UPPER SALEM RIVER WATERSHED RESTORATION AND PROTECTION PLAN: MODEL REPORT

Developed by the Rutgers Cooperative Extension Water Resources Program

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Acknowledgements

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This document has been produced by the Rutgers Cooperative Extension Water Resources Program (http://www.water.rutgers.edu/). **Mehran Niazi, Ph.D.**, Department of Environmental Sciences was responsible for the development and running of the Upper Salem River Watershed SWAT model, in addition to writing sections of this report. Principal authors were **Steven Yergeau, Ph.D.**, Post-Doctoral Associate; **Christopher C. Obropta, Ph.D., P.E.**, Associate Extension Specialist/Associate Professor, Department of Environmental Sciences; and **Robert J. Miskewitz, Ph.D.**, Assistant Research Professor, Department of Environmental Sciences.

Model Overview

A numerical model of the Upper Salem River Watershed was built using the Soil and Water Assessment Tool (SWAT). SWAT is a hydrologic model developed in the early 1990s by the United States Department of Agriculture–Agricultural Research Service to simulate pollutant transport to rivers in large agricultural watersheds (Arnold *et al*., 1998; Neitsch *et al*., 2010). SWAT has the advantage over other models in that it uses readily available data, can operate in large-scale basins, has the possibility of simulation for long periods of time, and has a history of successful usage (Arnold and Fohrer, 2005). SWAT has been used successfully in a wide range of watersheds throughout the U.S. to characterize both current hydrologic conditions and future management scenarios (Harmel *et al*., 2000; Spruill *et al*., 2000; Borah and Bera, 2004).

SWAT is a basin scale, continuous time model that operates on a daily time step and is designed to predict the impact of management on water, sediment, and agricultural chemical yields in ungauged watersheds. Major model components include weather, hydrology, soil temperature and properties, plant growth, nutrients, pesticides, bacteria and pathogens, and land management. In SWAT, a watershed is divided into multiple subwatersheds, which are then further subdivided into hydrologic response units (HRUs) that consist of homogeneous land use, management practices, and soil characteristics. The HRUs represent percentages of the subwatershed area and are not identified spatially within a SWAT simulation. Alternatively, a watershed can be divided into only subwatersheds that are characterized by dominant land use, soil type, and management activities. Gassman *et al.* (2007) provide a full description of SWAT and its utility in modeling watershed hydrology and water quality.

Much of the input data for the model were downloaded from the New Jersey Department of Environmental Protection (NJDEP) Bureau of Geographic Information Systems (GIS) website (http://www.nj.gov/dep/gis/download.htm). Data layers for topography, hydrography, soil types, and land use/land cover were selected for model input. These data were compiled using ArcSWAT. ArcSWAT is an ArcGIS graphical interface used to generate input files for the SWAT model (Arnold *et al*., 1998). It allows the user to employ readily available GIS layers and easily create model parameters, especially for large watersheds. Additional data were collected via site visits and from County Agents and the South Jersey Research, Conservation, and Development Council (SJRC&D).

The model domain was delineated into 27 subwatersheds using ArcSWAT (Figure 1). These basins include subcatchments that drain to the ten surface water sampling locations that were monitored as part of the Rutgers Cooperative Extension (RCE) Water Resources Program's Upper Salem River Watershed field sampling program (Figure 1). Although calibration was not possible at all 27 subwatersheds, the higher resolution associated with these smaller catchments enabled more accurate predictions of flow and pollutant source identification. ArcSWAT was then used to create 454 HRUs for the Upper Salem River Watershed; each of these corresponds to a unique subwatershed created by combining land use and soils data. The characteristics and predicted runoff/load from each of these HRUs can then be evaluated to determine those areas that represent sources of impairment to the watershed. Once the model has been validated, these HRUs can then be manipulated to predict the effects of best management practices (BMPs) that can be utilized in the watershed.

