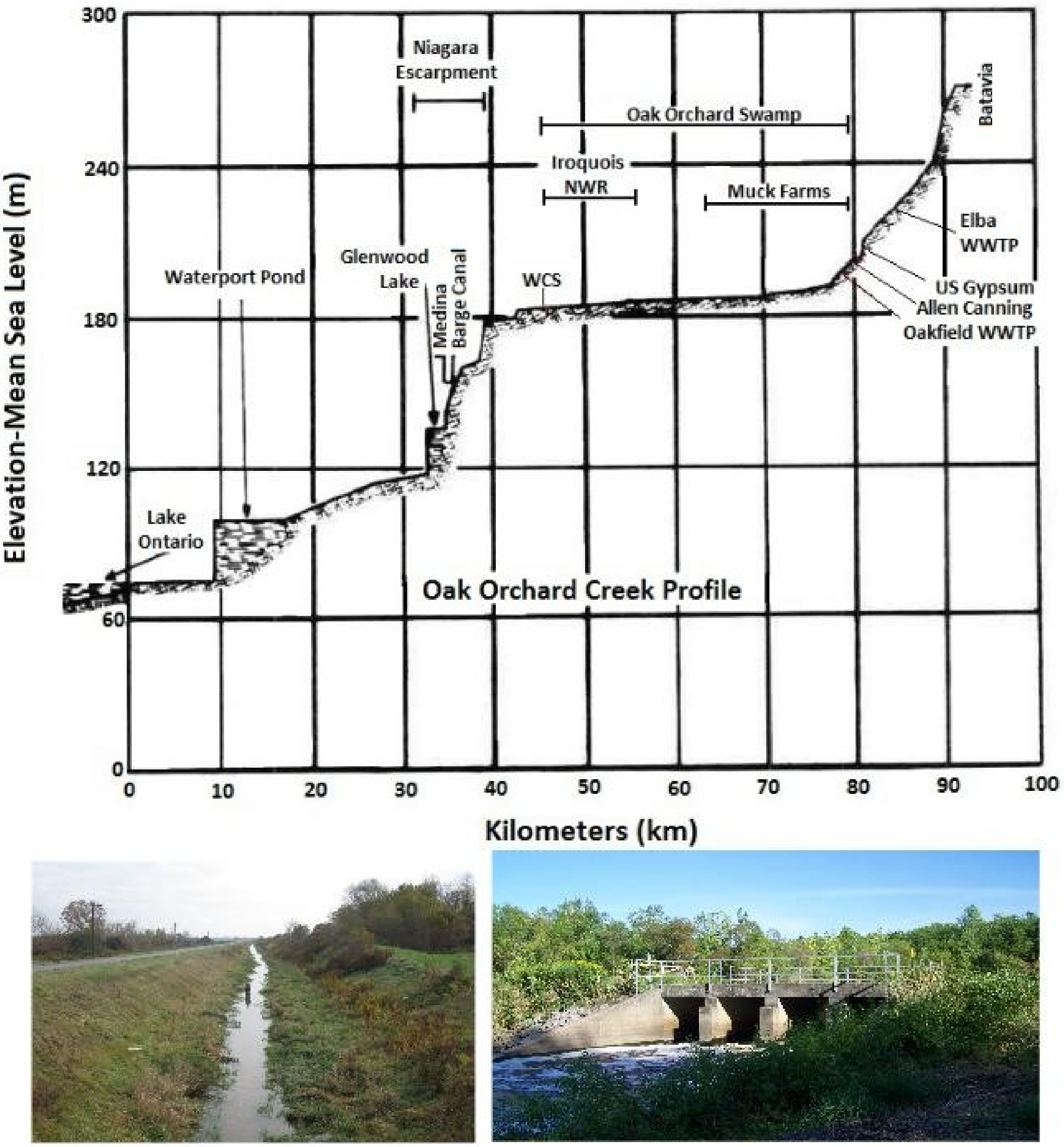


Figure 3 Longitudal profile of Oak Orchard River from its headwaters to the south to its discharge in Lake Ontario. Note the very low-sloped profile of the southern part of the river where the Muck Lands, INWR refuge and wetlands are. Many of the point sources of the watershed (including outflow from the Muck farms, left inset photo) are trapped Within this zone of low conveyence. This area probably represents an area where sequestration of particulates are significant. The water control structure (right inset photograph) operated by the Fish and Wildlife Service at the INWR is probably an important regulator of fluxes from this part of the watershed. Modified after

