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Upper Cohansey River Watershed Restoration and Protection Plan: Model Report

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Model Overview

A numerical model of the Upper Cohansey River Watershed was built using the Soil 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 areas (Arnold *et al*., 1998; Neitsch *et al*., 2002). 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 subdivided 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.

Input data for the model were downloaded from the New Jersey Department of Environmental Protection (NJDEP) geographic information system (GIS) website (http://www.nj.gov/dep/gis/). Data layers for topography, hydrography, soil types, and land use/land cover were selected for model input. These data were compiled using ArcView SWAT-X (AVSWAT-X). AVSWAT-X is a GIS interface that is used to generate input files for SWAT from GIS data layers (Gassman *et al.*, 2007). 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 ten subbasins using AVSWAT-X. These basins correspond to areas draining the ten surface water sampling locations that were monitored as part of Rutgers Cooperative Extension (RCE) Water Resources Program's Upper Cohansey River field sampling program (Figure 1). AVSWATX was then used to create 113 HRUs for the Upper Cohansey River Watershed; each of these corresponds to a unique subbasin 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

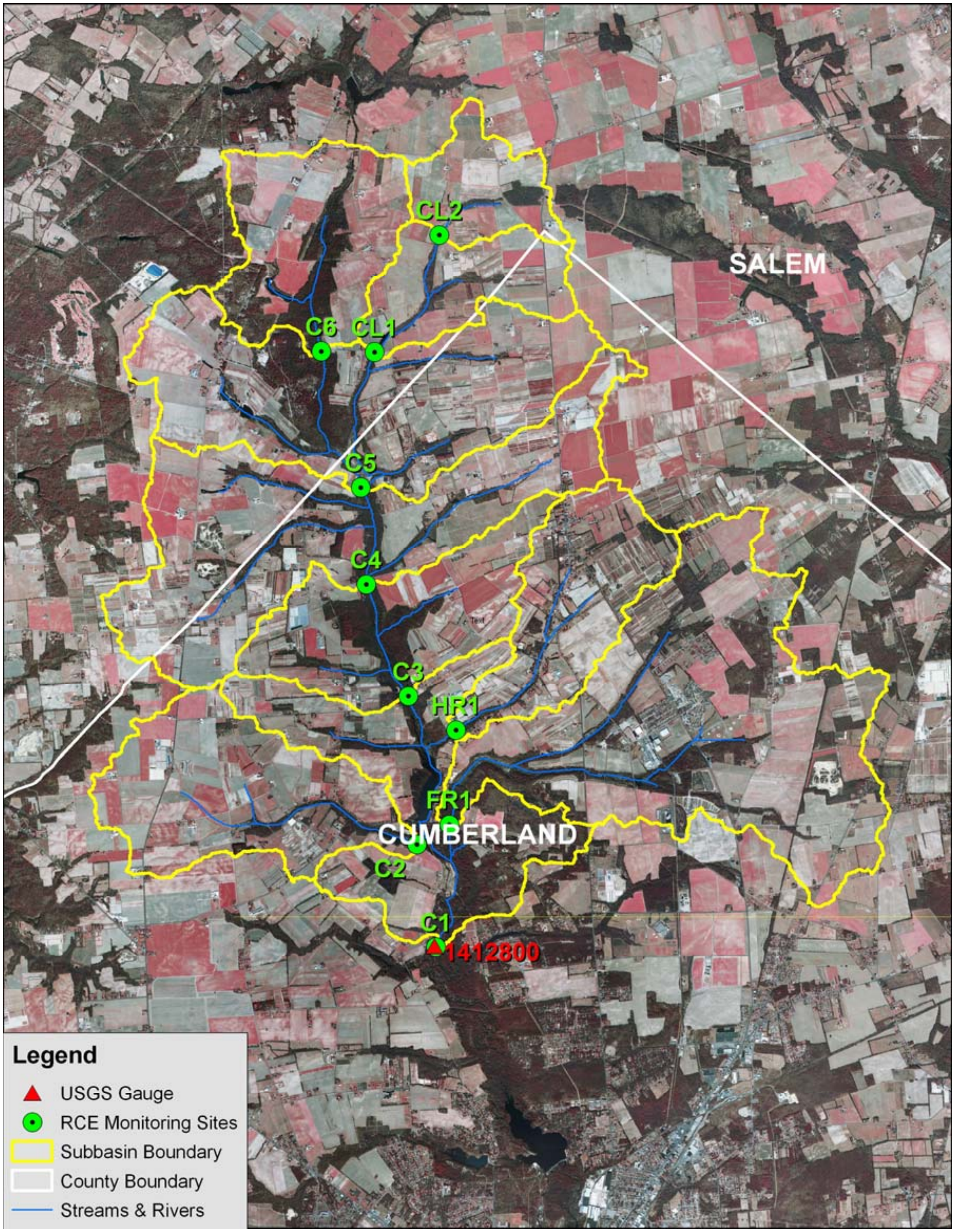

Figure 1: Ten Catchments Delineated According to Monitoring Stations

validated, these HRUs can then be manipulated to predict the effects of best management practices (BMPs) that can be installed in the watershed.

Calibration and validation of the model was completed by comparing flow rates predicted by the model at the outlet of the watershed (C1; Figure 1) to flow rates obtained from the U.S. Geological Survey (USGS) gauge at that location (USGS Gauge 01412800 Cohansey River at Seeley, NJ) (Figure 1). The model was calibrated on a daily time scale for a one year period (January 1, 2005 through December 31, 2005) and validated for a one year period (January 1, 2006 through December 31, 2006), as well. The fit of the model was determined via the Nash-Sutcliffe Efficiency Coefficient (NSE) (Nash and Sutcliffe, 1970). For the calibration and validation periods, the NSE values were calculated as 0.39 and 0.36, respectively. These indicated fair model performance (Parajuli *et al.* 2009). Additionally, flow measurements collected during the field sampling program were also compared to the predicted flow measurements at all ten of the sampling locations (Figure 1).

Once the existing conditions were successfully simulated via the validated model, four scenarios were run to assess different possible mitigation scenarios. The goal was to determine which scenarios would help meet the total maximum daily load (TMDL) reductions in total phosphorus (TP). These strategies address pollutant reductions on the watershed, subbasin, and HRU scales and include the following:

1. 15-meter filter strips around all agricultural land identified as growing row crops.
2. Bio-retention ponds that receive 80% of the runoff from subbasins C4 and C2.
3. Constructed wetlands that receive 80% of the runoff from subbasins C4 and C2.
4. Removal of those HRUs land uses that represent the largest sources of TP via a BMP that will result in runoff water quality and quantity equal to that being produced by an established forest system.

