A Land Conservation Extension of the StormWISE Model

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List of Acronyms and Abbreviations

BMP = Best Management Practice

CRCWA = Chester-Ridley-Crum Watersheds Association

CWA = Clean Water Act

GIS = Geographic Information Systems

HUC = Hydrologic Unit Codes (Crum Creek and Darby Creek are in HUC 02040202)

LCCW = Little Crum Creek Watershed

MRLC = Multi-Resolution Land Characteristic Consortium

NLCD 2001 = National Land-Cover Database 2001

NPDES = National Pollutant Discharge Elimination System

NPS = Nonpoint Source

PADEP = Pennsylvania Department of Environmental Protection

StormWISE = Storm Water Investment Strategy Evaluator

TMDL = Total Maximum Daily Load

TN = Total Nitrogen

TP = Total Phosphorus

TSS = Total Suspended Solids

Abstract

The purpose of this study is to integrate the use of traditional conservation easements into the Storm Water Investment Strategy Evaluator (StormWISE) model. They are considered in addition to structural Best Management Practices (BMPs) to reduce the pollutant loading in Little Crum Creek Watershed. Geographic Information Systems (GIS) was used to obtain the necessary information. Excel Solver was used to solve the StormWISE formulation to determine which practices should be used to decrease the level of total suspended solids. Traditional conservation easements were found to be a cost-effective tool for preventing water quality decline if they are donated but not cost-effective if they must be purchased.

Introduction

The StormWISE model has been used to assess how future investments in the water quality of Little Crum Creek Watershed should be made. StormWISE is based on the current land uses in a watershed. Only 12 miles away from Philadelphia, urbanization has been ongoing in LCCW. Increased pollutant loads caused by this urbanization can nullify pollutant load reductions gained by the installation of structural BMPs, which are only implemented after the water body has been polluted. In this study, the use of traditional easements is considered as a possible way of preventing some of the negative impact that further urbanization would have on this watershed. This makes some future point when LCCW is more urbanized the baseline, with BMPs and easements being possible ways of reducing pollutant loading in the watershed.

The previous work that considered easements in LCCW restricted their use to the riparian zone, which is limited by the small property size and current zoning (1). Traditional conservation easements may be able to utilize the larger parcels of land and therefore be more attractive to both conservancies and to landowners who would receive a larger tax deduction. Although the conservation of land in the riparian zone would be particularly beneficial to the quality of the water in LCCW, land in other areas of the watershed can also seriously impact the water quality, in negative or positive ways.

Background

History and Standards

The goal of the Clean Water act (CWA) is for all of the surface waters in the United States to be both “fishable” and “swimmable.” In other words, people should be able to swim or fish in any body of surface water without becoming ill and with fish still living in the waters. The Pennsylvania Department of Environmental Protection (PADEP) is responsible for maintaining the quality of surface waters at the level required by the Clean Water Act (CWA). Section 303(d) of the CWA requires states to make a list of water bodies that do not meet each standard set by the state. The PADEP and associated agencies must determine the Total Maximum Daily Load (TMDL) that can enter a water body without causing that water body to exceed the standards. After that, the Best Management Practices (BMPs) for improving the quality of the water must be determined (2) (3).

Little Crum Creek Watershed is on the 303(d) List for siltation, but it may be several years before the state requires a TMDL of the watershed. Because the sediment-heavy water pools in Ridley Park Lake, there are a number of concerned citizens in the Chester-Ridley-Crum Watersheds Association (CRCWA) who want to begin improving conditions before they are required to. This may also benefit them in their relationship with the PADEP when it is time to assess the TMDL. In the past few years, people in the CRCWA have worked in conjunction with Swarthmore College to construct a wetland in Ridley Township, restore a wetland in Swarthmore Borough and label many of the storm sewer inlets (4). The StormWISE model can be used to help the CRCWA assess how they should utilize the available funds to achieve the largest possible deduction of pollutant loading.

BMPs are activities or structures used to decrease the pollutant load on a water body. Some structural BMPs function by storing or rerouting runoff to decrease the peak volume and rate at which the water flows into a stream or lake. The flow rate is decreased because the amount of pollutant entering a water body increases with the velocity of the runoff. The primary purpose of other BMPs is to filter the water, remove the pollutant, or simply intercept the pollutant so that it cannot continue into the surface water. Structural BMPs include infiltration basins or trenches, retention basins, grass swales, constructed filters, porous pavement, vegetated roofs, rain barrels, constructed wetlands, water quality filters and more (5). Criteria for installing these types of BMPs include their cost, the pollutant reduction resulting from them, and where they can be installed.

Water Quality Parameters

The StormWISE model considers four water quality parameters: runoff volume, total suspended solids (TSS), total nitrogen (TN) and total phosphorus (TP). Large runoff volumes are a problem because the more of water running off during a storm event, the faster it runs over the land and the more pollutants it picks up. Furthermore, high volumes of water in a stream contribute to increased erosion of the stream bed and cause the water to pick up more sediment. Total suspended solids are problematic because water with high amounts of TSS has higher amount of bacteria and is more difficult to clean. It has more bacteria because cloudiness in the water prevents ultraviolet radiation reaching any significant depth in the water and killing the bacteria. This makes the water less 'swimmable' because the harmful bacteria in the water can cause diarrhea and other sickness. High levels of TSS can also prevent light from reaching bottom-dwelling plants, which can reduce the oxygen levels in the water. It also has the potential to increase the temperature of the water, further decreasing the oxygen levels. Thus, high levels of TSS sometimes results in fish kills, impeding the 'fishable' goal.

Nitrogen and phosphorus can be problematic because they are plant fertilizers. This can instigate the growth of a great deal of algae in the water. The tremendous algae blooms, such as those in the Gulf of Mexico, cause the water environment to be very unstable. During the day they produce oxygen and during the night they consume it. Thus, nighttime dissolved oxygen concentrations may drop so low that the aquatic populations are damaged, potentially resulting in fish kills. Therefore, high nutrient loading impedes the 'fishable' goal of the CWA.

Watershed Description

Little Crum Creek Watershed (Assessment ID- 10895, in HUC 2040202) is a 2,048 acre (3.2 mi^2) watershed located in Delaware County in Southeastern Pennsylvania. It drains much of Ridley Park, Ridley Township, Swarthmore Borough and parts of other municipalities (Figure 1). LCCW is designated as usable for aquatic life. The ultimate goal is to make it also suitable for contact recreation, such as swimming. It is on the 303(d) list for siltation. The pollutant sources listed are urban runoff, storm sewers, and habitat modification (6). Related to total suspended solids (TSS), bacteria levels are also higher than they should be after storm events.

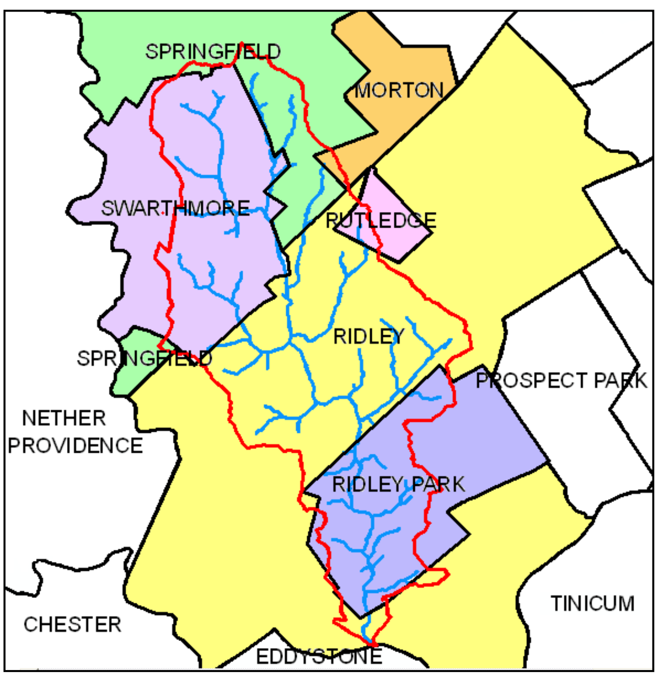


Figure 1. The extent of Little Crum Creek Watershed in shown in red. The streams in the watershed are shown in blue. Municipalities that overlap with the watershed are shown in color.

The types of land cover found in LCCW were grouped into six categories by Arthur McGarity: Open Water, Forest/Wetland, Developed Wooded/Fields, and Developed Low Intensity, Medium Intensity and High Intensity (Table 1) (1). All of these categories except for Forest/Wetland and Developed Wooded/Fields were used by the National Land Cover Database (NLCD) 2001 in the Multi-Resolution Land Characteristics Consortium (MRLC). NLCD 2001 processed satellite imagery to make land cover maps for the entire United States between 2001 and 2006 (7).

Table 1. Descriptions of land use categories made by the MLRC (http://www.mrlc.gov/nlcd_definitions.php) and consolidated by A. McGarity (1).

Land Cover Category	Description
Open Water	All areas of open water, generally with less than 25% cover of vegetation or soil.*
Forest/Wetland	All areas where total vegetation coverage is greater than 20 percent. This includes tidal wetlands, non-tidal wetlands, areas dominated by shrubs and areas dominated by any type of tree.#
Developed Wooded/Fields	Includes areas with a mixture of some constructed materials, but mostly vegetation. Impervious surfaces account for less than 20 percent of total cover.#
Developed Low Intensity	Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20-49 percent of total cover. These areas most commonly include single-family housing units.*
Developed Medium Intensity	Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50-79 percent of the total cover. These areas most commonly include single-family housing units.*
Developed High Intensity	Includes highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80 to100 percent of the total cover.*

*	These are the verbatim definitions given by the NLCD 2001.
#	These are a combination of several NLCD 2001 categories.

A. McGarity manually modified the NLCD 2001 map of LCCW to account for large structures that were built after those maps were made. Based on these modified maps, Developed Low Intensity (34.1%) and Developed Wooded/Fields (31.4%) currently occupy most of the area of the watershed. Forest/Wetland is 14.5%, Developed Medium Intensity is 13.5%, Developed High Intensity is 6.5% and Open Water is only 0.05%. Only the lake in East Lake Park is recognized as open water, although there are streams throughout the watershed. The distribution of these land covers are shown in Figure 2.

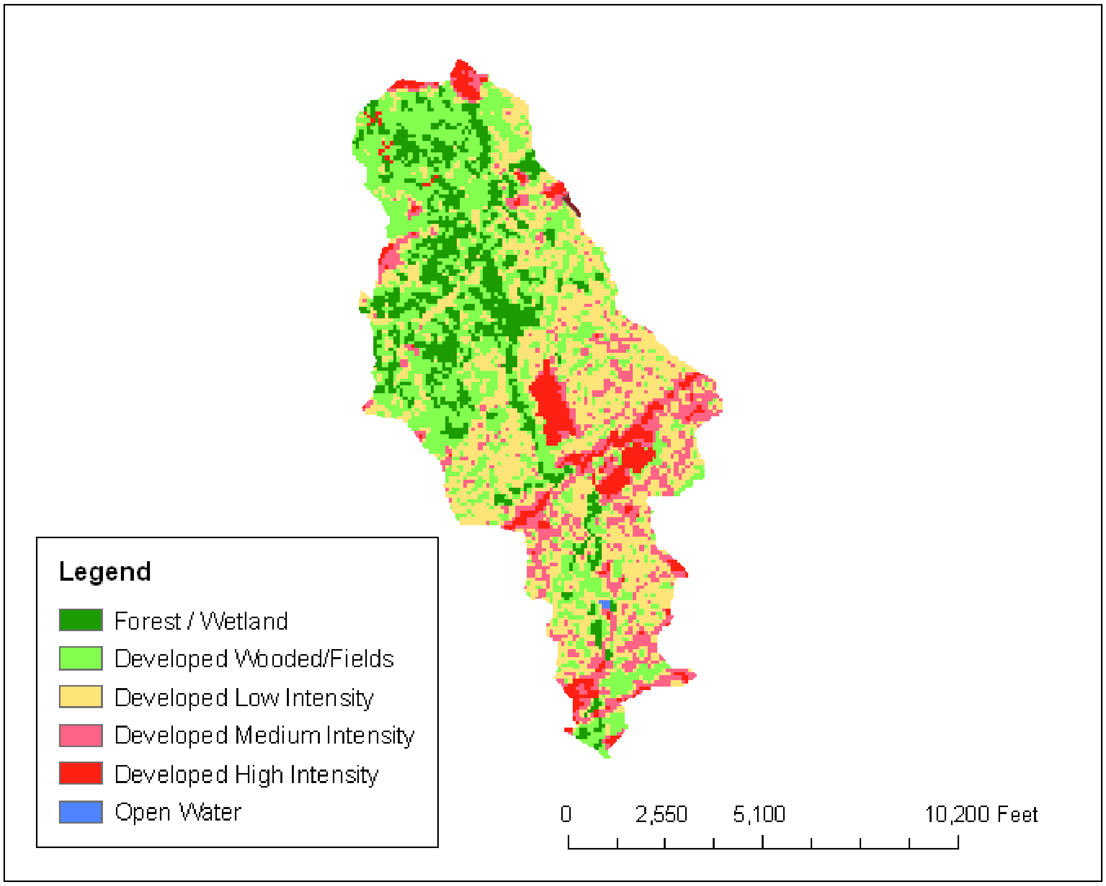


Figure 2. Land use cover in LCCW. Derived from satelite imagery by the MRLC and put into six categories by A. E. McGarity (1).

The majority of the land in LCCW is owned by individuals. The median parcel size is 0.1629 acres. Many of the parcels that are more than 1 acre are owned by institutions; some are owned by businesses.

Conservation Easements

Conservation easements are agreements made between a landowner and a government or nonprofit organization, known as an easement holder, to prevent particular uses of the owner's land. The biggest difference between this and selling the land to the easement holder is that when conservation easements are donated or sold, the landowner still owns the land. The easement holder is then responsible for enforcing the terms of the easement. It is applicable to all future owners of that land. Conservation easements typically protect forests, wetlands or other areas that are thought to have high conservation values. Landowners who donate conservation easements receive a federal tax deduction. The tax deduction is dependent on the value of the land that the easement regards. They may also be persuaded to donate easements of their property with local tax deductions (8).

Zoning

Zoning laws designate how property in specific locations can be used. Municipalities typically make zoning laws and regulations in order to ensure that new developments will be in line with what is already present. Zoning categories usually include the following: residential, commercial, industrial, recreational and agricultural. There are also subcategories so that the maximum use of the land in different areas can be specified. There are procedures for a developer or land-owner to be granted a *variance*, permission to build as an exception to the rules. These are only supposed to be granted in special circumstances (9). The procedure for applying for variances is different between different municipalities. The variance procedures in LCCW all include a review of the application by a zoning board or committee.

Previous Work

StormWISE 1.0 is a computer-based optimization model that has been verified by water quality monitoring. Data is entered into GIS and into a pollutant loading model via VBA user interfaces. The pollutant loading model requires cost data regarding the specific site in order to predict the marginal costs for each type of land use (10). GIS sends the information on the amount of land in different categories to the pollutant loading model, which then interacts with the data file before entering the AMPL MOD file. This file outputs where and which BMPs should be placed in the watershed for the largest deduction in nutrient loading (11).

Arthur McGarity of Swarthmore College worked with the CRCWA and the Keystone Conservation Trust to assess the possibility of including riparian zone practices, such as riparian easements, in conservation investment considerations. Riparian easements are used specifically to conserve the land that is directly adjacent to a water body. McGarity et al looked into the potential for the StormWISE model to also include ecological stability as an environmental benefit. They examined the SmartConservation ranking system for systematically stating the ecological value of sites on the basis of soils, wildlife, water quality and other descriptors. They also utilized the Ecological Green Infrastructure method of finding which connections would be the most valuable ecologically. They prioritized individual parcels on the basis of these two measures (1).

The researchers found that LCCW is not particularly well suited to riparian easements because the area is already largely urban with small lot sizes, and that existing zoning may prevent the riparian easements. They suggest that land preservation may be a cost-effective way of meeting water quality goals even when the easements must be purchased. They indicate that in LCCW, traditional conservation easements would most likely be more valuable to conservancies (1). The study discussed in this report builds upon what McGarity et al implemented in Microsoft Excel. They modified the RunQual model slightly in order to make it more suitable for what is known about LCCW.

Theory

The RunQual Model

The RunQual Model simulates daily pollutant loads and runoff over ten years based on given precipitation data. The model is a part of AVGWLF that is for urban areas. The volume of runoff is determined from the Soil Conservation Service (SCS) Curve Number method. The pollutant load is determined using build-up/wash-off functions, where the rate of wash off is dependent on precipitation data (1). It is much less accurate for watersheds as small as LCCW, but was used because it is the best available. It was integrated into Excel StormWISE, which was used in this study, by A. McGarity. It outputs the land areas, runoff and pollutant load for each landuse in each drainage area.

The StormWISE Model

The Storm Water Investment Strategy Evaluator (StormWISE) Model seeks to determine the minimum cost for which user-defined water quality benefits can be obtained in a watershed. It is a computer-based optimization model that has been verified by water quality monitoring in Delaware County, PA. It is intended as a management tool that can be used to decide which

BMPs should be used first to obtain some required level of environmental benefit. Data is found through GIS and entered into the model in Excel. The model requires data regarding the specific site in order to predict the marginal costs and treatable for each type of land use. Pollutant loading and washoff data is found using the RunQual Model (10). The StormWISE Model indicates where and which structural BMPs should be placed in the watershed for the largest deduction in nutrient loading. The location is not specific; the model indicates how much money should be spent in each landuse and each drainage zone (11). Non-structural BMPs are not considered in this model because of the difficulty in determining how effective they are .