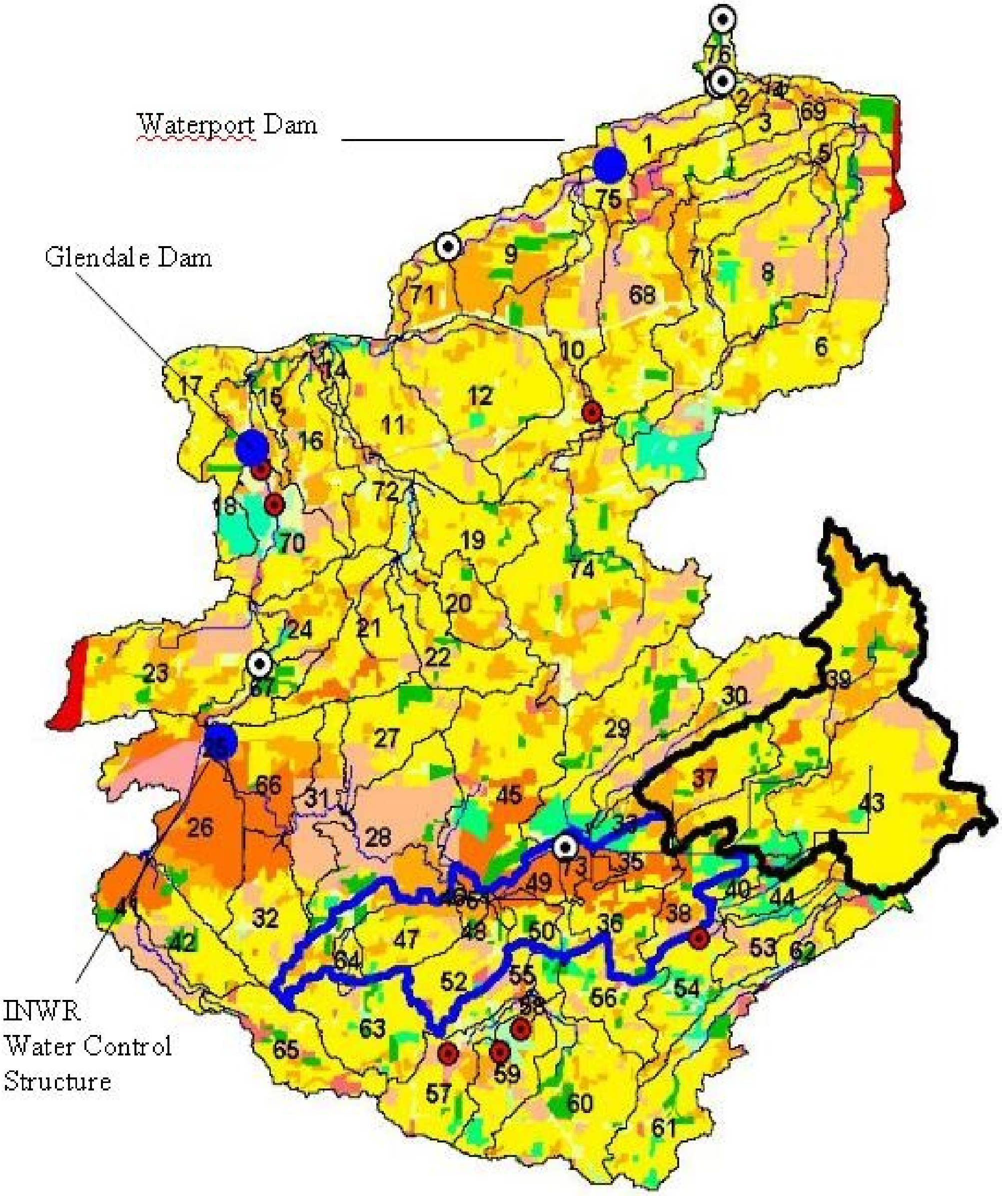


Figure 4 SWAT model of Oak Orchard watershed showing the locations of the three reservoirs (Blue), point discharges (Red) and validation sites (white). Heavy black subbasins are the mucklands which are parameterized as being tile-drained. The blue subbasins are "groundwater" subbasins which are parameterized to receive water flow from the Onondaga Escarpment. This is located outside of the model watershed. Groundwater fluxes were determined by balancing the missing flow in January thru March with just enough water to balance the observed flow in the calibration period.

