MODELING THE VALUE OF ECOSYSTEM SERVICES: APPLICATION TO SOIL LOSS IN SOUTHEASTERN ALLEGHENY COUNTY

By

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ABSTRACT

Putting a price on environmental services could encourage sustainable development and make conservation more appealing. However, one of the difficulties in conservation is being able to quantify the cost of environmental services. The Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) modeling tool, created by the Natural Capital Project and Stanford University, works as a toolbox in Geographic Information Systems (ArcGIS). The model was used to determine the impact on environmental services, specifically soil erosion in southeastern Allegheny County, Pennsylvania. The Allegheny, Ohio and Monongahela Rivers all receive runoff from the surrounding area and have been negatively impacted by an increase in development. Annual soil loss due to erosion, and the associated economic cost, were estimated using the InVEST model and manual calculations. The maps for soils, slope and watersheds, were provided by Pennsylvania Spatial Data Access (PASDA), the digital elevation maps, and the land use, land cover maps were provided by the EPA.

The estimated sediment load for the southeastern area of Allegheny County is 1024 tons/year, all from the Youghiogheny watershed, computed from the InVEST model. The cost of sediment removal is $129,024 per year. When using the Universal Soil Loss Equation for manual calculations, the sediment load ranges from 43,978 tons/year to 146,592 tons/year for the same study area that was used in InVEST.

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CHAPTER 1

INTRODUCTION

1.1 Background Information

In 1992 at the Earth Summit in Rio de Janeiro, the term sustainable development was defined. Sustainable development is the idea that a country's basic human needs are met, while leaving enough natural resources behind to meet the needs of those who come after us. While this is a lofty goal, it is hardly attainable in today's society. The American economy rewards those who are willing assume the financial risk of developing new businesses. This includes developing land that have never before been developed. There are very few incentives to redevelop abandoned property. In the United States developers tend to expand into suburban and rural areas and take up as much space as needed.

According to the Millennial Assessment completed in 2005, 60% of the ecosystem services are being degraded or used unsustainably, which is in direct contrast to sustainable development. Ecosystem services are beneficial functions provided by the environment, such as water filtration, flood management, erosion control, and wildlife habitat. "Between 1960 and 2000 the demand for ecosystem services increased as the world's population doubled" (MA, 2005). Food production, water use, and wood harvest increased to meet the needs of the population. Ecosystem services were consumed or diverted in response to the growing demand for food and water (MA, 2005). The overuse and degradation of these services have compelled some to advocate pricing of environmental services. The idea is, if a value is placed on the service, it would be less likely to be degraded, overused, or developed (Boyd & Banzhaf, 2007). Putting a price on environmental services could encourage sustainable development and make it more appealing.

As the standard of living increases in the United States, the distance to the city center also increases, created by a migration from urban areas to suburban areas. As people earn more money, bigger homes are purchased that require more space, which means living farther and farther from the middle of the city, developing more raw land as the population moves. In the 1940's, the average house size was around 1000 square feet; today it is over 3000 sq ft while the family size has decreased from 4.3 persons to 3.5 (Diamond & Moezzi, 2003). Metropolitan areas have seen the most growth in the United States, however, the majority of the growth has occurred in the suburbs, while the population in the city center has remained stable or has even decreased. In 2000 half the U.S. population lived in the suburbs (Hoobs & Stoops, 2002). In many cases, the urban areas left behind became desolate wastelands of steel and concrete.

Land cover change and pollution loading are major factors that have altered the earth's terrestrial and aquatic ecosystems. Human activities drive land use and therefore land change (Grimm, et al., 2008). Little planning is done with conservation or sustainability in mind, leading to land uses that are incompatible with conservation. Areas that were once trees and meadows are now parking lots with large department stores or do-it-yourself stores, leading to increased runoff, decreased infiltration, dirtier water, and decreased habitat due to the increase in impervious surfaces. The actual cost of the ecosystem services that are being destroyed are not taken into account or charged to the developer or home owners when natural areas are turned into parking lots or subdivisions.

Areas that have been previously developed and abandoned are unattractive to developers for several reasons. One is the cost of demolition; if the building that is on the premises does not suit their needs, they need to demolish the existing structure to build something that satisfies their requirements. Second is available space; if an area is not large enough for a company to build everything they want, they need to look for other areas that can accommodate their vision (Dougherty, 2009). Third, zoning laws could prohibit the company from building the desired structure (Brennan, 2009; Friedman, 2007). Fourth would be environmental laws such as the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) that transfers liability to a new owner for contaminants that previous owners may have left behind (EPA, 2009). These reasons would make it cheaper and easier to develop raw land. In addition, suburban and rural townships are anxious to increase their tax base and provide jobs to improve the community, and frequently use tax abatements and zoning changes to attract development.

In February 2009, Nelson, *et al.* published an article entitled, "Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales," that uses a modeling tool to help determine the cost incurred when environmental services are degraded or removed. The Natural Capital Project, in association with Stanford University, created the

Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) model that predicts changes in services, biodiversity and commodity production levels. This tool may help policy makers develop better zoning and land use plans by predicting the effect of "progress" on the environment (Nelson, *et al.*, 2009).

InVEST consists of a group of models that use land use and land cover patterns to estimate economic values of ecosystem services. Water quality, storm peak mitigation, soil conservation, carbon sequestration and pollination are some of the ecosystem services that can be modeled by using InVEST, with results reported in biophysical or monetary terms, depending on the needs of decision makers. Three different scenarios, conservation development, progressive development and current development, were compared using InVEST for the Willamette Basin, Oregon. The conservation development system was the system that best protected all environmental services in the basin, while the development system caused the most destruction to services.

Development will continue to occur in all areas of the United States for the years to come. Cities will continue to see growth in the suburbs with a movement out of the city center. Smart development will help conserve the green areas and the environmental services provided by those green areas.

1.2 Study Goals

Property abandonment is occurring at a high rate in Pittsburgh as the population moves out of the city into the large suburbs that surround it. Factories that were once a part of the large steel industry have been sitting vacant for a number of years (Smith, 2007). Buildings along the corridor of McKnight Road, a suburban area north of Pittsburgh, have been sitting vacant as well, as people move farther from the city and closer to Cranberry, Butler County, PA, where land is less expensive and taxes are lower. Cranberry Township has experienced an increase in development over the last ten years while the southern end of McKnight Road, with its vacant buildings, has been overlooked and previously undeveloped areas have fallen to the chain saws and backhoes of progress (Kane, 2005). Little thought has gone into the actual cost, including the cost of impact to environmental services, of developing raw land in comparison to remodeling or refurbishing developed areas. Other areas in Allegheny County have followed this trend as well, leading to large tracts of abandoned buildings closer to the city center, as well as in downtown Pittsburgh.

The InVEST model can be used for a portion of Allegheny County to determine the best way to plan for development. Soil conservation is an area that needs to be considered in the region when looking at new developments and planning. The Allegheny, Ohio and Monongahela Rivers all receive runoff from the surrounding area and have been negatively impacted by the increase in development. A better development planning strategy would help improve the storm water runoff quality and decrease the sediment load.

The goal of this project was to perform a trial application of the InVEST model to determine the impact of development on ecosystem services in a portion of Allegheny County. Specific objectives of the project where, 1: To estimate the annual soil loss under current land use conditions in southeastern

Allegheny County using the InVEST model; 2: To calculate the value of the ecosystem services lost due to development.

CHAPTER 2

LITERATURE REVIEW

2.1 Urban Sprawl

2.1.1 Causes

An urban area is defined as a densely populated place with a large number of inhabitants. Sprawl is defined as spreading out in an irregular or straggling way. When these two words are combined the resulting definition is a densely populated place that is spreading out in an irregular way. The 1980 Oxford American Dictionary defines urban sprawl as the uncontrolled growth of urban areas (Ehrlich, *et al.* 1980).

