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The Assiscunk Creek Watershed Restoration and Protection Plan: Model Report

Developed by the Rutgers Cooperative Extension Water Resources Program

Funded by the Burlington County Board of Chosen Freeholders
and the
NJDEP 319(h) Program
Grant Identifier: RP07-071
January 2011

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Model Overview

A numerical model of the Assiscunk Creek 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 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 subbasins, 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 subbasin area and are not identified spatially within a SWAT simulation. Alternatively, a watershed can be subdivided into only subbasins 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 systems (GIS) website (http://www.nj.gov/dep/gis/). Data layers for topography, 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 municipal officials, the Burlington County Department of Resource Conservation and the South Jersey Resource Conservation and Development Council (SJRC&D).

The watershed boundary used for The Assiscunk Creek Watershed Restoration and Protection Plan was subdivided into two modeled watersheds that have different outlets. One watershed is delineated as the "Assiscunk Creek" and includes the ASK1, ASK2, ANR and ASK3 subbasins. The outlet to this watershed is just downstream of Petticoat Bridge Road. The other watershed is the Upper Barkers Brook, which includes subbasins BB1 and BB2, and whose outlet is just upstream of Arneys Mount and

Monmouth Road. The outlet of each subbasin is a sampling location for the water quality monitoring portion of this project (Figure 1). ArcSWAT was then used to create 106 Hydrologic Response Units (HRUs) for the Assiscunk Creek Watershed and 46 HRUs for the Barkers Brook Watershed; each of these corresponds to a unique subbasin created by combining land use, soils and elevation 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 had been calibrated, the characteristics of these HRUs were manipulated to predict the effects of best management practices (BMPs).

Calibration of the model was completed by comparing flow rates predicted by the model at the outlet of the Assiscunk Creek Watershed (Figure 1) to flow rates determined from the surface water elevation at the outlet and a rating curve. The Water Resources Program created a rating curve from flow measurements taken during water quality sampling and surface water elevation measurements taken from pressure transducer installed at ASK3. The model was calibrated on a daily time scale for 122 days (May 23, 2008 through September 22, 2008). The fit of the model was determined via the Nash-Sutcliffe Efficiency Coefficient (NSE) (Nash and Sutcliffe, 1970). For the calibration period, the NSE values were calculated as 0.251. This indicated a satisfactory model performance (Parajuli *et al.* 2009). Flow data was not available to calibrate the Barkers Brook model. Adjustments were made to the model parameter of the Barkers Brook model to correspond to similar alterations made in the Assiscunk Creek model.

Once the existing conditions were successfully simulated via the calibrated model, three 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 phosphorus and bacteria. 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 Agriculture and Pasture.
2. Bioretention that receives 80% of the runoff from each of the subbasins.
3. Conversion of all the land uses designated “Agricultural Wetlands”, which currently are simulated as agricultural cropland in the model, into wetlands.

The pollutant removal capability and the effect on downstream phosphorus and bacteria concentrations were theoretically examined in the model using these three scenarios to evaluate the relative efficiency of the proposed BMPs.

Model Development

Input data for the model were obtained from several sources. Data layers for topography, soils, land cover/land use, and elevation were downloaded from the NJDEP's GIS website (http://www.nj.gov/dep/gis/). Supplemental input data were collected via site visits and input from the Burlington County Department of Resource Conservation and the South Jersey Resource Conservation and Development Council (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 subbasin boundaries. These topographic characteristics were calculated from NJDEP 10-meter Digital Elevation Model (DEM) raster data. The Assiscunk Watershed has an area of 28.85 km^2 (11.14 mi^2) and the Barkers Brook Watershed has an area of 8.89 km^2 (3.433 mi^2) for a total modeled area of 37.74 km^2 and 14.573 mi^2. The elevation ranges from 65.23 meters (214 ft) above sea level in the headwater area down to 7.01 meters (23 ft) above sea level at the outlet of the watershed (Figure 1). This decrease in elevation occurs over the course of seven river miles.

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, NJ028, NJ029, and NJ033. NJ028 and NJ029 are present throughout the watershed, while NJ033 is only present in the east (Figure 2). The relative distribution of these soils and related characteristics are listed Table 1.