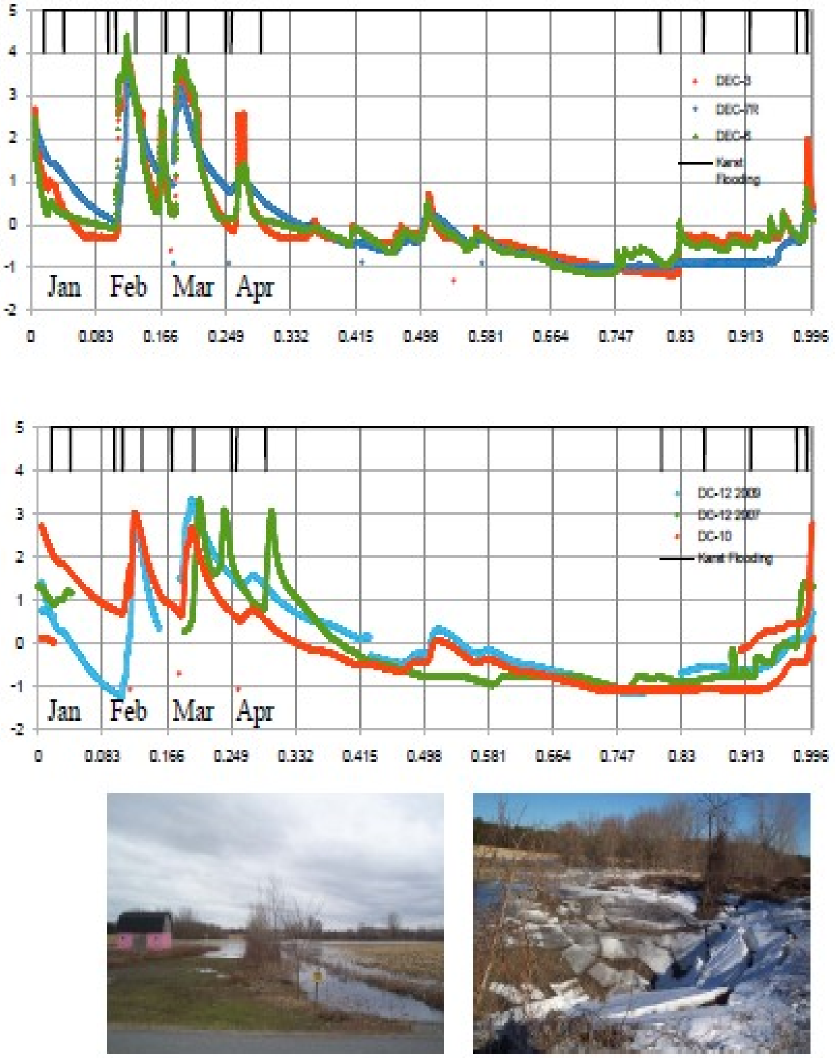


Figure 5 Graphs showing water table fluctuations in the Onondaga Formation expressed as standard anomalies (departure from the mean in standard deviation units). All of these wells have annual ranges that exceed forty feet. Note the occurrence of drastic water level rises that take place from January through April, which corresponds to the time period when our initial model grossly underpredicted water flow. Note also the occurrence of karst flooding events in the Quinlan Rd sinkhole (inset photographs). Based on this information, we believe that some of the missing water in the model is due to groundwater flows from the Onondaga escarpment. Water balance in the model was achieved by adding sufficient groundwater to balance the flow that was observed.