The pollutant removal capability and the effect on downstream phosphorus concentrations were examined not only to see if the BMPs were efficient, but also the extent to which the BMPs act to achieve the target concentrations stated in the TMDL for this waterbody (NJDEP, 2005). The Upper Cohansey River Watershed flows south and discharges into Sunset Lake, which also has a TP TMDL (NJDEP, 2005). Thus, the Upper Cohansey River Watershed is being held to the TP water quality standard of 0.05 mg/L designated for lakes (NJDEP, 2008), and the TP removal required according to the NJDEP TMDL document is set at 92% (NJDEP, 2005).

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/) and supplemental data were collected via site visits, County Agents, and SJRC&D. Preprocessing of the GIS data was accomplished using the AVSWAT-X 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 65 square kilometers (km^2; or 25 square miles, mi^2) with a maximum elevation of 125 feet above sea level in the headwaters and a minimum elevation of 20 feet above sea level at the outlet of the watershed (Figure 2). This decrease in elevation occurs over the course of six (6) river miles.

The main watershed was then divided into ten (10) subbasins in SWAT, each of which drains exclusively to the location of a sampling station used in the RCE Water Resources Program's field sampling campaign of 2006 (Figure 1). These locations were sampled biweekly for a period of six months, with three additional samples collected in June, July, and August. Results from the velocity measurements and flow calculations were used in the calibration and validation of this model.

Once the topographic features of the watershed were determined, the watershed was then characterized by land use and soil characteristics. Soil characteristics were obtained from the State Soil Geographic (STATSGO) 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 the watershed. This watershed was characterized by three identified soils, NJ025, NJ027, and NJ039. NJ027 was present in the northwest section of the watershed, while NJ039 was present in the southeast, and NJ025 was present in the center (Figure 3). The relative distribution of these soils is listed Table 1. Full descriptions of the attributes of these soils are given in Appendix A.

Table 1: Soil Type Distribution

Soil ID	**% of watershed**
NJ025	70.5
NJ027	10.45
NJ039	19.05

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 this state layer were insufficient at times to fit agricultural land use definitions within the SWAT framework. The additional information required more detail on the agricultural land uses than was available. The RCE County Agents were consulted, and field surveys were conducted in summer 2005 to acquire this information and fill in the data gaps. These additional agricultural classifications follow and are mapped in Figure 4. The watershed is dominated by row crop agriculture (AGRR) and a large ornamental nursery industry (NURS). These represent 42.6% and 21.3% of the land area, respectively. Urban commercial (UCOM) and low density urban (URLD) land uses account for less than 8%