The model formulation is shown below. The objective function seeks to minimize the total cost (z), which is the sum of the optimal spending levels (x_{ijk}) on BMP ‘k’ on landuse ‘j’ in drainage ‘i’. The first constraint states the requested environmental benefits ‘t’ must at least meet the requested reductions (y_t^{min}) in volume, TSS, TN and TP. The benefit slopes are denoted by S_{ijkt}, in m^3/\$ for runoff volume and in kg/\$ for the other three water quality parameters. The third constraint requires the optimum spending level to be less than the upper limit on spending U_{ijk} (12).

$$Min\, z = \sum_i \sum_j \sum_k x_{ijk}$$

$$\sum_i \sum_j \sum_k S_{ijkt} x_{ijk} \geq y_t^{\min} \qquad for\, all\, t$$

$$0 \leq x_{ijk} \leq U_{ijk} \qquad for\, all\, i, j, k$$

The benefit slope is the increase in specific environmental benefit resulting from money spent in landuse ‘j’ in drainage ‘i.’ It is dependent upon the efficiency of the BMP in each area (η_{ijkt}), the export coefficient for each pollutant in each area e_{ijt} (m^3/ha or kg/ha) and the marginal cost slope (C_{ijk}). The marginal cost slope data was obtained from site-specific cost studies of BMPs or local estimates (12).

$$S_{ijkt} = \frac{\eta_{ijkt}\, e_{ijk}}{C_{ijk}}$$

The upper limit on spending results from the amount of land that can be treated with a single BMP and marginal cost for each BMP. It is dependent on the marginal cost slope, the treatable fraction (f_{ijk}) and the total area of landuse ‘j’ in drainage ‘i’ (A_{ij}^{Tot}). The treatable fraction is the estimated fraction of the total area in a given landuse and drainage area that can be treated by BMP k. For the purposes of this model, the sum of the treatable fractions over all of the BMPs for each landuse and drainage area is required to be less than or equal to one (12). There may be cases when multiple BMPs are used in the same location, which would cause the sum of treatable fractions to exceed one, but this is rare.

$$U_{ijk} = C_{ijk} \times f_{ijk} \times A_{ij}^{total}$$

The optimization model can be represented as a matrix of tradeoff curves. For a single drainage zone and a single landuse, the tradeoff curve is linear for each BMP (Figure 3). The slope of for each BMP decreases for increased costs because of diminishing returns. As indicated in the formulation above, StormWISE takes the landuse and drainage zone into consideration (Figure 4). As shown, a greater number of BMPs are able to act on the more developed land uses. The landuse Forest/Wetland cannot usually be improved upon for water quality. As indicated in the constraints above, the objective function is constrained by having to meet the requirements for each BMP, as well (Figure 5).

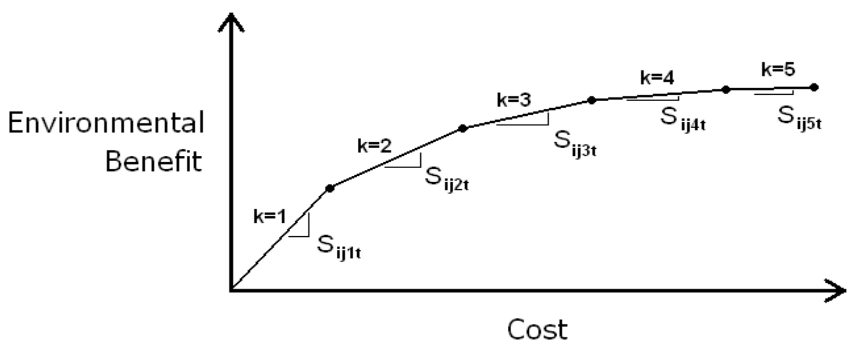


Figure 3. The piecewise linear tradeoff curve for one drainage zone, one landuse and five BMPs (k).

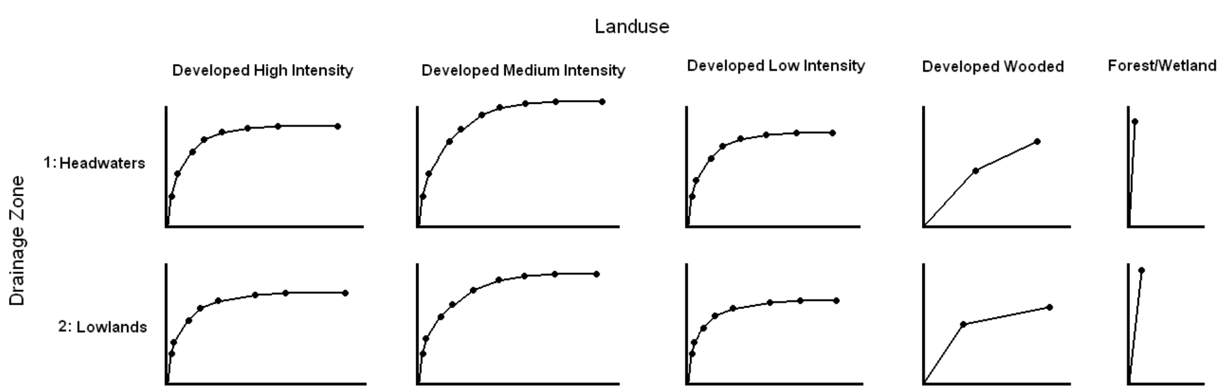


Figure 4. Tradeoff curves by drainage zone and landuse.

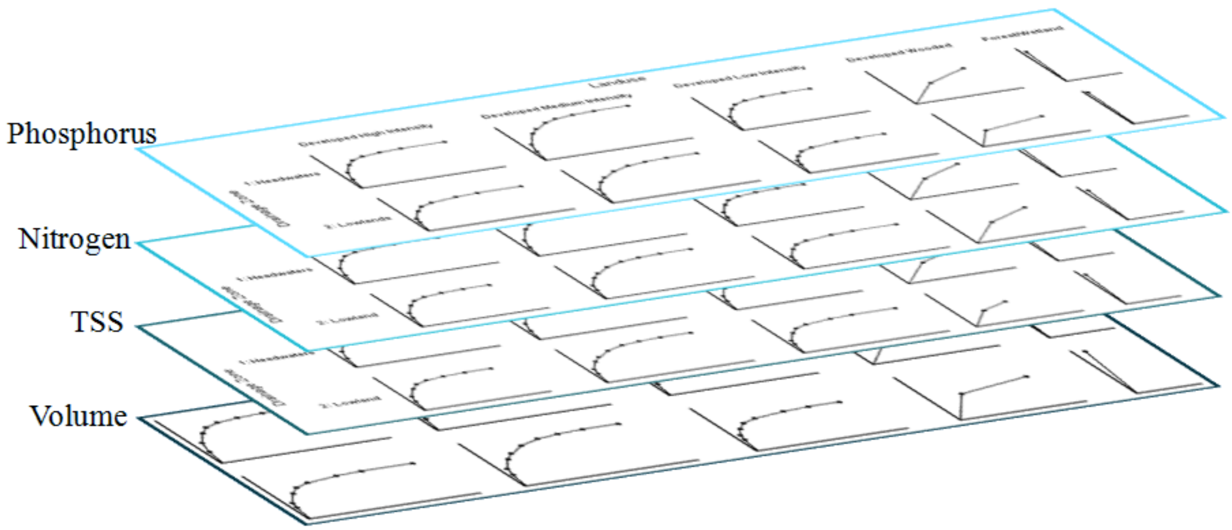


Figure 5. The information in StormWISE by landuse, drainage zone and water quality parameter.

For the StormWISE assessments in LCCW, the watershed was divided into two drainage zones: headwaters and lowlands. This was done based on Strahler stream order. The catchments that drain into the 1st, 2nd or 3rd order streams were joined and dubbed Headwaters. The catchments that drain into the 4th and 5th order streams were joined and called Lowlands.

NLCD 2001

The land use GIS layer and data is based on the 2001 U.S. National Land-Cover Database (NLCD 2001), part of the Multi-Resolution Land Characteristic Consortium (MRLC). The MRLC 2001 processed satellite images from Landsat 7 ETM+ and Landsat 5 TM that were taken during early, peak and late vegetation cycles. This was used to indicate vegetation phenology. In this type of land cover processing, error may arise from inconsistent correction of geometry, inconsistent or erroneous normalization of atmospheric effects, how illumination geometry was adjusted for and instrument errors. The second National Elevation Dataset was used to correct for terrain. The MRLC 2001 did not do topographic and atmospheric normalization (13).

"Urban masking" was done using population density data, buffered roads and NOAA City Lights (13). The spatial distribution of impervious surfaces was considered a continuous variable from 1 to 100 percent. The MRLC 2001 use four study sites to assess different kinds of land cover: Virginia (deciduous forest and agriculture), Nebraska and South Dakota (crop/prairie/pasture), Oregon (coastal forests, agriculture, shrublands) and Utah (shrubs/forests, irrigated agriculture) (13).

Decision tree classification was used to synthesize the tremendous amount of data into 29 land cover classes that could be described by mutually exclusive rules. MRLC 2001 researchers supervised the decision tree classifications. They initially found that independent data assessment and cross-validation estimates and cross-validation estimates resulted in similar accuracies. They did cross-validation analysis on three mapping zones. One of these, Zone 60, coincidentally includes LCCW (Figure 6). MRLC 2001 found that Zone 60 has the highest overall accuracy of the three zones tested (77.2%). They report a standard error of 1.2%.

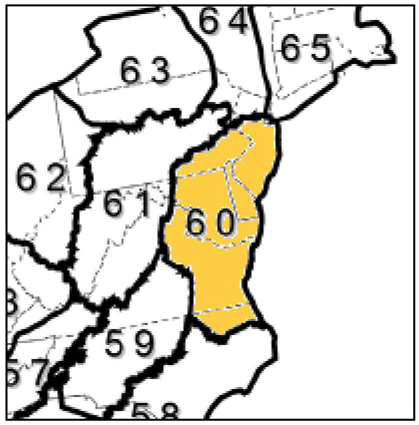


Figure 6. Mapping zones shown over state boundaries for the North East United States. Zone 60 (highlighted) is one of the three for which cross-validation analysis was done in the NLCD 2001 study (13).

Land Use Projection

The land cover map produced in NLCD 2001 and modified by A. McGarity was used as the current landuse map. The future landuses were projected based on zoning laws in LCCW and based on the current land uses. If Figure 7 (a) is the current land use, it is projected to become Figure 7 (b) if no conservation easements are used. As shown, this would result in all of the green spaces disappearing except for those that are explicitly set aside as parks. With conservation easements, the watershed will still urbanize, but the green spaces will not be developed (Figure 7 (c)). The baseline for the present study is comparable to Figure 7 (b). The conservation easement BMPs act to change the predicted future land uses in (b) to those landuses in (c) (Figure 7). In this way, they may be compared to structural BMPs that, for example, replace the current impervious pavement with pervious pavement.

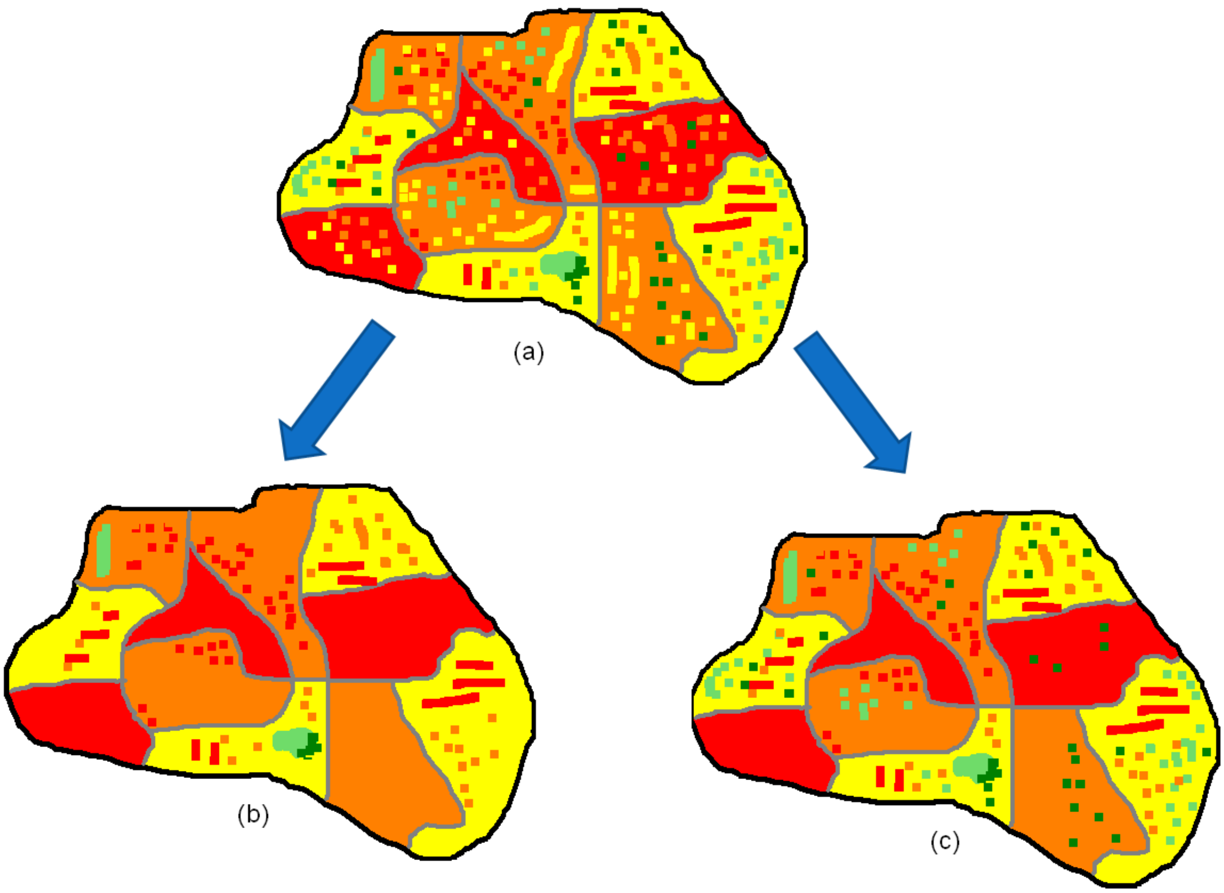


Figure 7. A schematic of the land use projection used. The current land uses (a) are predicted to become the future landuses (b) if no conservation easements are used, or landuses (c) if conservation easements are used.

Methodology

Zoning Maps

Zoning maps were used to project future land use. Zoning maps from the Borough of Morton (1989), Ridley Park (1982), Ridley Township (1977), Rutledge Borough (1998), Springfield Township (1986) and Swarthmore Borough (1976) were obtained from the Delaware County Planning Department. It was difficult to differentiate between zoning areas in some of the maps. More recent (2005) zoning maps for Rutledge Borough and Swarthmore Borough were found in the Multi-Municipal Comprehensive Plan for Nether Providence, Rose Valley, Rutledge and Swarthmore (14). Due to the improved quality and more recent making of these maps, the 2005 maps were used for Rutledge Borough and Swarthmore Borough.

The paper zoning maps from the Delaware County Planning Department and the Multi-Municipal Comprehensive Plan were used to make a zoning layer in ArcGIS ("Zones"). Each zoning area was added to the layer manually. The information from the various zoning maps was put into the attribute table in the zoning layer: the municipality that the particular feature is in, the zoning abbreviation used by the particular municipality (e.g., R1, Ca, etc.), the zoning description given by the municipality (e.g., Residential District Provisions, Commercial, etc) and the date the map was made (e.g., 2/12/1995, etc). After the zoning layer was complete, an area field was added to display the area in acres for each zoning area.

The zoning maps of the municipalities all included different zoning categories (Table 2). The zoning categories used in this study are essentially the broad categories that all of the zoning categories of the individual municipalities could fit into. The only consistent commonality in zoning between municipalities is that they all have some type(s) of residential zone(s). Ridley Township, Springfield Township and Swarthmore Borough differentiate between residential zones and zones that permit apartments, but the other municipalities do not. Only Swarthmore Borough has a separate zoning category for institutions such as schools and churches. Only Ridley Township has a zoning category specifically for land near streams. Business and Commercial zones were kept as separate zoning categories because Swarthmore defines its Business Apartment District as intended to "encourage and control a reasonable intensification of the existing commercial district" (14). Transportation zones were only used in two municipalities. This zone encompassed only the largest highways- not any of the smaller roads or train tracks. The "Special Use" zones are typically cases where uses other than those specified in the zoning have been permitted. These are often more unusual types of uses that may not fit well into existing zoning categories (15).

Table 2. The zoning categories assigned for the entire watershed and the zoning categories on the zoning maps of each municipality.

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

Zoning Map Revisions

The completed zoning layer was revised to reflect current land uses that would have required changes in zoning. Due to the ages of some of the maps, they do not show all of the current zoning accurately. For example, the zoning map of Ridley Township does not reflect the addition of a few schools since 1977. The use of this land for schools has changed the zoning of those parcels to Institutional, but this is not on the 1977 map. The revision of the zoning layer was done manually in GIS. All later analysis was based on the revised zoning map.