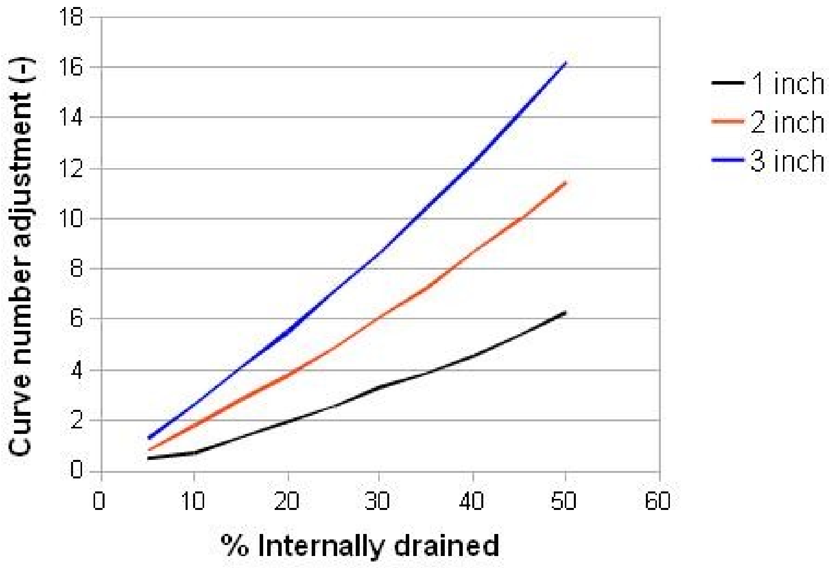


Figure 6 Curve number reduction plotted against % internally drained topography for three different rainfall excesses. If we assume that all the mucklands are connected to the river because of their extensive system of pumps, tiles and canals, the average % internally drained topography for the overall watershed is 18%. Curve number reduction does not include reductions based on management practices, soil and canopy characteristics. Since model discharge is dominated by events with large runoff excesses, we believe the reduction in curve number required for calibration in previous SWAT studies are due in part to topography. The curve number reduction required for our model (23%) is not too different from the reduction required for the Cannonsville Reservoir SWAT model (20%), another New York State watershed. (Tolson and Shoemaker, 2009).

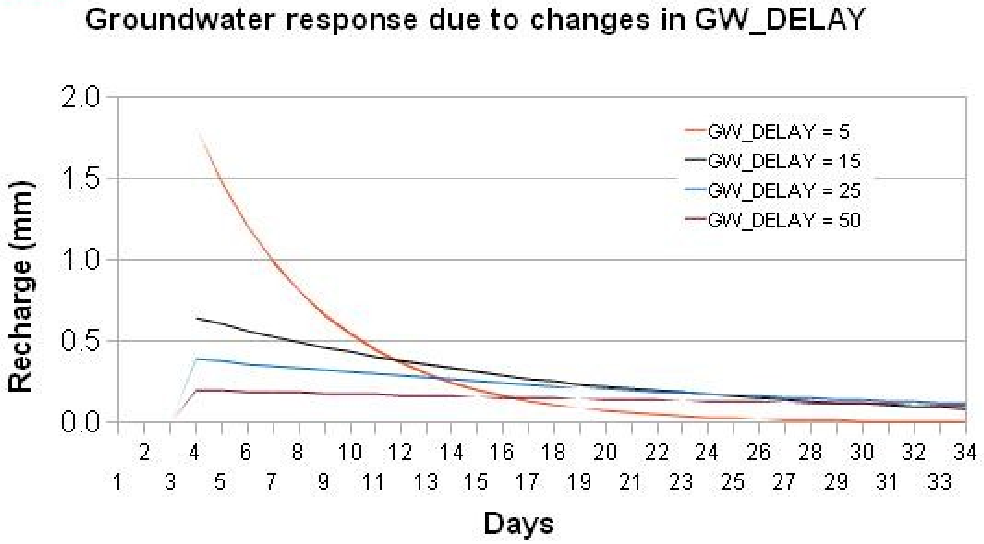


Figure 7 Recharge calculated for a variety of groundwater delays. Note that the time of arrival does not change significantly when expressed at the temporal resolution (daily) used by SWAT, but that the delay to the center of moment increases. Delay to the center of moment in observed well response data was used to extract groundwater delay for the watershed.

