Pennsylvania Coastal Zone Management Program

Riparian Corridor Best Management Practices

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- Chester-Ridley-Crum Watersheds Association
- Delaware County Planning Department
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Participants

The following persons contributed directly to this project through their participation in the Swarthmore College Undergraduate Summer Research Program, the Summer 2008 Environmental Science Research Outreach Program, and two courses at Swarthmore which were involved in this project thorough Community-Based Learning Exercises:

- Patrick Lindsay and Susan Willis , Engineering Students, Swarthmore College
- Paul McGibney, Science Teacher, Ridley High School and Peter Cosfol, Science Teacher, Chester High School, Gale Lauser, student, Ridley High School; Eva Roben and Rachel Knee, students, Strath Haven High School
- Students in the Spring 2008 offering of Engineering 4A, Introduction to Environmental Protection at Swarthmore College
- Students in the Fall 2008 offering of Engineering 63, Water Quality and Pollution Control at Swarthmore College

Executive Summary

Keystone Conservation Trust, the Engineering Department of Swarthmore College, and the Chester-Ridley-Crum Watersheds Association partnered on this project to foster a leading edge application of tools from both the land and water protection communities. The scope of this project focuses on fostering better management of the land/water interface within and adjacent to riparian corridors, encouraging municipal and private implementation of restoration and protection measures, and on building stronger, more synergistic interactions between the land conservation and water protection communities.

The context for this study is the Little Crum Creek watershed which drains four municipalities in Delaware County, Pennsylvania. A prioritization approach is used to ensure that the highest impact areas are identified and the most 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. Identify sites where the greatest impacts can be achieved for water quality improvements
Initial insights into siting of water quality improvement practices were obtained using StormWISE version 1.0 adapted to Little Crum Creek. In a parallel effort, GIS data layers were used to conduct parcel-level prioritization analyses of several hundred sites on the basis of parcel size, SmartConservation and Ecological Green Infrastructure (EGI) values, and proximity to headwaters and areas of convergence. This analysis identified 22 parcels in 4 municipalities as representing the best opportunities taking in to account land-based resources. Results from SmartConservation and EGI analyses led to revised formulations of StormWISE that were implemented in work element 3.

2. Engage and train land trusts and watershed organizations on the easement tools and BMPs
In addition to the team of Keystone Conservation Trust and Swarthmore College, this project closely involved the Chester-Ridley-Crum Watershed Association. The lead conservancy in the area, Natural Lands Trust, was also engaged in a preliminary analysis of riparian parcels for protection with easements. Our analysis examined parcels spanning a total of four municipalities -- co-sponsors of this project. This portion of the project also served as the context for a community-based learning exercise in an undergraduate course at Swarthmore College. Lastly, this methodology was discussed with members of the Schuylkill Action Network, including the Partnership for the Delaware Estuary, Montgomery County Lands Trust, Berks County Conservancy, Chester County Planning, and the Delaware Valley Regional Planning Commission.

3. **Extend Swarthmore College's StormWISE model to prioritize and select practices to apply including riparian corridor preservation and restoration along with structural BMPs.**
The StormWISE model was extensively reformulated to enable explicit treatment of different management practices, including both structural BMPs and preservation (or loss) of existing greenspace, especially in the riparian corridor. A field monitoring program was conducted to collect stormwater runoff samples for calibration of the pollutant loads used in model.

4. Apply the revised StormWISE model to the Little Crum Creek Watershed and map the impact areas and practices using GIS.

The revised model was run for a base case and for a scenario projecting further urbanization (build-out) of the watershed. Graphs are presented showing prioritization in terms of necessary spending based on three methods of categorizing priorities: (1) between watershed zones (headwaters vs. lowlands), (2) among different land use categories, and (3) among different management practices including those implemented in the riparian zone. Comparison of projected total BMP costs required to improve water quality under the build-out scenario (extremely expensive) with estimated current costs of achieving the same degree of improvement (much less expensive) demonstrate the potential economic advantages of a proactive approach towards preservation of undeveloped land by municipalities and stakeholders in the watershed.

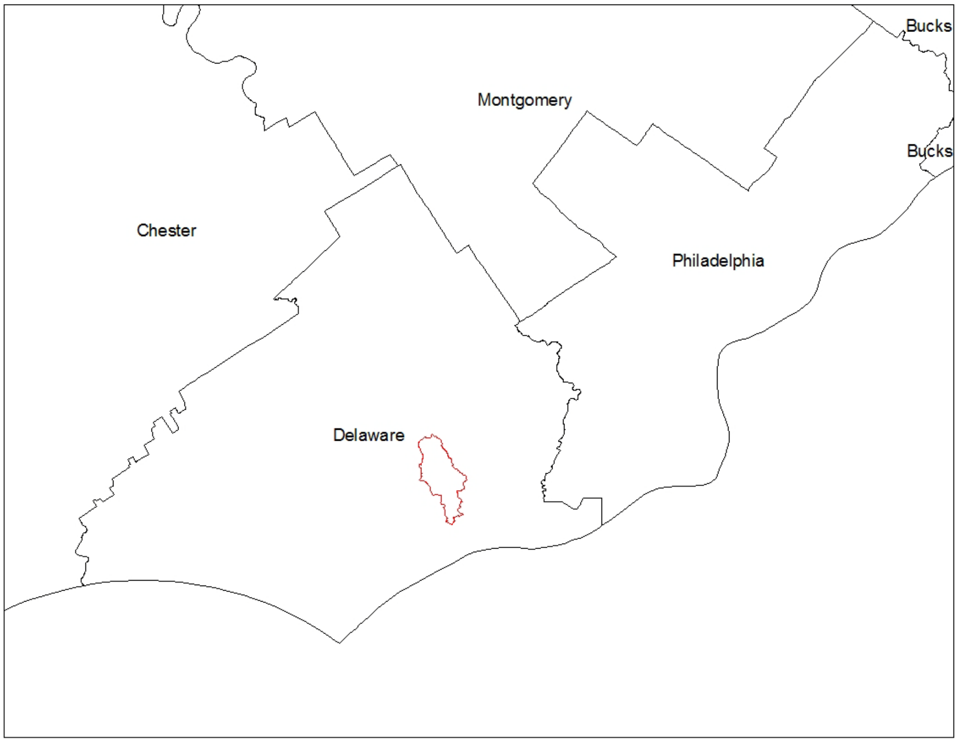
Purpose of Study

This project builds on and extends the work of two prior CZM-funded projects, 2003-PS.06 (McGarity and Horna, 2005a) and 2004-PS.08 (McGarity and Horna, 2005b), which developed, tested, and piloted the application of a science-based screening model for prioritizing sites for nonpoint pollution management measures. The model developed in these studies provided the foundation for the development of Swarthmore Colleges' Storm Water Investment Strategy Evaluator (StormWISE) optimization model with the support of the U.S. Environmental Protection Agency (McGarity, 2006a,b). This project extends the prior work on StormWISE by: (1) creating an enhanced tool, refining the model for broader applicability to a wider array of practices and ecosystems, and (2) applying the model to an entire urban watershed producing runoff that adversely impacts water quality in the coastal zone, especially during storm events.

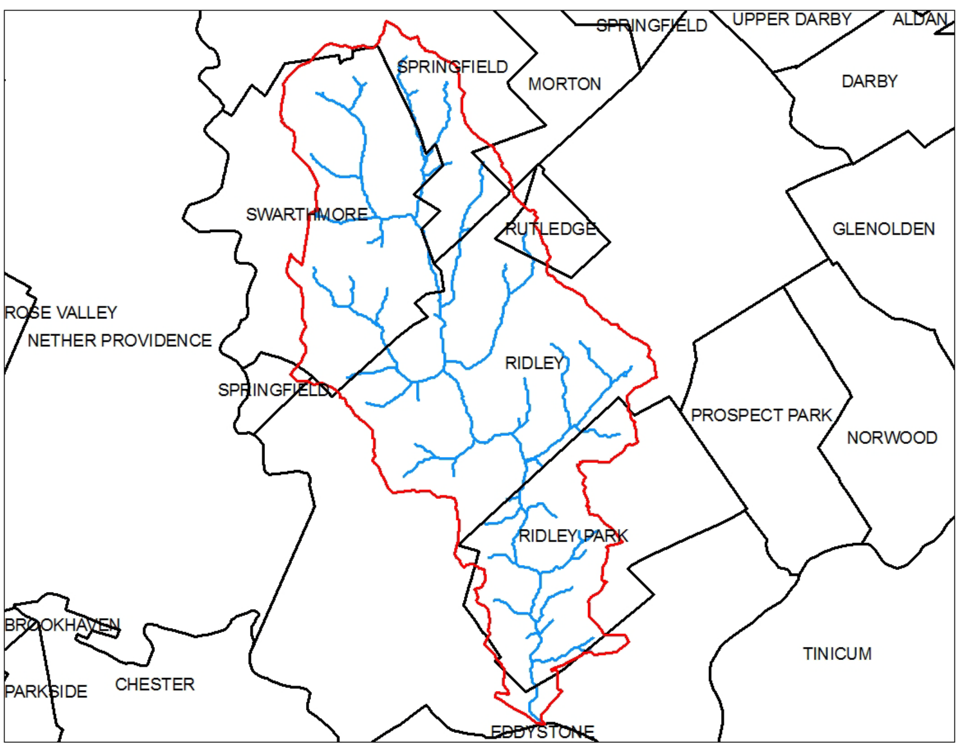
This project also involves interactions with land and water conservation organizations and municipal bodies to increase protection and remediation efforts in watersheds and their riparian corridors of the Pennsylvania Delaware Estuary Coastal Zone by identifying high impact opportunities for conservation efforts, and by seeking to foster greater use of new legal tools to accomplish permanent resource protection.

Greater emphasis on the perpetual management of the riparian corridors is critical to the improvement of water quality in both the coastal zone and across watersheds. This study investigates the potential for inclusion of riparian zone practices, including easements, in combination with structural best management practice in development of a comprehensive, multi-municipality action plan for restoration of water quality in an impaired urban watershed affecting the coastal zone, for which Little Crum Creek serves as a particularly relevant test case.

Figure 1 shows the location of the Little Crum Creek Watershed within the counties of Southeastern Pennsylvania. Figure 2 shows a close up of the Little Crum Creek Watershed with the municipalities it drains and other nearby towns. The watershed primarily drains, from north to south, Springfield Township, Swarthmore Borough, Ridley Township, and Ridley Park Borough. Small pieces of Rutledge and Morton Boroughs are also drained.



<u>Figure 1</u>. Location of Little Crum Creek Watershed within the counties of Southeastern Pennsylvania.



<u>Figure 2.</u> Little Crum Creek Watershed with stream segments, showing communities drained and nearby municipalities in Delaware County, Pennsylvania

The watershed occupies 3.2 square miles. Land uses in the watershed are typical for the "close-in" Philadelphia suburban areas where development began in the late 1800's followed by two periods of accelerated growth during the 1920's and 1950's. The land uses include "High Intensity" in the vicinity of commercial shopping districts, 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 3 shows the land use categories used in this study which were derived from satellite imagery (land cover) processed in 2001 by the Multi-Resolution Land Characteristics Consortium (MRLC) of U.S. government agencies. Note that the area of dark green "Forest/Wetland" land use follows the main stem of Little Crum Creek, shown in Figure 2, and some of the larger tributaries as well, indicating the prominence of this land use category in the riparian zone. This data layer was manually updated based on field observations in two significant instances. Manual conversion of land to "Developed High Intensity was performed to correspond with the expansion of Ridley High School near the center of the watershed in 2003 and expansion of the Harper Reality commercial complex in the middle eastern part of the watershed to include a Home Depot store, in 2004. A box culvert under the Home Depot store encloses a portion of a major eastern tributary of the creek.

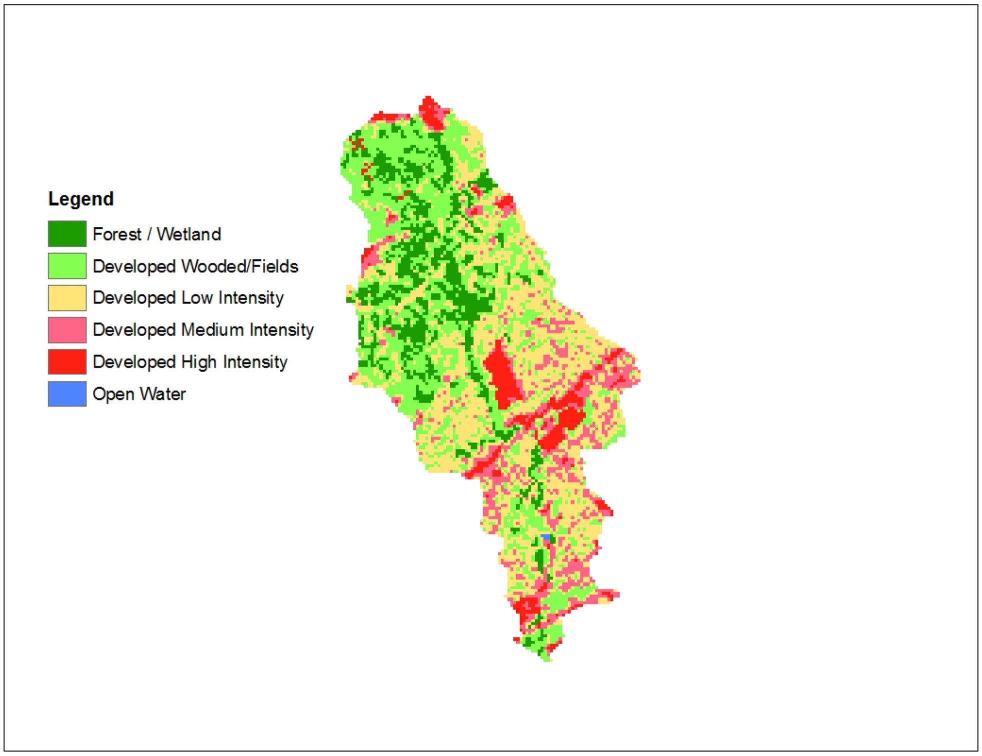


Figure 3. Little Crum Creek Watershed land use categories derived from Landsat satellite imagery and the 2001 dataset derived from these images by the Multi-Resolution Land Characteristics Consortium (MRLC) - http://www.mrlc.gov. Standardized MRLC land cover categories have been consolidated into categories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

Figure 4 shows how impervious surfaces are distributed throughout the watershed. These data are obtained from the Penn State PASDA web site (Carlson, 2000). A color ramp has been chosen to correspond somewhat with the colors used for the land use categories in Figure 3, with lower ranges of impervious percentage assigned to green and higher ranges assigned to yellow and red. Note the similarities of Figures 3 and 4 indicating how well impervious percentages correspond with land use categories. However, the correspondence is not exact, so mean and median values of impervious percentage have been calculated within our GIS software by overlaying these two map layers, and the results are shown in Table 1.

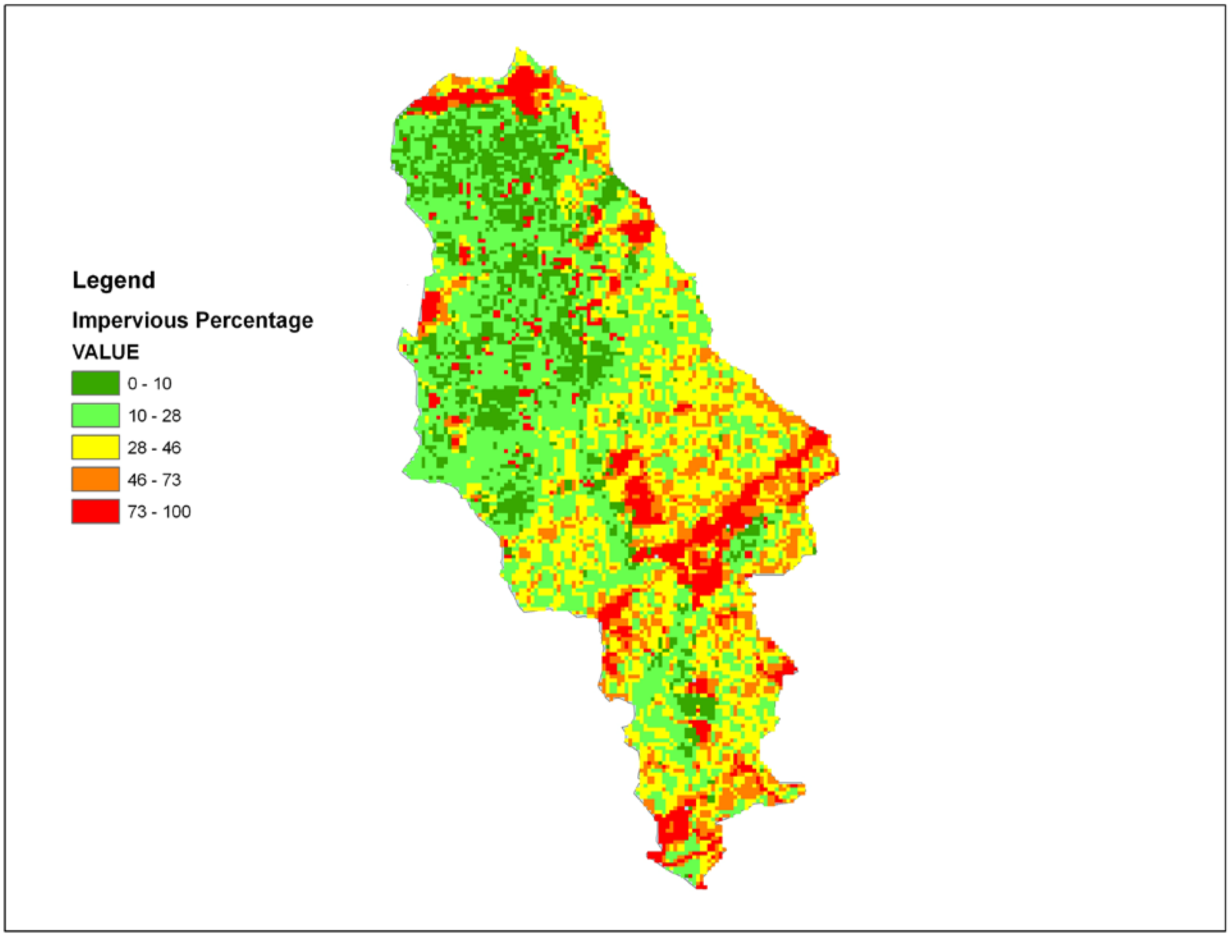


Figure 4. Little Crum Creek Impervious Percentage (derived from Carlson, 2000)

Table 1. Impervious Percentage for Each Land Use Category

Land Use Category	Mean	Median	Standard Deviation
Forest/Wetland	19%	15%	24%
Developed Wooded/Fields	27%	21%	25%
Developed Low Intensity	37%	32%	22%
Developed Medium Intensity	48%	41%	26%
Developed High Intensity	55%	50%	30%
All Land Uses:	**34%**	**28%**	**26%**

Methodology

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

1. Identify sites where the greatest impacts can be achieved for water quality improvements
2. Engage and train land trusts and watershed organizations on the easement tools and BMPs
3. Extend Swarthmore College's StormWISE model to prioritize and select practices to apply including riparian corridor preservation and restoration along with structural BMPs.
4. Apply the revised StormWISE model and map the impact areas and practices using GIS.

Results

We describe here the accomplishments related to each work element.

Task 1. Identify sites where the greatest impacts can be achieved for water quality improvements

Pollutant Load and BMP Modeling: Initial StormWISE Model Results. Our primary goal in this work element is to identify the best opportunities for cost-effective reduction of nonpoint pollution loading into the coastal zone (Delaware Estuary and Bay). We began this task by preparing data from GIS layers for Little Crum Creek from Penn State's PASDA repository and the AVGWLF nonpoint pollutant loading model. Swarthmore College students participated in this phase of the study through an Engineering Design thesis student (Lindsay, 2008) and through a community-based learning exercise in the course "Introduction to Environmental Protection" (Davalos and Post, 2008) which was a component of this project's involvement with and education of municipal officials and community stakeholders. Helpful feedback was solicited from participants in a Community Outreach Forum on Little Crum Creek held at Swarthmore College on April 30, 2008.

The AVGWLF/RunQual (Evans, 2008) pollutant load estimation model was run for the Little Crum watershed. This step required delineation of the watershed into seven small subwatersheds. These seven subwatersheds, the stream segments, and the associated riparian zones are shown in Figure 5.

The seven subwatersheds and the riparian zone were modeled as eight separate drainage areas for runs of StormWISE version 1.0 in order to obtain an order-of-magnitude estimate of costs required to obtain a specified sediment load reduction of 50,000 pounds (25 tons) per year. For this analysis, installation of filter strips in the riparian zone was modeled as having pollutant load reduction potential. The model output is displayed as a table and pie chart in Figure 6. The results indicate that optimal allocation of resources can achieve this level of annual sediment reduction for about $1.3 million of installed capital investment. This is equivalent to $26 per pound of annual sediment reduction or $2.6 per pound of sediment over 10 years. Note that operation and maintenance costs are not included at this stage of the analysis due to large uncertainties involved in estimating them.

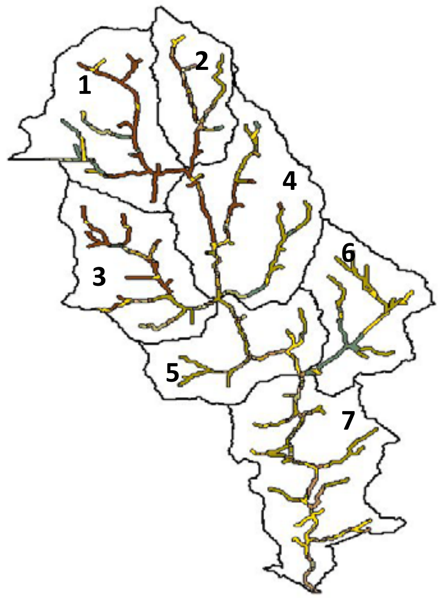


Figure 5. Seven subwatersheds used in initial StormWISE modeling in Task 1, including stream segments and associated riparian zones.

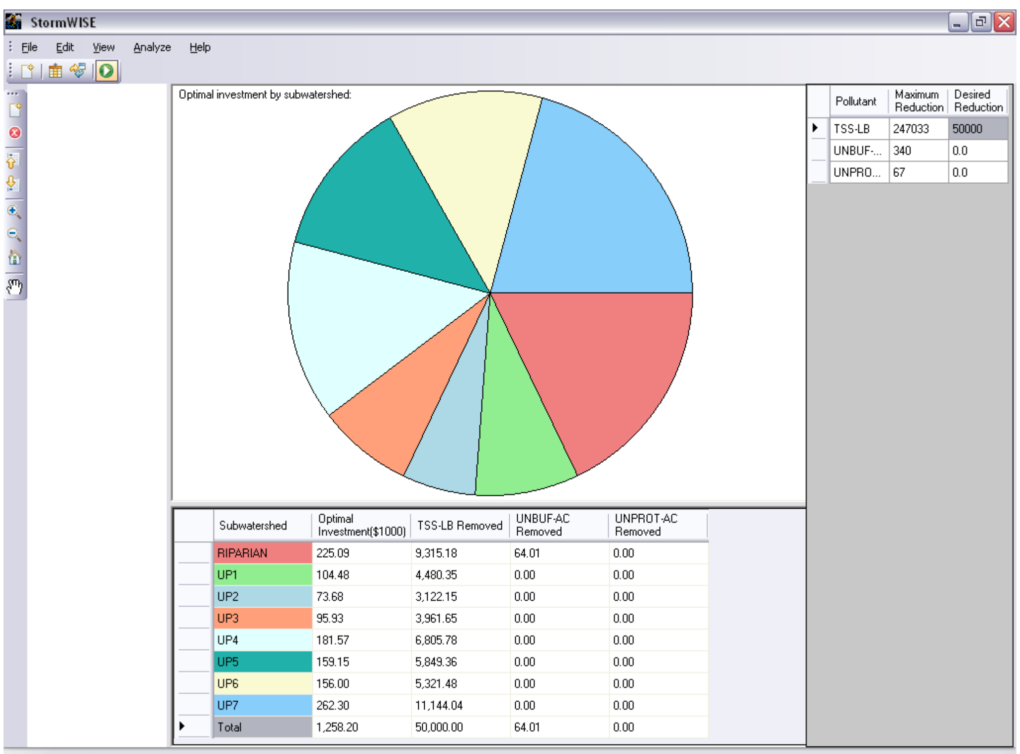


Figure 6. StormWISE model used in Task 1, treating riparian zone as a drainage area with sediment pollutant reduction potential. Optimal spending levels (based only on installation capital costs) are shown for the seven subwatersheds (labeled UP1 – UP7) and the riparian zone.

