Pennsylvania Coastal Zone Management Program

Little Crum Creek Assessment and Action Plan Phase 2

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The views expressed herein are those of the authors and do not necessarily reflect those of the U.S. Department of Commerce, NOAA, the PA DEP nor any of their sub-agencies.

Note: An electronic version of this report is available on Swarthmore College's Watershed Web Site at http://watershed.swarthmore.edu including color versions of maps and graphs.

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- Chester-Ridley-Crum Watersheds Association
- Delaware County Planning Department
- Swarthmore College

Participants

The following persons contributed directly to this project through their participation in the Swarthmore College Undergraduate Summer Research Program, the Summer 2009 Environmental Science Research Outreach Program, and courses at Swarthmore which were involved in this project thorough Community-Based Learning Exercises:

- Zachary Eichenwald , Engineering student, Swarthmore College
- Peter Cosfol, Science Teacher, Chester High School, Markia Collins, student, Chester High School; Richard Scott and Sophia Richardson, students, Strath Haven High School
- Students in the Fall 2008 offering of Engineering 63, Water Quality and Pollution Control at Swarthmore College
- Senior Engineering Design students (class of 2009) whose projects related directly to this project: James Nakamura, Karina Navarro, Nicolas Villagra, Susan Willis

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Executive Summary

The Engineering Department of Swarthmore College, and the Chester-Ridley-Crum Watersheds Association partnered on this project to apply advanced watershed analysis tools to an assessment of Little Crum Creek to recommend strategies to improve water quality in this impaired stream. The scope of this project focuses on identifying upstream sediment and nutrient supply sources and to evaluate stream restoration projects including stormwater best management practice (BMP) projects and low impact development (LID) implementation, as well as potential open space acquisitions, on the basis of performance and overall cost effectiveness.

The context for this study is the Little Crum Creek watershed which drains four municipalities in Delaware County, Pennsylvania. The project evaluation approach employed ensures that high impact areas are identified and that cost-effective practices are recommended for implementation by the participating municipalities.

Accomplishments related to each of the projects four work elements are described briefly below. Further discussion of each work element appears in the main body of the report.

1. Perform a geomorphic assessment of Little Crum Creek, a review of available open space, and a review of non-point source pollution.
A complete delineation of fifteen subcatchment zones above the Ridley Park Lake was performed using the GIS tool TauDEM. The Strahler order (Strahler, 1952) of the natural stream drainage system was determined by TauDEM, a map showing the Strahler classifications was created, and a table showing statistics on stream segments in each subcatchment was produced, including approximate lengths of stream enclosed in storm sewers. Land use characteristics in the watershed were investigated and mapped using two different approaches: municipal zoning maps and land cover GIS rasters obtained from satellite imagery, and the correspondence between the two approaches was determined. Impervious area was determined for each subcatchment using a combination of GIS analysis and hydrologic response modeled by USEPA's Storm Water Management Model (SWMM) calibrated with our field data (see Task 2, below). Stormwater runoff volumes and non-point source pollution loads were calculated using Swarthmore College's SSSM model on the basis of both land use category and subcatchment. Pollutants examined were (1) total sediment, (2) total nitrogen, and (3) total phosphorous. Export coefficients (runoff and pollutant load per acre) for this watershed were calculated for each land use category over the watershed and also on the basis of impervious acres in each subcatchment. Available open space in each subcatchment was determined using GIS, and the effects of conversion of open space to developed land uses was investigated by calculating incremental export coefficients. The analysis enables us to estimate the impacts of open space conversion including increases in runoff volumes and pollutant loadings per acre of open space lost as well as the maximum impacts if all open space is lost.

2. Perform an assessment of stream and watershed conditions.
Our field monitoring and laboratory analysis program, begun in Phase 1 of this project, was continued and expanded during the Spring and Summer of 2009. The monitoring station in Ridley Park, just upstream of the lake was continued in operation. Also, new sites at Girard Avenue and the Swarthmore Swim Club were established, and a semi-permanent site was established at Little Crum Creek Park in Swarthmore Borough. Data from monitoring sites are used in this project to assess stream and watershed hydrologic conditions including event based runoff volumes, peak flows and

measured nonpoint pollutant loads. The field data also enable us to accurately apply USEPA's SWMM computer simulation model to the watershed through calibration and validation using monitored storm events. The model is then used in Task 4 to simulate runoff volumes, peak flows, and nonpoint pollutant loadings over an entire year at five-minute intervals and to evaluate future stormwater management projects at specific sites.

3. Identify and prioritize improvement projects.
Best Management Practices (BMPs) and Low Impact Development (LID) practices, identified in Phase 1 of this project, were reviewed and potential project sites were selected. A Low Impact Development (LID) Best Management Practice (BMP) database was created and a web site established to enable convenient access by watershed stakeholders and municipal officials. GIS maps and aerial images of each site are included in the database along with site characteristics including acreage, GPS coordinates, BMP suggestions, and environmental benefits. Project costs are also estimated. Prioritization of projects is accomplished as part of Task 4.

4. Evaluate specific projects while focusing on flood mitigation, stream restoration, riparian buffers, open space, and stormwater best management practices.
The SWMM simulation model developed in Task 2 involves a very detailed representation of the watershed and stream network including runoff conveyance (through storm sewers and stream channels), temporary storage of runoff in stream channels and detention basins, overland runoff processes from pervious and impervious surfaces, and infiltration processes in soils. Thus, the model has the ability to examine changes in channel flows and pollutant loadings that would result from projects at specific sites. Improvement projects identified in Task 3 are modeled using SWMM to obtain estimates of the benefits that can be attributed to the projects. Project cost estimates, developed in Task 3 are combined with performance calculations, which enables ranking of projects on the basis of both benefits and costs.

Purpose of Study

This project builds upon and applies the work of three prior CZM-funded projects, 2003-PS.06 (McGarity and Horna, 2005a), 2004-PS.08 (McGarity and Horna, 2005b), and 2007-PD.14 (McGarity, et. al, 2009). These studies involved the development, testing, and piloting a science-based decision support model for prioritizing stormwater best management practices (BMP's) and land preservation tools to achieve improvements in water quality required by the federal Clean Water Act on impaired streams. The models developed in these studies provided the basis for ongoing development of Swarthmore College's Storm Water Investment Strategy Evaluator (StormWISE) optimization model, which has also been supported by the U.S. Environmental Protection Agency (McGarity, 2006a,b). This project is the second phase of a long-term program to develop and implement an action plan for improving water quality and natural habitat in the Little Crum Creek Watershed. It extends the Phase 1 project (CZM 2007-PD.14, McGarity et al., 2009) by building on its general recommendations to examine specific measures and management strategies that can be incorporated into the action plan. High priority measures are identified for funding and implementation in each of the four principal municipalities drained by the stream (Ridley Park Borough, Ridley Township, Springfield Township, and Swarthmore Borough) and in the watershed as a whole.

The Phase 1 report provides general background on the Little Crum Creek watershed including maps that show (1) the general location of the watershed in the Philadelphia metropolitan region,(2) a close-up of the watershed showing its boundaries as well as nearby municipal boundaries, (3) a map showing how various land use categories are distributed throughout the watershed, and(4) a map and table showing where impervious surfaces are concentrated. This report, with maps in color, is available on Swarthmore College's watershed web site: http://watershed.swarthmore.edu. For convenience, two figures are reproduced here (Figures 1 and 2, below).

The watershed occupies 3.2 square miles, draining primarily four municipalities, Springfield Township, Swarthmore Borough, Ridley Township, and Ridley Park Borough, and small sections of Morton Borough and Rutledge Borough. Figure 1 shows an outline of the watershed and the location of the natural pre-development stream channels as determined by digital elevation analysis using GIS (described below).

Methodology

Our project consists of four main work elements which comprise our methodology:

1. Perform a geomorphic assessment of Little Crum Creek, a review of available open space, and a review of non-point source pollution.
2. Perform an assessment of stream and watershed conditions.
3. Identify and prioritize improvement projects.
4. Evaluate specific projects while focusing on flood mitigation, stream restoration, riparian buffers, open space, and stormwater best management practices.

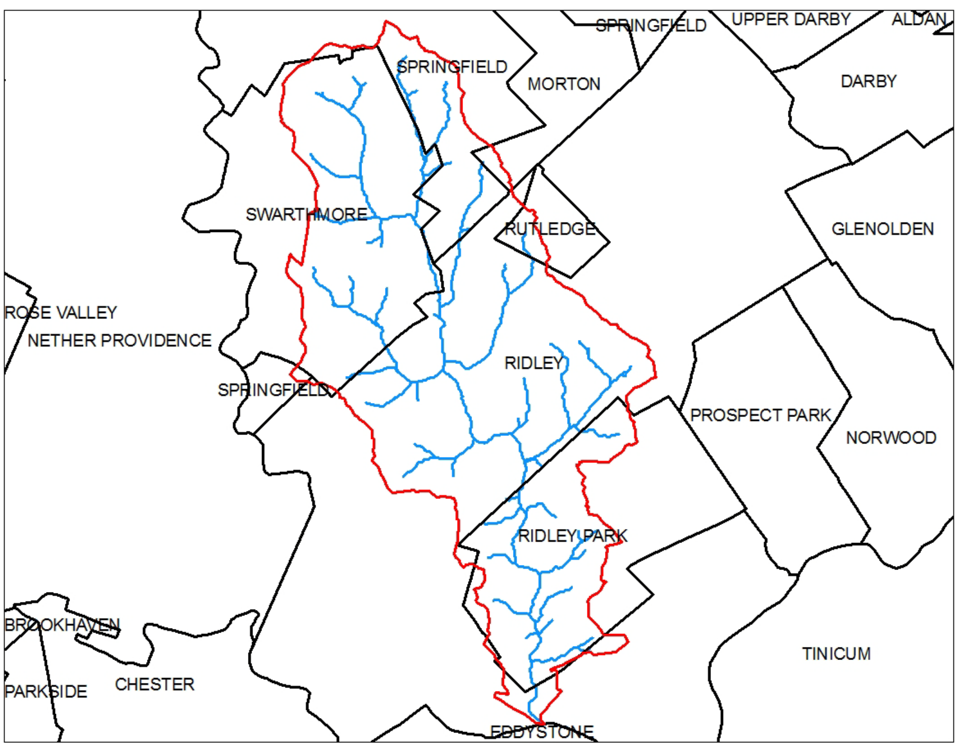

Figure 1. Little Crum Creek Watershed with stream segments, showing communities drained, nearby municipalities in Delaware County, Pennsylvania, and the natural pre-development stream channels (McGarity, et al., 2009).

Results

We describe here the accomplishments related to each work element.

Task 1. Perform a geomorphic assessment of Little Crum Creek, a review of available open space, and a review of non-point source pollution.

Creation of a high-resolution detailed drainage delineation map of Little Crum Creek Watershed . A complete delineation of all drainage zones above the Ridley Park Lake was performed using digital elevation GIS layers and the GIS tool TauDEM (Tarboton, 2002), run as an extension within ARCGIS 9.3. A total of fifteen subcatchments were delineated as shown in Figure 2. Total areas, impervious percentages, and land use categorizations were determined for each drainage zone and are displayed in Table 3. Most of the analyses in this report are performed for the zones that drain eventually into Ridley Park Lake because the water quality problems in the watershed are manifest most strongly at the lake.

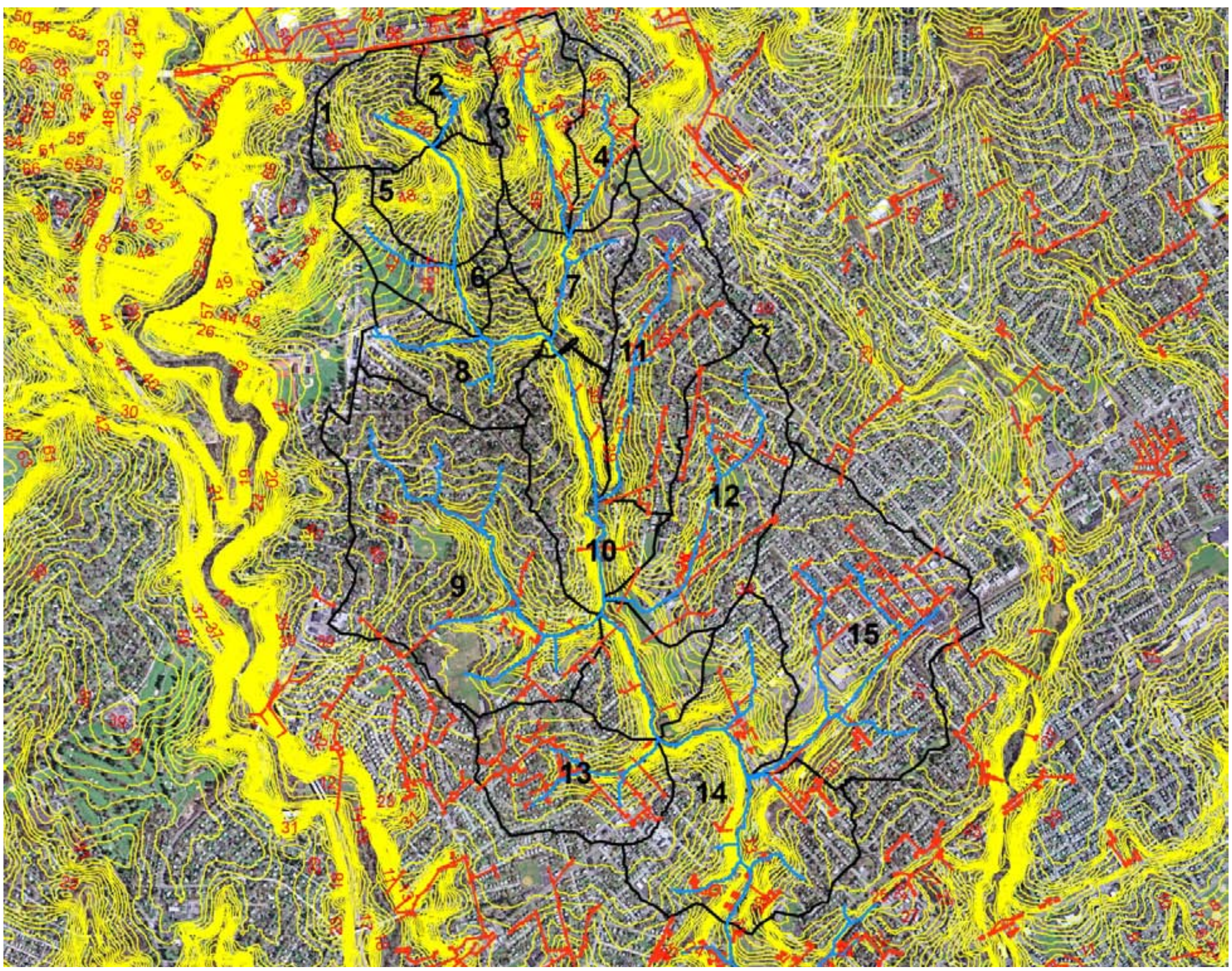

Figure 2. Fully delineated (fifteen) subcatchment zones for Little Crum Creek above Ridley Park Lake including elevation contours (yellow) and storm sewers (red) for Springfield, Ridley Twp., and Ridley Park (Swarthmore's storm sewers have not been digitized). The background layer of the map is an enhanced satellite image of the region showing streets and residential and commercial developed areas.

Geomophoric Assessment. The primary geomophoric characteristics of the Little Crum Creek watershed are created by its physical geographic location which spans the boundary between two of the major geophysical regions of the eastern United States, the piedmont and coastal plain regions. The upper (northern) headwaters of the stream are situated in the piedmont at elevations averaging around 200 feet above sea level. The elevation contours in Figure 3 reveal a rapid drop in elevation of roughly 75 feet along an east-west line that cuts across zones 3, 4, 5, and 6. This is the boundary between the piedmont to the north and the coastal plain to the south. The upper watershed drainage zones are characterized by steep average slopes in the range of 4% to 11%. The headwater tributaries to Little Crum Creek cut channels into the piedmont boundary making the dividing line jagged, and the stream banks in this zone have locally high slopes sometimes approaching 100% (45 degrees).

The lower headwaters of the stream drain areas of the upper coastal plain around the eastern and western perimeters of the watershed and are situated at elevations of 100-125 feet. Elevations taper off gradually in these drainage zones at slopes in the range 1% to 3% until the main channel of the stream is reached at the core of the watershed where the average slope is around 5%.

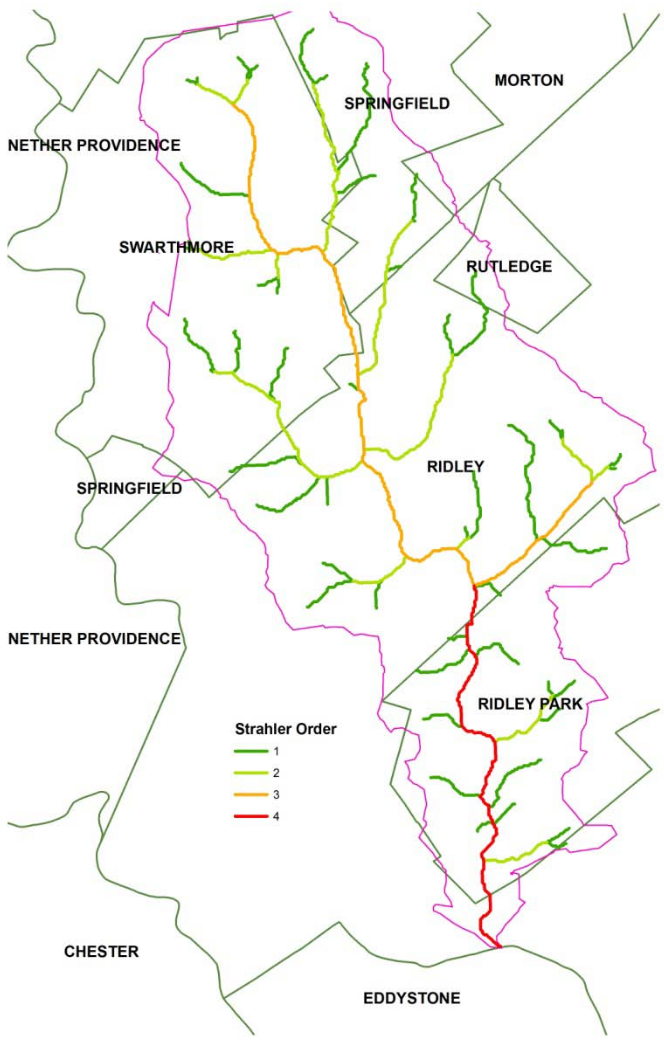

Figure 3. Strahler stream order classification of the entire Little Crum Creek showing the channels that would exist in the absence of the municipal storm sewer system, as determined by GIS analysis of a digital elevation map using TauDEM software.

Table 1. Geomorphic characteristics of the Little Crum Creek watershed above Ridley Park Lake by drainage zone including calculated pre-development stream channel lengths and Strahler Order plus estimated percentages of natural streams that have been enclosed in municipal storm sewers.

Zone	Area Drained (acre)	Average Elevation (ft)	Average % Slope	Pre-Development Natural Streams					Sewered Stream Length (approx.)
				Stream Length (ft)	1st Order Streams	2nd Order Streams	3rd Order Streams	4th Order Streams	
1	58.5	197	6	1,166	32%	68%	0%	0%	0%
2	32.4	193	6	1,470	60%	40%	0%	0%	0%
3	77.1	177	11	3,552	45%	55%	0%	0%	30%
4	43.6	168	4	2,482	100%	0%	0%	0%	60%
5	59.8	154	9	2,025	0%	2%	98%	0%	0%
6	52.4	146	4	2,783	58%	0%	42%	0%	0%
7	67.1	122	2	2,936	31%	60%	9%	0%	10%
8	83.5	120	3	4,346	25%	50%	25%	0%	20%
9	282.3	112	2	11,382	63%	37%	0%	0%	50%
10	155.6	96	5	6,730	3%	1%	96%	0%	30%
11	136.7	120	1	4,800	29%	71%	0%	0%	70%
12	142.3	110	2	6,237	48%	52%	0%	0%	90%
13	105.3	98	2	3,653	65%	35%	0%	0%	80%
14	210.2	83	3	9,829	52%	4%	20%	25%	50%
15	231.3	100	1	9,970	53%	15%	32%	0%	90%
TOTALS*	1,738.1			73,361	46%	29%	22%	3%	51%

***** Totals are for entire area above Ridley Park Lake

Municipal Zoning Land Use Maps. Municipal zoning regulations determine the legal aspects of how land in the watershed is used. Land use, in turn, has a tremendous effect on stormwater runoff volumes, nonpoint pollutant loads, and green space inventories. One important source of data on land use patterns is municipal zoning, so we include here an analysis of existing municipal zoning. Another important source of data on land use is "land cover" data obtained from satellite imagery, which is discussed in the next section.

As part of this study, a senior engineering design project was conducted by Karina Navarro and supervised by Prof. Arthur McGarity (Navarro, 2009). This study extends the "Build-out Scenario" analysis that was performed in Phase 1 of this project (McGarity, et al., 2009), and it is available online at http://watershed.swarthmore.edu. Navarro obtained zoning maps from the Borough of Morton (1989), Ridley Park (1982), Ridley Township (1977), Rutledge Borough (1998), Springfield Township (1986) and Swarthmore Borough (1976) from the Delaware County Planning Department and from the recent Multi-Municipal Comprehensive Plan for Nether Providence, Rose Valley, Rutledge and Swarthmore (MMCP , 2006). These maps were scanned and are included as an appendix in Navarro's report (Navarro, 2009).

The paper zoning maps were manually digitized, and GIS shapefiles were created to enable further analysis. The zoning layers contain attribute tables containing: (1) the municipality that the particular feature is in, (2) the zoning abbreviation used by the particular municipality (e.g., R1, Ca, etc.), (3) the zoning description given by the municipality (e.g., Residential District Provisions, Commercial, etc), (4) the date the map was made (e.g., 2/12/1995, etc), and (5) the area in acres for each zoning area.

Each municipality uses a different categorization scheme for its zones. Navarro constructed a unified scheme consisting of ten categories into which all of the different municipal zone categories could fit. Table 2 shows how the ten zone categories were assembled.

Table 1. Zoning categories assigned for the entire watershed and the zoning categories on the zoning maps of each municipality (Navarro, 2009).

Zoning Category for this study	Zoning Categories Used by Municipality					
	Morton	**Ridley Park**	**Ridley Township**	**Rutledge**	**Springfield**	**Swarthmore**
Apartment	-	-	Apartment	-	Residential Apartment	Apartment Residential District
Business	-	-	-	-	Business	Business Apartment District
Commercial	Neighborhood Commercial, General Commercial	C-1, C-2	Commercial A, B	-	Shopping Center	-
Industrial	Light Industry District provisions	Industrial	Industrial	-	Planned Industrial	-
Institutional	-	-	-	-	-	Institutional District
Parks	-	-	-	-	-	Parks District
Residential	Residential District Provisions: 1, 2, 3, 4	R-1, R-2, R-3	Residential: A, B, C	Residential, Service/High Density Residential	Residence: A, B, C	Residential Districts: A, B, C, AL
Riparian	-	-	Flood Plain	-	-	-
Special	Special Office District	-	-	-	Special Use	-
Transportation	-	Right of Way	Right of Way	-	-	-

Official zoning maps are not entirely accurate representations of actual land use because of variances that have been granted over many years. Thus, Navarro revised the zoning maps to better reflect current land uses. The land parcel GIS layer obtained from Delaware County during Phase 1 of this study as well as Google Earth^{TM} software were used to revise the zoning map on a parcel basis.