Table 1: Soil Type Distribution (STATSGO)

Soil ID	% of ASK Watershed	% of BB Watershed	Sand %	Silt%	Clay%	Rockvol%	Dominant Texture
NJ028	52.7%	11.2%	58-56	30-28	12-16	2-4	Sandy Loam
NJ029	42.0%	52.0%	61-56	29-33	10-11	2-3	Sandy Loam
NJ033	5.4%	36.9%	63-53	26-17	11-29	3-3	Sandy Loam to Sandy Clay

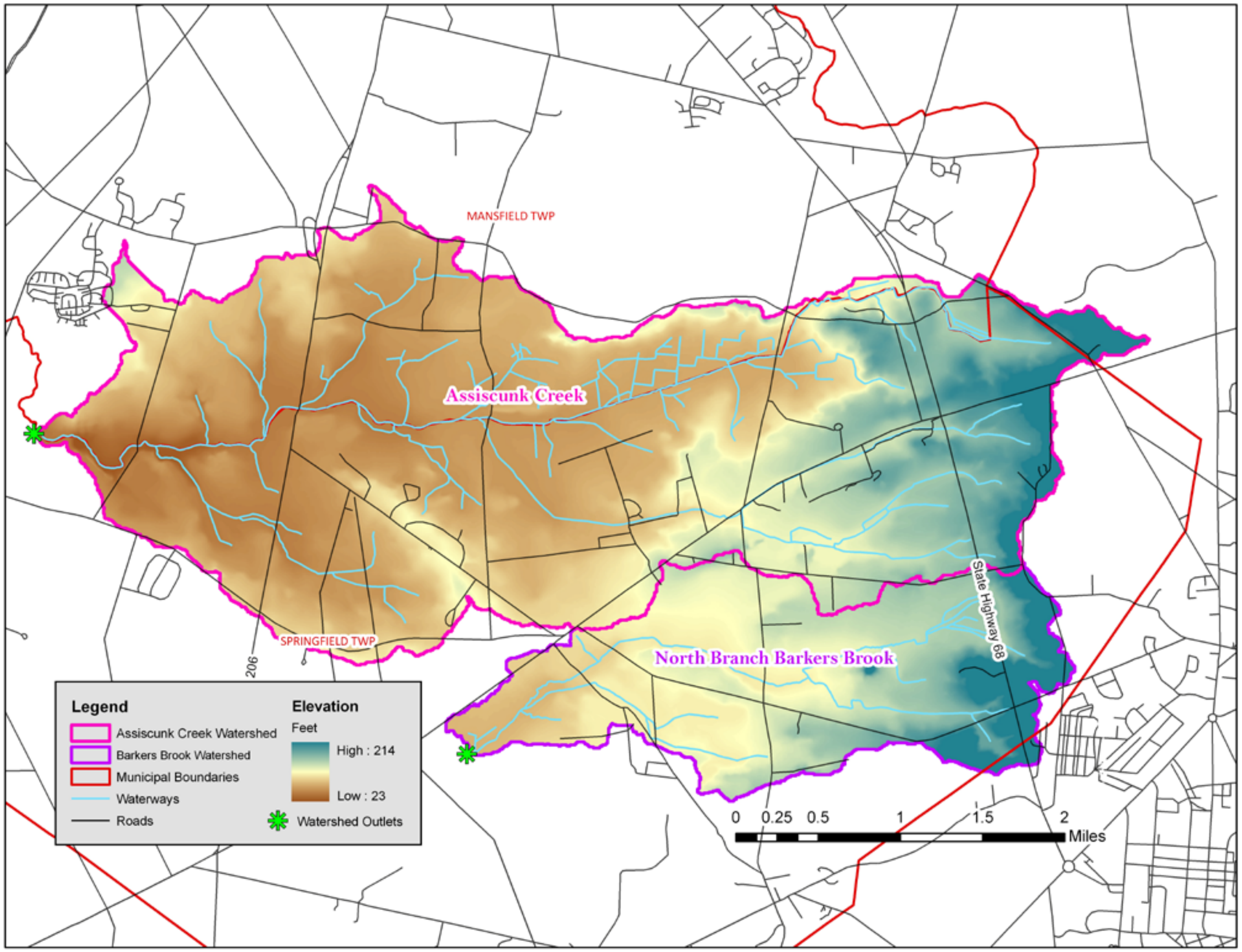

Figure 1: Model Subbasins on the NJ 10-meter Digital Elevation Map

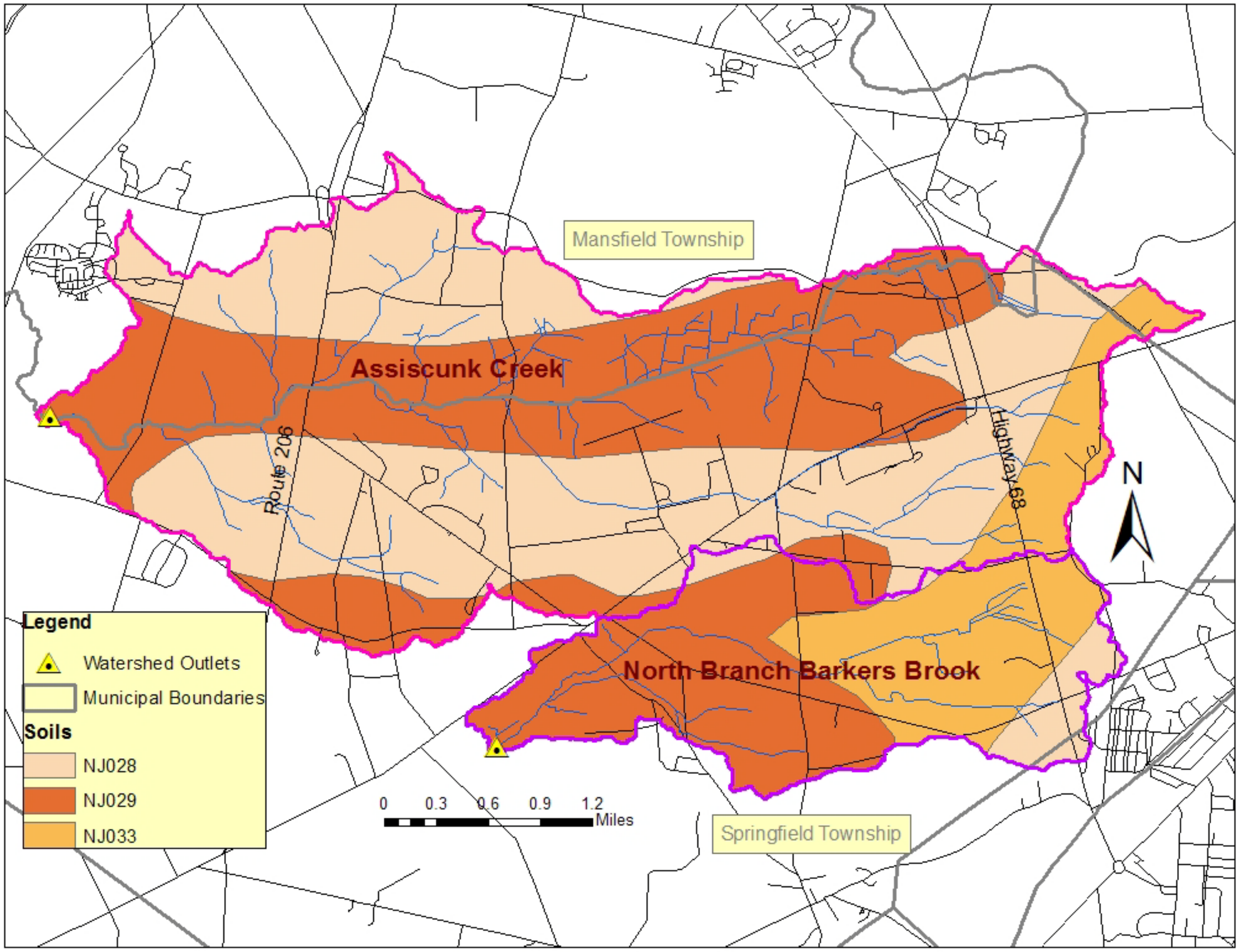

Figure 2: Assiscunk Creek Watershed Soils

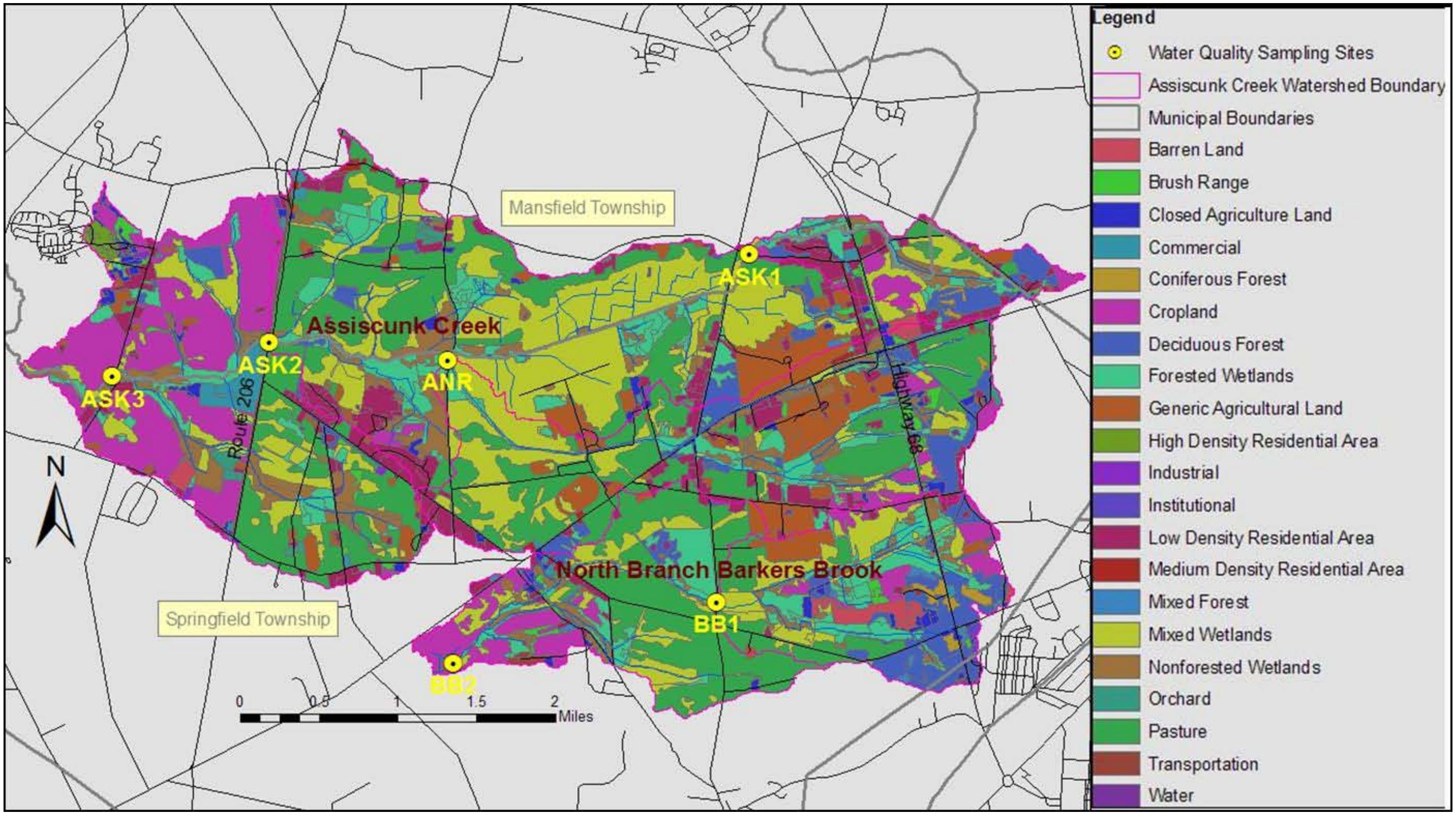

Figure 3: SWAT Land Uses for the Assiscunk Creek Watershed

The NJDEP 2002 land use/land cover GIS layer was utilized to initially characterize the land uses in the watershed (Figure 3, Table 2). However, the