These results suggest that there exists potential for cost-effective nonpoint pollution load reduction through restoration of the buffering capacity of the riparian zone. Also, these results indicate a slight preference for locating BMP projects in the subwatersheds 4, 5, 6, and 7. Further investigation of these results reveals that this preference is related to the mix of land uses in these zones rather than their location within the watershed.

In July, 2008, these StormWISE modeling results were presented by Arthur McGarity to the American Water Resources Association's Summer Specialty Conference: "Riparian Ecosystems and Buffers: Working at the Water's Edge," where helpful comments were received from conference participants. Extensions of the StormWISE model accomplished in Task 3 (discussed below) such as modeling headwaters and lowlands separately, provide additional capabilities to model riparian zone management practices.

One limitation of the initial StormWISE analyses involves its "static" nature. That is, the model allocates resources to BMP projects that will affect water quality over the long-term but its decisions are based on the present rather than future land use characteristics. Thus, the possibility exists that the water quality gains achieved by a watershed action plan developed from this analysis will be undone by conversion of undeveloped land, which presently contributes relatively little pollutant load, into developed categories thereby generating new sources of polluted storm water runoff. Thus, a watershed action plan should include enactment and enforcement of legal ordinances setting stringent requirements for storm water management on new development. In this study, we explore the potential for another approach to sustaining the gains achieved by expensive storm water management BMP installations in urban watersheds, which is the implementation of natural land preservation easements, especially riparian easements.

Riparian Easements. The riparian buffer easement or riparian buffer protection agreement is a tool to help private landowners work in partnership with local governments and/or conservation organizations to establish permanent riparian buffers. Used in conjunction with BMPs, the legally binding easement helps to ensure that activities and uses in the riparian buffer are sustainable, neither diminishing the biological integrity nor depleting the soil, forest and other natural resources within the riparian buffer over time.

The riparian protection easement achieves these conservation objectives while keeping the property in the landowner's ownership and control. A riparian buffer easement is a permanent restrictive covenant between a landowner and a conservation organization or governmental body (such as a municipality or county conservation district) which places permanent restrictions on activities that would harm the water, forest, or soil. The easement holder, either land trust or governmental body, commits to watch over the land and enforce the restrictions. The riparian buffer easement can be an appropriate tool to protect natural resources when it is necessary or desirable to keep the land in a private landowner's ownership and control.

For decades, land trusts have used conservation easements as a core approach to conserving land across the Commonwealth and across the nation. The riparian buffer easement is distinct from the traditional conservation easement in its targeting of much more finite land areas and its specific targeting of the land/water interface. The riparian protection agreement is tailored specifically for where the goal is to protect a relatively narrow ribbon of land along a waterway or lake. One model riparian easement tool, developed with funding from the Pennsylvania Department of Environmental Protection, can be found

on the website of the Pennsylvania Land Trust Association at
http://conserveland.org/model_documents/WQI_Commentary_050715.pdf

Introduction to Smart Conservation and Ecological Green Infrastructure. Today's gold standard for ranking conservation lands, SmartConservation was developed in the 1990s. Created to provide a decision tool for focusing finite funding and protection resources where they can do the most good, this science-based analysis created a standardized method for ranking the relative ecological importance of sites being considered for conservation. Including data on wildlife, soils, water quality and other characteristics, SmartConservation identifies conservation targets at the level of individual parcels.

Building from and expanding the science of SmartConservation, Ecological Green Infrastructure (EGI) examines opportunities for creating ecologically valuable landscape connections. To function properly, hubs or nodes of conservation lands should be connected to one another. Both nodes and corridors are needed to maintain healthy levels of genomic variation in wildlife populations and to support biodiversity in region. EGI analyzes parcels to determine which can serve a useful function by creating these connections, even if they have little or no intrinsic ecological value on a stand-alone basis. Like SmartConservation, EGI also identifies priorities at the parcel level.

Attachments A and B to this report provide more detailed background and technical information on the Smart Conservation and Ecological Green Infrastructure methodologies. Further information can be obtained from the web site: http://www.smartconservation.org/scmAbout.asp.

Little Crum Creek SmartConservation Analysis. For the *SmartConservation* Parcels Analysis portion of this project, KCT used the composite conservation resource value map generated for the extended Piedmont Ecoregion within Pennsylvania as a basis from which to select parcels in the Little Crum watershed that may warrant protection from an ecoregion-wide natural resource perspective.
Methodology:

1. In GIS, parcels within the Little Crum Watershed were overlaid with the *Composite SmartConservation Greensweep* values map (i.e. the combined 22 natural resource value analysis).
2. For simplicity on this project – the *SmartConservation* values were further grouped into 5 value classes, as follows:
    a. Best Conservation Resources (values 9 & 10 – classed as 10)
    b. Medium-High Conservation Resources (values 7 & 8 – classed as 8)
    c. Intermediate Conservation Resources (values 5 & 6 – classed as 6)
    d. Medium-Low Conservation Resources (values 3 & 4 – classed as 4)
    e. Worst Conservation Resources (values 1 & 2) – removed from project consideration.
3. Parcel information (parcel number, landowner name and contact information, etc) for all 61 parcels in categories (a) through (d) were then extracted from GIS, imported into Excel and prioritized according to *SmartConservation Greensweep* value class.
4. If a parcel qualified in multiple value classes, records were combined indicating all resource classes the parcel qualified under, and duplicates were removed.
5. The parcel data was then further prioritized by size. All parcels 3 acres and larger were identified and sorted by size.
6. The result is a list of *Little Crum Watershed parcels* that is therefore prioritized by both *SmartConservation Greensweep* value and size (largest being more valuable).

Little Crum Creek Ecological Green Infrastructure Analysis. For the *Ecological Green Infrastructure* Parcels Analysis portion of this project, KCT selected parcels in the Little Crum Watershed that may warrant protection based on recommendations the EGI plan makes for protection of biodiversity conservation hotspots and wildlife corridors in the ecoregion.

Methodology:

1. In GIS, parcels within the Little Crum Watershed were overlaid with the Ecoregional *Ecological Green Infrastructure* value plan.
2. Parcel information (parcel number, landowner name and contact information, etc) for all 594 parcels *intersecting* the proposed biodiversity conservation hotspots or wildlife corridors was then extracted from GIS and imported into Excel.
3. If a parcel qualified in multiple value classes, records were combined, indicating all resource classes the parcel qualified under, and duplicates were removed.
4. The parcel data was then further prioritized by size. All parcels 3 acres and larger were identified and sorted by size.
5. The result is a list of *Little Crum Watershed parcels* that is is therefore prioritized by both Ecological Green Infrastructure value and parcel size (largest being more valuable).

Little Crum Riparian Lands Protection. An integral element of this project was the diffusion of the project's conservation science and strategy to key stakeholders, both private and public. To advance the protection of the prioritized parcels in the Little Crum subwatershed, participating municipalities have been provided lists of the lands within their jurisdictions which merit greatest attention. A public presentation to property owners as well as municipal officials provided an overview of the project, its methods and scope and outcomes. Conversations with land trust professionals, municipal staff, county planning leadership, and conservation practitioners from across the southeastern Pennsylvania region have all been undertaken with the goal of fostering implementation action locally and more widespread use of an integrated approach regionally.

Notwithstanding the strong interest in the integrated planning and prioritization approach developed under this grant, our work did uncover important hurdles to the broad application of riparian easements as a primary land protection tool. During the course of the project, conversations with leading land trust and county personnel made it clear that a riparian buffer easement per se (as contrasted to the traditional conservation easement) is problematic in an area such as the Little Crum watershed. Local land use characteristics which impede the successful application of this tool included:

- the highly built out landscape
- the predominance of smaller lot sizes
- existing zoning and ordinances

Few unimproved lots exist within this subwatershed. This, along with the smaller lots and existing uses have produced a landscape in which there are many encroachments in to the buffer zones. While this reinforces the need for better protection of the riparian corridor, it diminishes the utility of the riparian easement as the tool for effecting this protection. In comparison to traditional conservation easements, easements of this size offer lesser value to the homeowner (in associated tax benefits) and may in fact cost more to establish than they yield in tax benefits. These easements are also of lesser value to the land conservation organizations while bearing similar costs to more attractive conservation easement projects. Since conservancies are able to achieve a greater 'bang for the buck' with larger, traditional conservation easements, riparian easements are likely to be relegated to a lower priority status.

Cost data on riparian easements were developed from multiple sources, including organizations actively involved in ecological restoration. Data on the transactional costs associated with easement creation and monitoring were developed using the combined expertise of KCT and leading land trust personnel. Data on the likely costs of easement acquisitions were developed from current cost data on land values using mean per acre prices based on estimates provided by commercial real estate professionals in the region and are presented in Table 2.

Table 2. Cost Data for Riparian Easements and Land Acquistion

COST COMPONENT	CATEGORY	COSTS
Acquisition of land costs		
(for 100 acres total within Little	Unbuildable	$26,000
Crum Creek riparian zone for	Residential buildable	$2,925,000
each category's actual acreage)	Commercial buildable	$7,410,000
	Industrial buildable	$4,140,000
Administraton & Legal Costs		
	Lump sum administration & legal cost (e.g. negotiate, do paperwork, complete & record easement)	$5,500
Monitoring Costs		
	Lump sum baseline & research monitoring	$2,000
Survey Costs		
	Lump sum for preliminary monitoring/benchmark report & legal documents	$2,500
Monitoring Cost		
	Annual monitoring cost	$672
	Endowment required for annual monitoring, landowner outreach & "reviews"	$13,436
	Endowment required for periodic minor violations	$2,722
	Endowment required for periodic major violations	$33,500
Management &/or Restoration Costs		
	Annual management cost	$1,202
	Endowment required for annual management & landowner outreach	$20,337
	Endowment required for periodic "management interventions"	$3,708
	Endowment required for periodic "minor restorations"	$4,737
	Endowment required for occasional "major restorations"	$100,500
Total Cost if Land Acquired	(100 acres)	$14,501,000
Avg. Cost per Acre if Land Acquired	(per acre)	**$145,010**
Total Lump Sum and Endowment Costs for Riparian Easement	(100 acres)	$178,940
Avg. Lump Sum and Endowment Costs for Riparian Easement	(per acre)	**$1,789**

In a traditional conservation easement there is a significant tax deduction for the landowner. There is also a conservation objective with personal meaning to the property owner in many cases. Thus there will most likely be no acquisition costs because the donor is motivated, and sufficiently compensated, by other factors.

In the case of a riparian corridor easement, the above traditional considerations may not hold making it likely that it will be necessary to pay for riparian easements in order to make them workable. The property owner may have no personal motivation for preserving the property. Absent a personal intent to see the property protected, it often becomes necessary to purchase the land because the tax deduction which the landowner receives is never equal to the fair market value of the land. Thus, the land owner may have to be able to bear a loss in property value with limited compensation which may severely limit the number of land owners willing to allow a riparian easement. To the degree that the land in question includes adjacent developable land, the land values would apply. In this case, the easement value would be the net reduction in the property value attributable to extinguishing the development rights. Thus, there may be little incentive to either landowner or land trust to complete transactions of this type. This misalignment of costs and benefits undercuts the attractiveness of the riparian easement to the central implementing organizations, the land trusts. While the tool may have better utility and value in more rural locales, in a region similar to this portion of Delaware County it simply does not make good land conservation sense.

Combined Priority Parcel Identification. The parcel prioritization done using Smart Conservation and Ecological Green Infrastructure have been combined with analyses of proximity to the riparian zone to produce a final selection of 48 priority parcels within the Little Crum watershed. These parcels are displayed on the map derived from GIS analyses in **Figure 7**. Priority parcels exist in all four municipalities. Detailed information on the 22 parcels that are greater than 3 acres are shown in **Table 3**. From this master list, municipality-specific lists of targets are developed. The resulting combined parcel prioritization list are being presented to each sponsoring municipality with a customized list of priority parcels to be targeted for protection and BMP implementation.

Task 2. Engage and train land trusts and watershed organizations on the easement tools and BMPs

In spite of the limited prospects for easements as a riparian zone protection tool, the goal of better integrating land and water protection practices remains highly attractive to practitioners and to local governments, so their options for merging land and water conservation practices are being considered. The nine meetings of municipal officials, watershed stakeholders, land conservation professionals, and watershed modeling experts that have occurred and two more that are currently planed related to this project are documented in Appendix B.

A working group consisting of both public and private organizations is examining alternatives for more effective nonpoint pollution reduction and riparian zone protections. KCT discussions with County staff leading this effort uncovered that regulatory options such as more stringent ordinances are under consideration.

Targeted land protection within the Little Crum watershed is being examined on a case by case basis. One group of parcels identified through the analyses of this project has been examined via review of municipal maps, site visits, and preliminary photo-documentation. This group of ten residential parcels appears in Figure 7 at a point near the upper center of the map where the boundaries of Swarthmore, Springfield Townshop, and Ridley Township merge. Conversations between municipal staff and the local watershed association indicate a high level of municipal interest in pursuing opportunities for protection of this corridor which involves an unused road right of way. Conversations between KCT and the local land trust have set the stage for subsequent follow up with the watershed association. Next steps for outreach to landowners will be decided upon by the local conservation practitioners.

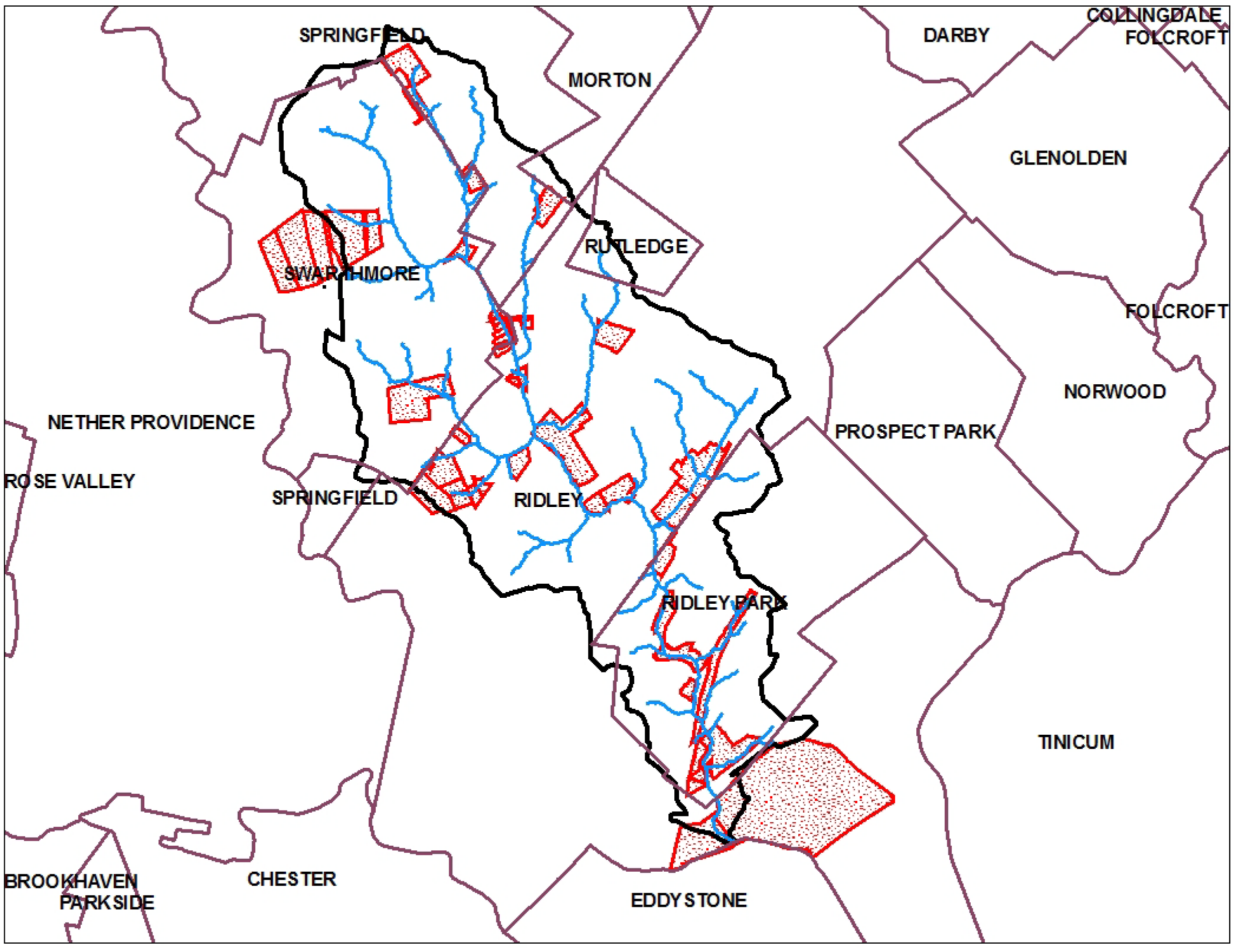


Figure 7. Priority parcels selected on the basis of three criteria: SmartConservation analysis, Ecological Green Infrastructure analysis, and riparian lands protection. 48 parcels were selected, but three large parcels belonging to Swarthmore College (northwest edge of the watershed) were subsequently removed because they are drained by the college's storm sewer system which has an outfall on the main branch of Crum Creek to the west.

KCT also undertook outreach to leading land and water conservation organizations and agencies active in other watersheds in southeastern Pennsylvania. Regional interest in better integration of land and water protection tools suggests near-term opportunities for building upon the work done under this grant. One prime opportunity exists in the Schuylkill River watershed. The Land Collaborative of the Schuylkill Action Network has expressed interest in the StormWise model and the work done in the Little Crum to integrate the SmartConservation data in a prioritization process. Related GIS-based resource prioritization science has been used to define land protection targets within the Schuylkill watershed. In fact the Schuylkill Watershed Priority Lands Strategy is also based upon SmartConservation data, suggesting that a parallel project in that watershed could readily build from the work done under this CZM grant.

Given the foregoing discussion of the barriers to riparian buffer easements, it is recommended that such future work look at alternative protection tools and/or incentivizing the creation of riparian buffer easements. It may well be that an incentivized approach in which the easement holder is a watershed association or governmental body could be workable and effective. If so, the outcomes would provide for the permanent protection of those riparian lands on which BMP investments are made. The greater permanence and improved sustainability which would result are benefits worthy of further examination.

Later in this report, we provide an estimate of the benefits that may be achieved through the use of land preservation incentives. In the Task 4 section, we show results obtained by running StormWISE under a build-out scenario. These results enable comparisons of the extremely high cost of restoring water quality after build-out with the much lower cost based on current land use patterns. The difference between these costs (costs after build-out minus current costs) can be compared with the riparian easement costs in Table 2. These comparisons suggest that in order to achieve federally mandated water quality goals, land preservation may turn out to be a bargain compared to the alternative of increased urbanization without land preservation, even if land must be purchased to preserve it.

Table 3 .

Prioritized Parcels Greater than 3 Acres and Identified by Combining SmartConservation, Ecological Green Infrastructure, and Riparian Lands Protection

OBJECTID	OWNER	ADDRESS	DESCRIPTION	NOTES	ACREAGE
(1) 198279	BOEING CO	INDUSTRIAL HWY, Ridley Twp.	INDUSTRIAL COMPLEX-NORTH	Boeing Industrial Land	137.50
(2) 120342	RIDLEY SCHOOL DIST	MORTON AVE, Ridley Twp.	BRK ADMIN BLDG	Ridley High School	23.41
(3) 194054	SWARTHMORE SCHOOL AUTH	RUTGERS AVE, Swarthmore	2 STY BRK SCH ATH.FIELD	Rutgers Ave School	20.55
(4) 143632	BOEING COMPANY	INDUSTRIAL HWY, Ridley Twp.	GRD	Boeing Industrial Land	19.54
(5) 188785	SWARTHMORE COLLEGE	550 ELM AVE, Swarthmore	STO HSE GAR	Athletic Field	18.37
(6) 184332	HARPER JOHN W SR &	300 MACDADE BLVD, Ridley Twp.	1 STY BLDG	Home Depot Retail	17.05
(7) 185164	COUNTY OF DELAWARE	230 CHESTER PK, Ridley Park	RECREATION CTR	Playing Fields	14.84
(8) 186114	RIDLEY PARK BOROUGH	DUPONT ST, Ridley Park		Ridley Lake Park	12.80
(9) 184135	SEPTA	Ridley Park		SEPTA Railroad	11.82
(10) 193589	HARPER JOHN W SR &	619 MORTON AVE, Ridley Twp.	SHOPPING CTR	Acme Retail	11.02
(11) 122618	NOTRE DAME CHURCH	1000 FAIRVIEW RD, Ridley Twp	2STY RECTORY	Church with school.	10.35
(12)190925	SPRINGFIELD SQUARE SOUTH LP	1001 BALTIMORE PK, Springfield Twp.	SHOP CENTER(82300 SQ FT)	Shopping Center	9.83
(13) 121290	DELAWARE COUNTY	MICHIGAN AVE, Ridley Twp.	GRD	Park and Playing Fields	8.56
(14) 198035	RIDLEY SCHOOL DIST	Ridley Twp.		School	7.79
(15) 197680	HOME PROPERTIES OF NEW YORK LP	111 MACDADE BLVD, Ridley Twp.	244 APTS - POOL	Low Rise Apartments	6.39
(16) 197849	PECO ENERGY COMPANY	500 YALE AVE, Springfield Twp.	GRD	Training Center and Wetland	6.17
(17) 196655	SWARTHMORE SCHOOL AUTH	COLLEGE AVE, Swarthmore	3 STY STO EXT 3 STY BRK	Swarthmore-Rutledge School	5.73
(18) 124473	RIDLEY PARK SWIM CLUB	HANCOCK AVE, Ridley Park	SWIM CLUB POOL BLDGS	Swim Club	4.84
(19) 198677	EASTLAWN CEMETERY	GIRARD AVE, Ridley Twp.	CEMETERY	Cemetery	4.40
(20) 187944	SWARTHMORE SWIM CLUB	RIVERVIEW RD, Swarthmore	SW POOL BATH HSE	Swim Club	3.74
(21) 193560	RIDLEY TWP	MACDADE BLVD, Ridley Twp	PLAYGRD	Playground	3.29
(22) 108670	SWARTHMORE BOROUGH	SWARTHMORE AVE, Swarthmore		Little Crum Creek Park	3.20

Task 3. Extend Swarthmore College's StormWISE model to prioritize and select practices to apply including riparian corridor preservation and restoration along with structural BMPs.

To launch this task, a full-day workshop was held at Swarthmore College on April 23, 2008 on the topic "Watershed Models: A Review of the State of the Art." Twenty participants, a combination of watershed modeling experts and users of these models heard presentations and participated in discussions on topics related to development of models and issues relating to their effective use for watershed management and for setting priorities in the preservation of undeveloped green space. The assembled participants represented a cross-section of professionals from both the watershed management and land preservation fields. Swarthmore College students who were participating in this study through course projects also attended.

The workshop agenda is included in this report as Appendix B. Formal presentations were made by (1) Claire Billett of Keystone Conservation Trust on GIS with an update on recent developments in GIS land cover data resources, (2) Patty Elkins of the Delaware Valley Regional Planning Commission on recent application of the SmartConservation and Ecological Green Infrastructure tools, and (3) Arthur McGarity and Patrick Lindsay of Swarthmore College on preliminary results from Task 1 StormWISE modeling.

The comments and suggestions obtained at the workshop led to revised formulations for the StormWISE model. A paper on the revised model was written by Arthur McGarity and presented at a conference of the American Water Resources Association (AWRA) in July, 2008: **Summer Specialty Conference on Riparian Ecosystems and Buffers** (McGarity, 2008). The paper is attached to this report as Appendix C. At the conference, additional comments and suggestions were obtained benefiting further development of the model. Also, several other presentations at the conference presented new research relevant to the role of riparian buffers in maintaining water quality in freshwater streams.

A list of specifications was developed for revisions to the StormWISE model, and these revisions are implemented as described below.