Revision of the zoning layer was done using the information from the zoning layer ("Zones"), a Google Earth image of the area ("all_subs_image1.img"), street information ("Streets") and parcel data ("Lower_Crum_Parcels_clip"). At a zoom level of approximately 1:7000, the watershed was visually scanned while oscillating back and forth between the zoning layer and the Google Earth image. When there were structures in the image that did not appear to be accounted for in the zoning layer, I zoomed in to it. For the first half or so, I identified the streets around the building/area and found it in Google Earth. Using that, I found out what the building was. I then modified "Zones" so that the area in question is zoned for what the Google Earth information indicated. For the second half, I stopped using Google Earth and instead used the parcel information to determine the zoning of that building. The zoning category "Open Water" was added to account for Ridley Park Lake, which has the land use of Open Water.

Land Use Projections

Projections of future land use were done based on the zoning maps and the NLCD 2001 the land use category definitions (Table 1). Areas zoned as Apartmental, Business, Commercial, Industrial, Special and Transportation were projected to be Developed High Intensity. Institutional zones are projected as Developed Medium Intensity. As student populations grow, schools add more buildings to accommodate them. They typically use most of the land they already own before purchasing more land and constructing a new school. Parks are projected to be entirely Developed Wooded. The area zoned as Riparian in Ridley Township are considered to be in the land use category Forest/Wetland.

Since the majority of the watershed is zoned residential and the MLRC both Developed Low Intensity and Developed Medium Intensity to be primarily residential areas, special care was taken in predicting the future land uses of this zone. The 70.6 acres of Developed High

Intensity land in the Residential zones of the watershed will almost certainly remain Developed High Intensity. Undeveloped land in the Residential Zone is unlikely to remain unused in LCCW. Therefore, we predict that the Developed Wooded and Forest/Wetlands will become Developed Low Intensity. The current Developed Low Intensity areas are likely to be further developed, so this and the Developed Medium Intensity land are predicted to become Developed Medium Intensity.

Alternate Ways of Predicting Land Use Change

Future land use is predicted in this study in order to compare easements in the same way as BMPs. Over twenty models were considered for predicting land use change. Some articles stated that they chose the land use change model they used based on the comparisons in the EPA summary of land-use change models, "Projecting Land-Use Change: A Summary of Models for Assessing the Effect of Community Growth and Change on Land-Use Patterns" (16). This was used for this study to determine which land use change models would be most compatible with StormWISE and its intended users.

Several criteria were used to limit the number of models considered. The first criterion for cutting the number of potential models was they any model used for this has to be free. This is in keeping with the fact that all of the software used in StormWISE is free and open source. The second criterion was how well documented the model is. No documentation or poor documentation could severely limit the number of people who could use it. Documentation that is available online is also preferred. Ease of transferring to other locations was another criterion. Finally, the equipment needs and required user expertise were considered. Since StormWISE requires knowledge of GIS, it seemed safe to assume that anyone using it would also be able to use land use change models that require it. Some models were cut because they require knowledge of C or C++ programming languages and having a gnu C compiler. StormWISE users do not necessarily have this equipment or programming knowledge.

Data in Excel StormWISE

Much of the data in Excel StormWISE was not altered for this study. The previously collected ten years of weather data from the Philadelphia Airport were used. The pervious and impervious SCS Curve Numbers for each land use were also left as they were. The accumulation rates for TSS, TN and TP were similarly unaltered. The marginal cost data for all of the preexisting BMPs was not modified. The treatable fractions of these BMPs were slightly altered in order for the total treatable fraction to add up to one for each land use. The treatable fraction for the Existing Riparian Buffer "BMP" was calculated as the proportion of predicted Forest/Wetland landuse in the riparian zone, 30 m on both sides of all of the streams in the watershed.

The Impervious Fraction for each predicted land use category (in the Pollutant Load Data section) was the current mean impervious fraction for each land use category, from "Riparian Corridor Best Management Practices" (1) (Table 3). The current impervious percentages in each land use category are not the same as the stated MRLC 2001 category descriptions. It is reasonable to assume that the impervious percentages in each land use category will remain approximately what they are now as the land use categories change due to an overall urbanization.

Table 3. Th impervious fraction of each land use used in this study.

Land Use	Imperv Fraction
Forest/Wetlands	0.19
Developed Wooded/Fields	0.27
Developed Low Intensity	0.37
Developed Medium Intensity	0.48
Developed High Intensity	0.55

The land area by drainage zone was determined using the layer 'Merge_Order_Dissolve.' This layer had been created using TauDEM in order to split the watershed into Headwaters and Lowlands. For all of the one-to-one projections (Commercial -> Developed High Intensity), the proportion of each zoning area in each stream order zone was cross tabulated using the Spatial Analyst toolbox , Zonal, and the Tabulate Area tool. The case was more complicated for the Residential Zone, which was mapped onto all three possible developed intensities of land uses. In order to obtain a layer that had both the residential zone and the stream zone it was in, Analysis Tools -> Overlay -> Intersect tool was used (ZoneRevisAlbersLCCW_Res_Order). The Tabulate Area tool was used with the newly created layer as the input zone data, the zone field was the stream zone, the input raster was lclu_Landuse.img and the class field was the value (1, 2, 3, 4, 5, 11). The final projected land uses by stream zone were determined in Excel.

The Marginal Cost for the Conservation Easement BMP, was approximated using cost data for easements and land acquisition in McGarity et al. (1). The cost of purchased conservation easements and the cost of donated conservation easements were considered separately. The average cost per acre for the zones grouped as high intensity (Commercial, Industrial) was added to the monitoring and management costs of easements in order to obtain the marginal cost for Developed High Intensity areas. The cost per acre for Residential buildable was added to the monitoring and management costs to obtain the marginal cost for Developed High Intensity and Developed Low Intensity land uses. The cost of donated conservation easements was simply the sum of the monitoring and management costs.

Table 4. The cost per acre for only monitoring, management and potential restoration (Donated) and for these costs plus the acquisition costs of the land (Purchase).

	Cost Per Acre	
Landuse Category	Donated	Purchased
For Low and Medium Intensity Developed	$1,789.40	$99,289.40
For High Intensity Developed	$1,789.40	$316,789.40

The Treatable Fraction using the Conservation Easement BMP was found using land use by zone data from GIS. The treatable fraction for the Developed High Intensity land use was found as the ratio of the total area with a green land use (G) in DHI zones to the total area (T) in the DHI zones. This assumes that none of the green space in the residential zone is in the Developed High Intensity areas. Here, 'green land uses' means either Forest/Wetland or Developed Wooded.

$$Treatable\ Fraction\ (DHI) = \frac{G_{Comm} + G_{Spec} + G_{Apar} + G_{Busi} + G_{Indu} + G_{Tran}}{T_{Comm} + T_{Spec} + T_{Apar} + T_{Busi} + T_{Indu} + T_{Tran} + T_{Resi}}$$

The treatable fraction for Developed Low Intensity and Developed Medium Intensity were found based on the percentage of Residential zone that is projected to be in each of those categories. The projected percentages for the Residential zone are 48.45% in DLI, 50.58% in DMI, and 0.97% DHI. Since it is assumed that none of the green spaces are in the DHI areas, the assumption was made that 51% of the Residential green spaces were in the DLI areas and 49% were in the DMI.

$$Treatable\ Fraction(DLI) = \frac{0.49 \times G_{Res}}{0.4845 \times T_{Res}}$$

The treatable fractions for Developed Medium Intensity areas were found using both the Residential and the Institutional information.

$$Treatable\ Fraction(DMI) = \frac{G_{Inst} + (0.51 \times G_{Res})}{T_{Inst} + (0.5058 \times T_{Res})}$$

StormWISE for Analysis of Present

The original StormWISE in Excel without conservation easements was compared to the extended StormWISE. For the purpose of this comparison, the same treatable fractions for the non-conservation easement BMPs were used in both even though this resulted in total treatable fractions of less than one for all of the land uses besides Developed Wooded. The Land Areas by Drainage Zone were found using GIS to calculate the amount of each landuse in each drainage zone. After running "StormWISE_Setup," the RunQual model implemented in StormWISE, the totals for each case were compared. The difference between the water quality parameters were then used as a the requested benefits for the case of donated easements.

Results

Land Use Prediction Models

Two land use change prediction models were selected as being able to provide the necessary data for this type of study while not requiring skills, equipment or funds that the StormWISE model does not require. These are Smart Grown Index® and UrbanSim. Both models are free and well documented, having both a website and a user's manual. Both require familiarity with land use modeling. The EPA study states that Smart Grown Index® can be effortlessly transferred to locations other than the original one(s), and that this is feasible in UrbanSim (13).

Smart Grown Index® is a GIS-based tool that is intended to help chose between alternative land-use and transportation possibilities. It can either give snapshots of a particular future time that are based on parcel data, or it can provide predictions over time. This model assumes that whether transportation and other infrastructure is available is directly related to the population growth. The land use categories are user defined; between six and thirty are typically used.

UrbanSim is intended to be used for integrated analysis of urban development, land use and transportation. It is based in its own software. Calibration requires familiarity with statistical and econometric software such as Alogit and Limdep. This model is intended for users without a significant technical background. The land use categories are user defined, generally with ten or more urban categories and any number of non-urban categories.

Zoning Maps

One zoning map was made based on the zones specified by each municipality (Figure 7), and the other was based on this, but revised for structures that were not accounted for by the zoning (Figure 8). Some of these may have been added since the zoning maps were made, others are simply accounted for by the zoning categories of a municipality. During the revisions, institutions were primarily added because most of the municipalities did not have a specific zoning category for institutions. They are typically part of residential zones. The large area zoned as Riparian in Ridley Township was removed because it is currently being used as a residential area. East Lake Park, in Ridley Park Borough, was added as a Riparian area because it currently functions as such. A number of commercial and business areas were added throughout the watershed to account for the businesses that are currently there according to the Google Earth image and parcel data.

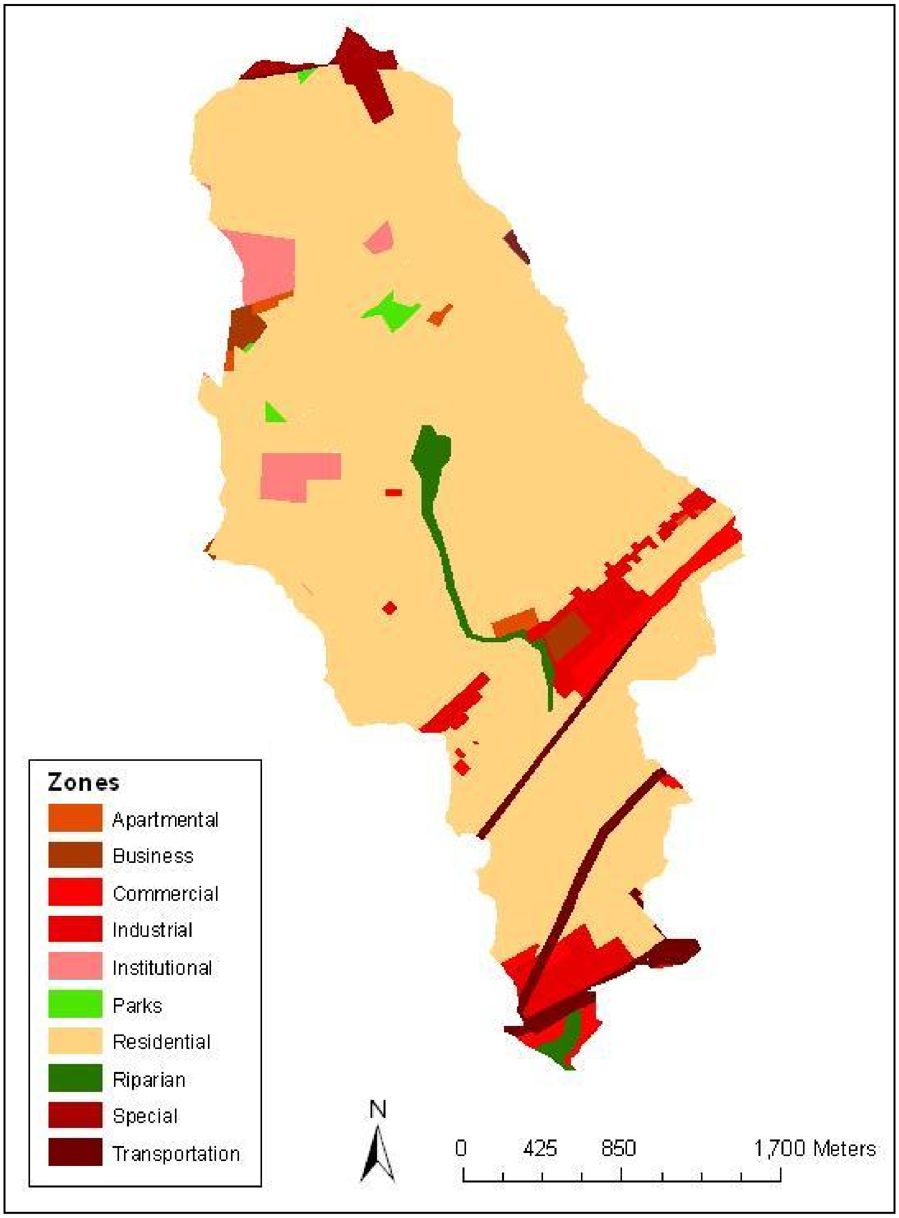


Figure 8. Zoning map of LCCW without modification. These zoning categories combine like categories from the zoning maps from each municipality in LCCW.

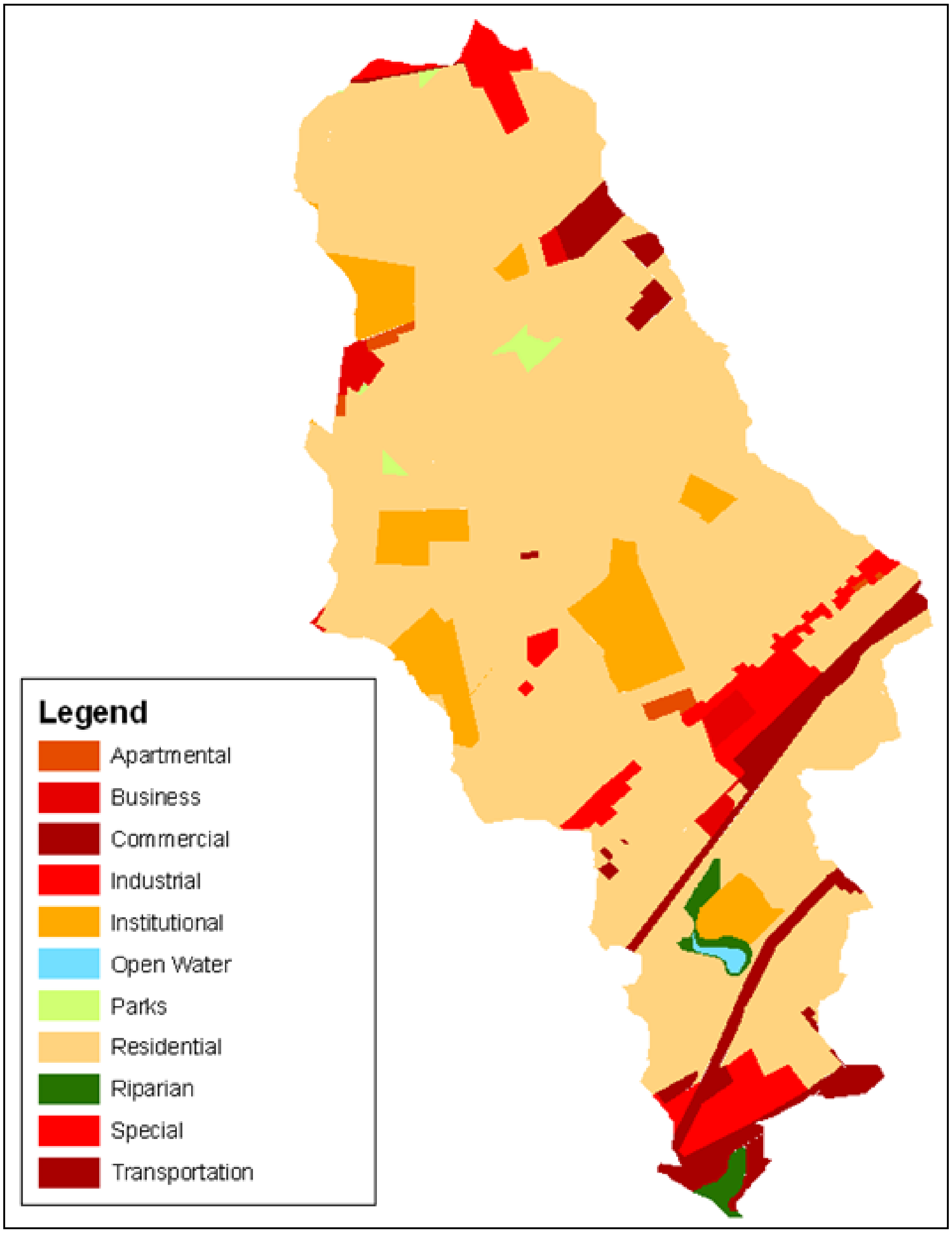


Figure 9. Zoning map of LCCW that has been modified to account for existing properties.

Three quarters of LCCW is zoned Residential (Figure 9). The similar zoning categories of Commercial, Business, and Special combined account for 11% of the area of the watershed. Only 0.11% of the watershed is Developed Wooded and 0.04% is Open Water.