land use labels given in this state layer did not provide a complete description of the agricultural land use definitions within the SWAT framework. Therefore, the Water Resources Program obtained the most recent farmland assessments provided by the Burlington County Department of Resource Conservation applications to provide additional details of the land use that is required for input to the SWAT model.

Table 2: Landuse for SWAT modeling efforts

Landuses	Assicunk Watershed (% of total area)	Barkers Brook Watershed (% of total area)
Agricultural Land-Close-grown	1.3	n/a
Agricultural Land-Generic	7.25	6.7
Southwestern US (Arid) Range	0.4	n/a
Commercial	1.2	n/a
Forest-Evergreen	0.2	n/a
Agricultural Land-Row Crops	33.5	11.9
Forest-Deciduous	4.6	3.4
Industrial	0.1	n/a
Forest-Mixed	0.2	n/a
Orchard	0.5	n/a
Pasture	22.4	24.9
Range-Brush	1.1	n/a
Residential-High Density	0.3	n/a
Residential-Low Density	8.9	9.9
Residential-Medium Density	0.2	n/a
Transportation	0.3	n/a
Water	0.1	n/a
Wetlands-Non-Forested	7.0	31.9
Wetlands-Forested	10.2	11.3
Wetlands-Mixed	0.1	n/a

Once the subbasins, soil types, and land uses were determined, HRUs were delineated within SWAT. Each HRU represents an individual drainage area, soil type, and land use. An HRU represents the finest detail available for the model output. In this effort, the 28.85 km^2 (11.14 mi^2) Assiscunk Creek Watershed was divided into 106 HRUs and the 8.89 km^2 (3.43mi^2) Barkers Brook Watershed was separated into 46 HRUs.