In the U.S., industrialization in the late 19th century fueled the growth of cities and also helped to create a larger middle class that could afford to travel to and from work. Increased car ownership and increased standard of living allowed those that could afford the scenic rural landscapes an opportunity to escape the overcrowded city. After World War II the increased use of the auto and the ability to build farther from the city center increased the proliferation of suburbia. Areas were developed farther and farther from the city center in a "leap-frog" fashion. Zoning laws were created to maintain the draw of suburbia by increasing plot size, creating areas where houses were not as dense. Different amenities, such as stores, homes, industry, and public spaces were kept separate from each other by these zoning laws, contributing to sprawl and the use of cars and to the need for pavement and parking lots for those cars (Frumkin, 2002). Lower density housing created areas where busses do not run, libraries are not built and businesses do not start, because there are not enough people to pay for those amenities (Friedman, 2007).

Human social and economic activities drive land use change and can influence the movement of materials via wind, water, and biological vectors. In industrialized nations urban land consumption is occurring at a higher rate than population growth. In the U.S., even in areas with low population growth there has been an expansion of urban and suburban land uses caused by a declining developmental density and an increase of land consumption per capita (Grimm, *et al*., 2008). In the United States the amount of area that has been urbanized is greater than the amount of land contained in the national and state parks (Cadenasso, *et al.*, 2007). The amount of developed land increased in the U.S. by more than 48% (or 14.2 million hectares) from 1982 to 2003. Open spaces are rapidly being developed to meet the demand for housing (NRCS, 2007). This increase in urban areas has led to a loss of forests, agricultural, and open lands. Predictions for land use indicate that an additional 10-20 million hectares of forested land will be impacted by urban growth by 2050 (White, *et al*., 2009).

2.1.2 Effects

Several descriptive phrases are used to create a better picture of the effects of urban sprawl e.g.; development, poor accessibility and automobile dependency, fragmented open space, lack of functional space, and high edge contrast. One of the most serious problems with urban sprawl is the destruction of natural lands and farmland (Berlin, 2008). The fragmentation of habitat by large subdivisions is a serious threat to biodiversity. Low-density developments contribute to an increase in impervious surfaces, miles driven, water use, energy use, air pollution and greenhouse gas emissions (Farr, 2008).

Wetlands are drained and paved which contributes to increased flooding and stormwater runoff (Berlin, 2008). The removal of forests and the increase in pavement and other impermeable surfaces changes the microclimate in areas, creating heat sinks. The removal of trees also causes an increase in sedimentation in rivers and streams leading to increased dredging, while the increase in storm water runoff causes stream bank erosion and habitat degradation (Newport, 2009).

Before vast amounts of land were paved, water would fall on vegetated land with a large layer of topsoil and this would allow large amounts of water to infiltrate into the ground, slowing and decreasing the amount of water that would reach a stream, river, or lake. Prior to industrialization, 0-10% of the precipitation would run over the ground and make it into the nearby water bodies, now over 60% flows off the land and into receiving water (Newport, 2009). Figure 2.1 compares the runoff that occurs on vegetated ground with runoff that occurs on impervious surfaces.

Stormwater runoff is the water that is generated when precipitation falls, and flows over land and impervious surfaces without infiltrating into the ground. As the runoff flows over surfaces it collects debris and pollutants that negatively affect water quality if it is not treated. In urban areas the stormwater is collected in a storm sewer system, becoming point source pollution, then released into a receiving body. Water that does not make it into the storm sewer runs over land and becomes nonpoint source pollution (EPA, 2009).

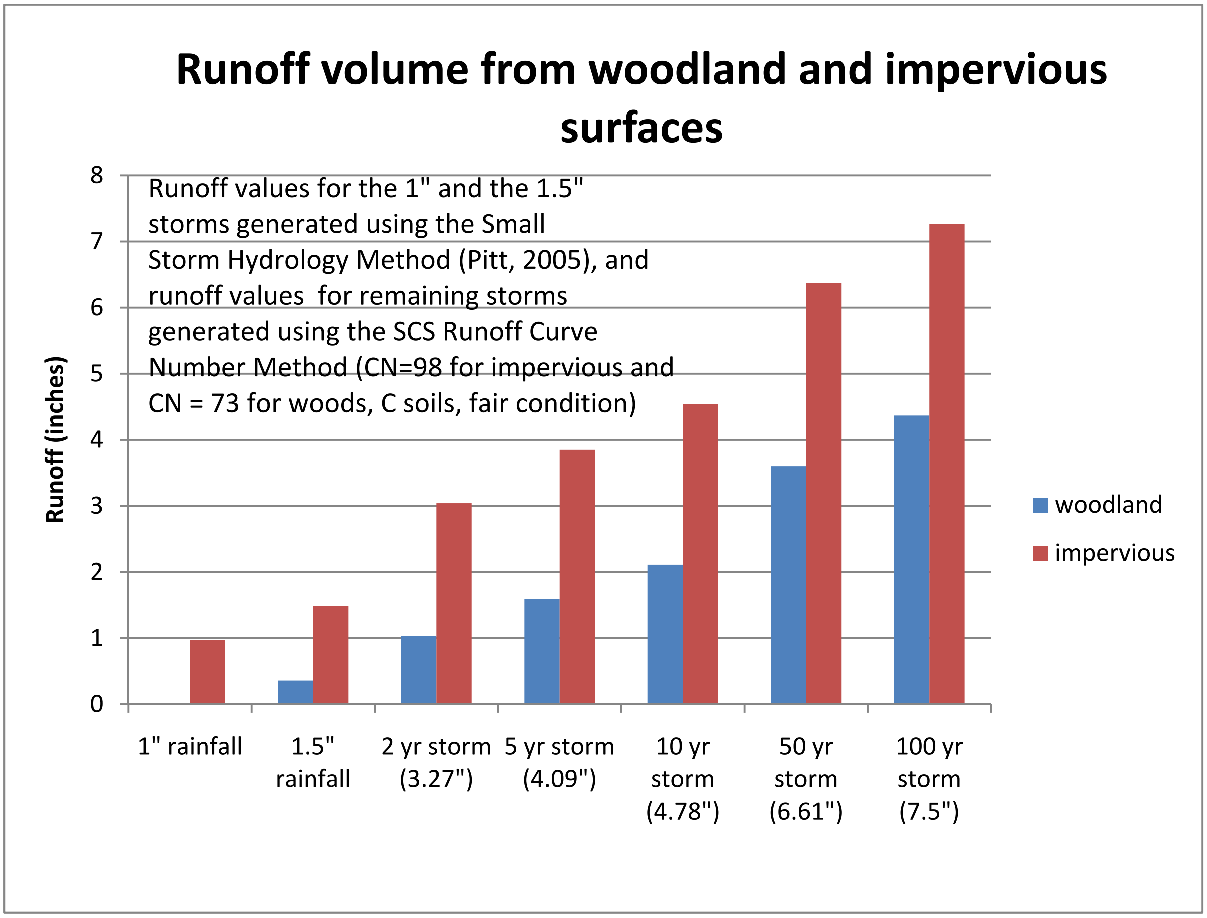


Figure 2.1 Comparison of runoff between impervious surfaces and woodlands areas, typical of watersheds in Pennsylvania (PaDEP, 2006)

Land development results in more rapid surface runoff, higher peak discharge in streams, and greater total volume of runoff during a storm event, as shown by the hydrographs in Figure 2.2. As the volume of runoff increases, the natural form of the stream changes due to more frequent bankfull conditions. Pools and riffles that support aquatic life are degraded to an unnatural level and the sediment in the stream increases from the erosion of the banks, which smothers stream bottom habitat. The majority of stream channel erosion happens during small to moderate precipitation events that occur frequently.