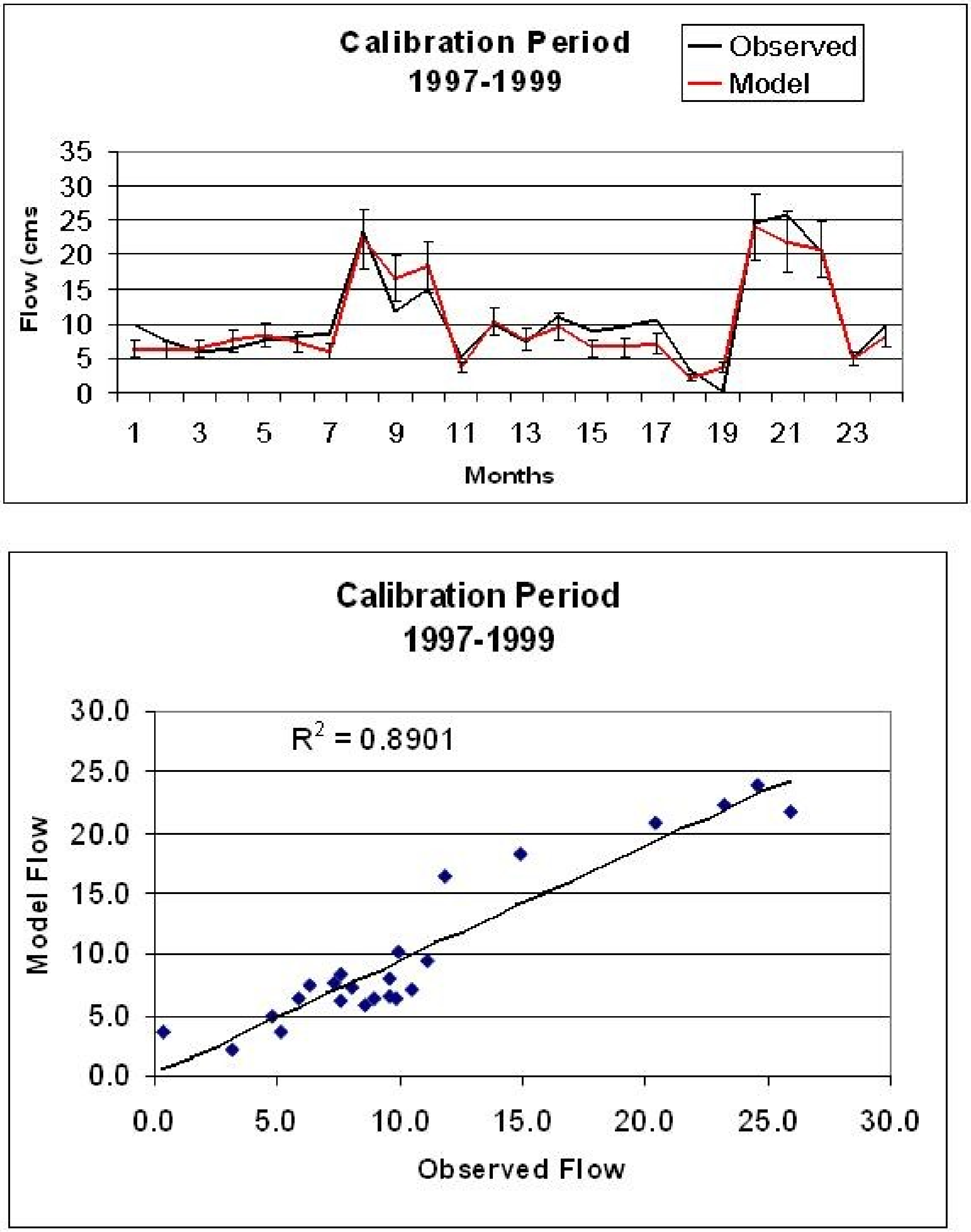
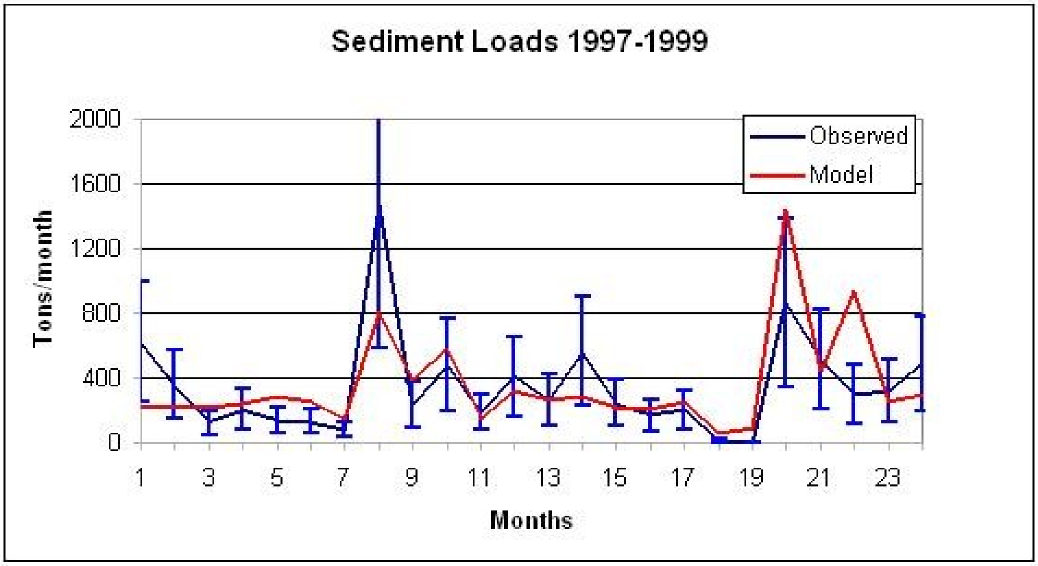