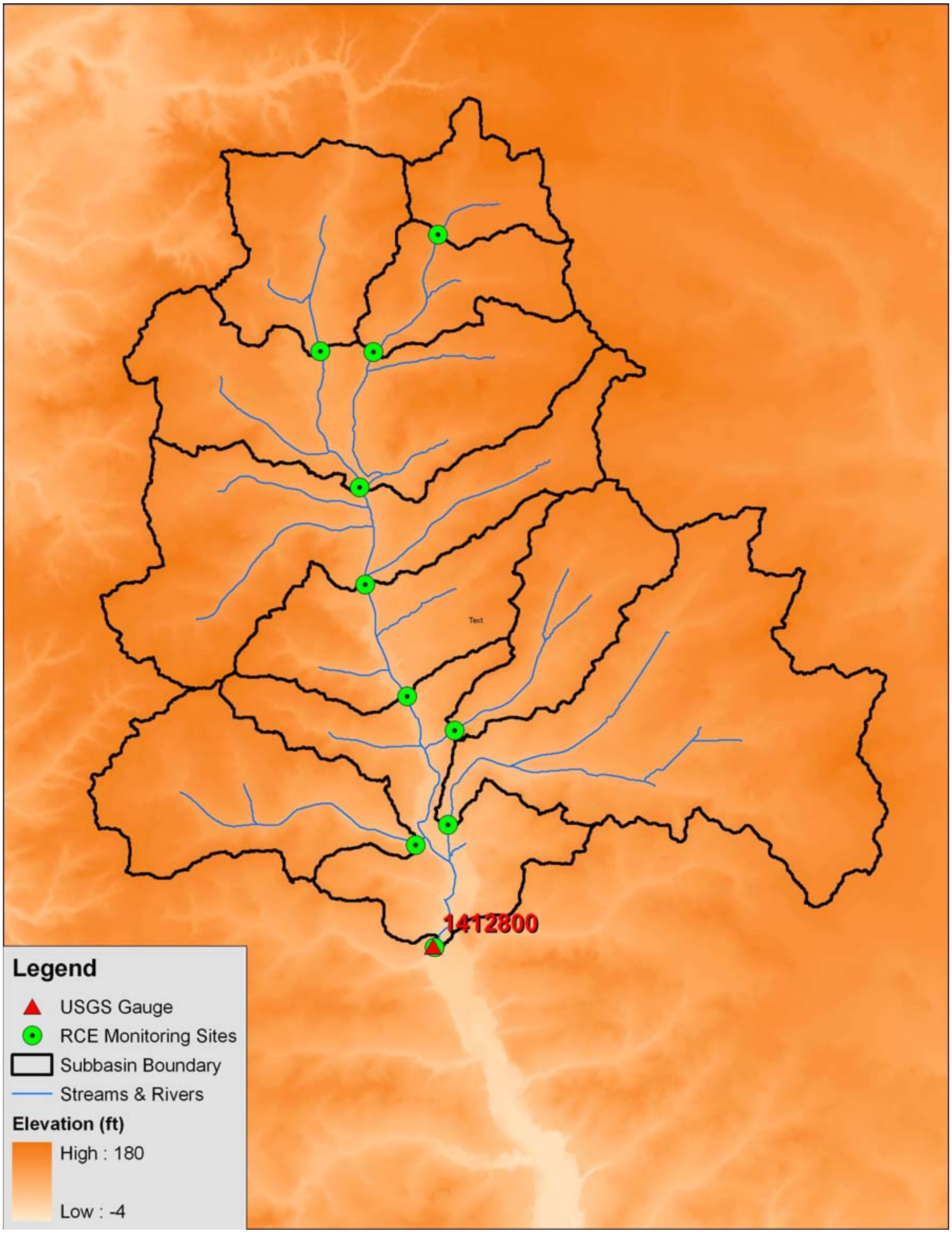

Figure 2: Model Subbasins on the NJ 10-meter Digital Elevation Map

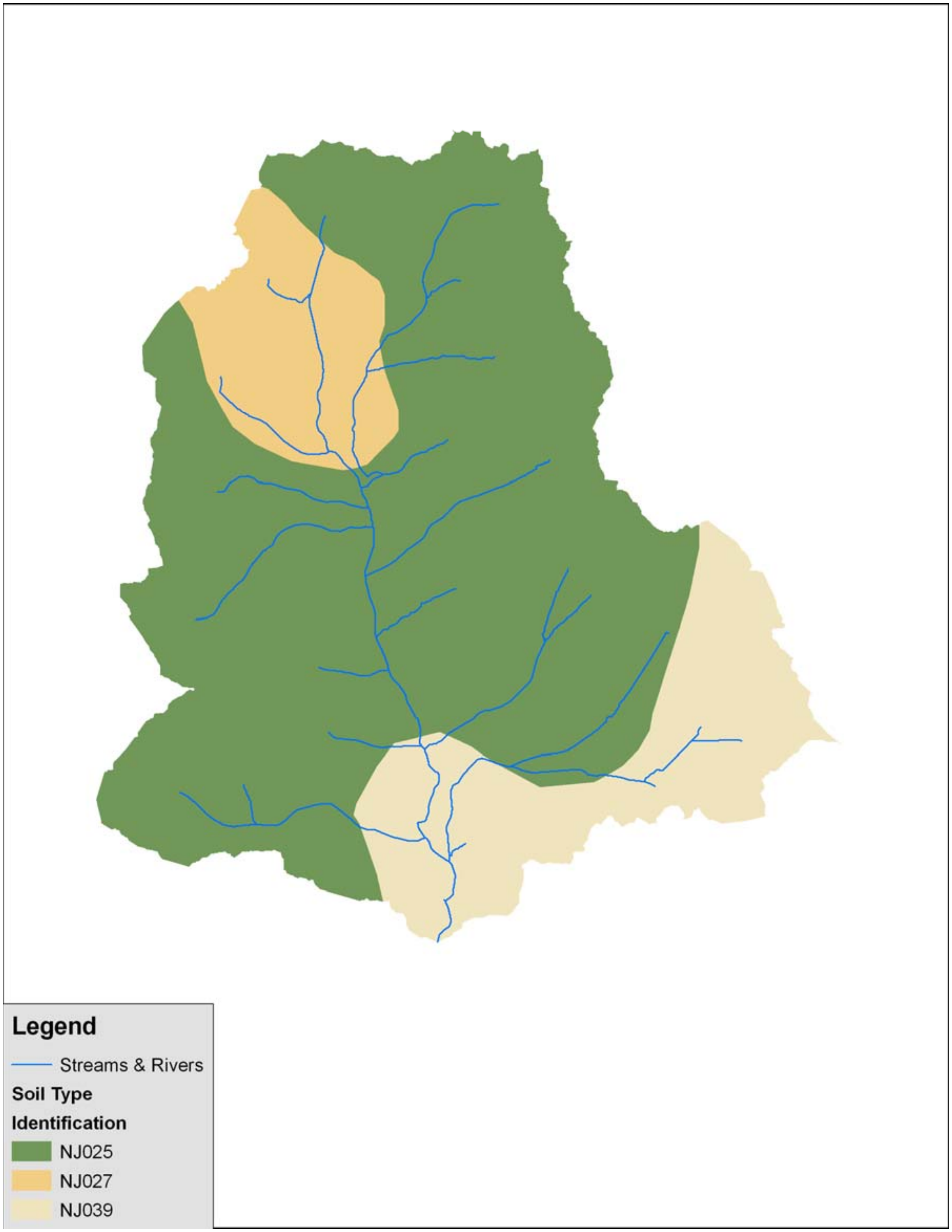

Figure 3: Upper Cohansey River Watershed Soils

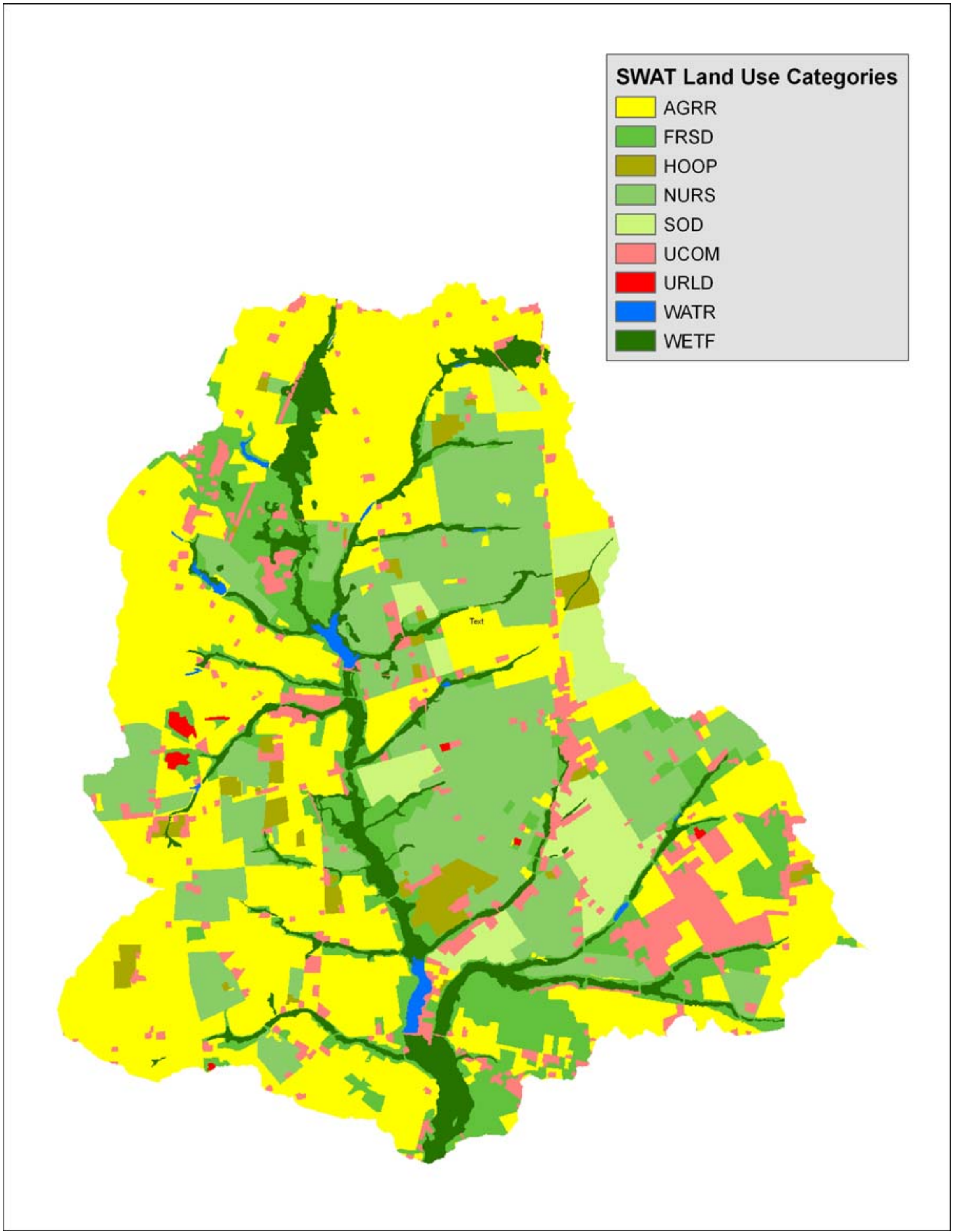

Figure 4: SWAT Land Uses for the Upper Cohansey River Watershed

of the watershed; natural land uses are approximately 20% of the watershed. Natural land uses consist of forested wetland (WETF) and deciduous forest (FRSD). The remaining lands are comprised of a fairly large sod industry that is approximately 5.5% of the land area (SOD), container nurseries (HOOP), and open water (WATR).

Once the subbasins, soil types, and land uses were determined, HRUs were delineated within SWAT. Each HRU represents an individual subbasin, soil type, and land use. These represent the finest detail available for the model output. In this effort, the 65 km^2 (25 mi^2) Upper Cohansey River watershed was divided into 113 HRUs. Additional model parameters included rainfall and temperature records downloaded from the Upper Deerfield weather station 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 loads.

Model Calibration

The model used to assess the Upper Cohansey River Watershed was calibrated for calendar year 2005. The calibration was completed using methods as described in the SWAT manual (Neitsch *et al*., 2002). 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 from the USGS gauge identified as Cohansey River at Seeley, NJ (01412800) was used. The location of this gauge corresponds to the outlet of subbasin 10, or C1, as it was identified in the water monitoring effort (Figure 1). Flow calibration was conducted on a daily scale for one calendar year. The procedure involved comparing the predicted average daily flow to the gauge data. Model parameters were modified to optimize the model and reduce the difference between