Figure 5 shows the revised zoning land use map showing how parcels in the ten different zoning land use categories are distributed throughout the entire watershed. Land uses in the watershed are typical for the "close-in" Philadelphia suburban areas where significant residential and commercial development began in the late 1800's followed by three periods of accelerated growth during the 1920's, 1950's, and the current decade.

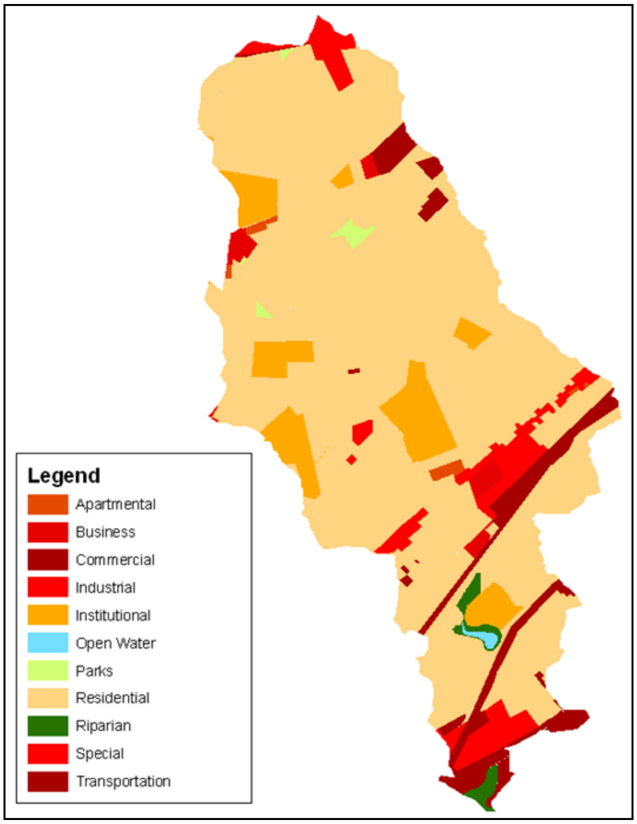

Figure 4. Zoning land use map of LCCW that has been modified to account for existing properties (Navarro, 2009).

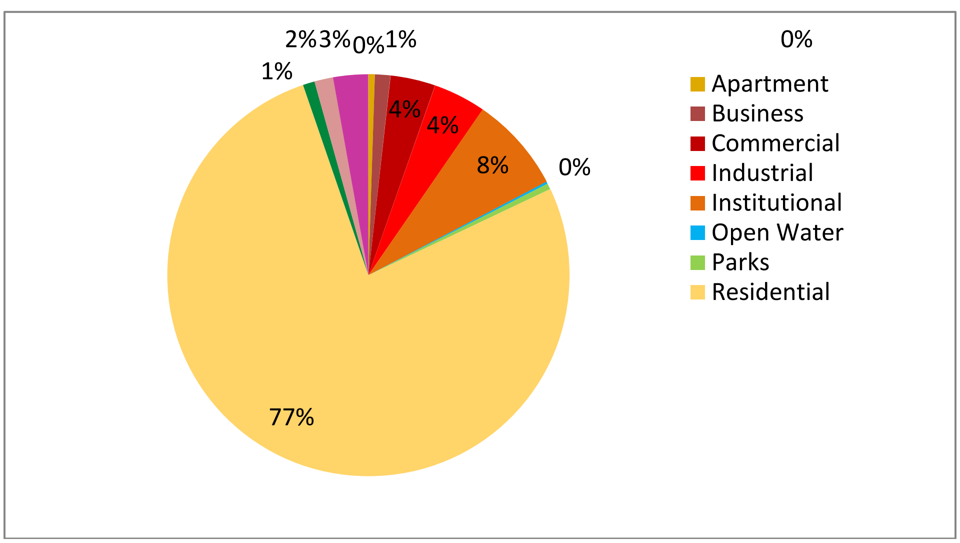

Figure 5. Percentages of entire watershed in different zoning areas (Navarro, 2009).

Land Use Categorization based on Land-Cover for Hydrological and Nonpoint Pollutant Modeling and for Open Space Assessment. Hydrological and nonpoint pollutant load modeling requires higher resolution in land use categorization than that which is available from zoning maps. Also, very little information about available open space is contained in zoning maps. Fortunately, satellite imagery can be used to generate higher resolution land use data that can be useful for such purposes. Satellite images have been processed into GIS rasters called "land cover" layers. We have used the land cover layers from the most recent (2001) U.S. National Land-Cover Database (NLCD 2001), which is produced by the Multi-Resolution Land Characteristic Consortium (MRLC). The MRLC 2001 was obtained from Landsat 7 ETM+ and Landsat 5 TM images and the National Elevation Dataset was used to correct for terrain. Cross-validation analysis were performed on three mapping zones. One of these, Zone 60, coincidentally includes the Middle Atlantic region where the Little Crum Creek watershed is located. Zone 60 has the highest overall accuracy of the three zones tested (77.2%) when land cover categorizations are compared with actual land use.

The 2001 version of the NLCD provides 29 different land cover categories. Thirteen of those categories occur in the Little Crum Creek watershed. For the purposes of this study, we combined certain of these categories to obtain a simpler categorization scheme which we treat as our land use categories for the purpose of our hydrological and nonpoint source pollution modeling, as shown in Table 3.

Table 3. Derivation of Little Crum Land Use Categories from the NLCD 2001 Land Cover Categories

Little Crum Land Use Categories	**NLCD 2001 Land Cover Categories**
1. Forest & Wetland	41 - Deciduous Forest, 42 - Evergreen Forest, 43 - Mixed Forest, 90 - Woody Wetlands, 95 - Emergent Herbaceous Wetlands
2. Developed Wooded/Fields	21 - Developed Open Space, 81 - Pasture/Hay, 82 - Cultivated Crops
3. Developed Low Intensity	22 - Developed Low Intensity
4. Developed Medium Intensity	23 - Developed Medium Intensity
5. Developed High Intensity	24 - Developed High Intensity
6. Open Water	11 - Open Water

Figure 6 shows a raster map image of the Little Crum Creek watershed obtained by applying the Little Crum Land Use Categories to GIS data obtained from the NLCD 2001 database downloaded from the MRLC web site http://www.mrlc.gov. Sites of significant development since 2001 have been added manually. Note that the area of dark green "Forest/Wetland" land use follows the main stem of Little Crum Creek, and some of the larger tributaries as well, indicating the prominence of this land use category in the riparian zone. The land uses tend to be distributed as follows: "High Intensity" in the vicinity of commercial shopping districts (including two major retail commercial complexes built on former green space during 2000 – 2006), institutional buildings and industrial operations (near the

Delaware River), "Medium Intensity" multifamily apartment complexes and condominiums, "Low Intensity" residential developments built in the 1950's in Springfield and Ridley Townships, lower density wooded residential developments dating to the early 20th century in Ridley Park and Swarthmore Boroughs, Recreational fields associated with schools and public parks, and significant acreage remaining in forests and wetlands, especially in the riparian zone of the creek.

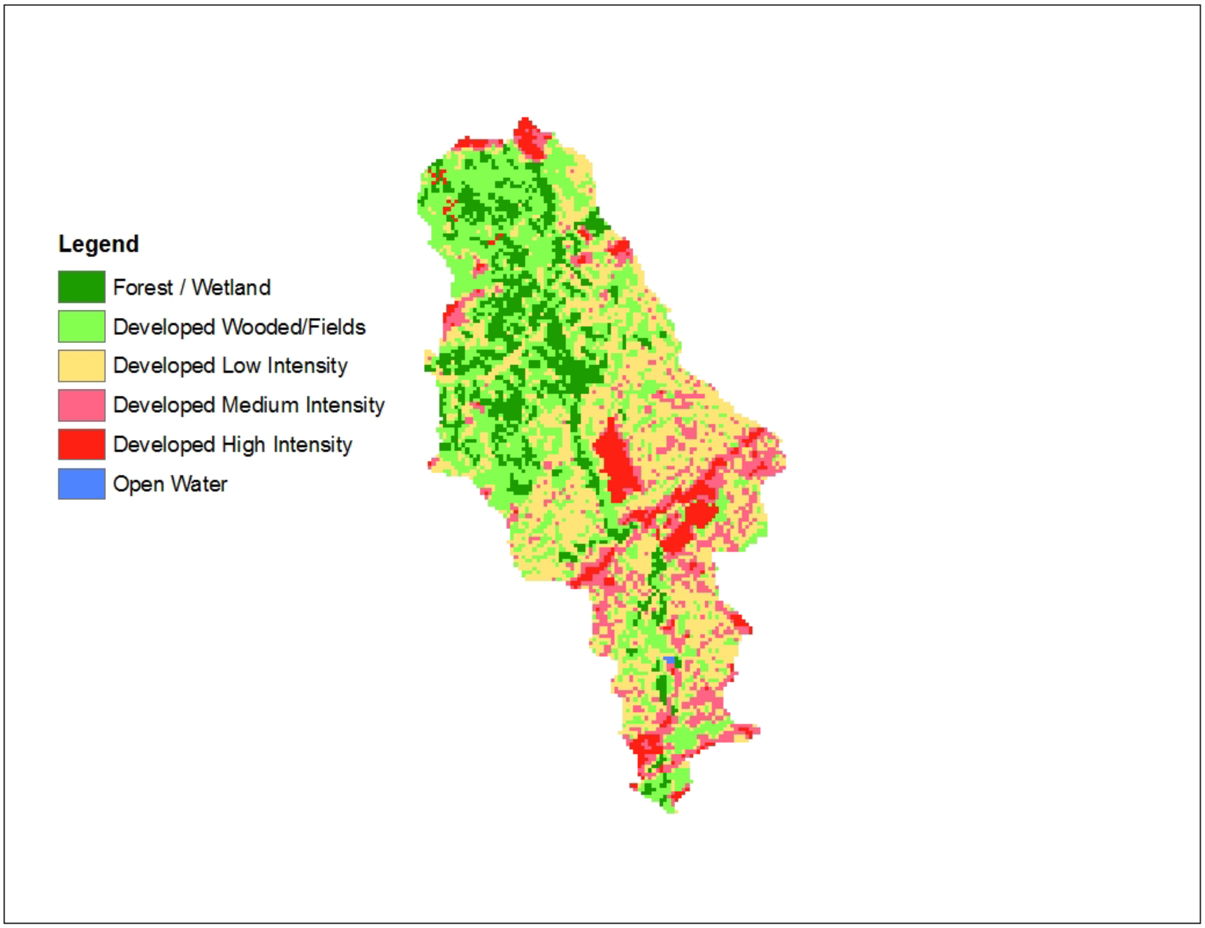

Figure 6. Little Crum Creek Watershed land use categories derived from Landsat satellite imagery and the 2001 dataset derived from these images by the Multi-Resolution Land Characteristics Consortium (MRLC) - http://www.mrlc.gov. Standardized MRLC land cover categories have been consolidated into categories relevant to this study as shown in Table 3.

Figure 7 contains a pie diagram that shows what percentages of the land in the entire watershed are categorized by each land use category.

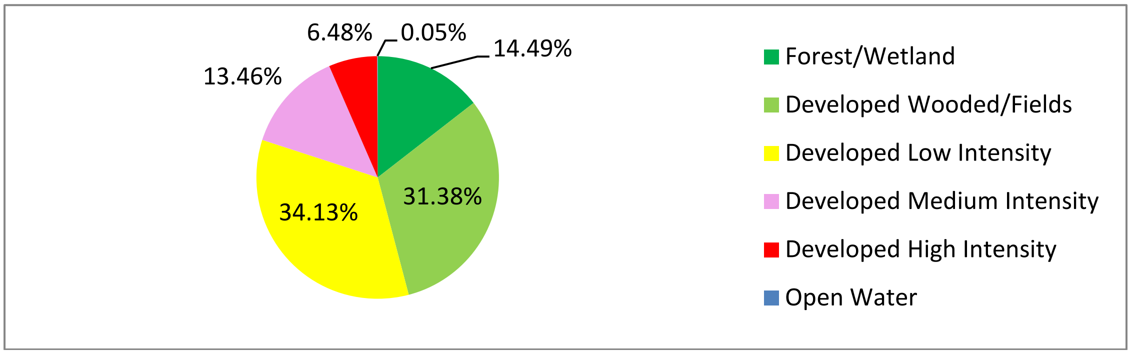

Figure 7. Percentages of Entire Watershed categorized according to Little Crum Land Uses

The relationship between the municipal zoning map (Figure 4) and the land use map (Figure 6) is explored in Figure 8. For each of the municipal zoning categories, a vertical bar is shown indicating the proportion of that zone that is classified in each of the different land use categories.   We see that the municipal zones tend to contain the types of land uses that one would expect.   For example, the Residential municipal zone contains significant Developed Low Intensity and Developed Wooded land uses while the Industrial municipal zone contains significant Developed High Intensity and Developed Medium Intensity land uses. However, Figure 8 also reveals that each municipal zone actually contains a range of different land uses, making clear the need for land use classifications based on land cover imagry for the purpose of hydrological and nonpoint pollution modeling.

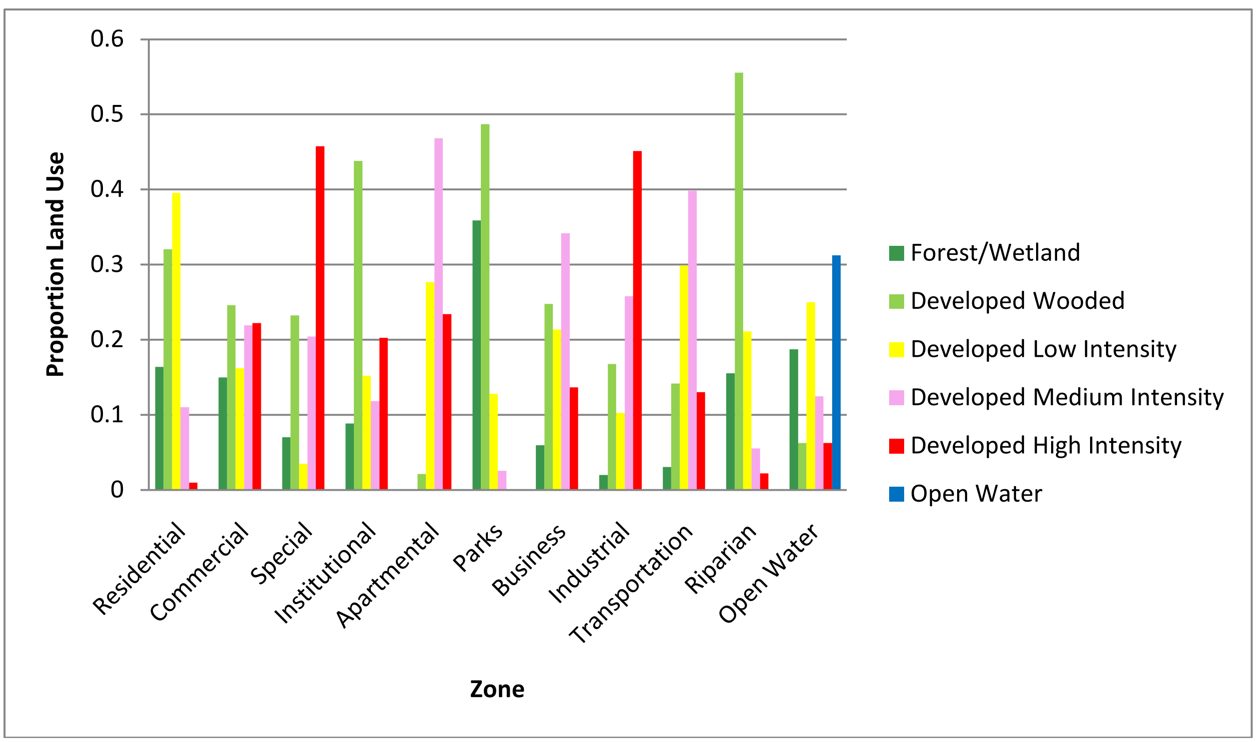

Figure 8. The proportion of each land use in each zone. The land use data are in the form of a raster from the NLCD 2001. The zoning data is based on zoning maps provided by the Delaware County Planning Department.

Non-point Source Pollution. Non-point pollution loading estimates were updated in this study using a revised version of the RunQual model adapted for suburban land uses to include erosion from unpaved surfaces associated with stormwater runoff. The RunQual model, developed at Cornell University and used in our Phase 1 Little Crum Creek study, models nonpoint pollution primarily as a build-up and wash-off process on impervious surfaces. However, suburban areas also have significant contributions to nonpoint pollution from erosive processes on pervious surfaces. In a senior engineering design project related to this study, Swarthmore College student Susan Willis extended the RunQual model to include daily calculations of erosion from pervious land surfaces using the Universal Soil Loss Equation as suggested by Limbrunner (2005). The new model is called the Swarthmore Subwatershed-scale Suburban Nonpoint Source Pollutant Loading Model (SSSN) (Willis, 2008; Willis and McGarity, 2010).

The water quality effects of stormwater runoff and nonpoint pollution in Little Crum Creek watershed are most severe in Ridley Park Lake and in the stream channels above the lake. Details of the current degraded state of the stream are presented in a recent study by the Delaware Riverkeeper Network (Gutzler, 2007), and several of the recommendations for further study made in that report are being addressed in the current study. The watershed above Ridley Park Lake has been delineated into 15 subcatchments, as shown in Figure 2, to facilitate an assessment of the sources and magnitudes of stormwater runoff and its associated nonpoint pollution. The first step in the analysis is a GIS analysis to determine drained area, impervious percentage, and percentages of land area in each of the land use categories. These results are shown in Table 4.

Table 4. Impervious Fractions and Land Use Categorizations+ by Subcatchment Above Ridley Park Lake

Sub-Catchment	Area Drained (acre)	Impervious Fraction@	Forests & Wetlands	Developed Wooded and Fields	Developed Low Intensity	Developed Medium Intensity	Developed High Intensity
1	58.5	38%	25%	61%	7%	1%	6%
2	32.4	42%	21%	72%	4%	3%	0%
3	77.1	46%	23%	51%	11%	7%	8%
4	43.6	53%	10%	34%	51%	3%	2%
5	59.8	28%	34%	54%	8%	1%	3%
6	52.4	34%	20%	61%	12%	6%	1%
7	67.1	32%	24%	41%	26%	6%	2%
8	83.5	37%	36%	34%	18%	8%	3%
9	282.3	41%	26%	45%	25%	4%	0%
10	155.6	48%	28%	32%	31%	3%	6%
11	136.7	58%	15%	32%	44%	6%	2%
12	142.3	63%	3%	24%	50%	9%	14%
13	105.3	62%	5%	24%	51%	14%	6%
14	210.2	78%	7%	15%	43%	26%	8%
15	231.1	78%	0%	10%	47%	30%	13%
TOTALS*	1,738.1	55%	16%	33%	34%	11%	6%

+ Based on the Multi-Resolution Land Characteristics (MRLC) Consortium http://www.epa.gov/mrlc

@ Based on satellite imagery adjusted for measured hydrologic response to rain events and SWMM model calibration (see section below on Task 2)

* Totals are for entire area above Ridley Park Lake

Figure 9 shows the fifteen subcatchments superimposed on the GIS land use raster map that was analyzed in ArcGIS to obtain the results in Table 4.

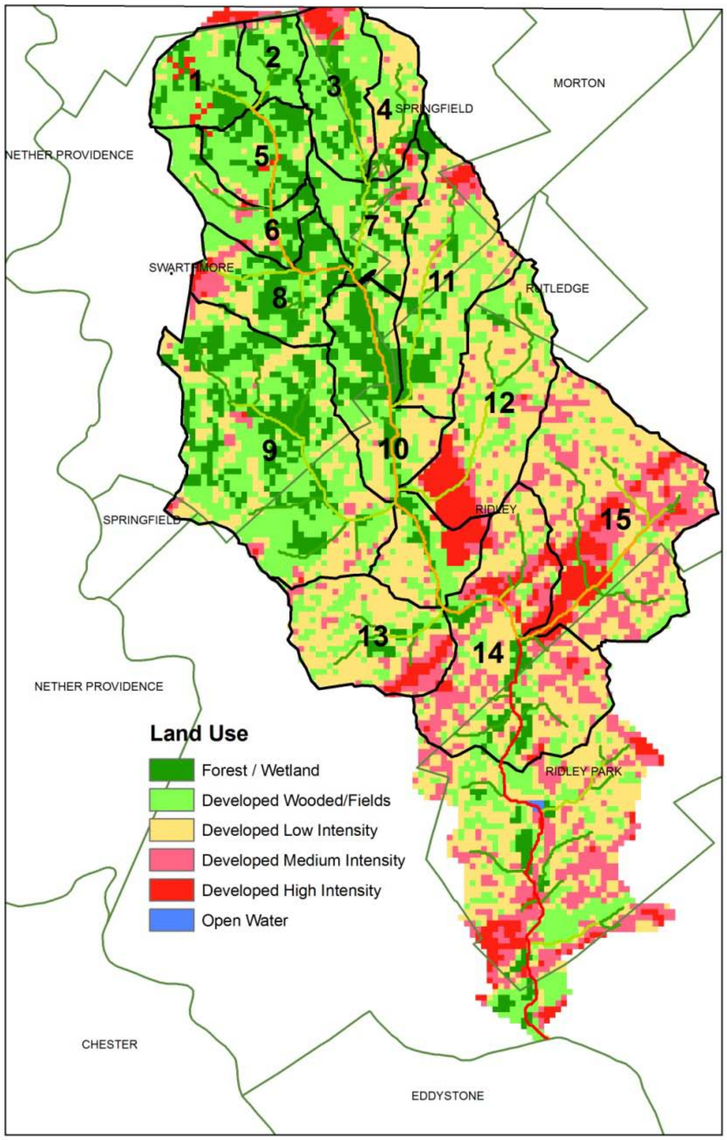

Figure 9. Land Use raster map showing the 15 subcatchments above RIdley Park Lake.

In order to calculate runoff volumes and nonpoint pollution loads, the SSSN model was configured to run a simulation of every day during a ten-year period using weather data from the Philadelphia Airport. Daily precipitation is applied to each land use category. Almost all of the precipitation runs off of impervious surfaces. For pervious surfaces, soil infiltration is calculated using Soil Conservation Service (SCS) curve numbers which depend on land use categories. Antecedent moisture conditions, which account for the saturating effects of recent precipitation also affect the curve numbers. If the outdoor temperature is below freezing, the precipitation accumulates as snow on impervious and pervious surfaces, and the runoff is delayed until it occurs as snow melt when the temperature rises above freezing.

