Pennsylvania Coastal Zone Management Program

"Non-Point Source Modeling – Phase 2: Multiobjective Decision Model"

By

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EXECUTIVE SUMMARY

We have developed a multiobjective decision model for application in small urban drainages to provide decision makers with guidance in the search for sites to implement management practices that control nonpoint pollution associated with stormwater runoff. Local stakeholders and decision makers were consulted to develop goals and objectives related to urban stormwater management. As a result, this (Phase 2) study includes consideration of concerns related to flooding expressed by municipal officials and goals related to urban freshwater stream restoration expressed by local watershed associations. Our optimization model, developed in Phase 1, has been applied in a way that incorporates these objectives in addition to the original objective of reducing the total loadings of nonpoint pollutants into the coastal waters (specifically, Delaware Estuary and Bay). The multiobjective aspects of the problem are modeled by focusing primarily on specific small drainages where flooding problems are frequently observed. We also focus on drainage areas where opportunities exist for installation of BMP's that reduce total pollutant loadings through filtration, runoff volume reduction, and, when feasible, groundwater infiltration. Thus, we attempt to identify sites where pollutant loadings to the coastal zone can be reduced while also reducing the frequency of out-of-bank events that cause flooding and while attenuating the high streamflow rates that erode banks and hamper efforts to restore local freshwater streams. Pollutant loadings are calculated by the RunQual model extended to include streambank erosion and calibrated using our own pollutant monitoring data for sites in Springfield, Pennsylvania. Sites are prioritized using the NPSOPT model developed in our Phase 1 study.
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PURPOSE OF STUDY

Springfield Township is located in Delaware County, which is a densely developed section of suburban Philadelphia (see Figure 1). It is drained by two third-order streams, Darby and Crum Creeks, which flow into the Delaware River Estuary Coastal Zone. The first phase of our research focused primarily on modeling nonpoint pollution loadings (sediment and nutrients) on these watersheds generated by runoff from eight second-order stream subwatersheds that originate in Springfield (McGarity and Horna, 2005). An optimization screening model, incorporating pollutant loadings plus BMP costs and efficiencies, was used to set priorities for the kinds of urban land uses to target for management measures. We concluded that high priority should be given to reducing pollutant loads that are associated with "barren" and "recreational" land uses where significant load reductions are achievable using on-site BMPs at fairly low cost. The high priority should also be given to reducing stream-bank erosion in second-order streams that drain densely developed residential and commercial land uses by reducing runoff volumes through more expensive biofiltration and groundwater infiltration methods.

The purpose of Phase 2 of this research is to investigate the potential for implementing, in Springfield Township, the results of the first phase so as to move closer to achieving actual pollutant load reductions. The approach we have taken is to focus the search for suitable BMP sites to those drainage areas that contain the high priority land-uses identified in Phase 1 and which also address the stormwater management concerns of stakeholders and decision makers in the municipality. This "multiobjective" approach has the potential to increase the prospects for implementation of effective management measures that can generate significant pollutant load reductions.

Planning is currently underway to follow this research project with an implementation project in Springfield Township to showcase a variety of different BMP's in operation on public land in a "BMP Park." Funding sources are currently being sought to implement this project.

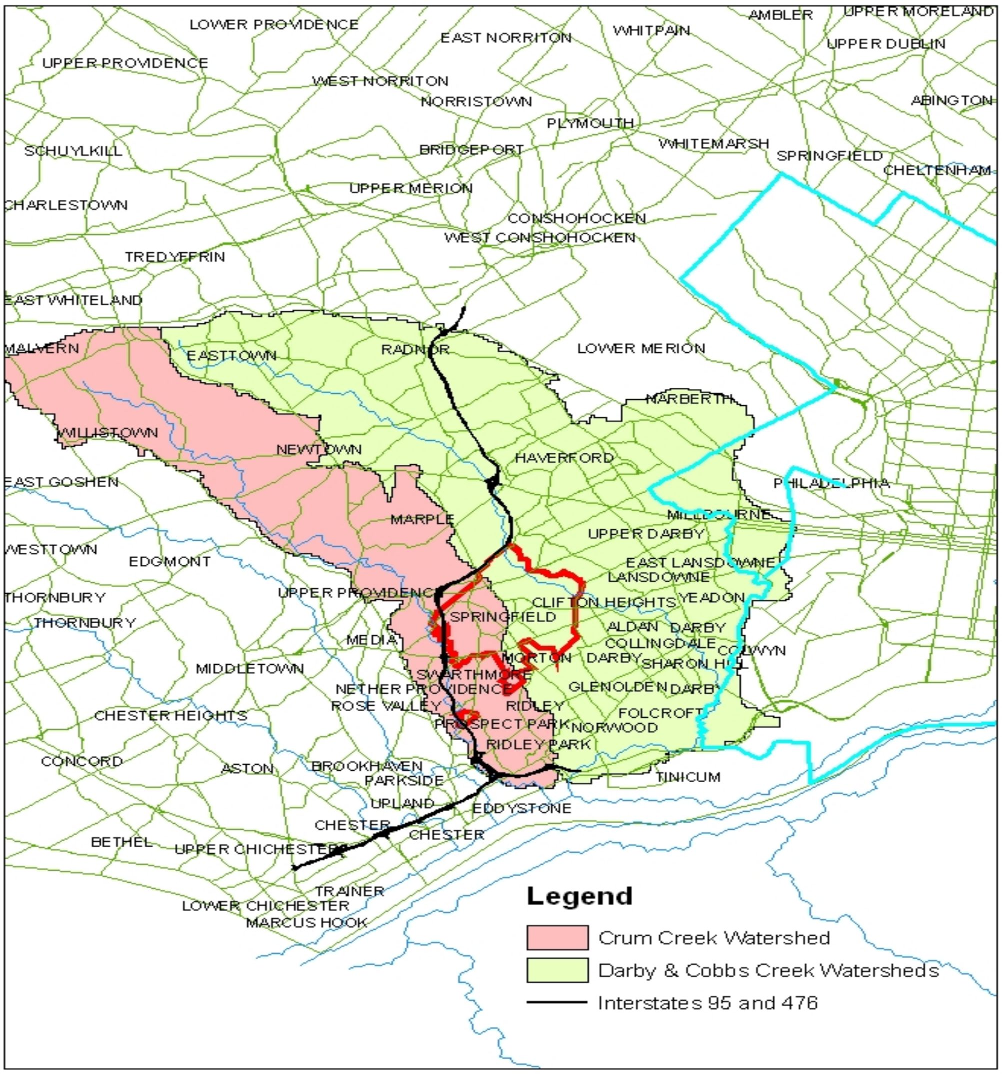


Figure 1. Springfield Township, outlined in red, is located in the Philadelphia suburbs. Its urban runoff drains into two watersheds Crum Creek (shaded red) and Darby Creek (shaded green) which flow into the Delaware Estuary below Philadelphia and above Chester City and eventually into Delaware Bay.