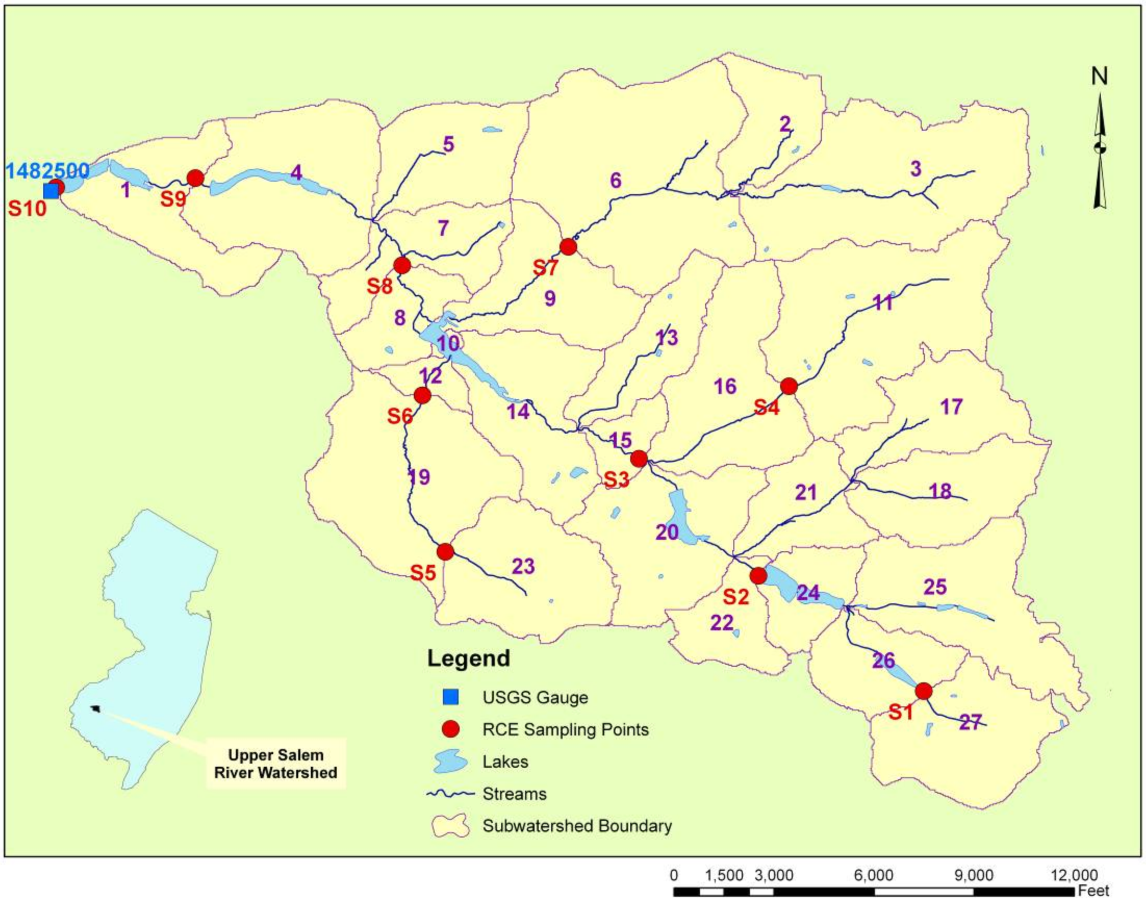

Figure 1: Delineated subwatersheds and RCE sampling locations in the Upper Salem River Watershed.

Calibration and validation of the model was completed by comparing flow rates predicted by the model at the outlet of the watershed (S10) and selected sampling stations throughout the watershed (RCE sampling locations S3, S4, S5, S7, and S8) to flow rates obtained from the U.S. Geological Survey (USGS) gauge at that location (USGS Gauge 01482500 Salem River at Woodstown, NJ) and data collected in the field (Figure 1). The model was calibrated on a daily time scale for a 1-year period (June 2007 through June 2008) and validated for a one year period (July 2008 through July 2009). Calibration and validation was performed on 26 of the 27 subwatersheds delineated in ArcSWAT (Figure 1). Subwatershed 10 was lumped into subwatershed 8 in the calibration and validation processes due to its small size (Figure 1). The fit of the model was determined via the Nash-Sutcliffe Efficiency Coefficient (NSE) (Nash and Sutcliffe, 1970). Additionally, water quality measurements collected during the field sampling program were also compared to SWAT-predicted water quality at the RCE Water Resources Program's sampling locations (Figure 1).

Once the existing conditions were successfully simulated via the validated model, one scenario was run to assess possible mitigation efforts in the watershed. The goal was to determine which scenarios would help meet the total maximum daily load (TMDL) reductions in total phosphorus (TP) and bacterial contamination using fecal coliform as an indicator organism. This strategy addresses pollutant reductions on the watershed and subwatershed scales and includes the following: 15-meter filter strips were placed around all agricultural land identified as row crops and pastures. The pollutant removal capability of filter strips was examined to evaluate the extent to which these BMPs act to achieve the target load reductions stated in the TMDLs appropriate for the Upper Salem River Watershed (NJDEP, 2003a; NJDEP 2003b).

Model Development

Input data for the model were obtained from several sources. Data layers (topography, hydrography, soils, land cover/land use, and elevation) were downloaded from the NJDEP's GIS website (http://www.nj.gov/dep/gis/download.htm) and supplemental data were collected via site visits, RCE County Agents, and SJRC&D. Preprocessing of the GIS data was accomplished using the ArcSWAT interface, which uses topographic characteristics of the area to determine the direction of flow and the extent of watershed and subwatershed boundaries. These topographic characteristics were calculated from NJDEP 10-meter Digital Elevation Model (DEM) raster data. The watershed that was delineated had an area of approximately 40 square kilometers (km^2; or 15 square miles, mi^2) with a maximum elevation of 166 feet above mean sea level in the headwaters and a minimum elevation of 31 feet above mean sea level at the outlet of the Upper Salem River Watershed (Figure 2). This decrease in elevation occurs over the course of 7.5 river miles.

The main watershed was then divided into 27 subwatersheds in SWAT, ten of which drain to the location of a sampling station used in the RCE Water Resources Program's field sampling campaign of 2007-2009 (Figure 1). These locations were sampled biweekly for a period of two years, with ten additional samples collected during June, July, and August of 2007. Results from the velocity measurements and flow calculations during monitoring, in addition to streamflow measurements taken from USGS gauge 01482500, were used in the calibration and validation of this model.