The rainfall records acquired from the Mansfield weather station within the SJRC&D weather system network (http://www.sjrcd.org/rise/) provided the rainfall data used in the calibration process.

Model Calibration

The model used to assess the Assiscunk Creek Watershed was calibrated to flow measurements collected for a portion of the calendar year 2008. The calibration was completed using methods as described in the SWAT manual (Neitsch *et al.*, 2002). This process involves preparing a model simulation and comparing resulting flow output ("predicted data") with flow data collected in the field ("observed data"). The closer this output data is to these field measurements, the closer the model is to representing the actual system. If model output values did not adequately match observed data, empirical parameters within the model were adjusted and simulations were run again.

Stream flow data was determined using the surface water elevations that were collected by pressure transducer over a period of fifteen months. A rating curve relating the water surface elevation to the flow at the outlet was developed using flow measurements and water surface elevation collected over a range of flows. This rating curve provided a correlation between the elevation data collected at ASK3 and measured flow data taken on water quality sampling days. The rating curve was found to have a correlation represented by an r-squared value of 0.78 (See Figure 4). This rating curve allowed for the development of a flow record at ASK3 based on the elevations collected by the pressure transducer. This created a continuous flow record that was then used to compare to model predictions of flow.

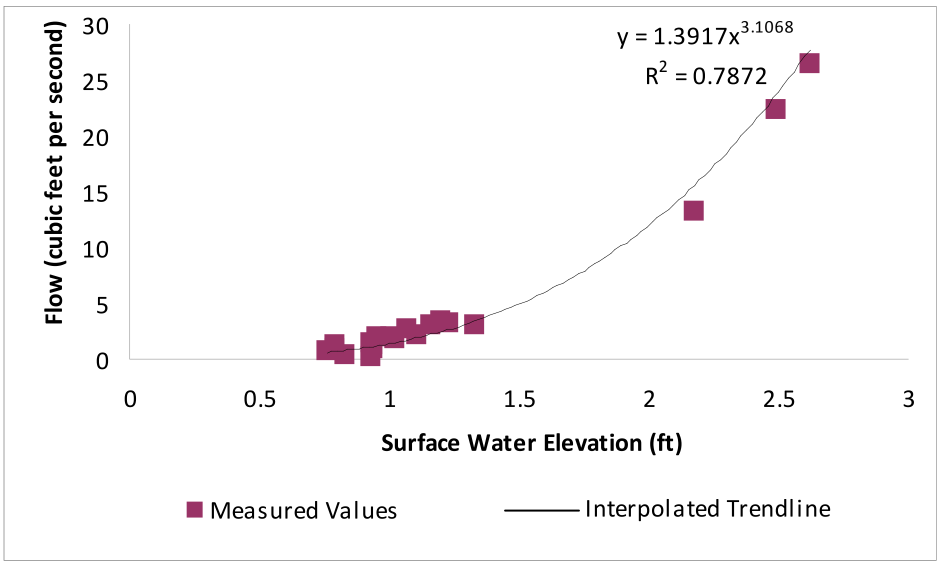

Figure 4: Rating Curve at ASK3

Flow calibration was conducted on a daily scale for 122 days. The procedure involved comparing the predicted average daily flow to the measured flow calculated using the rating curve analysis. Model parameters were modified to optimize the model simulation results and reduce the difference between predicted and measured values. The parameters modified during the calibration process included the delay time of groundwater exiting the soil profile into the shallow aquifer, the SCS runoff curve number, and the soil erosion compensation factor. The curve number is a determinant of the amount of runoff that is generated from each land area during a storm event. The soil erosion compensation factor allows the user to modify the depth distribution used to meet the soil evaporative demand.

The Nash-Sutcliffe Efficiency (*E*) statistic was used to determine how well the predicted daily flow values correspond to the measured flow. This value is 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.

Values calculated for *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 mean (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.

The Nash Sutcliffe coefficient (*E*) for the calibration period (May 23 – September 23, 2008) was calculated to be 0.25 (Figure 5). Since this stream is an ungauged stream, the data from the pressure transducer placed by RCE Water Resources Program was the sole source of data used to calibrate.