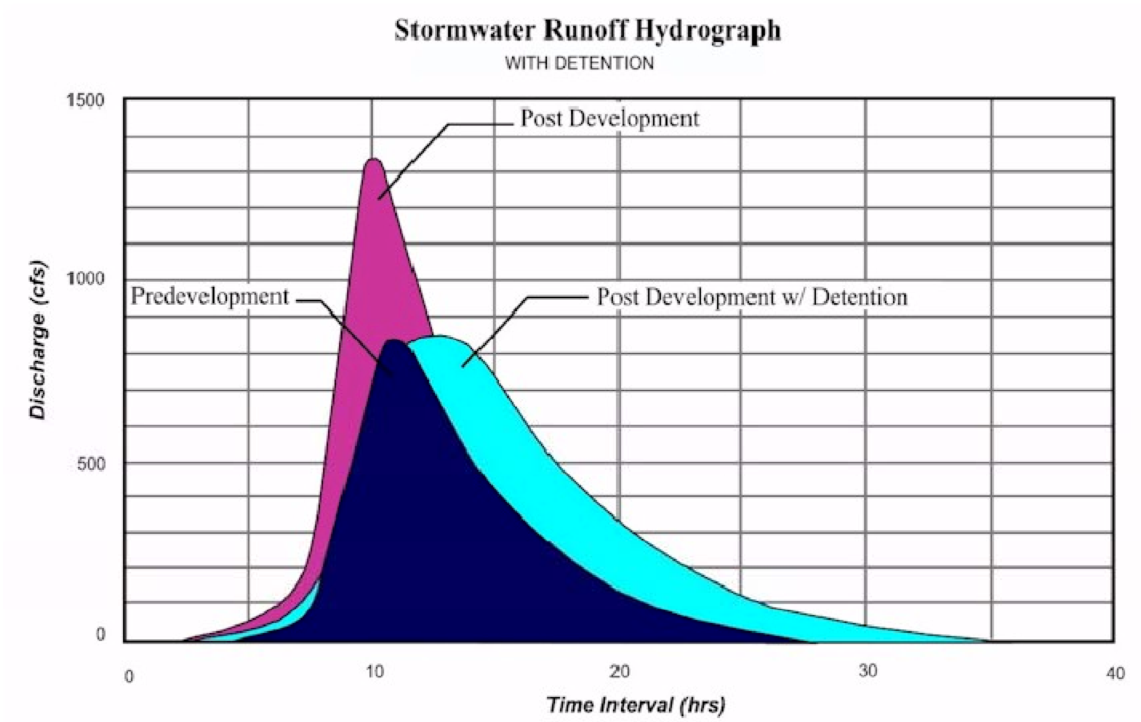


Figure 2.2 Impact of development on the stormwater runoff hydrograph (PaDEP, 2006)

In 1999 the Environmental Protection Agency (EPA) enacted Phase II of the Stormwater Program. This extends Phase I by including more entities (e.g., smaller cities) that are required to have an NPDES permit to discharge stormwater into bodies of water. The Phase II is the next step in the EPA's attempt to further reduce adverse affects to water quality and aquatic habitat by controlling unregulated sources of stormwater discharge. The Phase II final rule was published in the *Federal Register* on December 8, 1999 and the permitting agencies were required to issue general permits for small municipal separate storm sewer systems (MS4) and for small construction activities by December 9, 2002. Operators of small MS4s are required to design their programs to: reduce discharge of pollutants to the maximum extent possible, to protect water quality, and satisfy appropriate requirements of the Clean Water Act (EPA, 2005).

The EPA and many other state agencies have developed design guidelines for best management practices (BMPs) to control the quality and quantity of stormwater runoff. Non-structural BMPs include site development and planning that minimize effects on land, water and air, as well as maintaining urban forestry and riparian buffers. Preserving open space, protecting natural systems, and incorporating natural features such as wetlands and stream corridors are preferential BMPs that help maintain a more natural and functional landscape (PaDEP, 2006). Structural BMPs for post construction include many types of green infrastructure including, green parking, green roofs, bioswales, and rain gardens, all with the intent of containing stormwater runoff. Many cities and municipalities have already started working towards improving the quality and reducing the quantity of runoff by implementing the BMPs set forth by the EPA (EPA, 2005).

Soil erosion and deposition are natural processes that are affected by the pattern of land use and land cover. It affects water quality, availability and storage. Soil properties, precipitation patterns, slope of the landscape, vegetation, and land management are factors that affect the magnitude of the erosion and sediment transport (Tallis, *et al*., 2008). The increased sediment load decreases the life of reservoirs and increases the cost of water treatment (Elliot & Ward, 1995). Erosion reduces agricultural productivity, increases water volume by increasing flow rates and decreasing infiltration rates, and increases pollutant transport. The removal of surface soil by erosion causes a decrease in the amount of air, water, and nutrient availability to plants. Organic matter is removed by eroded sediments, which degrades soil structure and reduces fertility. Nutrients carried by sediment also contribute to the eutrophication of lakes and streams, while pesticides decrease surface water quality (Elliot & Ward, 1995). The loss of soil and nutrients create areas that are less favorable for plants to grow, contributing to loss in agricultural productivity (NRCS, 1996). Soil loss of 1/32 of an inch converts to 5 tons of soil per acre that is lost. 2.7 billion tons of sediment are transported by streams a year in the U.S. (Pimentel & Skidmore, 1999).

Erosion is caused by the impact of raindrops hitting the ground and by the power of running water on the surface of the soil. Rates of erosion depend on soil quality, landscape, and weather conditions. When plant cover is depleted, distance between plants increases, and soil structure is degraded by excessive disturbances, creating an acceleration of erosion. Sandy or clay soils are less erodible than loam or silty loam soils and rock fragments and biological crusts on soils are protection from rain drop impacts (NRCS, 2001).

Increased sediment removal beyond that of natural geologic erosion is caused by several things. One is increased human activity, such as development and agriculture. The other is vegetation removal by animals or other natural events. Impacts from animals include overgrazing which lead to vegetation death, compaction of soils and removal of soils by migration.

2.2 Ecosystem Services

2.2.1 Definition

Ecosystem services are benefits provided by ecosystems, which may be classified as: provisioning, regulatory, cultural, and supportive. Provisioning services include products obtained from the ecosystems, such as, food, water, timber, fiber and genetic resources. Moderation of floods, climate, diseases, and water pollution are part of regulatory services. Cultural services are nonmaterial benefits like recreation and aesthetic enjoyment, while supportive services, which are necessary for all other ecosystem services, include soil formation, pollination, and nutrient cycling (MA, 2005). All ecosystem services are connected; processes work together and are critical for maintaining ecosystem health and human well-being (Tallis & Polasky, 2009).

Gretchen C. Daily, 1997, wrote that ecosystem services are defined as "conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life. They maintain biodiversity and the production of ecosystem goods, such as seafood, forage timber, biomass fuels, natural fiber, and many pharmaceuticals, industrial products, and their precursors" (Daily, 1997). This is the definition generally used today when explaining ecosystem services.

In recent years, environmental economists have proposed a new definition in which ecosystem services are the aspects of nature that society uses, consumes or enjoys to experience environmental benefits. Ecosystem services are the end products that directly affect human well-being. The environmental benefits referred to in the definition include damage avoidance, recreation, human health, and crop harvesting (Bartelmus, 2009). While both of these definitions are beneficial in understanding environmental services and putting a dollar value on them, these definitions are just one component of the comprehensive approach necessary to decrease the overuse and degradation of natural resources.

2.2.2 Valuing ecosystem services

In the last 50 years, the demand for ecosystem services has grown significantly as the world's population has doubled. Food production has increased by two and a half times, water use has doubled and other services have doubled and/or tripled as well. Changes in land use significantly impact the amount and quality of ecosystem services (Phaneuf, *et al.,* 2008). Research done for the Millennial Assessment found that 60% of Earth's ecosystems are being degraded or used unsustainably. These services include water supply, waste treatment, regulation of erosion, water purification and natural hazard protection. The degradation of these services can cause significant harm to the human population (MA, 2005).