The annual averages of runoff volume (million gallons), sediment (tons), total nitrogen (pounds) and total phosphorous (pounds) are calculated for each land use category and divided by the associated acreage to obtain "Export Coefficients" for each land use, as shown in Table 5. The export coefficients are used to calculate the 10-year average annual totals for runoff and pollutant loads are shown in Table 6. Note that the units for **runoff** are million gallons per year, the units for **sediment** are tons per year, and the units for **total nitrogen** and **total phosphorous** are pounds per year.

Table 5. Annual Export Coefficients by Land Use derived from 10-year simulations using the SSSN model

Land Use Category	ANNUAL EXPORT COEFFICIENTS			
	Runoff (Million gal/acre-yr)	Sediment (ton/acre-yr)	Nitrogen (lb/acre-yr)	Phosphorous (lb/acre-yr)
Forest/Wetlands	0.14	0.02	0.39	0.04
Developed Wooded/Fields	0.20	0.09	2.43	0.30
Developed Low Intensity	0.28	0.17	2.71	0.28
Developed Medium Intensity	0.36	0.18	6.93	0.88
Developed High Intensity	0.45	0.27	8.83	0.99

Table 6. Average Annual Totals for Runoff Volume, Sediment, Nitrogen, and Phosphorous for Little Crum Creek above Ridley Lake

Land Use Category	TOTAL RUNOFF & POLLUTANT LOADS			
	Runoff (Million gal/year)	Sediment (ton/year)	Nitrogen (lb/year)	Phosphorous (lb/year)
Forest/Wetlands	40.2	6.5	366	37
Developed Wooded/Fields	115.7	53.5	686	83
Developed Low Intensity	163.0	99.3	1,545	156
Developed Medium Intensity	72.1	35.5	4,038	512
Developed High Intensity	46.2	27.8	1,753	197
Entire Area Above Ridley Park Lake	**437.2**	**222.5**	**8,389**	**986**

The export coefficients can also be used to calculate annual runoff volumes and pollutant loads by subcatchment as shown in Table 7. Note the wide range of variation across subcatchments caused by differences in both land use and total area. In order to investigate the connections between runoff volumes, pollutant loads, and land use, we also show in Table 7 the number of acres of impervious area in each subcatchment. The impervious area is a quantity that captures the intensity of development associated with the different land use categories. We see strong correlation between runoff volumes and pollutant loads and the impervious acreage. These correlations are shown graphically in Figures 10 a-d. Each data point in these figures is associated with one of the 15 subcatchments.

Table 7. Average Annual Runoff Volumes and Pollutant Loads by Subcatchment and Impervious Area

Sub-Catchment	Impervious Area (acre)	Runoff (Mgal)	Sediment (Tons)	Total Nitrogen (Pounds)	Total Phosphorous (Pounds)
1	**22**	12.3	5.5	174	19
2	**14**	6.4	2.7	102	11
3	**35**	17.7	8.2	270	30
4	**23**	10.7	5.8	225	27
5	**17**	11.8	4.9	182	20
6	**18**	11.1	5.0	190	21
7	**21**	14.8	7.0	278	33
8	**31**	17.8	7.8	325	38
9	**116**	60.2	27.7	1,156	134
10	**75**	35.8	17.3	645	77
11	**79**	32.9	17.1	688	82
12	**90**	41.2	23.2	744	89
13	**65**	29.1	16.0	618	73
14	**164**	61.3	33.1	1,294	153
15	**180**	73.9	41.3	1,498	178
TOTALS	**950**	**437.2**	**222.5**	**8,389**	**986**

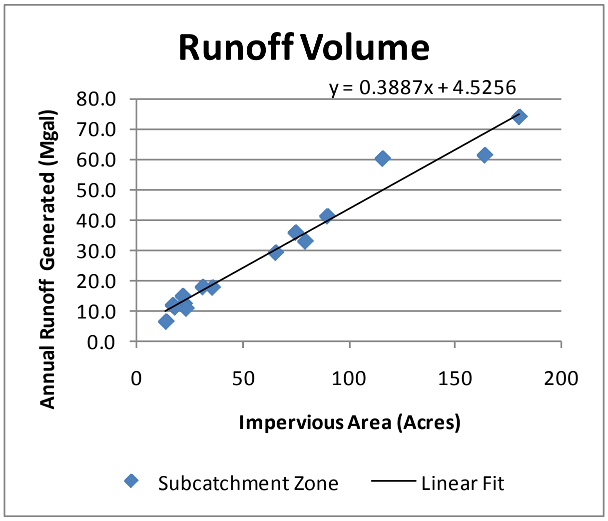

Figure 10-a. Annual Runoff vs. Impervious Area

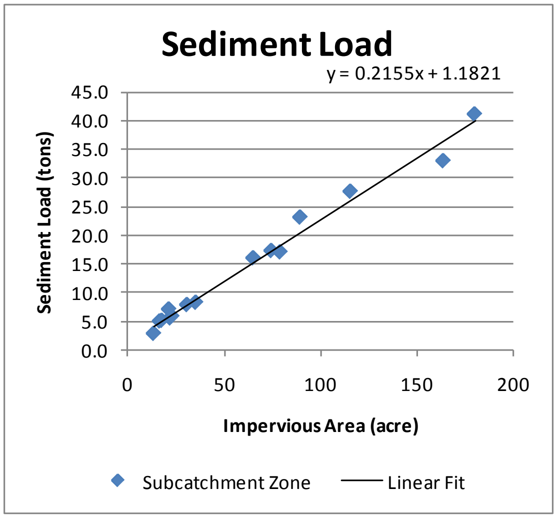

Figure 10-b. Annual Sediment Load vs. Impervious Area

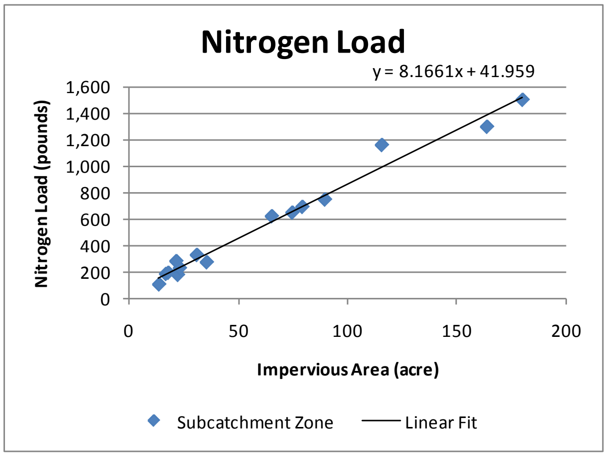

Figure 10-c. Annual Total Nitrogen Load vs. Impervious Area

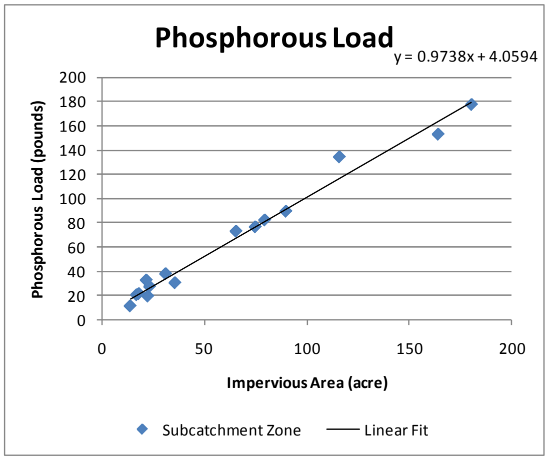

Figure 10-d. Annual Total Phosphorous Load vs. Impervious Area

The correlations in Figures 10 a-d show that the long-term average annual runoff volumes and pollutant loads (as calculated by SSSN) have a strong linear dependence on impervious area. The slopes of the straight lines fit to the results provide an alternative type of export coefficient based on a single parameter, impervious area, that for the purpose of this analysis seems to capture the overall effects of land use variations. The slopes have been calculated and are displayed in Table 8.

Table 8. Alternative Export Coefficients based on Impervious Area in each Subcatchment

ALTERNATIVE ANNUAL EXPORT COEFFICIENTS*			
Runoff (Million gal/ imperv. acre)	**Sediment (ton/ imperv. acre)**	**Total Nitrogen (lb/ imperv. acre)**	**Total Phosphorous (lb/ imperv. acre)**
0.39	0.22	8.2	0.97

***** Slopes of linear fits to data in Figures 10 a-d are alternative export coefficients based on impervious area

Open Space Assessment. We have clearly demonstrated that low runoff volumes and pollutant loads are associated with low impervious acreage. Furthermore, comparing Table 7 and Figure 9, we see that the subcatchments with low impervious acreage correspond to areas with significant quantities of land categorized as forest/wetland which is our land use category most closely associated with open space. Phase 1 of this study demonstrated that preservation of open space is a cost effective approach to preventing degradations in water quality associated with stormwater runoff and nonpoint pollution.

Using the forest/wetland category as a surrogate for open space, we have used ArcGIS to calculate the total amounts of open space available for preservation in each of the subcatchments and in the watershed above Ridley Park Lake, as shown in Table 9. We can use the annual export coefficients in Table 5 to examine the effects on stormwater runoff volumes and nonpoint pollutant loads associated with loss of open space. Table 10 shows the incremental increase in the open space export coefficients associated with conversion of open space to each of the developed land uses. For example, each acre of open space converted to low intensity developed land results in 140,000 additional gallons of runoff, 300 additional pounds (0.15 ton) of sediment, 2.32 additional pounds of nitrogen, and 0.24 additional pounds of phosphorous every year into Ridley Park Lake.

Table 9. Open Space Availability by Subcatchment

Sub-Catchment	Open Space Percentage	Open Space Area (acre)
1	25%	14.6
2	21%	6.8
3	23%	17.7
4	10%	4.4
5	34%	20.3
6	20%	10.5
7	24%	16.1
8	36%	30.1
9	26%	73.4
10	28%	43.6
11	15%	20.5
12	3%	4.3
13	5%	5.3
14	7%	14.7
15	0%	0.0
TOTALS	**16%**	**282.2**

Table 10. Incremental Annual Export Coefficients Associated with Loss of Open Space showing increased loads associated with conversion of one acre of open space to a developed land use

Conversion from Open Space to:	INCREMENTAL EXPORT COEFFICIENTS			
	Runoff (Million gal/acre)	Sediment (ton/acre)	Nitrogen (lb/acre)	Phosphorous (lb/acre)
Developed Wooded/Fields	0.06	0.07	2.05	0.26
Developed Low Intensity	0.14	0.15	2.32	0.24
Developed Medium Intensity	0.22	0.16	6.55	0.84
Developed High Intensity	0.31	0.25	8.45	0.96

The maximum overall increases in annual runoff volume and pollutant loads associated with conversion of all open space above Ridley Park Lake, we multiply the incremental export coefficients by the total current open space area which is 282.2 acres. These maximum increases are shown in Table 11.

Table 11. Increased Annual Runoff Volumes and Nonpoint Pollutant Loads Associated with Loss of Open Space

Conversion from Open Space to:	MAXIMUM ANNUAL LOAD INCREASES			
	Runoff (Million gal)	Sediment (ton)	Nitrogen (lb)	Phosphorous (lb)
Developed Wooded/Fields	17	20	578	72
Developed Low Intensity	39	42	655	67
Developed Medium Intensity	62	44	1848	237
Developed High Intensity	88	70	2384	270

Task 2. Perform an assessment of stream and watershed conditions.

Our field monitoring and laboratory analysis program begun in Phase 1 of this project was continued and expanded during the Spring and Summer of 2009. We used two ISCO^{TM} automated samplers which record precipitation, flow depth, flow velocity, and volumetric flow rate every minute, continuously. New sites at Girard Avenue and the Swarthmore Swim Club were established, and a semi-permanent site was established at Little Crum Creek Park in Swarthmore Borough. Data from three monitored sites draining progressively larger areas of the watershed are used in this project to assess stream and watershed hydrologic conditions including event based runoff volumes, peak flows and measured nonpoint pollutant loads. The field data also enable us to accurately apply USEPA's SWMM computer simulation model to the watershed through calibration and validation using monitored storm events. In Task 4, the calibrated model is used to simulate runoff volumes, peak flows, and nonpoint pollutant loadings over an entire year at five-minute intervals.

Here, we present monitored data and SWMM modeling results for representative storm events at three sites. We begin with a hydrologic assessment at the Swarthmore Swim Club site (near the boundary between Swarthmore and Springfield) on a first-order stream segment at the outlet of Subcatchment 4 which is an area of primarily low intensity residential development in Springfield. We then move to the Little Crum Creek Park site at the Yale Avenue bridge over the creek in Swarthmore, which is in the main stem of the stream (a third-order segment), that carries runoff from subcatchments 1 through 8. Finally, we move to the Ridley Park site, which is on the fourth-order segment of the stream just above the sediment forebays upstream from Ridley Park Lake where transported sediment accumulates and is periodically dredged. This site, which carries flows from all fifteen subcatchments, is used for event-based calibration of the SWMM model for hydrologic and for evaluating the performance of storm water management measures in Task 4. The SWMM model maps showing subcatchments, conduits, junctions, and storage basins are presented in Appendix B.

Swarthmore Swim Club Site and SWMM Model Calibration. Our flow monitoring station was set up at the Swarthmore Swim Club from 4 August 2009 until 24 September 2009. Precipitation, depth, velocity, and volumetric flow rate channels were recorded. The station was located in a rectangular concrete channel behind the club house, and the rain gage was located on the roof of the club house. Data on six storm events were captured. Here, we examine the event with the largest precipitation, a 1.7 inch rain event that occurred on 9 August.

The flow at the Swim Club site is produced almost entirely by storm event runoff from the residential developed area drained by Subcatchment 4 (Figure 2) having an area of 43.6 acres, an average elevation of 168 ft., an average slope of 4%. There is virtually no base flow in the storm sewers and first-order stream segment that feeds this site. The storm sewer network empties into a detention basin in Springfield at the intersection of Millison Drive and Lincoln Ave. Based on our flow observations, we calculate that the detention basin has an effective volume of about 125,000 gallons and this estimate is consistent with the physical dimensions of the basin obtained from a site visit.

The peak flow rate of about 13 cubic feet per second (cfs) was observed twice, on 8 August for a 1.7" rainfall and again on 22 August for a 1" rainfall. We have closely examined data from the 8 August event and have used it to calibrate our SWMM model for subcatchment 4. Figure 11 shows the excellent agreement that was obtained between measured and simulated flow hydrographs after the calibration exercise was completed. Subcatchment 4 was subdivided into five sub-zones for the model, as shown in Appendix B, Figure B.1. SWMM model calibration was accomplished by first modeling the subcatchment without conduits or storage (which have negligible effects on the total event runoff volume). For pervious surfaces, infiltration was modeled using the Horton equation with parameters set for types C and D soils, which are typical in the watershed. The simulated total event runoff volume is most sensitive to the impervious percentage parameters that express the directly connected impervious percentage for each sub-zone. A high resolution satellite image was used in ArcGIS to estimate, manually, the total directly connected impervious area. These impervious percentages produced results for total event runoff that were slightly high. Reducing these values by 15% resulted in a total event runoff that was within 2% of the measured value.

When stream and storm sewer conduits were added to the model, the flow hydrograph was examined to compare the timing and magnitude of simulated and measured flows over each 5-minute interval. With conduits alone, the peak flow was much too high (28 cfs) and the hydrograph had a jagged appearance, resembling the rainfall hyetograph. Also, the simulated flow dropped to zero soon after the rain ceased whereas significant measured flow continued for almost six hours longer. The measured data clearly indicated the presence of significant storage of runoff in the subcatchment. This result led to a search on the GIS satellite imagery for a detention basin. The basin (mentioned above) was discovered by following the storm sewers to a point where three main lines have outfalls in close proximity. At this location, the imagery shows the faint outline of a detention basin overgrown with tall trees and shrubs. Further investigation using historical imagery available from Google Earth™ clearly shows the outline of the detention basin without vegetation in 1992. A visit to the site on Millison Drive confirmed the existence and dimensions of a dry detention basin. It is designed to accomplish flood control, with a barrel riser at its deepest point having an orifice at the bottom to an underground drain. The orifice allows low flows to pass through with minimal effect. A weir at the top of the barrel allows high flows, which are restricted by the orifice, to spill into the drain when the basin is full.

In order to accommodate the detention basin, three additional components were added to the SWMM model: a storage unit, an orifice, and a weir. The parameters of these components were estimated and then fine tuned to obtain the results shown in Figure 11. The shape of the hydrograph reveals the performance of the detention basin. At about 08:15 we see that the flow rate jumps abruptly up from 5 cfs to almost 13 cfs and then, about one-half hour later, it drops sharply down to about 4 cfs and then over the next seven hours, it slowly tapers to zero. Clearly, the detention basin was able to control the flow until it reached 5 cfs at which point the basin filled up and began to spill excess flow through the weir. A half-hour later, in response to decreased precipitation, the water level in the basin dropped below the level of the weir, and the basin slowly discharged through the orifice over the next seven hours. It is interesting to note that of the six rain events observed at this site, three of them show clear evidence that the detention basin was full at some time during the event. All three of these events have rainfall totals exceeding 1".

The details of SWMM model calibration at the Swarthmore Swim Club site are provided to give the reader a sense of the analysis required for the calibration exercise and to establish confidence in the validity of the results produced for this project with the model. Similar efforts were necessary to calibrate the model at the Little Crum Creek Park site, and our experience with both of these sites led to suitable calibrations for the entire watershed above Ridley Park Lake for the model runs used in Task 4. Table 12 summarizes the simulation model results for the entire rain event of 8 August for both the Swim Club site and the Little Crum Creek Park site, as well as SWMM simulation results for other rain events, as described below. The runoff coefficient is the ratio of the total runoff to the total precipitation, and it is an indicator of the amount of impervious surface in the watershed and also depends on the amount of moisture in the soil prior to the rain event, so it can vary with rain events.

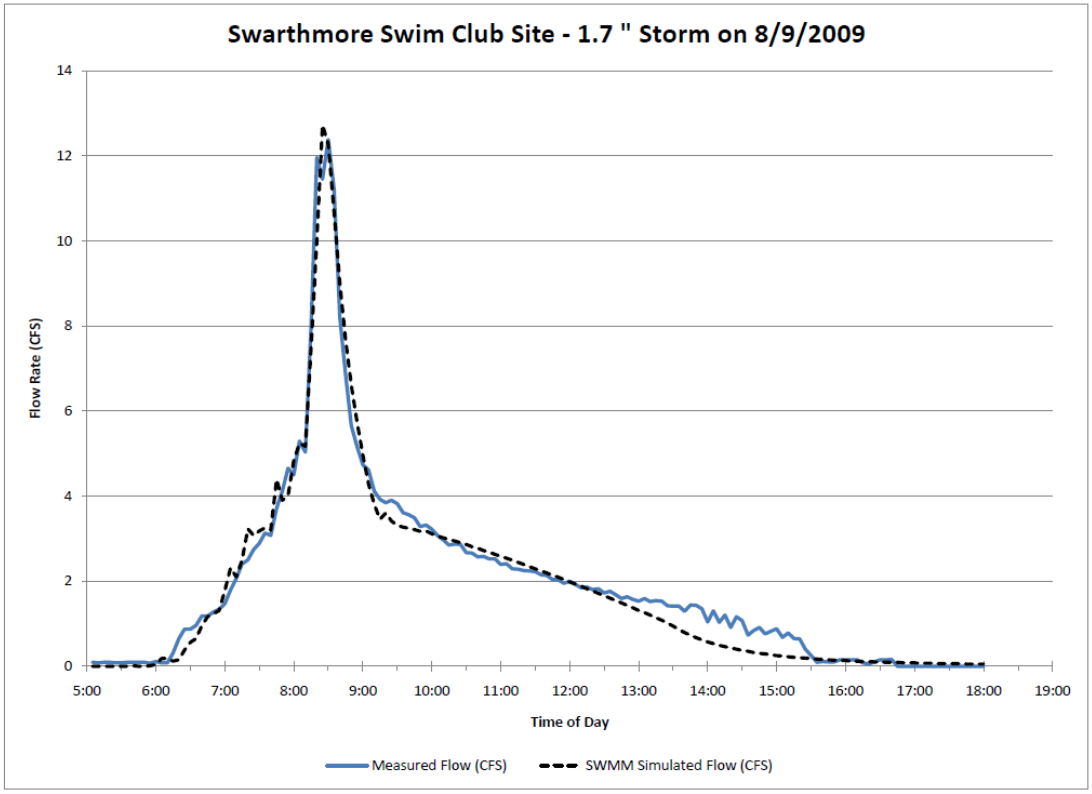

Figure 11. Measured and Simulated Flow Hydrograph at Swarthmore Swim Club for the SWMM model calibration rain event on 9 August, 2009.

Table 12. Summary of SWMM Simulation Results for the Monitored Storm Events

Site	Date	Total Precipitation (inches)	Total Infiltration (inches)	Total Runoff (inches)	Total Runoff (Million Gallons)	Runoff Coefficient	Peak Outflow at Site (cfs)
Swarthmore Swim Club	8/9/2009 (calibration)	1.72	1.13	0.57	0.65	0.33	12.8
Little Crum Creek Park	8/9/2009 (calibration)	1.72	1.25	0.46	6	0.27	121
Little Crum Creek Park	7/17/2009 (validation)	0.47	0.35	0.11	1.4	0.23	59
Ridley Park Lake	5/14/2009 (calibration)	0.48	0.22	0.22	10	0.45	147
Ridley Park Lake	6/4-6/2009 (validation)	0.95	0.44	0.49	22	0.51	54

Little Crum Creek Park Site and SWMM Model Calibration and Validation. A similar procedure was followed to assess storm events at the Little Crum Creek Park site. The SWMM model map is shown in

Appendix B, Figure B.2. Note that a storage unit is modeled in Subcatchment 3 which represents the detention tank underneath the parking lot at Springfield Square Shopping Center. This tank was installed in early 2009 as part of an expansion project. It provides for retention and infiltration of a small portion of the runoff associated with the new parking lot extension, but for most of the shopping center's runoff, it provides only peak flow control for flood conditions. The SWMM model parameters for the storage tank were set to model a one foot depth of water quality volume infiltrating into type D soil.

The rain event on 9 August, 2009 was also used as the calibration event for the SWMM model at the Little Crum Creek Park site. Figure 12 shows a comparison of the measured and simulated hydrographs. Again, excellent agreement is obtained. Table 12 (above) shows numeric results for the entire event enabling comparisons of the two sites for the same event.