predicted and measured values. The parameters modified during the calibration process were GW_DELAY (delay time of groundwater exiting the soil profile into the shallow aquifer), ALPHA_BF (the "baseflow alpha constant", which is a direct index of groundwater flow response to changes in recharge), REVAPMN (threshold depth of water in the shallow aquifer for "revap," or percolation to the deep aquifer, to occur), GW_REVAP (groundwater revap coefficient), CH_N1 (Manning's coefficient for tributary channels), and OV_N (Manning's coefficient for overland flows) (Neitsch *et al*., 2002). Sensitivity analyses have shown that these parameters affect SWAT model output.

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 coefficient (*E*) for the calibration period (January 1, 2005 – December 31, 2005) is 0.39 (Figure 5). To determine if the model will have use beyond the 2005 calibration year, the model was run again for 2006 (January 1, 2006 – December 31, 2006) 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 2006 and then running the simulation at appropriate time intervals. Validation results were similar to calibration with an NSE coefficient of 0.36 calculated for 2006 (Figure 5).

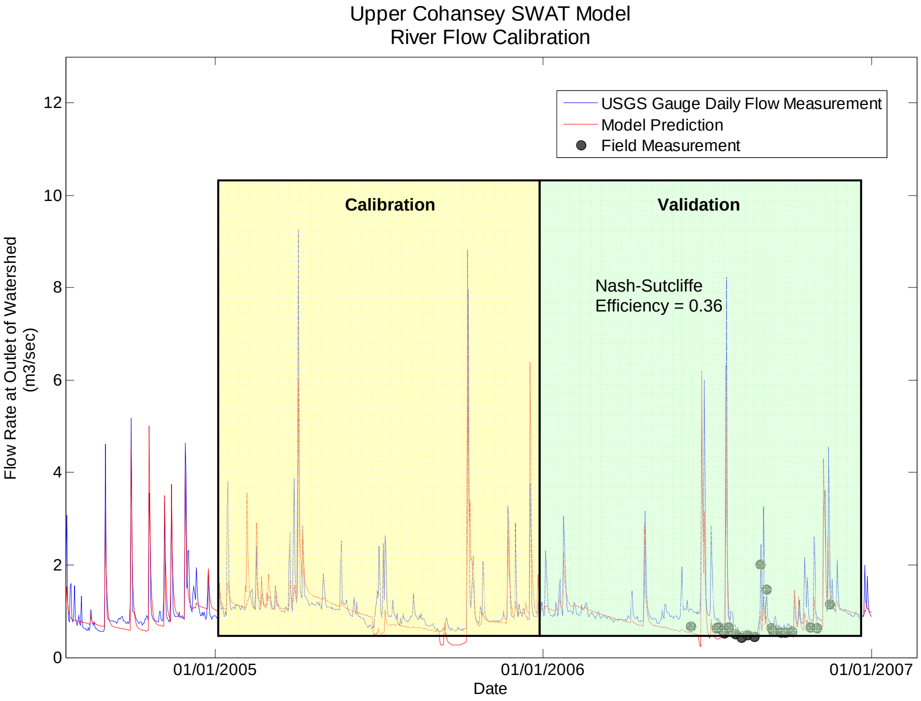

Figure 5: Flow Predictions and Measurements at Seeley Lake Gauge

In addition to the USGS gauge's recorded flow, measurements were collected by the RCE Water Resources Program field personnel during sampling events conducted in 2006. Velocities were measured at stream cross-sections at the ten 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).

While these were point measurements collected at one time on a given day and are compared to daily average values, it can be seen that the predicted values are reasonable when visually compared to both these field measurements and flows from the USGS gauge at the watershed outlet (Figure 6).