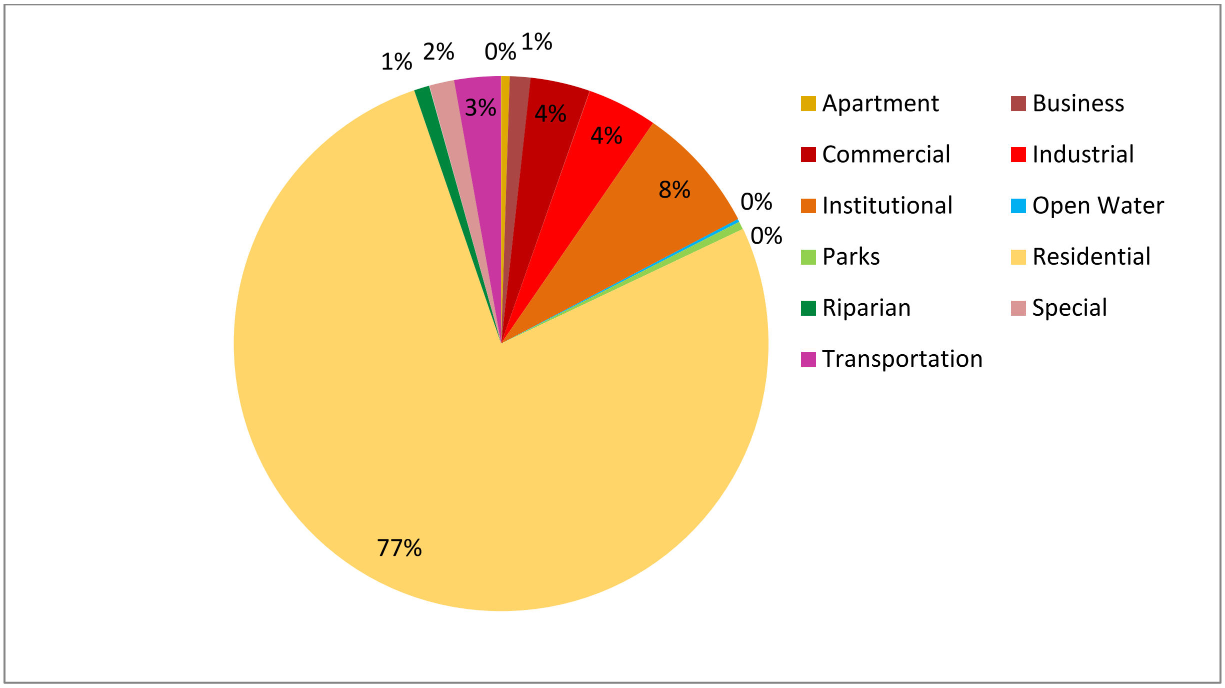


Figure 10. Percentage of watershed in different zoning areas.

Land Use and Zoning

The proportion of land in each land use category was assessed using ArcGIS. The program indicates that the most common land uses in the watershed are Developed Low Intensity and Developed Wooded/Fields (Figure 10). Forest/Wetland makes up 14.5% of the area. The fact that Developed Wooded/Fields and Forest/Wetland together account for 45.9% of the watershed area suggests that conservation easements may still be worthwhile in this watershed.

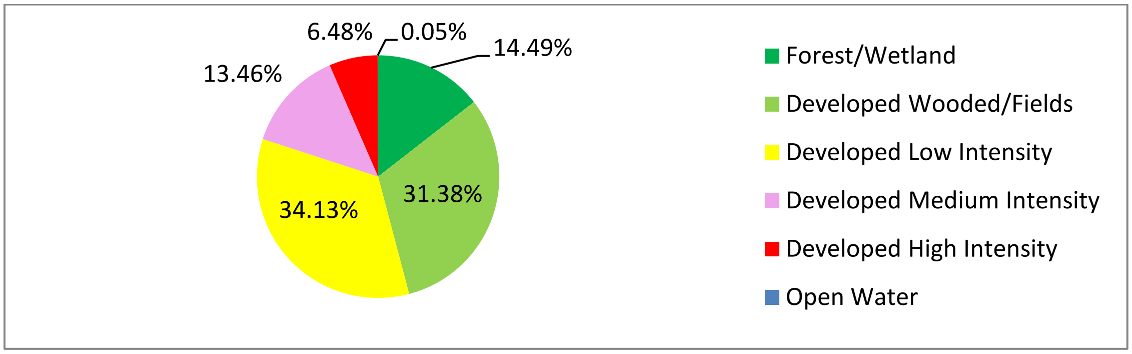


Figure 11. The current percentage of each land use in the watershed.

Using the spatial analyst toolbar in ArcGIS, the current amount of each land use in each zoning area was assessed. Due to the large proportion of the land area that is designated Residential, the greatest acreage of all of the zoning categories except for Developed High Intensity and Open Water occurred there (Figure 11). Many of the zoning categories, such as Commercial, have current land uses on the less developed end of what is permitted. The Residential Zone was found to be primarily composed of Developed Low Intensity and Developed Wooded land uses (Figure 12).

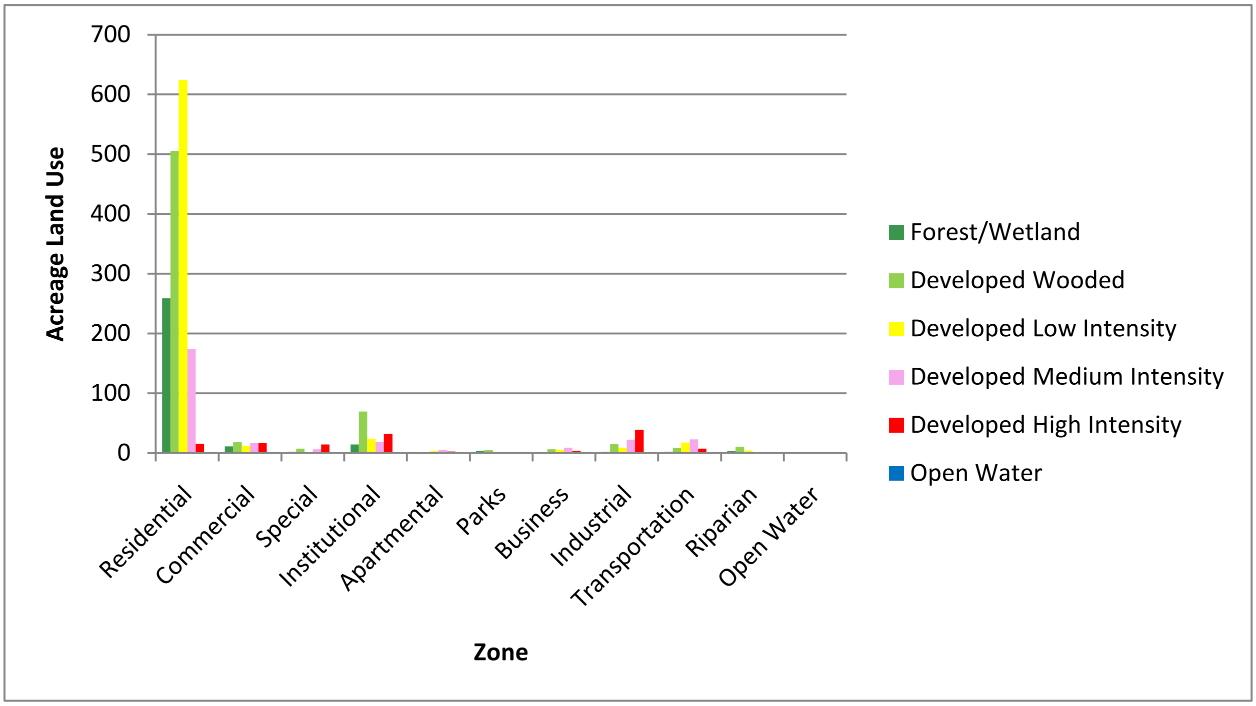


Figure 12. The acreage of each land use in each zone. The land use data is in the form of a raster from the NLCD 2001. The zoning data is based on zoning maps given by the Delaware County Planning Department.

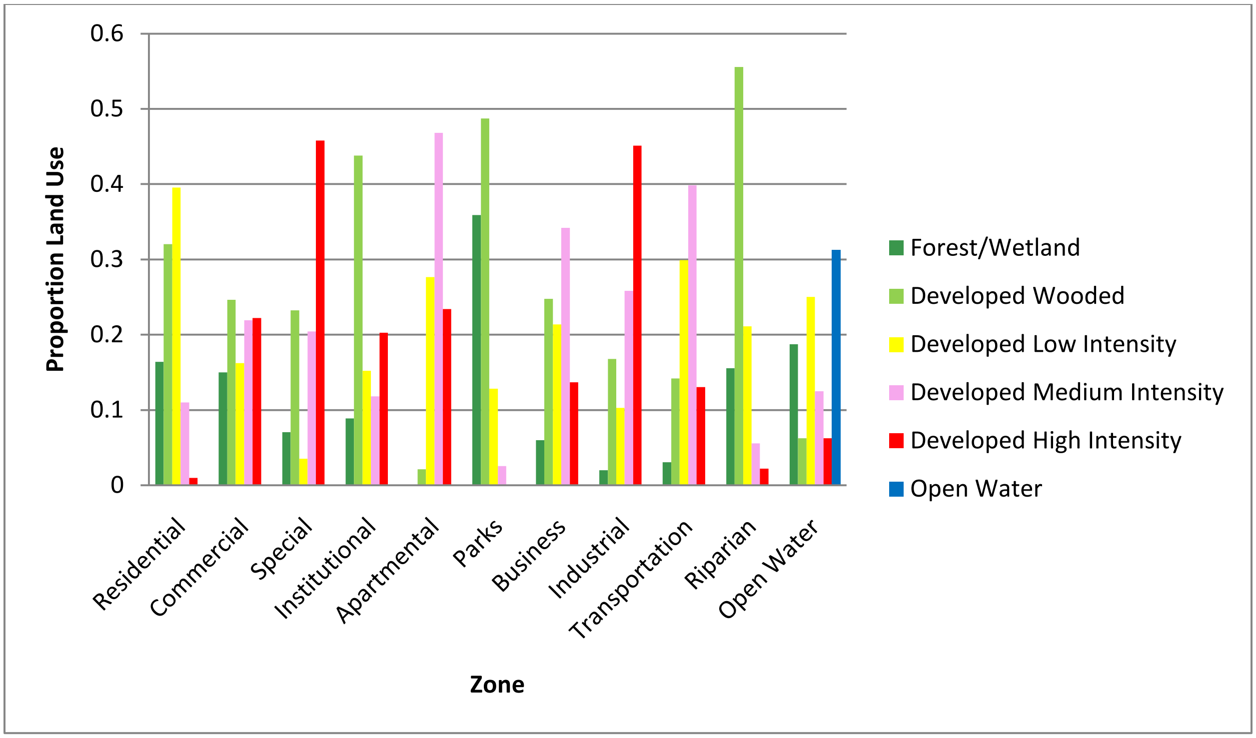


Figure 13. The proportion of each land use in each zone. The land use data is in the form of a raster from the NLCD 2001. The zoning data is based on zoning maps given by the Delaware County Planning Department.

The percent of impervious surface is expected to grow throughout the watershed. The area used as developed wooded/fields is predicted to drop to the areas specifically set aside as Parks, 10.4 acres. The area that is Forest/Wetland will also decrease. The only Open Water will continue to be Ridley Park Lake, which takes up approximately 4 acres. The Developed Medium Intensity landuse is expected to grow the most (Figure 13).

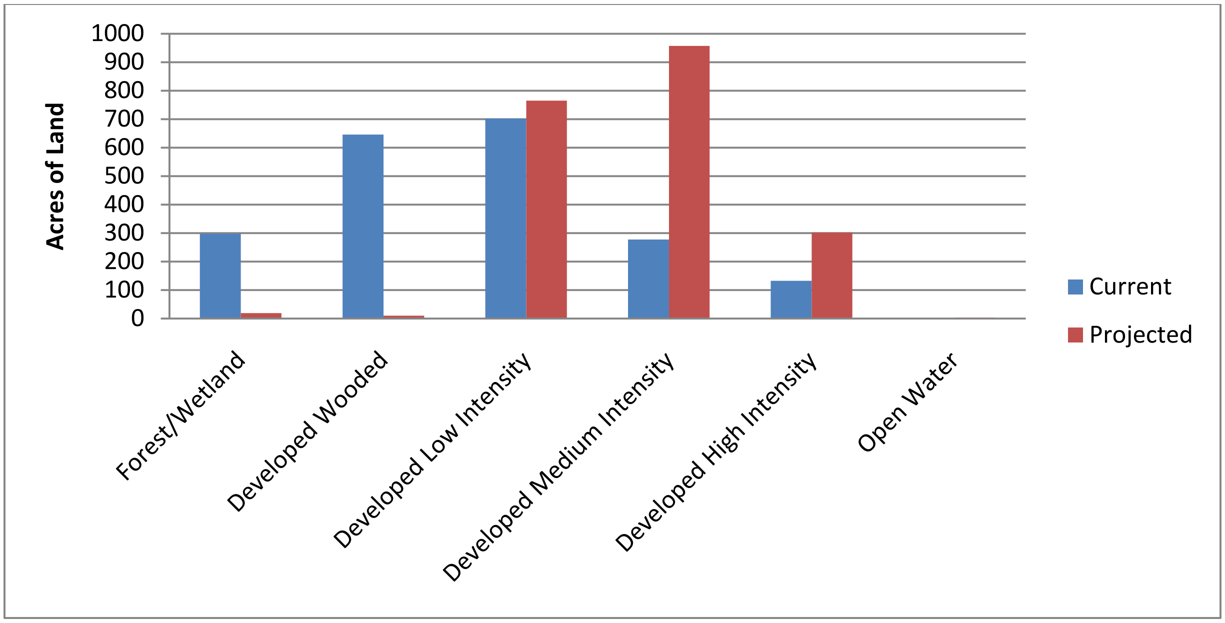


Figure 14. The current and projected acreage of each land use category.

Headwaters and Lowlands

Fifty-one percent of the land in the watershed is in the Headwaters and 49% is in the Lowlands. Nearly all of the land that is zoned Riparian is in the Lowlands (Figure 14). Similar amounts of land that is predicted to become Developed High Intensity are found in both drainage areas.

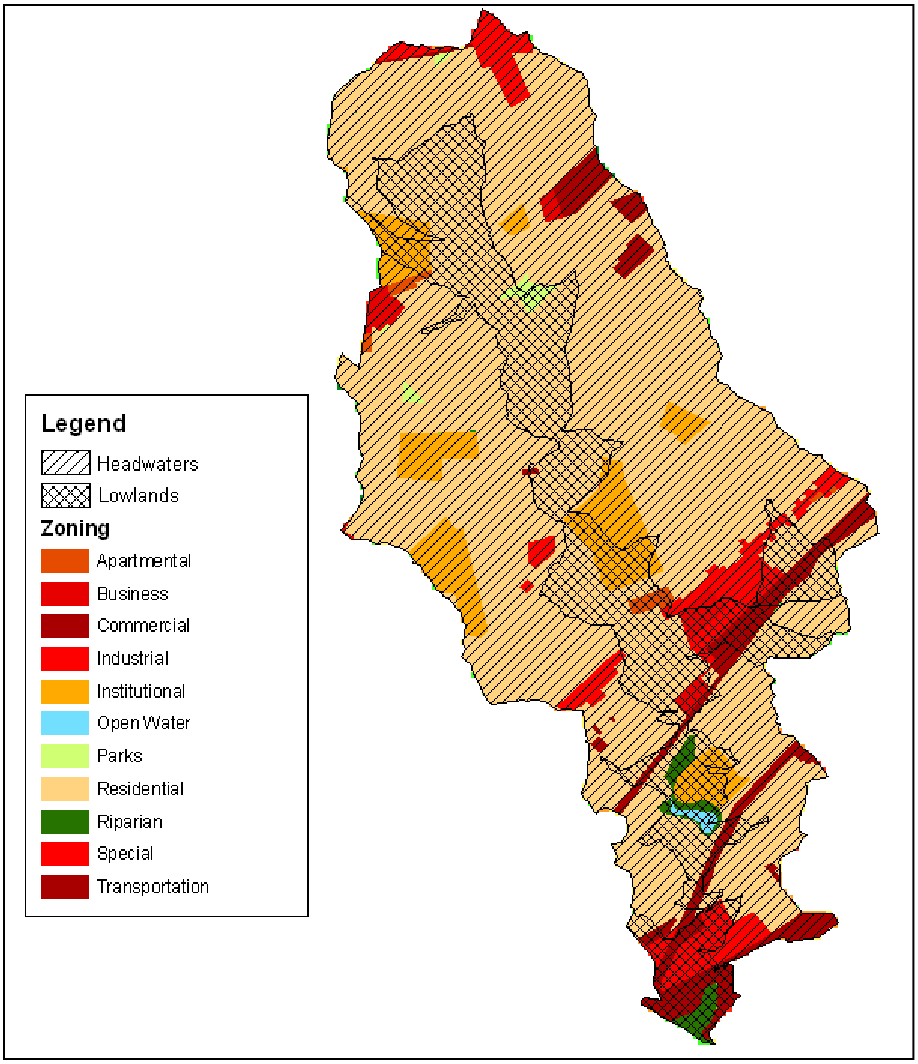


Figure 15. The headwaters and lowlands of the watershed with the current zoning areas.

Treatable Fraction

The treatable fractions for the Conservation Easements of Developed Wooded/Fields were higher than those for Conservation Easements of Forest/Wetland in all of the landuses where they may be used. This results in a possible 167.3 acres (0.261 mi^2) of Forest/Wetland that may be conserved and a possible 347.8 acres (0.543 mi^2) of Developed Wooded/Fields may be conserved. This is 25% of the land area in the watershed.