The value of ecosystem services is currently ignored or underestimated. A majority of resource decisions are influenced by the supply and demand of resources that enter a market; the services and benefits that do not enter a market are often overlooked, lost or degraded (MA, 2005). However, many environmental services that are not traded are essential for the production of goods that are. If current trends continue, human demand for ecosystem services may exceed Earth's ability to provide them (Bennett, *et al.,* 2005). There is little incentive for decision makers, such as governments, corporations, or landowners, to account for ecosystem services in their decision making. These individuals or companies continue to get paid a fair market value for the product that has been produced, while they do not bear the full cost associated with the loss of an ecosystem service (Tallis & Polasky, 2009).

One of the challenging aspects of putting a value on ecosystem services is that different disciplines, philosophical views, and schools of thought assess services differently. One concept puts a value on services in relation to what can be provided to humans for them to use. Part of this concept is also a non-use value, where a value is placed on a service due to its potential use or just its existence (i.e. conservation of the service) (MA, 2005). Other challenges in putting a price on nature are the technical problems and cultural objections. In order for ecosystems to survive they must be able to compete in the world's financial market today (Jenkins, 2002). "Without benefit measures it is impossible to judge whether the restoration or creation of one ecosystem is an adequate trade for the loss of another (Boyd & Wainger, 2003)."

Currently ecosystem services are not clearly defined which makes it extremely difficult to put a price on them. Some have proposed a "green GDP," which includes the benefits of ecosystems in the gross domestic product (GDP). In determining the GDP for any country, two things are involved: price of products and units sold. For environmental services, such as water filtration, flood management and many others, there are is no way to isolate a price or define a unit for that service. Most environmental services are considered public goods and are not traded on any market; therefore governments would need to define the units as well as the price (Boyd & Banzhaf, 2007).

One idea for paying for environmental services is to charge an eco-tax or tradable pollution permit to pay for the cost of the damage to environmental services. The problem with this idea is that the cost for damage must be determined and has not been standardized. Assessing welfare effects of damages to services is another idea of how payment could be determined. This system, however, would rely on a willingness to pay, which would be different in different areas, depending on social norms, lifestyle, as well as standard of living (Bartelmus, 2009).

An example of an eco-tax can be found in Brazil. In most states in Brazil there is an 'ecological' value-added tax. The Imposto sobre Circulaçã de Mercadorias e Serviços, ICMS-E, is the first economic instrument to pay for services provided by standing forests in Brazil (May, *et al*., 2002). The ICMS-E creates revenue that is paid to the municipalities based on their performance in various environmental areas. There are incentives to create conservation areas where there is low productive agriculture. The ICMS-E was developed to compensate the states for costs they incurred by the restrictions created from conservation of large areas of land. The funds the municipalities receive from the ICMS-E are used at the discretion of the local government and are used for wells, tractors, maintenance of seedling nurseries, garbage collection, landfills and environmental education (May, *et al.,* 2002). The ICMS-E legislation has been associated with an increase in conservation areas.

An example of a tradable pollution permit can be found in the U.S., where wetland banking has become the standard for wetland mitigation. The objective of wetland banking is to provide a replacement for the biological and chemical functions of the original wetland resource which was lost due to impacts; in essence it is a habitat trading program. The 1995 guidelines from the EPA provided this definition for a wetland bank, "A site where wetlands and/or other aquatic resources are restored, created, enhanced, or in exceptional circumstances, preserved expressly for the purpose of providing compensatory mitigation in advance of authorized impacts to similar resources is a mitigation bank." Wetlands banks are set up by a third party, the area of the proposed bank is approved by the EPA and the Army Corps of Engineers (ACOE) and the owner sells credits to developers that would like to build on a current wetland. The guidelines for banks include goal setting, site selection, technical feasibility, inclusion of upland areas, and planning, all of which are monitored and approved by the EPA and ACOE (EPA, 1995). This process helps to diffuse the conflict created by peoples wish to live on or near the coast while still enforcing strong laws that are in place to protect wetlands (Salzman & Ruhl, 2002).

2.3 InVEST

There are several aspects that impede the creation of tools that put a price on ecosystem services and enable ecosystem-based management. One challenge is understanding how ecosystems work together and the benefits and processes that cross ecosystem boundaries, as well as how their structure and function determine the different levels of services provided. A second challenge is the generation of a value for the ecosystem services (Tallis & Polasky, 2009).

The Natural Capital Project has developed a tool that addresses ecosystem-based management. The tool, Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST), is a computer modeling tool that is based on ecological production functions and economic valuation methods. InVEST is used to bring the biophysical and economic information about ecosystem services together to impact conservation and natural resource decisions. InVEST looks at relationships between multiple services, focuses on services rather than biophysical processes, provides output in economic terms, and is spatially explicit (Tallis & Polasky, 2009).

The Avoided Reservoir Sedimentation (ARS) model is a specific tool in the InVEST model that calculates average soil loss, valuing the ability of the land to retain sediment and assessing the cost of removing accumulated sediment from a certain area on an annual basis. The ARS uses the Universal Soil Loss Equation (USLE) to estimate the average annual rate of erosion for each landscape unit (Tallis, *et al*., 2008).

The USLE is shown in equation 2.1

$$A = R*K*LS*C*P \tag{2.1}$$

A = average annual soil loss in tons/acre

R = rainfall and runoff erosivity index for a geographic location

K = soil erodibility factor

LS = slope steepness and length factor in meters

C = cover management factor

P = conservation practice factor

These factors help to determine the soil loss potential of an area. The InVEST model "uses the USLE, the reservoir location and the avoided cost of sediment removal to value the capacity of a parcel of land to retain sediments. The avoided cost of sediment removal is the savings due to the reduced need for sediment removal as a result of upland vegetation and watershed land use practices (Tallis, *et al.,* 2008)."

Originally the USLE was developed for small scale conservation purposes but has gained acceptance for use in broad scale applications for several reasons. First, the soil erosion is dependent on a set of measurable environmental controls and allows for data input over large land area. Second, it consistently reveals the response of soil erosion to a change in management practices. Lastly, the USLE is a simple mathematical form that allows for easy calculations with large data sets (Lu, *et al.*, 2003).

2.4 Sustainable Development

"Conservation is costly, since land preservation requires society to forego disruptive economic activity on protected lands (Ando & Getzner, 2005)." "When building a green project, the most common concerns of sustainable development must be weighed against practicality, marketability, quality and cost (Friedman, 2007)." Mixed land use, high density development, and a range of housing types are the three ideas that need to be considered for sustainable development. When land uses are mixed, public amenities are located near housing, reducing reliance on cars and roads. With high density developments there is an opportunity to increase green space. A range of housing types will encourage integrated neighborhoods of singles, families, and seniors from all income levels (Friedman, 2007).

When planning a high density development, special attention must be paid to the sites natural conditions and zoning. Trees can be preserved when building are planned for already open areas. Land is preserved when lot sizes are reduced; however, the arrangement of houses may need to be reconfigured for privacy. Apartment buildings and multi-family homes should be included in the design of a neighborhood to increase the density without increasing the space used. Non-residential buildings, such as retail stores, libraries and hospitals, should also be considered in a high density development. These buildings can be placed at the center of the development within easy access to all neighborhood residents, or on the periphery, still easy to access, but also available to nearby communities. The mixed uses will create a different neighborhood dynamic and encourage walking instead of driving (Friedman, 2007).