METHODOLOGY

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

1. Consult stakeholders and decision makers to develop goals and objectives for stormwater related nonpoint pollution and develop weighting factors for inclusion of multiple objectives in a ranking model;
2. Construct a multi-objective ranking model and validate the model through field measurements;
3. Incorporate preliminary cost estimates for BMP remediation of priority sites and adapt the ranking model to account for costs and preferences of stakeholders and decision makers.
4. Create a ranked listing of nonpoint pollution remediation projects and publish a final report documenting methodology, findings, and recommendations.

RESULTS

We describe here the accomplishments related to each work element.

1. Consultation with Stakeholders and Decision Makers

The primary goal of our research is to identify the best opportunities for significant reduction of nonpoint pollution loading into the coastal zone (Delaware Estuary and Bay). In Phase 1 of our research, we learned that there are many different strategies for achieving this goal, and we applied the criterion of optimal cost effectiveness to narrow the search for solutions. In Phase 2, we narrow the search still further by considering the *feasibility* of implementation, and we have consulted stakeholders and decision makers in the community and the affected watersheds for guidance. These are the people who will conceive specific projects, obtain funding, push through the approval process, oversee installation, and insure proper maintenance of management practices so that they operate successfully into the future.

We have received input from a range of different environmental, community, and local government contacts. Our primary link to the community of Springfield is a member of our project team, Paul Horna, who also serves as community liaison. Horna has lived in Springfield for 30 years and he has many years of service on the township's Environmental Advisory Council (see Arbour, et al., 2000). The Springfield EAC has provided the formal link to the municipal government including professional staff (Township Manager and Engineer) and elected officials (Township Council). We also received helpful input from nonprofit watershed organizations including the Chester-Ridley-Crum Watersheds Association, the Darby Valley Watersheds Association, and the Crum Creek Watershed Partnership. The Delaware County Planning Department and the county's Conservation District Office also provided assistance.

We have found that the goals and concerns of the different stakeholders and decision makers vary in ways that can significantly affect the outcome of the "decision making processes" that influence the selection of projects that are developed and funded. Watershed organizations are primarily concerned about restoring the quality of water and aquatic life in the local freshwater streams. They are also concerned about aesthetics, animal and plant habitat in the riparian zone, and access to natural areas for recreation. The concerns of elected municipal officials focus on the problems faced by their constituents, and in Springfield, stormwater-related problems are primarily connected with flooding problems in low-lying areas of poor drainage, especially in the Darby Creek drainages. Municipal governments also have great interest in responding to the new requirements of state and federal stormwater management regulations such as new stormwater management ordinances required by Pennsylvania (Act 167) and the NPDES Phase II federal regulations (Federal Clean Water Act). The Environmental Advisory Council (EAC) works with local watershed organizations and with the municipal government and provides a liaison with the citizens of the community. We have found the members of the EAC to be a particularly helpful and balanced source of guidance in weighting the different goals such as improvement of water quality and reduction of flooding.

During the course of this study, we were able to obtain from the elected Township Commissioners a ranked list of nine different sites in the community where stormwater related problems exist. These sites were called "Pressure Points" by the Township Engineer, and they are all sites where frequent complaints are received from residents because of flooding problems. We reexamined our Phase 1 study results in light of the high weight placed by township officials on flood control objectives. We decided to search for opportunities to install filtration and runoff volume control BMP's that can reduce streambank erosion (a Phase 1 study priority targeting nonpoint pollution) and simultaneously help reduce the frequency of flooding problems at the identified pressure points and also help attenuate the high streamflow rates that hamper efforts to restore local freshwater streams

Our Phase 1 study results also suggest targeting "barren" and "recreational" sites having exposed soil with little or no vegetation. These are sites where opportunities exist to reduce highly concentrated discharges of suspended solids from erosion of exposed soil using inexpensive low-technology BMP's such as planting native vegetation and installation of grass filter strips. Thus, we also decided to search for locations in the township where significant erosion from exposed soil is occurring.

During the summer of 2005, we made site visits to suspected barren land sites and to all of the designated pressure points. We then used high resolution aerial color photography obtained from an internet service (Google Earth™) to further analyze the drainage areas associate with these locations. We applied the general guidance obtained from our Phase 1 study to select six sites for further analysis including field monitoring and computer modeling of nonpoint pollutant loads. Figure 2 shows a map of Springfield with the six sites and their associated drainage areas. Also shown are the eight subwatersheds that were analyzed in the Phase 1 study.

Figure 2. Six sites selected for field monitoring (draining portions of the subwatersheds), including a site having significant exposed soil (orange dot) and five drainage points (red dots) with their associated drainage areas (shaded red) that were modeled using the RunQual and NPSOPT models. Selections were made by combining our Phase 1 results with multiobjective considerations, including the stormwater "pressure points" designated by the Township Engineer and elected officials. The eight subwatersheds analyzed in the Phase 1 study are outlined in green. The boundary of Springfield Township is shown as a solid black line.

2. Modeling and Field Verification

Review and Selection of Models.

Our Phase 1 report contains an extensive discussion of the various considerations required in selecting a model for calculating nonpoint pollution loadings (McGarity and Horna, 2005). For the Phase 1 "screening model," we selected the Penn State University AVGWLF model for our analysis at the second-order subwatershed level. However, AVGWLF is not presently well suited for analyzing the much smaller urban drainages required for the current study. For our more site-specific analysis with small urban drainages, we need a model with the ability to easily incorporate land use parameters associated with such drainages and which can be readily calibrated using our field monitoring data. It must also be able to accommodate manually derived land use data obtained from our field verification of land use categories within each drainage. We selected the model "RunQual" which is an extension of GWLF (without a built-in GIS interface) developed by Haith at Cornell University that is better suited for urban drainages than GWLF. The website for RunQual at Cornell University is: http://wri.eas.cornell.edu/products/software/runqual/. The numerical parameters required to model the selected drainages with RunQual were obtained from manual analysis of GIS data layers using ARCMAP 9.0 software from ESRI. Since the drainages we modeled are fairly small, the manual approach was feasible, and it also enabled us to incorporate land use information obtained from our site visits.

One disadvantage of RunQual is that it does not handle streambank erosion as does AVGWLF. However, the literature contains details (Evans, 2003) of the method used in AVGWLF to calculate stream bank erosion including formulas (with regressions for Pennsylvania) that we have adapted to calculate sediment loading from stream bank erosion. We have used the hydrological calculations in RunQual to obtain monthly average runoff volumes for use in the streambank erosion formulas and have used our own monitoring data to calibrate the models, as described below.