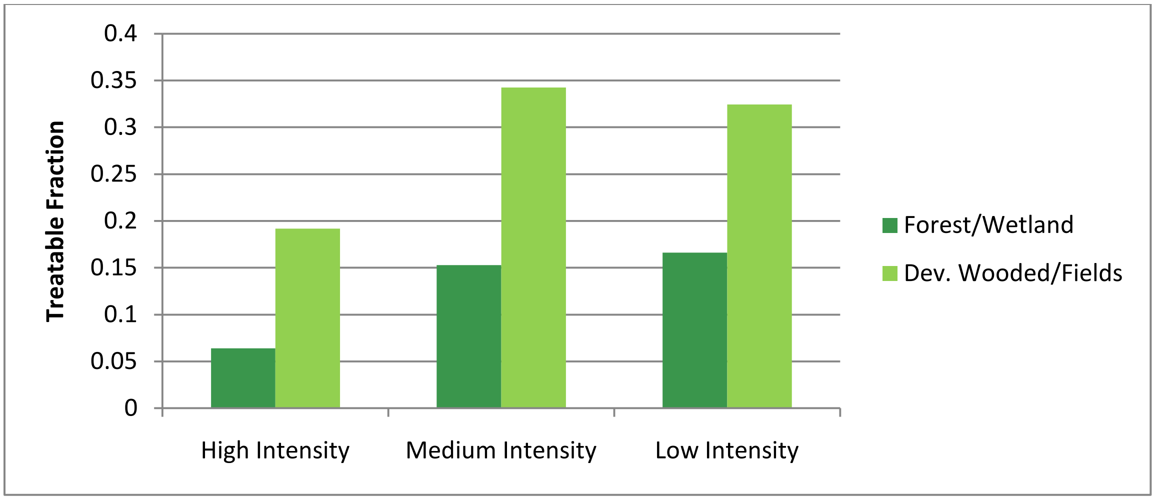


Figure 16. The treatable fractions used for the Conservation Easement of Forest/Wetland BMP and the Conservation Easement of Developed Wooded/Fields BMP.

StormWISE Analysis- Cost Slopes

The cost slope (benefit/$) indicates which BMPs should be used first for each water quality parameter and landuse. These were compared for the assumption that BMPs are donated and for the assumption that they are purchased. For the costs of donated easements, the Conservation Easement BMPs compared favorably to the structural BMPs (Figure 16). In Low and High Developed Intensity, there were two and one BMPs with more benefit per dollar than the Conservation Easements, respectively. In Developed Medium Intensity, the conservation easements have the highest benefit per dollar.

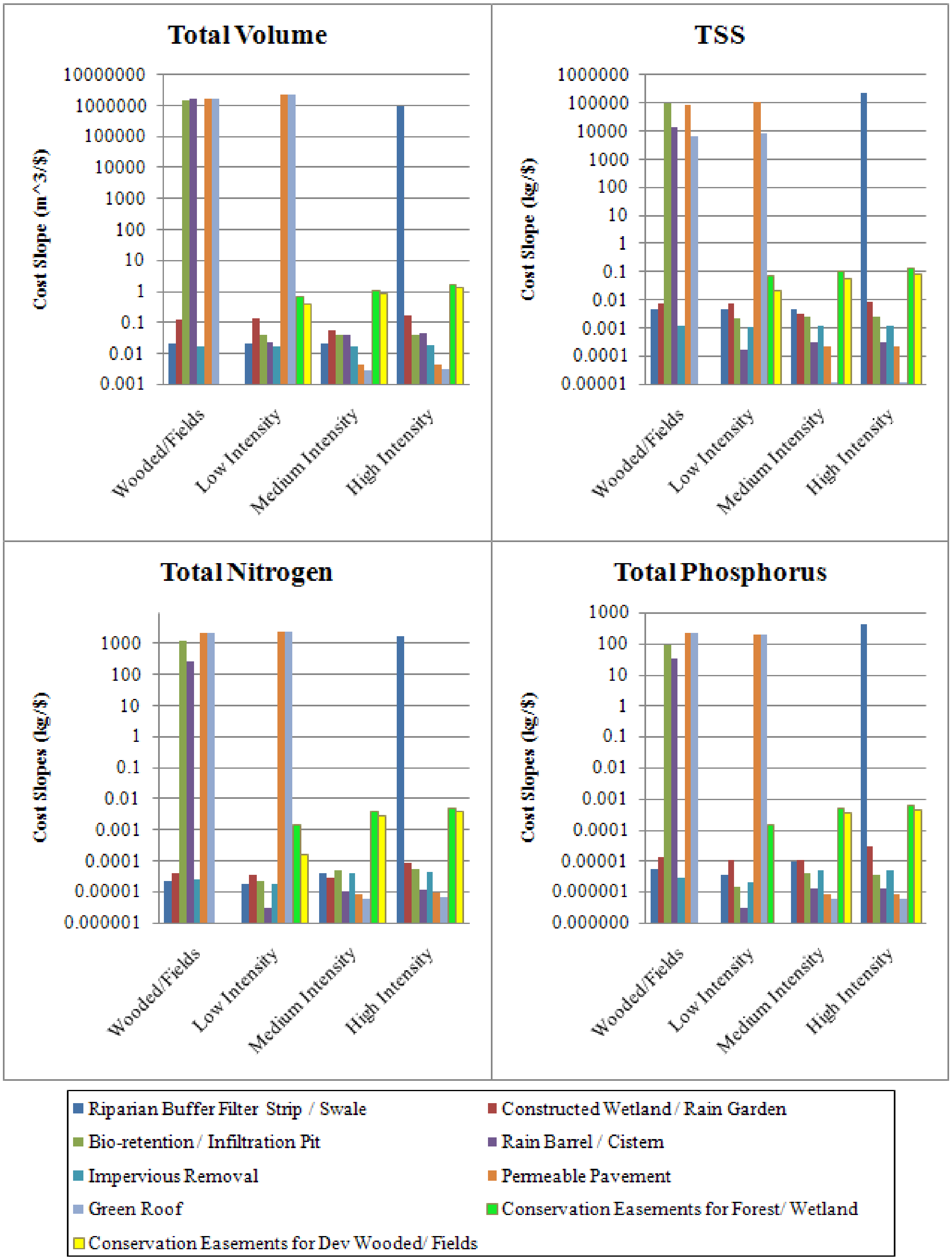


Figure 17. The cost slopes of each BMP in each land use except for Forest/Wetland. The cost slopes of the conservation easements use the donated costs.

The conservation easement BMPs are a much less favorable option when the cost of purchase is included (Figure 17). The conservation easements continue to be more cost effective than the Green Roof BMP and the Permeable Pavement BMP, but are no longer among the first to be used. In both cases, Conservation Easements for Forest/Wetland yields a greater benefit per dollar than Conservation Easements for Developed Wooded/Fields. This was anticipated because the same costs were used for both while less runoff is generated from the less developed Forest/Wetland landuse.

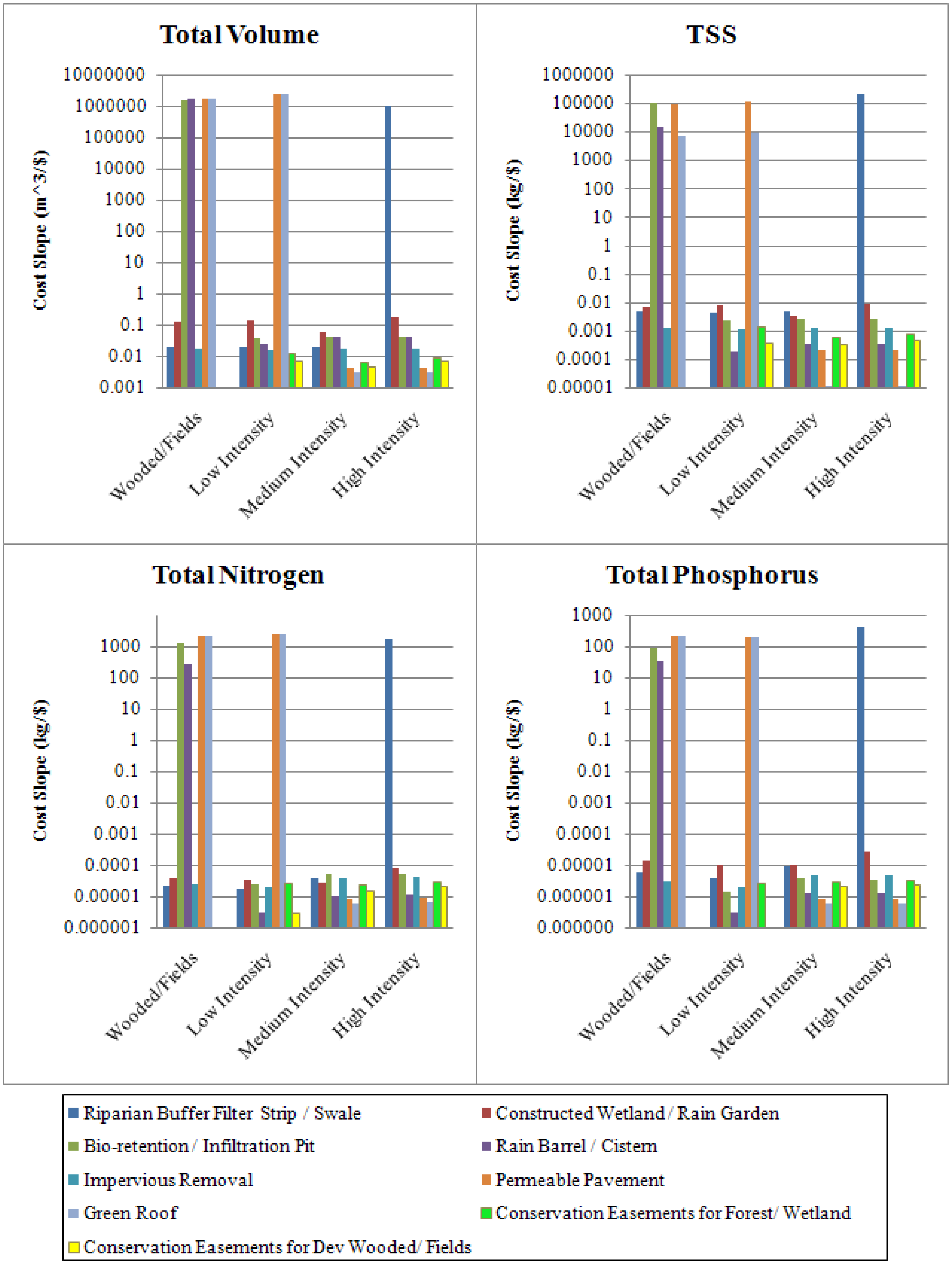


Figure 18. The cost slopes of each BMP in each land use except for Forest/Wetland. The cost slopes of the conservation easements use the purchased costs.

StormWISE Analysis- 25% of Maximum

When donated costs were used for the conservation easements, the optimal total cost was \$1,017,845 and only three BMPs were used. The highest optimum spending level was for the Constructed Wetland/Rain Garden BMP (Figure 18), which contributed the least to each pollutant and runoff removal (Figure 19). Conservation Easements for Developed Wooded/Fields contributed the most to the reduction of each pollutant and runoff and was less than half of the cost of the Constructed Wetland/Rain Garden BMP. StormWISE recommends using conservation easements in all of the potential locations for them.

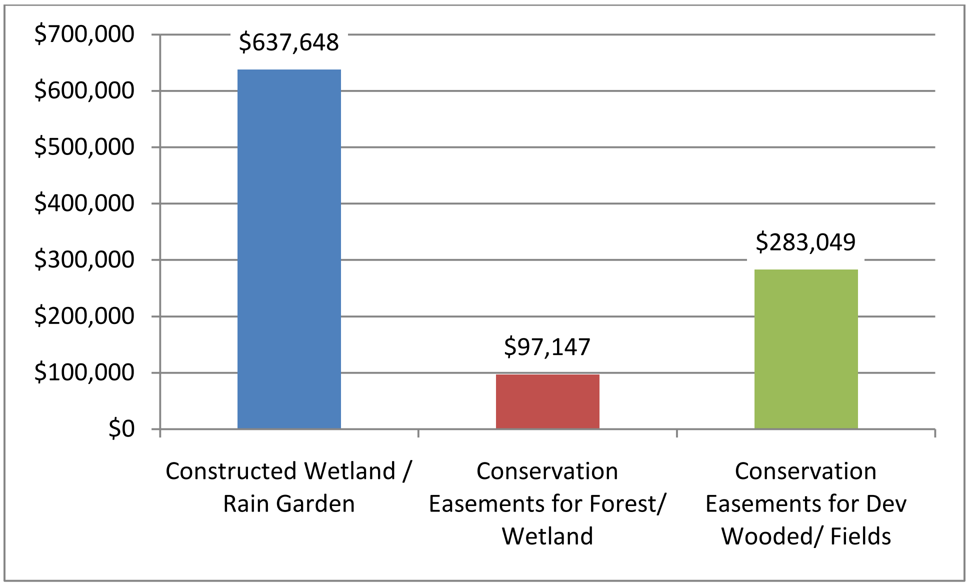


Figure 19. The optimum spending level for each BMP for the case of 25% of the maximum possible benefits being requested and donated costs used for conservation easements. The BMPs with an optimum spending level of zero are not shown.

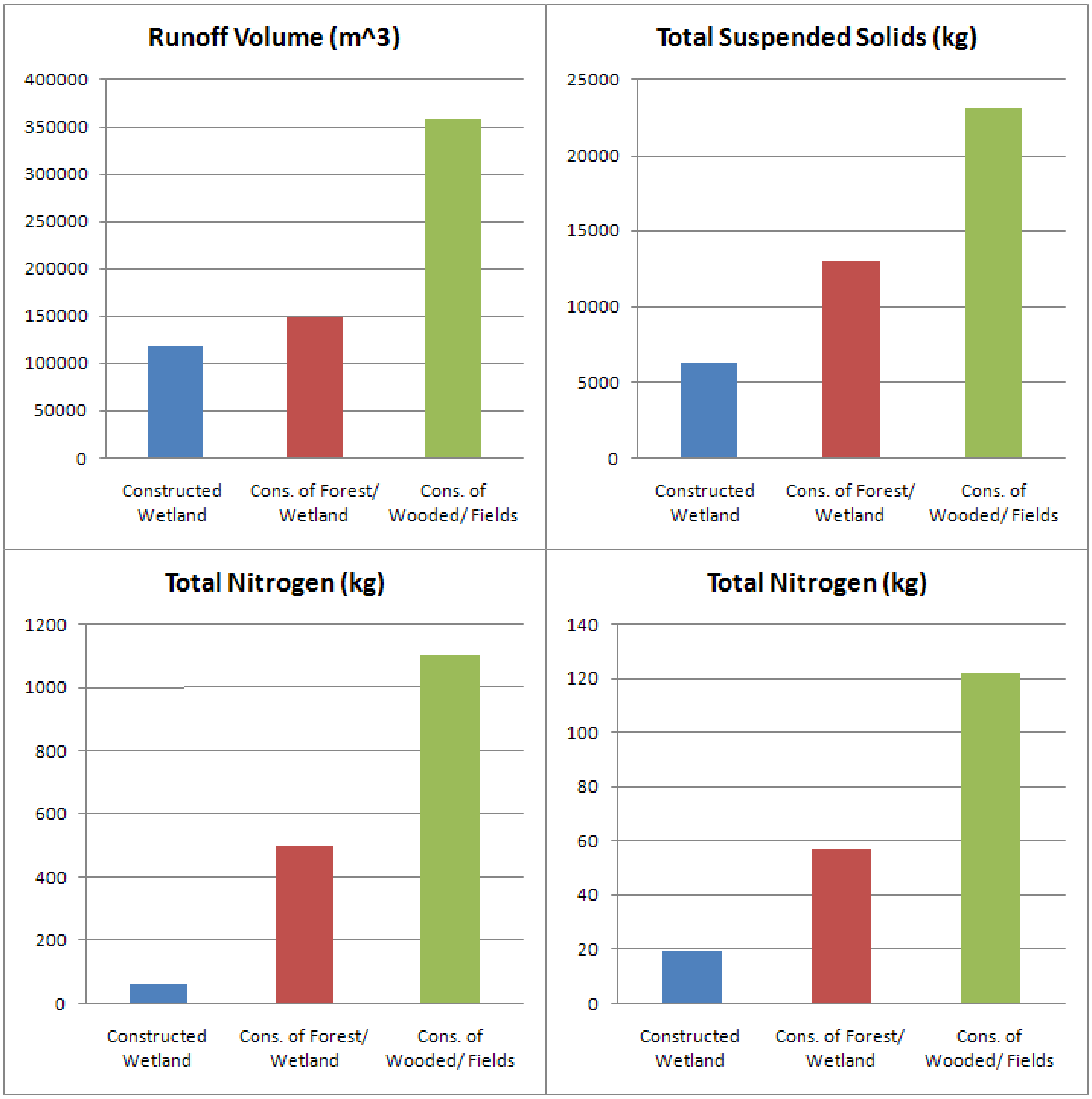


Figure 20. The benefit of each BMP for the case of 25% of the maximum possible benefits being requested. The donated costs were used for the conservation easements. The BMPs with a benefit level of zero are not shown. The Existing Riparian Buffer 'BMP' is also not shown because all of it is always used.

When purchased costs were used for the conservation easements, the optimal total cost was $25,299,950 and five BMPs were used. The costs of Conservation Easements for Forest/Wetland and Conservation Easements are similar to the costs of Bio-retention/Infiltration Pits and Constructed Wetland/Rain Garden, respectively (Figure 21). In this case, the Conservation Easements for Forest/Wetland make the smallest contribution to the reduction of each of the pollutants and runoff. This was used on 38% of the possible area and the Conservation Easement for Developed Wooded was used on only 3% of the possible area.