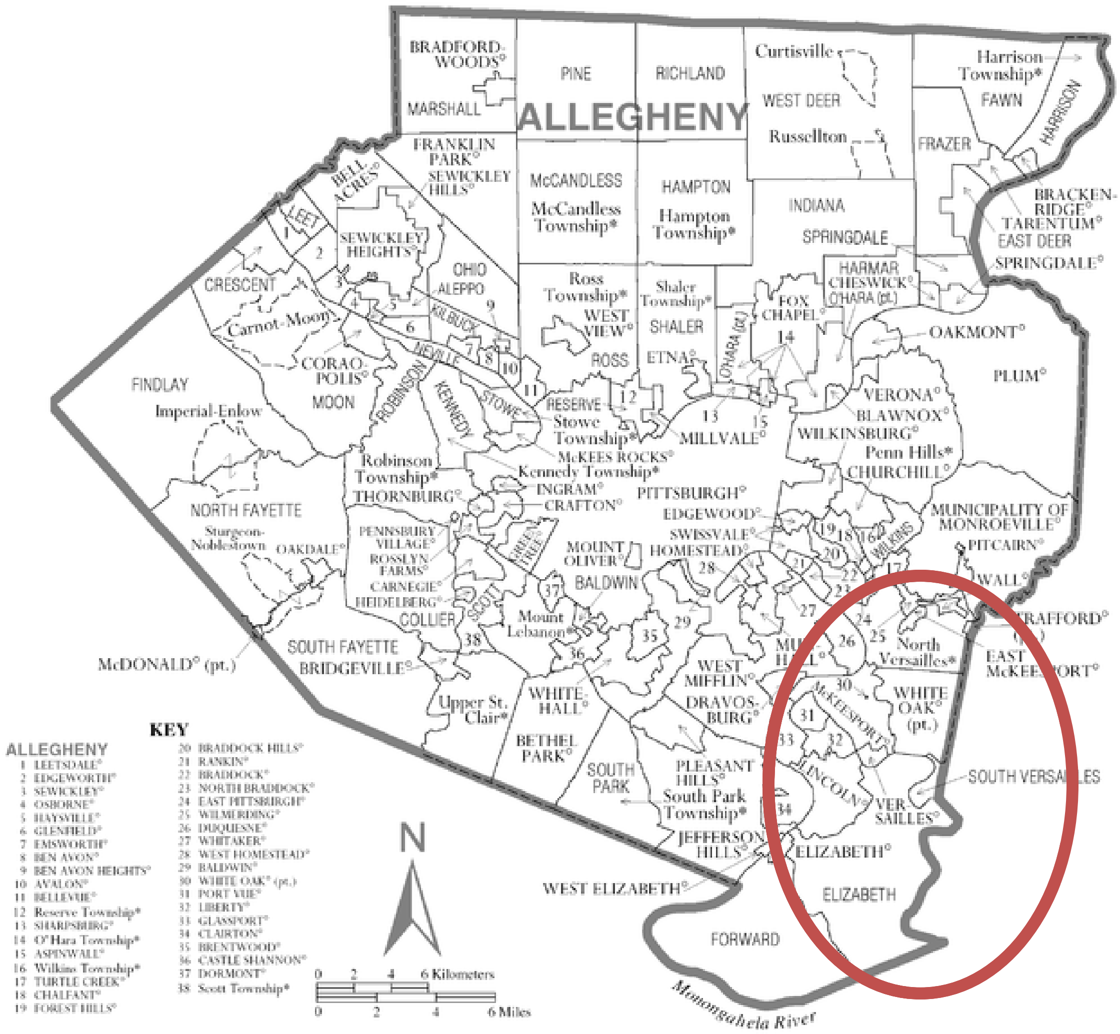
CHAPTER 3

METHODS AND PROCEDURES

3.1 General Description of Original Data

3.1.1 Study Area

The area used for the model application was a portion of southeastern Allegheny County, Pennsylvania. It included the boroughs of McKeesport, White oak, Liberty, Versailles, North Versailles, Elizabeth, and Lincoln. The total area is 75 sq. miles or 48,308 acres (Figure 3.1). The population from the 2000 U.S. census of the area was 50, 823. The population is decreasing in these areas, at a rate similar to the rest of Allegheny County. The trend for the county is a migration to the suburbs and an emptying of the city center, as well as a net population migration out of the county. Several areas in the county have had to manage large amounts of sediment that have been deposited in navigation channels and reservoirs used for recreation. The ACOE has a part of their budget specifically appropriated for dredging of the navigation channels in the river (Hawk, 2010).



3.1.2 Sources of Data

The maps that were necessary to run the InVEST model were obtained from the Pennsylvania Spatial Data Access (PASDA), the Pennsylvania Geospatial Data Clearinghouse and the BASINS software provided by the U.S. EPA. The digital elevation maps (DEM's) and the land use/land cover were provided by BASINS, while the soil, watershed, and basins were provided by

PASDA. All maps were entered into ArcGIS and clipped to the boundaries of study area.

The soil information was gathered from the Allegheny County soil survey of 1981. The survey provided the information on the soil types (Newbury, *et al.,* 1981). The soil erodibility (K) was determined by using the soil type provided in the survey and entering it in the chart generator from the National Resources Conservation Service website, which creates charts that contain physical properties of soils (NRCS, 2009). A summary of the inputs obtained for the soils in Allegheny County is shown in Table 3.1

Table 3.1 Common soil types in Allegheny County, with soil erodibility factor (K) and rainfall and runoff erosivity index (R). (Soil Survey of Allegheny County 1981)

abbr	name	%slope	K	R
AgB	Allegheny silt loam	2-8%	0.32	111
At	Atkins silt loam	0-3%	0.32	111
BrB	Brinkerton silt loam	2-8%	0.32	111
CkB	Clarksburg silt loam	3-8%	0.37	111
CwB	Culleoka-Weikert silt loam	3-8%	0.32	111
DoB	Dormont silt loam	2-8%	0.37	111
ErB	Ernest silt loam	2-8%	0.43	111
EvB	Ernest-Vandergrift silt loam	3-8%	0.35	111
GlB	Gilpin silt loam	2-8%	0.43	111
GpB	Gilpin-Upshur silt loam	3-8%	0.49	111
GuB	Guernsey silt loam	2-8%	0.43	111
GvB	Guernsey-Vandergrift silt loam	3-8%	0.35	111
HaB	Hazleton loam	3-8%	0.17	111
Ln	Lindside silt loam	0-3%	0.32	111
RaA	Rainsboro silt loam	0-3%	0.43	111
UCB	Urban land-Culleoka complex	0-8%	0.16	111
UGB	Urban land-Guernsey complex	0-8%	0.21	111
WhB	Wharton silt loam	2-8%	0.37	111

Rainfall erosivity index (R) is the potential energy of rainfall. This index corresponds to the potential erosion risk in a given region where sheet erosion appears on a bare plot with a 9% slope (unknown, 2010). Texas A&M University maintains a website that calculates the erosivity in any specific area, for a given zip code, for certain times of the year. The R values for zip codes in the study area vary from 97 to 102. Texas A&M also provides a zone distribution map that provides the average erosivity for each general zone in the U.S. The erosivity index for the zone that contains Allegheny County is 111 (TAMU, 2003). The model was run with the average, 111, for the zone, as well as 100, to determine if there was a significant difference in the result.

The land use/land cover information, Figure 3.1, which was used in the soil loss equation by the model, was from a publication from the USGS Land cover Institute. James Anderson, *et al.*, published a paper "A Land Use and Land Cover Classification System for Use With Remote Sensor Data," that includes the codes that were necessary in the model (Anderson, *et al.,* 2001). The codes were also used to determine the cover management factor (C), the conservation practice factor (P) and the sediment retention value, all of these were part of the table of input data that was used to run the model.

The conservation practice factor and the cover factor for the USLE were determined using the graphs and tables provided in the publication, "Predicting Rainfall Erosion Losses: A Guide to Conservation Planning" produced by the U.S. Department of Agriculture (Wischmeier & Smith, 1978). Factor *C* is the ratio of soil lost from land under specified conditions to the corresponding loss from clean tilled, continuous fallow. This measures the combined effect of the interrelated cover and management variables (Wischmeier & Smith, 1978). Residential land, urban and industrial land use areas had a *C* value of .9 to1, since there is no canopy or vegetation cover on the soil. The C value for agriculture areas was .1 to .35, and for forests it is 0 (Figure 3.2).