1. **Model pollution reduction benefits in the riparian zone.** This was accomplished by modeling the riparian buffer zone in GIS and intersecting it geographically with the land use layer (see Figure 3) to determine the capacity of the existing riparian zone and the potential for restoration of the disturbed riparian zone. Pollution removal in the riparian zone is modeled as a grass swale / filter strip.
2. **Model the performance, cost, and utilization of specific BMP's in the optimization model.** The original formulation of StormWISE uses a "saturation function" to model the "law of diminishing returns" in watershed-scale BMP cost effectiveness. For an initial screening analysis, these functions can be calibrated by a single "median BMP" to obtain a ball-park estimate of watershed-wide costs for specified levels of pollutant load reduction. This approach implicitly models a range of different BMP costs and efficiencies, but does not directly identify the BMP's that are being used. The results shown in Figure 6 are based on this type of analysis. For the revised model, a piecewise linear benefit function was developed with each linear segment accounting for the cost and pollutant removal efficiency of a specific BMP. The solution process tends to select BMP's having higher benefit slopes (such as sediment removal per dollar) before those with lower slopes. When the user specifies levels simultaneously for multiple benefits, such as specific amounts of runoff volume reduction, sediment removal, and nutrient removal, then the model can find the best mix of BMP's to achieve the specified benefits at least cost.

3. **Integrate the pollutant loading calculations with the optimization components of the model.** Difficulties were encountered, while performing Task 1, in obtaining values for runoff volumes and annual pollutant loads (sediment and nutrients) for Little Crum Creek. Different models produced greatly varying results (Willis and McGarity, 2008). We decided to implement our own version of the RunQual model (Haith, 1993) to facilitate calibration of pollutant loads for agreement with our field measurements obtained through monitoring storm events in Little Crum Creek. RunQual uses a daily simulation time step to calculate runoff and pollutant loads for each day over a ten-year period based on precipitation totals for each day. Runoff volume is calculated using the Soil Conservation Service (SCS) Curve Number method, with curve numbers for each land use category varying daily based on the five-day antecedent moisture conditions. Pollutant loadings are calculated using a buld-up/wash-off functions with build-up rates specified by the user for each land use category, and wash-off rates depending on recorded precipitation and calculated snow melt. Outdoor temperature records are required in the input data set to enable calculation of snow pack accumulation and melt.

   The RunQual model was implemented in the VBA language (Visual Basic for Application) within Microsoft Excel and results were verified using the original DOS version of RunQual. Then, the StormWISE optimization formulation was implemented as a linear program using Excel's "Solver" add-in which is available in the standard distribution of Excel. Solver is able to generate cost minimizing solutions to the linear programming model quite efficiently, enabling rapid generation of scenarios that find the watershed-wide costs and BMP selections based on increasing levels of environmental benefits. Implementation within Excel also has the potential to increase the user base of StormWISE and to facilitate the training of municipal officials and watershed managers in the use of the model.

4. **Include benefits of reduced stream channel erosion resulting from reductions in runoff volume.** The various BMP's available for storm water management have different efficiencies for reduction of the components of runoff: volume, sediment loading, nutrient loading, etc. BMP's that are effective in reducing runoff volume have the potential to also reduce stream channel erosion that occurs with high velocity stream flows. Our storm event monitoring program has determined that such flows occur many times each year in the urbanized watersheds of Southeastern Pennsylvania based on the current study and previous studies (McGarity and Horna, 2005 a,b). The revised StormWISE model allows the user to specify the percentage of annual flow that occurs at velocities at or above the trigger level for channel erosion and then calculates an erosion sediment load which it adds to the land surface wash-off sediment load to obtain total sediment loading. Thus, in the BMP optimization phase of the model, BMP's that are particularly effective in reducing runoff volume are given a "bonus credit" for their contribution to reduction of erosion sediment.

5. **Define drainage zones based on the order of the stream into which they drain rather than subwatersheds.** Earlier versions of StormWISE generated solutions to optimally allocate funds for stormwater management based primarily on the runoff and pollutant loads generated by the different land use categories and the costs and efficiencies of the BMP's assigned to treat each land use category. The geographic location of the subwatershed drainage zone is not really relevant in the pollutant loading models we are using (although it would be if a more advanced model were used that routes pollutants through the watershed). Calibrating an advanced loading model such as EPA's SWMM model for Little Crum Creek is well beyond the scope of this project. However, another approach was developed that is fairly easy to implement within the

current StormWISE modeling context. The GIS based watershed model TauDEM was used with a digital elevation layer to delineate drainage zones in the watershed and to determine the Strahler order (Strahler, 1952) of the stream segment into which each zone drains. Drainage areas associated with first and second order streams were then combined and designated as "Headwaters," while those areas associated with third and fourth order streams were combined and designated as "Lowlands." With these methods of categorizing land drainage zones, we have a meaningful physical basis for setting differing runoff modeling parameters and BMP treatment efficiencies that is capable of capturing many of the effects associated with physical location of land within the watershed.

Task 4. Apply the revised StormWISE model to the Little Crum Creek Watershed and map the impact areas and practices using GIS.

This task was accomplished as a set of sub-tasks described below.

1. Storm Event Monitoring Program. Matching funds from Swarthmore College's Environmental Science Education Outreach Program were used to help fund a storm event monitoring program during Summer, 2008 which extended into Fall, 2008 as a community-based field exercise conducted by students in Dr. McGarity's engineering course "Water Quality and Pollution Control." Figure 8, parts a, b, and c show the locations of the five monitoring stations. The three shown in Figure 8a have no drainage area in common. The "Virgo" site (named for a restaurant near the site) drains the same area as the "Home Depot" site plus additional area that includes a commercial district with high impervious percentage (Figure 8b).

The Ridley Park Lake site (Figure 8c) is located just upstream from Ridley Park Lake which is subjected to high sediment loadings during storm water runoff events. A sediment detention pond just below our monitoring station experiences clogging by sediment bars that must be removed frequently by expensive dredging operations.

Our storm event monitoring program was conducted from July through December, 2008 and our monitoring station was moved among these sites during this time. We acquired a second monitoring station in September so we operated two stations for three of the events. A total of 14 events were observed out of a total of about 20 events that occurred during this period. A total of 57 million gallons of runoff were monitored, and the total pollutant loadings measured were 133.4 metric tons of sediment, 612 kg of nitrogen, and 119 kg of phosphorous. Isco™ autosamplers with depth/velocity probes were deployed to obtain the data.

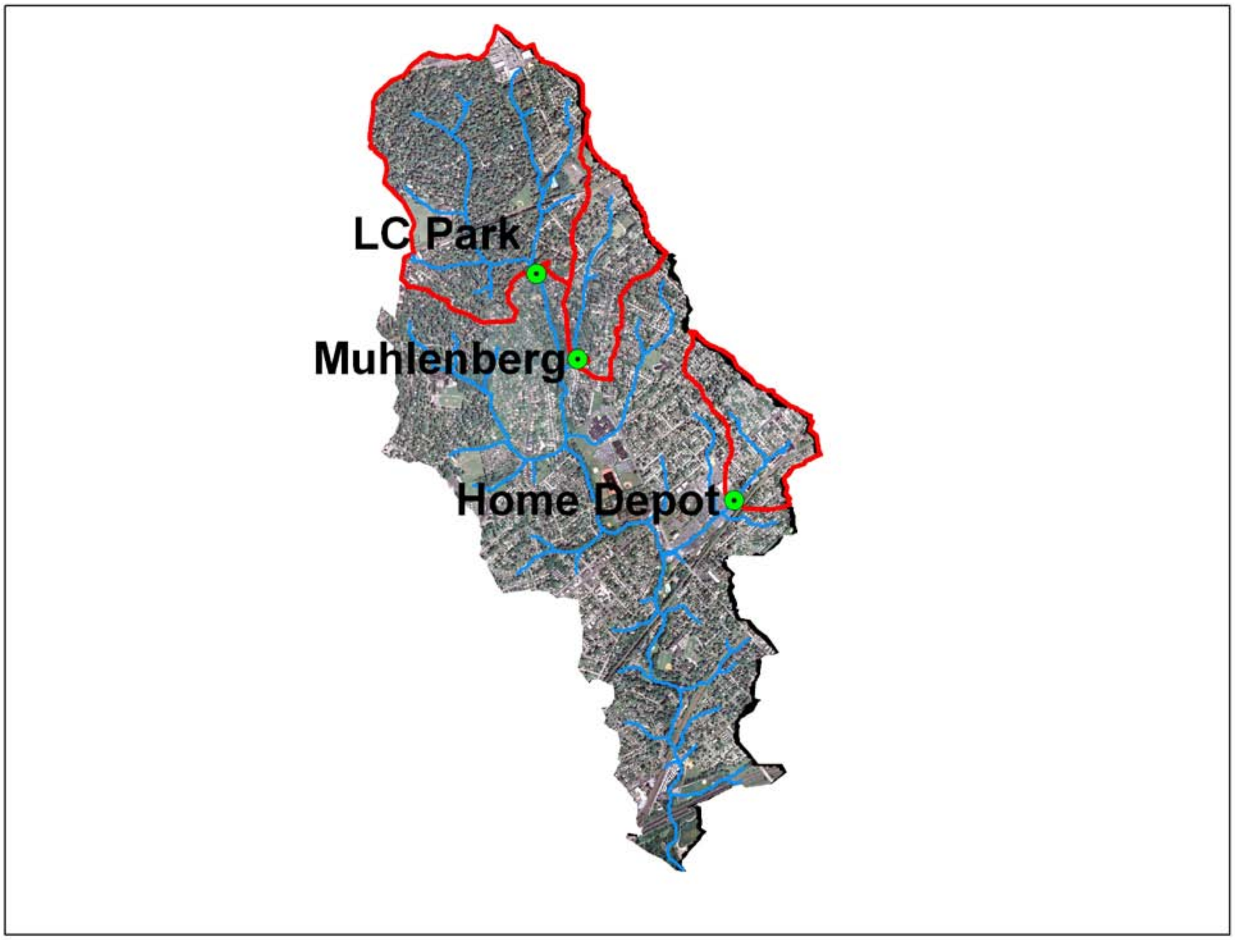


Figure 8a. Three non-overlapping monitoring sites: Little Crum Creek Park in Swarthmore Borough, Muhlenberg Avenue in Ridley Township, and the area drained upstream from the Home Depot parking lot in Ridley Township. Green dots indicate the monitoring points and red lines indicate the area that drains into each monitoring point. Blue lines show the stream segments, and the background is a satellite image of the watershed.

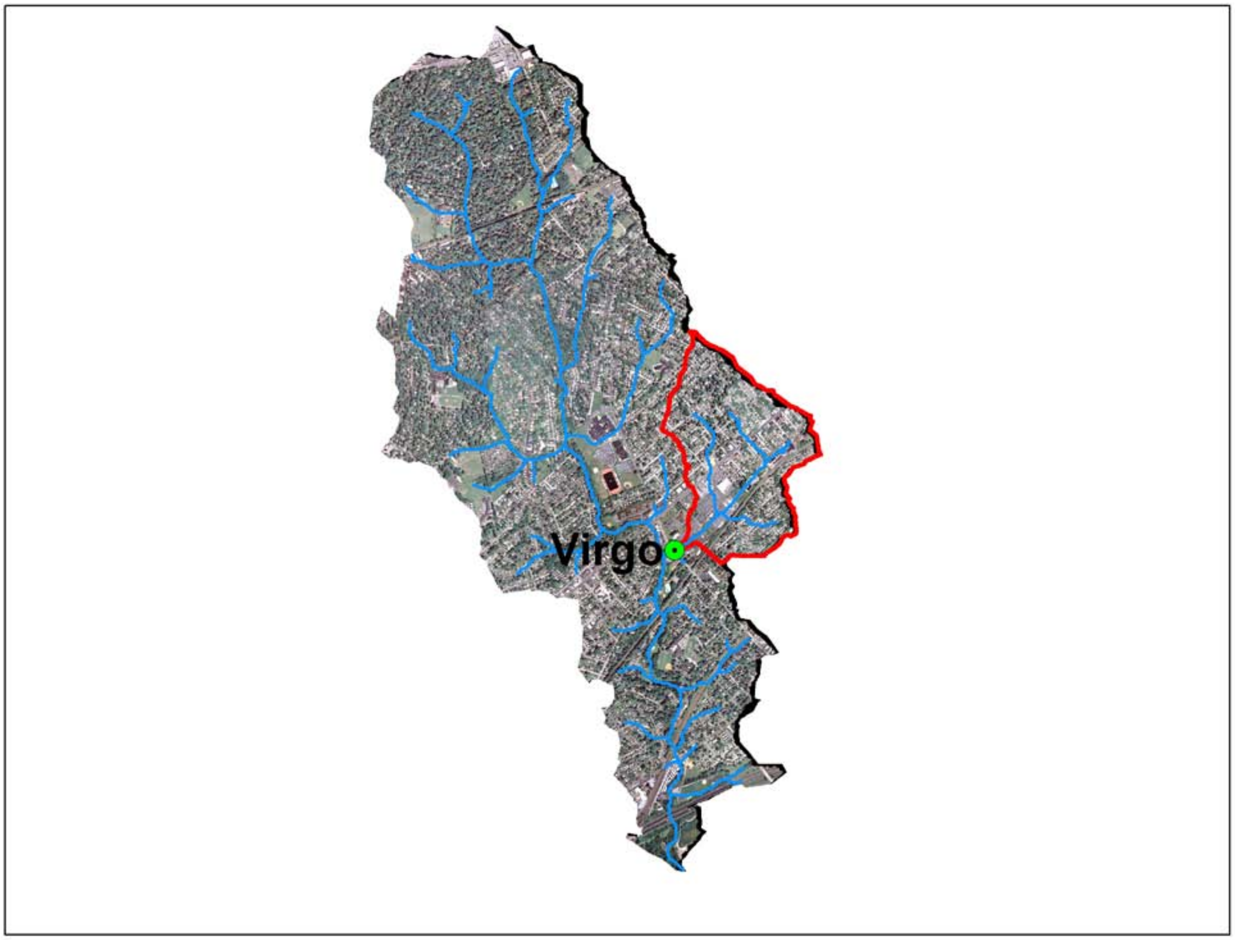


Figure 8b. The "Virgo" site in Ridley Township which includes the same area drained by the "Home Depot" site in its headwaters plus a commercial district with high impervious percentages in its lower drainage. The green dot indicates the monitoring point and the red line indicates the area that drains into the monitoring point.

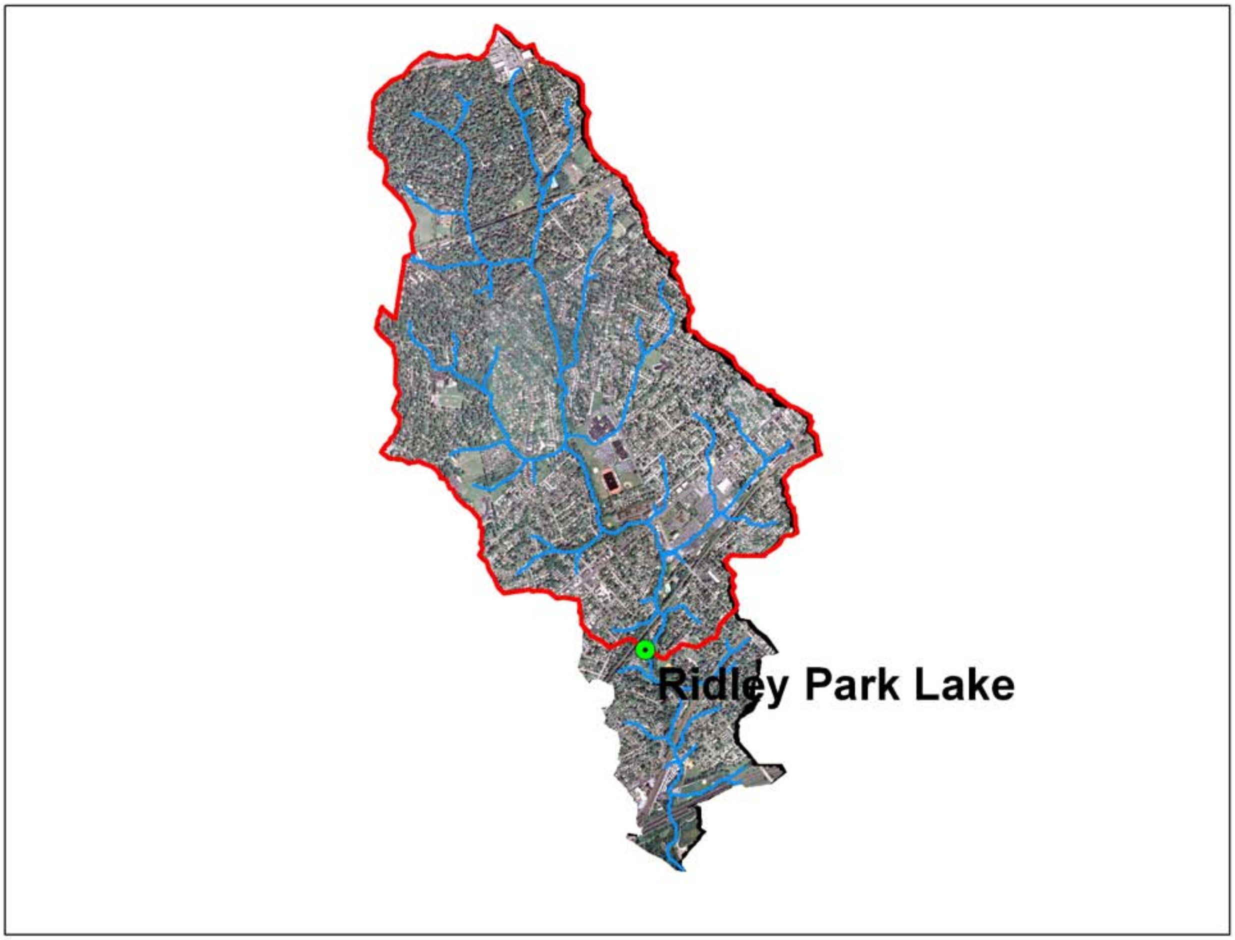


Figure 8c. The Ridley Park Lake site in Ridley Township which is an outlet point for most of the watershed and immediately upstream from a sediment pond and recreational lake that requires frequent dredging of sediment resulting from upstream sediment loads related to storm water runoff. The green dot indicates the monitoring point and the red line indicates the area that drains into the monitoring point.

Tables 4 and 5 display detailed results for each site. Comparisons of total loadings at each of site are of limited value since different numbers of storm events were monitored at each site. However, it is significant to note that by far the largest loadings were measured at the Ridley Park Lake site which is expected since it is near the bottom of the watershed. Nutrient measurements were obtained by measuring the dissolved portion as Nitrate (NO_3) and Phosphate (PO_4) and then adjusting the readings for total Nitrogen and Total Phosphorous based on typical ratios found in the literature.

Table 6 shows long-term (10 year) average results for Little Crum Creek generated by the RunQual load simulation model runs that were used for the StormWISE modeling. Direct comparisons with our monitoring are very difficult to make since we observed a small number of events compared to the number that are modeled over a 10-year period. Also, the simulated results are categorized by land use and apply to the entire watershed rather than the areas drained above the monitoring stations.

Table 4. Pollutant Loadings Measured at the 5 Monitoring Sites

		Loadings Monitored				
Site	**Number of events monitored**	**Volume (million gallon)**	**Volume (cubic meter)**	**TSS (kg)**	**TN (kg)**	**TP (kg)**
LC Park	2	1.8	6,963	2,943	10	4
Home Depot	2	0.4	1,525	431	2	1
Virgo	7	7.7	29,203	3,201	101	20
Muhlenberg	3	2.0	7,437	263	8	5
Ridley Park Lake	3	44.8	169,584	6,502	491	89
Totals	**14***	**56.7**	**214,712**	**13,340**	**612**	**119**

* The 3 events monitored at Muhlenberg site were also monitored at Ridley Park Lake

Table 5. Event Mean Concentrations Measured at the 5 Monitoring Sites

Site	**TSS (mg/L)**	**NO_3 (mg/L)**	**TN (mg/L)**	**PO_4 (mg/L)**	**TP (mg/L)**
LC Park	423	0.41	1.37	0.21	0.59
Home Depot	283	0.34	1.15	0.13	0.37
Virgo	110	1.04	3.47	0.25	0.70
Muhlenberg	35	0.33	1.11	0.23	0.65
Ridley Park Lake	38	0.87	2.90	0.18	0.52

Table 6. 10-year Average Export Coefficients and Event Mean Concentrations Simulated by RunQual

		EXPORT_COEFFICIENTS			**EVENT MEAN CONCENTRATIONS**		
Land Use Category	**Runoff(cm)**	**TSS (kg/ha)**	**TN (kg/ha)**	**TP (kg/ha)**	**TSS (mg/L)**	**TN (mg/L)**	**TP (mg/L)**
Forest/Wetlands	11	35.88	0.38	0.04	31	0.34	0.03
Developed Wooded/Fields	15	110	2.16	0.26	72	1.42	0.17
Developed Low Intensity	23	156	2.65	0.27	67	1.15	0.12
Developed Medium Intensity	30	210	6.73	0.86	70	2.26	0.29
Developed High Intensity	40	266	9.06	1.02	66	2.27	0.26

In spite of the issues mentioned above, it is worthwhile to compare measured event mean concentrations (the average of measured concentrations weighted by the volumetric flow rate observed at the time the sample was taken from the stream) with the simulation model's long-term average pollutant loading divided by the long-term average flow volume, which is equivalent to a long-term average event mean concentration over all storm events during the 10-year period. These comparisons can be made in Tables 5 and 6 by examining the shaded columns.

The values in corresponding columns compare reasonably well with the exception of some excessively large TSS (Total Suspended Solids) values at the LC Park, Home Depot, and Virgo sites. The first point to make in explaining these high results is to note that most of these rain events occurred in during the summer season when most events occur as thunderstorms with periods of high rainfall intensity creating surges in stream flow that generate excess sediment loads. Closer examination of the raw data revealed an interesting behavior: at multiple sites, when the stream velocity exceeded about 2.5 ft/sec, the TSS concentrations abruptly jumped from less than 100 mg/L into much higher ranges, in one case as high as 2000 mg/L during a particularly intense summer thunder storm at the Little Crum Creek Park site in Swarthmore. We attribute this behavior to the addition of stream channel sediment from the bed and banks to the sediment washed off from land surfaces when the velocities exceed a threshold which in our observations appears to be around 2.5 ft/s. This phenomenon leads to much higher event mean concentrations when the observation record includes such storm events. The percentage of the observed flows that occurred at velocities greater than 2.5 ft/s were 72% and 60 % at the LC Park and Home Depot sites, respectively, but only 7% and 11 % at the Virgo and Muhlenberg sites, respectively. At the Ridley Park site, no flows were observed at velocities greater than 2.5 ft/s during the three events that we observed, and all of these events were during November and December, associated with large frontal systems generating low-intensity, long duration storms as opposed to the short, high intensity storms that were observed LC Park and Home Depot sites.

Overall, 20 % of the runoff we monitored occurred at the channel mobilizing velocity of 2.5 ft/s or greater. This fraction is used as an estimate of total annual runoff that generates channel erosion that adds sediment to the total sediment load.

2. BMP Costs. Several sources of BMP costs were obtained and analyzed including the following references listed in the bibiography: Narayanan and Pitt (2006), Center for Watershed Protection (2008), and Wossink and Hunt (2003), and Muthukrishnan, et al (2004). Functions were obtained relating the cost of various BMP's to their size, usually in volume units. The volume was matched to calculated water quality volumes for different land use categories (with different impervious percentages) and typical costs were calculated. These costs were then adjusted for inflation to the current year and also adjusted for the Philadelphia metropolitan region. No attempt was made to include operating and maintenance costs. The total capital cost, installed, was then divided by the contributing area to obtain a marginal cost value in $/acre for each land use category. These values are entered into the StormWISE input sheet. BMP volume reduction and pollutant removal efficiencies were also obtained from the literature and used as StormWISE input.

For any given BMP, costs per acre of contributing area vary over a wide range depending on the land use category to which it is applied, primarily because of wide variations in impervious area. In the StormWISE runs for this study, specific BMP costs were used for each different land use category modeled. However, it is interesting to compare the BMP's based on the <u>average</u> cost per unit of contributing area as obtained for the actual land uses and impervious percentages encountered in the

Little Crum Creek watershed. Table 7 shows the average value of cost per acre and also per square foot for the seven different BMP's included in the analysis. These average costs are specific to the particular mix of land uses and impervious percentages found in the Little Crum Creek Watershed, so readers are cautioned not to use them for guidance in a different watershed unless it has similar land use characteristics.

Table 7. Average BMP Cost per unit of Contributing Area Based on Little Crum Creek Land Uses

	Cost per Contributing Area*	
BMP	($/acre)	($/sq. ft.)
Pocket Wetland / Rain Garden	$9,724	$0.22
Riparian Buffer Filter Strip	$12,191	$0.28
Bioretention / Infiltration Pit	$28,301	$0.65
Impervious Removal	$32,369	$0.74
Rain Barrel / Cistern	$36,083	$0.83
Permeable Pavement	$337,469	$7.75
Green Roof	$478,081	$10.98

* Note that BMP costs per unit of contributing area vary greatly with land uses and the impervious percentages associated with different land uses. Thus, these values, derived for Little Crum Creek, should be compared only with other watersheds having similar land uses.