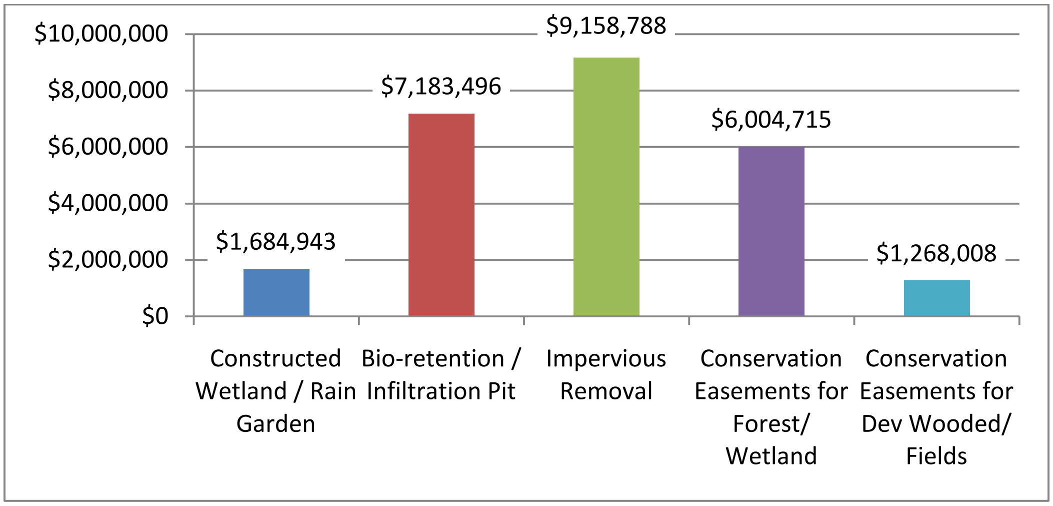


Figure 21. The optimum spending level for each BMP for the case of 25% of the maximum possible benefits being requested and purchase costs used for conservation easements. The BMPs with an optimum spending level of zero are not shown.

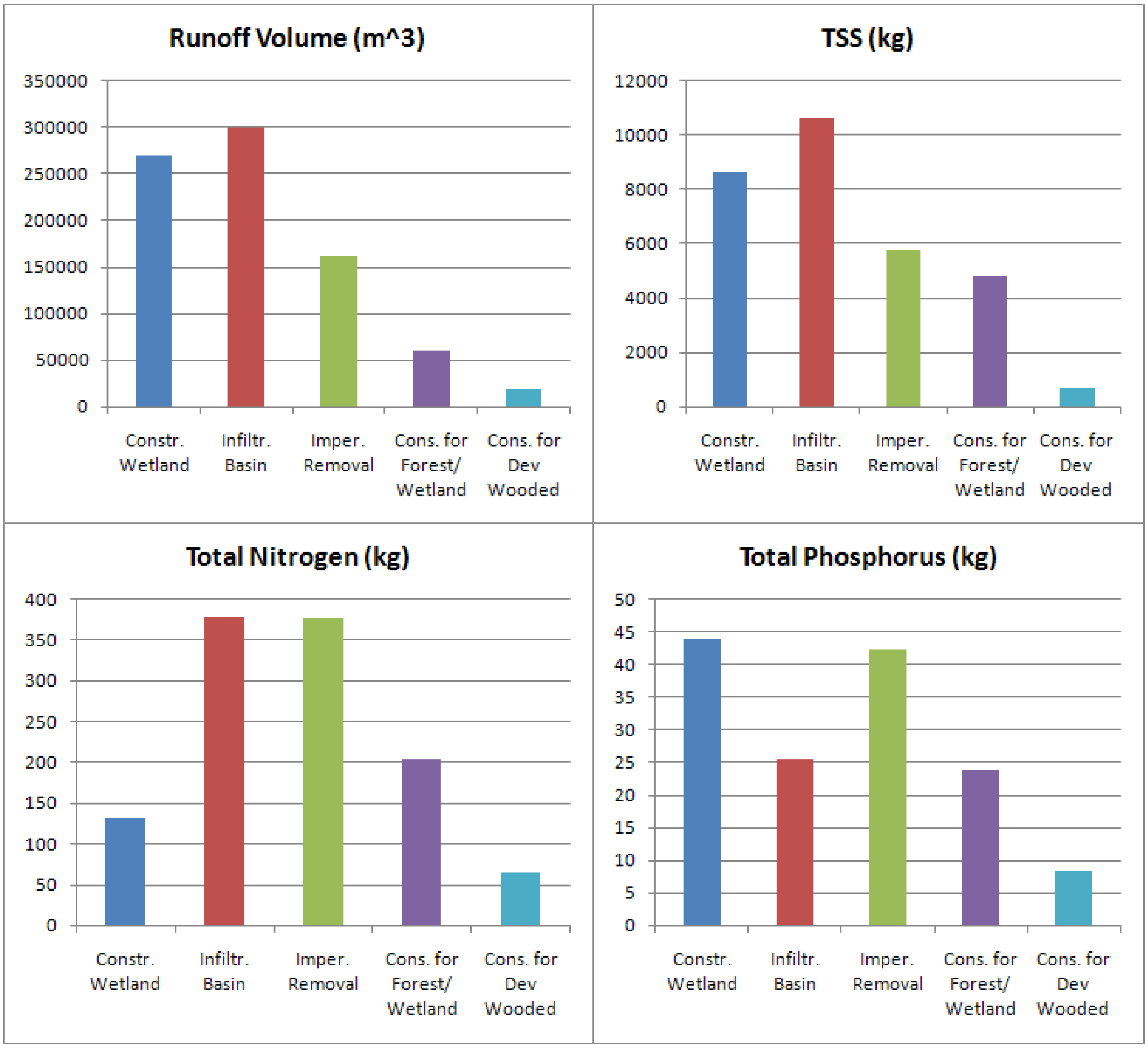


Figure 22. The benefit of each BMP for the case of 25% of the maximum possible benefits being requested. The purchased costs were used for the conservation easements. The BMPs with a benefit level of zero are not shown. The Existing Riparian Buffer 'BMP' is also not shown because all of it is always used.

Compared to Present

The differences between water quality parameters in the present and predicted future were tremendous (Table 5). The differences for the nutrients were actually higher than the maximum achievable benefits in the revised StormWISE model. Therefore, 2,000 kg was used as the requested benefit for TN and 200 kg for TP. These values were used so that the arbitrarily requested reductions would not necessitate a greater Runoff Volume and TSS reduction than required by the demands made on them.

Table 5. The runoff and pollutant loads in the present, future, and the difference between them.

	Runoff Volume (m^3)	TSS (kg)	TN (kg)	TP (kg)
Present	2,018,411	133,699	3,023	349
Future	3,358,526	227,617	7,765	879
Difference	1,340,115	93,918	4,742	530

When donated costs were used for the conservation easements, the optimal total cost was \$15,175,131. Both conservation easements, the Riparian Buffer Filter Strip and the Rain Barrel BMP were used as much as they could be. The optimal spending levels for the Conservation Easements for Forest/Wetland and the Conservation Easements for Developed Wooded/Fields were low relative to the spending levels of the other BMPs (Figure 22). The benefit gained from the conservation developed wooded/field land uses was the highest of the BMPs (Figure 23). The Conservation Easements for Forest/Wetland resulted in the second highest mass reduction of nutrient loads.

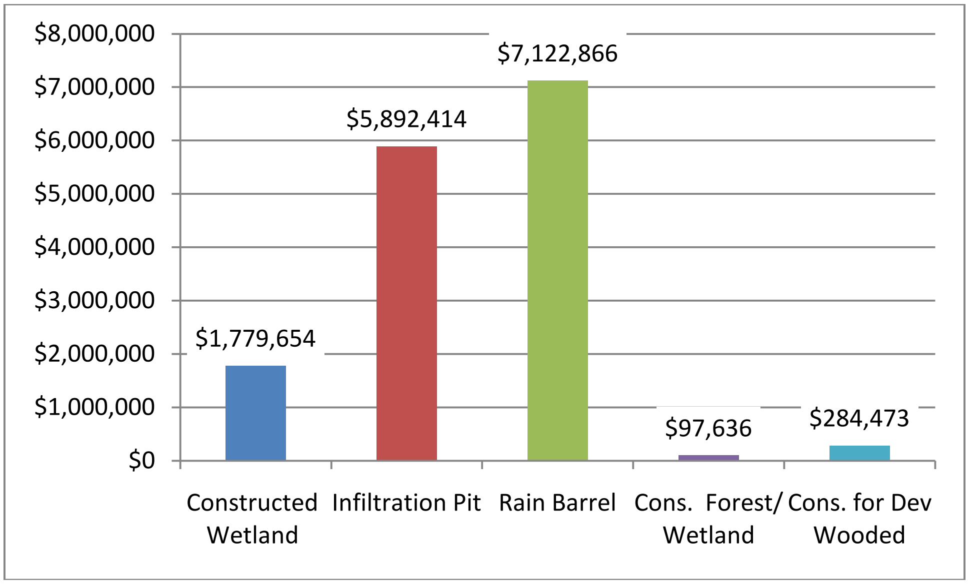


Figure 23. The optimum spending level for each BMP for the case in which the requested benefits are equivalent to the difference between pollutant loads. The marginal costs for the conservation easements were the donated costs. The BMPs with an optimum spending level of zero are not shown.

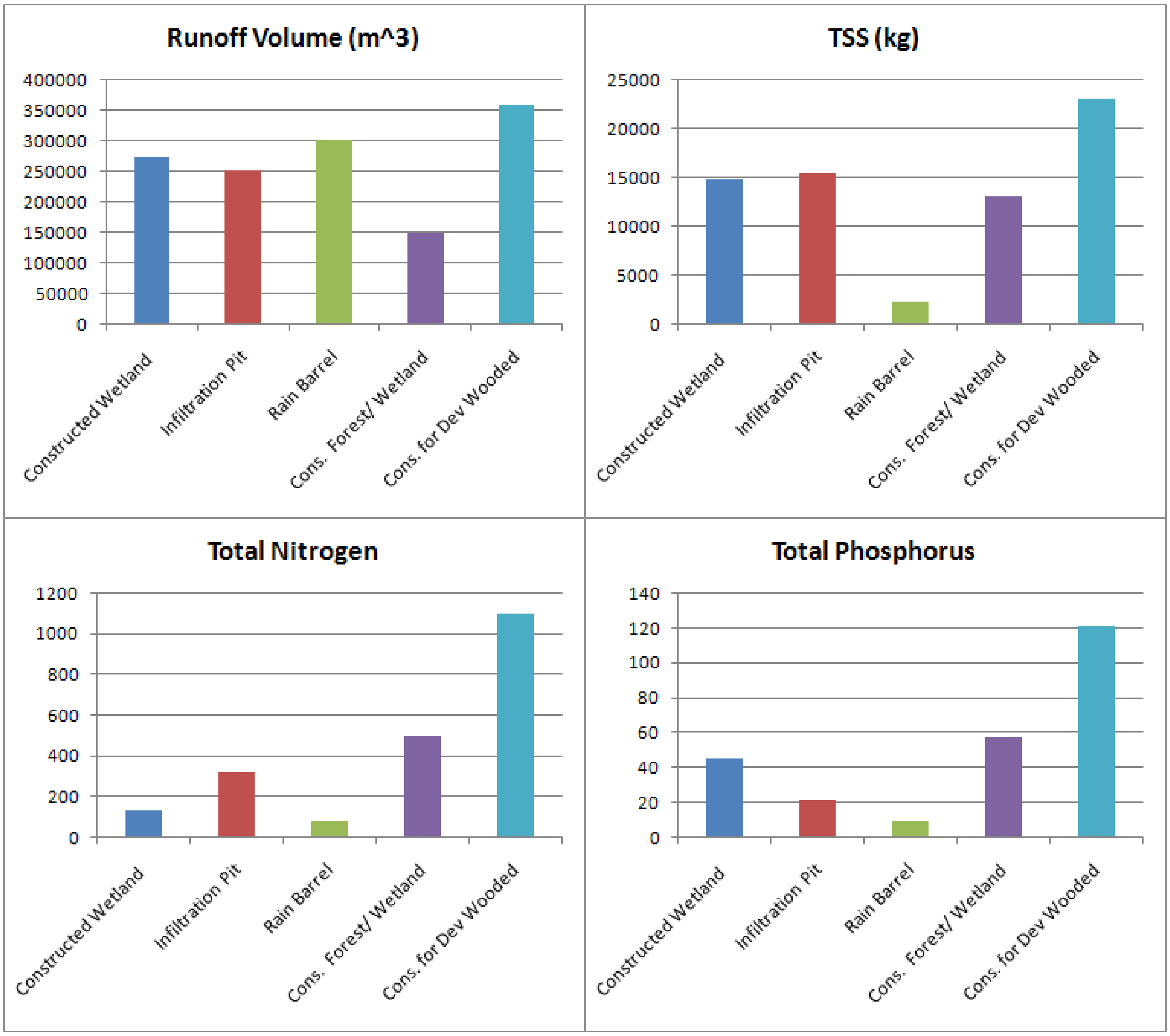


Figure 24. The optimum benefit level of each BMP for the case in which the requested benefits are equivalent to the difference between pollutant loads. The marginal costs for the conservation easements were the donated costs. The BMPs with a benefit level of zero are not shown. The Existing Riparian Buffer 'BMP' is also not shown because all of it is always used.

Nearly all of the BMPs were utilized to some degree for the case in which purchase costs were used for the conservation easements. The total cost in this case was $62,885,856. The Riparian Buffer Filter Strip, Constructed Wetland, Infiltration Pit and Conservation Easement for Forest/Wetland BMPs were all used as much as they could be. Forty-seven percent of the possible for Conservation Easement for Developed Wooded/Fields was used. This BMP would represent the highest cost in this case (Figure 24). The Conservation Easement for Forest/Wetland BMP would have the second highest optimum spending level. Although these two BMPs result in the greatest reduction of nutrient loads, they are some of the least effective at reducing Runoff Volume and average at reducing TSS loading (Figure 25).

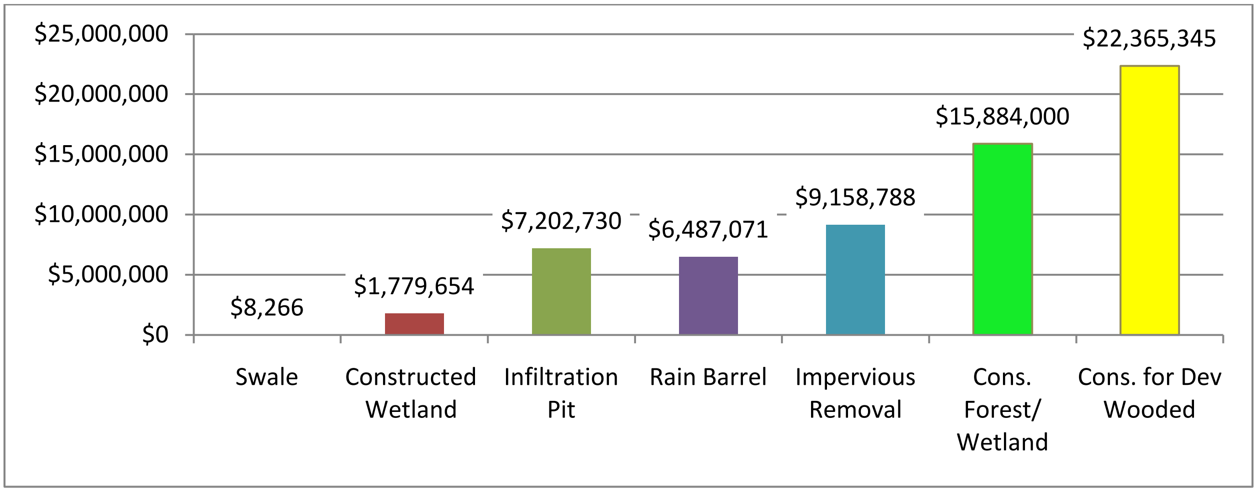


Figure 25. The optimal spending level for for each BMP for the case in which the requested benefits are equivalent to the difference between pollutant loads. The marginal costs for the conservation easements were the purchased costs. The BMPs with an optimum spending level of zero are not shown.