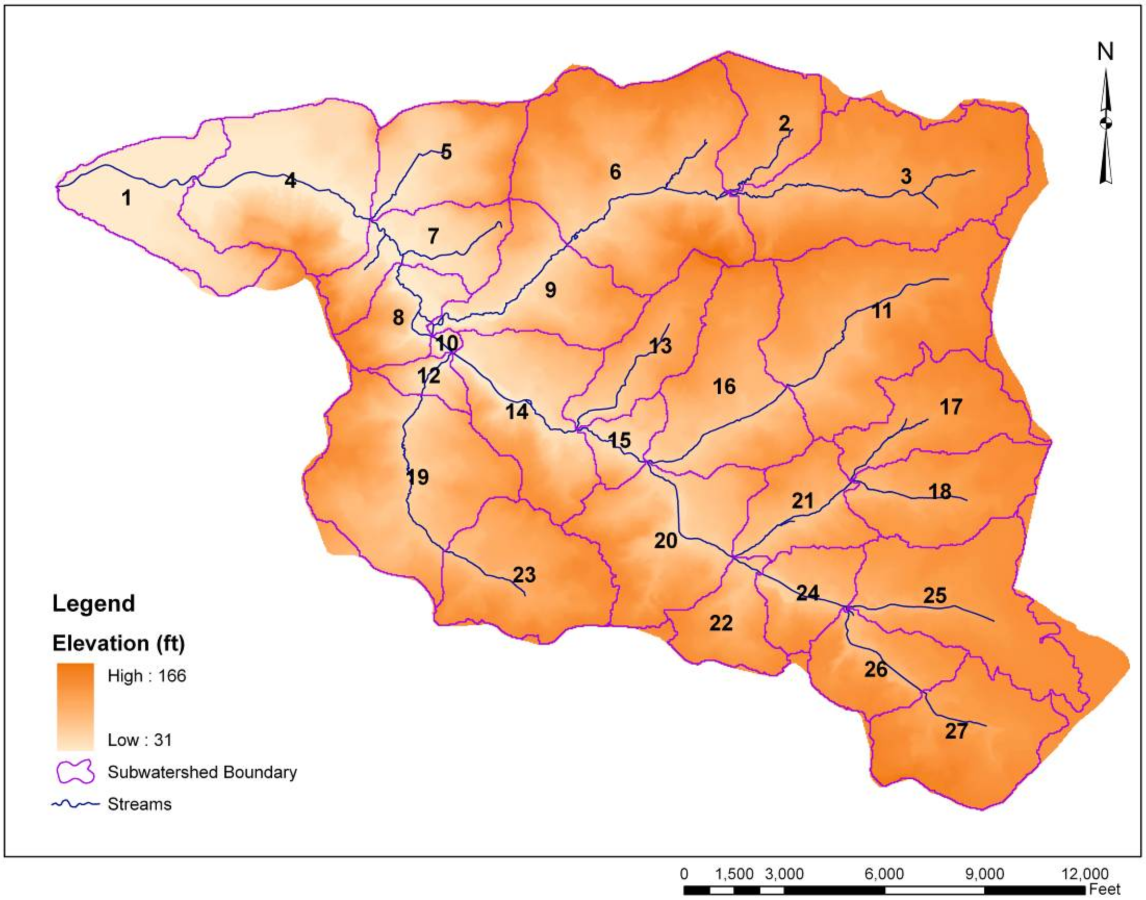

Figure 2: Topography of the SWAT-delineated model subwatersheds.

Once the topographic features of the watershed were determined, it was then characterized by land use and soil characteristics. Soil characteristics were downloaded from the U.S. Department of Agriculture's (USDA) State Soil Geographic (STATSGO) online database (http://soils.usda.gov/survey/geography/statsgo/). The STATSGO database contains an inventory of soil types and associated characteristics derived from more detailed state soil surveys. Soil characteristics have a large effect on infiltration rates, groundwater flows, and fate and transport of nutrients in a watershed. The Upper Salem River Watershed contains four identified soils: NJ025, NJ026, NJ029, and NJ039 (Table 1; Figure 3). NJ029 is present in the northwest section of the watershed, while NJ039 is present in the northeast. NJ025 is present in the south and east, and NJ026 is present in the center (Figure 3). Soil type NJ025 makes up the majority of the soils within the Upper Salem River Watershed (Table 1; Figure 3). Full descriptions of the attributes of these soils are given in Appendix A.

Table 1: Distribution of soil types within the Upper Salem River Watershed.

Soil ID	% of Watershed
NJ025	51.90
NJ026	20.50
NJ039	13.81
NJ029	13.76

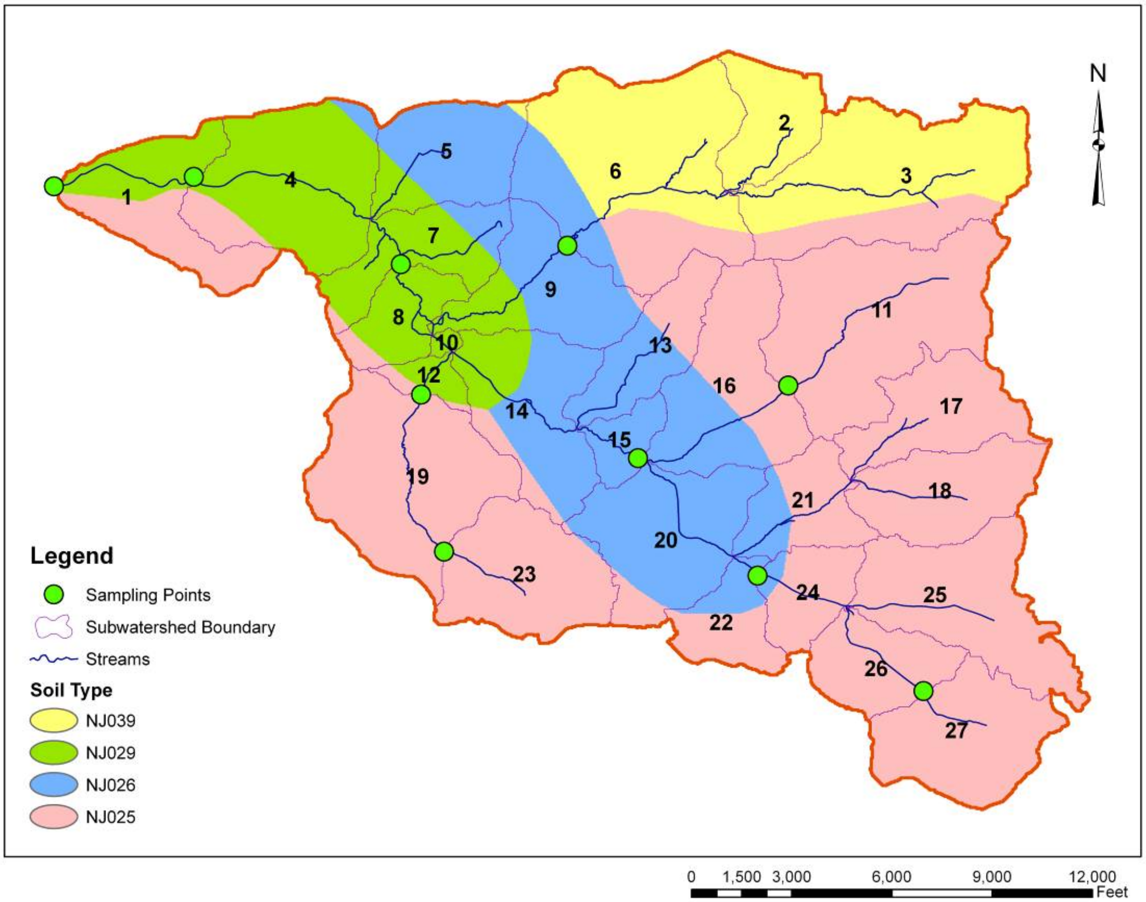

Figure 3: Upper Salem River Watershed soils.