Figure 8 Monthly observed and model flows for the calibration gage site in subbasin 72. The Nash-Sutcliffe prediction efficieny was excellent for the calibration period (NS = 0.81). The R square for the model and observed flow was 0.83. Model flow under predicted total observed flow by 2%. Uncertainty for the observed data was considered to be 20% based on the measurement technique.



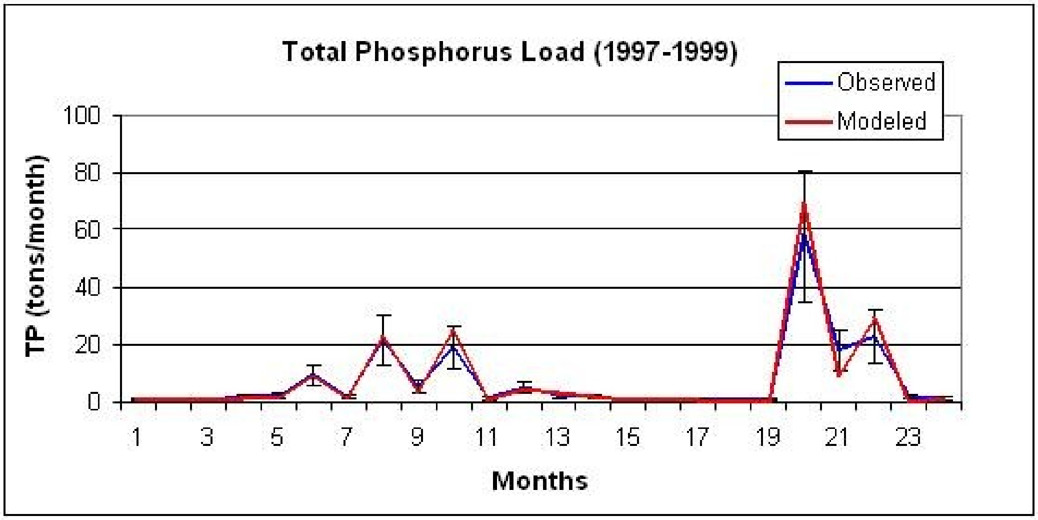


Figure 9 Monthly observed and modeled loads for sediment and phosphorus over the calibration time period. Uncertainty in the observed data was judged to be 60% and 40% for sediment and phosphorus respectively. Total cumulative load prediction was within 2% for Sediment and phosphorus.