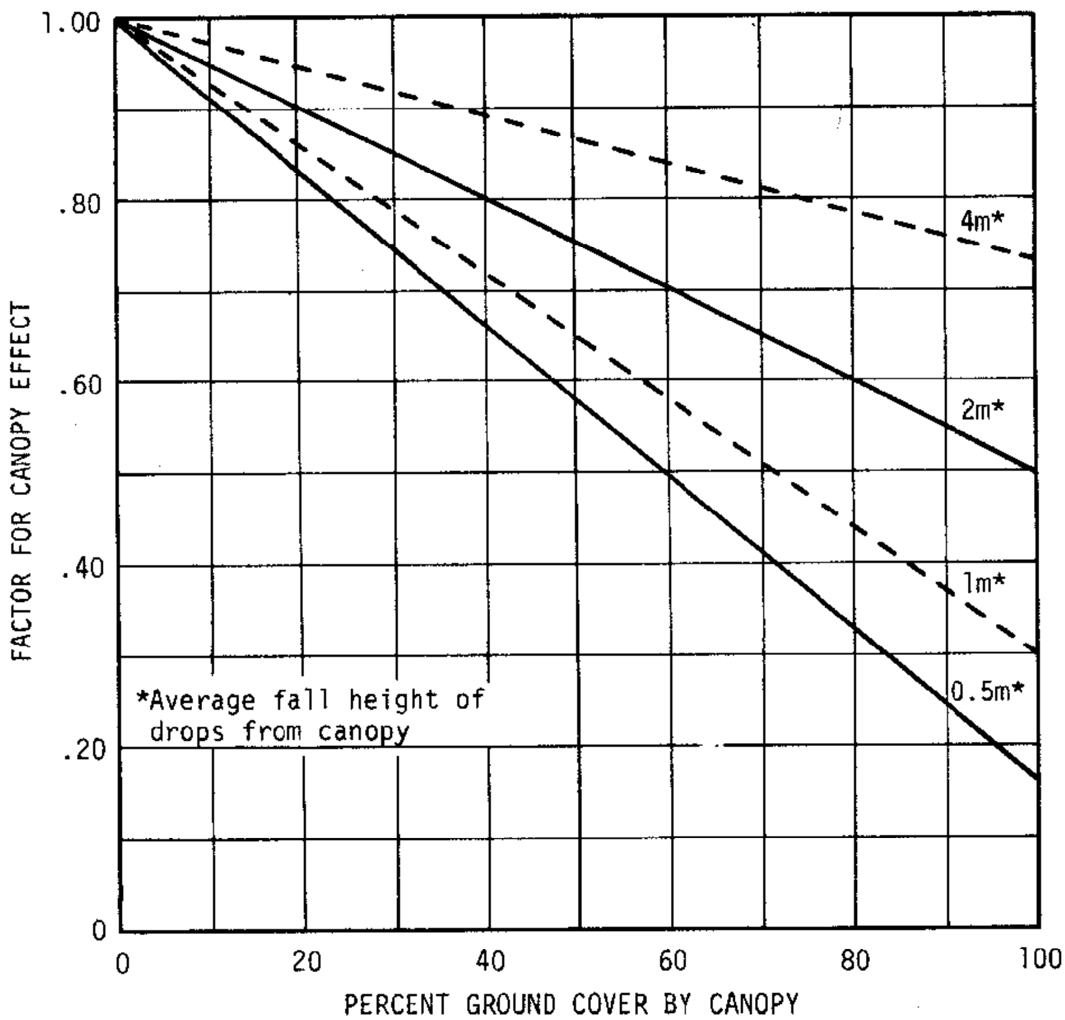


Figure 3.2 graph to determine C value (Wischmeier & Smith, 1978)

The support practice factor (P*)* is the ratio of soil loss with the specific support practice (e.g. contouring, strip cropping, terracing) to the corresponding loss with no erosion control (Wischmeier & Smith, 1978). Because of the large amount of hilly areas in Allegheny County, contour farming is the accepted mode of tilling, which has a P value of .6. For land use areas that included other agriculture such as, fruit tree orchards or pastures for cattle, the P value was .5. For forested areas and for residential and industrial areas the P value was 1.

The length-slope factor (LS), the distance that a drop of rain or sediment travels until its energy dissipates, was calculated automatically within the model while computing the soil loss. To check model results, sample calculations were performed using the table provided in the "Predicting Rainfall Erosion Losses" by Wischmeier & Smith (Figure 3.3) (Wischmeier & Smith, 1978). The slope length in the model was set at 72.5 feet, so that was the value used to determine the LS factor for manual calculations. The region used in the model has a slope of .5-3%. Manual calculations were run using both .5% and 3% in Excel, using the LS values determined from table 3.2. Slope was determined to be .5% in the study area using the Streamstats website (USGS, 2010). Soils in the study area have slope range of 0-3%. Manual calculations were performed with slope of 3% to obtain the upper limit of soil loss estimates.

Table 3.2 Values of LS for specific combinations of slope length and steepness (Wischmeier & Smith, 1978)

Percent slope	Slope length (feet)											
	25	50	75	100	150	200	300	400	500	600	800	1,000
0.2	0.060	0.069	0.075	0.080	0.086	0.092	0.099	0.105	0.110	0.114	0.121	0.126
0.5	.073	.083	.090	.096	.104	.110	.119	.126	.132	.137	.145	.152
0.8	.086	.098	.107	.113	.123	.130	.141	.149	.156	.162	.171	.179
2	.133	.163	.185	.201	.227	.248	.280	.305	.326	.344	.376	.402
3	.190	.233	.264	.287	.325	.354	.400	.437	.466	.492	.536	.573
4	.230	.303	.357	.400	.471	.528	.621	.697	.762	.820	.920	1.01
5	.268	.379	.464	.536	.656	.758	.928	1.07	1.20	1.31	1.52	1.69
6	.336	.476	.583	.673	.824	.952	1.17	1.35	1.50	1.65	1.90	2.13
8	.496	.701	.859	.992	1.21	1.41	1.72	1.98	2.22	2.43	2.81	3.14
10	.685	.968	1.19	1.37	1.68	1.94	2.37	2.74	3.06	3.36	3.87	4.33
12	.903	1.28	1.56	1.80	2.21	2.55	3.13	3.61	4.04	4.42	5.11	5.71
14	1.15	1.62	1.99	2.30	2.81	3.25	3.98	4.59	5.13	5.62	6.49	7.26
16	1.42	2.01	2.46	2.84	3.48	4.01	4.92	5.68	6.35	6.95	8.03	8.98
18	1.72	2.43	2.97	3.43	4.21	3.86	5.95	6.87	7.68	8.41	9.71	10.9
20	2.04	2.88	3.53	4.08	5.00	5.77	7.07	8.16	9.12	10.0	11.5	12.9

[1] $LS = (\lambda/72.6)^m (65.41 \sin^2 \theta + 4.56 \sin \theta + 0.065)$ where λ = slope length in feet; m = 0.2 for gradients $<$ 1 percent, 0.3 for 1 to 3 percent slopes, 0.4 for 3.5 to 4.5 percent slopes, 0.5 for 5 percent slopes and steeper; and θ = angle of slope. (For other combinations of length and gradient, interpolate between adjacent values or see fig. 4.)

InVEST estimates values of ecosystem services by assessing the cost of dredging sediment from reservoirs. Valuation of sediment erosion/deposition in the model requires the remaining lifespan of a reservoir, dead volume (the volume below the turbine), as well as cost of removal. Since information on reservoirs in study area was not available the valuation calculation was performed outside the model.