To characterize the land uses in the watershed, the NJDEP 2002 land use/land cover GIS layer was utilized. However, the land use labels given in the NJDEP layer were insufficient at times to fit agricultural land use definitions within the SWAT framework, as well as to fully define agricultural practices. The additional information required more detail on the agricultural land uses than was available in the NJDEP layer. The RCE County Agents were consulted, and field surveys were conducted to acquire this information and fill in the data gaps. These additional agricultural classifications are mapped in Figure 4. The watershed is dominated by agriculture with grain cropland (GRSG) and pastureland (PAST) making up to 95% of the agricultural lands in the Upper Salem River Watershed (Figure 4). The remaining agricultural lands are orchards (ORCD) and confined animal feeding operations (CAFO; AGRC in SWAT) (Figure 4). Low density urban (URLD) lands account for less than 10% of total land use while natural land uses (forest, wetland and water) represent the remaining land area (Figure 4).

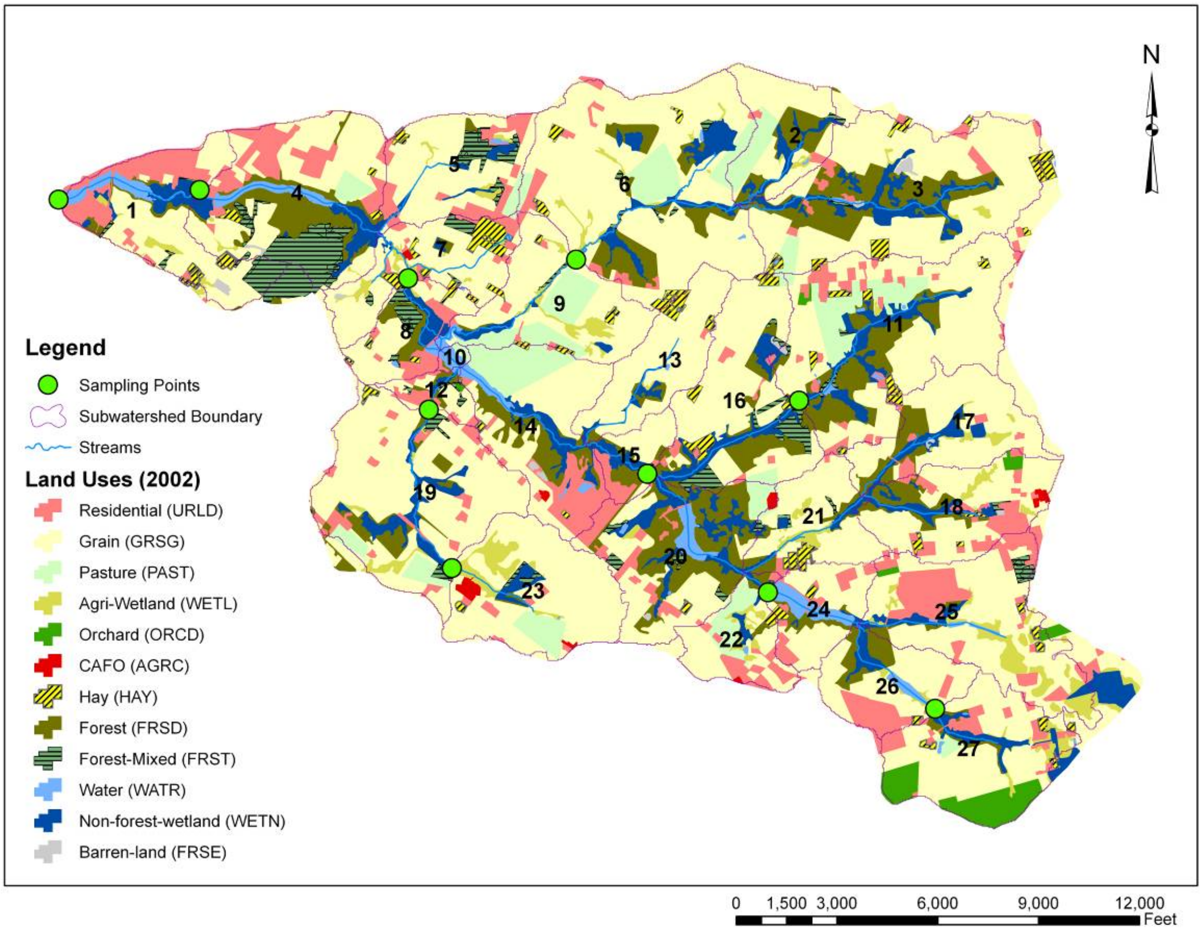

Figure 4: SWAT land uses for the Upper Salem River Watershed.

Once the subwatersheds, soil types, and land uses were determined, HRUs were delineated within SWAT. Each HRU represents an individual subwatershed, soil type, and land use based upon a combination of these three factors. HRUs represent the finest detail available for the model output. In this effort, the 40 km^2 (15 mi^2) Upper Salem River Watershed was divided into 454 HRUs. Additional model parameters included rainfall and temperature records downloaded from the Upper Deerfield and Clayton weather stations maintained as part of the SJRC&D weather system network (http://www.sjrcd.org/rise/). Also, information regarding fertilizer application practices was gained from the County Agents and the farming community to be used in the model to properly allocate phosphorus and bacteria loads.