3. Baseline StormWISE Runs.

Figure 9 shows the GIS representation of the Baseline StormWISE runs. The polygons associated with the two drainage zones are shown superimposed on top of the land use raster. The Headwaters zone is the outer perimeter shown slightly shaded. The Lowlands zone is the inner core shown without shading.

Two cases are examined with the baseline land use data. For Case 1, StormWISE is run so that it *favors reduction of stormwater runoff volume*. For Case 2, the model is *run favoring sediment reduction*. For each case, the model is run 22 times. Case 1 is run for target runoff volume reductions ranging from 30,000 m^3 / year to 1,000,000 m^3/ year (reduced from a calculated total annual runoff volume of 1.7 million m^3/year for current land use patterns in the watershed). Case 2 is run for target sediment reductions ranging from 3,000 kg/year to 150,000 kg/year (reduced from a calculated total annual sediment load of 252,164 kg/year for current land use patterns).

Appendix D presents tabular results showing runoff volume and pollutant loads for all 22 runs of each case. Also shown are optimal spending levels categorized by (1) drainage zone, (2) land use category, and (3) BMP type. Plots of these results are show in Figures 10 - 15.

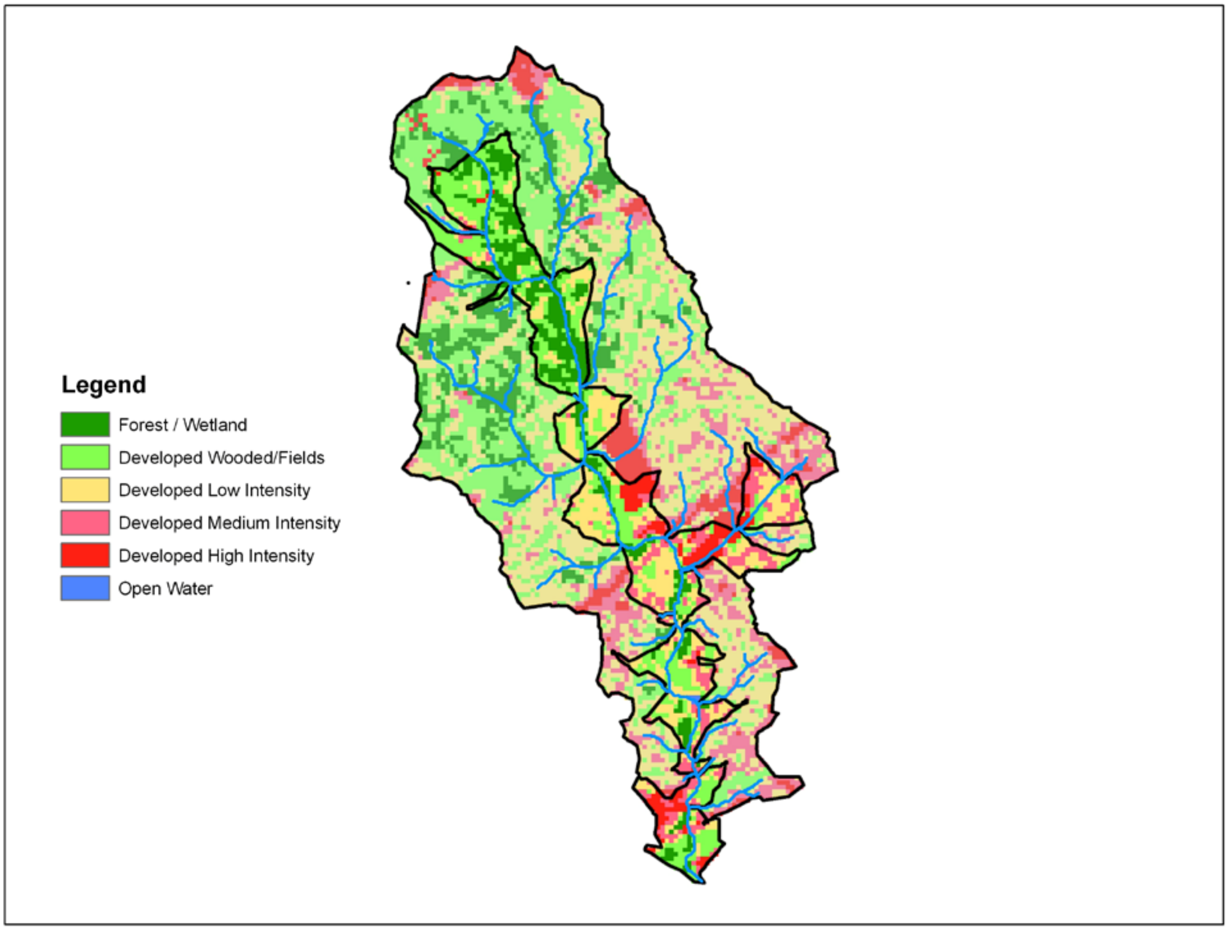


Figure 9. Drainage zones used in StormWISE superimposed on the land use categories used in the **base case scenario**. Headwaters are in the lightly shaded outer perimeter, and Lowland are in the unshaded inner core.

For both cases, StormWISE is configured to estimate the runoff volume and pollutant loadings that are prevented by the currently existing riparian buffers that are classified in the forest/wetland category. This is accomplished by considering these existing buffer zones to be zero-cost BMP's performing the same as a grass swale filter strip BMP having zero marginal cost. For both cases, the first entry in the tables provide an estimate of the water quality benefits currently being provided for free in terms of runoff volume and pollutant loads avoided. The model estimates that without the existing riparian zone buffers, total runoff volume would increase by 10,000 m^3/yr and total sediment would increase by 3500 kg/yr (3.5 metric tones)

Case 1 Results: StormWISE Baseline Runs Favoring Reduction of Runoff Volume

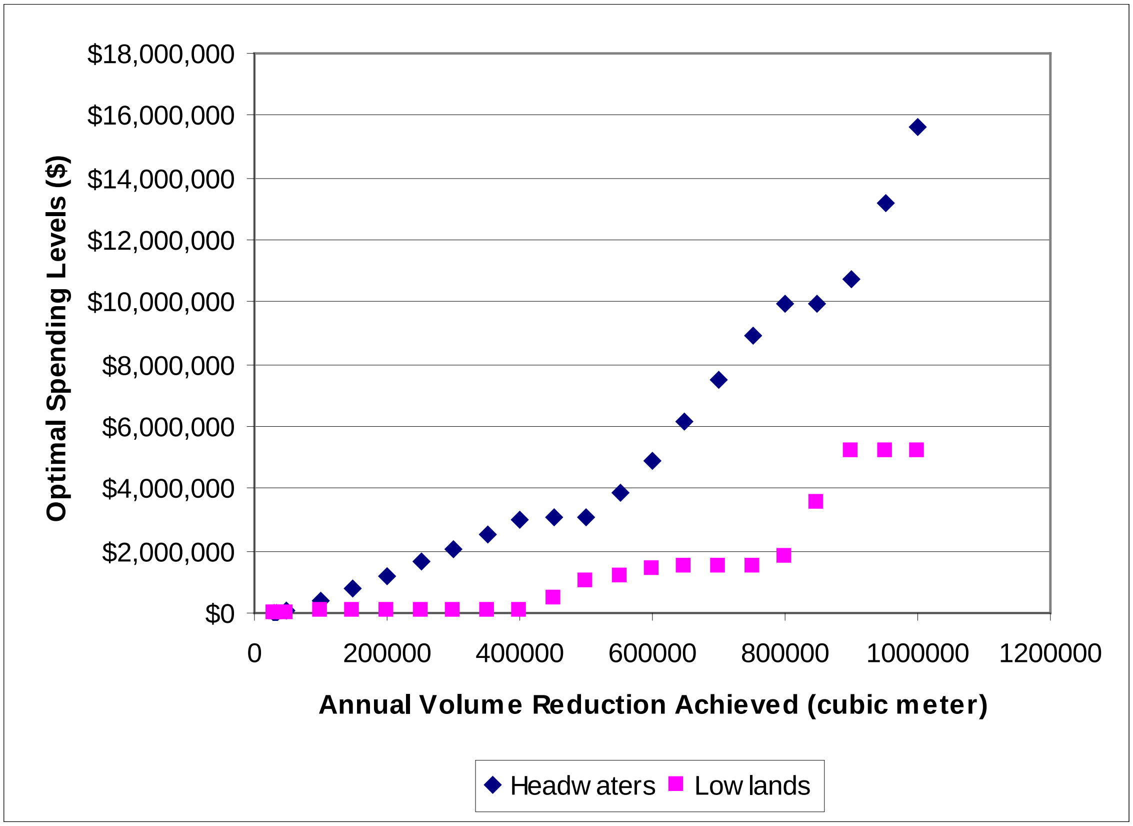


Figure 10. Optimal spending levels by drainage zone for solutions that favor reduction of runoff volume

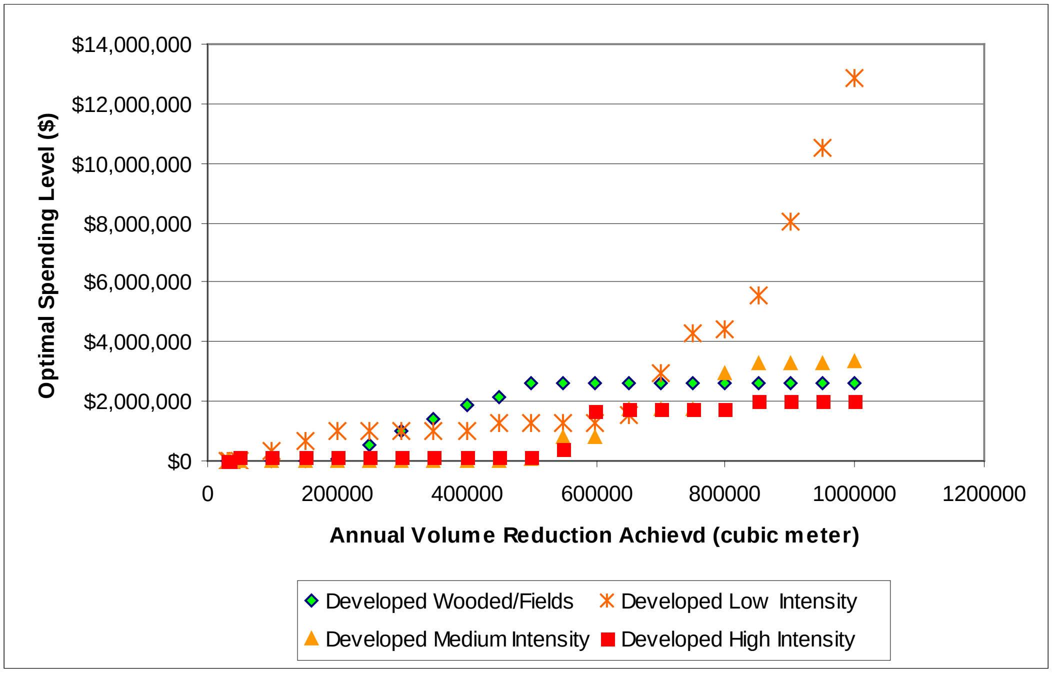


Figure 11. Optimal spending levels by land use category for solutions that favor reduction of runoff volume

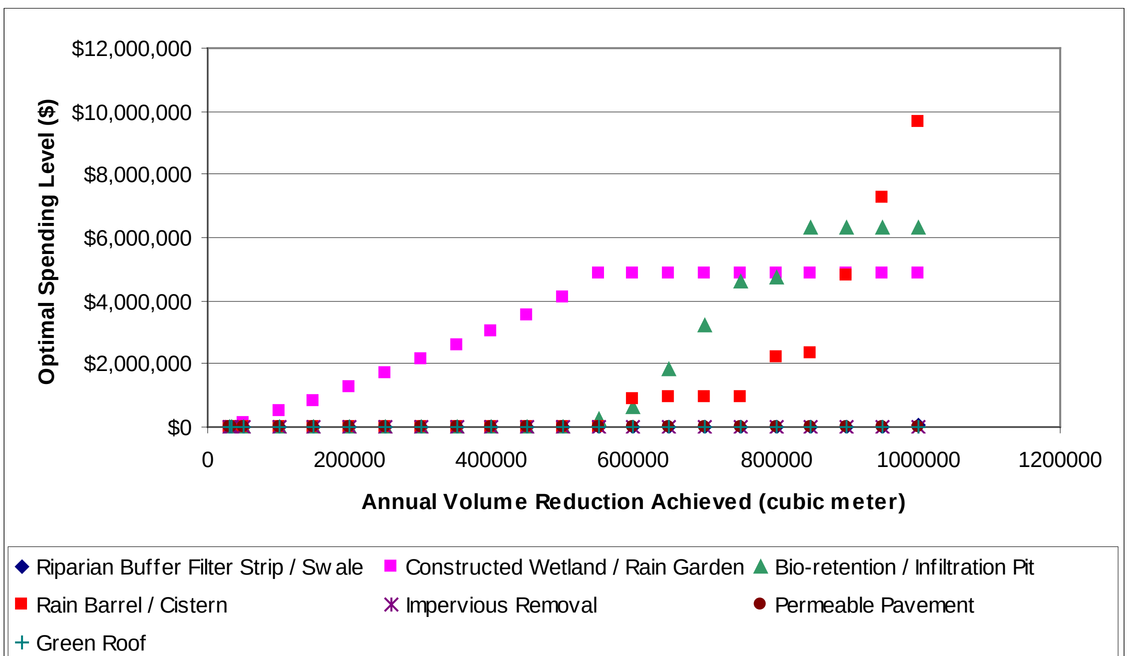


Figure 12. Optimal spending levels by BMP for solutions that favor reduction of runoff volume

Case 2 Results: StormWISE Baseline Runs Favoring Reduction of Sediment

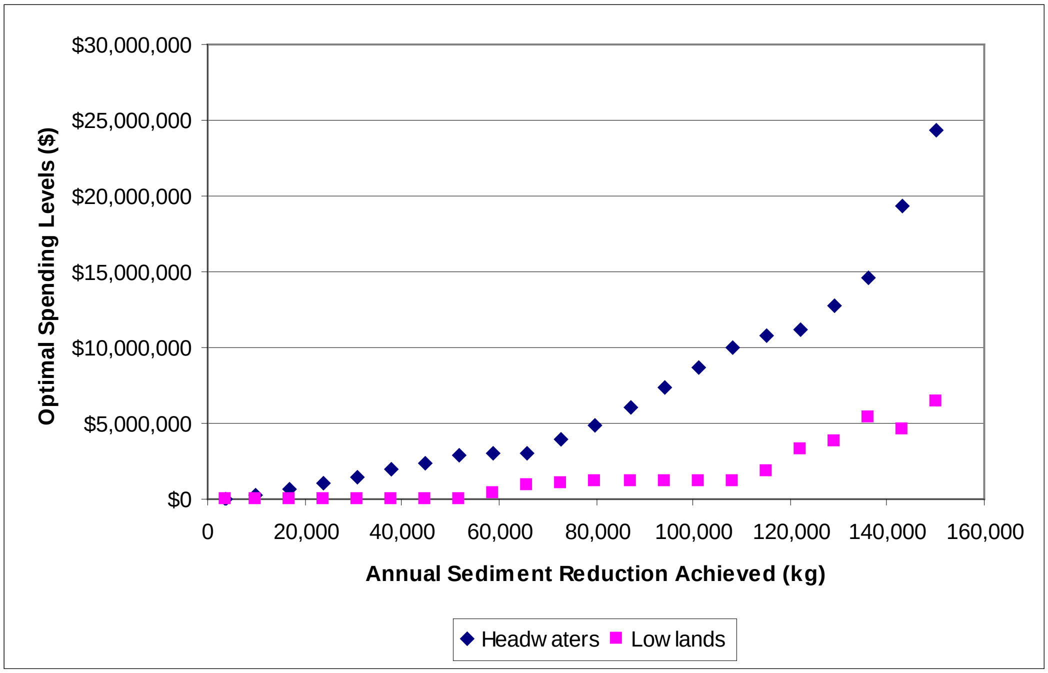


Figure 13. Optimal spending levels by drainage zone for solutions that favor reduction of sediment

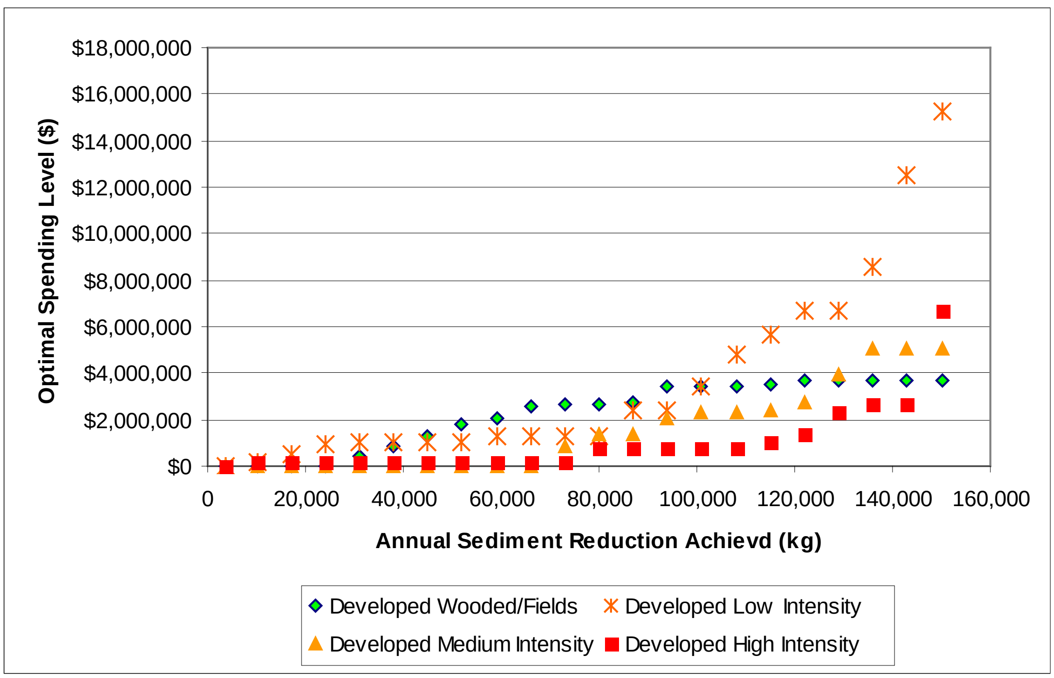


Figure 14. Optimal spending levels by land use category for solutions that favor reduction of sediment

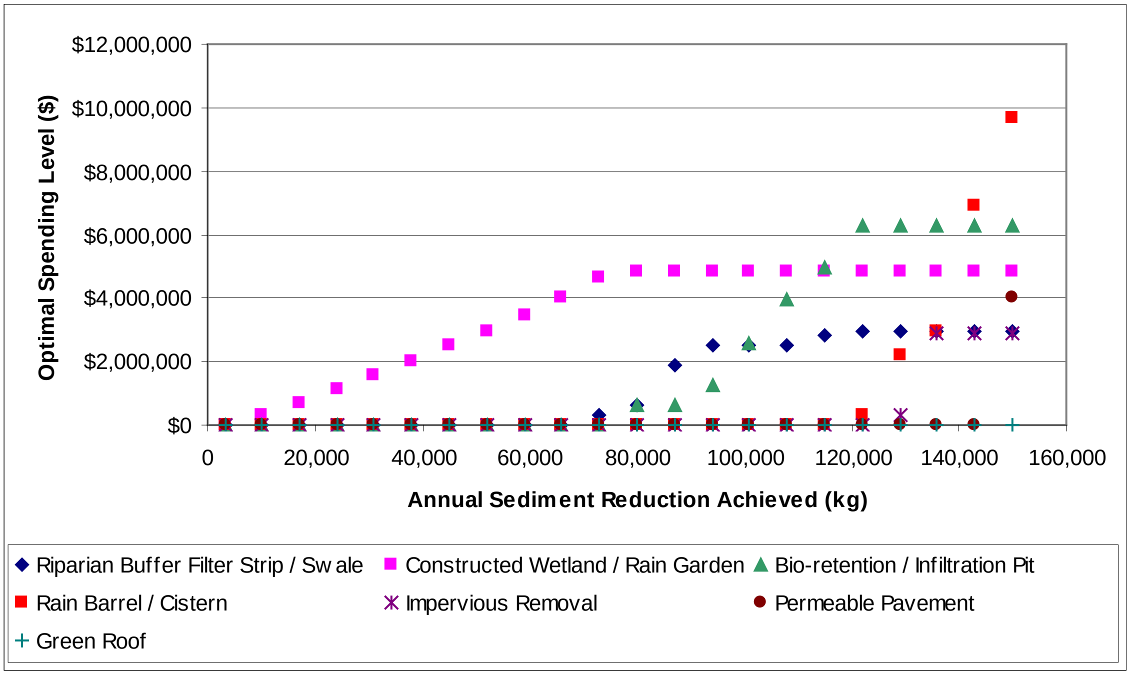


Figure 15. Optimal spending levels BMP for solutions that favor reduction of sediment

The results presented in Figures 10 – 15 can be used to develop spending priorities for BMP projects in the Little Crum Creek watershed. All points on these plots represent solutions that achieve the indicated environmental benefits (either volume reduction or sediment reduction) at the lowest possible cost. Stormwise actually determines optimal spending levels for all combinations of drainage zone (headwaters and lowlands), land use category, and BMP. These results are aggregated in Figures 10-14. Watershed managers can use these results first to balance environmental benefits and costs to determine reasonable targets for runoff and pollution reduction and for spending. Then, the specific solutions associated with these targets can be closely examined in order to prioritize spending on drainage zones and land use categories within the zones. Identifying priority zones and land uses can help to narrow the search for candidate sites for BMP implementation projects by closer examination of those land parcels that intersect high priority areas.

The plots of optimal BMP spending versus environmental benefits can be used to prioritize categories of BMP's for implementation in the watershed. Comparison of Figures 12 and 15 reveal some interesting differences in priorities depending on whether volume reductions or sediment reductions are favored. The more cost effective BMP's for achieving runoff volume reduction are, in order of priority, (1) constructed wetlands/rain gardens, (2) bioretention/infiltration pits, and (3) rain barrels/cisterns. When sediment reduction is favored, constructed wetlands/rain gardens are still the highest priority, but riparian buffer filter strip/swales are second highest followed by significant but less prominent roles for bioretention/infiltration pits and rain barrels/cisterns.

4. StormWISE Runs for a Watershed Build-out Scenario. Additional runs of StormWISE were made to investigate a watershed build-out scenario. Delaware County, Pennsylvania is in transition. Communities closer in to Philadelphia are becoming increasingly "built out" to an extent that there is virtually now green space remaining. This process is well underway in the communities that drain into the Little Crum Creek. However, as we can see from our analysis, significant acreage still remains in the land use category we call "Forest/Wetland." Also, we have seen that much of this land that remains is in the riparian zone, and it provides water quality benefits in the form of avoided runoff volume and pollutant loadings. Our parcel-based land preservation analyses (SmartConservation and Ecological Green Infrastructure) indicate that a significant number of high-value parcels exist in the watershed that have potential for preservation or restoration. However, the list of parcels reveals that many of those parcels are already occupied by high intensity development. If this trend continues, the communities in this watershed will begin to resemble the completely built-out communities a short distance to the east.