Site Visits and Model Calibration using Field Data

Our efforts to develop guidance for decision makers that is more site-specific than the second-order subwatershed-level results produced by Phase 1 required an extensive program of site visits throughout Springfield Township during summer, 2005. Our selection of sites to visit was guided by the results of our screening model which suggested a focus on barren and recreational sites and sites experiencing severe streambank erosion. We also visited all of the sites designated by municipal officials as "pressure points" where flooding problems occur. We returned to selected sites during storm events to take samples for laboratory analysis of nonpoint pollutants and to take photographs.

Barren and Recreational Sites

Barren land (also referred to as "Transitional") is a land use category associated with exposed, non-vegetated soil that is easily eroded. Nonpoint pollution loading models predict very high pollutant loads from such land, especially when it is located on slopes. Such land is easily recognized on active construction sites where the land has been disturbed. Of course, most construction sites are temporary, and standard measures of sediment control should limit the pollutant loading on nearby streams. However, when construction projects are delayed for any reason, such as project financing difficulties or contractor delays, then such sites can become a long-term source of excessive sediment loading on the streams if erosion control measures are not well maintained. We identified several construction sites in Springfield that could become significant sources of sediment loading if silt fences and other erosion control measures are not maintained (see Photos 1 and 2 in Appendix A of such a site in a county park on the boundary with Springfield). Another type of barren land we observed is poorly maintained utility rights of way, especially those that pass through wooded areas near streams (see Photos 3 & 4 in Appendix A). Thus, an important and fairly inexpensive nonstructural BMP would be implementation of programs to assure that all contractors operating in the Township are aware of the required sediment control practices and enforcement of regulations by municipal and county officials. Also, educational programs and enforcement actions aimed at assuring proper erosion control by utility companies that maintain rights of way could also achieve significant pollutant reductions at fairly low cost.

We also made visits to recreational land use sites including public parks and golf courses. Our Phase 1 study indicated that top priority should be given to the Lownes Run subwatershed, based on the frequency of barren land use occurrences in the GIS data layers and based on the steep slopes that appear in the elevation data layers. Photos 5 and 6 (Appendix A) show some examples of bare and eroding soil associated with recreational areas at this site. We returned to this site on 8 July, 2005 when the remnants of Tropical Storm Cindy passed through the area. Photos 6 and 7 document the development of the sediment laden runoff and Photo 8 shows the sediment plume where the runoff joins Lownes Run. Samples of this runoff were taken and analyzed in our laboratory. The concentration of total suspended solids (TSS) in the runoff stream were measured at 486 mg/L which equates to 3 pounds of sediment in every 100 cubic feet of runoff. The flow rate of the runoff was measured to be 0.07 ft^3/s from which we can estimate a sediment loading rate of 7 to 8 pounds per hour from a single source among many such outfalls in the subwatershed .

Our survey of sites in Springfield yielded three other locations with potential for producing significant sediment from barren or recreational land uses, and all of these sites are located within drainages associated with flooding pressure points. A wooded area in the upper part of the Stony Creek subwatershed that drains into the “Stony Creek at Woodland Avenue” pressure point has areas of exposed soil and an active construction site. Similar conditions exist in the drainage area associated with the “Darby Tributary #2 at North Rolling Road” pressure point. Also, a private golf course with exposed soil caused by severely eroded stream banks contributes a large part of the runoff into Darby Unnamed Tributary #1 which feeds the “Darby Tributary #1 at West Rolling Road” pressure point. The presence of barren and recreational land uses in these drainages was a factor in our selection of both of these pressure points for further modeling and monitoring in this study.

Our site visits and storm event measurements appear to validate the conclusions reached in our Phase 1 study that sites having exposed soil are common in densely developed suburban areas and that they can contribute significant amounts of nonpoint pollution to local streams and coastal waters, especially when they are located on steep slopes. Fortunately, these sources of pollutants can be controlled at fairly low cost if sufficient attention is directed towards them. Enforcement of construction site erosion control regulations at temporary construction sites, and planting and maintenance of native vegetation and ground cover in recreational areas can eliminate erosion in most instances. In some cases, low cost structural BMP's such as grass swales and filter strips may also be necessary. These management measures should be implemented wherever such conditions exist throughout the township, and further analysis or modeling of such sites for prioritization is not required.

Pressure Points

Our multiobjective modeling efforts now focus on the more difficult decisions related to sites where more expensive volume reduction BMP's are necessary. All nine of the sites identified by municipal officials as "pressure points" were visited and the drainages associated with them evaluated for potential to implement management practices that can simultaneously reduce nonpoint pollution and reduce the frequency of out-of-bank events that cause flooding. We ruled out sites where nonpoint pollution BMP's installed in Springfield would have negligible impact on flooding problems (such as the pressure point at West Rolling Road and Rutherford Drive that floods when the nearby Darby Creek, a third-order stream floods as a result of upstream flows) and sites where our Phase 1 study indicated that volume reduction BMP's in the drainage would be extremely expensive (such as Little Crum Creek at Cresson Lane).

Five drainage points were chosen for field monitoring and for modeling of nonpoint pollutant loading and as candidates for further consideration for BMP implementation in their associated drainages, as shown in Table 1. Four of the selected sites are located at designated pressure points and one (Levis at Township Building) is upstream of a pressure point.

Table 1. Drainage Points Selected for Further Analysis

Site	Reasons for selection
Darby Tributary #1 at West Rolling Rd.	Flooding pressure point draining residential areas and a golf course (recreational land use category)
Darby Tributary #2 at North Rolling Rd.	Flooding pressure point draining residential, wooded, and barren land use categories
Levis Run at Township Building	Site of a proposed BMP demonstration park on public land and upstream of a flooding pressure point
Muckinipattis Creek at Bishop Rd.	Flooding pressure point draining residential and commercial areas
Stony Creek at Woodland Avenue	Flooding pressure point draining residential, commercial, institutional, recreational, barren, and wooded land use categories

Model Calibration using Field Data

The next step in our analysis involves calculating the nonpoint pollutant loading from each of the five drainages associated with pressure points. As mentioned above, we selected the RunQual model for these calculations since it uses the same urban runoff calculation method as AVGWLF, but it is more easily adapted to small urban drainages and manual land-use determination based on field visits. We also conducted a storm event monitoring program during the Summer of 2005 to obtain data on nonpoint pollutants for use in calibrating the model.

Our field monitoring capability was substantially improved for our Phase 2 study through acquisition of an ISCO™ Model 6712 autosampler with a rain gage and a flow sensor, through funds provided by Swarthmore College and its Howard Hughes Medical Institute supported undergraduate research and community outreach program. The autosampler is shown in Photo 9 installed in a protective cinderblock and aluminum enclosure that we designed to prevent damage from weather or vandalism. The enclosure was designed so that it could be disassembled and moved to different locations. Photo 10 shows the autosampler installed at the pressure point site "Stony Creek at Woodland Avenue, with the minimal dry-weather flow in the concrete channel and the suction tube and sensor cables leading into the channel. Photo 11 shows the autosampler at the same site as Photo 10 during the rain event on 7/8/2005. The autosampler was installed at all five of the selected pressure point sites listed in Table 1 between July 7 and September 21, 2005 and all rain events having significant runoff that occurred during that period were monitored. Although this period was fairly dry, we were able to obtain data from at least one rain event at each site, and most of this data was useful in calibrating the nonpoint pollution loading model.