Model Calibration & Validation

The model used to assess the Upper Salem River Watershed was calibrated for the time period of June 2007 through June 2008 (hereafter referred to as '2007-2008') using flow data from USGS gauge 01482500. The calibration was completed using methods as described in the SWAT manual (Neitsch *et al.*, 2010). This process involves running a model simulation and comparing resulting output ("predicted data") with data collected in the field ("observed data"). The closer this output data is to these field measurements, the closer the model is to accurately representing the real environment. If model output values did not adequately match observed data, parameters within the model were adjusted and simulations were run again. To calibrate the model, stream flow data for sampling locations S3, S4, S5, S7, S8, and S10 were used (Figure 1).

In addition to the USGS gauge's recorded flow, velocity measurements were collected by the RCE Water Resources Program field personnel during sampling events conducted from 2007 to 2009. Velocities were measured at stream cross-sections at the ten upstream sampling locations (Figure 1) with a Marsh-McBirney, Inc., Flo-Mate Model 2000 Flowmeter, and discharge was calculated for each station during each event sampled. Transects were established at each station with flow and depth measurements taken at increments along this transect (Marsh-McBirney, Inc., 1990). Depths were measured in feet to the nearest 0.1 foot using a top-setting wading rod that is marked at both 1 foot and 0.1 foot intervals. Flows were measured by following the "60% rule." This method measures flow at a depth equal to 60% of the overall water depth, which is the theoretical mean velocity at that point along the transect (Marsh-McBirney, Inc., 1990). This is accepted as a valid method of obtaining mean velocity from streams, rivers, and open channels (Marsh-McBirney, Inc., 1990). After depths were measured, velocities were measured by pointing the flow sensor into the direction of flow and adjusting the sensor to 60% of water depth by lining up the foot scale on the sliding rod with the tenth scale on top of the depth gauge portion of the top-setting-wading rod (Marsh-McBirney, Inc., 1990). Velocities were recorded in meters per second (m/s). The procedure that occurred at increments along the transect was as follows: 1) measure depth, 2) adjust height of sensor to 60% of depth, and 3) measure velocity. Flows were calculated as cubic meters per second (m^3/s) by multiplying cross sectional area (converted to meters) by velocity (Marsh-McBirney, Inc., 1990).

The parameters modified during the calibration process were determined through sensitivity analysis (Neitsch *et al.*, 2010). Sensitivity analysis aims to reduce the number of parameters that are adjusted during the calibration process and identifies those that have the largest or least impact on model output (van Griensven *et al.*, 2006). Two methods were used to determine those parameters for the Upper Salem River Watershed SWAT model: Latin-Hypercube (LH) simulation and One-factor-At-a-Time (OAT) design. The LH method was used for calibrating stream flow and OAT was used on the water quality parameters (TP and bacteria). LH simulation involves dividing the distribution of each parameter in *N* levels with a probability of occurrence of 1/*N* (van Griensven *et al.*, 2006). Sensitivity analysis results for flow are presented in Table 2. The OAT method consists of repeated model simulations where targeted parameters are altered by a small change in their values (van Griensven *et al.*, 2006). For the Upper Salem River Watershed SWAT model, selected parameters (Table 3) were increased and decreased by 20% of their value to determine their impact on model output. Both of these methods are described in detail in van Griensven *et al.* (2006).

Table 2: Parameters ranked by their impact on model flow results for the six calibrated sampling stations as determined during LH sensitivity analysis.

Sampling Station	Rank 1	Rank 2	Rank 3	Rank 4
S3	Alpha-BF (baseflow alpha factor)	GW_RVAP (groundwater revap coefficient)	ESCO (soil evaporation compensation)	CN2 (SCS runoff curve number)
S4	Alpha-BF (baseflow alpha factor)	GW_delay (groundwater delay)	ESCO (soil evaporation compensation)	CN2 (SCS runoff curve number)
S5	GW_RVAP (groundwater revap coefficient)	CN2 (SCS runoff curve number)	Alpha-BF (baseflow alpha factor)	SOL_AWC (soil availability capacity)
S7	CN2 (SCS runoff curve number)	Alpha-BF (baseflow alpha factor)	GW_delay (groundwater delay)	SOL_AWC (soil availability capacity)
S8	CN2 (SCS runoff curve number)	GWQMN (threshold depth of water)	SOL_AWC (soil availability capacity)	ESCO (soil evaporation compensation)
S10	Alpha-BF (baseflow alpha factor)	CN2 (SCS runoff curve number)	ESCO (soil evaporation compensation)	GW_delay (groundwater delay)

Table 3: Parameters selected for OAT sensitivity analysis for bacteria water quality calibration.

Parameter
THBAC (temperature adjustment factor)
BACTKDDB (bacteria partition coefficient in manure)
BACTKDQ (bacteria partition coefficient in surface runoff)
WDPQ (die-off factor for persistent pathogens in soil solution)
WDLPQ (die-off factor for less persistent pathogens in soil solution)
Quantity (quantity of manure applied to land and direct input to stream)

The statistic used to determine how well the predicted values correspond to the measured flow is the NSE coefficient (E), one of the most widely used comparison statistics in hydrologic modeling. The coefficient, E, is calculated as one minus the sum of the absolute squared differences between the predicted (P_i) and observed (O_i) values normalized by the variance of the observed values (Krause *et al.*, 2005):

$$E = 1 - \frac{\sum_{i=1}^{n} (Oi - Pi)^2}{\sum_{i=1}^{n} (Oi - \overline{O})^2}$$

where, $\bar{O}$ = mean of observed values.