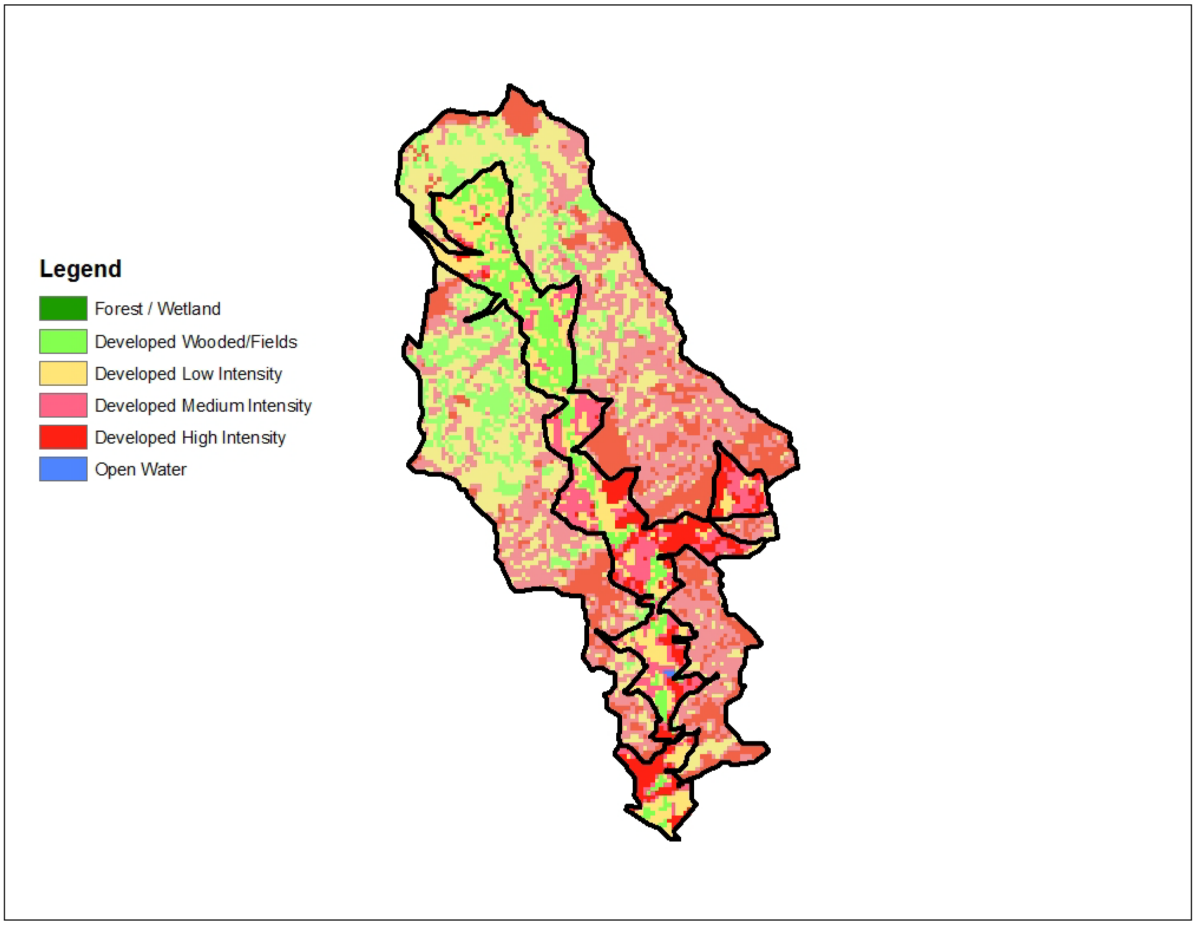


Figure 16. Drainage zones used in StormWISE superimposed on the land use categories used in the **build-out scenario**. Headwaters are in the lightly shaded outer perimeter, and Lowland are in the unshaded inner core. Contrasting to Figure 9, note the loss of land in the "Forest/Wetland" category and increasing land shown in a shade of red indicating more intense development.

Figure 16 shows the land use distribution associated with the build-out scenario. This was created in GIS by reassigning all land in the "Forest/Wetland" category to the "Developed Wooded/Fields" category. Moreover, all land previously in the "Developed Wooded/Fields" category was reassigned to the "Developed Low Intensity." Continuing in the same fashion, land in each of the other categories was reassigned to the next higher category of development intensity. The Developed High Intensity category includes all land that is currently in that category plus all land that is currently in the "Developed Medium Intensity" category. Certainly this method of constructing a build-out scenario is simplistic and coarse. However, the results obtained by running StormWISE with the revised acreages in each land use category is revealing when compared with the baseline runs. Through these comparisons, we are able to show the increase in spending that would be necessary to achieve a specified level of improvement in water quality if build-out occurs compared with the current situation.

Tables 8 and 9 show the runoff volume and pollutant load results for the two cases based on runs of the RunQual model within StormWISE. Total runoff volume increases under the build-out scenario from 1,722,196 m^3/year to 2,289,453 m^3/year, an increase of 33%. Similar calculation are used to determine that sediment loadings increase 35%, nitrogen loadings increase 69%. and phosphorous loadings increase 72%.

Table 8. Annual Runoff Volumes and Pollutant Loads for the Current Baseline

Headwaters	Area (ha)	Runoff Volume (m3)	Sediment (kg)	Nitrogen (kg)	Phosphorous (kg)
Forest/Wetlands	76	86,864	2,732	29	3
Developed Wooded/Fields	191	291,143	21,059	412	50
Developed Low Intensity	222	512,474	34,803	588	60
Developed Medium Intensity	84	249,041	17,583	563	72
Developed High Intensity	36	145,402	9,727	330	37
Lowlands		**Runoff Volume (m3)**	**Sediment (kg)**	**Nitrogen (kg)**	**Phosphorous (kg)**
Forest/Wetlands	44	50,003	1,572	17	2
Developed Wooded/Fields	69	104,998	7,595	149	18
Developed Low Intensity	59	136,051	9,239	156	16
Developed Medium Intensity	27	79,800	5,634	180	23
Developed High Intensity	17	66,418	4,443	151	17
Stream Channel Erosion:			137,776		
		Runoff Volume (m3)	**Total Sediment (kg)**	**Total Nitrogen (kg)**	**Total Phosphorous (kg)**
Totals:	**825**	**1,722,196**	**252,164**	**2,576**	**299**

Table 9. Annual Runoff Volumes and Pollutant Loads for the Build-out Scenario

Headwaters	Area (ha)	Runoff Volume (m3)	Sediment (kg)	Nitrogen (kg)	Phosphorous (kg)
Forest/Wetlands	0	0	0	0	0
Developed Wooded/Fields	74	112,400	8,130	159	19
Developed Low Intensity	188	433,664	29,451	498	51
Developed Medium Intensity	223	662,236	46,755	1,498	191
Developed High Intensity	118	470,314	31,463	1,068	121
Lowlands		**Runoff Volume (m3)**	**Sediment (kg)**	**Nitrogen (kg)**	**Phosphorous (kg)**
Forest/Wetlands	0	0	0	0	0
Developed Wooded/Fields	47	71,004	5,136	101	12
Developed Low Intensity	73	167,368	11,366	192	20
Developed Medium Intensity	61	181,827	12,837	411	52
Developed High Intensity	48	190,639	12,754	433	49
Stream Channel Erosion:			183,156		
		Runoff Volume (m3)	**Sediment (kg)**	**Nitrogen (kg)**	**Phosphorous (kg)**
Totals:	**831**	**2,289,453**	**341,049**	**4,359**	**516**

We have chosen a point of comparison between the current baseline and the build-out scenario to be a 25% decrease in either runoff volume or sediment from current baseline levels. A 25% reduction in baseline runoff volume would decrease annual runoff by about 431,000 m^3 per year to a new level of around 1,290,000 m^3 per year. The baseline StormWISE runs indicate that to reduce the volume by this amount under current land use conditions would require a spending level of $3.25 Million. Reducing to this same level, but starting out at the higher runoff volume of the build-out scenario, the amount of volume reduction required would be about 1,000,000 m^3 per year. The StormWISE runs for the build-out scenario indicate that to achieve this level of reduction under more intensively developed build-out conditions would require a spending level of $19 Million. Thus, almost $16 million in additional spending is required to achieve the same level of water quality under the build-out scenario.

Similar calculations based on a 25% reduction in baseline sediment load and with StormWISE runs favoring sediment reduction result in spending levels of $3.5 Million under current baseline land use but $23 Million under build-out, which is an additional $19 Million. These results are summarized in Table 10.

Table 10. Comparison of Costs to achieve similar water quality under the Baseline and Build-out Scenarios

	Spending Level Minimized by StormWISE		
Basis of Comparison	Baseline ($Million)	Build-out ($Million)	Additional Spending necessary under Build-out ($Million)
25% Reduction in Runoff Volume From Current Baseline*	3.25	19	15.75
25% Reduction in Sediment Load from Current Baseline*	3.5	23	19.5

*It is not yet known whether a 25% reduction in volume or sediment is sufficient to achieve water quality goals because a total maximum load determination study has not been conducted for this impaired watershed.

Comparison of these results with land preservation costs, shown in Table 2, suggests that land preservation easements as well as outright acquisition of land for water quality protection may be economical alternatives to the current trend towards complete build-out in the Little Crum Creek watershed. Opportunities for land preservation should continue to be investigated by the municipalities in the Little Crum Creek Partnership. The alternative appears to be greatly increased costs in the future to attain the water quality goals required under the federal Clean Water Act on this impaired waterway. Future regulatory action pertaining to this watershed may lead to the specification of a total maximum daily load (TMDL) which would establish target requirements for runoff and pollutant load reductions. However, our results suggest that if the municipalities of the Little Crum Creek Partnership are successful in adopting a proactive approach towards storm water runoff management, including land preservation and riparian zone restoration, then the eventual cost of regulatory compliance and the accompanying environmental quality improvements may be kept at an acceptable level.

Recommendations and Conclusions

Our project has investigated the potential for combining the methods of analysis used by the land preservation community and the water quality modeling community to address the problem of storm water management in an urban watershed. The potentials for both land preservation measures and water quality best management practices are explored. Special attention is given to land preservation and BMP implementations in the riparian zone where most of the remaining green space in this watershed exists.

Application of GIS-based tools recently developed by the land preservation community to Little Crum Creek indicates that there are several parcels of land worthy of further investigation with regard to their preservation value as measured by two different indices associated with SmartConservation and Ecological Green Infrastructure. Many of these parcels are in or near the riparian zone, indicating that there would be water quality benefits associated with preservation of these parcels. However, investigation of the riparian easement as a way to accomplish land preservation suggests many difficulties in implementing these easements compared with traditional conservation easements usually involving much larger land areas.

The Storm Water Investment Strategy Evaluator (StormWISE) model has been extended to enable inclusion of riparian zone analyses and to include credit for preservation of undeveloped land in the creation of optimal BMP implementation scenarios that identify cost-effective water quality benefits. StormWISE now includes explicit consideration of specific BMP's and includes an updated model to calculate BMP costs per acre of contributing area. Our StormWISE runs on the baseline case give results that enable us to display costs associated with levels of reduction in storm water impacts in a variety of different ways such as by drainage zone (headwaters and lowlands), land use categorizations, and BMP's deployed. The tables and plots showing increasing optimal spending levels associated with increasing stormwater impact reduction can help to guide municipal officials and watershed organizations in prioritizing drainage zones, land uses, and BMP's in the search for specific sites to implement projects aimed at improving water quality. The next phase of work for the Little Crum Creek Partnership will be to identify such sites based on the results of this study and further analysis using the tools applied in this project.

Our runs of StormWISE on a build-out scenario reveal the potential for huge increases in the future cost of storm water management if increased urbanization occurs in the Little Crum Creek watershed to the extent that it has already occurred just a short distance to the east towards Philadelphia. The Little Crum Creek is already listed as impaired because of storm water runoff on the federal 303D list, so it is likely that future regulatory action will be taken in the watershed requiring significant local investment in storm water infrastructure. Our results clearly demonstrate that steps taken now to facilitate the preservation of the remaining undeveloped land in the watershed can significantly reduce the eventual cost of compliance with water quality regulations.

Bibliography

Carlson, Toby (2000). "Impervious surface area for Southeast Pennsylvania, 2000," Pennsylvania Spatial Data Access (PASDA) Web Site, http://www.pasda.psu.edu.

Center for Watershed Protection (2008). **Urban Stormwater Retrofit Practices**, Volume 3, Appendicies, http://www.cwp.org.

Davalos, Adrain and Laura Post (2008). "Optimization of Resources: Achieving Pollutant Reductions at Minimum Cost in the Little Crum Creek Watershed," poster presentation, **Little Crum Creek Community Outreach Forum**, Swarthmore College, April, 2008.

Evans, Barry (2008). **AVGWLF Version 7**, The Penn State Institutes on Energy and the Environment, http://www.avgwlf.psu.edu/.

Lindsay, Patrick (2008). **BMP Optimization for Little Crum Creek using the StormWISE Model**, Senior Design thesis submitted to the Swarthmore College Department of Engineering, May, 2008.

Haith, Douglas A (1993). **RUNQUAL: Runoff Qlulaity from Development Sites, User's Manual**, Deparment of Agricultural and Biological Engineering, Cornell University, June 30, 1993.

McGarity, Arthur E. and Paul Horna (2005a). **Decision Making for Implementation of Nonpoint Pollution Measures in the Urban Coastal Zone,** Pennsylvania Department of Environmental Protection Coastal Zone Program, Harrisburg, PA, final report for project 2003-PS.06, March, 2005.

McGarity, Arthur E. and Paul Horna (2005b). **Non-Point Source Modeling – Phase 2: Multiobjective Decision Model**, Pennsylvania Department of Environmental Protection Coastal Zone Program, Harrisburg, PA, final report for project 2004-PS.08, October, 2005.

McGarity, Arthur E. (2006a). **Screening Optimization Model for Watershed-Based Management of Urban Runoff Nonpoint Pollution**, U.S. Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, final report for project AW-83238401-0, November, 2006.

McGarity, Arthur E. (2006b). "A Cost Minimization Model to Prioritize Urban Catchments for Stormwater BMP Implementation Projects," **Proceedings of the American Water Resources Association Annual Meeting**, Baltimore, MD, November 6-9, 2006.

McGarity, Arthur E. (2008). "Optimal Application of Riparian Easements and Best Management Practices to Reduce Stormwater Runoff Pollution: A Multiobjective Tradeoff Model," **Proceedings of the American Water Resources Association Summer Specialty Conference on Riparian Ecosystems and Buffers**, Virginia Beach, VA, July, 2008.

Muthukrishnan, Swarna, Bethany Madge, Ari Selvakumar, Richard Field, and Daniel Sullivan (2004). **The Use of Best Management Practices in Urban Watersheds**, U.S. Environmental Protection Agency Publication EPA/600/R-04/184, September 2004.

Narayanan, Arvind and Robert Pitt (2006). **Costs of Urban Stormwater Control Practices**, report for the U.S. Environmetal Protection Agency.

Strahler, Arthur N. (1952). "Hypsometric Analysis of Erosional Typology," **Bulletin of the Geological Society of America**,.

Willis, Susan and Arthur E. McGarity (2008). "Application of Nonpoint Source Pollutant Loading Models to Little Crum Creek Watershed," Summer Research Symposium, Sigma Xi Scientific Research Society, Swarthmore College, September 26, 2008.

Wossink, Ada and Bill Hunt (2003). **The Economics of Structural Stormwater BMP's in North Carolina,** http://www.bae.ncsu.edu/stormwater/pubs.htm.

Appendix A. Participation in Developing Little Crum Creek Watershed Action Plan under CZM Grant (as of February 28, 2009)

The following is a list of public outreach events conducted through February 28, 2009, for the purpose of obtaining public input into the nonpoint source model for Little Crum Creek and for use in compiling the Little Crum Creek Watershed Action Plan. Reported by A. Murphy/ Chester- Ridley- Crum Watersheds Association—A McGarity/Swarthmore College- 2/28/2009

1. Art McGarity presentation on Stormwise Model and application to Little Crum Creek Watershed Plan, November 2007, Little Crum Creek Watershed Partnership, Ridley Township. All four municipalities- Springfield, Swarthmore, Ridley Township, Ridley Park Borough, plus Delaware County Planning Department, CRC, and CDCAwere represented. Swarthmore College students also attended.

2. Art McGarity Presentation- Stormwise Model and application to Little Crum Creek Watershed Plan, February 2008, Ridley Park Borough. Ridley Park Borough Council, Swarthmore, and a member of Department of Community of Economic Development attended.

3. April 23, 2008, “Watershed Models: A Review of the State of the Art”,- organized by Swarthmore College and Keystone Conservation Trust. , April, 2008. Day long workshop with experts and users in the field to exchange expertise on developing models for improving water quality. 20 in attendance.

4. Poster Fair and Community Outreach Session, “ A Community Outreach Forum on Little Crum Creek”, April 30, 2008. Swarthmore College students present their projects as they relate to the nonpoint source modeling or watershed action plan .Attended by 40, including, CRC Board members, Swarthmore Borough manager Jane Billings, and other members of Swarthmore Community.

5. Fall presentation of Dr. McGarity and Susan Willis at, Summer Research Poster Session, “Application of Nonpoint Source Pollutant Loading Models to Little Crum Creek Watershed,” sponsored by Sigma Xi Scientific Research Society, Swarthmore College, on September 25, and September 26

6. Little Crum Creek Stakeholders Meeting, Little Crum Creek Watershed Action Plan, November 20, 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.

7. New research posters by Swarthmore College engineering students working on various aspects of the nonpoint source modeling for Little Crum Creek Watershed Plan and Model, displayed at Swarthmore Borough Hall, November 20.

8 Technical Advisory review of model and final products, January 23. Included members of CRC Board, Catania Engineering, Keystone Conservation Trust, and Princeton Hydro.

9. ArtMcGarity presentation to Partnership for the Delaware Estuary, June 2007.

10. Future Public Stakeholder Meeting: CRC and Swarthmore Borough applied for and received a matching grant from the PA Department of Community and Economic Development. Under this grant, another public meeting for Little Crum Creek stakeholders will be held on April 30, 2008,reviewing the report and the results of the modeling. Aseparate training session for decision makers will be organized by CRC. These sessions will be reported under the subsequent CZM grant period.

11. Future- Posters and Illustrated Project Findings and Study Results on both Swarthmore College and CRC web sites

Appendix B. Watershed Models for Managing Water Quality and Quantity: A Review of the State of the Art with a focus on cost-benefit methods to enable consideration of investments in land preservation and/or ecological restoration as well s BMP technologies

- a workshop held at Swarthmore College on April 23, 2008, Keith Room, Lang Center for Civic and Social Responsibility

AGENDA

BACKGROUND & ISSUES DISCUSSION:

Keystone Conservation Trust (www.keystoneconservation.org) has partnered with Professor Art McGarity of Swarthmore College on a project that aims to refine and improve the StormWISE watershed model (http://watershed.swarthmore.edu/stormwise/index.htm) that Art has already developed and has applied to portions of the Crum and Darby watersheds in suburban Philadelphia.

Our initial project goals are to focus on ***adding functionality*** such that ***land use change and urban growth predictions*** (including preserving conservation lands and or maintaining beneficial land cover), as well as ***restoration ecology BMPs*** (such as riparian buffer installations, infiltration and recharge projects, etc) can be projected for watersheds on a ***future-scenarios*** basis. When woven with a ***cost-benefit analysis*** module – the improved watershed modelling tool will help users ***prioritize*** not only ***which subwatersheds*** to work in, but also ***which specific projects offer the best cost benefit*** for ***improving or maintaining water quality or water quantity***.

As part of our project scope, we feel it important to attempt to benchmark the state-of-art for watershed models in the region; to assess areas of potential overlap with alternative models; and identify where there may be functionality gaps between existing models.

We are starting our model development process by benchmarking – in the form of hosting an all-day review and focus event at Swarthmore College on Wednesday April 23rd .

You have been selected as an invitee, either because you are a recognized technical expert in the field, or because you are a conservation practioner who could be critical in ensuring the relevance and applicability of the refined watershed modeling tool.

Arising from this review meeting, KCT would subsequently like to convene a Coordination Group of volunteer stakeholders -- to ensure that our project focuses on issues that are most relevant and needed by users and focus on providing the best decision support possible to address those issues that most remain to be resolved in the watershed modelling field (rather than wasting resources developing functionalities that others have already achieved). We imagine the Coordination Group can do most of its work virtually, primarily via email reports and comments – but assume several meetings may also be necessary during the first 6 months of the project.

We also envision facilitating the convening of a technical advisory subgroup of the Coordinating Group – encouraging those of you working on similar models to stay in touch through a series of convened meetings -- perhaps on a 6-week/2 month basis over the next 4-6 months.

What other issues are likely to come into play?

Our goal is to refine the StormWISE mode so it is:

Credible and ***replicable*** – as well as ***complimentary and compatible with other watershed modelling efforts*** (to the extent practical, given funding and infrastructural limitations). The result must be a useful watershed modelling tool that is also ***defensible, relevant***, and ***applicable*** for use by the conservation community within the Delaware Estuary basin (at a minimum).

Beyond conservation NGO use, we believe that this watershed modelling tool should be very user-friendly -- and particularly relevant for municipality use.

The following water quality and quantity-related planning issues are, or will likely be, of increasing importance at the municipal planning and implementation level in the coming years;

- New MS4 (stormwater) regulations
- Need to meet TMDL benchmarks
- Need to address carbon sequestration
- Need to address transportation planning requirements for smart growth
- Need to better quantify and understand wetland preservation/management contributions to water quantity and quality
- Need to better quantify the impacts of existing ordinances and zoning (SALDO) on resulting water quantity and quality

As such, we hope watershed modeling decision-support tools can be developed and refined to help meet their anticipated needs for more cost-effectively investment of tax-payer dollars -- in order to comply with these impending legislative issues, State or Federal directives.

Issues for discussion:

how can we provide for adequate decision-support across an entire watershed in order to better help maintain or improved water quality and quantity?
What has been accomplished so far?
What is "in-process"?
What still remains to be accomplished?
How can we best coordinate, as a community of invested stakeholders, to ensure that those watershed modelling requirements that are identified can be met?

Appendix C. Paper on StormWISE model revisions presented at the American Water Resources Association Summer Specialty Conference on Riparian Ecosystems and Buffers, Virginia Beach, VA, July, 2008.

AWRA 2008 SUMMER SPECIALTY CONFERENCE
Virginia Beach, Virginia
June 30-July 2, 2008

OPTIMAL APPLICATION OF RIPARIAN EASEMENTS AND BMP TECHNOLOGIES:
A MULTIOBJECTIVE TRADEOFF MODEL

Arthur E. McGarity*

ABSTRACT: Watershed managers, stewardship organizations, and government funding and regulatory agencies have many options for reducing nonpoint pollution into impaired waterways. The number of options is large and can be overwhelming when total pollutant loadings over an entire watershed are considered, as is the case when a total maximum daily load is imposed. Recent progress has been made developing decision-support models for choosing technologies and sites for implementation of best management practices (BMP's). One example of such a model is StormWISE, developed by the author (McGarity, 2006, 2007) However, a model that deals only with BMP site selections may fail to consider opportunities for preventing *future* nonpoint pollutant loadings through application of land use management tools such as riparian easements. This paper presents a multiobjective tradeoff model that can be used to identify optimal, cost-effective combinations of riparian easements, and similar tools, for undeveloped sites along with BMP technologies for developed sites. The goal is to achieve the watershed-wide pollutant load limits that are necessary to meet water quality goals as well as ecological benefits associated with habitat preservation and enhancement.

Optimal levels of BMP implementation and riparian easement acquisition are aggregated at the subwatershed level. BMP's are further categorized by the particular land uses to which they should be applied in each subwatershed. However, the model does not attempt to identify specific BMP or easement sites. Rather, the model prioritizes subwatersheds across the entire watershed substantially reducing the geographic areas over which managers must search for specific sites. The model is being incorporated into the StormWISE software to facilitate widespread application to impaired watersheds.
KEY TERMS: stormwater modeling; BMP technology; riparian easements; optimization; multiple objectives; trade-offs

INTRODUCTION

Optimization techniques have been applied in the field of Water Resources since the 1960's (ReVelle, et al., 1967), but only recently to management of nonpoint pollutants in stormwater runoff. There are two approaches: site-specific models and screening models. A site-specific model is "bottom-up." It requires specification of potential sites for BMP implementation throughout the watershed, application of detailed runoff simulation models to each of the sites (enabling linking of upstream and downstream sites), and then exploration of many thousands of possible BMP configurations using an optimization engine such as a genetic algorithm or a scatter search (Yu, et al., 2002, Lai, et al., 2006). A screening model is "top-down." It lumps sites together across a sub-drainage area of the watershed according to common characteristics such as land use category and models runoff from the entire sub-drainage using simplified hydrology and pollutant loadings with event mean concentrations or export coefficients. Environmental benefits of BMP's are connected to costs through watershed-scale benefit-cost functions. Watershed-wide total costs of BMP implementations are minimized while achieving a specified level or, in the case of a TMDL, a required level of environmental benefits (McGarity, 2006, 2007).

A screening model is primarily used for prioritizing sub-drainage areas over a large watershed in order to narrow the search for specific BMP sites. It could also be used as a front-end for a site-specific model. The StormWISE model, developed by the author and released as open-source software in 2007, is an example of a screening model. In this paper, extensions of the StormWISE model are formulated that enable inclusion of riparian-zone restoration projects and protective easements as water quality improvement options, along with the traditional BMP technologies. The extended model is currently being applied to develop a stormwater management plan for the Little Crum Creek watershed in suburban Philadelphia.