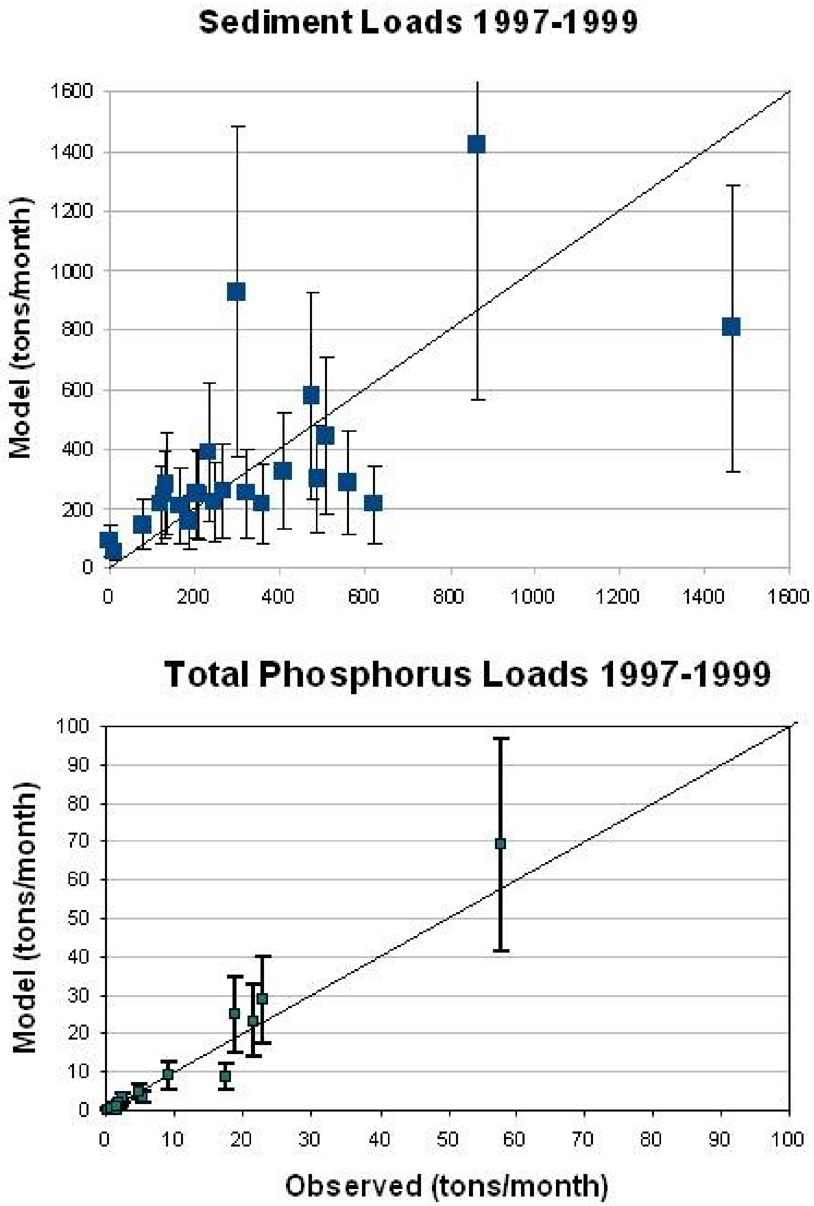


Figure 10 Predicted vs observed sediment and phosphorus loads during the calibration period. R squares were 0.32 and 0.91 for sediment and total phosphorus respectively.