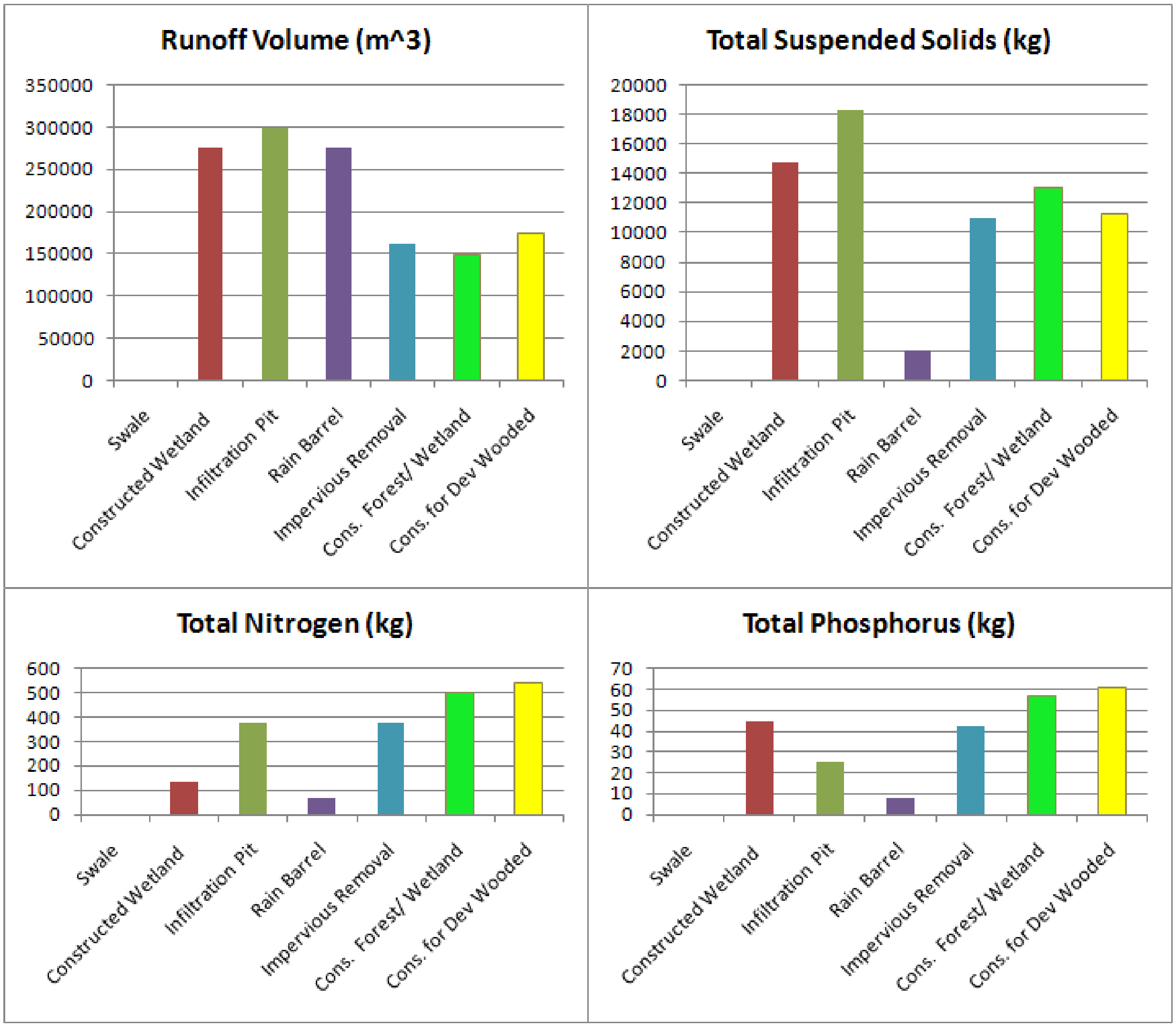


Figure 26. The optimum benefit levels for each BMP for the case in which the requested benefits are equivalent to the difference between pollutant loads. The marginal costs for the conservation easements were the donated costs. The BMPs with a benefit level of zero are not shown. The Existing Riparian Buffer 'BMP' is also not shown because all of it is always used.

In three of the test cases examined, approximately 96% of the money would be spent in the Developed High Intensity Landuse (Figure 26). In the case in which conservation easements are purchased and a 25% reduction in each water quality parameter was requested, it was recommended that 91% of the total cost be spent in the Developed High Intensity landuse and 9% be spent in the Developed Medium Intensity landuse.

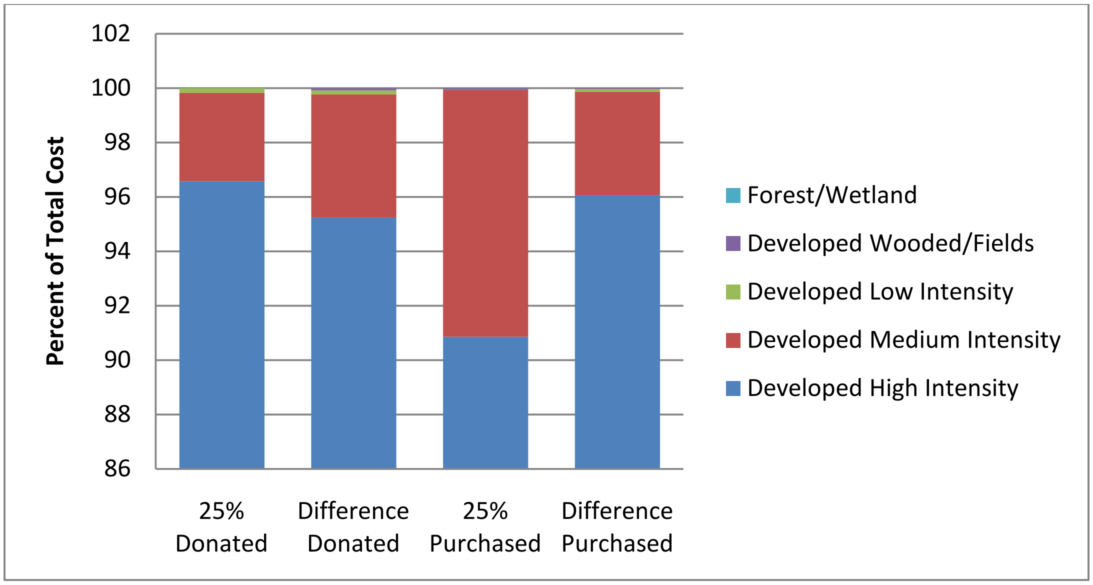


Figure 27. The percent of total cost that is spent in each landuse for each case.

The model developed here consistently recommends that over half of the funds should be spent in the Headwaters (Figure 27). The percent spent in the Headwaters was lowest in the case in which the conservation easements represented a small fraction of the total cost of water quality improvement (Figure 22).

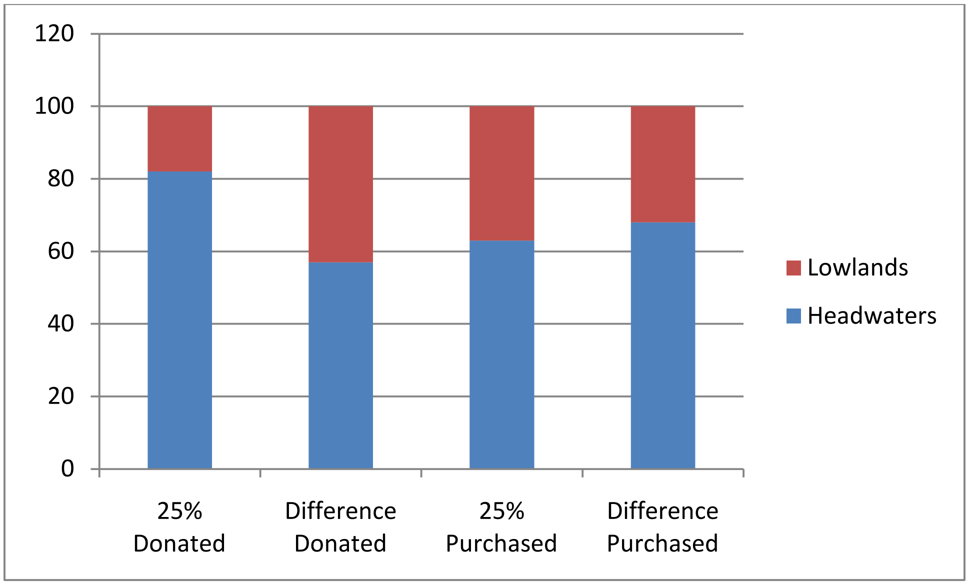


Figure 28. The percent of total cost that is spent in each of the two drainage areas for each of the cases considered.

Conclusions and Recommendations

The conservation of Developed Wooded/Fields and Forest/Wetland is a cost-effective way of preventing some of the water quality effects of urbanization when the land does not have to be purchased to be conserved (Figure 16). The tremendous total cost of returning the future runoff volume and TSS loads to the current levels demonstrates the importance of conservation for water quality.

The relatively low percent of the money spent on Developed High Intensity Land in the case in which conservation easements are purchased and a 25% reduction in each water quality parameter was requested (Figure 26) results in part from the lack of Conservation Easements for Developed Wooded/Fields being used for the Developed High Intensity Land. This is because the cost of purchase makes conservation easements less cost-effective than structural BMPs (Figure 17).

In contrast to what was suggested by McGarity et al (1), land preservation is not cost-effective when the land must be purchased (Figure 17, Figure 20 Figure 21). The markedly higher cost of reducing the pollutants and runoff to some specified level if the conservation easements must be purchased demonstrates the importance of easement donation. Thus, the CRCWA should consider public outreach aimed at informing the community about the benefits of easement donation. If the municipalities that make up the watershed were willing to offer additional local tax deductions for easement donation, this would be another way to incentivize the donation of easements. It may be worthwhile to incrementally increase the cost of easements within the StormWISE model in order to determine the points at which it becomes less cost effective than other BMPs. This could give the municipalities an idea of how much they may want to monetarily incentivize the donation of easements.

The fact that the difference between the current and predicted future nutrient levels is greater than the future maximum achievable reductions demonstrates the effect of the other urbanization that is expected to occur. The anticipated shift from Developed Low Intensity to Developed Medium Intensity in much of the watershed (Figure 13) accounts for the increased impervious cover that would not be prevented by conservation easements.

There are a number of sources of error in this work. One is that we are using land cover, which is essentially the physical material on the land (vegetative versus constructed, etc), as land use, which is how people utilize the land (residential versus business, agricultural versus pasture, etc). Another is that the initial land use map, upon which the present case and the treatable fraction for conservation easements were based, was only 77% accurate (13).

While this study does demonstrate the possibilities of conservation easements for preventing water quality decline with urbanization, many of the assumptions may not completely reflect reality. One example of this is the treatable fraction values used. It is very unlikely that all of the landowners in the watershed who would be able to donate easements would actually be willing to do so. Thus, it is unlikely that the conservation easements would be able be used as widely as is suggested here.

Another case in which the assumptions to not completely reflect reality is the cost of the structural BMPs. These do not include the cost of purchasing or gaining the rights to the land on which they would be placed, nor the cost of maintenance. This is because maintenance costs vary widely with location and other variables. However, these one-time costs are actually worth different amounts from the maintenance and management costs used for donated easements because they are in different time scales. It would be informative if both costs were to be divided into one-time costs and annual costs and if the estimated life of each were indicated so that present worth analysis could be used compare the actual costs of the BMPs. If specific information can be gained regarding these neglected costs, the accuracy of the model would be improved by their inclusion.

The StormWISE model is open to the inclusion of other benefits besides those that directly affect water quality. Consideration of the SmartConservation and Ecological Green Infrastructure ratings of the land in LCCW would be interesting to do again now that traditional conservation easements have been examined. The locations of potential easements could be ranked as they were in McGarity et al (1). If the people in the municipalities in LCCW decide that conservation for ecological stability is also very important, they may be willing to invest in the purchase of conservation easements in some parts of the watershed.

The StormWISE model may be further improved by allowing the user to define how much money they can spend prior to running the model. They could indicate which problem(s) is/are the most important in their watershed and maximize the environmental benefits, outputting the maximum environmental benefits that could be obtained and which BMPs should be used. This would make sense in LCCW because the work proceeds in chunks of grant money that the Chester Ridely Crum Watershed Association obtains. This program could also be utilized in the proposal of such grants for the implementation of BMPs. They would be able to say, "according to StormWISE, if we get this grant to implement X BMPs, we will reduce the TSS by Y."

While this study was being done, other parts of StormWISE were being altered for improved accuracy. These will have to be integrated into a single functional unit in order to maximize the utility of each of these extensions and alterations.

Acknowledgements

This project could not have happened without the work, guidance and troubleshooting of Arthur McGarity. I would also like to thank David Long, GIS Coordinator at the Delaware County Planning Department. He scanned and sent me zoning maps for every municipality in the watershed and answered my questions about the zoning categories.

Works Cited

1. **McGarity, A.E., et al.** Riparian Corridor Best Management Practices. March 31, 2009.

2. Federal Water Pollution Control Act (Clean Water Act). *Federal Wildlife and Related Laws Handbook.*

3. Federal Water Pollution Control Act. *National Weather Service.* [Online] October 31, 1992. [Cited: August 2, 2008.] http://www.nws.noaa.gov/climate.

4. *Crum Creek Water Quality Restoration and Protection Projects: Growing Greener Program Final Report.* 2004. SE 10403.

5. **PA DEP.** Stormwater Management Program. *PA DEP.* [Online] 2007. [Cited: December 1, 2008.] http://www.depweb.state.pa.us/watershedmgmt/cwp/view.asp?a=1437&q=529063&watershedmgmtNav=|.

6. 2008 Pennsylvania Integrated Water Quality Monitoring and Assessment Report- Streams, Category 5 Waterbodies, Pollutants Requiring a TMDL. *Commonwealth of Pennsylvania Department of Environmental Protection.* [Online] 2008. [Cited: November 15, 2008.] http://www.depweb.state.pa.us/watersupply/lib/watersupply/2008_integratedlist/streamscat5_createdaug1.pdf.

7. **U.S. Department of the Interior and U.S. Geological Survey.** National Land Cover Database 2001 (NLCD 2001). *Multi-Resolution Land Characteristics Consortium (MRLC).* [Online] October 30, 2008. [Cited: April 12, 2009.] http://www.mrlc.gov/nlcd.php.

8. **Little Traverse Conservancy.** Conservation Easements. *Little Traverse Conservancy.* [Online] [Cited: April 12, 2009.] http://landtrust.org/ProtectingLand/EasementInfo.htm.

9. **Bennett, Sherrie.** Zoning Ordinances and Regulations. *Real Estate Lawyers.* [Online] 2009. [Cited: 3 15, 2009.] http://www.realestatelawyers.com/Zoning-Permits.cfm.

10. **McGarity, Arthur.** 2007 Pennsylvania Stormwater Management Symposium. [Online] October 25, 2007. [Cited: November 16, 2008.] http://egrfaculty.villanova.edu/public/Civil_Environmental/WREE/VUSP_2007_Symposium/Web/07abstracts_text.htm.

11. **McGarity, A.E.** *StormWISE Software Documentation.* 2007. Version 1.0.

12. **McGarity, A.** StormWISE: L.P. Model Formulation. *E66 Exercise 9.* Swarthmore : s.n., 2009.

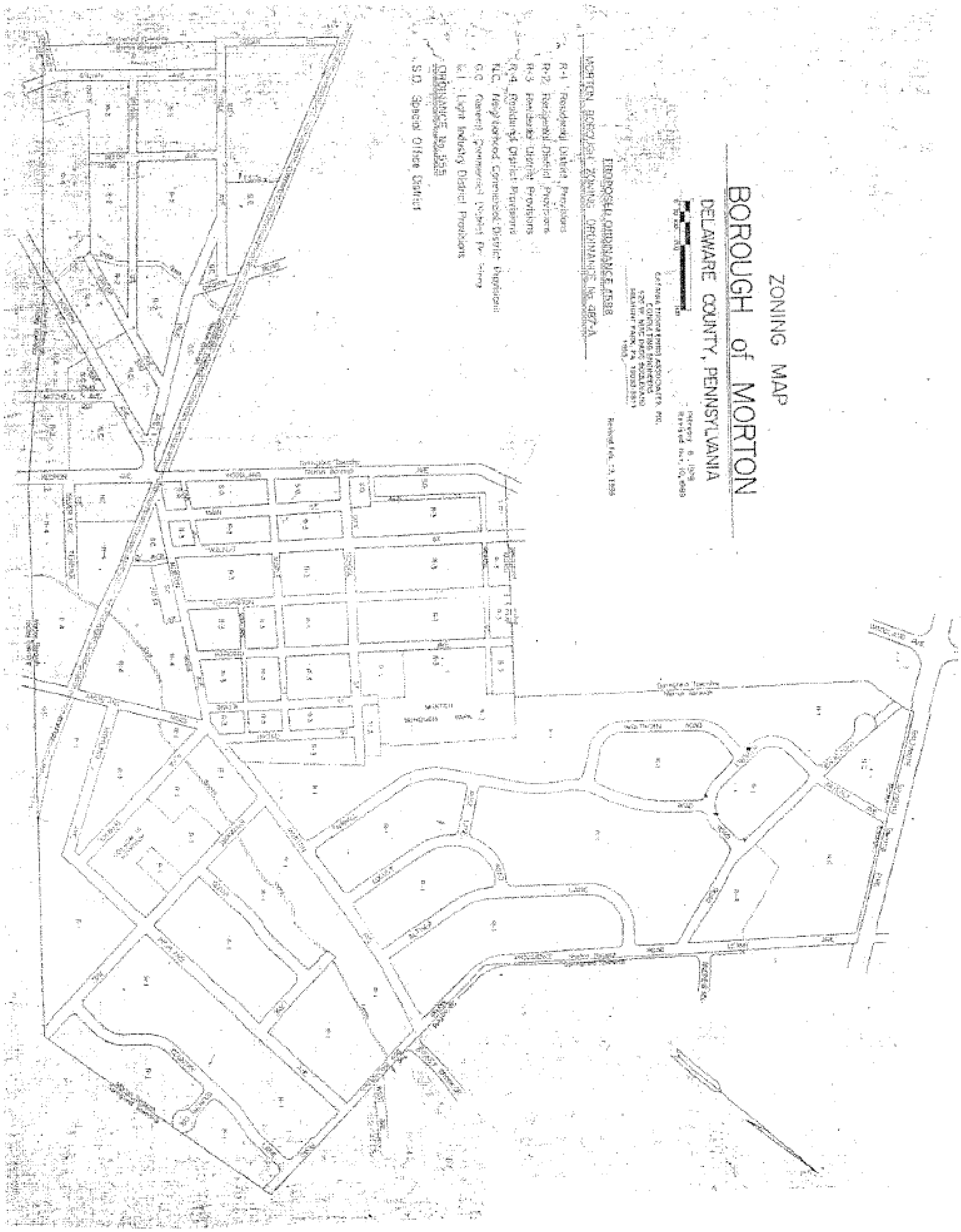
13. *Development of a 2001 National Land-Cover Database for the United States.* **Homer, Collin, et al.** 7, s.l. : American Society for Photogrammetry and Remote Sensing, 2004, Vol. 70.