Nonpoint pollutant load modeling was accomplished in two steps. First, RunQual was run to calculate the urban wash-off components of the loads. RunQual was run with local meteorological data for a ten-year period. During periods without rain, buildup of pollutants on pervious and impervious surfaces were modeled at rates, specific to land use category, that are typical for heavily developed areas, as specified in the RunQual manual. Then, during periods of rain, the pollutants are washed off into streams at rates that depend on the amount of rainfall.

The hydrological components of RunQual provide runoff volumes from which average monthly stream flow rates can be calculated. For the purpose of calculating streambank erosion, we equated stream flow with storm event runoff because all of our monitored pressure points, base flows are insignificant. We applied the regression formula developed for AVGWLF by Evans, et al (Evans, 2003) to calculate local coefficients for the streambank erosion formula. This formula accounts for factors specific to the drainage area including the percent developed, livestock density, soil erodability, SCS curve numbers, and topographic slope. This formula was developed for use throughout Pennsylvania, and it was calibrated using data that included many rural watersheds. We had to adjust the coefficients as required to obtain agreement with our monitoring data on total suspended solids, which is the main factor determining nonpoint pollution from streambank erosion. The resulting calculated "lateral erosion rate" was then applied to the length of exposed streams in the drainage which was obtained by subtracting the length of sewered first and second-order streams from the total length of streams as obtained from delineation based on digital elevation data.

At all but one of our monitored sites, we obtained rain event data that appeared to contain sediment loading contributed by streambank erosion. At these sites, we observed rain events having at least one surge in streamflow accompanied by a spike in total suspended solids (TSS), indicating that upstream exposed stream banks were contributing sediment. These events produced event mean concentrations of TSS that significantly exceeded the concentrations that RunQual predicts from urban wash-off alone. Thus, we attributed the excess sediment to streambank erosion, and used the excess TSS values to scale the results from the streambank erosion model to calibrate it for our local drainages.

Table 2 shows the measured event mean concentrations of TSS (the flow-weighted average of the measured TSS concentrations) and the calculated equivalent ten-year average TSS concentrations from RunQual for the month corresponding to the monitored event. In all cases, the measured TSS is greater than the calculated TSS attributed only to urban washoff. The difference is attributed to streambank erosion in the four cases where the data suggest that sufficient flow occurred to generate streambank erosion. In one case (9/15/2005) the precipitation was light, and the data suggest that streambank erosion did not occur. In this case, the measured TSS is only slightly larger than the modeled urban washoff TSS. In the first four cases, the column from Table 2 labeled "Difference Attributed to Streambank Erosion" was used to calibrate the streambank erosion model for each drainage. Since we could not observe an occurrence of streambank erosion at the fifth site (Levis at Twp. Building), we used the average calibration scale factor from the other four sites for our analysis of that site.

Table 2. Field Data for Calibration of Streambank Erosion Model

Date of Rain Event	Site	Measured Event Mean TSS (mg/L)	Urban Washoff Mean TSS from RunQual (mg/L)	Difference Attributed to Streambank Erosion (mg/L)
7/8/2005	Stony at Woodland Av.	488.8	95.3	393.5
8/8/2005	Darby Trib. #2 at North Rolling Rd.	332.9*	181.0	151.9
8/15/2005	Darby Trib. #1 at West Rolling Rd.	490.9	184.9	306.0
8/27/2005	Muckinipattis at Bishop Rd.	225.2	158.3	66.9
9/15/2005	Levis at Twp. Building	114.6	110.0	n/a+

* - estimated due to flow data acquisition failure
+ - the rain event on 9/15/2005 had fairly light precipitation which did not produce a flow pulse that indicated streambank erosion occurred

Ideally, we would have much more field data on which to base our model calibrations. The calibrations would be more accurate if we had multiple years of data at every site for rain events in every month of the year. However, the effort and expense required to obtain such data would be enormous. We believe that our results have incorporated site-specific data so as to make them as accurate as possible given the current state of the art in nonpoint pollution load modeling and the overall scope of our project. Appendix B contains a summary of all data obtained from our rain event monitoring with the autosampler, including nutrient data on Total Nitrogen, Nitrate, Total Phosphorous, and Phosphates.

3. Combining Stakeholder and Decision Maker Preferences with Costs and Performance in BMP Selection

Results of Nonpoint Pollution Load Modeling

By focusing our analysis on the drainage areas associated with each of the selected drainage points, we are incorporating stakeholder and decision maker preferences relating to stormwater management in Springfield Township. These drainage areas were delineated using the ArcHydro Toolbox (Maidment, 2002) running under ArcMap™ 9.0 from ESRI. After delineation of drainages, percent impervious data were calculated by overlaying the drainage areas with impervious surface data layers from Pennsylvania Spatial Data Access (PASDA, 2005) web site link http://www.pasda.psu.edu/summary.cgi/isa_pa/pa2000isaa_se.xml which contains results from Thematic Mapper data using algorithms developed by Dr. Toby Carlson.

RunQual model parameters were available for five different land uses for calculating runoff volumes and pollutant washoff loadings: Commercial, Residential, Institutional, Recreational, and Wooded. Land use delineations were made manually using ArcMap™ graphic tools with recent aerial photography images obtained from the Google Earth™ internet service and verified by field visits to selected sites. Table 3 shows results from the delineations that were used in RunQual. We also calculated percent impervious data for each land use in each drainage area for use in the model.

Table 3. Delineation Data for Land Areas Associated with the Selected Drainage Points

Name	Area (Acres)	Percent Impervious	Commercial (Acres)	Residential (Acres)	Institutional (Acres)	Recreational (Acres)	Wooded (Acres)
Darby Trib #1 at West Rolling Rd.	209	22.0	0.00	101.3	0.0	108.2	0.0
Darby Trib #2 at North Rolling Rd.	342	21.8	0.00	186.6	0.0	95.6	60.3
Levis Run at Twp. Building	171	31.5	6.4	120.1	8.4	38.6	0.0
Muckinipattis at Bishop Rd	206	38.3	41.0	125.3	0.0	41.3	0.0
Stony at Woodland Av.	296	40.4	81.3	173.2	2.2	13.1	26.4
TOTALS	**1226**	**30.5%**	**128.7**	**706.5**	**10.6**	**296.8**	**86.7**

The RunQual model was run for the land areas associated with each of the selected drainage points to obtain the monthly and annual runoff volumes and nonpoint pollutant loadings (suspended solids, nitrogen, and phosphorous) generated by urban washoff. The monthly runoff volumes were then used in the streambank erosion model which incorporated calibrations obtained from our field monitoring, as described in Section 2. Monthly sediment, nitrogen, and phosphorous loadings from streambank erosion were then calculated. Annual averages of these model results are shown in Tables 4 and 5 (based on ten-year runs of the model).