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MODEL THEORY

Watershed-Scale Environmental Benefit-Cost Functions

Pareto Optimal Solutions

The key theoretical component of the StormWISE screening model is the watershed-scale environmental benefit-cost function, which plots environmental benefits achieved in a sub-drainage area versus the level of resources devoted to implementation of management practices. Benefit-cost functions at the sub-drainage scale demonstrate the "law of diminishing returns," which is typical in situations where the number of sites is limited, and the costs of projects per acre vary over a wide range. The environmental benefits, measured in a variety of units, such as annual tons of sediment load reduction or acres of riparian wetland restored, are plotted on the vertical axis while resources devoted (costs in dollars) are plotted on the horizontal scale. The slope of the curve decreases as the marginal productivity of each additional project declines.

Figure 1 reveals that the benefit-cost function is actually a "Pareto-optimal frontier" that selects, for each possible level of investment on the horizontal axis, the particular configuration of projects that maximizes the environmental benefits, as indicated by the diamond symbols. Pareto optimal solutions are those that can not be improved upon without increasing the level of investment. The points that reside below this frontier represent "inferior" solutions because they can be improved upon by selecting a different combination of projects in the sub-drainage area that yields higher environmental benefits at the same or lower cost. A watershed-scale benefit-cost function is a smooth curve drawn through the set of Pareto optimal points. Figure 1 shows a smooth curve generated using a single-parameter "saturation model," which is described below.

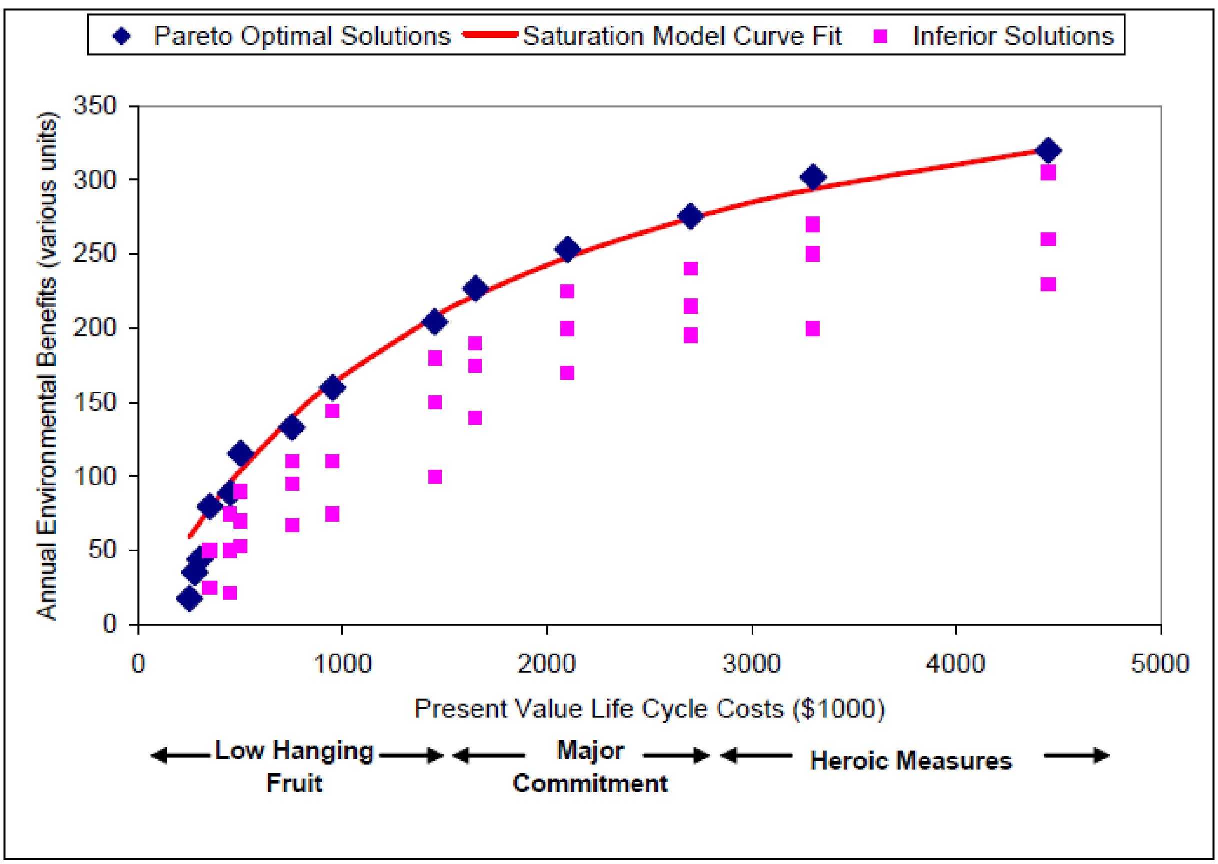


Figure 1. Watershed-scale benefit-cost curve fit to data (Pareto optimal solutions) derived from a modeling study of optimal sizing and placement of detention ponds by Yu, Zhen, and Zhai (2002) in which the environmental benefits are calculated as annual tons of sediment reduction.

Figure 1 identifies three different zones on the cost axis: (1) low hanging fruit, (2) major commitment, and (3) heroic measures. The "low hanging fruit" zone represents projects that can be readily accomplished for a relatively minor investment of resources. These are the kinds of activities that are often mentioned in general watershed conservation plans ranging from street sweeping in urban areas and replanting disturbed construction zones to installing rain barrels in residential areas and installing grass swales in public parks. Most watershed management plans in the U.S. are, at present, just entering this stage. The "major commitment" zone represents a concerted effort by watershed managers, residential, commercial, and industrial landowners, and government officials to improve water quality through strategic investments in effective technologies such as bioretention infiltration cells and green roofs, in restoration riparian buffers, and in protection of undeveloped green-space in the headwaters. In StormWISE model applications to date, investments of this type have been used as the primary calibration data for the benefit-cost functions. The "heroic measures" zone represents the projects having the highest marginal costs because they would have to be installed under very unfavorable conditions in order to achieve any environmental benefits. The methods would likely be the similar to those used in the major commitment zone, but they may have to be installed in the least suitable sites, such as high density urban land uses where each project must be adapted to a small drainage area, pollutant removal efficiencies are low, and economies of scale are limited.

In StormWISE, a benefit-cost curve is calibrated for each land use category that exists in each sub-drainage area of the watershed. Each combination of land use and sub-drainage is treated as a "decision variable." Then, the model's optimization modules sort through all of the different possible combinations of investment levels in each land use and each sub-drainage area to determine where the most cost-effective investments should be made in order to achieve the desired improvements in environmental quality. More is written on this aspect of the model below.

Saturation Functions

The mathematical form of the function in StormWISE that is used for the benefit-cost curve is that of "surface saturation phenomena." In physical systems in which a limited number of surface sites are available, and the effectiveness of the driving forces that populate the sites diminishes as the fraction of sites already populated increases towards 100%. One example is the Langmuir adsorption equation (Langmuir, 1918) that is widely used to model equilibrium adsorption of gas or liquid molecules on surfaces in response to increasing partial pressure or concentration. This equation is also used in technology assessment studies, such as a market penetration study for new energy efficiency technologies [Moore, et al. 2005]. When the equation is applied to the problem of populating potential sites for water quality improvement projects, the driving force is the level of economic resources devoted to a drainage area and the response is the fraction of land area that can be treated, restored, or protected.

The Langmuir surface saturation equation applied to BMP performance and cost over a subwatershed-scale drainage area takes the form shown in Equation (1), below:

$$f = \frac{X}{(H + X)} \qquad (1)$$

where:

f = fraction of land area treated by BMPs

X = resources devoted to BMPs ($1000)

H = "half-cost" – the resources required to treat one-half of the land area ($1000) – determined by the calibration procedure described elsewhere (McGarity, 2007).

Equation (1) is used to calculate environmental benefits by multiplying f by the maximum possible annual environmental benefit achievable if 100% of the available land in a particular land use in the sub-drainage is treated, restored, or protected, and by efficiency factors, as shown in Equations (2) and (3), below.

$$B = f\, B^{\max} \qquad (2)$$

where:

B = annual environmental benefits (eg. pollutant load reduced, acres of riparian buffer)

$B^{\max}$ = annual environmental benefit if 100% of available land area is treated

$$B^{\max} = f_T \eta_{BMP} B^{tot} \qquad (3)$$

where:

f_T = achievability fraction (eg. 90% of runoff treated for a water quality BMP, or 60% of residential riparian land could be bufferable)

η_{BMP} = estimated annual pollutant removal efficiency for treatable runoff for BMP's and riparian buffers.

B^{tot} = annual pollutant loading for each land use (pounds) or total acreage of a specific land use in riparian buffer zones.

Optimization Model for Watershed-Scale Prioritization

With a set of desired environmental benefits defined for a watershed, and calibrated benefit-cost functions as described above, a watershed manager is ready to solve the next stage of the problem, which is determining the optimal levels of investment for each sub-drainage area and for each land use category within each sub-drainage. The solution is obtained by solving the mathematical formulation below.

Minimize: $$\sum_{(i \in SW,\, j \in LU)} x_{ij} \qquad (4)$$

Subject to: $$\sum_{(i \in SW,\, j \in LU)} \frac{x_{ij}}{H_{ij} + x_{ij}} B_{ijk}^{\max} \geq B_k^{\min} \quad for\ k \in BE \qquad (5)$$

where:

x_{ij} = resources devoted to environmental quality improvement in subwatershed i for land use j,

$i \in SW,\ j \in LU$

H_{ij} = half cost of treatment, restoration, or protection of land use j in sub-drainage i, $i \in SW,\ j \in LU$

$B_k^{\min}$ = desired (or required) minimum level of environmental benefit k, $k \in BE$

SW = set of subwatersheds in the larger watershed

LU = set of land use categories

BE = set of environmental benefits desired (eg. pounds reduced of nutrients or sediment, acres of riparian buffer, etc.)

This formulation represents a convex nonlinear programming problem that possesses a well defined global minimum. The optimal solution and the corresponding values of the variables x_{ij} can be obtained using standard optimization codes.

MODEL APPLICATION

The model is applied by delineating meaningful sub-drainage areas in the watershed under study. Typical sizes for sub-drainages are one square mile or less in urban areas. This size is small enough to help narrow the search for specific project sites, but it also typically provides a range of different land use categories in each sub-drainage, especially in developed suburban areas. When restoration or preservation of riparian buffers is an option, distinct land use categories are created for the riparian zone. Thus, land use categories that appear both in the riparian zone and in the upland sectors of the sub-drainage are split into two different land use categories. For example, residential land use becomes "riparian residential" and "upland residential." Thus, a different set of treatment, restoration, and preservation options and a different set of benefit-cost curves can be generated for the riparian and upland zones. Also, a distinct set of decision variables x_{ij} are generated for the riparian zones.

Figure 2 shows a map of the Little Crum Creek Watershed in the western suburbs of Philadelphia. This small watershed drains four municipalities having a wide mix of different land uses ranging from low-intensity residential in the north to heavy industry in the south. The extended StormWISE model presented here will be applied to this watershed to develop a stormwater management plan to be implemented by the four municipalities. Seven sub-drainages have been delineated for use in our study. Riparian zones along the tributaries and main branches of the stream have been identified, as shown below. The different colors of the segments indicate the variety of land uses found in the riparian zone corresponding to a wide range of options for treatment, restoration, and preservation.

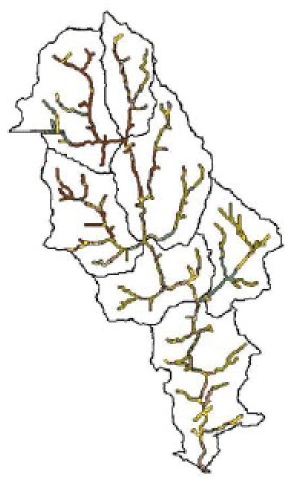


Figure 2. The Little Crum Creek Watershed in suburban Philadelphia, Pennsylvania

The addition of riparian zone restoration and preservation to the StormWISE model presents some interesting prospects for incorporating multiobjective analysis. Restoration and preservation of land have obvious water quality benefits that can be calculated as pollutant load reductions and added to similar benefits generated by BMP technologies installed throughout the watershed. But the riparian options have additional environmental benefits associated with them that are not directly related to water quality, such as habitat restoration and preservation for wildlife. A watershed management plan should consider both kinds of benefits when prioritizing sites for investments in environmental quality. Through repeated solution of the optimization model for a range of weights placed on water quality and habitat-based benefits, a trade-off curve can be generated to identify the set of noninferior (Pareto optimal) solutions for use by decision makers in selecting a best compromise solution. This is a solution that does a good job of satisfying both types of objectives simultaneously.

There are challenges involved in applying the optimization model to decisions involving land restoration and preservation. Calibrating the benefit-cost functions for the various riparian land uses requires familiarity with successful practices and knowledge of costs involved in restoring buffer zones and in obtaining easements so that the benefits can be sustained. Moreover, predicting the water quality benefits of land preservation options is difficult because development trends must be forecast regarding the type of land use that would have occurred if a land preservation easement had not been put in place so that credits can be estimated for the avoided pollutant loadings. The Little Crum Creek study currently underway is providing an opportunity to explore these issues in a realistic setting, and the lessons learned will be of value in similar urbanized areas.

CONCLUSIONS

This paper reports on new developments in decision support modeling for stormwater management on a watershed basis. The StormWISE model has been extended to include options for land restoration and preservation in the riparian zone. The result is a framework for prioritizing projects implementing stormwater BMP's and riparian easements over an entire watershed enabling watershed managers to achieve desired (or required) environmental quality benefits in a cost effective manner. The model extensions will be tested on the Little Crum Creek Watershed during 2008-09 and will most likely be incorporated into the StormWISE open source software for distribution in late 2009.

ACKNOWLEDGMENTS

The research reported here is being sponsored by the Coastal Zone Program of the Pennsylvania Department of Environmental Protection and the National Oceanic and Atmospheric Association through a grant to the Keystone Conservation Trust (KCT) and Swarthmore College. Staff members of KCT contributing to this research are Phil Wallis, John Rogers, and Clare Billett. The Chester Ridley Crum Watersheds Association is providing support through coordination with municipalities and public education through Anne Murphy, Executive Director. Additional financial support is provided by the Land Use Planning and Technical Assistance Program of the Pennsylvania Department of Community and Economic Development and from PECO Energy Company. The four Pennsylvania municipalities drained by the Little Crum Creek are also supporting this project: the Townships of Ridley and Springfield, and the Boroughs of Ridley Park and Swarthmore. Patrick Lindsey, senior engineering student at Swarthmore College, developed the watershed sub-drainage delineation analysis using the open source GIS software MapWindow with the TauDEM extension.

REFRENCES

Lai, F., J. Zhen, J. Riverson, and L. Shoemaker, 2006. SUSTAIN – An Evaluation and Cost-Optimization Tool for Placement of BMPs. ASCE Conference Proceedings Paper. Proceedings of the 2006 World Environmental and Water Resources Congress, ed. by Randall Graham.

Langmuir, I, 1918. The Adsorption of Gases on Plane Surfaces of Glass, Mica, and Platinum. *Journal of the American Chemical Society* [**40**, 1361].

McGarity, A.E. (2006). A Cost Minimization Model to Priortize Urban Catchments for Stormwater BMP Implementation Projects. American Water Resources Association National Meeting, Baltimore, MD, November, 2006.

McGarity, A.E. (2007). The StormWISE Model: Priortizing Subwatersheds and Land-Uses for Stormwater BMP Implementation. Proceedings of the Pennsylvaina Stormwater Symposium, Villanova University, October, 2007.

Moore, M.C., D.J. Arent, and D. Norland, 2005. R&D Advancement, Technology Diffusion, and Impact on Evaluation of Public R&D, National Renewable Energy Laboratory, Golden, Colorado, NREL/TP-620-37102.

ReVelle, C. D.P. Loucks, and W.R. Lynn, 1967. A Management Model for Water Quality Control. Journal of the Water Pollution Control Federation, vol.39, no. 7.

Yu, S., J. X. Zhen, and S.Y. Zhai, 2002. Development of Stormwater Best Management Practice Placement Strategy for the Virginia Department of Transportation. Final Contract Report, VTRC 04-CR9, Virginia Transportation Research Council.

Appendix D. Tabular Results from StormWISE Baseline Case

Case 1. StormWISE Baseline Results **Favoring Reduction of Runoff Volume**:

Table D1: Environmental Benefits Achieved: Runoff Volume and Pollutant Load Reduction Favoring Reduction of Runoff Volume

StormWISE Run Number	Runoff Volume Reduction (m^3/year)	% of maximum Runoff Reduction	Sediment Load Reduction (kg/year)	Nitrogen Load Reduction (kg/year)	Phosphorous Load Reduction (kg/year)
1*	30,000	2%	3,343	6.7	0.8
2	35,000	3%	3,973	8.7	1.4
3	50,000	4%	5,965	16	3.8
4	100,000	8%	12,637	30	8.2
5	150,000	12%	19,315	42	11.8
6	200,000	16%	26,022	55	15.7
7	250,000	20%	32,875	70	21.1
8	300,000	24%	39,728	85	26.5
9	350,000	28%	46,581	100	31.9
10	400,000	32%	53,434	114	37.3
11	450,000	36%	60,192	128	41.7
12	500,000	40%	67,040	143	47.3
13	550,000	44%	73,875	176	55.2
14	600,000	48%	79,046	203	57.5
15	650,000	52%	86,013	255	61.3
16	700,000	56%	93,069	286	63.2
17	750,000	60%	100,125	317	65.1
18	800,000	64%	104,815	333	66.8
19	850,000	68%	111,724	373	69.5
20	900,000	72%	116,101	380	70.1
21	950,000	76%	120,479	386	70.8
22	1,000,000	80%	125,079	394	71.9

* Zero cost run showing credit for existing riparian zone buffer

Table D2: Optimal Spending Levels by Drainage Zone Favoring Reduction of Runoff Volume

StormWISE Run Number	Total Capital Cost ($1000)	Optimal Spending for Headwaters BMP's ($1000)	Optimal Spending for Lowlands BMP's ($1000)
1	$0	$0	$0
2	$20	$20	$0
3	$106	$106	$0
4	$476	$424	$52
5	$849	$797	$52
6	$1,235	$1,183	$52
7	$1,686	$1,634	$52
8	$2,137	$2,085	$52
9	$2,587	$2,536	$52
10	$3,038	$2,987	$52
11	$3,534	$3,045	$490
12	$4,119	$3,102	$1,016
13	$5,104	$3,896	$1,208
14	$6,330	$4,904	$1,426
15	$7,645	$6,137	$1,508
16	$9,020	$7,512	$1,508
17	$10,395	$8,887	$1,508
18	$11,804	$9,959	$1,846
19	$13,505	$9,959	$3,546
20	$15,955	$10,756	$5,199
21	$18,406	$13,207	$5,199
22	$20,859	$15,660	$5,199

Table D3: Optimal Spending Levels by Land Use Category Favoring Reduction of Runoff Volume

StormWISE Run Number	Total Capital Cost ($1000)	Developed Wooded/Fields ($1000)	Developed Low Intensity ($1000)	Developed Medium Intensity ($1000)	Developed High Intensity ($1000)
1	$0	$0	$0	$0	$0
2	$20	$0	$0	$0	$20
3	$106	$0	$0	$0	$106
4	$476	$0	$311	$0	$165
5	$849	$0	$684	$0	$165
6	$1,235	$71	$999	$0	$165
7	$1,686	$522	$999	$0	$165
8	$2,137	$972	$999	$0	$165
9	$2,587	$1,423	$999	$0	$165
10	$3,038	$1,874	$999	$0	$165
11	$3,534	$2,114	$1,255	$0	$165
12	$4,119	$2,641	$1,255	$58	$165
13	$5,104	$2,641	$1,255	$788	$420
14	$6,330	$2,641	$1,255	$788	$1,646
15	$7,645	$2,641	$1,554	$1,721	$1,729
16	$9,020	$2,641	$2,929	$1,721	$1,729
17	$10,395	$2,641	$4,304	$1,721	$1,729
18	$11,804	$2,641	$4,426	$2,975	$1,762
19	$13,505	$2,641	$5,584	$3,274	$2,005
20	$15,955	$2,641	$8,035	$3,274	$2,005
21	$18,406	$2,641	$10,486	$3,274	$2,005
22	$20,859	$2,641	$12,889	$3,324	$2,005

Table D4: Optimal Spending Levels by BMP Favoring Reduction of Runoff Volume

StormWISE Run Number	Total Capital Cost ($1000)	Riparian Buffer Filter Strip / Swale ($1000)	Constructed Wetland / Rain Garden ($1000)	Bio-retention / Infiltration Pit ($1000)	Rain Barrel / Cistern ($1000)	Impervious Removal ($1000)	Permeable Pavement ($1000)	Green Roof ($1000)
1	$0	$0	$0	$0	$0	$0	$0	$0
2	$20	$0	$20	$0	$0	$0	$0	$0
3	$106	$0	$106	$0	$0	$0	$0	$0
4	$476	$0	$476	$0	$0	$0	$0	$0
5	$849	$0	$849	$0	$0	$0	$0	$0
6	$1,235	$0	$1,235	$0	$0	$0	$0	$0
7	$1,686	$0	$1,686	$0	$0	$0	$0	$0
8	$2,137	$0	$2,137	$0	$0	$0	$0	$0
9	$2,587	$0	$2,587	$0	$0	$0	$0	$0
10	$3,038	$0	$3,038	$0	$0	$0	$0	$0
11	$3,534	$0	$3,534	$0	$0	$0	$0	$0
12	$4,119	$0	$4,119	$0	$0	$0	$0	$0
13	$5,104	$0	$4,849	$255	$0	$0	$0	$0
14	$6,330	$0	$4,849	$605	$876	$0	$0	$0
15	$7,645	$0	$4,849	$1,838	$958	$0	$0	$0
16	$9,020	$0	$4,849	$3,213	$958	$0	$0	$0
17	$10,395	$0	$4,849	$4,588	$958	$0	$0	$0
18	$11,804	$0	$4,849	$4,744	$2,212	$0	$0	$0
19	$13,505	$0	$4,849	$6,296	$2,359	$0	$0	$0
20	$15,955	$0	$4,849	$6,296	$4,810	$0	$0	$0
21	$18,406	$0	$4,849	$6,296	$7,261	$0	$0	$0
22	$20,859	$50	$4,849	$6,296	$9,664	$0	$0	$0

Case 2. StormWISE Baseline Results **Favoring Reduction of Sediment**:

Table D5: Environmental Benefits Achieved: Runoff Volume and Pollutant Load Reduction Favoring Reduction of Sediment

StormWISE Run Number	Runoff Volume Reduction (m^3/year)	Sediment Load Reduction (kg/year)	% of maximum Runoff Reduction	Nitrogen Load Reduction (kg/year)	Phosphorous Load Reduction (kg/year)
1*	31,604	3,522	2%	7	1
2	80,260	10,000	6%	25	7
3	132,666	17,000	10%	38	11
4	185,071	24,000	15%	51	14
5	236,322	31,000	19%	66	20
6	287,394	38,000	23%	81	25
7	338,465	45,000	28%	96	31
8	389,537	52,000	32%	111	36
9	441,306	59,000	36%	125	41
10	492,377	66,000	40%	141	46
11	536,162	73,000	45%	168	55
12	577,787	80,000	49%	217	62
13	600,388	87,000	53%	238	67
14	635,489	94,000	58%	280	72
15	684,892	101,000	62%	318	74
16	734,495	108,000	66%	349	76
17	777,459	115,000	70%	385	80
18	829,251	122,000	75%	419	82
19	905,485	129,000	79%	449	86
20	958,847	136,000	83%	519	94
21	1,038,806	143,000	88%	529	95
22	1,111,357	150,000	92%	569	99

* Zero cost run showing credit for existing riparian zone buffer

Table D6: Optimal Spending Levels by Drainage Zone Favoring Reduction of Sediment

StormWISE Run Number	Total Capital Cost ($1000)	Optimal Spending for Headwaters BMP's ($1000)	Optimal Spending for Lowlands BMP's ($1000)
1	$0	$0	$0
2	$328	$277	$52
3	$720	$668	$52
4	$1,111	$1,059	$52
5	$1,562	$1,511	$52
6	$2,023	$1,971	$52
7	$2,483	$2,432	$52
8	$2,944	$2,892	$52
9	$3,436	$3,045	$392
10	$4,012	$3,045	$967
11	$4,954	$3,938	$1,016
12	$6,102	$4,894	$1,208
13	$7,314	$6,106	$1,208
14	$8,565	$7,358	$1,208
15	$9,907	$8,699	$1,208
16	$11,271	$10,064	$1,208
17	$12,683	$10,833	$1,849
18	$14,398	$11,125	$3,273
19	$16,639	$12,761	$3,878
20	$19,972	$14,627	$5,345
21	$23,891	$19,303	$4,588
22	$30,687	$24,298	$6,389