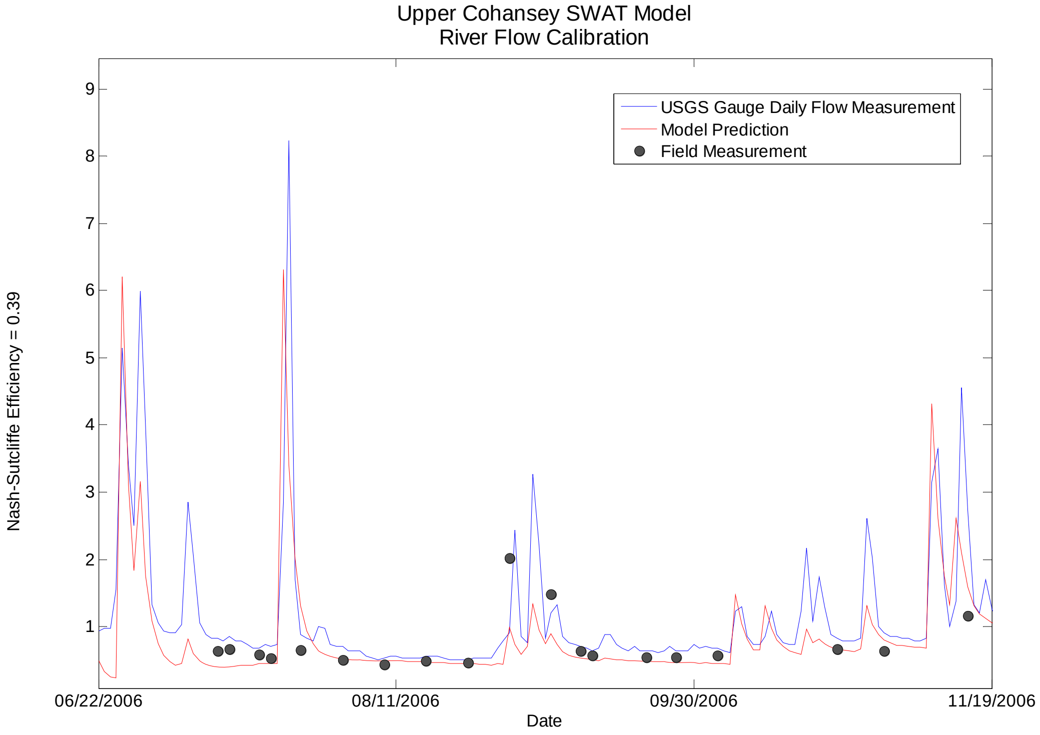

Figure 6: Flow Predictions at Site C1 and Field Measurements at USGS Seeley Lake Gauge

A similar comparison as the one made in Figure 6 was made at each of the ten sampling locations (Figure 7). It is apparent from visual inspection of these graphical comparisons that the predictions at all ten (10) locations are acceptable. However, due to the limited amount of measurements, a formal calibration at each of these points was not possible.

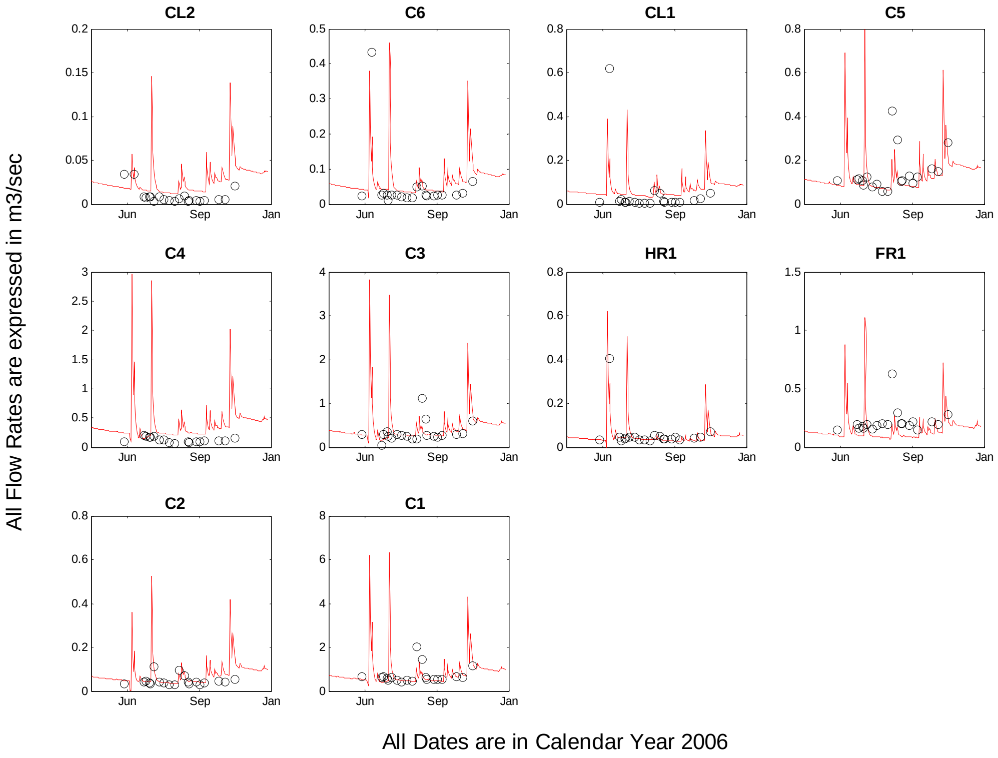

Figure 7: Flow Measurements (Open Circles) and Predictions (Red Lines) at All Sampling Locations

The model was not calibrated for phosphorus due to the inherent inaccuracy that would be present from unaccounted sources such as wildlife, failing septic systems, and other activities that could not be entered into the model. With this in mind, it is important to stress that the strength of this model is not as a tool to analyze actual conditions but rather as a means to compare the relative effects of current practices and land uses and the potential impact that BMPs could make on water quality and discharge.

Results

The model calibration and validation runs for the calendar years of 2005 and 2006, respectively, were used to simulate water quality in the Upper Cohansey River Watershed within these years. TP loads were calculated from each subbasin on an annual basis. The load normalized by the subbasin area was also calculated to compare subbasin loading rates (Table 2). These rates were compared to the areal loading coefficients that are commonly used by the NJDEP for TP. The 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 total annual TP loading rates predicted using the

SWAT model (Table 2) for 2005 (1.70 kg/acre) and 2006 (0.85 kg/acre) are higher than the NJDEP coefficient for agriculture (0.60 kg/acre/year). This may be due to higher soil erodibility, high watershed slopes, and different agricultural practices used in the Upper Cohansey River Watershed as opposed to those watersheds used to develop the NJDEP coefficients. If these higher values are representative of conditions in the Upper Cohansey River Watershed, the need for water quality improvement is reinforced in this project. As a result, it appears that the predicted loading rates are satisfactory for our purposes.