To determine the valuation, the cost of sediment removal per cubic meter is needed. To acquire this information, the company that is currently removing sediment from North Park Lake in northern Allegheny County was contacted. The company is Charles J. Merlo, Inc. of Mineral Point, Pennsylvania and Mike Waksmunski provided the necessary data. The price of removal depends on the area where it will occur. Most of Allegheny County is heavily populated and the sediment, once removed, must be transported some distance to a dump site, increasing the cost. The reservoirs in Allegheny County would incur a cost of about $25 per cubic meter, $50 per acre, to remove and dispose of the sediment. This price does not include the preliminary set up before dredging can occur or set up of the disposal site, which was determined before the project started. Jay Hawk from the Pittsburgh office of the Army Corps of Engineers provided information about the annual budget that the ACOE has for the removal of sediment in the navigation channels in the rivers. The ACOE budgets from $61 to $100 per cubic meter for dredging of navigation channels. To include all the costs, the highest, $100 and the lowest, $25 were averaged and $63 per cubic meter, $126 per acre, was used for the amount it would cost to remove and dispose of the sediment from any reservoir in Allegheny County. The price per cubic meter was converted to price per ton, by assuming a soil density and porosity. Aquatic sediments with in-situ porosity of 0.75 and soil density of 2000kg/m^3 would contain approximately 0.5 tons of sediment per cubic meter (Yahaya, 2004).

InVEST has the capability of comparing several development strategies. The three that can be used are “plan,” a continuation of current development trends, “development,” a loosening of current policies to allow for freer rein of market forces, and “conservation,” which places a greater emphasis on ecosystem protection and restoration (Nelson, *et al*., 2009). The comparison of development strategies was beyond the scope of this project and was not completed.

3.1.3 Programs Used

All maps were downloaded into ArcGIS. The InVEST model is a toolbox that was downloaded into ArcGIS from the Natural Capital Project website. Individual models within InVEST are accessed through the toolbox functions. The model that I used was the Avoided Reservoir Sedimentation Model. For the Avoided Reservoir Sedimentation Model, the main equation used is the universal soil loss equation (NCP, 2007). The model user handbook provided the list of necessary data for running of the model.

All maps were in GIS raster format as .img files or .dbf files. A raster map is a picture of the data that is presented originally in a polygon form. The DEM, watershed, land use/land cover and soil maps all had to be converted to raster maps from polygons to be able to run in the InVEST program. The watershed dataset had to be converted to an .img raster file. Cover and management use factor (C) are necessary to run the model. The C value falls within a range for each land use type. For forested land the smallest C value of.0001 was used and for orchard and vineyards .10. For pasture and croplands the values ranged from .004 to .7; .37 the average of the highest and lowest value was used, since Allegheny County has similar amounts of cropland and pasture areas. To place a value on sediment removed, a sediment table was necessary in the model. The categories included in the table are the cost of sediment removal per cubic meter (m^3), discount rate, depth of reservoir, and dead volume (Tallis, *et al,* 2008).

The digital elevation map (DEM) required conversion to a dimensionless DEM. A DEM may originally have sinks, which ArcGIS reads as water going into an area and not being able to flow out, so a dimensionless DEM must be created by filling sinks (i.e. assuming level ground to fill in missing data). This was accomplished by determining flow direction, finding the sinks in the map, and filling sinks using the GIS toolbox for hydrology. Since all sinks where small and within river boundaries where elevation information was unavailable, the soil loss calculations would not be affected by this process.

A complication encountered while running the map in the InVEST model was identifying incomplete watersheds, which are watershed that have boundary lines that do not meet. When a watershed polygon was incomplete the model would “catch” on that watershed and return to the same watershed to calculate soil loss over and over, creating a never ending loop. To fix this complication the raster map had to be converted back into a polygon and the watersheds with missing borders were identified. There were no watersheds that contained missing borders; however, numerous watersheds were “pinpoints” (i.e., single points, rather than polygons). While the model was running the first time, watersheds that continued to repeat were noted. Those watersheds were pinpoint watersheds found along the edge of the map. Those were deleted and then the repaired map was converted back into raster format to run in the model. Once the pinpoint watersheds were removed the model was able to run to completion. The amount of land area that was removed to fix this malfunction was negligible in the calculations.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Soil loss

4.1.1 Overview of model inputs

Erosivity (R) and erodibility (K) values were input using information from the soil survey provided by the NRCS (Table 4.1). Erodibility values are dependent on slope and soil type.

Table 4.1 Erosivity (R) and erodibility (K) values input into InVEST.

abbr	name	%slope	K	R
AgB	Allegheny silt loam	2-8%	0.32	111
At	Atkins silt loam	0-3%	0.32	111
CkB	Clarksburg silt loam	3-8%	0.37	111
CwB	Culleoka-Weikert silt loam	3-8%	0.32	111
DoB	Dormont silt loam	2-8%	0.37	111
ErB	Ernest silt loam	2-8%	0.43	111
EvB	Ernest-Vandergrift silt loam	3-8%	0.35	111
GlB	Gilpin silt loam	2-8%	0.43	111
GpB	Gilpin-Upshur silt loam	3-8%	0.49	111
GuB	Guernsey silt loam	2-8%	0.43	111
GvB	Guernsey-Vandergrift silt loam	3-8%	0.35	111
HaB	Hazleton loam	3-8%	0.17	111
Ln	Lindside silt loam	0-3%	0.32	111
RaA	Rainsboro silt loam	0-3%	0.43	111
UCB	Urban land-Culleoka complex	0-8%	0.16	111
UGB	Urban land-Guernsey complex	0-8%	0.21	111
WhB	Wharton silt loam	2-8%	0.37	111
Hu	Huntington silt loam	0-3%	0.28	111
RaA	Rainsboro silt loam	0-3%	0.43	111
UB	Urban land	0-3%	0	111
URB	Urban land-Rainsboro complex	0-8%	0.21	111
WhB	Wharton silt loam	2-8%	0.37	111

The digital elevation layer shown in figure 4.1 was required in the model to calculate the length slope in the USLE. .

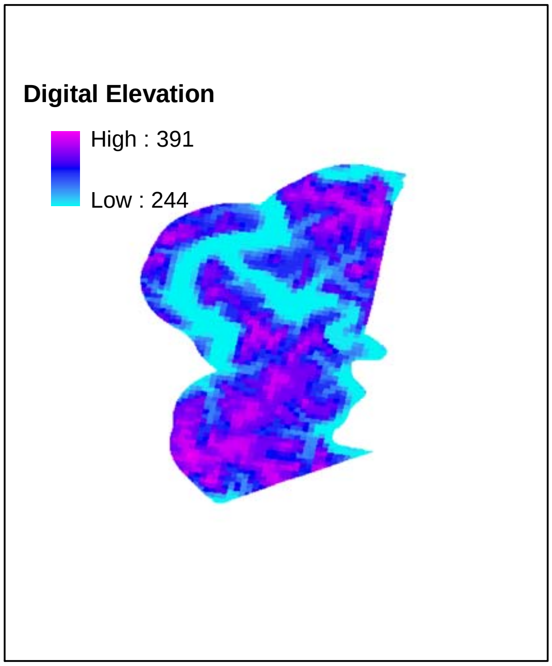


Figure 4.1 Digital elevation map used in InVEST

The erodibility layer shown in figure 4.2 was created in ArcMAP from soil data from NRCS and input into the model.