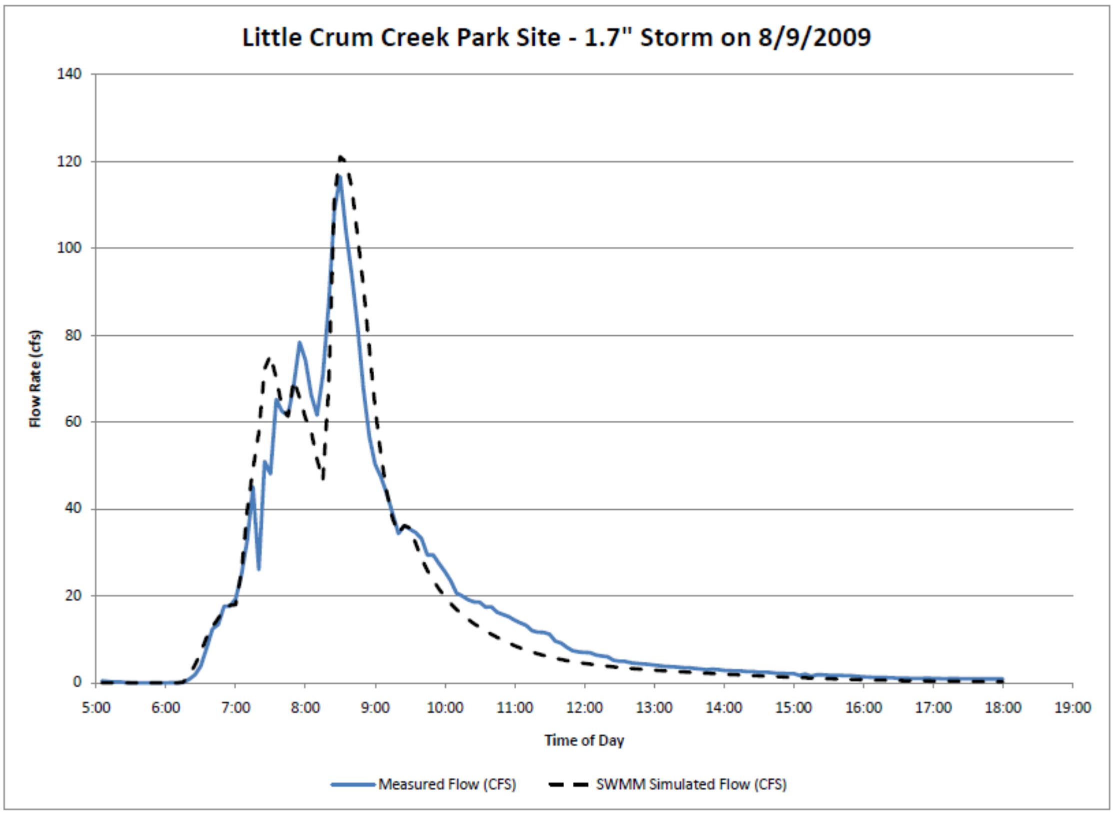

Figure 12. Measured and Simulated Flow Hydrograph at Little Crum Creek Park for the SWMM model <u>calibration</u> rain event on 9 August, 2009.

Whenever possible, it is useful to verify that a hydrologic simulation model is producing accurate results by running the calibrated model on a different event than the one that was used to calibrate it. This is done here by running the SWMM model for Little Crum Creek Park, using the parameters obtained from the 9 August event, to model a different storm event that occurred on 17 July, 2009 with a total rainfall of 0.47". Figure 13 presents a comparison of measured and simulated results that shows excellent correspondence, indicating that the calibration is robust, and validating the accuracy of the simulation when used to model events other than the one for which it was calibrated. This result gives us confidence to use SWMM for long term continuous simulations to generate an annual assessment.

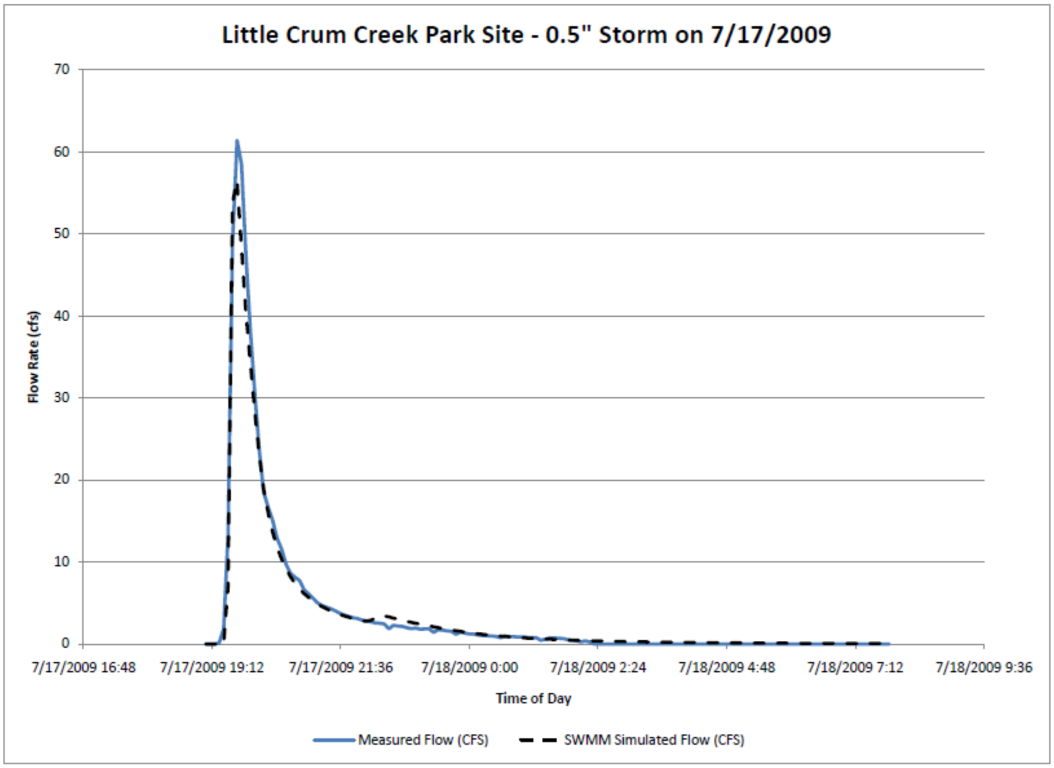

Figure 13. Measured and Simulated Flow Hydrograph at Little Crum Creek Park for the SWMM model <u>validation</u> rain event on 7 July, 2009 using parameters calibrated by the event on 9 August, 2009.

Ridley Park Lake Site and SWMM Model Calibration and Validation. Data from our Ridley Park Lake site was assessed for storm events including analysis of stream flow and pollutant loadings. A SWMM simulation was also developed for this site. The SWMM model map is shown in Appendix B, Figure B.3. A known retention basin at the Ridley Shopping Center behind the Home Depot store in Subcatchment 15 was included in the model as a storage unit. The simulation results with this storage alone were not adequate, producing a hydrograph that decayed much too rapidly after storm events indicating that additional storage is present in other subcatchments as well. In order to obtain a suitable calibration, storage units were also added in Subcatchments 9, 10, 11, and 12. Although we were unable to locate actual detention facilities to associate with these storage units, we are confident that an actual total storage capacity having approximately the same total capacity as our modeled storage units must exist in the lower subcatchments because of our ability to obtain suitable calibration and validation using monitored storm events. Figure 14 shows a comparison of measured and simulated hydrographs for a half-inch rainfall event on 14 May, 2009, and Figure 15 shows a similar comparison for a 0.95 inch rain event that was spread over three days during 4-6 June, 2009. Excellent correspondence is obtained for the calibration event, and good comparisons are achieved for the validation event. It is interesting to note that the model calibrated using a fairly intense rain storm over a few hours performed well in modeling a low intensity storm spread over three days.

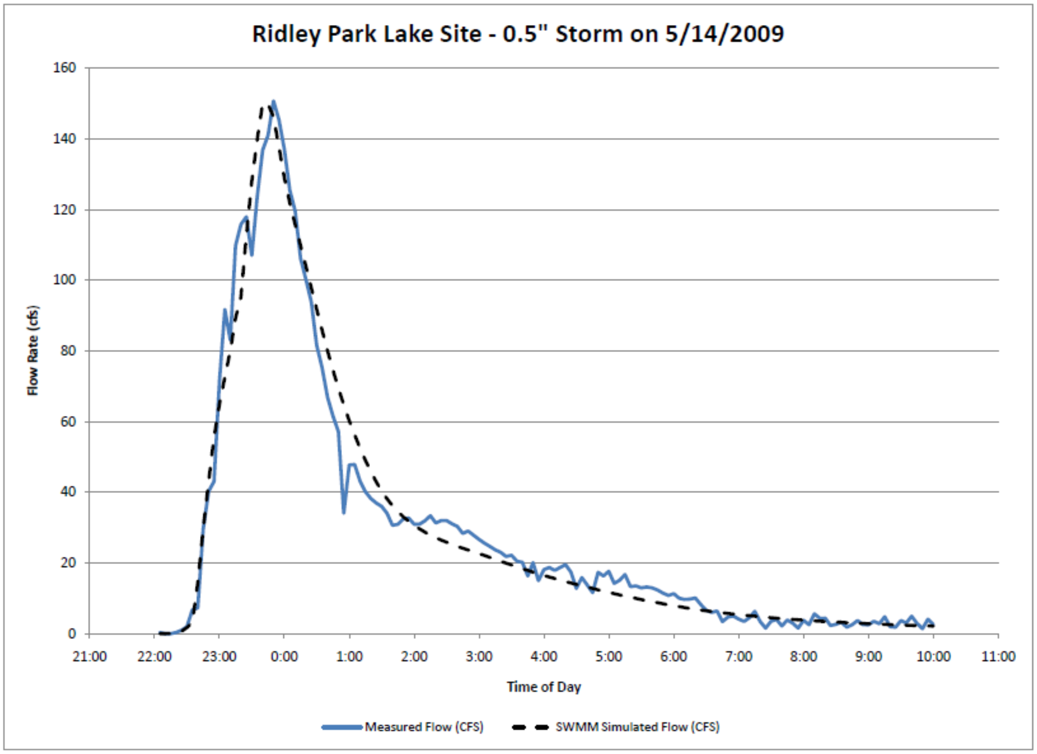

Figure 14. Measured and Simulated Flow Hydrograph at Ridley Park Lake for the SWMM model <u>calibration</u> rain event on 14 May, 2009.

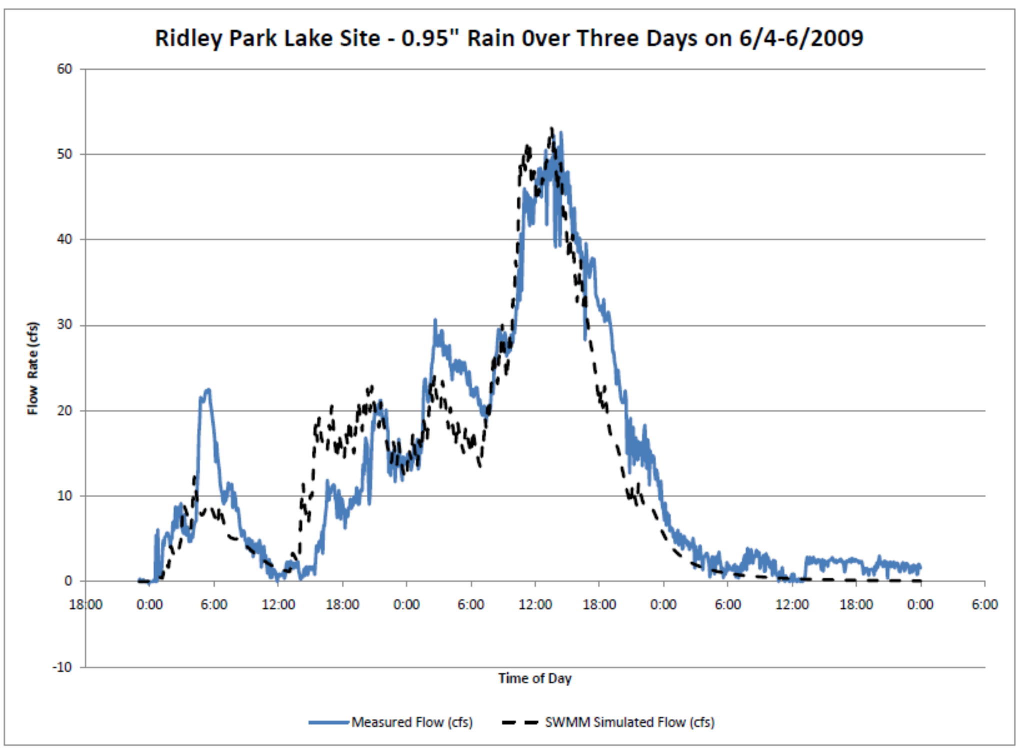

Figure 15. Measured and Simulated Flow Hydrograph at Ridley Park Lake for the SWMM model <u>validation</u> three-day rain event on 4-6 June, 2009 using parameters calibrated by the event on 14 May, 2009.

Nonpoint Pollutant Load Simulation using SWMM. The SWMM model can also calculate nonpoint pollutant loads. We have used our field data to calibrate the SWMM model for the Ridley Park Lake site so that SWMM can be used to examine reductions in pollutant loads resulting from site-specific watershed improvements. Our ISCO™ automated samplers have the ability to capture up to 24 water samples in a bottle carousel during a rain event. These bottles must be taken to our laboratory at Swarthmore College for analysis of pollutant concentrations. At the Ridley Park Lake site, sampling was triggered by an increase flow depth that indicated a rain event was in progress. A 500 mL sample bottle was filled every 30 minutes until the stream depth returned to the base level or until all 24 bottles were filled. In the laboratory, each sample was tested for turbidity and for concentrations of total suspended solids (TSS), Nitrate Nitrogen (NO_3-N), and Phosphate (PO_4). All results below for nutrient pollution are in terms of Nitrate Nitrogen and Phosphate, rather than Total Nitrogen and Total Phosphorous, so that we could use these conveniently measured chemical species for our model calibrations.

Our Nitrate Nitrogen and Phosphate readings at Ridley Park Lake site showed no clear pattern of variation during the course of a rain event. However, TSS readings showed strong correlation with the flow rate in the stream because of the significant contribution to sediment loads from stream channel erosion in this watershed. In order to accurately model these two different modes, we used two different options available in SWMM for modeling nonpoint pollution. For the nutrients (Nitrate Nitrogen and Phosphate), we used the Event Mean Concentration technique which involves calculating flow-weighted averages of the concentrations obtained in the laboratory. These concentrations appear directly in the simulation model as parameters and are shown in Table 13.

For simulation of sediment loading, we used SWMM's Rating Curve technique which scales the pollutant mass loading rate to the runoff volumetric flow rate generated by each subcatchment using a power law function: $m = C_1Q^{C2}$ where m is the mass loading rate, Q is the volumetric flow rate, and C_1 and C_2 are calibration constants. For the Ridley Park Lake site, C_1 and C_2 were determined using two rain events (16 and 19 December, 2008) for which we had measurements of total sediment load. The values of C_1 and C_2 giving suitable accuracy for both events are shown in Table 13.

Table 13. SWMM Parameters for Nonpoint Pollutant Load Simulation

	Sediment		Nitrate Nitrogen	Phosphate
Parameter Value Used in SWMM	$C_1^{\#}$	C_2^{+}	EMC* (mg/L)	EMC* (mg/L)
	314	1.45	0.75	0.17

- Rating Curve Coefficient   + - Rating Curve Exponent   * - Event Mean Concentration

Table 14 shows the total measured and simulated sediment loads (in tons) for the 16 and 19 December, 2008 events that were used to set the values for C_1 and C_2. The 16 December event was a low intensity storm with 0.65 inches of precipitation occurring over a period of 18 hours and a maximum rainfall intensity of 0.25 inches per hour. The 19 December event had an intense pulse of rain at the beginning, peaking briefly at an intensity of 2.75 inches per hour, and most of the storm's 0.47 inches fell within 45 minutes. This pulse behavior produced a brief period of very high TSS concentration resulting in higher total sediment load for this event that occurred in the 16 December event which had greater total precipitation.

Table 14. Rain Event Total Sediment Loads at Ridley Park Lake Site: Measured and Simulated

Date	Rainfall Total (inches)	Measured Load (tons)	Simulated Load (tons)
12/16/2008	0.65	2.01	2.03
12/19/2008	0.47	3.49	3.45

Task 3. Identify and prioritize improvement projects.

Creation of the Little Crum Creek Priority Project Database. A Low Impact Development (LID) Best Management Practice (BMP) database was created and a web site established to enable convenient access by watershed stakeholders and municipal officials. The prioritization process began with our Phase 1 study which applied McGarity's Storm Water Investment Strategy Evaluator (StormWISE) model to the watershed. Combining results from StormWISE modeling, stakeholder input, and monitoring program, the database was created (using XML web-based data technology to facilitate updates) for use by the Little Crum Creek Partnership and hosted on Swarthmore College's Watershed web site. The database contains extensive information on high priority project sites including GPS coordinates, location in the watershed, close-up aerial imagery, BMP and land preservation recommendations, and downstream sites affected. The database was made available online to inform the public about the results of this project and to solicit review comments. The database will be revised and updated as necessary as the Little Crum Creek Action Plan evolves. As of the publication date of this report, the database contains information on 12 sites: two in Ridley Park, three in Ridley Township, three in Springfield Township, and four in Swarthmore. A total of 18 projects are recommended for the 12 sites.

Appendix C presents the current contents of the database, including maps and aerial images of the sites. For the site evaluations in this report, costs have been estimated based on the unit area costs developed for the Phase 1 report.

Sites, Projects, Contributing Areas, and Costs. Table 15 lists the 12 sites and the 18 recommended high priority projects including estimates of the contributed area served and costs for each project.

Project Prioritization, Funding, and Implementation. All of the projects in the database have potential to generate significant, cost effective water quality, natural habitat, and recreational benefits in the Little Crum Creek watershed, as determined by our Phase 1 study. Some will require public funding in the form of grants and subsidies to property owners. Others may be achieved through enforcement of new stormwater ordinances required by future state and federal regulatory action that results from the impaired status of Little Crum Creek through enforcement of the federal Clean Water Act. In the case of low intensity residential developments, some implementation of rain barrel and rain garden projects may be achieved by public education and volunteer labor.

In Task 4, we use our calibrated SWMM model to calculate certain benefits related to reduction of runoff volume and nonpoint pollution. This analysis can further inform the process of setting priorities.

Table 15. Recommended High Priority Projects by Municipality and Site

Municipality	Site	Project	Area Served (acre)	Cost per Acre ($1000)	Total Cost (Million$)
Ridley Park	Middle and Elementary Schools	**RP_1A:** Green Roofs	3.3	520	1.72
Ridley Park	Low Intensity Residential	**RP_2A:** Disconnect Downspouts, Rain barrels, Rain Gardens	103#	6.3	0.65@
Ridley Twp.	Ridley Shopping Center	**RT_1A:** Green Roofs on buildings	6.6	520	3.43
Ridley Twp.	Ridley Shopping Center	**RT_1B:** Bioretention islands in parking lot (with infiltration)	31	34	1.04
Ridley Twp.	Planned Super Wawa Convenience Store	**RT_2A:** Constructed wetland sized to treat upstream runoff from Ridley Shopping Center	31	8.4	0.26
Ridley Twp.	Planned Super Wawa Convenience Store	**RT_2B:** Stream bank restoration below site	0.5	24	0.01
Ridley Twp.	Low Intensity Residential	**RT_3A:** Disconnect Downspouts, Rain barrels, Rain Gardens	524#	6.3	3.28@
Springfield Twp.	Springfield Square Shopping Center	**SP_1A:** Green Roofs on buildings	2.4	520	1.25
Springfield Twp.	Springfield Square Shopping Center	**SP_1B:** Bioretention islands in parking lot (with infiltration)	14.7	33.6	0.49
Springfield Twp.	Farmhouse Circle Dry Detention Basin	**SP_2A:** Convert to Constructed Wetland	52	8.4	0.44
Springfield Twp.	Low Intensity Residential	**SP_3A:** Disconnect Downspouts, Rain barrels, Rain Gardens	142#	6.3	0.89@
Swarthmore	Swarthmore Swim Club	**SW_1A:** Restoration of wetland and stream bank	0.5	24	0.01
Swarthmore	Swarthmore Swim Club	**SW_1B:** Constructed Wetland achieving partial treatment of upstream runoff from Springfield	4	8.4	0.03
Swarthmore	Business District	**SW_2A:** Green Roofs	2.8	520	1.46
Swarthmore	Business District	**SW_2B:** Porous Pavement	4.1	367	1.51
Swarthmore	Riparian Zone	**SW_3A:** Restoration throughout Borough	49	8.8	0.43
Swarthmore	Riparian Zone	**SW_3B:** Conservation Easements at Rutgers Ave. School and Harvard Ave. Right of Way	26	1.8*	0.05
Swarthmore	Low Intensity Residential	SW_4A: Disconnect Downspouts, Rain barrels, Rain Gardens	467#	6.3	2.93@
				TOTAL FOR ALL PROJECTS:	**18.82**

* - Conservation easement cost includes costs of administering and monitoring easements, but exclude the cost of the land which is assumed to be donated (based on our Phase 1 report, McGarity, et al., 2009)
# - Acreage having Low Intensity Residential land use that drains into watershed above Ridley Park Lake.
@ - Total costs for low intensity residential rain barrels and rain gardens assume 100% participation by residents. Anticipated participation is more likely to be in the range 10-25% in the near term. Alternative costs can be calculated by scaling these results by estimates of percentage participation.

Task 4. Evaluate specific projects while focusing on flood mitigation, stream restoration, riparian buffers, open space, and stormwater best management practices.

To accomplish Task 4, we use the EPA Storm Water Management Model (SWMM), that is used in Task 2 for assessment of stream and watershed conditions, to analyze the downstream impacts of 15 projects that are amenable to modeling in the LID/BMP database, developed in Task 3. SWMM configurations were developed for each of the individual LID/BMP projects and were integrated into the watershed model to predict the reductions in loadings. Decreases in total runoff volumes and three kinds of pollutant loads were calculated in terms of the loads conveyed by storm sewers and streams into the lake. Guidance on modeling LID/BMP technologies was obtained from the recently published SWMM Application Manual (Gironas, et al., 2009).

Annual calculations using continuous simulation. The SWMM calibration and validation runs performed for Task 2 were for specific storm events, for which we have our own precipitation data taken within the watershed. For Task 4, we need to simulate an entire year using precipitation data for all four seasons as well as the dry periods between rain events. Since we do not have an entire year of continuous precipitation data from our own observations, we used a year of data for Philadelphia obtained from the National Weather Service. Our continuous simulations were run with hourly precipitation data for the entire year of 2008, the most recent complete year available. Table 16 shows the annual runoff and pollutant loadings obtained from the continuous simulations.

Table 16. Total Loadings Calculated by SWMM using Continuous Simulation for a Full Year

	Loads Generated on Land in the Watershed Above Ridley Park Lake (Annual)				**Loads Conveyed to Ridley Park Lake (Annual)**			
	Runoff (10^6 gal)	Sediment (ton)	NO_3-N (lb)	PO_4 (lb)	Volume (10^6 gal)	Sediment (ton)	NO_3-N (lb)	PO_4 (lb)
Existing Loadings at Ridley Park Lake	1,045	173	6,564	1,462	1,036	174	6,500	1,448

Project Performance and Cost Evaluations for Prioritization. Table 17 shows the results of continuous annual SWMM runs for the 15 projects that can be simulated. The annual reductions in total annual flow volume (million gallons), sediment load (tons), Nitrate (NO_3) load (pounds), and Phosphate (PO_4) load (pounds) were calculated by comparing the baseline loadings in Table 16 with the revised loadings calculated by SWMM with each of the LID/BMP projects in place. The capital cost of each project, taken from Table 15 was annualized using a project lifetime of 20 years and an interest rate of 5% to determine the entries in the "Annual Cost" column. Then, cost effectiveness measures were calculated for runoff volume and sediment by dividing the annual costs by the annual load reductions to produce results in $ per 1000 gallons of runoff reduction and $ per pound of sediment reduction. It is very important to note that these results consider only the water quality benefits at Ridley Park Lake. These projects will generate additional benefits to the communities such as aesthetic improvements in residential neighborhoods enhancing property values and reduced energy consumption and roof maintenance for businesses that install green roofs on their buildings.