Table D7: Optimal Spending Levels by Land Use Category Favoring Reduction of Sediment

StormWISE Run Number	Total Capital Cost ($1000)	Developed Wooded/Fields ($1000)	Developed Low Intensity ($1000)	Developed Medium Intensity ($1000)	Developed High Intensity ($1000)
1	$0	$0	$0	$0	$0
2	$328	$0	$328	$0	$0
3	$720	$0	$720	$0	$0
4	$1,111	$0	$1,111	$0	$0
5	$1,562	$0	$1,562	$0	$0
6	$2,023	$0	$2,023	$0	$0
7	$2,483	$0	$2,483	$0	$0
8	$2,944	$0	$2,944	$0	$0
9	$3,436	$0	$3,436	$0	$0
10	$4,012	$0	$4,012	$0	$0
11	$4,954	$296	$4,658	$0	$0
12	$6,102	$647	$4,849	$605	$0
13	$7,314	$1,859	$4,849	$605	$0
14	$8,565	$2,482	$4,849	$1,235	$0
15	$9,907	$2,482	$4,849	$2,576	$0
16	$11,271	$2,482	$4,849	$3,940	$0
17	$12,683	$2,847	$4,849	$4,987	$0
18	$14,398	$2,961	$4,849	$6,296	$292
19	$16,639	$2,961	$4,849	$6,296	$2,212
20	$19,972	$2,961	$4,849	$6,296	$2,968
21	$23,891	$2,961	$4,849	$6,296	$6,887
22	$30,687	$2,961	$4,849	$6,296	$9,664

Table D8: Optimal Spending Levels by BMP Favoring Reduction of Sediment

StormWISE Run Number	Total Capital Cost ($1000)	Riparian Buffer Filter Strip / Swale ($1000)	Constructed Wetland / Rain Garden ($1000)	Bio-retention / Infiltration Pit ($1000)	Rain Barrel / Cistern ($1000)	Impervious Removal ($1000)	Permeable Pavement ($1000)	Green Roof ($1000)
1	$0	$0	$0	$0	$0	$0	$0	$0
2	$328	$0	$328	$0	$0	$0	$0	$0
3	$720	$0	$720	$0	$0	$0	$0	$0
4	$1,111	$0	$1,111	$0	$0	$0	$0	$0
5	$1,562	$0	$1,562	$0	$0	$0	$0	$0
6	$2,023	$0	$2,023	$0	$0	$0	$0	$0
7	$2,483	$0	$2,483	$0	$0	$0	$0	$0
8	$2,944	$0	$2,944	$0	$0	$0	$0	$0
9	$3,436	$0	$3,436	$0	$0	$0	$0	$0
10	$4,012	$0	$4,012	$0	$0	$0	$0	$0
11	$4,954	$296	$4,658	$0	$0	$0	$0	$0
12	$6,102	$647	$4,849	$605	$0	$0	$0	$0
13	$7,314	$1,859	$4,849	$605	$0	$0	$0	$0
14	$8,565	$2,482	$4,849	$1,235	$0	$0	$0	$0
15	$9,907	$2,482	$4,849	$2,576	$0	$0	$0	$0
16	$11,271	$2,482	$4,849	$3,940	$0	$0	$0	$0
17	$12,683	$2,847	$4,849	$4,987	$0	$0	$0	$0
18	$14,398	$2,961	$4,849	$6,296	$292	$0	$0	$0
19	$16,639	$2,961	$4,849	$6,296	$2,212	$321	$0	$0
20	$19,972	$2,961	$4,849	$6,296	$2,968	$2,897	$0	$0
21	$23,891	$2,961	$4,849	$6,296	$6,887	$2,897	$0	$0
22	$30,687	$2,961	$4,849	$6,296	$9,664	$2,897	$4,020	$0

Attachment A

Note: The material in this attachment was developed separately from this project through activities funded by Natural Lands Trust, Pennsylvania Department of Conservation and Natural Resources, Pennsylvania Department of Environmental Protection, and the William Penn Foundation

SmartConservation™ "GREENSWEEP"

INTERIM ECOLOGICAL RESOUCE MAPPING ASSESSMENT – as of June 2004

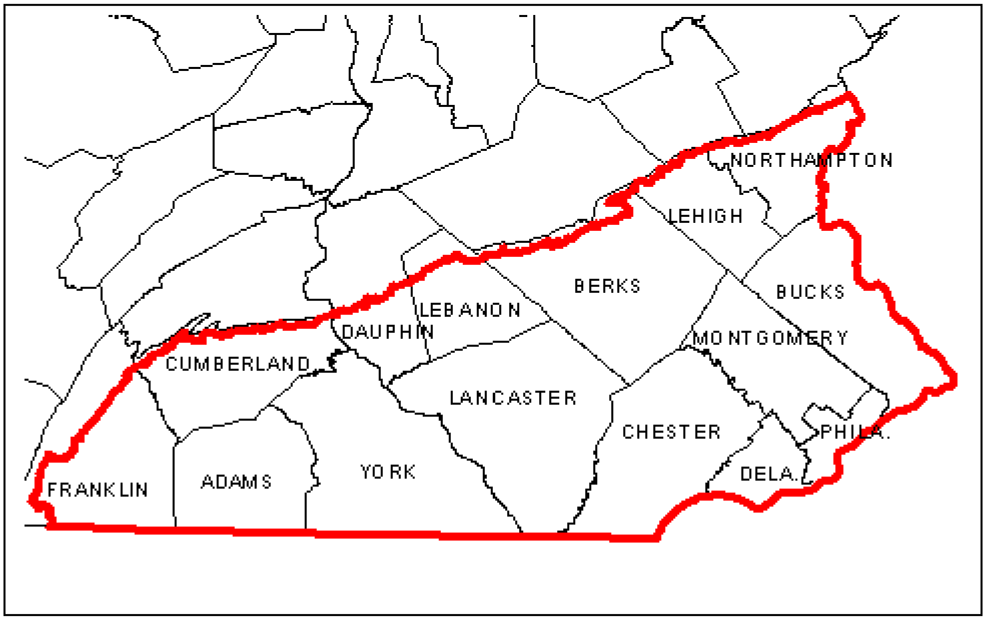
Introductory Note:

It is important to emphasis that several of the GIS data layers which were used in this analysis were developed based on the most recent satellite land cover data sets available for our use at the time of this project; 1992-1994. More updated land cover data was unavailable for use in this project as of October 2003.

Given the rate of development in SE Pennsylvania over the last decade, since this satellite land cover data was generated, it is clear that some of the ecological conservation values implied by this mapping project have probably already been lost. It is proposed that any future updates of this project include the most recent land cover data available. The impact of the age of the land cover layer can be somewhat mitigated by overlaying a more updated "Developed" lands data layer (e.g. the 2000 NLCD) at the end of the ecological assessment process. This updated development "mask" will screen out all sites in the region where development now displaces natural resources. Users can also verify new development by overlaying the most recent B&W aerial photography (currently from 1999) using the quarter-quad tiles now available throughout the Expanded Piedmont ecoregion.

In the meantime, values displayed in this analysis should be considered a functional over-estimate of the ecological conservation resources remaining in the region – which means the call to preserve the best of what remains is all the more critical.

Finally, it is also important to note that the ecological resource values contained in this mapping were generated for the entire Expanded Piedmont ecoregion, which equates to portions of 15-counties across south-east and south-central Pennsylvania. Any data clipped from this Expanded Piedmont data set should be used as is. In other words, no reclassing or recalibration of the data should be undertaken to express the conservation values for the data ranges within just the geographic subset of the ecoregion in question. This is a deliberate policy since the Expert Taxa Advisory Groups help NLT developed ecological value systems that were appropriate to use throughout the Extended Piedmont region and most of the value-added data was developed on a 10-quantile basis (i.e. 10% of the value ranges of the entire expanded piedmont ecoregion were assigned to each of 10 classes). Any geographic subset of this data should therefore represent conservation resource values related directly to conditions throughout the entire Expanded Piedmont ecoregion, rather than just within the geographic subregion in question. In other words, if an area within a geographic subset of the ecoregion scores a 10 for a particular ecological component, that location will be part of the top 10% of locations throughout the Piedmont for that component.



Expanded Piedmont Ecoregion

This represents the area over which the ecological values for SmartConservation™ have been developed to date.

DATA LAYERS USED IN THE FINAL *SmartConservation* ECOLOGICAL VALUES MAPPING ASSESSMENT: (as available through 10-27-03) INCLUDE:

A. Potential Vertebrate *(Animal)* Habitat SUBGROUP

Potential Mammals Conservation Value (CV)
Potential Fish CV
Potential Herps CV
Potential Birds CV
IBAs

B. Aquatic Habitat SUBGROUP

Water Quality (DEP's Unassessed Waters 303 [d] List)
National Wetland Inventory
Hydric Soils
Floodplains
Forested Water Quality
Riparian Buffer Quality
Headwaters Protection
Impervious Cover 2000
Impervious Cover Change 1985-2000

C. Terrestrial Habitat SUBGROUP

Steep Slopes
Interior Forest Habitat
Natural Vegetation Habitat Blocks
Contiguous Grassland Habitat
Contiguous Barren-Transitional (Scrub-Shrub) Habitat

D. Rarity SUBGROUP

A - Potential Vertebrate (*Animal)* Habitat SUBGROUP

Mammals CV; Fish CV; Birds CV; Herps CV:

These data layers originated from the Penn State/ERRI/Pennsylvania Gap project. In 2001, PSU/ERRI released their habitat modeling layers to *predict* where vertebrate species are most likely to be found in Pennsylvania according to land cover, species range and other habitat determinants, such as elevation, topography or other mapable spatial determinants (such as stream corridors for Louisiana water thrush).

NLT took these predictive statewide species GIS layers and, working with the Expert Taxa Advisory Groups convened to inform the *SmartConservation*™ project, culled the species lists in each of the 4 primary taxon groups (Birds, Mammals, Fish, and Herps) to remove any non-native species or any species not endemic to the Pennsylvania Expanded Piedmont ecoregion. Once the species lists had been compiled and finalized, each species was then ranked by the Expert Advisory Groups according to 'Conservation Value' (CV). Conservation value was derived by considering various aspects of a species' role in the ecosystem, such as whether it is a keystone species, sensitive to disturbance, fragmentation, or whether it is overabundant. General population trends were also considered, (to the extent known), while population size [primarily in relation to trends] was also a consideration if such information was known. CV values ranged from 0 to 10, with 0, 2, 5, and 10 being used to represent "no, little, medium and high" CV respectively. Upon finalization of the CV allocations, NLT added each species, using its CV weight, according to the taxa group to which it belongs. Results were normalized to a 0-10 scoring scale using a 10% quantile classification system (i.e. 10% of the values were assigned to each of the 10 class categories).

Important Bird Areas (IBAs)

IBAs have been defined as core and buffer polygons across areas of SE PA by the Pennsylvania Audubon Society. These areas are shown, essentially, as boost scores to supplement the Birds CV. Core areas were assigned a 3 score and buffers where assigned 1 (or essentially 33% of the value).

Note that Important Mammal Areas and Important Herp Areas are also GIS data layers that are either in development, or planned for development by others within the next few years. When these data sets are available, they too can be added as boost scores to the potential vertebrate habitat analysis.

B – Aquatic Resources SUBGROUP

National Wetland Inventory (NWI):

Wetlands were assigned scores by type as follows, based on input from the Taxa Advisory Committees:

Substrate-only type wetlands (e.g. no vegetation, just rock, sand or mud types)	1
Open water and aquatic bed wetlands	2
Unconsolidated emergent or forested wetlands	4
Emergent, shrub-shrub and forested wetland types and all combinations therein	10

Hydric Soils:

Data was compiled from SSURGO soil survey digital mapping for counties throughout the piedmont. Hydric soils were mosaiced into a single coverage, clipped for the NLT expanded Piedmont ecoregional area and reclassed to give a boost score of 3.

Floodplains:
Data was gathered from PASDA, mosaiced into a single coverage for the piedmont area, and was then clipped for the NLT expanded Piedmont ecoregional area and reclassed to give a boost score of 5.

Forested Water Quality:
The percent of first and second order streams was expressed per Pennsylvania Small Watershed and the results reclassed according to a 10-quantile distribution. Forested landcover was selected from the regional land cover data set and expressed as a percent of all landcover types for each Pennsylvania Small Watershed, also using a 10% (10-quantile) classification system. The two data sets were then added together and divided by 2, and then normalized once again on a 10% quantile basis. A Pennsylvania Small Watershed classed "1" represents a watershed that is in the lowest 10% for a combination of forested and 1st and 2nd order streams, while a "10" score for a PA Small Watershed indicates it is in the top 10% of watersheds for forested land cover and percent length of first and second order streams.

Riparian Buffer Quality:
Riparian buffers of approximately 100 feet were created on either side of all streams or water bodies in the Piedmont. The regional landcover was ranked for quality of riparian buffers in support of aquatic habitat conditions by the Aquatics Expert Advisory Committee, such that the 15 original landcover classes were assigned one of four habitat quality weighting as follows:

Commercial; Urban; Suburban, Quarries, Bare transitional	0
Row Crops; Recreational grass	2
Hay/Pasture	5
All forest, water and wetland types, as well as natural bare rock/sand	10

A Focal Variety algorithm was run on the clipped riparian buffer landcover areas to indicate where aggregations versus fragmentation of land cover types existed. A 0, 2, 5, or 10 score was assigned where there was 4, 3, 2 or 1 landcover types within the focal variety zone of analysis (which used a 3 cell by 3 cell analysis area).

The Focal Variety results were then multiplied by the weighted Aquatics Land cover habitat results and divided by 10.

Streams and water body results were then split into separate data layers so they could be+ mosaiced back together using the weights noted below (as suggested and approved by the Aquatics Expert Advisory Committee).

All 1st and 2nd order streams	10	(or 0.625)
All 3rd to 5th order streams	5	(or 0.3125)
All 6th+ order streams and isolated water bodies	1	(or 0.0625)

The resulting data layer represents riparian buffer quality in very small linear spatial arrangements, (which would essentially get "buried" when compiled with broader spatial surfaces during the regional mapping process). To address this issue, we converted the linear riparian quality values into averages per Pennsylvania Small Watershed, classified by 10% quantiles, as a more appropriate spatial representation of riparian corridor values to add to the region-wide assessment.

Water Quality (2002) 303[d] List:

Stream segments from the 303 [d] GIS data set were clipped to the PA Small watershed boundaries and an average score obtained based on the quality ranking system provided above. The resultant map was then recalibrated to show results on a 10-quantile basis (i.e. with 10% of each of the values spread assigned to each class).

Since this data set is still incomplete across the entire ecoregion at this time (i.e. using the most recently available data set from 2002), we are using an interim 10-point ranking system that averages water quality results per PA Small Watershed throughout the Extended Piedmont ecoregion, as follows:

Attaining = 10
Unattaining = 0
Unassigned = 5

Headwaters Protection
The Aquatics Expert Advisory Committee have expressed on numerous occasions their desire to highlight the critical importance of headwater features, such as seeps, springs and ephemeral streams, as well as the importance of first and second order streams in maintaining water quality in general. It has also been noted by the group that headwater areas are more defensible from upstream pollution threats. As such, they tasked NLT with a way to generate a measure that indicated "Location in watershed", such that lands lower in a watershed were less valuable than lands higher in a watershed. NLT eventually decided that the best way to represent these values was through use of a flow accumulation grid. This grid was created from the piedmont regional DEM, and the classification scheme implemented used the following classes:

# of cells running into the cell in question	SC score	(APPROX. EQUIVALENCE)
0-2	10	½ acre – watershed ridge location
2-4	9	½ acre - pre-channel flow (e.g. seeps/springs/ephemeral streams, etc)
4-22	7	1st order streams
22-112	5	1st & 2nd order streams
112-1414	3	2nd & 3rd order streams
1414-2828	2	3rd & 4th order streams
2828-5656	1	4th order streams and above
5656+	0	More than 4th order streams

Values were expressed as averages per Pennsylvania Small Watershed, with final results displayed as 10% quantiles.

Impervious Cover, 2000

The Aquatics Advisory Committee helped NLT assign values to this data set, which became available from PSU via PASDA in early winter 2003. Impervious Cover averages were generated per

'Pennsylvania Small Watershed'. An 'impact' of impervious cover ranking system was used to classify the results, centered around critical threshold impact values provided by Woods Hole Research Station

(WHRS) and the Center for Sustainable Watershed (CSW) of 6%, 10% and 20% respectively, where WHRS has research that implies water quality is largely unimpacted below 6% impervious cover watershed wide; and the CSW proposes that water quality is less impacted where impervious cover is 10% or less watershed wide and greatly impacted where impervious cover is 20% or greater watershed wide. Using these cornerstones for the ranking system provides us with the following value system:

>20% Impervious Cover	0
18-20%	1
16-18%	2
14-16%	3
12-14%	4
10-12%	5
9-10%	6
8-9%	7
7-8%	8
6-7%	9
<=6%	10

Impervious Cover Change, 1985 to 2000

Using the Impervious Cover data from PSU from 1985 and 2000, and averaging it per 'Pennsylvania Small Watershed' as described above, the 2000 condition was compared to the 1985 condition and the difference mapped in a new data set. Resulting values were classified using a 10-quantile classification system such that 10% of the watershed values were assigned to each class. Thus a 10-score represents the watersheds which show the top 10% of Impervious Cover increases across the region, while a 0 score represents the lowest 10% of watershed values.

Note also that "Water Consumption" data layers (such as the DRASTIC recharge data set; wellhead protection data sets; Chapter 93 and others typically analyzed through the Source Water Assessment process) are not included in this analysis since these data sets address human water use issues rather than analysis of aquatic habitat conditions. NLT intends to develop a subgroup of GIS value-added data sets that address Water Consumption within the next 6-months, but it will likely be treated as a stand-alone data subgroup that is not incorporated within the conservation resource and habitat analysis being represented by this assessment.

C - Terrestrial Resources SUBGROUP

Steep Slopes

Historically, steep slopes have deterred development to such an extent that they are somewhat of a predictor of intact forest conditions across the region. If a slope is steep enough, there is a good chance that extensive timbering and thus, high grading and soil compaction, has been avoided in these areas. In addition, these slopes should be protected to reduce the threat of erosion.

Slopes were generated for the region from the Digital Elevation Model (DEM), and assigned boost scores as follows:

0-15%	0
15-25%	2
25%+	4

Interior Forest Habitat
NLT obtained an Interior Forest Habitat layer from PSU-ERRI, which selected forest types from the MRLC landcover data set and applied a 300-foot buffer to clip away external "edge". The remaining forests were considered Interior Forest Habitat and were ranked according to size (in acres) as suggested by the Birds Expert Advisory Committee (which have been calibrated specifically to reflect conditions across the Pennsylvania Piedmont region):

0-25 acres	0
25-50 acres	1
50-100 acres	2
100-150 acres	3
150-225 acres	4
225-300 acres	5
300-400 acres	6
400-500 acres	7
500-750 acres	8
750-1000 acres	9
1000+ acres	10

Natural Vegetation Habitat Blocks
All natural vegetation and land cover classes were split out from the regional landcover data layer[1]. Regional road data was compiled to show regional landscape fragmentation and size of remaining landscape blocks. Block size values were assigned based on input primarily from the Mammals Expert Advisory Committee, with regional adjustments based on conditions across the Pennsylvania Piedmont, as follows:

0-35 acres	0
35-70 acres	1
70-100 acres	2
100-150 acres	3
150-250 acres	4
250-500 acres	5
500-875 acres	6
875-1375 acres	7
1375-2025 acres	8
2025-3000 acres	9
3000+ acres	10

<u>Contiguous Grassland Habitat Blocks</u>
All hay/pasture land cover types were clipped from the regional land cover data set (92-94) for the Expanded Piedmont Ecoregion. The layer was then intersected with the regional landscape blocks, as used in the Interior Forest and Natural Vegetation descriptions. Each contiguous Hay/Pasture polygon within a landscape block was then ranked according to size, using a boost scoring system, as follows:

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[1] Landcover classes excluded from the "Natural Vegetation" layer were: Commercial; Urban; Suburban; Quarries; Bare Transitional; Row Crops; Recreational Grass; & Hay/Pasture. All forest (3 classes), water and wetland types (2 classes), as well as the natural bare rock/sand class, were included in the definition of "Natural Vegetation".

0-25 acres	0
25-160 acres	1
160-250 acres	3
250-400 acres	4
>400 acres	5

Note: This ranking system was developed based on consideration of grassland habitat sizes necessary for viable grassland bird habitat, modified to reflect the range of contiguous grassland polygon sizes throughout the ecoregion.

Contiguous Scrub/Shrub or Barrens Habitat Blocks

All Bare/Transitional land cover types were clipped from the regional land cover data set (92-94) for the Expanded Piedmont Ecoregion. The layer was then intersected with the regional landscape blocks, as used in the Interior Forest and Natural Vegetation descriptions. Each contiguous Bare/Transitional polygon within a landscape block was then ranked according to size, using a boost score, as follows:

<5 acres	0
5-25 acres	1
>25 acres	4

Note: This ranking system was developed based on consideration of the value of barrens, scrub/shrub and transitional (i.e., successional clear cuts, etc) habitats to mammals and plant species. These biological considerations were then modified to reflect the range of contiguous Bare/Transitional polygon sizes throughout the ecoregion.

Weightings for these data sets are assigned as boost scores since both the original assignment of the land cover category and the biodiversity value of the category type are subject to some of the poorest levels of interpretation from the entire satellite imagery data set. Also – these land cover categories are subject to the most potential successional change over time, and their land cover category assignment from 1992-4 may no longer reflect the actual land cover type present on the ground today.

D – County Natural Areas Inventory & Pennsylvania Natural Heritage Program SUBGROUP

Please see attached methodology for rarity calculations. Data used is as of date of the most recent update of the CNAI publication within each county; with the exception of rare plants which were updated through March 2002 for each county in the Expanded Piedmont Ecoregion.

SUBGROUP COMPILATION & FINAL ECOLOGICAL RESOURCE RESULTS

Each layer was added with the others in its Subgroup. Final scores were then normalized back to a 0-10 (10%) quantile classification system. While reclassing the data back to a 10% quantile system has the benefit of allowing easy data compilation and comparison as part of a relative ranking system, it also has the disadvantage of changing the proportional weight of each Subgroup from its original value to a uniform 25% for each subgroup (since there are 4 subgroups). The Conservation Science Forum Expert Taxon Advisory Groups recommended that the Rarity subgroup should represent 20% of the final mapping score, while keeping the other layers and subgroup weightings at their original *relative* weighting values. In order to accomplish these goals, an adjustment factor was required when combining all 4 subgroups to create the Interim Conservation resource map. The adjustment factors used to accomplish this goal are shown in the attached spreadsheet.

The final ecological resource assessment map was then recalibrated once again to show results as 10% quantiles.

The attached spreadsheet summarizes the mathematical additions, weightings and adjustment factors used by layer and by subgroup composite to produce the final ecological value composite map. Note that these layers and their method of compilation is interim[2] and was proposed for use in this project by a steering committee of NLT staff experts at a meeting held in March 2003. This interim methodology was also reviewed and ratified by the Greenspace Alliance Board at a meeting held on May, 2003.

IMPORTANT NOTICES:

NLT has ***NOT*** consistently excluded conservation resources from areas that satellite land cover would otherwise determine to be developed, protected or undevelopable (e.g. large water bodies), on the understanding that these lands can be screened out of the GIS analysis at the end of the data compilation process.

DEVELOPED, PROTECED and WATER cover type updates can be extracted from updated NLCD Satellite data sets (year 2000 data is due for release imminently) or other recent GIS land use data layers (e.g. DVRPC's 2000 aerial photo interpretation of the 5-county Philadelphia region, etc), once available; and from new data sets currently under development by others (e.g. the state-wide NGO protected lands being developed by The Conservation Fund and PEC); or even manually on a quarter-quad by quarter-quad basis using the most recent B&W aerial photography available (currently 1999).