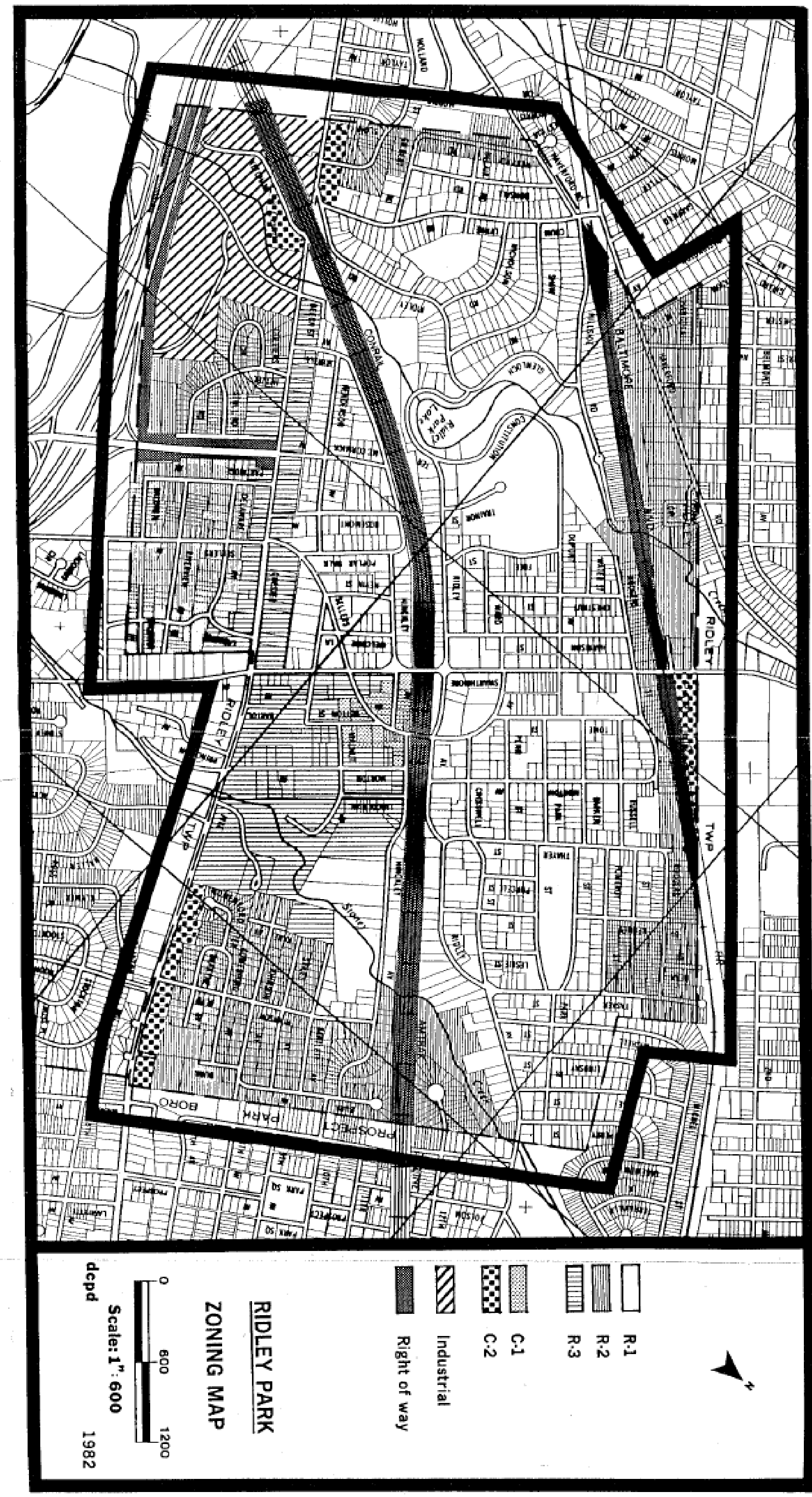
14. Multi-Municipal Comprehensive Plan. *The Borough of Swarthmore.* [Online] October 2006. [Cited: March 6, 2009.] http://www.swarthmorepa.org/government/documents/Multi-MunicipalComprehensivePlan.pdf.

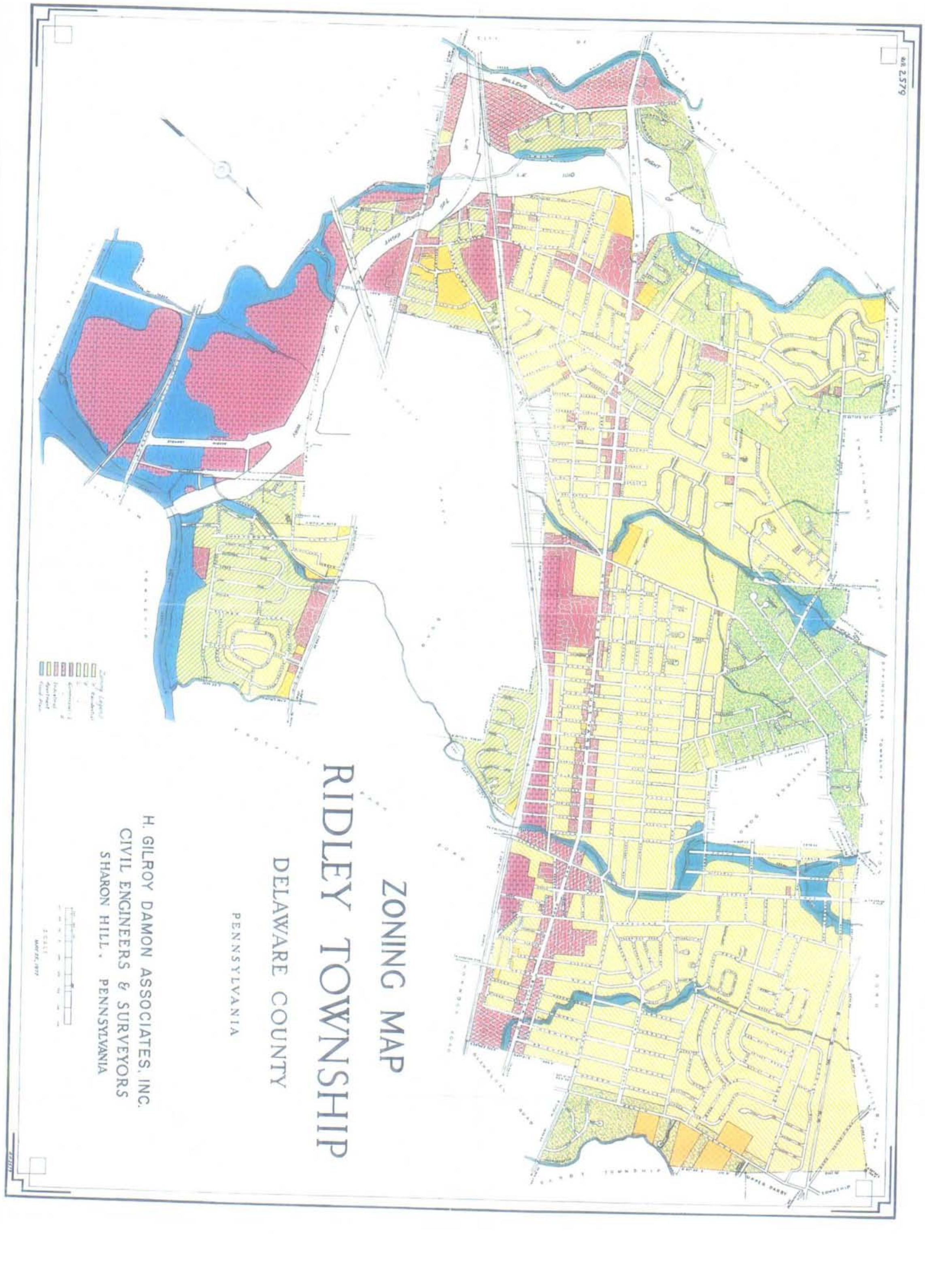
15. **Long, David.** *Delaware County Zoning.* Delaware County, March 26, 2009.

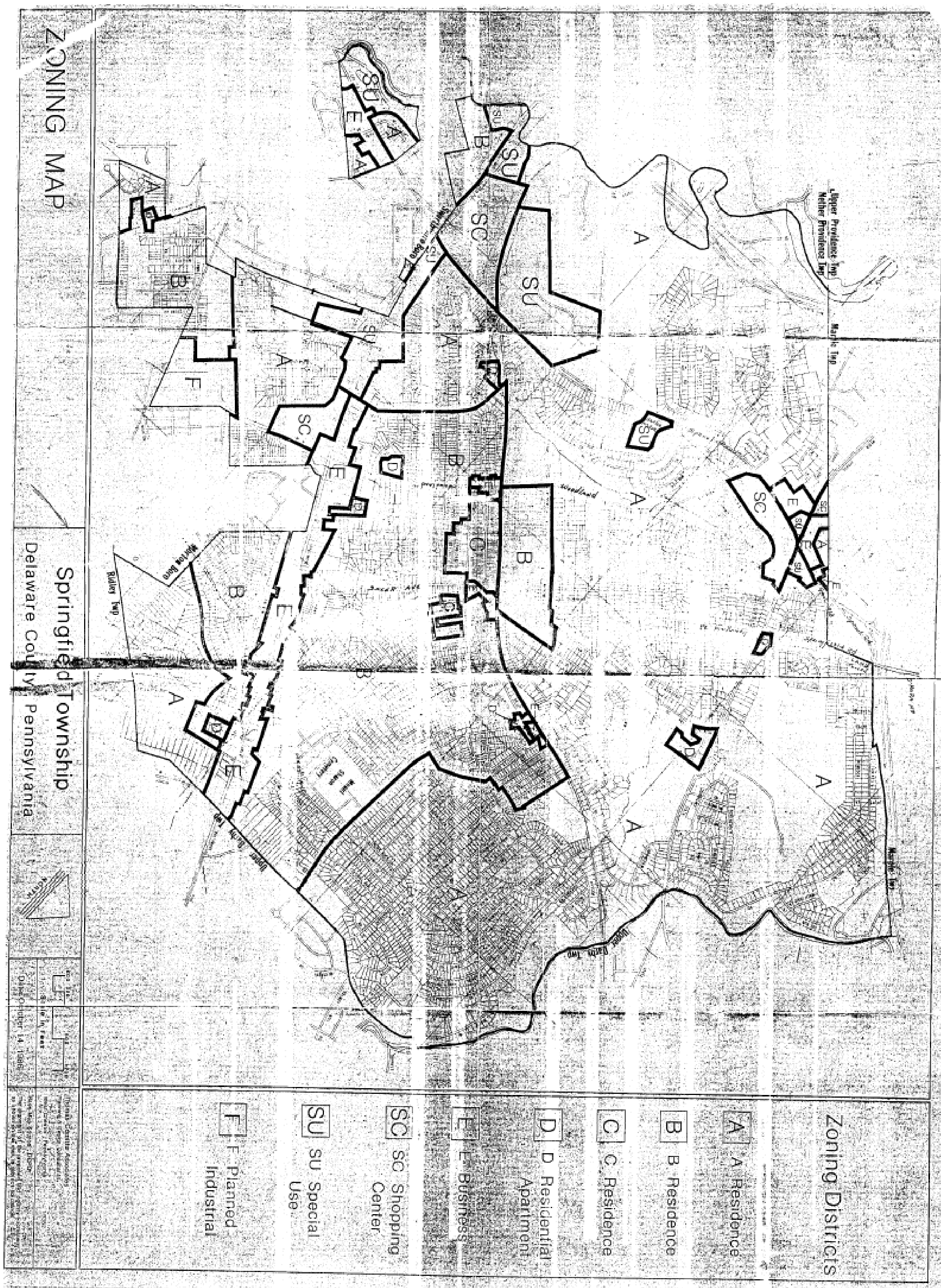
16. **Science Applications International Corporation.** *A Summary of Models for Assessing the Effects of Community Growth and Change on Land-Use Patterns.* Cincinnati : U.S. Environmental Protection Agency, 2000.

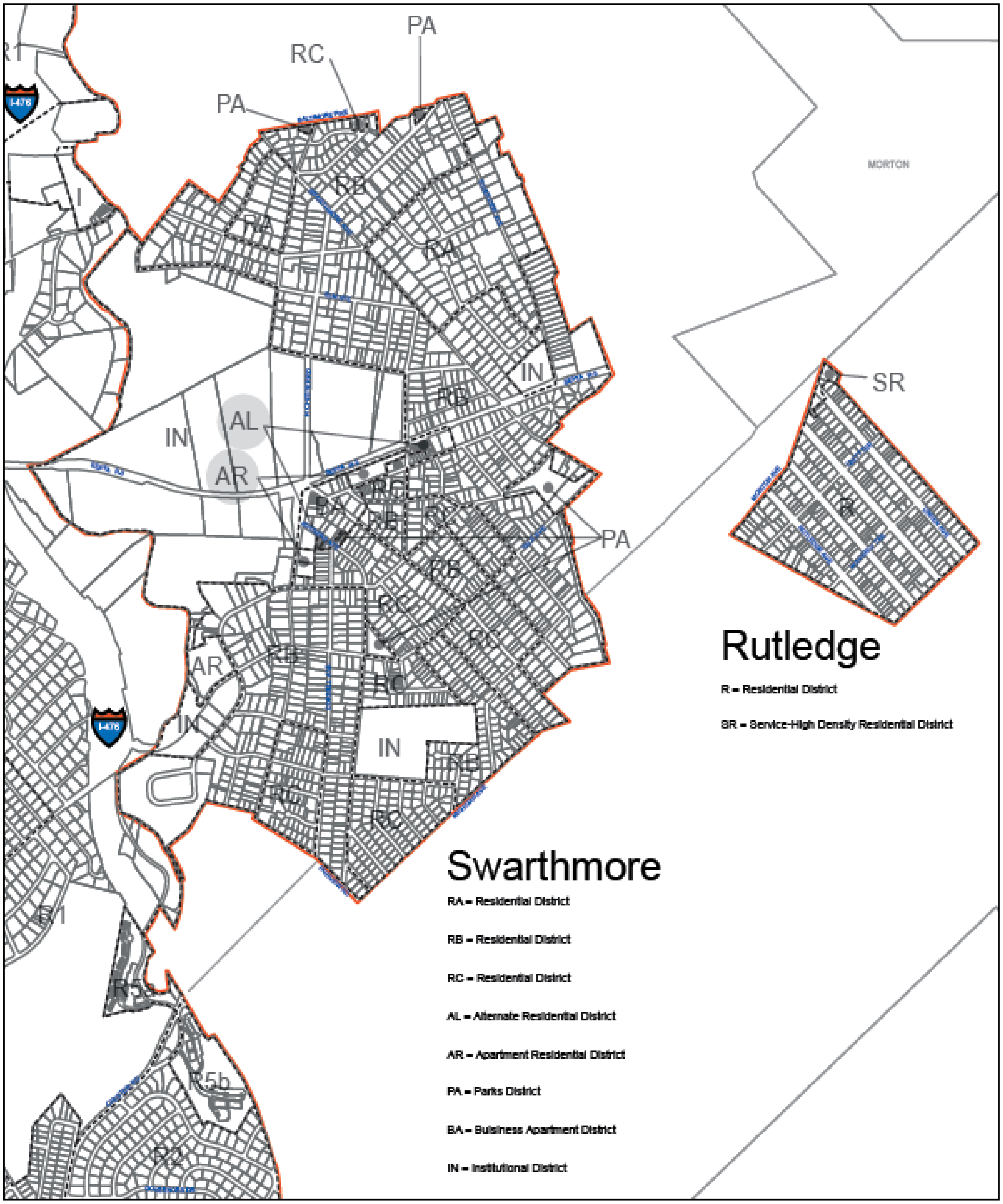
Appendix


ZONING MAP
BOROUGH of MORTON
DELAWARE COUNTY, PENNSYLVANIA
R-3 Residential District Provisions
L-I Light Industry District Provisions
S.O. Special Office District


RIDLEY PARK
ZONING MAP
R-1
R-2
R-3
C-1
C-2
Industrial
Right of way
Scale: 1": 600
0
600
1200
dcpd
1982
RIDLEY
TWP
BORO
PARK
PROSPECT


ZONING MAP
RIDLEY TOWNSHIP
DELAWARE COUNTY
PENNSYLVANIA
H. GILROY DAMON ASSOCIATES, INC.
CIVIL ENGINEERS & SURVEYORS
SHARON HILL, PENNSYLVANIA


ZONING MAP
Springfield Township
Delaware County, Pennsylvania
Zoning Districts
A Residence
B Residence
C Residence
D Residential Apartment
E Business
SC Shopping Center
SU Special Use
F Planned Industrial



This zoning maps is from the "Multi-Municipal Comprehensive Plan for Nether Providence, Rose Valley, Rutledge, Swarthmore."
(http://www.swarthmorepa.org/government/documents/Multi-MunicipalComprehensivePlan.pdf)