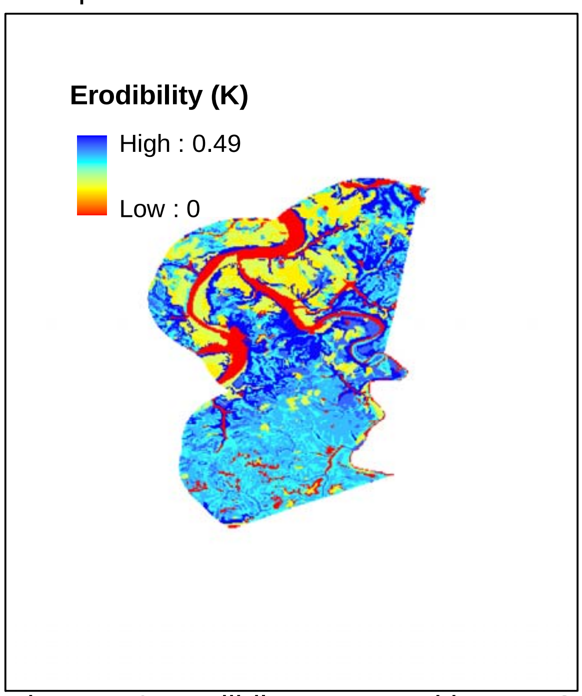


Figure 4.2 Erodibilty map used in InVEST

The land use/ land cover layer in figure 4.3 was input for the model and was used to determine cover management factor (C) and conservation practice factor (P) values for calculation in the USLE.

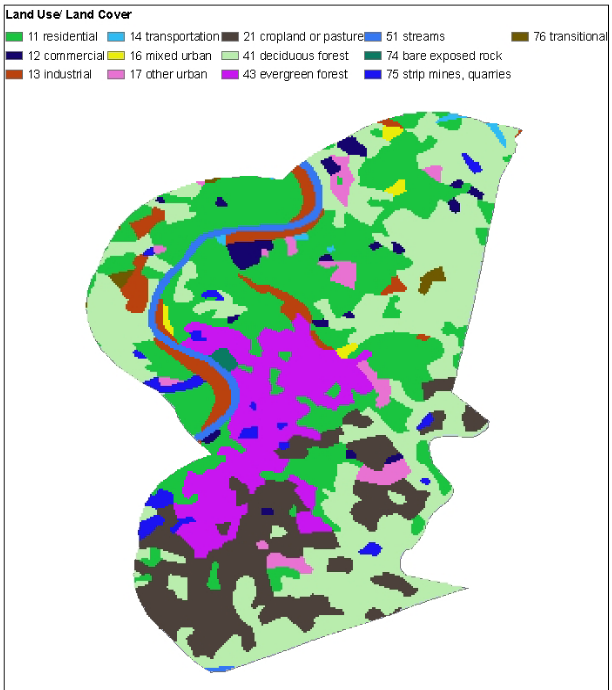


Figure 4.3 land use/land cover map input to InVEST

4.1.2 Soil Loss Calculated by InVEST

The InVEST model predicted a soil loss of 1024 tons/ year in the Youghiogheny River watershed. The 1024 tons is the total amount of sediment that is exported to the mouth of the watershed in a year. All other watersheds in the area produced minimal to no sediment. The model was run twice with two values for erosivity, 111 and 100. There was not a significant difference in the results when comparing the two values. The cost of removal of 1024 tons of sediment is $129,024 per year. This is if the sediment were to be removed on a yearly basis.

4.1.3 Manual calculations of soil loss

The "manual" calculation of soil loss by the USLE in Microsoft Excel resulted in larger values than were produced by the InVEST model. Using the resultant soil loss in tons/acre/yr from the USLE and multiplying it by the acreage of each land use class the total soil loss for the entire study area would be 43,978 tons per year with a .5% slope and 146,592 tons per year for an area with a 3% slope (Table 4.1). When calculated in Excel, the difference in erosivity (R) did not significantly affect the resulting soil loss, changing the results by approximately 2 tons/yr.

Table 4.2 Soil loss in tons/year for each land use type in the study area.

lulc code	Description	Acres	min. soil loss in tons/yr	max soil loss tons/yr
11	residential	14207	24127	80425
12	commercial & services	2000	3396	11322
13	industrial	161	273	911
14	transportation & utilities	260	441	1472
15	industrial	0	0	0
16	mixed urban	0	0	0
17	other urban	1332	2262	7540
21	cropland or pasture	7532	5150	17168
22	orchards	0	0	0
24	other agricultural	0	0	0
41	deciduous forest	15514	3797	12657
42	evergreen forest	0	0	0
43	mixed forest	5829	1426	4756
51	streams & canals	1070	0	0
52	lakes	0	0	0
53	reservoirs	0	0	0
76	transitional	217	607	2023
75	strip mines	892	2495	8317
			0	0
	totals	**49014**	**43978**	**146592**

4.1.4 Discussion

After the initial run of the model the predicted soil loss was zero or a very small number, for example .0006 tons per year. There could have been several reasons for this, some of which were the incorrect cover and management factor or the support practice factor. After consulting with the expert at InVEST, the model was rerun with slightly different parameters; the p values for some of the areas were changed to better reflect the land use. With the different parameters, the result was a significant amount of sediment in one watershed in the area, the Youghiogheny River watershed. The land use/ land cover in the area could have made an impact on the results of the sediment loading. There is a significant amount of agriculture in the southeast section on Allegheny County so the predicted sediment loss seems low for all watersheds in the study area. One reason for the lack of sediment in the area might be that there are large tracts of forest between the agriculture areas and the outlet of the watershed. The forested areas trap the sediment, holding it and decreasing sediment load farther down the watershed. It is unclear why the model produced zero soil loss in the other areas.

Erodibility (K) value is dependent on the land use and the soil type in any given area. It was not feasible to determine a weighted average for K for all given land uses in the study area. Soil types were studied and an intermediate K value was used for manual calculations in Excel (refer to table 3.1).

The manual calculations predicted a much larger amount of sediment (43,978 tons/yr) in this study area than was predicted by InVEST (1024 tons/yr).

One reason for this could be that in the manual calculations, directionality was not taken into account. In the model for example, sediment that is washed out of agriculture areas but then trapped in forested areas results in a decreased sediment load. The manual calculations predict the amount of sediment that will come from all land types, as if they were directly discharged to the mouth of the watershed. The study area has an average slope of 0.5% therfore, the soil loss estimates that resulted from the .5% slope would be considered the best estimate. The soil loss estimated with 3% slope is considered the upper limit for the study area.

The cost of removal of sediment does not account for the loss of commerce in shipping lanes or the loss of recreation in reservoirs that occurs when those areas need to be dredged or cleaned. Most rivers are not cleaned once a year but are cleaned on a rotating basis allowing sediment to build up which increases pressure on the dams, thereby increasing maintenance costs. Reservoirs are not cleaned yearly or on a rotating basis; generally they are cleaned when the sediment load creates a threat to habitat or water quality and quantity. North Park Lake has never been cleaned and the resulting price tag is now over $15 million dollars to remove 70 years of sediment accumulation.

CHAPTER 5

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary and Conclusions

5.11 Scope of Work

The goal of this project was to determine the amount and cost of sediment eroded from the land in portion of southeastern Allegheny County. Maps were gathered from various sources and downloaded into ArcMAP. The InVEST program was downloaded and the information gathered from the maps was run in the model to determine the amount of sediment that was produced in various watersheds in the southeastern section of the county.

5.1.2 Results and Conclusion

The area that was processed by the model was 75 sq. miles of southeast Allegheny County. The total amount of sediment produced, using the InVEST model, from the study area in the southeast region of Allegheny County was 1024 tons/year. The majority of the sediment was produced from the Youghiogheny watershed; all other watersheds in the region produced very little sediment. Removal of the sediment would be $123,024 a year if removal occurred every year.

Better conservation and storm water management practices in the area could help to decrease this amount and thereby decrease the amount of money spent on dredging. The decrease in sediment loss would also improve with agriculture practices in the area, since about 12% of this area is used for agriculture (Table 4.1).

5.2 Recommendations

As the Natural Capital Project works on improving the InVEST model, it could become a valuable tool for engineers and planners to help minimize the ecological impacts and costs while developing raw land. This model could be run on the entire county (or selected parts) with the three different scenarios that are possible in the model. Different environmental services could be examined as the updates for the InVEST model become available.

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