Under existing conditions, the subbasins that produced the largest TP loads were C4 and C2 in 2005 and C4 and C1 in 2006 (Table 2). When normalized by area, the largest loading occurred in subbasins C2 and C6 in both 2005 and 2006 (Table 2).

Table 2: Subbasin Total Phosphorus Loadings

	Total Phosphorus (kg)		Total Phosphorus (kg/acre)	
Subbasin	**2005**	**2006**	**2005**	**2006**
CL1	434.81	235.11	1.83	0.99
CL2	524.32	315.50	1.70	1.02
C6	1,158.43	620.00	2.29	1.23
C5	775.68	388.02	1.60	0.80
C4	2,963.97	1,189.39	1.84	0.74
C3	715.10	276.66	1.28	0.50
HR1	258.02	130.90	0.54	0.27
FR1	943.79	637.22	0.81	0.55
C2	1,998.55	789.30	3.12	1.23
C1	1,492.74	887.90	2.03	1.21
Watershed Total	11,265.40	5,470.00	1.70	0.85

The predicted loading rates were calculated to provide a baseline so as to gauge the effectiveness of the four mitigation scenarios tested in this modeling effort. The four scenarios built into the model are the following:

1. 15-meter filter strips around all agricultural land identified as growing row crops.
2. Bio-retention ponds that receive 80% of the runoff from subbasins C4 and C2.
3. Constructed wetlands that receive 80% of the runoff from subbasins C4 and C2.
4. Removal of those HRUs that represent the largest sources of total phosphorus (TP) via a BMP that will result in runoff water quality and quantity equal to that of an established forest system.

All scenarios were run for 2005 and 2006 using appropriate data.

Scenario 1. 15-Meter Vegetated Filter Strip Surrounding all Row Crop Agricultural Land Uses

The first scenario was run for the same time period under the same conditions as the baseline, with the exception that each of the row crop agricultural land uses (27 km^2) throughout the watershed were surrounded by a 15-meter vegetated filter strip. SWAT removes TP from runoff as it flows through the filter strip. The efficiency of the filter strip to remove nutrients is 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 was 8,981 kg in 2005 and 4,352 kg in 2006, which corresponds to reductions of 80% for both years (Table 3). The use of 15m vegetated filter strips around all row crop agricultural land uses was predicted to have the greatest mitigation effect at the watershed outlet with approximately 80% removal.

Table 3: Subbasin Total Phosphorus Reductions from Filter Strips

	Total Phosphorus (kg)		Total Phosphorus with Filter Strips (kg)		Percent Reduction	
Subbasin	**2005**	**2006**	**2005**	**2006**	**2005**	**2006**
CL1	434.8	235.1	82.0	43.4	81.2%	81.5%
CL2	524.3	315.5	109.3	63.9	79.2%	79.8%
C6	1,158.4	620.0	210.8	113.1	81.8%	81.8%
C5	775.7	388.0	145.6	72.8	81.2%	81.2%
C4	2,964.0	1,189.4	617.0	264.0	79.2%	77.8%
C3	715.1	276.7	173.5	71.6	75.7%	74.1%
HR1	258.0	130.9	89.0	39.6	65.5%	69.8%
FR1	943.8	637.2	189.5	125.8	79.9%	80.3%
C2	1,998.6	789.3	376.5	150.5	81.2%	80.9%
C1	1,492.7	887.9	290.9	172.8	80.5%	80.5%
Watershed Total	11,265.4	5,470.0	2,284.0	1,117.5	79.7%	79.6%

This mitigation strategy would require a collaborative effort by the entire agricultural community in the watershed. It is important to note, however, that since the effect of installing these filter strips is cumulative, and each individual installation will have some positive effect on water quality.

Scenario 2. Installation of Bioretention Basins to collect 80% of Subbasin Drainage

The second mitigation strategy was to address the two subbasins that represent the largest loads of TP to the system. These are identified as subbasins C4 and C2, primarily due to their relatively larger catchment areas (Figure 1). Subbasin C2 produced the second largest load in 2005, according to the model, and the third largest load in 2006 (Table 2). It was decided that analysis of this subbasin would be more useful than subbasin C1 because C2 is technically a headwater stream, while C1 is a downstream subbasin similar to C4 (Figure 1). The bioretention basins are configured to receive runoff from 80% of each subbasin. These bioretention basins were designed according to guidelines established in the NJDEP BMP Manual (NJDEP, 2004). The total volume of runoff was calculated as the volume of water produced by a New Jersey water quality storm (1.25 inches) by multiplying each subwatershed area by 1.25 inches. This volume was reduced by 80% in SWAT to represent to simulate bioretention system reductions in each of the target subwatersheds (C2 and C4). The reduced runoff is used in the Modified Universal Soil Loss Equation (MUSLE; Arabi *et al.*, 2008):

$$S = 11.8 \times (Q \times q \times A)^{0.56} \times K \times C \times P \times LS \times F$$

where, S = sheet erosion (metric tons)
Q = surface runoff volume (millimeters)
q = peak runoff rate (m^3/s)
A = area (hectares)
K = USLE erodibility factor
C = USLE cover and management factor
P = USLE support practice
LS = USLE topographic factor, and
F = coarse fragment factor

This has the effect of reducing sediment loads, and associated nutrients (i.e., TP) attached to said particles, to the waterways.

Since the volume calculated is the volume from precipitation and not from runoff proper, estimates of runoff may be higher due to the lack of inclusion of infiltration and evaporation losses. Thus, the basin design being modeled is conservative. The model was run for the same interval as the existing conditions (2005 and 2006) to allow comparison to the model's existing conditions (Table 2).

The predicted removal efficiencies are excellent for subbasins C4 and C2 (Table 4). The overall effect on the total watershed load for the entire Upper Cohansey River Watershed is a TP reduction of 36% in 2005 and 30% in 2006 (Table 4). The calculated removal rates for the modeled bioretention systems are higher than the 60% predicted in the NJDEP BMP manual for the individual subbasins (NJDEP, 2004). This is presumably due to the fact that the system was designed to hold a larger volume than the water quality storm. As a result, the system is oversized, and the predicted removal efficiencies appear to be high.