Table 17. LID/BMP Project Evaluations Based on Performance and Cost

BMP Option and Combinations	Decreases in Loads Conveyed to Ridley Lake				Cost Comparisons			
	Volume (10^6 gal)	Sediment (ton)	NO_3 (lb)	PO_4 (lb)	Capital Cost (10^6 \$)	Annual Cost (\$)	Runoff (\$/1000 gal)	Sediment (\$/pound)
Ridley Park Borough:								
RP_1A Green Roofs on Schools	4	1.0	23	5	1.72	137,754	38.28	66.75
RP_2A Residential Low Impact Retrofit	78	12.9	490	109	0.65	51,810	0.66	2.01
Ridley Township:								
RT_1A Shopping Ctr Green Roof	4	0.4	22	5	3.43	275,232	77.82	309.25
RT_1B Shopping Ctr Bioretention	27	3.0	172	38	1.04	83,452	3.04	13.75
RT_2A Super Wawa Constructed Wetland	13	2.9	118	28	0.26	20,863	1.59	3.56
RT_3A Residential Low Impact Retrofit	297	39.2	1,866	416	3.28	263,576	0.89	3.36
Springfield Township:								
SP_1A Springfield Sq Green Roof	2	0.19	15	3	1.25	100,303	43.20	266.09
SP_1B Springfield Sq Bioretention	2	0.46	12	3	0.49	39,319	20.13	42.93
SP_2A Farmhouse Circle / PECO Energy Constructed Wetland	9	3.0	110	29	0.44	35,307	4.14	6.27
SP_3A Residential Low Impact Retrofit	66	6.0	413	92	0.89	71,416	1.09	5.54
Swarthmore Borough:								
SW_1B Swarthmore Swim Club Constructed Wetland	6	0.75	40	9	0.03	2,407	0.38	1.62
SW_2A Swarthmore Business District Green Roofs	3	0.52	19	4	1.46	117,154	38.24	112.08
SW_2B Swarthmore Business District Porous Pavement	4	0.75	28	6	1.51	121,166	27.08	80.45
SW_3A Swarthmore Riparian Zone Restoration	56	9.48	354	79	0.43	34,504	0.62	1.82
SW_4A Residential Low Impact Retrofit	181	19.1	1,135	253	2.93	235,111	1.30	6.15

Recommendations and Conclusions

Municipal stormwater regulations alone are not likely to achieve federal clean water goals, especially in the case of in urban and suburban watersheds impaired by stormwater runoff. In Pennsylvania, stormwater regulations differ widely depending on the municipality, and they are applied to individual projects with little regard for the overall watershed impacts.   Thus, it is difficult to develop an effective watershed-based stormwater management strategy in watersheds that drain multiple municipalities, as is usually the case in southeastern Pennsylvania. In the impaired Little Crum Creek watershed in suburban Philadelphia, the nonprofit Chester-Ridley-Crum Watersheds Association (CRCWA) serves as the main advocate for the watershed and has taken on the challenge of getting municipalities to work together towards achieving water quality goals.

Swarthmore College is working closely with CRCWA and their municipal partners to apply methods of systems analysis for watershed management to create an action plan for the watershed. This plan must be designed to achieve measurable results in the short-run. It must also be cost effective because its implementation will depend largely on funding from grants and on voluntary cooperation among the municipalities to "push the envelope" beyond the minimum requirements of their stormwater regulations. This report describes the second phase of a multi-year effort to apply state-of-the-art watershed management tools to develop an action plan for the Little Crum Creek Watershed that will show how resources from all available sources can be directed towards projects in the four municipalities that will improve water quality through cost-effective investments in best management practices and retrofit low-impact development.

This report demonstrates that our Phase 2 project successfully completed four main work elements:

1. Perform a geomorphic assessment of Little Crum Creek, a review of available open space, and a review of non-point source pollution.
2. Perform an assessment of stream and watershed conditions.
3. Identify and prioritize improvement projects.
4. Evaluate specific projects while focusing on flood mitigation, stream restoration, riparian buffers, open space, and stormwater best management practices.

Our recommendations for the Little Crum Creek Action Plan were developed in Tasks 3 and 4 and are summarized in Tables 15 and 17, with details provided in Appendix C.   We recommend that serious consideration be given to each of the 18 projects described in Table 15. Our analysis focuses on loadings at Ridley Park Lake because that is where the effects of excessive runoff and pollutant loads are most severe, with frequent dredging of accumulated sediments is required at substantial cost. We emphasize that additional benefits to the communities will result from these projects including aesthetic improvements in residential neighborhoods enhancing property values and reduced energy consumption and roof maintenance for businesses that install green roofs on their buildings.

It is important to realize that none of these projects are likely to be required by existing municipal storm water regulations. However, since Little Crum Creek has been designated as "impaired" because of storm water runoff, it does not satisfy federal water quality standards, and implementation of corrective measures throughout the watershed will be necessary in the not-too-distant future. The four municipalities have an opportunity at present to take control of the process by developing their own strategy to remove Little Crum Creek from the impaired list before potentially less desirable alternatives are imposed by the state and federal governments. We hope that the results of our multi-year study will stimulate a process that leads to the development and implementation of stormwater management projects, throughout the watershed, and a revived Little Crum Creek with clean streams supporting a high quality of life, scenic neighborhoods, and a healthy natural habitat.

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<u>Appendix A</u>. Public Participation and Review in Developing Little Crum Creek Watershed Action Plan under CZM Grant

The following is a list of public outreach activities conducted during the grant period through January 2010, for the purpose of obtaining public input into and review of the nonpoint source model for Little Crum Creek and for use in compiling the Little Crum Creek Watershed Action Plan. Reported by A. Murphy for the Chester- Ridley- Crum Watersheds Association and A. McGarity of Swarthmore College.

1. Little Crum Creek Stakeholders Meeting, Little Crum Creek Watershed Action Plan, November 20, 2008, Swarthmore Borough Hall, 7:30 PM. Sponsored by Little Crum Creek Watershed Partnership . 50 attended, primarily residents of Little Crum Creek or Crum Creek watershed.

2. Research posters by Swarthmore College engineering students in the course "Water Quality and Pollution Control" working on various aspects of the nonpoint source modeling for Little Crum Creek Watershed Plan and Model, displayed at Swarthmore Borough Hall, November 20, 2008 with oral presentations by students before the meeting.

3. Little Crum Creek Stakeholders Meeting, Little Crum Creek Watershed Action Plan, April 30, Ridley Township Hall, 7:00 PM. Sponsored by Little Crum Creek Watershed Partnership. 15 attended, primarily residents of Little Crum Creek watershed.

4. Research posters and oral presentations by Swarthmore College senior engineering design students following the Little Crum Creek Stakeholders Meeting, April 30, 2009.

5. Senior engineering design project formal presentations for evaluation by Swarthmore College engineering faculty and open to the public May 5-6, 2009:

   a. James Nakamura and Nicolas Villagra, "Modeling Urban Stormwater Runoff in the Little Crum Creek Watershed."

   b. Karina Navarro, "A Land Conservation Extension of the StormWISE Model."

   c. Susan Willis, "Development of a Computer-Based Nonpoint Source Loading Model for Small Suburban Watersheds."

6. Meeting about stormwater management at the future Ridley Wawa convenience store site with representatives from Bohler Engineering, Wawa Dairy, CRCWA, Ridley Township, Harper Realty, and Swarthmore College, January 28, 2009 at Ridley Township Municipal Building.

7. Future Public Stakeholder Meeting: at Swarthmore Borough Hall, scheduled for March 4, 2010.

8. Research papers submitted for presentation at professional conferences during 2009-10.

   a. Arthur E. McGarity, "Multiobjective Optimization Combining BMP Technology and Land Preservation for Watershed-based Stormwater Management," presented at the 2009 Fall Meeting of the American Geophysical Union, 14-18 December, 2009, San Fransisco, California.

   b. Arthur E. McGarity, "Watershed-based Optimal Stormwater Management Part 1: Application of StormWISE to the Little Crum Creek in Suburban Philadelphia," submitted for presentation and inclusion in the proceedings of the American Society of Civil Engineers World Environmental and Water Resources Congress 2010, May 16-20, 2010, Providence, Rhode Island.

c. Zachary Eichenwald and Arthur E. McGarity, "Watershed-based Optimal Stormwater Management Part 2: Hydrologic Modeling of LID/BMP Sites on Little Crum Creek in Suburban Philadelphia," submitted for presentation and inclusion in the proceedings of the American Society of Civil Engineers World Environmental and Water Resources Congress 2010, May 16-20, 2010, Providence, Rhode Island.

d. Susan K. Willis and Arthur E. McGarity, "A Computer-Based Nonpoint Source Pollutant Loading Model for Small Suburban Watersheds: Swarthmore Subwatershed-scale Suburban Nonpoint Source Pollutant Loading Model," submitted for presentation and inclusion in the proceedings of the American Society of Civil Engineers 2010 Watershed Management Conference, August 23-27, 2010, Madison, Wisconsin.

<u>Appendix B</u>. SWMM Model Maps for Modeled Sites

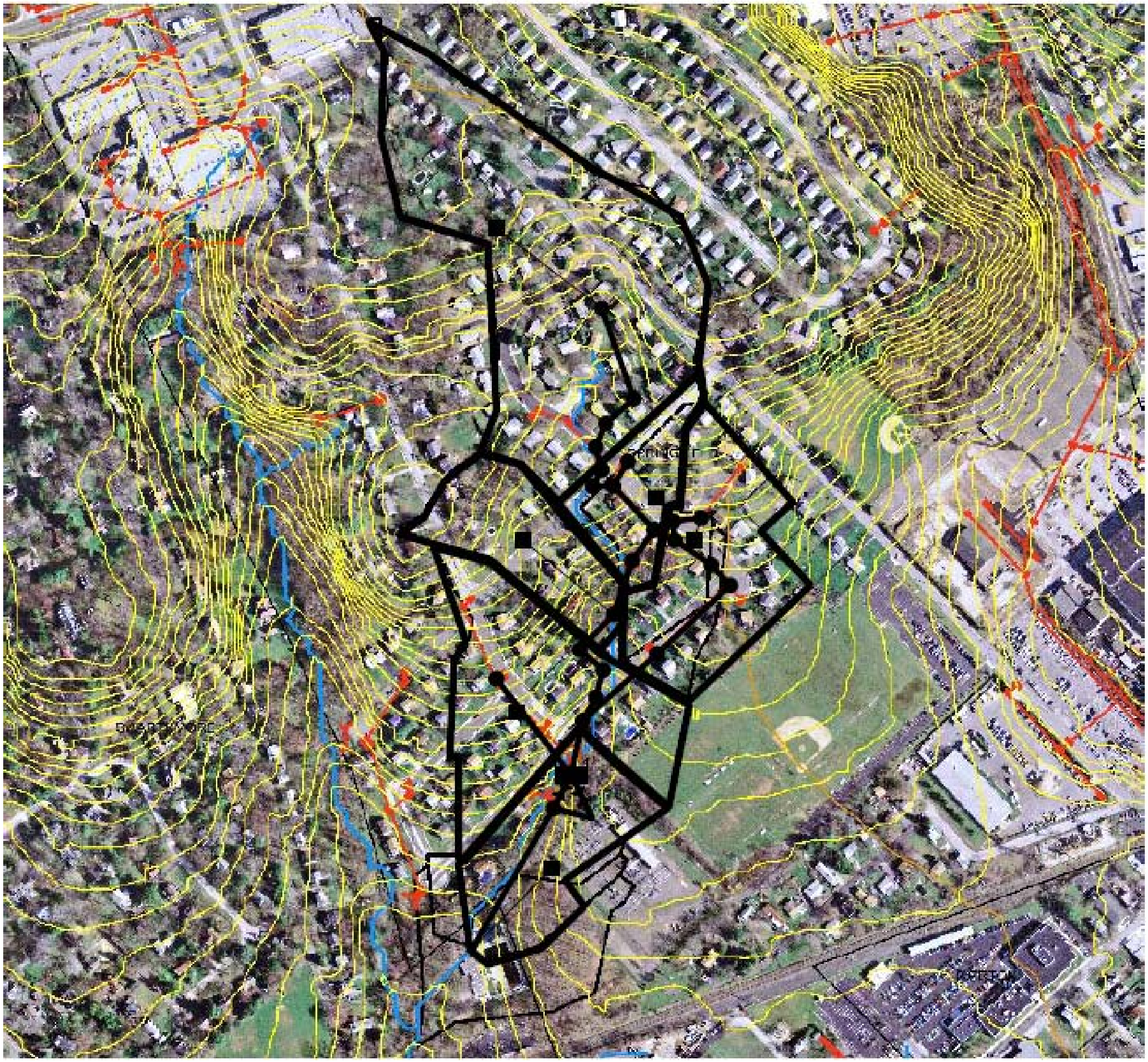


Figure B.1<u>. Swarthmore Swim Club Site</u> draining Subcatchment 4 with background satellite image, elevation contours and storm sewers. The five sub-drainage zones modeled in the SWMM simulation are shown along with the conduits (mostly enclosed storm sewers) and the retention basin (black rectangle) at Millison Drive and Lincoln Ave. in Springfield.

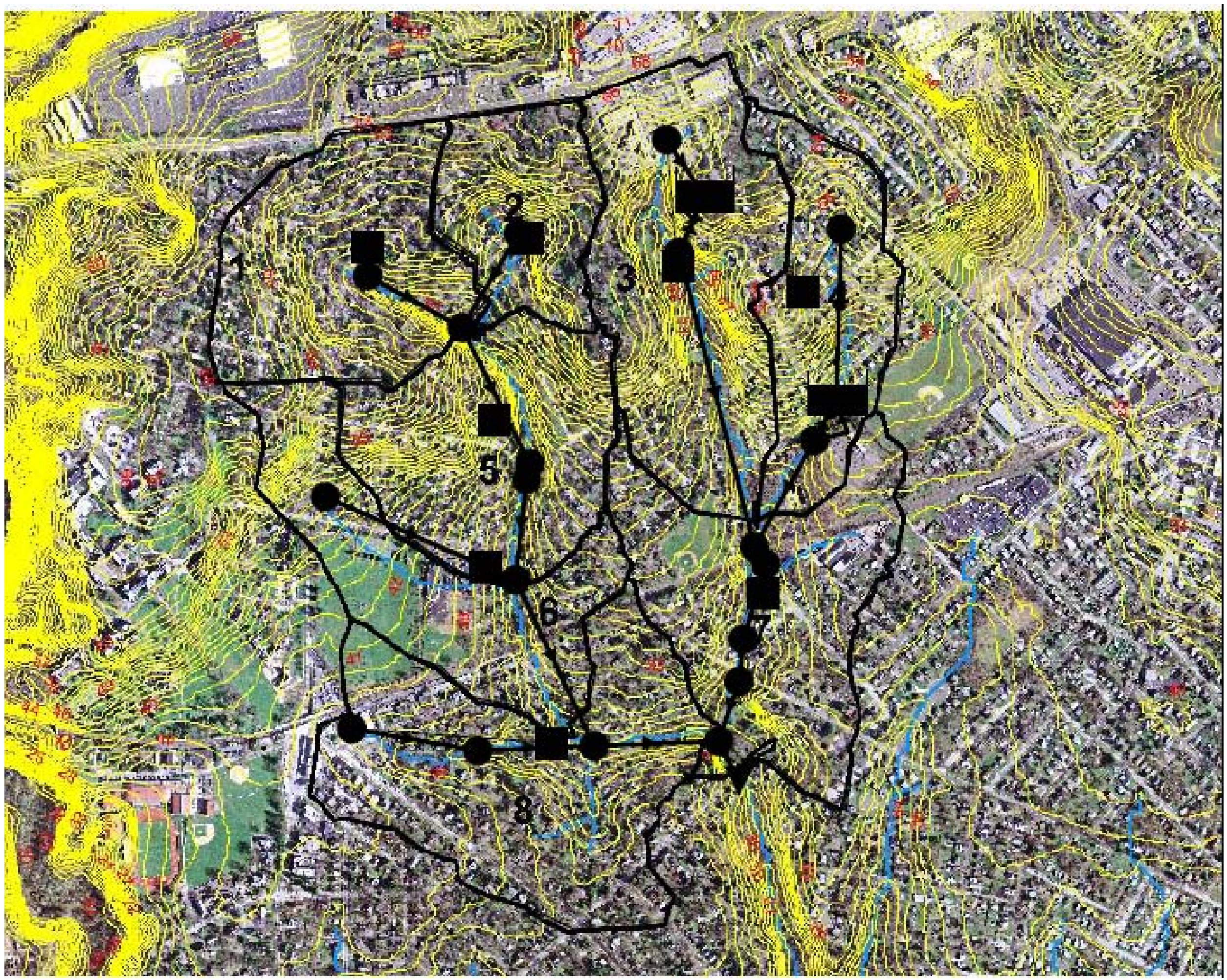


Figure B.2. **<u>Little Crum Creek Park Site</u> with background satellite image showing elevation contours and the eight SWMM subcatchments modeled (including subcatchment 4 shown in Figure B.1), conduits (a mix of storm sewers and stream channels), and retention basins at Millison Drive and Lincoln Ave. in Springfield and at Springfield Square shopping center on Baltimore Pike in Springfield.**

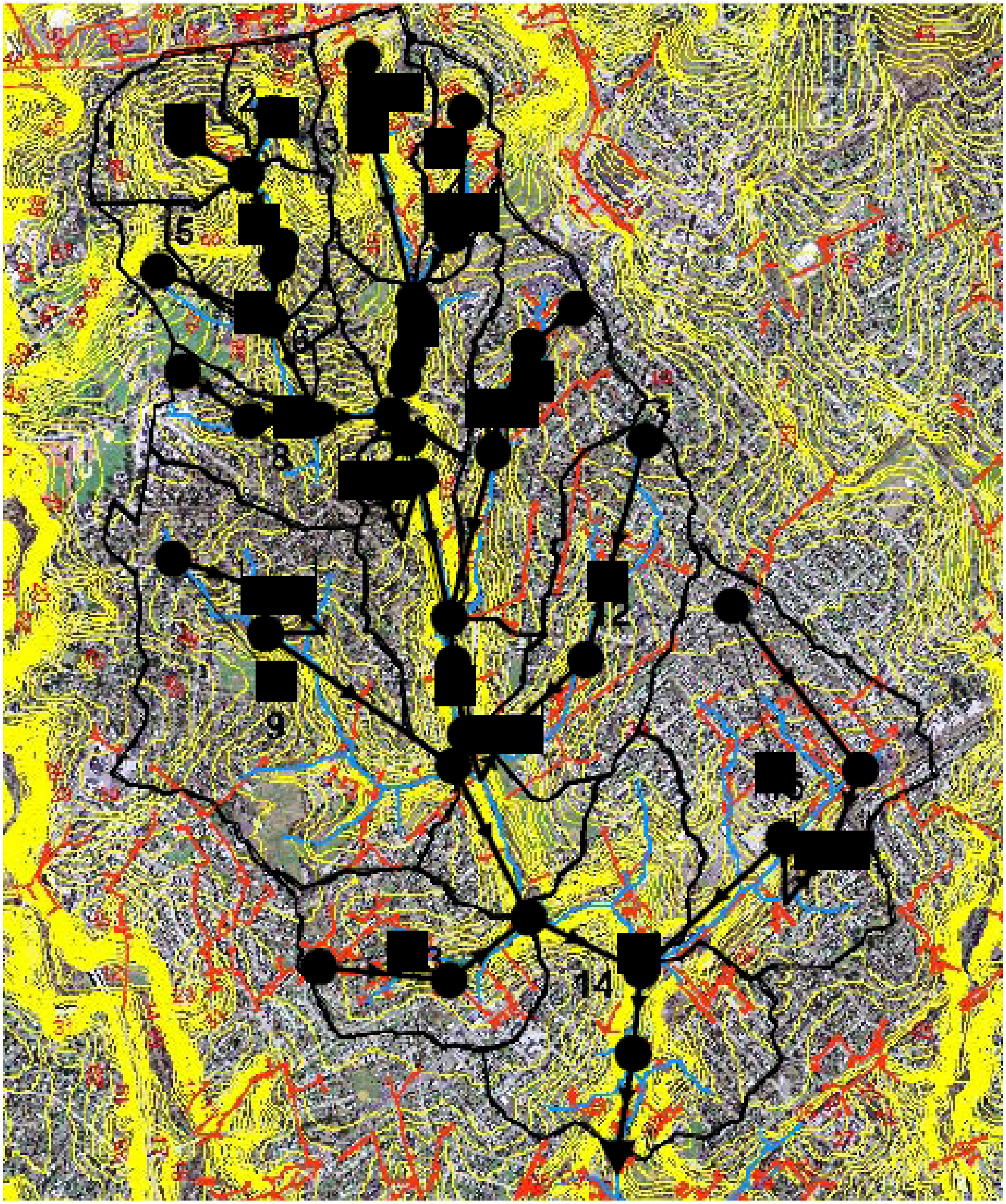


Figure B.3. Ridley Park Site with background satellite image showing elevation contours and the 15 SWMM subcatchments modeled (including the areas drained by the Swim Club and Little Crum Creek Park sites), conduits (a mix of storm sewers and stream channels), and retention basins at various sites throughout the watershed. Some retention basin sites and sizes were estimated as part the SWMM model calibration process. A comprehensive survey of retention basins throughout the watershed was not conducted.

Appendix C. Little Crum Creek Watershed Improvements Database

The contents of the database as of January 30, 2010 are presented here. The reader may wish to view the database online, where it is fully interactive, using the internet link: http://watershed.swarthmore.edu/littlecrum/Little_Crum_BMP.htm. The database will be updated as necessary to incorporate revisions resulting from stakeholder involvement. If this report is being read online, the images accessed through the hyperlinks imbedded in this document may be active, depending on whether the reader has access to the internet. The images are also included here as figures in case the hyperlinks are not active and for hardcopy versions of this report.

Municipality: Ridley Park Borough

1. **Site:** Ridley Middle and Elementary Schools
   Map of Location in Watershed (click to view or see Fig. C.1 - site outlined in red)
   Aerial Image of Site (click to view or see Fig. C.1 - site outlined in red)
   Coordinates - Latitude: 39d_52m_42s NORTH, Longitude: 75d_19m_45s WEST
   Elevation: 70 ft
   Hydrologic Zone: lowlands
   Riparian? : yes
   - **BMP:** Green Roofs on flat roofs of school buildings
     Infiltration? : no
     Contributing Area: 3.0 (acre)
     Benefits:
       - Volume Reduction
       - Energy Savings
       - Heat Island Reduction

     Comment: Green roof is ideally suited for large flat roofs. Roof lifetime is extended significantly which reduces future maintenance expenses.