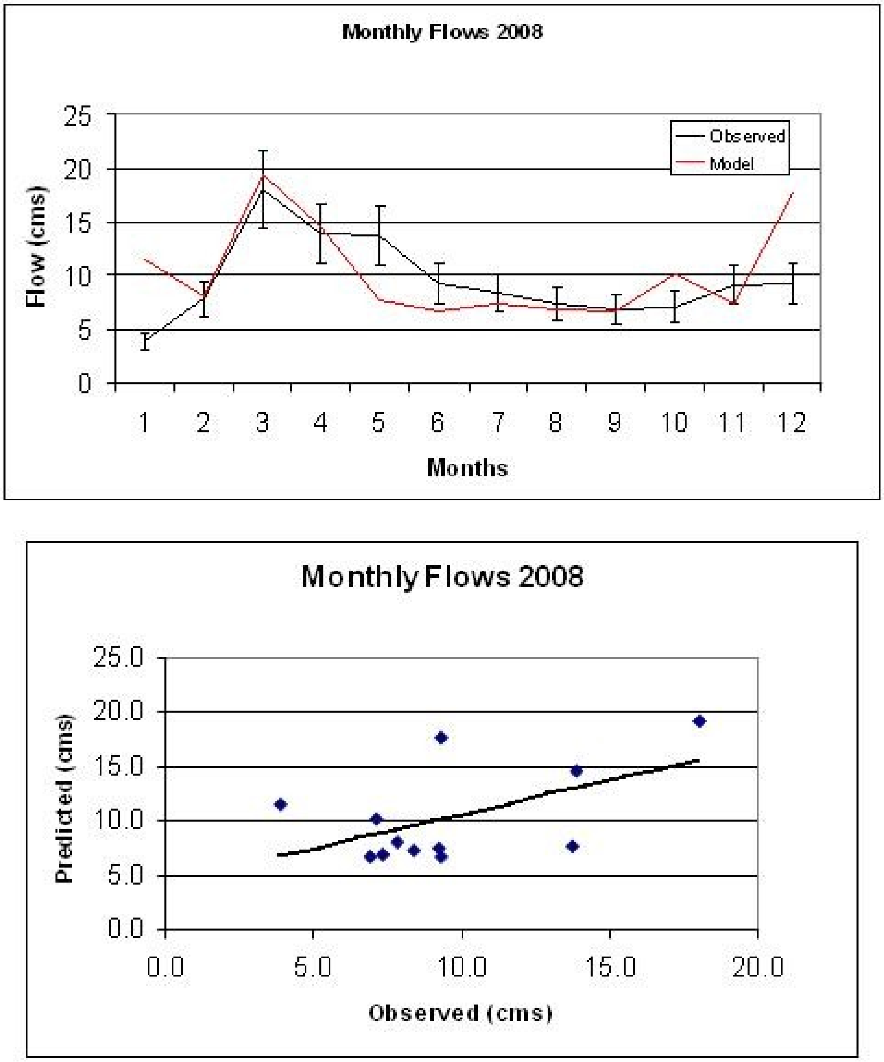


Figure 11 Monthly observed and model flows for the calibration gage site during the validation period (2008). The R square for the model and observed flow was 0.28. Model flow Overpredicted total observed flow by 7.9%. Uncertainty for the observed data was considered to be 20% based on the measurement technique. Inaccurate climate information, incomplete Understanding of groundwater inputs from the Onondaga escarpment, and the limited number of months of available validation data probably contributed to these poor results.

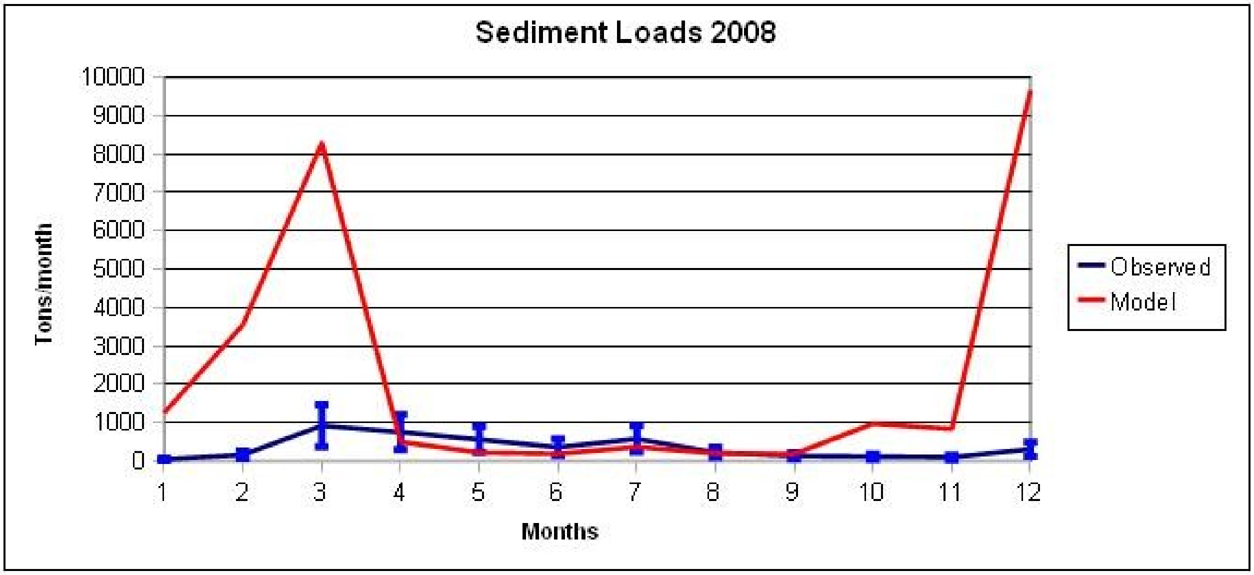


Figure 12 Monthly observed and model sediment loads for the calibration gage site during the validation period. The model grossly overpredicted sediment transport during the spring and in December. This was due to the poor flow estimations by the model during these periods.