Table 4. Modeled Annual Runoff and Sediment Loadings for Selected Drainage Points

Name	Annual Runoff per Area (inches/yr)	Total Annual Runoff (1000 ft3/yr)	Sediment from Washoff (tons/yr)	Sediment from Stream Bank Erosion (tons/yr)	Overall Sediment Suspended Solids Loading (tons/yr)
Darby Trib #1 at West Rolling Rd.	7.24	5506	23	43	66
Darby Trib #2 at North Rolling Rd.	7.05	8761	36	34	70
Levis Run at Twp. Building	9.06	5653	24	37	61
Muckinipattis at Bishop Rd	10.71	8011	31	14	45
Stony at Woodland Av.	11.73	12618	45	177	222
TOTALS	**9.11**	**40550**	**160**	**304**	**464**

Table 5. Modeled Nutrient Loadings for Selected Drainage Points

Name	Nitrogen from Washoff (pounds/yr)	Nitrogen from Streambank Erosion (pounds/yr)	Overall Total Nitrogen (pounds/yr)	Phosphorous from Washoff (pounds/yr)	Phosphorous from Streambank Erosion (pounds/yr)	Overall Total Phosphorous (pounds/yr)
Darby Trib #1 at West Rolling Rd.	718	256	973	96	18	114
Darby Trib #2 at North Rolling Rd.	1086	204	1290	145	14	159
Levis Run at Twp. Building	741	220	961	97	15	113
Muckinipattis at Bishop Rd	987	85	1072	127	6	133
Stony at Woodland Av.	1441	1062	2503	184	74	258
TOTALS	**4973**	**1826**	**6799**	**650**	**128**	**778**

Results of Optimization Model

The results of the nonpoint pollution loading model were fed into the NPSOPT model developed in our Phase 1 study. A full description of the mathematical formulas used in the BMP cost and performance models as well as the optimization formulation is presented in the report (McGarity and Horna, 2005). A key feature of the model is its use of a nonlinear cost model for BMP implementation that can accommodate the wide range of marginal costs that are experienced with different BMP technologies installed at various sites throughout a drainage area. Here, we will focus primarily on the results produced by NPSOPT when the model is applied in the multiobjective framework of the current study.

As in the Phase 1 study, NPSOPT was configured to achieve a specific reduction in nonpoint pollution while minimizing the total resources devoted to stormwater management over the entire township. Cost effective allocation of resources was achieved in the model by varying the extent of BMP applications within the five different drainages and for each land use within the drainages until the exact combination was found to minimize the total cost. The mathematical technique used by the solver to find the solution is called "nonlinear programming." The end result is a target amount of funds to allocate to each drainage and land use. The relative ranking of the funding amounts provides a method of ranking potential BMP sites within the drainages.

The primary focus for nonpoint pollution reductions was total sediment (from both washoff and streambank erosion). Reductions in nutrient pollution (Nitrogen and Phosphorous) were simultaneously achieved. NPSOPT was run ten times, starting at 25 tons/year of total sediment reduction across all five drainage areas, and increasing in increments of 25 tons/year to a maximum reduction of 250 tons/year. Complete, detailed results obtained from the runs of NPSOPT are shown in Appendix C.

4. Recommended Ranking of Sites

Our Phase 1 study assigns top priority to improving management of barren land associated with exposed soil. Our field visits conducted Phase 2 and our field measurements confirm the existence of such sites in Springfield Township, and we recommend that top priority be given to implementing a program of monitoring and correcting problems at such sites in all location in the township, especially in areas with steep slopes such as Jane Lownes Park. Implementation of corrective measures such as native plantings, well maintained erosion control measures at temporary construction sites, and grass swales and filter strips at recreational land use sites are particularly cost-effective ways to reduce nonpoint pollution loads on local streams and the coastal zone.

The more difficult ranking choices are associated with reducing runoff volumes that erode stream banks and with removing urban washoff pollutants from developed sites in the community. We formulate our recommendations for ranking the implementation of retrofit measures at these sites by focusing on the first 100 tons of sediment reduction obtained in our runs of the NPSOPT optimization model. Our estimate of resources required to reduce sediment loadings by 100 tons is about $1.4 million. 100 tons represents about one fifth of the total annual sediment load from all five of the selected drainages associated with flooding pressure points.

Figure 3 shows how the total required resources are allocated by NPSOPT to drainage areas and land uses for sediment reduction levels of 25, 50, 75, and 100 tons/year. Top priority goes to **(1)** residential land uses in the area that drains to the pressure point at Stony Creek at Woodland Avenue for all amounts of total sediment removal. Also receiving attention at the 25 ton level are **(2)** the recreational land uses in the Darby Tributary #1 (primarily, a golf course) that drain to the pressure point Darby Tributary #1 at West Rolling Road, **(3)** commercial land uses (automobile dealerships, filling stations, restaurants, and a pharmacy on Baltimore Pike) and **(4)** recreational land uses in the Stony Creek drainage that feeds the pressure point at Stony Creek at Woodland Avenue.