The following data layers are ***NOT*** currently included in this assessment:
No aquatic or terrestrial invertebrate data is included in this assessment. After many meetings with regional and State invertebrate experts over a 2-year period, NLT deemed to infeasible (not cost-effective) to try to develop any kind of invertebrate assessment since there are no known GIS data layers that would appropriately interpret invertebrate ecological values across the entire expanded Piedmont ecoregion.

NLT hopes to eventually develop the following data layers to supplement our SmartConservation mapping project as indicated below:
Data Set & Status as of 2/26/04:

UNDER DEVELOPMENT (anticipated completion date – Summer 2004)

[2] NLT is still developing the final ecological values mapping project for the Expanded Piedmont through the *SmartConservation*™ project, and expects to have a final, fully ratified product available mid-2004. The products provided in this project are interim products that were available for use as of the date of this project, as notes above.

Landscape Ecology	A composite of values from all the GIS layers noted above, plus landscape ecology principals to define the "best" value nodes & corridors to create an interconnected, viable, self supporting network of the most ecologically valuable conservation lands in the Expanded Piedmont ecoregion.
Ecological/Green Infrastructure/ Ecoregional Mapping	To create an interconnected, viable, self supporting network of the most ecologically valuable conservation lands in the Expanded Piedmont ecoregion.
TO BE DEVELOPED (No completion date anticipated at this time due to funding limitations)	
Additional "*Water Consumption"* Resources	†Bridges/Culverts/Gravel Roads by subwatershed Floodways/Dams/Sewer Treatment Plants/Point Sources by impact area Impervious cover/watershed landcover - 2 miles vs. all upstream Chpt93 water quality/wellhead protection/surfacewaterintakes/ DRASTIC/Trout Streams/CW-WW/EV-HQ, etc
Predictive Wetland Mapping	Subject to finding additional grant funding, this as of 12-31-03 is unavailable.
Predictive Plant Community Mapping	Subject to additional grant funding, this as of 12-31-03 is unavailable. To be based on regional interpretation of TNC EDU GIS abiotic analysis. To be used to address "representation" of conservation resources in the final Green Infrastructure mapping.
Predictive Aquatic Community Mapping	Subject to additional grant funding, this as of 12-31-03 is unavailable. To be based on regional interpretation of TNC EWU GIS abiotic analysis. To be used to address "representation" of conservation resources in the final Green Infrastructure mapping.

CONSERVATION RESOURCE GROUP	VALUE SYSTEM	% of Total with original values	% of subgroup	Adjustment Factor	% of Total after AF weights
Potential Vertebrate Habitat					
Mammals CV	10	6.10	23.26		5.19
Fish CV	10	6.10	23.26		5.19
Herps CV	10	6.10	23.26		5.19
Birds CV	10	6.10	23.26		5.19
IBAs	3	1.83	6.98		1.56
	43	26.22	100.00	0.223	22.34
			(25%)*		
Aquatic Resources					
NWI	10	6.10	12.82		5.19
Hydric	3	1.83	3.85		1.56
Floodplains	5	3.05	6.41		2.60
Riparian Buffers	10	6.10	12.82		5.19
Forested Water Quality	10	6.10	12.82		5.19
Headwaters Protection	10	6.10	12.82		5.19
Water Quality [303 (d)]	10	6.10	12.82		5.19
Impervious Cover	10	6.10	12.82		5.19
Impervious Cover Change 85-2000	10	6.10	12.82		5.19
	78	47.56	100.00	0.405	40.52
			(25%)*		
Terrestrial Resources					
Interior Forest Habitat	10	6.10	30.30		5.19
Natural Vegetation Habitat Blocks	10	6.10	30.30		5.19
Steep Slopes	4	2.44	12.12		2.08
Contiguous Grassland Habitat	5	3.05	15.15		2.60
Contiguous Scrub-Transitional Habitat	4	2.44	12.12		2.08
	33	20.12	100.00	0.171	17.14

			(25%)*		
CNAI (Rarity)					
	10	6.10	100.00		20
	10	6.10	100.00	0.200	20
			(25%)*		
	164	**100**		**1.000**	100

* shows % contribution of subgroup to overall score after 0-10 quantile recalibration by subgroup.

To correct this back to the original weightings, while accommodating the CNAI at 20% instead of 6.10%, the Adjustment Factor was used (as indicated above).

Attachment B

Note: The material in this attachment was developed separately from this project through activities funded by Natural Lands Trust, Pennsylvania Department of Conservation and Natural Resources, Pennsylvania Department of Environmental Protection, and the William Penn Foundation

DRAFT
SmartConservation™ Ecological Green Infrastructure (EGI)

Preliminary Assessment – as of January 2005

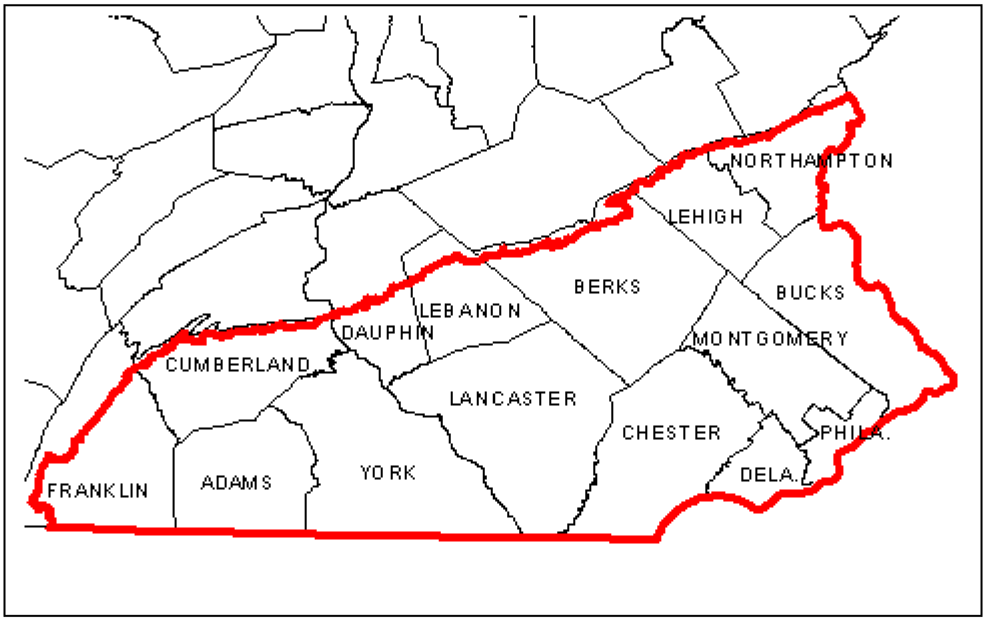
Introductory Note:

It is important to emphasis that several GIS data layers used in this analysis were developed based on the most recent satellite landcover data sets available for our use at the time of this project; 1992-1994. More updated landcover data was unavailable for use in this project as of October 2003, when many of the preliminary GIS maps on which the Ecological Green Infrastructure was generated were first developed.

Given the rate of development in SE Pennsylvania over the last decade, since this satellite landcover data was generated, it is clear that some of the ecological conservation values implied by this mapping project have probably already been lost. It is proposed that any future updates of this project include the most recent landcover data available. The impact of the age of the land cover layer can be somewhat mitigated by overlaying a more updated "Developed" lands data layer (e.g. the 2000 NLCD) at the end of the ecological assessment process. This updated development "mask" will screen out all sites in the region where development now displaces natural resources. Users can also verify new development by overlaying the most recent B&W aerial photography (currently from 1999) using the quarter-quad tiles now available throughout the Expanded Piedmont ecoregion.

In the meantime, values displayed in this analysis should be considered a functional over-estimate of the ecological conservation resources remaining in the region – which means the call to preserve the best of what remains is all the more critical.

Finally, it is also important to note that the ecological resource values contained in this mapping were generated for the entire Expanded Piedmont ecoregion, which equates to portions of 15-counties across south-east and south-central Pennsylvania (see map below). Any data clipped from this Expanded Piedmont data set should be used as-is. In other words, no reclassing or recalibration of the data should be undertaken to express the conservation values for the data ranges within just the geographic subset of the ecoregion in question. This is a deliberate policy since the Expert Taxa Advisory Groups help NLT developed ecological value systems that were appropriate to use throughout the Extended Piedmont region and most of the value-added data was developed on a 10-quantile basis (i.e. 10% of the value ranges of the entire expanded piedmont ecoregion were assigned to each of 10 classes). Any geographic subset of this data should therefore represent conservation resource values related directly to conditions throughout the entire Expanded Piedmont ecoregion, rather than just within the geographic subregion in question. In other words, if an area within a geographic subset of the ecoregion scores a 10 for a particular ecological component, that location will be part of the top 10% of locations throughout the Piedmont for that component.



<u>Expanded Piedmont Ecoregion</u>

This represents the area over which the ecological values for SmartConservation™ have been developed to date.

DATA LAYERS USED IN THE FINAL *SmartConservation* ECOLOGICAL VALUES MAPPING ASSESSMENT:
(as available through 10-27-03) INCLUDE:

Potential Vertebrate *(Animal)* Habitat SUBGROUP
Potential Mammals Conservation Value (CV)
Potential Fish CV
Potential Herps CV
Potential Birds CV
IBAs

B. Aquatic Habitat SUBGROUP
Water Quality (DEP's Unassessed Waters 303 [d] List)
National Wetland Inventory
Hydric Soils
Floodplains
Forested Water Quality
Riparian Buffer Quality
Headwaters Protection
Impervious Cover 2000
Impervious Cover Change 1985-2000

C. Terrestrial Habitat SUBGROUP
Steep Slopes
Interior Forest Habitat
Natural Vegetation Habitat Blocks
Contiguous Grassland Habitat
Contiguous Barren-Transitional (Scrub-Shrub) Habitat

D. Rarity SUBGROUP

For a detailed description of how these layers were developed, ranked and combined, see the accompanying white paper:

SmartConservation™ "GREENSWEEP"

INTERIM ECOLOGICAL RESOUCE MAPPING ASSESSMENT – as of June 2004

The individual and cumulative layers noted above, are also available from NLT (separately) along with a summary 'plain English" summary.

The spreadsheet which explains how the 24-data layers (above) are combined and weighed in the *SmartConservation™* Greensweep mapping follows:

CONSERVATION RESOURCE GROUP	VALUE SYSTEM	% of Total with original values	% of subgroup	Adjustment Factor	% of Total after AF weights
Potential Vertebrate Habitat					
Mammals CV	10	6.10	23.26		5.19
Fish CV	10	6.10	23.26		5.19
Herps CV	10	6.10	23.26		5.19
Birds CV	10	6.10	23.26		5.19
IBAs	3	1.83	6.98		1.56
	43	26.22	100.00 (25%)*	0.223	22.34
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	78	47.56	100.00 (25%)*	0.405	40.52
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Interior Forest Habitat	10	6.10	30.30		5.19
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Contiguous Scrub-Transitional Habitat	4	2.44	12.12		2.08
	33	20.12	100.00 (25%)*	0.171	17.14
CNAI (Rarity)	10	6.10	100.00		20
	10	6.10	100.00 (25%)*	0.200	20
	164	**100**		**1.000**	100

* shows % contribution of subgroup to overall score after 0-10 quantile recalibration by subgroup.
To correct this back to the original weightings, while accommodating the CNAI at 20% instead of 6.10%, the Adjustment Factor was used (as indicated above).

Philosophical statement and goals:

Note that this is an overview of the process and values used to generate a PRELIMINARY ***ecologically-based*** green infrastructure network for the Expanded Piedmont Ecoregion of PA. No consideration was taken of agricultural, recreational, cultural, scenic or historical resources during this analysis. It is our contention that these other conservation resources, while critical in their own rights, have been considered by planners for many years, while a basic understanding and interpretation of ecological values has been too difficult to address and interpret for end-users to adopt. We see that this analysis can help 'level the playing field.' so to speak, and ensure that ecological resources can receive equal consideration when local implementers (NGOs, municipalities and county planning commissions) make choices about what to recommend and incorporate into their open space and comprehensive plan.

Further, it is our contention that the other conservation resources can be preserved in the landscape as ah-hoc, stand alone components, essentially viable in their own right without reference to other conservation components. However, the long-term viability of ecological resources is COMPLETLY dependent on effective population-scaled connectivity across the landscape. Without development of such networked ecological green infrastructure systems, the entire ecological basis of the ecoregion could be irrevocably compromised. While it would be 'nice' for the other resource components to be embedded in a supporting green infrastructure system, it is ***essential*** that ecological resources be protected in this manner.

Development of Merged, Ranked Ecoregional Nodes

Nodes were compiled from 3 primary input:

Rarity polygons (updated through March 2002, and made available by PA DCNR Pennsylvania Natural Heritage Partnership [PNHP].

Protected Lands (see separate write up on data inputs and processing, attached)

Top 20% of Conservation Resources (i.e. the cumulative GIS layer derived from adding the prior 20-value-interpreted GIS layers of data – as documented in the Greensweep discussion noted above).

Rarity was already ranked on the standard *SmartConservation* 0-10 scoring system according to previously developed ranking methods (see separate document to detail ranking procedure).

The top 20% was already ranked as either a 9 or a 10 score since it came into the node merging process pre-ranked through the "Greensweep" process.

Protected lands were ranked according to a process reviewed and approved by our Expert Advisory Committee(s). Ranking was based on assessment of "protectedness" which included consideration of what level of protection and who the holder of the protection was – and how robust that protection was assumed to be. It also considered whether the protected lands had an ecologically viable, or at least valid, land management plan to ensure long-term ecological health (to the extent known, or assumed). Details of the ranking process and results are available in a separate document, which is available from NLT on request).

The nodes were then merged in GIS, using spatial analyst. Where any of the three inputs overlapped, the highest "score" was assigned. Also, were polygon boundaries didn't match – the largest area of any one of the polygons was assigned. In other words – were erred on the side of generosity and assigned the highest rank and the largest geospatial extent during the merge.

After the merge, a shrink-swell GIS procedure was applied. This was to 'round-off" the sharp edges and minor fragmentations of the nodes so that regionally insignificant rough edges and strips of nodes were removed from consideration.

At the end of the process, one GIS layer was obtained that represented the "best" lands for conservation resources – which should cover at least 20% of the land area of the Expanded Piedmont Ecoregion. Each 30x30m cell, or pixel, in the resulting "node" layer has a 0-10 score representing node "value".

Corridors Development

Greenspace Network Hierarchy:

Corridors were developed to connect each node in the region with every other node, on the basis of a predetermined hierarchy as follows.

For nodes >= 1,000 acres, each node must be connected by a corridor to every other node in a 20-mile zone.

For nodes >= 500 acres, each node must be connected by a corridor to every other node in a 8-mile zone.

For nodes >= 250 acres, each node must be connected by a corridor to every other node in a 4-mile zone.

Note that the hierarchy is cumulative and nested. The hierarchy was assigned 'region', 'subregional' and 'local' labels, respectively.

Next Steps:

Once the hierarchy had been reviewed and approved by the Expert Advisory Committee, the following process was used to generate the corridors themselves:

A 'cost-surface' was developed in GIS, consisting primarily of a compilation of "barriers" to movement of a generic, medium-sized mammal (e.g. a raccoon or fox?).

The cost surface was made up by considering both type and class of barrier, and also barrier density:

Type and Class of Barriers:

GIS layers were compiled from the following layers:
Roads
Networked, ordered streams

Railway ROWs

Each element class within each GIS data layer was assigned a “barrierness” score. For example – the PA Turnpike was assigned a 100 out of 100 score, while dirt roads were assigned a 5 out of 100 score. The differentiation of data in the railways ROW layer was minimal, so the NE Corridor (Amtrak, Septa, Conrail, etc) was assigned a 90, while all others were assigned a 35 due to lack of being able to effectively distinguish other categories)

The networked, ordered stream layer represented a special case where some hard decisions needed to be made. Streams and larger rivers can both facilitate movement in the landscape – which has been the traditional, rather simplistic assumption used when compiling greenspace networks. However, especially for larger order rivers (4, 5, 6, 7 and above), rivers can pose significant “barriers” to animal movement across the landscape. It an animal is running parallel with a rover corridor, it is likely to act as a facilitator, but if an animal runs perpendicular to a stream or river (i.e. wants to actually cross it), then the size, depth, speed of water and season of the year can affect how much of a barrier the river could be. Since we have no attributes in the networked stream GIS layer which we could use to quantify “barrierness” other than it’s order – that was used to assign barrierness score. It was decided that networked stream could be added to address their “facilitation” function in a greenspace system later, after the cost-surface and connection processing was complete, but that it would be more useful to develop the connectivity model using the stream and river barrier information as a place to start.

50% of the barrier score was compiled from compiling and merging the ranked spatial locations of the three barrier classes noted above. As previously stated – wherever the rank or geographic extent of the barriers varied, the highest ‘rank’ and greatest extent was selected in the merge.

<u>Barrier Density:</u>

It was acknowledged that the “density” of various barrier types in the landscape can also be a significant deterrent to animal movement in the landscape. Where one or more ‘barriers’ – e.g. a stream, road and railway – all come together to share a narrow path through a particular landscape area – say in a narrow valley between some hills were there is a stream corridor (as often happens with transportation networks), then the “barrierness” to movement should reflect the increased friction and threat to movement. Where cells returned cumulative “barriers”, barrier density scores increased accordingly.

50% of the cost surface was obtained by generating a density barrier score for each cell in the ecoregion grid.

<u>Barrier Density Plus Type/Class/Modified Surface & Least Cost Path Analysis:</u>

The two separate barrier layers were then added together and a cumulative average obtained.

Once the combined “barrierness” scores were obtained, the resulting “cost surface” was then modified by tow additional components:

The ‘gravitational’ pull of “nodes” (assumed to be important since corridors should be looking to connect with nodes to improve connectivity throughout the region); and
The “original” value of conservation resources for each cell. For example – you could be a fox on Game Commission property trying to find a way to cross the PA Turnpike; or a fox in an urban active recreation

park trying to cross the PA Turnpike. One habitat provides a more “supportive” habitat than the other while you figure the road-crossing conundrum out. So, the conservation value of the supporting habitat you are in should be acknowledged as a minor component in the connectivity model. As such, the 0-100 “barrierness” cost surface is mitigated by conservation value (0-10 score) and also by “gravitation pill” of nodes (0-10) basis. The equation that reflect this might look like:

Modified cost surface (difficult of movement) =
(50% barrier type/class + 50% barrier density [0-100]) minus
((node gravitational pull [0-10])+(conservation value [0-10]))

The resultant modified cost surface is a grid of 30x30m cells with each cell recording a score between 0-100.

A final step is a ‘smoothing’ process, which levels the barrier score in the landscape across 1000-ft swaths. This is undertaken since the corridors we are recommending are generically 1000-ft wide (now a generic national benchmark, as evidenced by it’s use by MD DNR in their Green Print mapping). Normally, the next step in the analysis would be to run a ‘least cost path’ analysis on the cost surface to connect all the nodes. But a least cost path selects the ‘least cost path’ on the basis of one cell in a grid at a time. It can’t select the least cost path for a broader width of cells (it would need to use a swath of 3 cells - to represent the average barrierness condition for a corridor of ~1,000-feet width). Our contention is that vast misrepresentations could occur by choosing a corridor’s best path (lowest barrierness) on the basis of the value of just one cell width (90m=~300-feet), and then assuming it can be ‘buffered’ by a cell on either side. Those additional cells could have extremely high barrier scores. We therefore concluded that corridors needed to be developed on the basis of the ‘average’ condition across a 3-cell width of the cost surface; the only way by which to address that requirement at the current time (given ESRI software limitations) is to ‘smooth’ (or ‘average, so to speak) the entire data set across 3 cells (100-feet) prior to running the ‘least cost path’ analysis.

Connecting the Nodes:

Once the Modified cost surface was finalized (smoothing was completed), the GIS system was then set up to run according to the hierarchy rules established earlier:

Every node in the region of qualifying size was assigned to connect to every other node of qualifying size, within the requisite connecting zone by determining the ‘least cost path’ between the two nodes. This action was iteratively repeated at all hierarchy levels until all node connections were completed. After literally weeks of computer time, the resulting hundreds of GIS least cost path layers were recompiled into six distinct layers as follows:

Nodes >=1000 acres
Nodes >= 500 acres
Nodes >=250 acres
Corridors connection 1000-acre nodes up to 20 miles apart
Corridors connection 500-acre nodes up to 8 miles apart
Corridors connection 250-acre nodes up to 4 miles apart

Caveats:

Clearly – the results from the computer analysis and modeling are preliminary and need refinement. Specifically, the following items need to be considered and addressed where possible:

Restoration Corridors
Where gaps in the 'dumb' recommendation from the computer analysis are too big (as defined by Expert Advisory Committee members with conservation biology and/or landscape ecology backgrounds, ideally), then new 'restoration' corridors need to be recommended and located. Restoration corridors could then be protected, set aside for restoration and managed back to a higher conservation barrier level and/or a lower barrier level, over time, as resources allow).

Aquatic Corridors
As noted earlier – aquatic corridors were treated as 'barriers' in the initial ecological green infrastructure modeling. Now that preliminary recommendation for nodes and corridors have been made on this basis, we would like to add back in the networked, ordered streams data layers to address the 'facilitation role that aquatic corridors undoubtedly also play. However, this should be accompanied by a ranking and prioritization system, ideally, that has yet to be designed, reviewed and approved by an Expert Advisory Committee.

3. Substitution Recommendations - Potential Barrier Crossings
Where it is clear that an overly long, circuitous route has been selected by the computer to connect two nodes due to a large, but surmountable, barrier, a rationalization and feasibility analysis needs to ensue to evaluate whether it would be cheaper and easier to circumvent the barrier than to attempt to create and protect the corridor. For example – it may actually end up more cost-effective to build wildlife road bridge crossings than to protect miles of wildlife corridor.

4. 'Edge Effects' of the analysis need to be acknowledged. As the 'edges' of the ecoregion are approached, the connectivity modeling gets increasingly corrupted as data in the 20-, 8- and 4-miles connection zones becomes less available. The ideal solution to this issue would be to re-run the analysis using data that extended beyond the project's ecoregional boundary by a minimum of 20-miles. However, these data sets have not been developed since funding to compile and recalibrate them has been unavailable. Until such funding is available, we can only acknowledge and live with the 'edge' effects that are clearly embedded in the data sets.

5. Refining Nodes & Corridor Prioritizations:
It is an unfortunate fact that even though the preliminary green infrastructure network represents probably only 2-30% of the land surface of the ecoregion, this will realistically be still too much to preserve given current resource levels and funding for permanent land protection. It therefore becomes essential to develop a robust, scientifically-defensible prioritization system that can be applied to the lands within the EGI network itself.

Several fairly complex prioritization systems can be developed to prioritize the value of all the components of the ecological green infrastructure system, once the upgrades and refinements (1-3 , or 1-4, as noted above) have been completed. Such systems could include some or all of the concepts briefly listed below:

e.g.	Least critical	nodes
		broadest cost corridor
		narrowest cost corridors
	Most critical	corridors w/1000ft buffer only

Corridors Rank Prioritization Options:

- By number of times corridor selected between different nodes
- By corridor value
- By the value of the nodes at either end of the corridor
- By corridor length

NLT has applied to PA DCNR (as of October 2004) for funding to address these upgrades and refinements, but has not yet heard whether we will be approved to complete this work.

Ranking and Prioritizing Preliminary Ecological Green Infrastructure elements:

In the meantime, NLT has suggested an interim, working, very simplistic ranking system which can begin the process of testing, evaluation and gathering essential ranking feedback from users as NLT attempts to implement adoption of the EGI throughout the region.

The following interim, simplistic ranking system is being employed until further notice:

	Corridors	Cost Corridors	Nodes
0			
1			250a
2		250a	500a
3		500a	1000a
4	250a		
5		1000a	
6	500a		
7			
8			
9			
10	1000a		

The definition of corridors and nodes are now self-evident in the above table; however, cost corridors have not been addressed. A brief word needs to be added to describe these components:

Cost corridors are a facilitation/implementation component in the EGI network that will hopefully allow the corridor recommendations to be implemented on the ground in the real word in a more realistic way. As every planner knows, it is extremely difficult to actually build corridors (whether for anthropocentric use – or ecological) through the landscape; sometimes it is even difficult to recommend them. To address this issue, cost corridors were developed as part of the EGI network so that users can see where the landscape is flexible, more forgiving and more adaptive to rerouting changes; and where there are no real alternatives to the route selected. At these narrow pinch-points, the modified barrier cost-surface tell us that there is no, or limited flexibility to reroute a recommended corridor without dramatically loosing its value. Where the cost corridor is broad, barrier costs are generally lower and a corridor can be rerouted with a certain level of confidence that, although not the best route, the corridor selected will still be of relatively high value.