Table 4: Total Phosphorus Reductions from Bioretention Basins

	Total Phosphorus (kg)		Total Phosphorus with Bioretention Basins (kg)		Percent Removal	
Subbasin	2005	2006	2005	2006	2005	2006
C4	2,964.0	1,189.4	426.3	176.0	85.6%	85.2%
C2	1,998.6	789.3	419.8	155.9	79.0%	80.3%
Watershed Total	11,265.4	5,470.0	7,146.6	3,822.6	36.6%	30.1%

Scenario 3. Installation of Constructed Wetlands to Collect 80% of Subbasin Drainage

The third mitigation strategy used constructed wetlands to treat the runoff from 80% of subbasins C4 and C2. Similar to Scenario 2, the constructed wetlands were designed to exist as very small pooled areas under normal conditions and fill to capacity during the water quality storm, retaining the full volume of water.

The results of this analysis show that wetlands are predicted to be an effective method of phosphorus removal, only slightly lower than the bioretention system (Table 4; Table 5). The predicted removal rates for subbasins C4 and C2 are higher than the 50% predicted in the BMP manual (NJDEP, 2004). Similar to the bioretention system, this is presumably due to the fact that the system is designed conservatively and holds a greater volume than called for in the manual.

Table 5: Total Phosphorus Reductions from Constructed Wetlands

	Total Phosphorus (kg)		Total Phosphorus with constructed wetland (kg)		Percent Removal	
Subbasin	2005	2006	2005	2006	2005	2006
C4	2,964.0	1,189.4	589.7	263.7	80.1%	77.8%
C2	1,998.6	789.3	492.1	202.8	75.4%	74.3%
Watershed Total	11,265.4	5,470.0	7,383.2	3,958.9	34.5%	27.6%

Scenario 4. Installation of BMPs to Address Runoff from Specific HRUs

The fourth nutrient mitigation scenario involved installation of BMPs that would result in water quality and quantity of runoff from a specific HRU that is equal to that from an established forest area. The first step in this analysis was to determine "hotspots" where HRUs which produced the highest load of phosphorus in runoff were located. This was accomplished by examining the yearly phosphorus loads predicted for each HRU for existing conditions. The highest loads were from a row crop agricultural HRU in subbasin C3 in 2005 and a row crop agricultural HRU in subbasin C1 in 2006 (Figure 8). The predicted loads from these HRUs were 663 kg and 509 kg, respectively. To predict the effect of a highly efficient BMP, the conditions in these HRUs were adjusted to conditions which approximate an established forest system. This was accomplished by changing the runoff coefficients for these areas from those for agricultural areas to those of forested/natural land uses. The BMP that could be used this effectively is not specified, only its effects. The resulting loads from the HRUs were 60 kg and 75 kg, respectively, for the periods of concern. The effects that these had on subbasin and watershed-wide TP loads were also examined.

As with the other modeled scenarios, the effects of the BMPs were simulated for both 2005 and 2006. The BMPs installed in C3 were predicted to remove 92% and 89% of the phosphorus load, while the BMPs installed in C1 were predicted to remove 63% and 57%. The overall effect of just these two BMP systems was an overall reduction in the phosphorus load of 15% in 2005 and 16% in 2006 in the entire Upper Cohansey River Watershed.

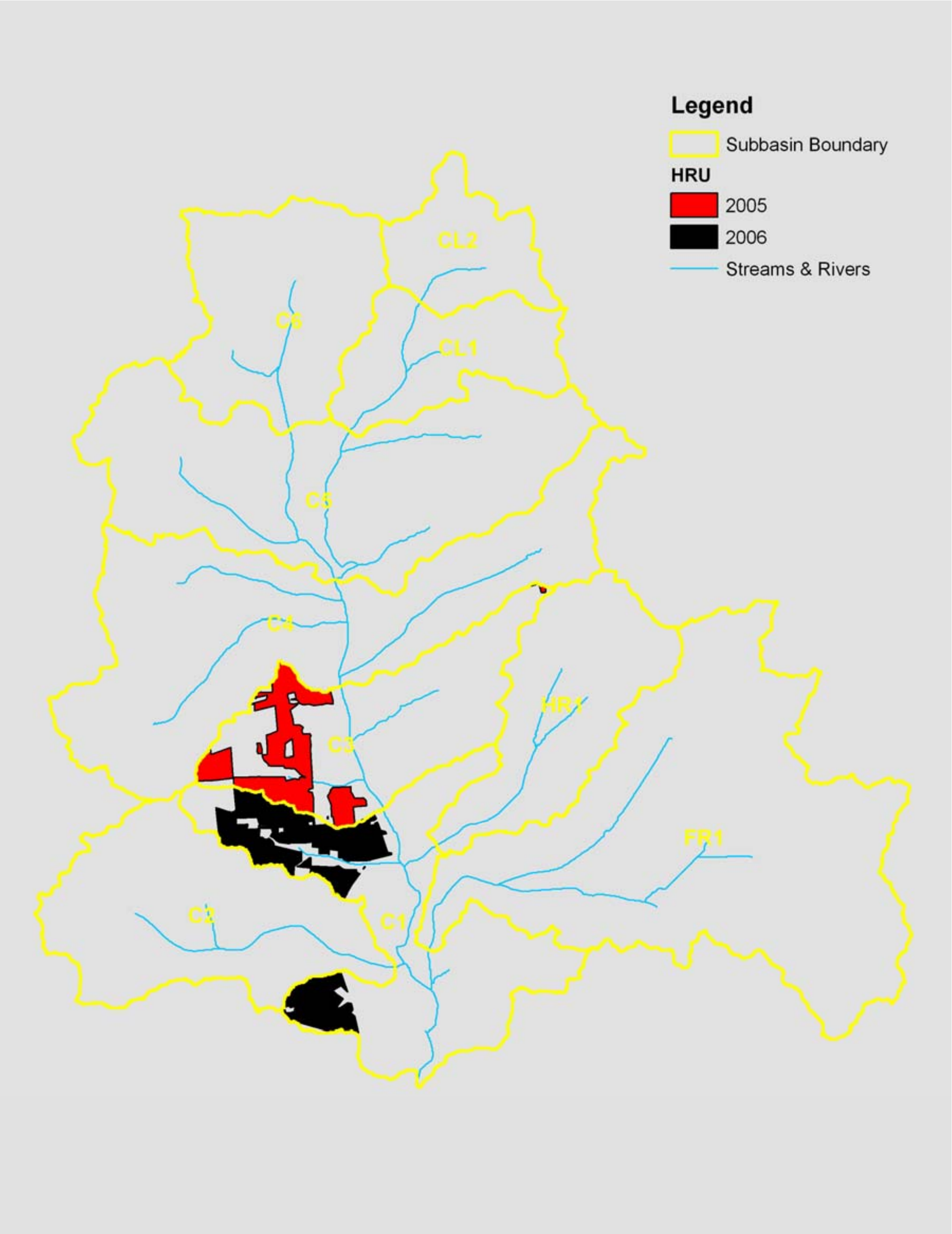

Figure 8: HRU "hotspot" locations used in BMP Scenario 4.