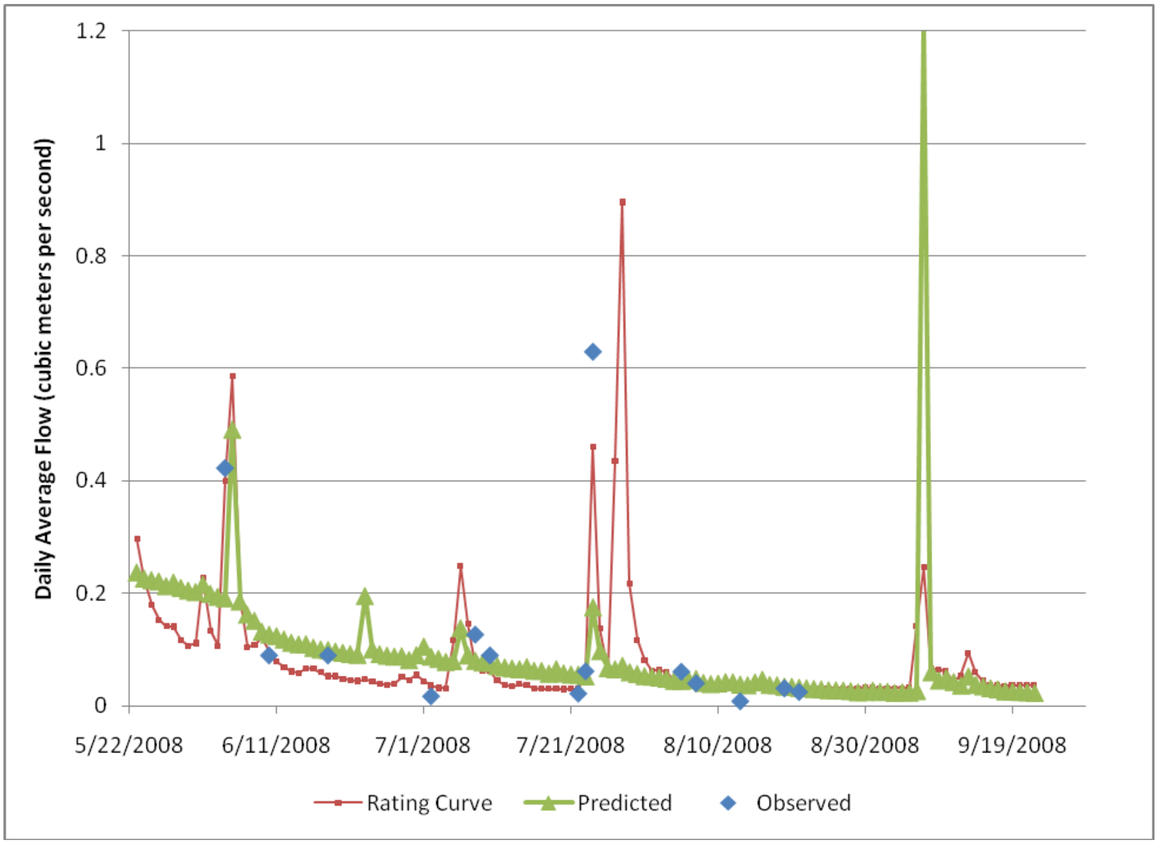

Figure 5: Rating Curve Flow Predictions, Model Flow Predictions and Flow Measurements

The model was not calibrated for phosphorus and bacteria due to the inherent inaccuracy that would be present from the undocumented spatial distribution of bacterial sources including wildlife, manure application, and farm animal location. This tool will therefore be used as a means to compare the relative effects of current practices and land uses and the potential benefit that BMPs could make on water quality and discharge.

Mitigation Scenarios

The precipitation events for 2008 were used in the hydrologically calibrated SWAT model to simulate a full year of total phosphorus (TP) and bacteria loading from the six delineated subbasins. This total load was normalized by the subbasin area to compare subbasin loading rates per acre (Table 3).

Table 3: Modeled Loading: Phosphorus and Bacteria

		Predicted Subbasin Loading		Predicted Load Normalized by Subbasin Area	
Subbasin	Area (acres)	Phosphorus (kg/yr)	Bacteria (org/yr)	Phosphorus (kg/acre/yr)	Bacteria (org/acre/yr)
ASK1	473.1	674.4	3.21E+06	1.26E-01	6.00E+02
ASK2	2120.5	3108	9.00E+13	5.81E-01	1.68E+10
ASK3	2465.0	4503	8.98E+13	8.41E-01	1.68E+10
ANR	1929.9	1562	1.65E+07	2.92E-01	3.08E+03
BB1	1034.6	716	1.47E+13	5.84E-02	1.20E+09
BB2	1074.9	934	1.52E+13	8.20E-02	1.33E+09
Totals		11497.4	2.10E+14	0.11	2.09E+09

This simulation provided loading rates representative of existing conditions. These loads and loading rates will provide a baseline to compare the effectiveness of the three mitigation scenarios prepared for this modeling effort. The best management practice scenarios represented in three model simulations consisted of the following information:

1. Installation of 15-meter filter strips around all agricultural land identified as growing row crops.
2. Installation of bioretention ponds that will receive 80% of the runoff from each of the subbasins.
3. Conversion of all the lands currently assigned the land use designation of "agricultural wetlands" to natural wetlands

All scenarios were simulated using the 2008 precipitation data set.