   - **BMP:** Bioretention
     Infiltration? : possible depending on site tests
     Contributing Area: 3.3 (acre)
     Benefits:
       - Volume Reduction
       - Groundwater Recharge
       - Pollutant Washoff Reduction
       - Enhanced Evapotranspiration

     Comment: Parking lots well suited for bioretention islands with evapotranspiration

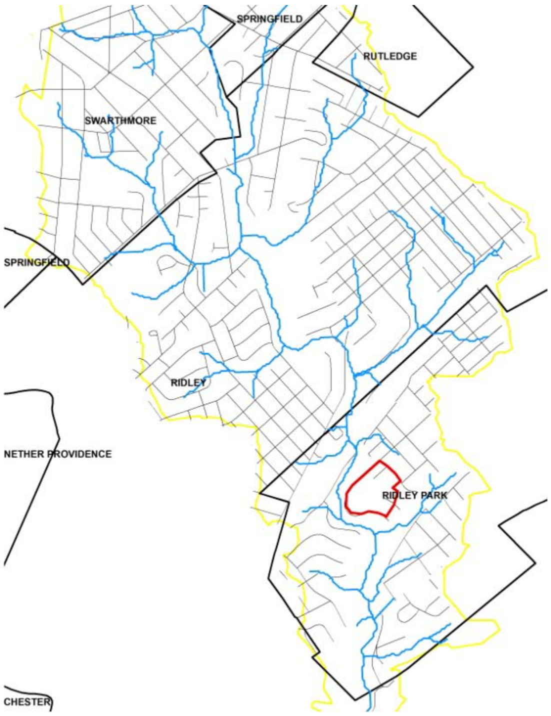
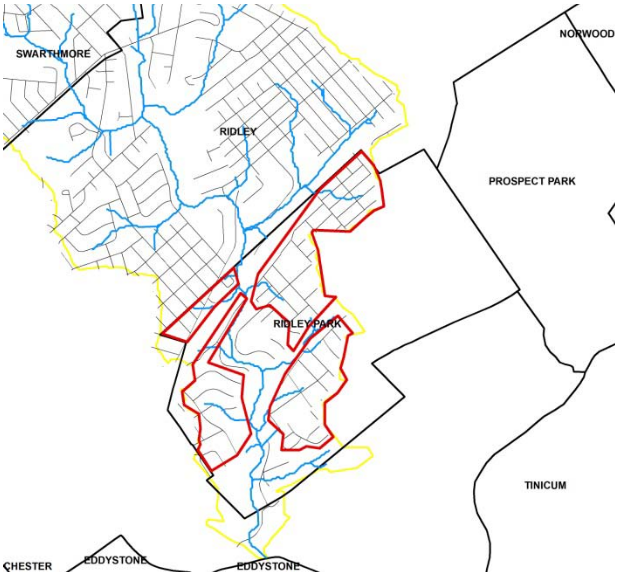


Figure C.1. Map and Image of Ridley Middle School Site

2. **Site:** Low Intensity Residential Developments
   [Map of Location in Watershed](click to view or see Fig. C.2 - site outlined in red)
   [Aerial Image of Site](click to view or see Fig. C.2 - site outlined in red)
   Coordinates - Latitude: 39d_52m_50s NORTH, Longitude: 75d_19m_41s WEST
   Elevation: 85 ft
   Hydrologic Zone: headwaters and lowlands
   Riparian? : partially
   - **BMP:** Disconnect Downspouts from Storm Sewer
     Infiltration? : yes, in headwaters sections
     Contributing Area: 228 (Acres) of which 103 acres drain into Ridley Park Lake
     <u>Benefits:</u>
     - Runoff Volume Reduction
     - Water Quality
     - Pollutant Washoff Reduction
     - Enhanced Evapotranspiration

     Comment: Develop a program in the Borough to encourage and subsidize private residential land owners to install rain barrels and rain gardens and to connect roof gutters and other drains to them while disconnecting them from the storm sewer system.



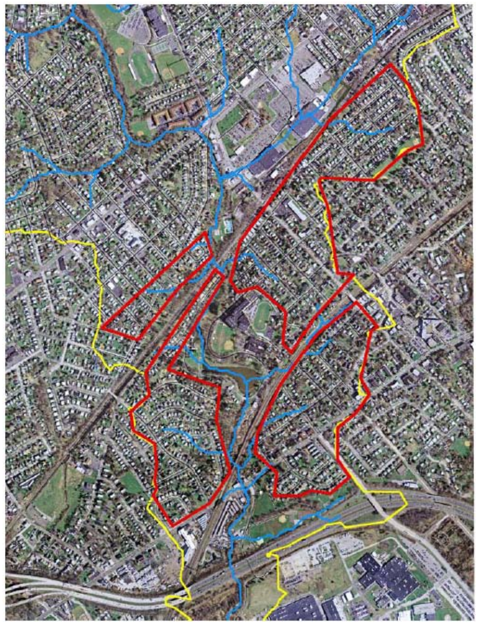


Figure C.2. Map and Image of Ridley Park Low Intensity Residential Developments that drain into Little Crum Creek

Municipality: Ridley Township

1. **Site:** Ridley Shopping Center (Home Depot, Acme, Staples, Pathmark, etc.)
   Map of Location in Watershed (click to view or see Fig. C.3 - site outlined in red)
   Aerial Image of Site (click to view or see Fig. C.3 - site outlined in red)
   Coordinates - Latitude: 39d_53m_11.5s NORTH, Longitude: 75d_19m_38.4s WEST
   Elevation: 78 ft
   Hydrologic Zone: lowlands
   Riparian? : yes
   - **BMP:** Green Roofs on flat roofs of commercial buildings
     Infiltration? : no
     Contributing Area: 6.6 (acre)
     <u>Benefits:</u>
       - Volume Reduction
       - Energy Savings
       - Heat Island Reduction

     Comment: Green roof is ideally suited for large flat roofs.

   - **BMP:** Bioretention
     Infiltration? : no
     Contributing Area: 14.7 (acre)
     <u>Benefits:</u>
       - Volume Reduction

- Groundwater Recharge
- Pollutant Washoff Reduction

Comment: Parking lot well suited for bioretention islands with evapotranspiration.

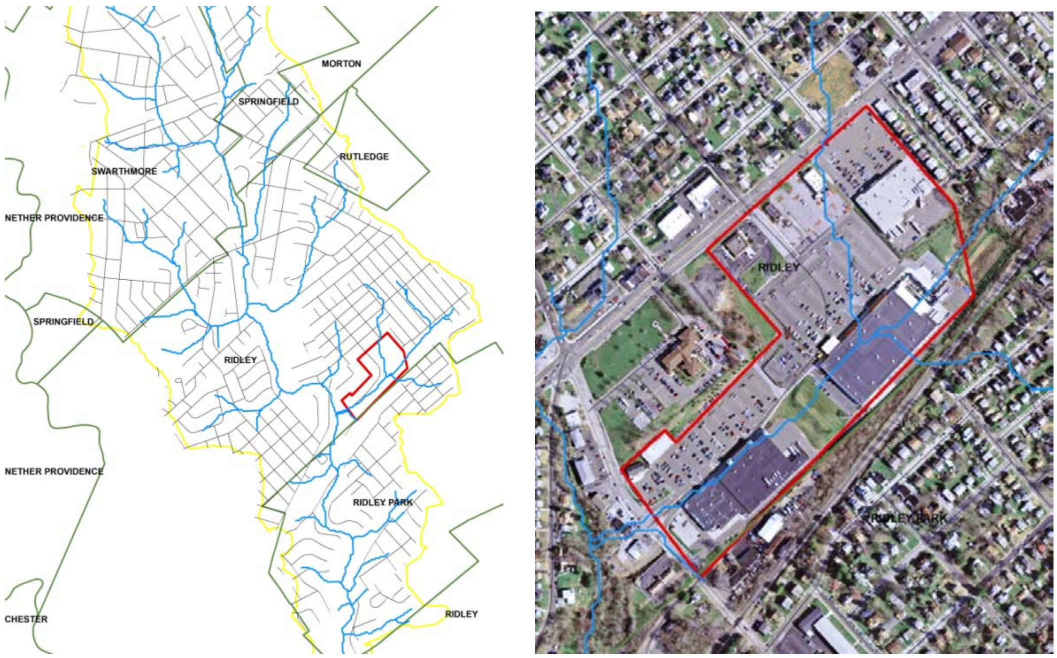


Figure C.3. Map and Image of Ridley Shopping Center

2. **Site:** Harper Realty Planned Super Wawa Site
   Map of Location in Watershed (click to view or see Fig. C.4 - site outlined in red)
   Aerial Image of Site (click to view or see Fig. C.4 - site outlined in red)
   Coordinates - Latitude: 39d_53m_1.5s NORTH, Longitude: 75d_19m_48.5s WEST
   Elevation: 54 ft
   Hydrologic Zone: lowlands
   Riparian? : yes
   - **BMP:** Constructed wetland or wet detention pond
     Infiltration? : yes
     Contributing Area: 33 (acre)
     Benefits:
       - Peak Flow Reduction
       - Stream Channel Erosion Reduction
       - Pollutant Washoff Reduction

     Comment: The size of the proposed stormwater retention facilities can be increased beyond that required by the municipal ordinances to also capture excess upstream runoff generated by Ridley Shopping Center to reduce sediment loads and protect the stream from excessive bank erosion.

- **BMP:** Restoration of stream bank downstream of new Wawa site
  Infiltration? : no
  Contributing Area: 0.5 (acre)
  <u>Benefits:</u>
    - Riparian Habitat Restoration and Preservation
    - Water Quality
    - Enhanced Evapotranspiration

  Comment: New commercial property will cover the channel of a major tributary to Little Crum Creek. But significant stream length downstream of the site exists on property owned by the developer. In this area, the stream banks can be restored to their natural state rather than enclosing them in concrete. These projects can help to compensate for habitat loss in covering the stream channel.

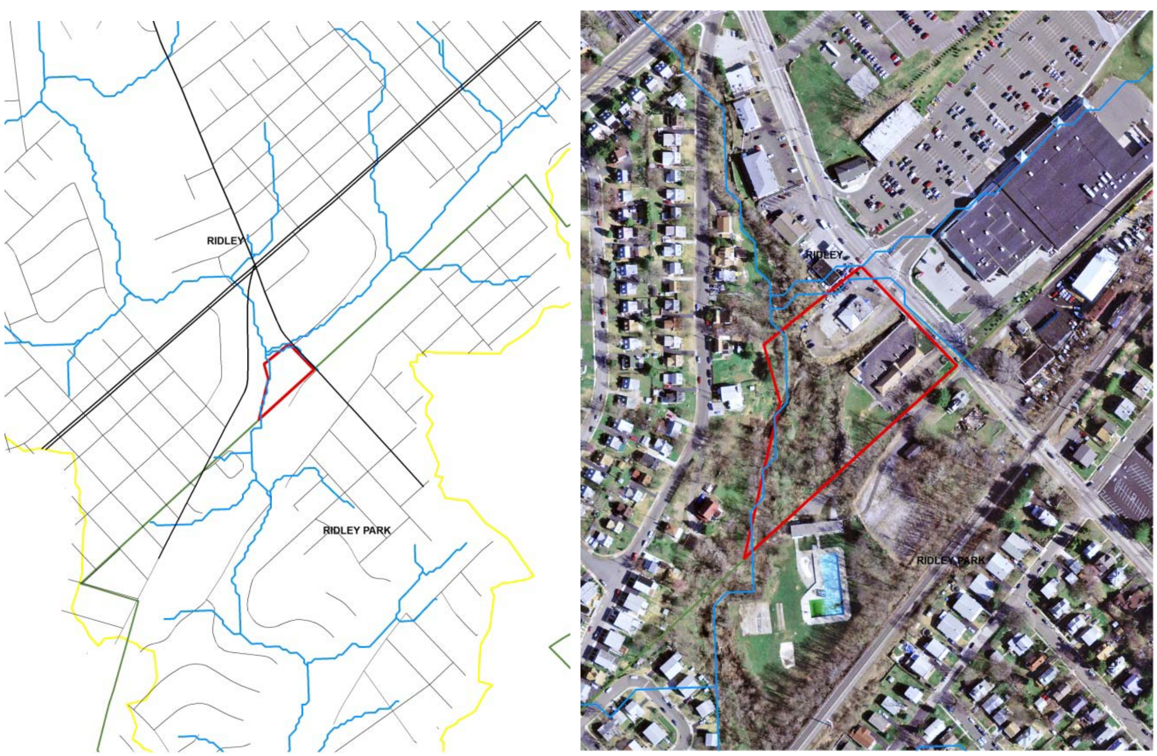


Figure C.4. Map and Image of Harper Realty Planed Super Wawa Site

3. **Site:** Low Intensity Residential Developments
   Map of Location in Watershed (click to view or see Fig. C.5 - site outlined in red)
   Aerial Image of Site (click to view or see Fig. C.5 - site outlined in red)

Coordinates - Latitude: 39d_53m_32s NORTH, Longitude: 75d_19m_45s WEST
Elevation: 110 ft
Hydrologic Zone: headwaters and lowlands
Riparian? : partially

- **BMP:** Disconnect Downspouts from Storm Sewer
  Infiltration? : yes, in headwaters sections
  Contributing Area: 524 (Acres)
  Benefits:
  - Runoff Volume Reduction
  - Water Quality
  - Pollutant Washoff Reduction
  - Enhanced Evapotranspiration

  Comment: Develop a program in the Township to encourage and subsidize private residential land owners to install rain barrels and rain gardens and to connect roof gutters and other drains to them while disconnecting them from the storm sewer system.

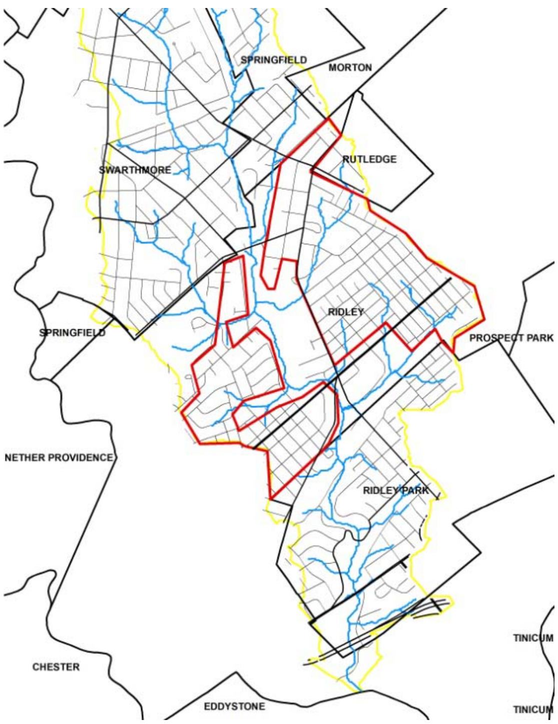


Figure C.5. Map and Image of Ridley Twp. Low Intensity Residential Developments that drain into Little Crum Creek

Municipality: Springfield Township

1. **Site:** Springfield Square
   Map of Location in Watershed (click to view or see Fig. C.6 - site outlined in red)
   Aerial Image of Site (click to view or see Fig. C.6 - site outlined in red)
   Coordinates - Latitude: 39d_54m_48.53s NORTH, Longitude: 75d_20m_3.14s WEST
   Elevation: 200 ft
   Hydrologic Zone: headwaters
   Riparian? : yes
   - **BMP:** Green Roof
     Infiltration? : no
     Contributing Area: 2.4 (acre)
     Benefits:
       - Volume Reduction
       - Energy Savings
       - Heat Island Reduction
       - Flood Frequency Reduction
         - Location: Cresson Lane, Springfield
         - Location: Georgetown Road, Ridley Twp

     Comment: Green roof is ideally suited for large flat roofs.

   - **BMP:** Bioretention
     Infiltration? : yes
     Contributing Area: 14.7 (acre)
     Benefits:
       - Volume Reduction
       - Groundwater Recharge
       - Pollutant Washoff Reduction
       - Flood Frequency Reduction
         - Location: Cresson Lane, Springfield
         - Location: Georgetown Road, Ridley Twp

     Comment: Parking lot well suited for bioretention islands with infiltration since located in headwaters. Recent (July, 2009) addition to lower parking lot covers old stormwater detention basin visible in the image. Detention basin was replaced by concrete retention box under parking lot extension adds capacity to hold 1 foot of depth encouraging infiltration of a portion of the water quality volume.

Figure C.6. Map and Image of Springfield Square Shopping Center

2. **Site:** Farmhouse Circle / PECO Training Facility
   Map of Location in Watershed (click to view or see Fig. C.7 - site outlined in red)
   Aerial Image of Site (click to view or see Fig. C.7 - site outlined in red)
   Coordinates - Latitude: 39d_54m_7.31s NORTH, Longitude: 75d_20m_9.03s WEST
   Elevation: 112 ft
   Hydrologic Zone: headwaters
   Riparian? : yes
   - **BMP:** Constructed Wetland
     Infiltration? : yes
     Contributing Area: 62 (acre)
     <u>Benefits:</u>
     - Volume Reduction
     - Groundwater Recharge
     - Enhanced Evapotranspiration
     - Pollutant Washoff Reduction
     - Flood Frequency Reduction
     - Location: Georgetown Road, Ridley Twp
     - Aesthetics Enhance Property Value

Comment: Convert dry detention basin into small constructed wetland with infiltration and evapotranspiration and install constructed wetland on PECO training facility at southwest corner of property.

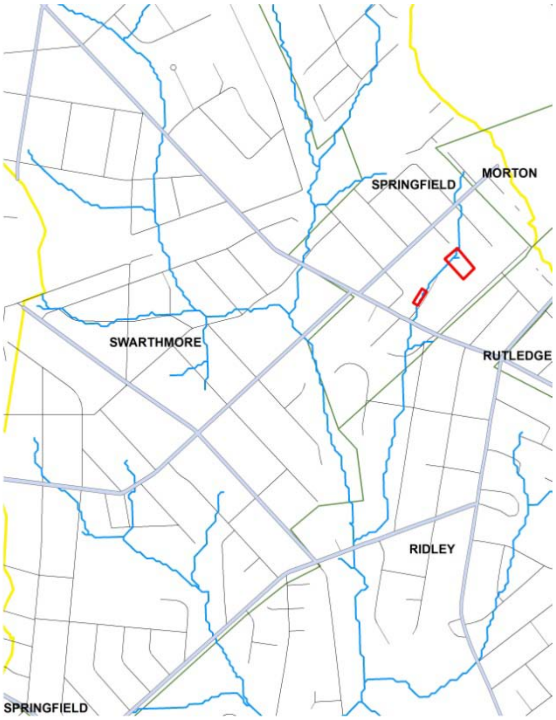


Figure C.7. Map and Image of Farmhouse Circle Detention Pond to Wetland Conversion Project and PECO Energy Training Facility Constructed Wetland Project

3. Site: Low Intensity Residential Neighborhoods
Map of Location in Watershed (click to view - site outlined in red)
Aerial Image of Site (click to view - site outlined in red)
Coordinates - Latitude: 39d_54m NORTH, Longitude: 75d_19m WEST
Elevation: 140 ft
Hydrologic Zone: headwaters and lowlands
Riparian? : partially

- **BMP:** Disconnect Downspouts from Storm Sewer
  Infiltration? : yes
  Contributing Area: 142 (Acres)
  <u>Benefits:</u>
  - Runoff Volume Reduction
  - Water Quality
  - Pollutant Washoff Reduction
  - Enhanced Evapotranspiration

Comment: Develop a program in the Township to encourage and subsidize private residential land owners to install rain barrels and rain gardens and to connect roof gutters and other drains to them while disconnecting them from the storm sewer system.

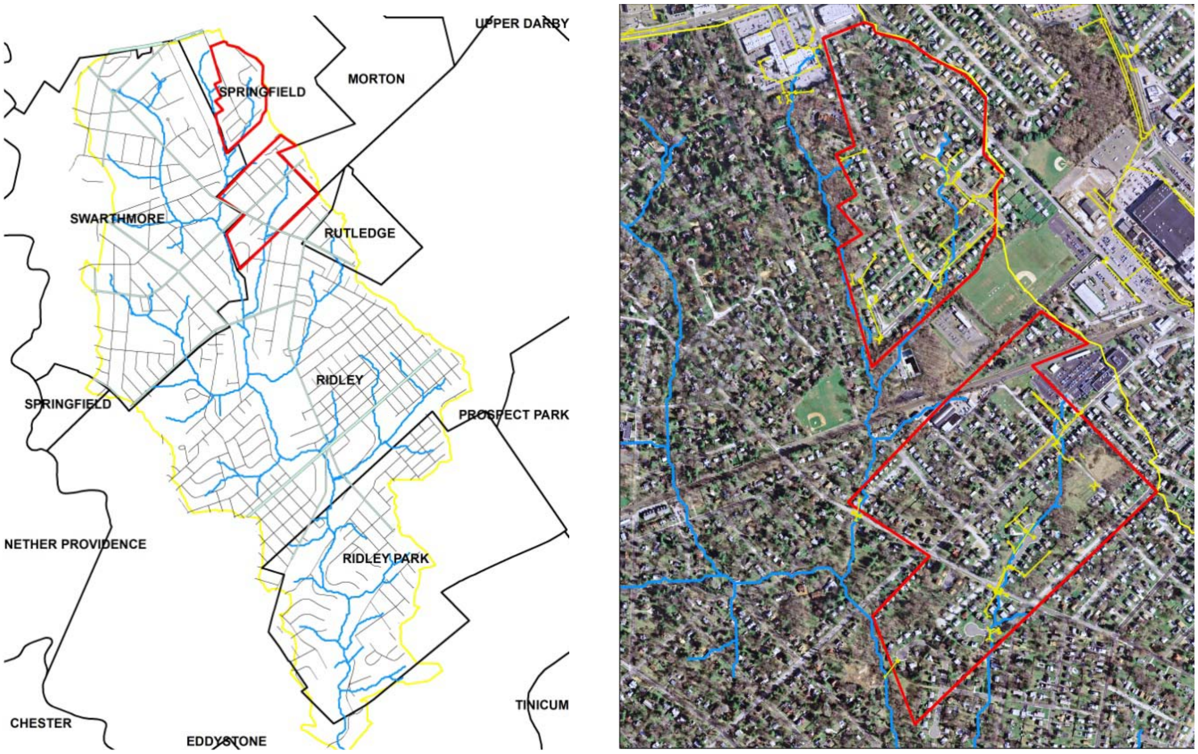


Figure C.8. Map and Image of Springfield Twp. Low Intensity Residential Developments that drain into Little Crum Creek

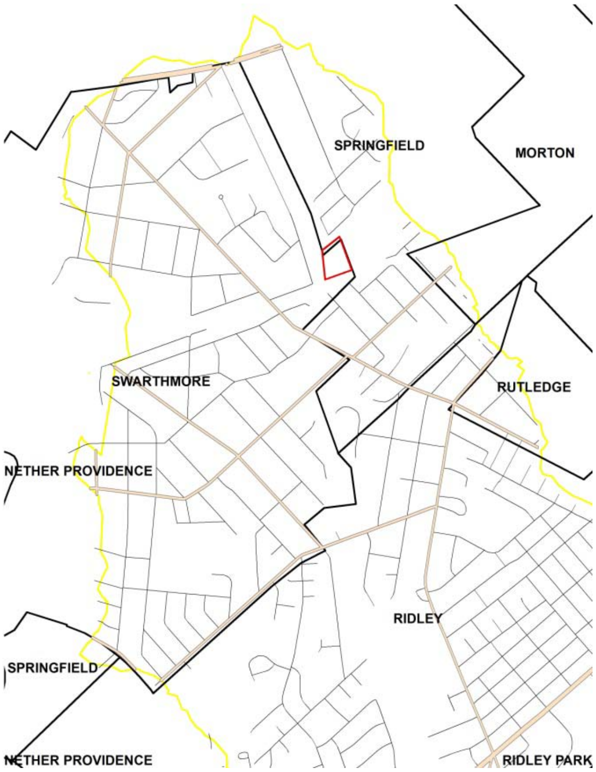
Municipality: Swarthmore Borough

1. **Site:** Swarthmore Swim Club
   Map of Location in Watershed (click to view or see Fig. C.8 - site outlined in red)
   Aerial Image of Site (click to view or see Fig. C.8 - site outlined in red)
   Coordinates - Latitude: 39d_54m_23.10s NORTH, Longitude: 75d_20m_18.63s WEST
   Elevation: 134 ft
   Hydrologic Zone: headwaters
   Riparian? : yes
   - **BMP:** Restoration of Wetland and Stream Bank
     Infiltration? : no
     Contributing Area: 0.5 (acre)
     Benefits:
       - Riparian Habitat Restoration and Preservation
       - Water Quality
       - Enhanced Evapotranspiration

     Comment: Removal of damaged concrete channel replaced with restored natural streambank. Restore natural flow through existing riparian wetland and enhance with native wetland plantings.