Conclusions

The SWAT model that was created to simulate the conditions present in the Upper Cohansey River Watershed was shown to reasonably predict water flow 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 TMDL, vast improvements in water quality could be achieved if implemented. The use of 15m vegetated filter strips around all row crop agricultural land uses was predicted to have the greatest mitigation effect at the watershed outlet with approximately 80% removal. However, this strategy requires the greatest investment of land and financial resources on a watershed scale. The installation of bioretention basins or constructed wetlands in subbasins C2 and C4 was tested and found to be very successful at removing large amounts of nutrients. However, there is a certain amount of difficulty involved in the implementation of this method. The method assumes 80% of runoff is captured but it may be difficult to locate bioretention basins or wetlands to capture 80% of runoff. This may involve construction of many smaller systems that could prove costly. Therefore, this BMP strategy may be extremely difficult to implement and replicate the result simulated in the model.

Identification of two hotspot HRUs that represent the two largest individual sources of overall phosphorus loading indicates that a more targeted approach could be successful in implementing BMPs. Restoration of these HRUs would not in itself achieve the TMDL goal, but removals of 15% and 16% with installation of only two BMPs suggests that targeting hotspots would be effective as a strategy. This method also has the added benefit of being highly efficient in terms of land and financial resources and may expedite implementation towards TMDL achievement in this watershed.

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Appendix A. STATSGO Soil Parameters

MUID	NLAYERS	HYDGRP	SOL_ZMX	ANION_EXCL	SOL_CRK	TEXTURE
NJ025	3	B	1574.80	0.500	0.500	L
NJ027	3	C	1524.00	0.500	0.500	SL-SL-GR--S
NJ039	4	B	1574.80	0.500	0.500	Loamy Sand

MUID	SOL_Z1	SOL_BD1	SOL_AWC1	SOL_K1	SOL_CBN1	CLAY1	SILT1	SAND1	ROCK1	SOL_ALB1	USLE_K1	SOL_EC1
NJ025	203.00	1.10	0.15	83.32	3.30	14.00	50.00	36.00	0.00	0.00	0.43	0.00
NJ027	254.00	1.13	0.15	97.00	2.62	12.50	19.65	67.85	3.33	0.01	0.28	0.00
NJ039	457.00	1.40	0.07	330.20	2.80	6.00	50.00	44.00	0.00	0.00	0.20	0.00

MUID	SOL_Z2	SOL_BD2	SOL_AWC2	SOL_K2	SOL_CBN2	CLAY2	SILT2	SAND2	ROCK2	SOL_ALB2	USLE_K2	SOL_EC2
NJ025	1499.00	1.60	0.11	78.74	1.80	25.00	40.00	35.00	0.00	0.00	0.20	0.00
NJ027	711.20	1.42	0.11	27.00	0.87	17.50	15.28	67.22	5.64	0.04	0.24	0.00
NJ039	762.00	1.55	0.70	101.60	2.50	6.00	50.00	44.00	2.00	0.01	0.32	1.00

MUID	SOL_Z3	SOL_BD3	SOL_AWC3	SOL_K3	SOL_CBN3	CLAY3	SILT3	SAND3	ROCK3	SOL_ALB3	USLE_K3	SOL_EC3
NJ025	1839.00	1.55	0.08	256.54	1.80	18.00	30.00	52.00	0.00	0.00	0.20	0.00
NJ027	1524.00	1.48	0.06	80.00	0.29	9.50	0.75	89.75	13.91	0.13	0.28	0.00
NJ039	1016.00	1.58	0.05	330.20	0.05	4.00	52.00	44.00	3.00	0.01	0.20	1.00

MUID	SOL_Z4	SOL_BD4	SOL_AWC4	SOL_K4	SOL_CBN4	CLAY4	SILT4	SAND4	ROCK4	SOL_ALB4	USLE_K4	SOL_EC4
NJ025	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NJ027	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NJ039	1524.00	1.58	0.09	261.62	2.50	14.00	44.00	42.00	4.00	0.01	0.20	1.00

Parameter	**Definition**
MUID:	Soil type name
NLAYERS	Number of soil layers in soil type. Layer is indicated by number after parameter name.
HYDGRP	Soil hydrologic group (A, B, C, or D). This variable is required only by the SWAT ArcView interface. The U.S. Natural Resource Conservation Service (NRCS) classifies soils into four hydrologic groups based on infiltration characteristics of the soils. NRCS defines a hydrologic group as a group of soils having similar runoff potential under similar storm and cover conditions.
SOL_ZMX	Maximum rooting depth of soil profile (mm). If no depth is specified, the model assumes the roots can develop throughout the entire depth of the soil profile.
ANION_EXCL	Fraction of porosity (void space) from which anions are excluded.
TEXTURE	Texture of soil layer.
SOL_AWC(layer #)	Available water capacity of the soil layer (mm H_2O/mmsoil).
SOL_K(layer #)	Saturated hydraulic conductivity (mm/hr).
SOL_CBN(layer #)	Organic carbon content (% soil weight).
CLAY(layer #)	Clay content (% soil weight).
SILT(layer #)	Silt content (% soil weight).
SAND(layer #)	Sand content (% soil weight).
ROCK(layer #)	Rock fragment content (% total weight).
SOL_ALB(layer #)	Moist soil albedo.
USLE_K(layer #)	USLE equation soil erodibility (K) factor (units: 0.013 (metric ton m_2 hr)/(m_3-metric ton cm)). Some soils erode more easily than others even when all other factors are the same. This difference is termed soil erodibility and is caused by the properties of the soil itself.
SOL_EC(layer #)	Electrical conductivity (dS/m).