Results of E range from negative infinity to 1, with values closer to 1 showing greater agreement between model predictions and observed values (Krause *et al.*, 2005). A calculated value of zero indicates that the mean of the observations is adequate for modeling and would be just as good a predictor as the model (Krause *et al.*, 2005). Negative values of E may either indicate that the mean of observation data is a better predicator or indicate model bias. Negative values of E are representative of an unsatisfactory model.

The NSE coefficients (E) for the calibration period (2007-2008) are presented in Table 4. The results of calibration indicate good model performance, especially at the watershed outlet at S10 (Parajuli *et al.*, 2009). To determine if the model will have use beyond this calibration time period, the model was run again for an additional year (July 2008 through July 2009; hereafter referred as ‘2008-2009’) as a validation procedure. Validation is the process in which a second set of data are input into a calibrated model and results are compared to ensure that the model suitably describes observed phenomena. Unlike calibration, no parameters that would affect predictions are altered during model validation. Model validation was accomplished by taking the calibrated model, entering appropriate data for 2008-2009 and then running the simulation at appropriate time intervals. Validation results for the 2008-2009 time period are presented in Table 4.

Table 4: NSE coefficients (*E*) for selected stations during the calibration and validation processes for streamflow.

Sampling Station	*E* (Calibration)	*E* (Validation)
S3	0.70	0.71
S4	0.50	0.48
S5	0.45	0.40
S7	0.36	0.20
S8	0.58	0.48
S10	0.69	0.53

In addition to flow, the model was calibrated and validated for fecal coliform (FC) and *Escherichia coli* (*E. coli*) based upon water quality data collected during the monitoring component of the Upper Salem River Watershed restoration planning project. Many sources of these pollutants are present in the watershed including, but not limited to, wildlife and pets, livestock, failing septic systems, and agricultural practices. The model presents a means to estimate the relative effects of current practices and land uses on waters within the Upper Salem River Watershed and the potential impact that BMPs could have on improving water quality and reducing discharge volume. Calibration of the model for 2007-2008 resulted with NSE coefficients ranging from 0.07 to 0.47 calculated for FC (Table 5), and 0.03 to 0.39 for *E. coli* (Table 6). These results indicate fair to good model performance (Parajuli *et al.*, 2009). Validation of the SWAT model for these water quality parameters for the 2008-2009 time period resulted in NSE coefficients of -0.94 to 0.33 for FC (Table 5) and -0.81 to 0.31 for *E. coli* (Table 6). Due to the complexity of modeling pathogens (FC or *E. coli*) within SWAT, comparisons between predicted and observed values indicate that the model over-predicts pathogen concentrations during some months and under-predicts in other months. Even though the calculated NSE coefficients for the pathogen models were low compared to the flow calibration and validation NSE coefficients (Table 5; Table 6), the pathogen calibration and validation NSE coefficients indicate that the model is a better predictor than the average value of the bacteria loads (Krause *et al.*, 2005) and was used for modeling of the future management scenario.

Table 5: NSE coefficients (*E*) for selected stations during the calibration and validation processes for fecal coliform.

Sampling Station	*E* (Calibration)	*E* (Validation)
S3	0.23	0.11
S4	0.07	0.04
S5	0.47	0.29
S7	0.36	0.33
S8	0.13	-0.94
S10	0.12	0.11

Table 6: NSE coefficients (*E)* for selected stations during the calibration and validation processes for *E. coli*.

Sampling Station	*E* (Calibration)	*E* (Validation)
S3	0.39	0.19
S4	0.03	0.24
S5	0.36	0.31
S7	0.33	0.31
S8	0.25	-0.81
S10	0.24	0.20

Results

The model calibration and validation runs for the years of 2007-2008 and 2008-2009, respectively, were used to simulate water quality in the Upper Salem River Watershed. TP loads were calculated from subwatersheds on an annual basis and then normalized by subwatershed drainage area to determine loading rates (Table 7). These rates were compared to areal loading coefficients used by the NJDEP for TP. Areal loading coefficients for agricultural land uses, low density residential, and natural lands are 0.60, 0.30, and 0.05 kg/acre/year, respectively (NJDEP, 2004). The normalized total annual TP loading rate estimated using the SWAT model (at the watershed outlet at station S10) for 2007-2008 (0.27 kg/acre) is lower than the NJDEP coefficient for agricultural lands (0.60 kg/acre/year), while the rate for 2008-2009 (0.76 kg/acre) is higher (Table 7). This higher loading rate may be due to higher soil erodibility, high watershed slopes, and different agricultural practices used in the Upper Salem River Watershed as opposed to those watersheds used to develop the NJDEP coefficients (NJDEP, 2004). If the higher value is representative of conditions in the Upper Salem River Watershed, the need for water quality improvement becomes essential.

Under existing conditions, the subwatersheds that produced the largest TP loads were S10, S8, and S3 in both 2007-2008 and 2008-2009 (Table 7). When normalized by area, the largest loading rates were also in subwatersheds S10, S8, and S3 in 2007-2008 and S10, S8, and S4 in 2008-2009 (Table 7).

Table 7: Estimated subwatershed TP loads from the Upper Salem River SWAT model.

Subwatershed	TP Load (kg)		TP Loading Rate (kg/acre)	
	2007-2008	2008-2009	2007-2008	2008-2009
S3	493	421	0.13	0.11
S4	31	158	0.05	0.24
S5	14	37	0.04	0.10
S7	66	90	0.04	0.05
S8	767	2,150	0.10	0.28
S10	2,420	6,790	0.27	0.76

Like TP loads, FC loads were also estimated using the SWAT model. FC loads were calculated from each subwatershed on an annual basis for 2007-2008 and 2008-2009 and then normalized by subwatershed drainage area to calculate subwatershed loading rates (Table 8). Unlike TP, there are no areal loading coefficients used by the NJDEP for FC. Normalized total annual FC loading rates estimated using the SWAT model (at the watershed outlet at station S10) were 88.4 billion (8.84E+10) colony forming units per acre (cfu/ac) for 2007-2008 and 150 billion (1.50E+11) cfu/ac for 2008-2009 (Table 8). These are much higher than estimated loads from agricultural lands (39 billion per acre) used to develop TMDLs for shellfish-impaired waters in Watershed Management Area 17, which contains the Upper Salem River Watershed (NJDEP, 2006).