   - **BMP:** Constructed Wetland
     Infiltration? : yes
     Contributing Area: 4 (acre)
     Benefits:
       - Volume Reduction
       - Groundwater Recharge
       - Pollutant Washoff Reduction
       - Bank Erosion Reduction

     Comment: Divert a portion of stormwater flow presently carried in culverts into constructed wetlands proposed to be build adjacent to natural riparian wetlands to handle runoff from parking lot, service road, rooftop, pool deck, and an existing diversion from adjacent wooded PECO property in Springfield.



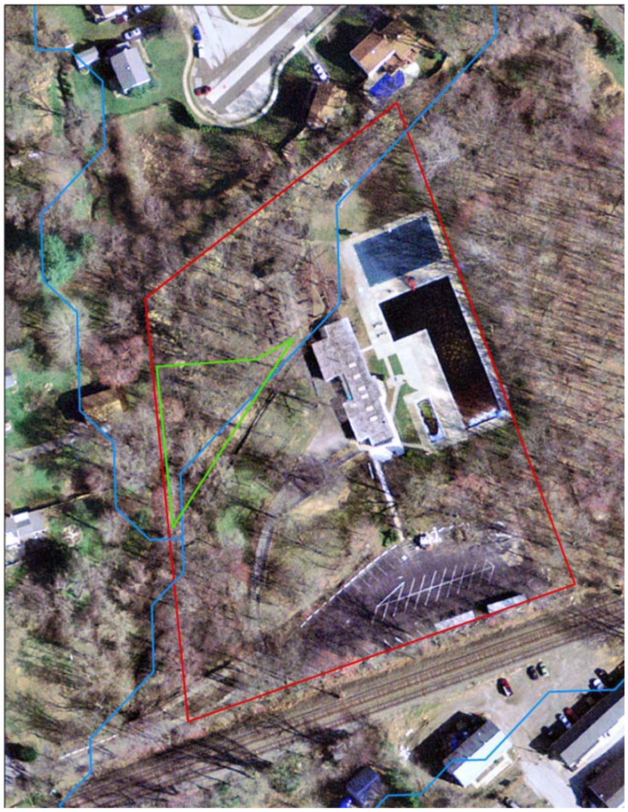


Figure C.9. Map and Image of Swarthmore Swim Club Site. The green polygon in the image shows the location of the proposed constructed wetland.

2. **Site:** Swarthmore Business District
   Map of Location in Watershed (click to view or see Fig. C.9 - site outlined in red)
   Aerial Image of Site (click to view or see Fig. C.9 - site outlined in red)
   Coordinates - Latitude: 39d_54m_6.7s NORTH, Longitude: 75d_20m_58.6s WEST
   Elevation: 129 ft
   Hydrologic Zone: headwaters
   Riparian? : no
   - **BMP:** Green Roofs
     Infiltration? : no
     Contributing Area: 2.8 (acre)
     Benefits:
       - Runoff Volume Reduction
       - Peak Flow Reduction
       - Enhanced Evapotranspiration
       - Pollutant Washoff Reduction

     Comment: Installation of green roofs on buildings with flat roofs in commercial district and nearby high density residential buildings.

- o **BMP:** Permeable Pavement
  Infiltration? : yes
  Contributing Area: 4.1 (acre)
  Benefits:
    - Runoff Volume Reduction
    - Peak Flow Reduction
    - Pollutant Washoff Reduction

  Comment: Includes parking lots serving businesses and apartment buildings including street parking. Green roofs and permeable pavement projects will involve transferring Swarthmore College's recent experience with cost and performance of both of these technologies.

Figure C.10. Map and Image of Swarthmore Business District Site

3. **Site:** Riparian Zone in Swarthmore Borough including the never used Harvard Avenue Right of Way and the Rutgers Avenue (CADES) School woods.
   Map of Location in Watershed (click to view or see Fig. C.10-a - site outlined in red)
   Zoom to Harvard Avenue Right of Way (click to view or see Fig. C.10-b - site outlined in red)
   Coordinates - Latitude: 39d_53m_52.9s NORTH, Longitude: 75d_20m_19.3s WEST
   Elevation: 85 ft
   Hydrologic Zone: headwaters and lowlands
   Riparian? : yes

- **BMP:** Riparian Zone Restoration
  Infiltration? : no
  Contributing Area: 4.1 (stream length) (miles)
  Benefits:
    - Riparian Habitat Restoration and Preservation
    - Water Quality
    - Pollutant Washoff Reduction

  Comment: Develop a program in the Borough to encourage and support private residential land owners in the riparian zone to develop buffer strips with shrubs, trees, and runoff filtering grasses with limited mowed areas.

- **BMP:** Riparian Conservation Easements
  Infiltration? : no
  Contributing Area: 26 (acre)
  Benefits:
    - Riparian Habitat Restoration and Preservation
    - Water Quality
    - Pollutant Washoff Reduction

  Comment: Develop a program in the Borough to promote conservation easements to preserve the riparian zones having high priority as identified in Phase 1 of the Little Crum Creek Action Plan report. **Rutgers Ave. School Woods:** This undeveloped, wooded riparian area behind the Rutgers Ave. School is owned by the Wallingford-Swarthmore School District. **Harvard Ave. Right of Way.** This strip of heavily wooded green space is on several parcels of private property along a historic transportation right of way which at one time was to have been an extension of Harvard Avenue. The right of way extends into the upper part of Ridley Township.

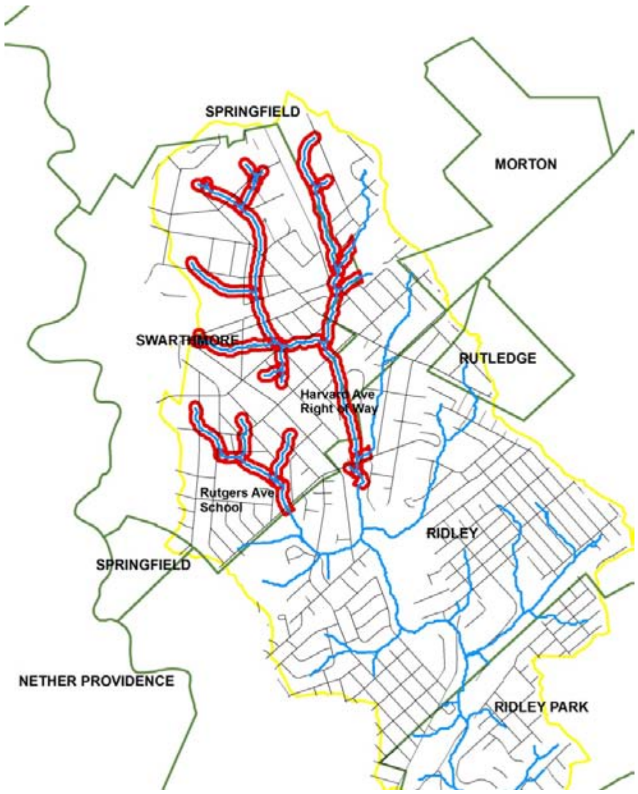


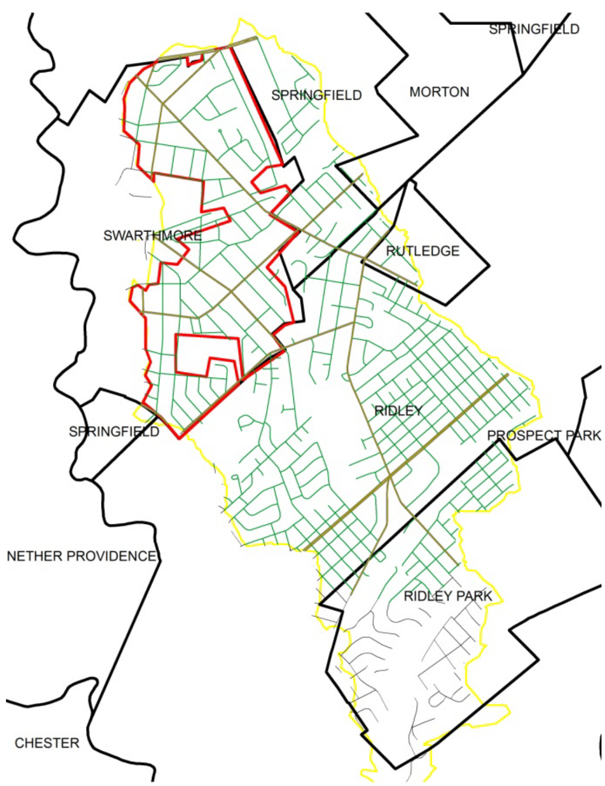
Figure C.11-a. Map of Swarthmore Riparian Zones on Little Crum Creek

Figure C.11-b. Images of High Priority Swarthmore Riparian Zones. <u>Left</u>: Rutgers Avenue School Woods; <u>Right:</u> Unused Harvard Avenue Right of Way

4. **Site:** Low Intensity Residential Neighborhoods
   Map of Location in Watershed (click to view - site outlined in red)
   Aerial Image of Site (click to view - site outlined in red)
   Coordinates - Latitude: 39d_54m NORTH, Longitude: 75d_21m WEST
   Elevation: 132 ft
   Hydrologic Zone: headwaters and lowlands
   Riparian? : partially

   - **BMP:** Disconnect Downspouts from Storm Sewer
     Infiltration? : yes
     Contributing Area: 467 (Acres)
     Benefits:
       - Runoff Volume Reduction
       - Water Quality
       - Pollutant Washoff Reduction
       - Enhanced Evapotranspiration

     Comment: Develop a program in the Borough to encourage and subsidize private residential land owners to install rain barrels and rain gardens and to connect roof gutters and other drains to them while disconnecting them from the storm sewer system.



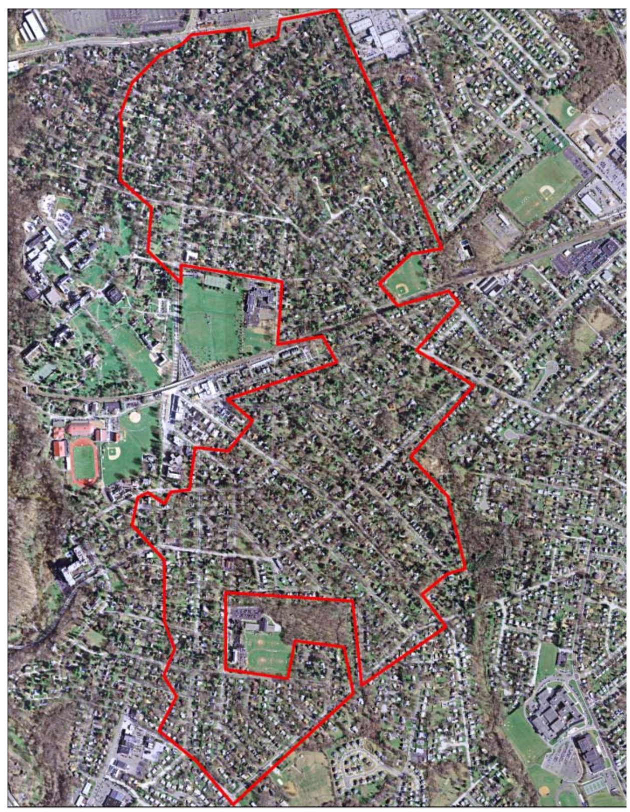


Figure C.12. Map and Image of Swarthmore Residential Areas that drain into Little Crum Creek

Appendix D. Update on Site RT_2 - Proposed Wawa Construction in Ridley Township

On January 28, 2010, a meeting was held at Ridley Township Hall to discuss this report's proposal for a constructed wetland and stream channel restoration at the proposed site of a "Super Wawa" convenience store and gas station, the site we call RT_2. The meeting included representatives from the engineering and environmental remediation firms doing the design, the property owner, the convenience store's corporate headquarters, Ridley Township, as well as the authors of this report. The developers had already prepared designs for storm water management at the site which included treatment of runoff from the impervious surfaces at the site, as required by local ordinances, plus stream channel restoration and enhancement to compensate for the loss of existing uncovered stream channel at the site. This plan is currently awaiting approval from Pennsylvania Department of Environmental Protection.

At the meeting, the developers were receptive to the idea of incorporating additional water quality enhancement measures at the site. Subsequently, we created a SWMM model of the developers' proposed design and then examined low-cost modifications to their design that would achieve sediment and nutrient removal from runoff flows passing through the site that originate at upstream developments including a large shopping center and residential neighborhoods. The motivation for this analysis is to take advantage of the opportunity presented by new development to achieve, at fairly low cost, water quality benefits that are necessary to change the impaired status of Little Crum Creek.

The analysis indicates that low-cost modifications of the proposed design can achieve significant reductions in runoff volume and nonpoint pollution at Ridley Park Lake that achieve a large fraction of the potential reductions identified in this report (Task 4). A report containing these results was sent to the developers on February 16, 2010 in the form of a memo, which is attached below.

Arthur E. McGarity
Professor of Engineering
Department of Engineering
Hicks Hall

Fax: (610) 328-8082
Voice: (610) 328-8077
email:amcgarity@swarthmore.edu

Swarthmore College, Swarthmore, Pennsylvania 19081

Memo to:
June Spring, Wawa, Inc.
Bill Rearden, Bohler Engineering
cc:
Charles Catania, Jr., Catania Engineering Assoc.
Thomas D. Cordrey, DelVal Soil
John Harper, Harper Assoc.
Anne E. Howanski, Ridley Township
Anne Murphy, CRC Watersheds Association

Date: 16 February, 2010

Re: Ridley Township Wawa site stormwater management for water quality

This report is a follow-up to the meeting at Ridley Township Hall on January 28, 2010 with representatives from Ridley Township, Wawa, Inc., Bohler Engineering, Harper Associates, DelVal Soil, Catania Engineering, Chester Ridley Crum Watersheds Assoc. and Swarthmore College, listed above.

I have modified the hydrologic and pollutant loading model that I developed for the site, which we call RT_2 in the recently completed Coastal Zone Management Program report for PADEP entitled "Little Crum Creek Assessment and Action Plan - Phase 2." The model runs in software called SWMM which is maintained by the US Environmental Protection Administration. It was calibrated for Little Crum Creek using flow, sediment, and nutrient date collected from our monitoring program.

The project proposed in the report, designated as RT_2A, would effectively replace the existing stream channel downstream of the site with a constructed wetland that would receive the tributary's base flow as well as a portion of storm event flows equivalent to the runoff from the upstream shopping center. Extra stormwater flow would be directed, as it is presently, into the main branch of Little Crum Creek. A sediment forebay would be installed at the inlet to the constructed wetland. This design achieves significant sediment removal at Ridley Park Lake, calculated by SWMM to be about 3 tons of sediment reduction per year (Table 1). Sediment removal efficiencies would be high (85%) for the water directed through the forebay and the wetland, but the excess flows would bypass and receive no treatment because there is not enough land area at the site to treat all of the storm water flowing in the tributary during larger rain events.

At the meeting, Bill Rearden, from Bohler Engineering, presented Wawa Inc.'s proposed design for creating a restored stream channel on the site to compensate for the loss of open stream channel to the new Wawa store, which will cover a portion of the existing channel. Base flow would be maintained in the channel sufficient to preserve the existing population of fish (Blacknose Dace). The channel would be deep enough to contain the 2-year flow. Storm events exceeding the 2-year flow would spill onto the land to the south of the channel where a wetland presently exists. This proposed design addresses PADEP's concerns regarding mitigation of the loss of freshwater stream habitat caused by covering more of the existing tributary.

I have changed my SWMM model of the site so that water flows into the wetland only when the water depth in the channel exceeds one foot. All other flows bypass the wetland. This model approximates Wawa's proposed design. The results of running the modified model using hourly precipitation data for an entire year (2008) show that the wetland receives inflow from the stream only four times during the year (Figure 1), once in the spring, twice during the summer and once in late autumn. All other rain events during the year entirely bypass the wetland (Figure 2). These results are not surprising because they are fairly consistent with the design specification that the restored channel contain all flows except those exceeding the two-year storm event. Figures 3 and 4 show the implications of this design specification for the wetland. The wetland is fed by the stream only four times during the year, and a measurable depth of standing water occurs only three times. There is no outflow from the wetland during the entire year. Note that this result considers only water inputs to the wetland from the stream and ignores inputs from direct precipitation onto the wetland and also ignores inflows of runoff from the proposed Wawa's parking lots. However, the proposed design directs parking lot runoff into a bioretention basin which will contain the water and significantly reduce the spill from it into the wetland.

My concern about the Wawa proposed design is that much of the flow into the wetland from the existing site will be cut off, and the infrequent inflows from the stream will be insufficient to support a water balance necessary to maintain its wetland characteristics and to sustain the wetland plant species. I am also concerned that this design realizes virtually none of this parcel's potential to achieve additional stormwater treatment, so as to improve the water quality of Little Crum Creek and to move it towards delisting from the federal 303-D list of impaired streams. My SWMM model of this design shows an annual reduction of sediment at Ridley Park Lake of only 0.05 tons (101 pounds) compared to as much as 3 tons reduction if the site is fully utilized.

I have revised my original RT_2A design for this site with the goals of addressing PADEP's concerns regarding maintaining freshwater stream habitat in the tributary while still achieving significant reductions in nonpoint pollution. The revised design would build a small flow diversion structure at the top of the restored stream channel to allow flow into the wetland whenever storm events raise the level in the stream above 0.45 feet. Also, a spillway with a crest two feet above the lowest point in the wetland is installed at the outflow of the wetland on the bank of the main branch of Little Crum Creek. The spillway could probably be made of inexpensive riprap. All of the base flow in the stream would still flow in the restored channel, thus maintaining the fish population. However, a large number of storm events would generate flow into the wetland each year. Figures 5 and 6 show the SWMM simulated flows into the wetland and the bypass flows throughout the year (2008). Comparing the two graphs shows that runoff from the smaller precipitation events (as well as the base flow) is carried entirely by the stream channel, but approximately 37 storms generate significant flow into the wetland. Note that these graphs show only the flows resulting from storm events, so a bypass runoff flow of zero means that flow remains in the stream is at the non-zero base level.

Figure 7 shows the depth of water accumulating in the wetland. The simulation indicates that the wetland would be inundated for a period of a several days around ten times during the year with an equal number of shorter periods under water. There are also several extended periods without inundation. This flow pattern should be well suited to support of a variety of native wetland plant species. Twice during this year, there is a brief period of flow over the spillway (Figure 8). During infrequent, extreme flood events, flows over the spillway could be much greater.

In order to calculate reductions of sediment and nutrients in the revised constructed wetland design, it is necessary to reevaluate the pollutant removal efficiencies. The wetland is handling higher flow rates in this design than it would have had to accommodate in the original design, where the higher flows were diverted into the main branch of the stream. Thus, the removal efficiencies were decreased to account for higher flow rates and, in particular, the sediment removal efficiency was dropped from 85% to 40%. However, the reduced removal efficiency is offset somewhat by greater amounts of sediment being diverted into the wetland during the higher storm event flows, which carry higher concentrations of sediment. The net result is an annual reduction in sediment load at Ridley Park Lake of 2.4 tons which is only one-half ton less than the reduction achieved by original constructed wetland design. The three different designs are compared in Table 1.

Table 1. Comparison of Flow and Pollutant Reductions for three designs

Wawa Site Design Option	Decreases in Loads Conveyed to Ridley Lake			
	Volume (10^6 gal)	Sediment (ton)	NO_3-N (lb)	PO_4 (lb)
Original RT_2A Constructed Wetland Design	13	2.9	118	28
Wawa Proposed Design	0.23	0.05	1.46	0.33
Revised Constructed Wetland Design	9.4	2.4	64	14

The revised design can be accomplished for relatively low additional cost. Some additional detailed engineering design would be required, primarily in the design of the inflow structure. Some consideration should also be given to the species of plants to be planted in the wetland with regard to frequency of inundation. The result would be significant decreases in sediment and nutrient pollution in the stream and in Ridley Park Lake, almost realizing the site's full potential for improving water quality, and enhancing the wetland habitat without compromising the freshwater fish habitat.

Thank you for this opportunity to present these findings, which are part of a broader multi-municipality partnership effort to improve water quality throughout the Little Crum Creek watershed. I will be glad to answer any questions you have about this analysis.