Scenario 1: Installation of 15-Meter Vegetated Filter Strip Surrounding all Row Crop Agricultural Land Uses

The first scenario simulated the same time period under the same conditions as the baseline, with the exception that each of the agricultural land uses (31.57 km^2) throughout the watershed was 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 trapping efficiency of the filter strip for bacteria is also a function of filter width (Moore et al., 1988):

$$trap_{ef\_bact} = \frac{12 + 4.5 * FILTERW}{100}$$

Where $trap_{ef\_bact}$= trapping efficiency of bacteria.

The amount of TP and bacteria removed via this mitigation strategy was 3076 kg/yr and 7.20E+13 org/yr, which corresponds to reductions of 68% and 80% respectively (Table 4).

Table 4: Modeled Removal by Filter Strips

	Phosphorus			Bacteria		
Watershed	**Baseline Prediction (kg/yr)**	**Load Prediction with Filter Strips (kg/yr)**	**Percent Reduction**	**Baseline Prediction (org/yr)**	**Load Prediction with Filter Strips (org/yr)**	**Percent Reduction**
Assiscunk (Outlet)	4503	1427	68%	9.00E+13	1.80E+13	80%
Barkers Brook (Outlet)	934	446	52%	1.50E+13	3.10E+12	80%

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

The second mitigation strategy was to address the three subbasins that represent the largest loads of total phosphorus and bacteria to the system. These are identified as subbasins ANR, ASK2 and BB2 (refer to Figure 1). The bioretention basins are configured to receive runoff from either 80% of total land area or 80% of agricultural land use in each subbasin. These bioretention basins were designed according to guidelines established in the NJDEP BMP Manual (NJDEP, 2004).

Using the baseline predicted loading calculated within the SWAT model, a bioretention conservative pollutant removal rate of 60% was applied within the three subbasins. Available data for the removal of total suspended solids, an indicator of pollutant removal, suggests a removal rate of 80-90% depending on the depth of the planting bed. Other studies suggest a 70-83% removal of total phosphorus from the use of bioretention (Bitter, 1994) and a 90% removal for bacteria (Davis, 1998, Rusciano and Obropta, 2007). Results of these modeled simulations are reported in Table 5.

80% of runoff from all land use treated with bioretention						
	Phosphorus			Bacteria		
Subbasin	Baseline Prediction (kg/yr)	Load Prediction with Bioretention	Percent Reduction	Baseline Prediction(org/yr)	Load Prediction with Bioretention	Percent Reduction
ASK1	674.4	350.7	48%	3.21E+06	1.67E+06	48%
ASK2	3108.0	1616.2	48%	9.00E+13	4.68E+13	48%
ASK3	4503.0	2341.6	48%	8.98E+13	4.67E+13	48%
ANR	1562.0	812.2	48%	1.65E+07	8.58E+06	48%
BB1	716.0	372.3	48%	1.47E+13	7.64E+12	48%
BB2	934.0	485.7	48%	1.52E+13	7.86E+12	48%
Total	***11497.4***	***5978.6***	***48%***	***2.10E+14***	***1.09E+14***	***48%***
80% of agricultural and pasture land use treated with bioretention						
	Phosphorus			Bacteria		
Subbasin	Baseline Prediction (kg/yr)	Load Prediction with Bioretention	Percent Reduction	Baseline Prediction(org/yr)	Load Prediction with Bioretention	Percent Reduction
ASK1	674.4	450.9	33.1%	3.21E+06	2.39E+06	25.6%
ASK2	3108.0	2158.6	30.5%	9.00E+13	6.53E+13	27.4%
ASK3	4503.0	2973.1	34.0%	8.98E+13	6.52E+13	27.4%
ANR	1562.0	1099.4	29.6%	1.65E+07	1.23E+07	25.6%
BB1	716.0	398.9	44.3%	1.47E+13	8.77E+12	40.3%
BB2	934.0	558.4	40.2%	1.52E+13	9.53E+12	37.3%
Total	***11497.4***	***7639.3***	***33.5%***	***2.10E+14***	***1.49E+14***	***29.0%***

Table 5: Modeled Removal by Bioretention

When bioretention implementation was applied as a simulation to manage the stormwater runoff from 80% of all land uses within the subbasins, the pollutant load reduction to the predicted baseline values were 52% across the board. When the bioretention implementation was focused strictly on the agricultural land uses within the subbasins, larger reductions of both phosphorus (56-70%) and bacteria (60-75%) were predicted.