Under modeled conditions, the subwatersheds that produced the largest FC loads were S3, S8, and S10 in both 2007-2008 and 2008-2009 (Table 8). When normalized by area, the largest FC loading occurred in subwatersheds S5 and S7 in 2007-2008 and S10 in 2008-2009 (Table 8).

Table 8: Estimated subwatershed FC loadings from the Upper Salem River SWAT model.

Subwatershed	FC Load (cfu)		FC Loading Rate (cfu/acre)	
	2007-2008	2008-2009	2007-2008	2008-2009
S3	3.47E+14	1.79E+14	9.41E+10	4.85E+10
S4	2.05E+13	4.57E+13	3.06E+10	6.82E+10
S5	8.20E+13	3.07E+13	2.17E+11	8.15E+10
S7	2.30E+14	8.56E+13	1.39E+11	5.17E+10
S8	4.15E+14	3.30E+14	5.49E+10	4.36E+10
S10	7.92E+14	1.34E+15	8.84E+10	1.50E+11

E. coli loads were also estimated in SWAT for the Upper Salem River Watershed. *E. coli* loads were also calculated from each subwatershed on an annual basis for 2007-2008 and 2008-2009 and then normalized by subwatershed drainage area to estimate subwatershed loading rates (Table 9). Like FC, there are no areal loading coefficients used by the NJDEP for *E. coli*. Normalized total annual *E. coli* loading rates estimated using the SWAT model (at the watershed outlet at station S10) were 99.5 billion (9.95E+10) cfu/ac for 2007-2008 and 323 billion (3.23E+11) cfu/ac for 2008-2009 (Table 9).

Using these modeled conditions, the subwatersheds that produced the largest *E. coli* loads were S3, S8, and S10 in both 2007-2008 and 2008-2009 (Table 9). When normalized by area, the largest FC loading occurred in subwatersheds S5 and S7 in 2007-2008 and S10 in 2008-2009 (Table 9).

Table 9: Estimated subwatershed *E. coli* loadings from the Upper Salem River SWAT model.

Subwatershed	***E. coli* Load (cfu)**		***E. coli* Loading Rate (cfu/acre)**	
	2007-2008	**2008-2009**	**2007-2008**	**2008-2009**
S3	3.59E+14	1.36E+14	9.74E+10	3.68E+10
S4	2.05E+13	4.12E+13	3.06E+10	6.14E+10
S5	7.13E+13	5.20E+13	1.89E+11	1.38E+11
S7	2.32E+14	8.56E+13	1.40E+11	5.17E+10
S8	5.34E+14	3.82E+14	7.06E+10	5.04E+10
S10	8.92E+14	2.89E+15	9.95E+10	3.23E+11

Note that the loading rates for TP, as well as fecal coliform and *E. coli*, were calculated based upon the total acreage of the watershed that drains to the sampling point (i.e., subwatershed S3 is comprised of the drainage areas of S1, S2, and S3, since these areas drain collectively to sampling point S3; Figure 1).

The predicted loading rates were calculated to provide a baseline so as to gauge the effectiveness of a mitigation scenario tested in this modeling effort. The scenario built into the model is the following: 15-meter filter strips were placed around all agricultural land identified as growing row crops and pastures. This scenario was run for the 2008-2009 validation period using appropriate data.

Scenario: 15-Meter Vegetated Filter Strips Surrounding Row Crop Agricultural Land Uses

The first scenario was run for the validation period (2008-2009) under the same conditions as the validated model, with the exception that each of the row crop agricultural land uses (approximately 21.6 km^2) throughout the watershed were surrounded by a 15-meter vegetated filter strip. A vegetated filter strip is an area of land surrounding a waterbody, potentially capable of filtering nonpoint source pollution in runoff from adjacent lands. Riparian buffers may remove pollutants from runoff through a variety of processes, mainly deposition, infiltration, dilution, sorption, uptake by vegetation, and microbial activity. Factors that affect these filtration methods are mainly due to physical characteristics of the riparian buffer, including buffer width, slope, soil type, and type of vegetation. SWAT removes TP from runoff as it flows through the filter strip as a function of its width (Arabi *et al.*, 2008):

$$trap_{ef\_TP} = 0.367 \times FILTERW^{0.2967}$$

where, $trap_{ef\_TP}$ = trapping efficiency of TP, and

$FILTERW$ = filter strip width (m).

The amount of TP removed via this mitigation strategy at the watershed outlet (S10) was 4,685 kg, which corresponds to a reduction of 69.0% for the entire watershed (Table 10). The use of 15m vegetated filter strips around all row crop agricultural land uses was predicted to have the greatest mitigation effect in subwatershed S5 with an estimated 81.1% removal of TP (Table 10).

Table 10: Estimated subwatershed TP load reductions from filter strips.

Subwatershed	TP Loads (kg)		Percent Reduction
	No Filter Strip	With Filter Strip	
S3	421	126	70.1%
S4	158	41	74.1%
S5	37	7	81.1%
S7	90	22	75.6%
S8	2,150	559	74.0%
S10	6,790	2,105	69.0%

The SWAT pathogen modeling approach involves developing a comprehensive and flexible pathogen sub-model that allows simultaneous risk evaluation of pathogen, nutrient, and sediment loadings associated with various land management practices in a watershed. This sub-model has been successfully applied to watersheds in Missouri, USA (Baffaut and Benson, 2003), Kansas, USA (Parajuli *et al.*, 2009), France (Bougeard *et al.*, 2011), and Ireland (Coffey *et al.*, 2010) for modeling either *E. coli* or fecal coliform.