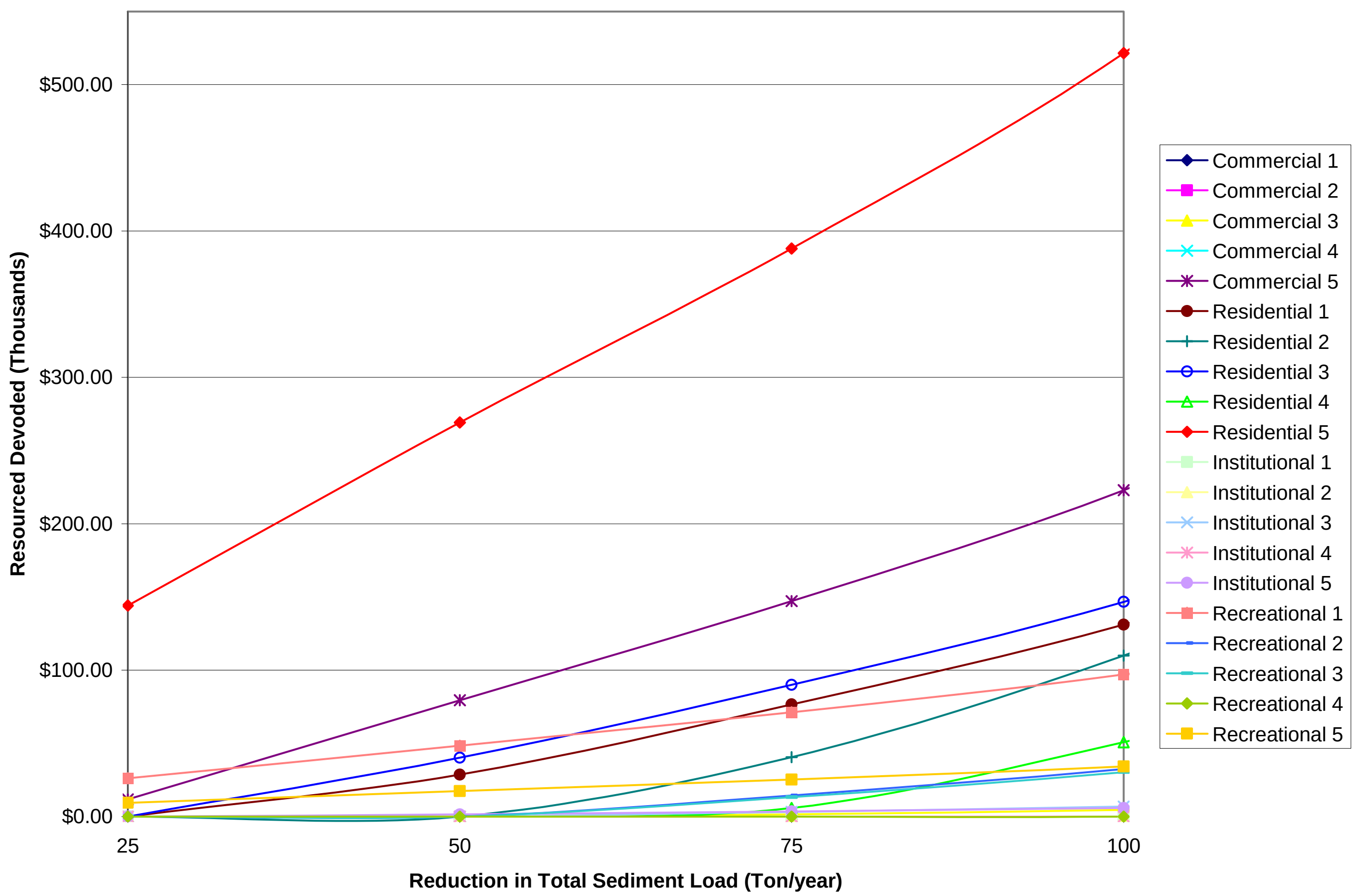
At the 50 ton/year level, additional measures at the sites above are accompanied by initial measures at residential sites in two more locations: **(5)** the upper Levis Run drainage and **(6)** the Darby Tributary #1 drainage. To achieve reductions of 75 tons/year, BMP implementation projects should also be identified at **(7)** residential sites in the Darby Tributary #2 drainage which feeds the pressure point Darby Tributary #2 at North Rolling Road. Finally, to achieve sediment reductions of 100 ton/year, we should include BMP implementation projects in **(8)** the residential sections of the Muckinipattis Creek drainage that feed the pressure point "Muckinipattis Creek at Bishop Road," and the recreational land uses in **(9)** the Darby Tributary #2 and **(10)** the upper Levis Run drainages. The results of our ranking scheme are summarized in Table 6.

Table 6. Priorities for implementation of retrofit stormwater management measures to achieve runoff volume reduction and nonpoint pollution removal in the five selected drainage areas associated with flooding pressure points

Priority	Drainage Point	Land Use
1	Stony Creek at Woodland Avenue	Residential
2	Darby Tributary #1 at West Rolling Road*	Recreational
3	Stony Creek at Woodland Avenue+	Commercial
4	Stony Creek at Woodland Avenue*	Recreational
5	Levis Run at Township Building+	Residential
6	Darby Tributary # 1 at West Rolling Road	Residential
7	Darby Tributary #2 at North Rolling Road	Residential
8	Muckinipattis Creek at Bishop Road	Residential
9	Darby Tributary #2 at North Rolling Road	Recreational
10	Levis Run at Township Building	Recreational

* - Further interpretation of Figure 3 shows that at the higher amounts of total sediment reduction and total resources allocated, the recreational land uses in the Darby Tributary #1 and Stony Creek drainages become fully saturated with BMP's, as indicated by flattening of these curves, and

+ - the commercial land uses in the Stony Creek drainage and the residential land uses in the Levis Run drainage become the second and third priorities, respectively.



Drainage Point Key:
1 – Darby Tributary #1 at West Rolling Road
2 – Darby Tributary #2 at North Rolling Road
3 – Levis Run at Township Building
4 – Muckinipattis Creek at Bishop Road
5 – Stony Creek at Woodland Avenue

Figure 3. Priorities for the first 100 Tons/year of sediment reduction by BMP implementation based on multiple runs of the NPSOPT model. The legend identifies which land uses and drainage areas (with a numbering scheme shown in the Drainage Point Key) should receive priority as the total sediment reduction is increased in 25 ton/year increments.

RECOMMENDATIONS AND CONCLUSIONS

Recommendations for Use of Prioritization Results

Our model provides guidance for watershed managers and municipal officials regarding the locations in Springfield Township where sites for retrofit stormwater BMP's should be located so that nonpoint pollution loadings are reduced at minimum total cost. The top three candidates are the (1) residential and (2) commercial land uses in the Stony Creek drainage upstream from the pressure point at the Woodland Avenue crossing and (3) the recreational land uses (golf course) in the Darby Tributary #1 drainage upstream from the pressure point at West Rolling Road. This ranking applies to a BMP retrofit program with target sediment reduction levels up to 50 tons and costing about $500 thousand. Above this level, further sediment reductions from recreational land in the Darby Tributary #1 drainage are impractical, and this category is replaced in the top three by (3) residential land uses in the upper part of the Levis Run drainage.

It is interesting to compare these results with some general guidance regarding prioritization that is in the literature related to imperviousness in developed areas. Schuler, for example, suggests that the ecological degradation created by new development can be minimized by concentrating the associated additional impervious surfaces in areas that are already highly impervious and, therefore, already degraded, based on impervious area greater than 25%. Schuler goes on to suggest that watershed managers my have to "confront the fact that to save one stream's quality it may be necessary to degrade another" (Scheuler, 2000).

Our modeling approach produces somewhat similar results when the Phase 1 screening model eliminates certain drainages that are so heavily developed that few opportunities exist for cost-effective implementation of BMP's. But strict application of the 25% impervious criterion would eliminate three drainage areas having impervious percentages greater than 25% (see Table 3) that we did select for further consideration in our model. Our results show that certain land-use categories in two of these three drainages (Levis Run at Township Building and Stony Creek at Woodland Avenue) are found by NPSOPT to be among the high priority drainage points for implementation of retrofit BMP's (as shown in Table 6). Thus, our results suggest that prioritization of areas based on a single criterion such as impervious percentage may eliminate sites from consideration that would be included in a more thorough, multiobjective analysis.