Scenario 3: Conversion of Agricultural Wetlands to Wetlands

The third nutrient mitigation scenario involved the conversion of all the land in the watershed that is currently classified as “agricultural wetlands” to a mixed (forest/shrub) wetland. During the calibration of the watershed models, the land use named “agricultural wetlands” were simulated as cropland because that is the current use.

The acreage of the “agricultural wetlands” was determined from the NJDEP 2002 land use layer. This acreage was deducted proportionately from the agricultural input to the original baseline simulations (corn, pasture and hay crops) and added to the acreage of simulated wetlands. The loading was then recalculated by using the appropriate loading coefficients determined from the baseline scenario.

Under this strategy, the simulated pollutant loads were reduced in all subbasins for both total phosphorus and bacteria (Table 6). Phosphorus reductions ranged from 8.7% in ASK3 (the outlet of the Assiscunk Creek Watershed) to 72.5% in ASK2 (the subbasin immediately upgradient of ASK3). This was a factor of the larger area within subbasin ASK2 that was originally designated "ag wetlands" in the land use layer.

Table 6: Modeled Removal from Wetland Alternative Landuse

		Phosphorus			Bacteria		
Subbasin	"Ag Wetlands" area converted (acres)	Baseline Prediction (kg/yr)	Prediction with conversion from ag wetlands to forest/shrub wetlands (kg/yr)	% reduction	Baseline Prediction (org/yr)	Prediction with conversion from ag wetlands to forest/shrub wetlands (org/yr)	% reduction
ASK1	66.15	674.4	558.3	17.2%	3.21E+06	2.60E+06	19.0%
ASK2	921.43	3108.0	854.7	72.5%	9.00E+13	2.44E+13	72.9%
ASK3	225.84	4503.0	4110.6	8.7%	8.98E+13	8.31E+13	7.4%
ANR	346.22	1562.0	1294.2	17.1%	1.65E+07	1.34E+07	18.6%
BB1	152.62	716.0	420.8	41.2%	1.47E+13	9.37E+12	36.2%
BB2	164.95	934.0	808.2	13.5%	1.52E+13	1.39E+13	8.4%
Total	***1877.21***	***11497.4***	***8046.7***	***30.0%***	***2.10E+14***	***1.31E+14***	***37.6%***

Results and Conclusions

The SWAT model that was created to simulate the conditions present in the Assiscunk Creek Watershed was shown to reasonably predict water flow characteristics. As a result, the predictions regarding the effectiveness of mitigation strategies can offer an indicator of the changes that may be expected with implementation.

An analysis of the percent reduction of the pollutant loading was performed for the outlets of the two watersheds modeled (Table 7). It can be seen that a simulated reduction in total phosphorus and bacteria was achieved in all three mitigation strategies. The extent of the reduction of phosphorus was similar in the filter strip scenario and the bioretention scenario. The agricultural wetland conversion was simulated as providing a much lower percent reduction when compared to the first two strategies.

The highest percent reduction of simulated bacteria loading to the outlets of the watersheds was achieved with the installation of filter strips, with the bioretention scenario following with slightly lower removal efficiencies. The conversion of agricultural wetlands to natural wetlands did provide pollutant loading reduction, but at a significantly lower level than the first two strategies.

Table 7: Mitigation Strategy Pollutant Loading Percent Reduction

	Phosphorus			Bacteria		
Subbasin	Filter Strips (% Reduction)	Bioretention (All land/Ag Only) % Reduction	Conversion to Wetlands (% reduction)	Filter Strips (% Reduction)	Bioretention (All land/Ag Only) % Reduction	Conversion to Wetlands (% reduction)
ASK3	68%	48% / 34%	8.7%	80%	48% / 27.4%	7.4%
BB2	52%	48% / 40.2%	13.5%	80%	48% / 37.3%	8.4%

The SWAT model created for the Assiscunk Creek Watershed and the Barkers Brook Watershed has provided a prediction of potential annual pollutant contribution to the streams. Three mitigation scenarios were then simulated using literature values or model input parameters. Each of the three mitigation scenarios provided a reduction in the pollutant loading to the system, with a range of values showing effectiveness. These scenarios can present the relative value of options available to address the pollutant loading in these watersheds.

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