The pathogen sub-model of SWAT uses Chick's Law first order decay equation to model *E. coli* and fecal bacteria die-off and re-growth. Chick's Law determines the quantity of pathogens that are removed or added by die-off and growth, respectively, as described by Sadeghi and Arnold (2002). Vegetated filter strip efficiency for pathogens (FC or *E. coli*) is also based upon the filter strip width and is calculated in SWAT with the following equation (Moore *et al.*, 1992):

$$E_{pathogen} = \frac{11.8 + (4.3 \times FILTERW)}{100}$$

where, $E_{pathogen}$ is the fraction of bacteria load (either FC or *E. coli*) trapped by the filter strip.

The amount of FC removed with filters strips at the watershed outlet (S10) was estimated to be 835 (8.35E+14) trillion cfu, or a 62.1% reduction in FC load rates (Table 11). Use of 15m vegetated filter strips are estimated to have the largest reduction of FC in subwatershed S8, with 64.9% of the loads retained within the filter strips (Table 11).

Table 11: Estimated subwatershed FC load reductions from filter strips.

Subwatershed	**FC Load Rate (cfu/mo)**		**Percent Reduction**
	No Filter Strip	**With Filter Strip**	
S3	1.79E+14	6.62E+13	63.0%
S4	4.57E+13	1.87E+13	59.1%
S5	3.07E+13	1.20E+13	60.9%
S7	8.56E+13	3.60E+13	57.9%
S8	3.30E+14	1.16E+14	64.9%
S10	1.34E+15	5.09E+14	62.1%

Similar results were seen in estimated *E. coli* reductions through the use of vegetated filter strips in the Upper Salem River Watershed (Table 12). *E. coli* loads are predicted to be reduced by 62.0%, or 1.76 quadrillion (1.76E+15) *E. coli* cfu at S10 (Table 12). The largest losses of *E. coli* are estimated to occur in subwatershed S8, with 65.1% of loads reduced through filter strips (Table 12).

Table 12: Estimated subwatershed *E. coli* load reductions from filter strips.

Subwatershed	***E. coli* Load Rate (cfu/mo)**		**Percent Reduction**
	No Filter Strip	**With Filter Strip**	
S3	1.36E+14	5.02E+13	63.0%
S4	4.12E+13	1.69E+13	58.9%
S5	5.20E+13	2.03E+13	61.0%
S7	8.56E+13	3.60E+13	57.9%
S8	3.82E+14	1.33E+14	65.1%
S10	2.89E+15	1.10E+15	62.0%

This mitigation strategy would require a collaborative effort by a large proportion of the agricultural community in the Upper Salem River Watershed. It is important to note, however, that since the effect of installing these filter strips is cumulative each individual installation will have a positive effect on water quality.

Conclusions

The SWAT model that was developed to simulate the hydrologic conditions present in the Upper Salem River Watershed was shown to reasonably predict water flow and water quality characteristics. Nutrient management parameters that were applied in the model were gathered from various well-informed sources in the area and were found to agree with loading rates commonly used by the NJDEP. As a result, it is believed that the predictions regarding the effectiveness of these mitigation strategies offer a sound indicator of the relative gains to be expected compared to the continuation of current practices.

The strategies tested showed that while none were able to reach the goals set by the TMDLs for TP and FC, improvements in water quality could be achieved, if implemented properly. The use of 15m vegetated filter strips around row crop agricultural land uses was predicted to reduce TP loads at the Upper Salem River Watershed outlet (S10) by 69.0% and FC loadings by 62.1% (Table 10; Table 11). The TP TMDL for the Upper Salem River requires an 88% load reduction (NJDEP, 2003a) and the FC TMDL requires an 84% reduction in bacteria loading (NJDEP, 2003b). While the vegetated filter strips were unable to achieve this goal on their own, as a mitigation strategy they would still be able to reduce a large proportion of the pollution entering the Salem River and its tributaries. However, this mitigation strategy requires the greatest cooperation among the members of the farming community and a large investment of land and financial resources on a watershed scale.

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Appendix A. STATSGO Soil Parameters

MUID	#LAYERS
NJ025	2
NJ026	2
NJ027	2
NJ039	2

LAYER 1

MUID	AWC_L1	SAND%_L1	SILT%_L1	CLAY%_L1	ROCKVOL_L1	DOMTEXT_L1	DTB
NJ025	6	23	62	15	1	SiL	153
NJ026	4	59	31	10	5	SL	148
NJ027	6	61	29	10	2	SL	152
NJ039	3	65	26	9	8	SL	152

LAYER 2

MUID	AWC_L2	SAND%_L2	SILT%_L2	CLAY%_L2	ROCKVOL_L2	DOMTEXT_L2	DTB
NJ025	14	25	54	21	3	SiCL	153
NJ026	9	54	30	15	10	SL	148
NJ027	13	56	33	11	3	SL	152
NJ039	8	58	30	12	13	SL	152

Parameter	**Definition**
MUID	Soil type name (map unit identifier).
AWC	Available water capacity (centimeters (cm)).
SAND%	Percent of sand in soil.
SILT%	Percent of silt in soil.
CLAY%	Percent of clay in soil.
ROCKVOL	Percent of rock fragments, by volume.
DOMTEXT	Dominant soil texture class. S = Sand LS = Loamy sand SL = Sandy Loam L = Loam SiL = Silt Loam Si = Silt L = Loam SCL = Sandy Clay Loam SiCL = Silty Clay Loam CL = Clay Loam SC = Sandy Clay SiC = Silty Clay C = Clay OM = Organic Materials W = Water BR = Bedrock O = Other
DTB	Mean depth to bedrock (cm).