Our results for Springfield Township provide a scientifically sound basis for proceeding to the next step in the process, i.e. identifying specific projects within these drainage areas and conducting feasibility studies and, in the case of structural BMP's, preliminary design and cost studies. Then, funding can be sought from public and private sources to implement the projects. Some of these projects may be necessary to satisfy the requirements of new stormwater management regulations. Additional projects may be required to meet future water quality standards associated with a Total Maximum Daily Load (TMDL) specification for the Darby and Crum watersheds. Other projects may be developed to take advantage of special funding sources such as Pennsylvania's Growing Greener II program.

There are many sources of information on selection of specific BMP technologies. One particularly helpful source of such information for Pennsylvania is the *Pennsylvania Stormwater Best Management Practices Handbook*, currently in draft form and prepared by Cahill Associates, Inc. (PADEP/Cahill, 2005).

The Springfield Township Environmental Advisory Council has evaluated BMP technology specifically for application in Springfield Township in a multiobjective context which integrates nonpoint pollution loading reduction, stream water quality, and reduction of peak flows to reduce the frequency of flooding. Table 7 summarizes their guidance for selection of specific BMP projects that can implement the findings of this study.

Table 7. Examples of Cost-Effective Retrofit Water Quality/ Volume Control BMP's for Springfield Township, the Overall Goal, and the Desired End Result

RESIDENTIAL & COMMERCIAL:	
	More trees and vegetative systems for evapotranspiration
	Rooftop disconnects
	Rain gardens and bioretention with infiltration for disconnected runoff (i.e. a bioretention cell that includes an infiltration gallery constructed underneath its drainage bed)
	Right-of-way bioretention cells with infiltration
	Sidewalk and curb-cuts
	Greenroofs as feasible
	Forested riparian buffer restorations on 1^{st} & 2^{nd} –order streams
MUNICIPAL, SCHOOL DISTRICT, AND RAIL TRANSPORTATION:	
	BMP Parks for education
	Street sweeping expansion
	Groundwater infiltration galleries for parking lots and key street intersections
OVERALL GOAL:	
	Restore natural bank-full streamflow statistical frequency of 1.5 years in each second-order subwatershed through water quality BMP's
DESIRED END RESULT:	
	"Peak rate control (is) integrated into volume control BMP's in ways that eliminate need for additional peak rate control detention systems" … while removing nonpoint pollution. (PADEP/Cahill, 2005)

Incentives are necessary to encourage voluntary construction of stormwater management BMP's. Examples of possible incentives include a stormwater authority set up at the county level allowing the revenue stream from properties served by the voluntary BMP's to be utilized by the local municipality to operate and maintain them, including those that already exist and those to be constructed in the future.

Conclusions

This project has successfully completed its four work elements as demonstrated in the Results section. We have consulted with stakeholders and decision makers to develop goals and objectives for stormwater related nonpoint pollution. In addition to our Phase 1 study objective of reducing total nonpoint pollutant loadings on local streams and the Delaware Estuary, we identified peak flow control for reducing the frequency of flooding events as an objective that should also be weighted heavily in a multiobjective analysis.

We constructed a multi-objective ranking model that uses an improved model for urban washoff pollutant loads and a streambank erosion component calibrated for local conditions using our own site-specific monitoring data and field verification. We adapted the BMP cost and optimization components of the NPSOPT model developed in our Phase 1 study for use on smaller drainages selected for their potential to reduce the frequency of out-of-bank flows and flooding. We ran NPSOPT ten times for increasing total sediment removal to obtain a ranked list of drainages and land uses within those drainages where cost-effective BMP projects can be implemented.

We evaluated the top three sites and determined how the rankings might change as the target for total sediment removal is increased. Finally, we examined the application of these results in the context of current and future stormwater management regulations, and we presented suggestions for specific BMP technologies to be considered for specific projects within the designated top priority drainage areas.

BIBLIOGRAPHY

Evans, B.M., S.A. Sheeder, and D.W. Lehning, 2003. "A Spatial Technique for Estimating Streambank Erosion Based on Watershed Characteristics," J. Spatial Hydrology, Vol. 3, No. 1.

Evans, B.M., S.A. Sheeder, K.J. Corradini, and W.S. Brown, 2004. *AVGWLF Version 5.0 Users Guide*, Environmental Resources Research Institute, The Pennsylvania State University, University Park, PA.

Haith, D.A. and L.L. Shoemaker, 1987. "Generalized Watershed Loading Functions for Stream Flow Nutrients," Water Resources Bulletin, 23 (3), pp. 471-478.

Maidment, D.R. (ed), 2002. *ArcHydro: GIS for Water Resources*, Redlands, CA, ESRI Press.

McGarity, A.E. and Paul E. Horna (2005). *Decision Making for Implementation of Nonpoint Pollution Measures in the Urban Coastal Zone*, Final Report, Pennsylvania Department of Environmental Protection, CZM Proj. No. 2003-PS.06; also, a summary of this report was presented at the 2005 Pennsylvania Stormwater Management Symposium, Villanova University, October 12, 2005, internet link: http://egrfaculty.villanova.edu/public/Civil_Environmental/WREE/VUSP_2005_Sym/Web/

PADEP, 2005. *Pennsylvania Stormwater Best Management Practices Manual*, Second Draft, prepared by Cahill Associates, Inc., 2005, http://www.dep.state.pa.us/dep/subject/advcoun/Stormwater/stormwatercomm.htm

PASDA, 2004, Pennsylvania Spatial Data Access (PASDA) web site link maintained by the Pennsylvania State University: http://www.pasda.psu.edu/.

Schuler, T.R. and H. K. Holland (ed.), 2000. "Article 1: The Importance of Imperviousness," *The Practice of Watershed Protection*, Center for Watershed Protection, Ellicott City, MD.

Appendix A – Photos

Photos 1 & 2. Construction site in Smedley Park adjacent to Crum Creek at boundary with Nether Providence Twp.

Photos 3 & 4. Utility right of way with exposed soil on steep slopes in Jane Lownes Park near Lownes Run.

Photos 5 & 6. Recreational areas in Jane Lownes Park with eroding exposed soil

Photos 5 & 6. Recreational areas in Jane Lownes Park with eroding exposed soil


Photo 7. Sediment laden runoff from Jane Lownes Park creating additional erosion as it flows down a steep slope towards Lownes Run.

Photo 8. Sediment laden runoff from Jane Lownes park creates a visible plume where it joins the main flow in Lownes Run. The runoff is flowing down a steep slope from left to right in the photo. It joins Lownes Run which is flowing from the lower right to the upper middle of the photo. The sediment plume is the turbid brown portion in the flow adjacent to the left bank of Lownes Run.

Photo 9. Isco Model 6712 autosampler installed in a protective cinderblock and aluminum enclosure for obtaining storm event sediment and nutrient data with associated rainfall and flow measurements.