Arthur E. McGarity
Professor of Engineering

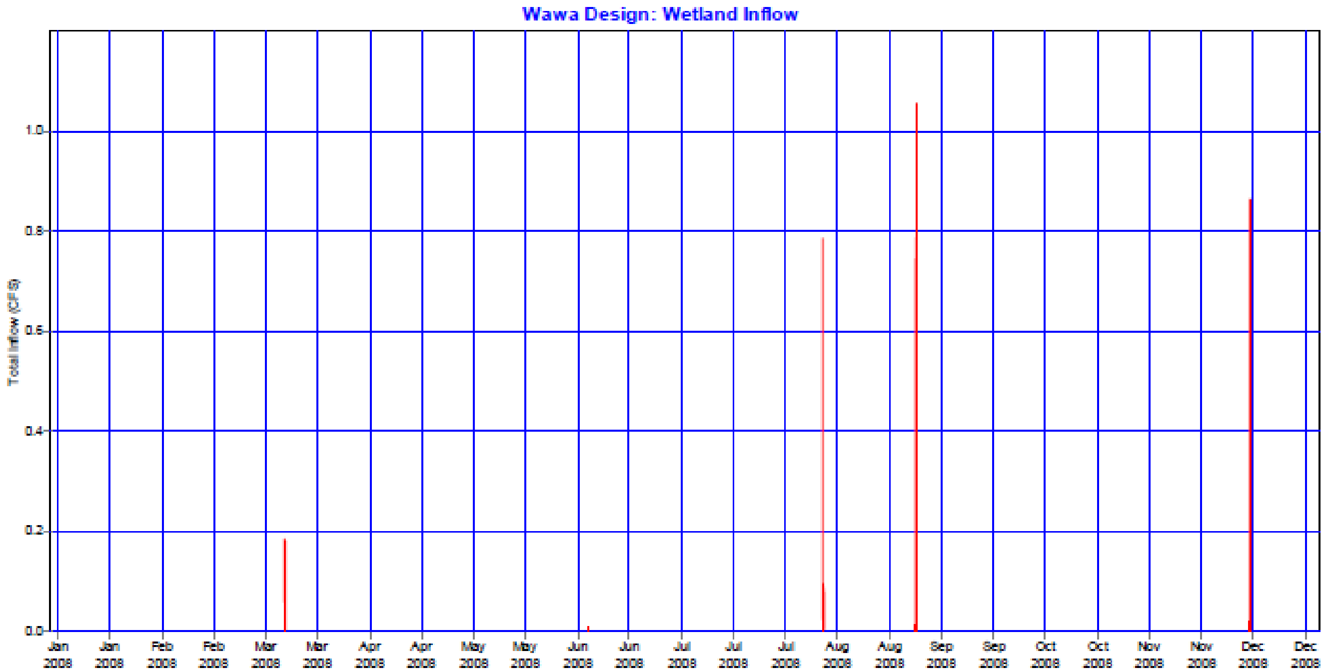


Figure 1. Flow rates into the wetland for the proposed Wawa design as simulated by SWMM for 2008 showing very infrequent inflows.

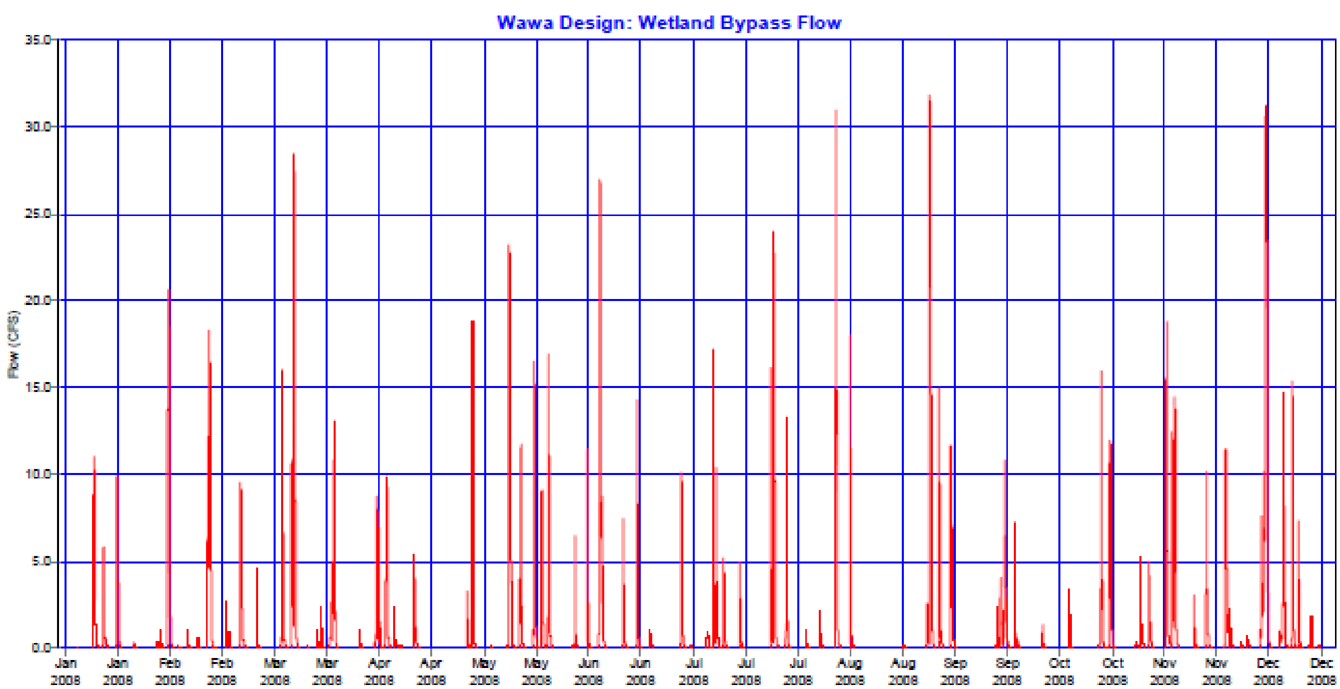


Figure 2. Runoff flow in the restored stream during rain events for the proposed Wawa design. Runoff flows of zero correspond to a base flow condition in the stream. These flows bypass the wetland.

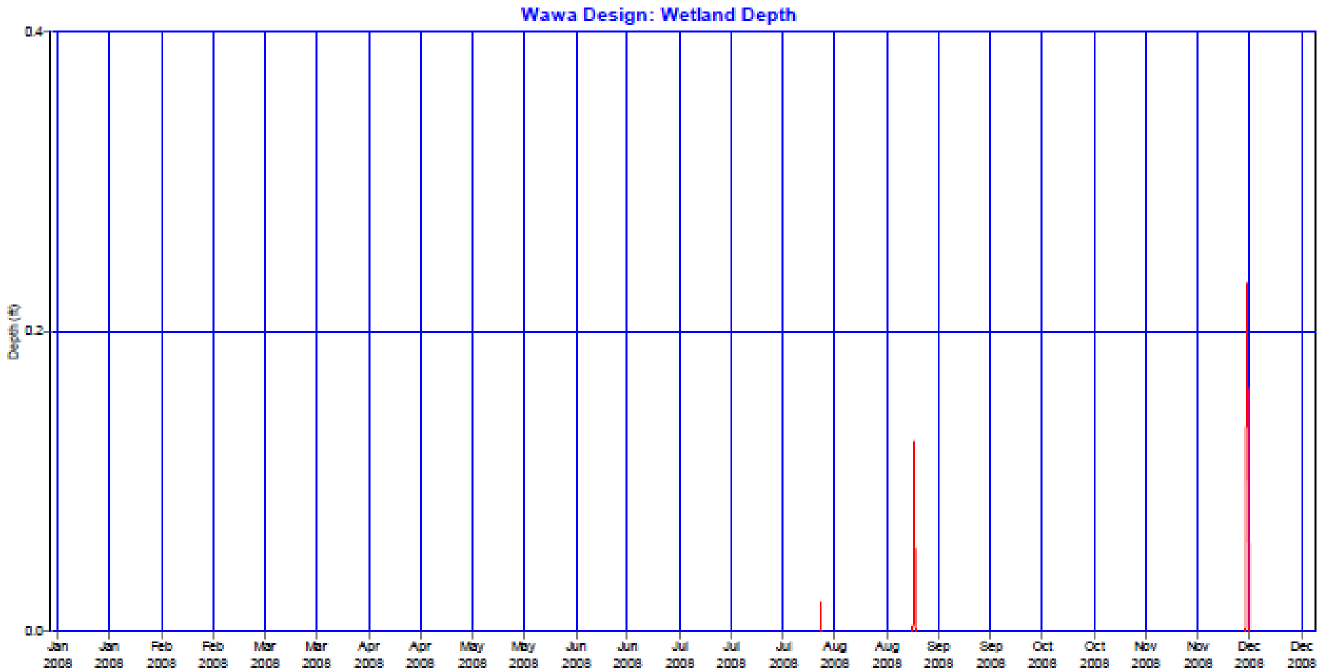


Figure 3. Depth of water in the wetland for the proposed Wawa design showing very infrequent accumulation of water and indicating virtually no removal of nonpoint pollution by the wetland.

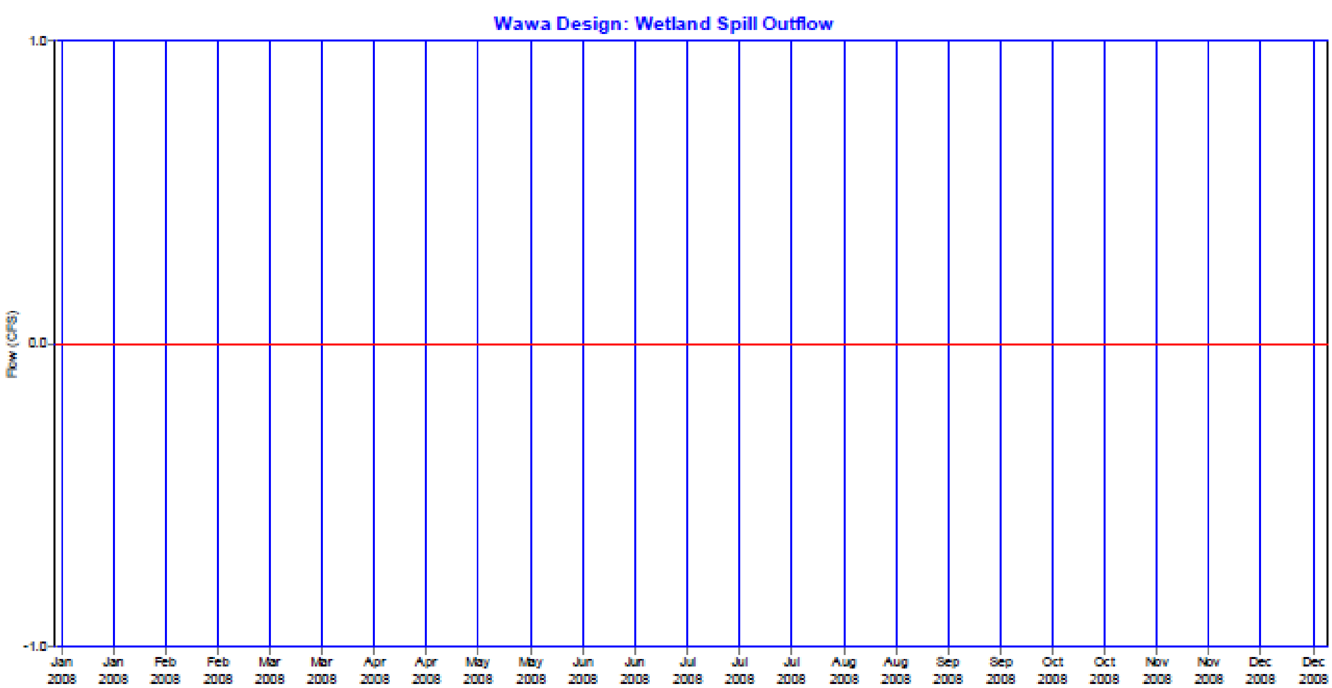


Figure 4. Outflow from the wetland would never have occurred in 2008 with the proposed Wawa design.

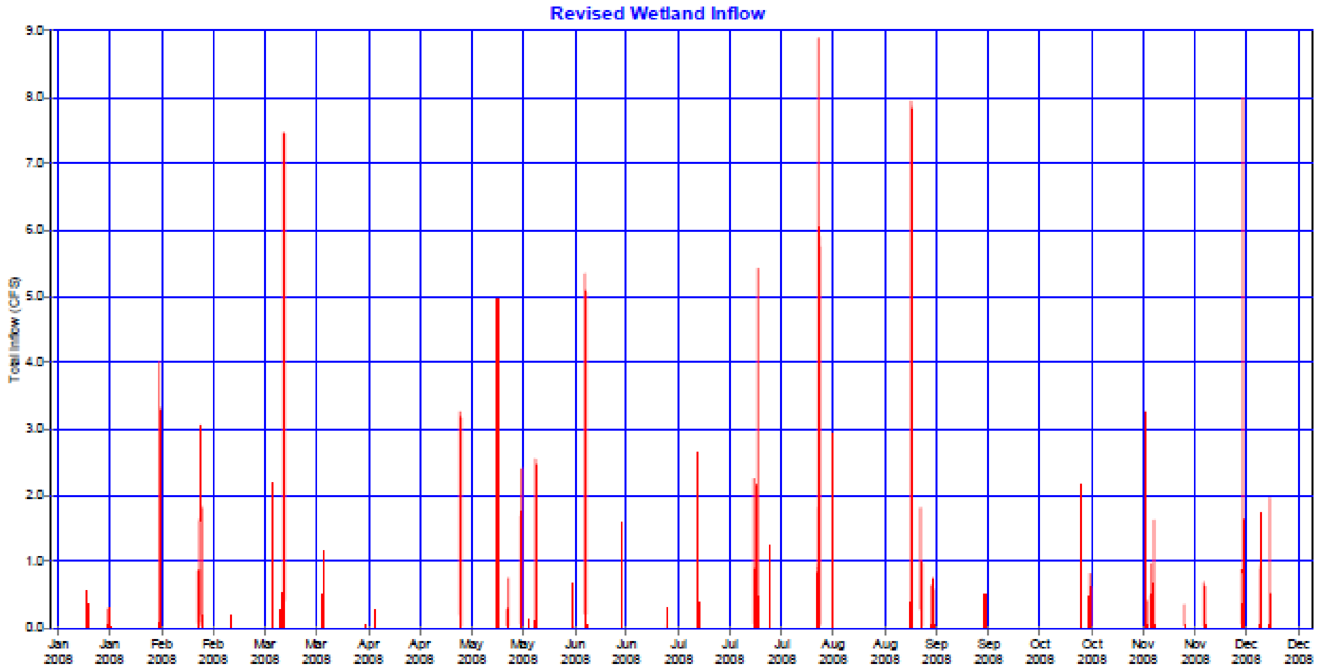


Figure 5. Flow rates into the wetland for the revised constructed wetland design as simulated by SWMM for 2008 showing frequent inflows from the tributary

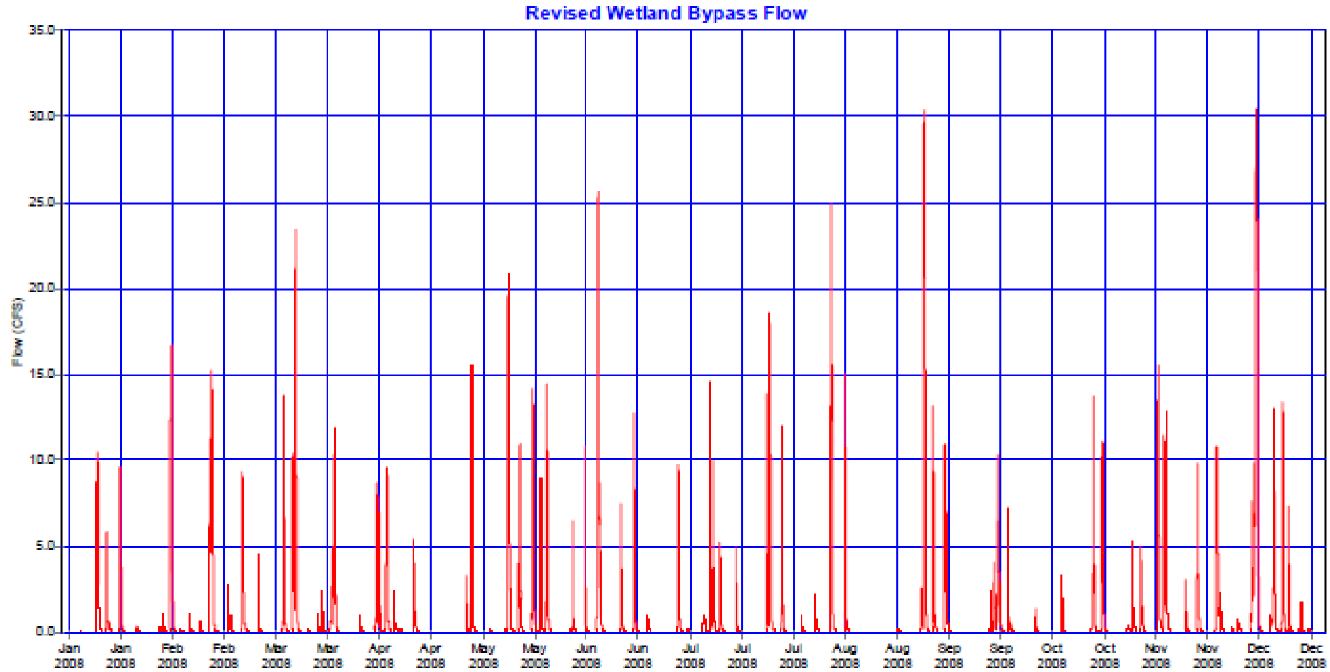


Figure 6. Runoff flow in the restored stream during rain events for the revised constructed wetland design. Runoff flows of zero correspond to a base flow condition in the stream. These flows bypass the wetland.

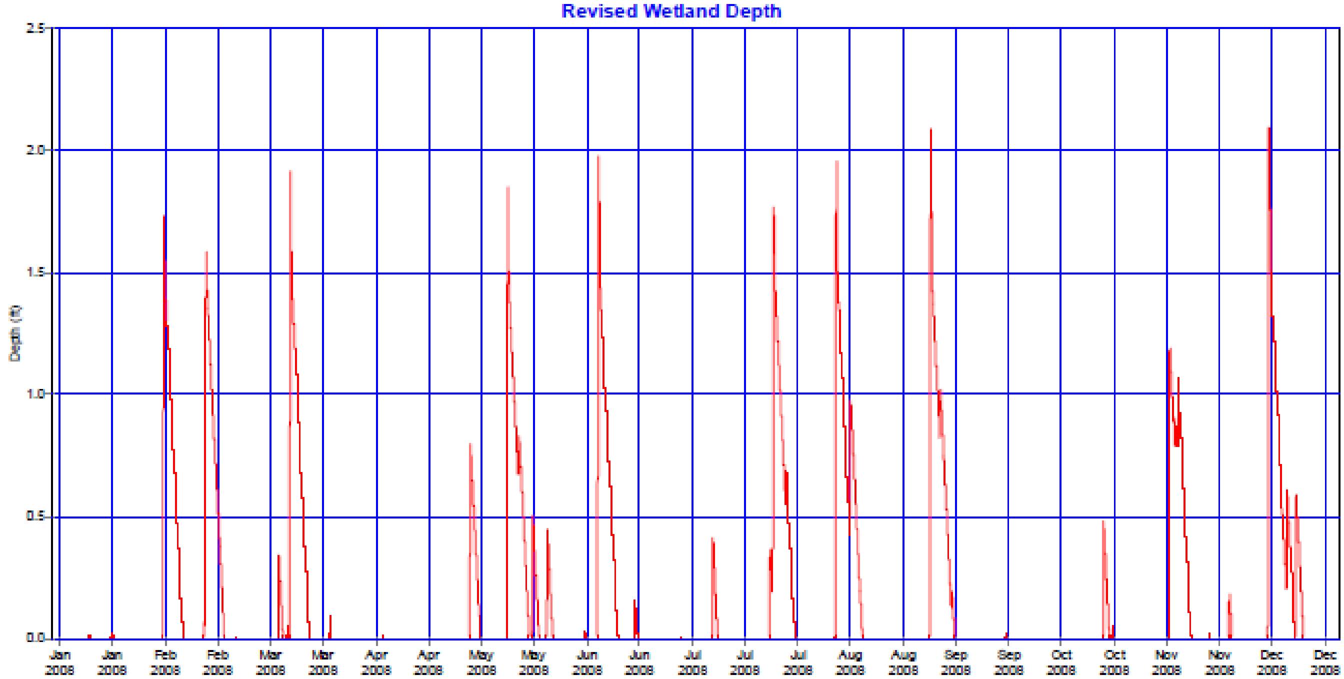


Figure 7. Depth of water in the wetland for the revised constructed wetland design showing many periods of inundation for several days and indicating favorable conditions for wetland plant species and performance consistent with significant removal of nonpoint pollution by the wetland.

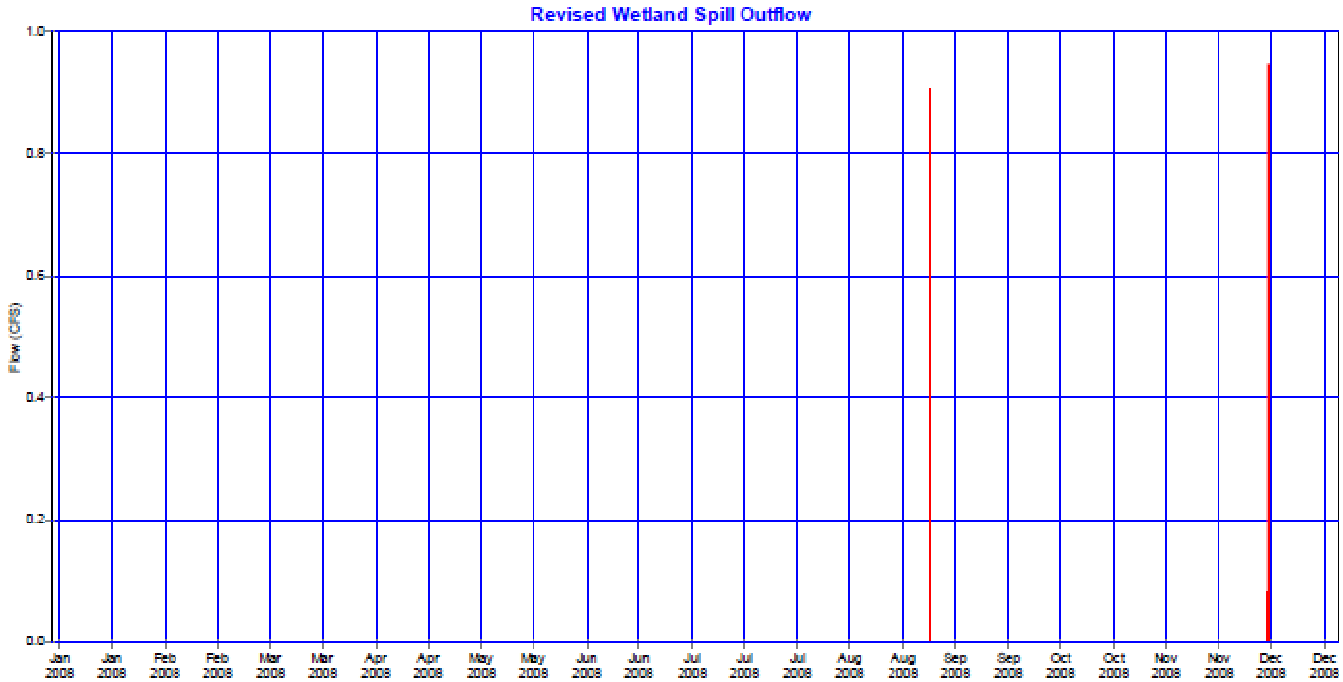


Figure 8. Outflow from the wetland would occur twice in 2008 with the revised wetland design and would occur at higher flow rates for major events such as the 50-year or 100-year storm.