Photo 10. Installation of the autosampler in its protective enclosure at the pressure point "Stony Creek at Woodland Avenue." The sampling suction tube and the cables for the flow sensor and the rain gage are routed out of an opening in the bottom of the enclosure. Dry weather flow at the time of the photo in the concrete channel is minimal.

Photo 11. Autosampler (inside enclosure) during the rain event on 7/8/2005 at the pressure point “Stony Creek at Woodland Avenue.”

APPENDIX B

MONITORING DATA SUMMARIES

Site	Date/Sample	TSS (mg/L)	Total Nitrogen (mg/L)	Nitrate (mg/L)	Total Phosphorous (mg/L)	Phosphate (mg/L)	Flow (CFS)
Stony at Woodland Av	7/8/2005						
	1	17.20	4.85	2.18	1.09	0.30	2.3
	2	9.90	2.50	1.02	0.79	0.33	4.3
	3	17.46	4.26	0.97	0.95	0.29	8.9
	4	582.00	4.96	0.56	5.14	0.38	78.7
	Event Mean	**488.78**	**4.78**	**0.66**	**4.45**	**0.36**	
Darb Trib #2 at North Rolling Rd	8/8/2005						
	1	94.4		4.07		1.13	
	2	396.4	6.18	2.04	0.32	0.15	
	3	18.4		7.78		0.18	
	4	5.9	6.03	5.30	0.58	0.48	
Darby Trib #1 at West Rolling Rd	8/15/2005						
	1	811.0		3.15		1.18	40
	2	229.0		3.70		2.03	25
	3	74.0		4.26		2.03	15
	Event Mean	**490.94**		**3.53**		**1.61**	
Muckinipattis at Bishop Rd	8/27/2005						
	1	361.6		3.48		0.59	14.5
	2	85.6		1.54		0.35	10.4
	3	36.8		1.81		0.30	2.8
	Event Mean	**225.23**		**2.58**		**0.47**	
Levis at Twp. Building	9/15/2005						
	1	292.40					1.6
	2	126.60					14.2
	3	35.40					5.8
	Event Mean	**114.63**					

APPENDIX C

OPTIMIZATION MODEL DETAILED RESULTS

Drainage Point Key:

1 – Darby Tributary #1 at West Rolling Road
2 – Darby Tributary #2 at North Rolling Road
3 – Levis Run at Township Building
4 – Muckinipattis Creek at Bishop Road
5 – Stony Creek at Woodland Avenue

Table C-1. NPSOPT Output for BMP's on Commercial Land Uses

Total Sediment Reduction	Total Resources	Resources Devoted to BMP's on Commercial Land Uses Feeding Drainage Point ($Thousands) :				
(Tons)	($K)	1	2	3	4	5
25	$191	$0.00	$0.00	$0.00	$0.00	$11.82
50	$485	$0.00	$0.00	$0.00	$0.00	$79.45
75	$881	$0.00	$0.00	$1.47	$0.00	$147.20
100	$1,394	$0.00	$0.00	$4.60	$0.00	$222.97
125	$2,075	$0.00	$0.00	$8.72	$0.00	$322.88
150	$3,005	$0.00	$0.00	$14.23	$19.49	$453.84
175	$4,327	$0.00	$0.00	$22.07	$59.35	$638.13
200	$6,330	$0.00	$0.00	$34.19	$119.94	$916.54
225	$9,662	$0.00	$0.00	$54.62	$221.03	$1,372.13
250	$16,113	$0.00	$0.00	$96.52	$417.73	$2,245.11

Table C-2. NPSOPT Output for BMP's on Residential Land Uses

Total Sediment Reduction	Total Resources	Resources Devoted to BMP's on Residential Land Uses Feeding Drainage Point ($Thousands):				
(Tons)	($K)	1	2	3	4	5
25	$191	$0.00	$0.00	$0.00	$0.00	$144.19
50	$485	$28.62	$0.00	$40.28	$0.00	$269.14
75	$881	$76.63	$40.61	$89.99	$5.78	$388.04
100	$1,394	$131.02	$110.02	$146.69	$50.75	$521.50
125	$2,075	$203.03	$200.31	$222.01	$107.79	$698.28
150	$3,005	$297.98	$317.22	$321.45	$183.72	$933.06
175	$4,327	$432.44	$479.87	$462.58	$290.38	$1,261.27
200	$6,330	$638.78	$722.81	$679.65	$450.83	$1,754.75
225	$9,662	$988.54	$1,117.74	$1,048.61	$718.71	$2,571.80
250	$16,113	$1,678.44	$1,862.64	$1,783.27	$1,233.40	$4,127.06

Drainage Point Key:

1 – Darby Tributary #1 at West Rolling Road
2 – Darby Tributary #2 at North Rolling Road
3 – Levis Run at Township Building
4 – Muckinipattis Creek at Bishop Road
5 – Stony Creek at Woodland Avenue

Table C-3. NPSOPT Output for BMP's on Institutional Land Uses

Total Sediment Reduction	Total Resources	Resources Devoted to BMP's on Residential Land Uses Feeding Drainage Point ($Thousands):				
(Tons)	($K)	1	2	3	4	5
25	$191	$0.00	$0.00	$0.00	$0.00	$0.00
50	$485	$0.00	$0.00	$0.03	$0.00	$1.50
75	$881	$0.00	$0.00	$3.18	$0.00	$3.52
100	$1,394	$0.00	$0.00	$6.81	$0.00	$5.93
125	$2,075	$0.00	$0.00	$11.67	$0.00	$9.11
150	$3,005	$0.00	$0.00	$18.02	$0.00	$13.28
175	$4,327	$0.00	$0.00	$27.16	$0.00	$19.14
200	$6,330	$0.00	$0.00	$41.13	$0.00	$28.06
225	$9,662	$0.00	$0.00	$65.45	$0.00	$42.50
250	$16,113	$0.00	$0.00	$114.02	$0.00	$70.39

Table C-4. NPSOPT Output for BMP's on Recreational Land Uses

Total Sediment Reduction	Total Resources	Resources Devoted to BMP's on Residential Land Uses Feeding Drainage Point ($Thousands):				
(Tons)	($K)	1	2	3	4	5
25	$191	$26.11	$0.00	$0.00	$0.00	$9.36
50	$485	$48.45	$0.00	$0.00	$0.00	$17.51
75	$881	$71.32	$14.45	$13.30	$0.00	$25.27
100	$1,394	$97.03	$32.45	$30.31	$0.00	$34.19
125	$2,075	$131.82	$55.90	$52.82	$4.52	$45.93
150	$3,005	$177.91	$86.70	$82.56	$24.39	$61.37
175	$4,327	$244.06	$129.76	$125.29	$52.78	$83.15
200	$6,330	$345.18	$194.36	$191.55	$96.52	$115.61
225	$9,662	$517.66	$300.22	$304.38	$167.51	$170.77
250	$16,113	$867.21	$501.77	$531.68	$309.66	$274.22