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Pennypack Creek Watershed Study

Edited by Md Mahbubur R Meenar

Draft report submitted to the Federal Emergency Management Agency, William Penn Foundation, and participating municipalities of the Pennypack Creek Watershed

Center for Sustainable Communities
TEMPLE UNIVERSITY

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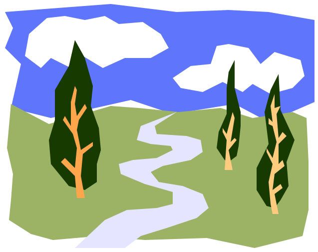
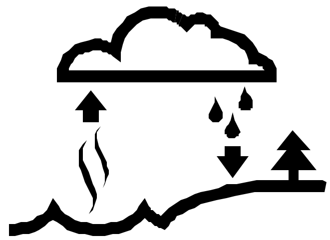


HYDROLOGIC MODELING

FLOODPLAIN MAPPING & GIS INVENTORY

WATER QUALITY STUDIES



STORMWATER MANAGEMENT

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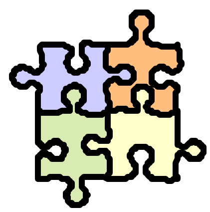

RECOMMENDATIONS

Pennypack Creek Watershed Study

A research report on Pennypack Creek Watershed project, conducted by the Center for Sustainable Communities at Temple University

Edited by Md Mahbubur R Meenar

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“Floodplains are floodplains for a reason. Undisturbed floodplains and associated riparian buffers attenuate flood flow, recharge groundwater, provide valuable habitat, prevent stream bank erosion, and help improve water quality. Although developmental pressures and economics have dictated floodplain regulations that allow reasonable development in floodplains, year after year, many millions of dollars continue to be spent on flood recovery efforts, often in the same community. These dollars would be better spent in buying out the affected areas and replenishing the floodplains.”

Paul DeBarry
Watersheds: Processes, Assessment, and Management

Contents

Preface

The Pennypack Creek Watershed Study was conducted by the Center for Sustainable Communities (CSC) of Temple University. The research team consisted of Temple University faculty members, experts, and students from disciplines such as landscape architecture, horticulture, geology, geography, geographic information systems, urban and suburban studies, land use policy and planning, environmental economics, environmental justice, and civil engineering.

The research study has used and cited the work of others, especially in describing the flooding and other relevant issues in the watershed as well as in acquiring existing digital or non-digital data. We are grateful for the cooperation and permissions that we have received from local and regional planning agencies, including City of Philadelphia Water Department, Delaware Valley Regional Planning Commission, Montgomery County Planning Commission, Bucks County Planning Commission, and Pennypack Ecological Restoration Trust. We also acknowledge the help of John Granger, Derron LaBrake, Scott Morgan, Trout Unlimited, Huntingdon Valley Country Club, and especially the homeowners who provided access for water quality sampling and stormwater management assessments.

The research was funded by several grants obtained by the CSC from the William Penn Foundation, Federal Emergency Management Agency (FEMA), and participating municipalities of the Pennypack Creek Watershed area, including Abington Township, Bryn Athyn Borough, Hatboro Borough, Horsham Township, Jenkintown Borough, Lower Moreland Township, Rockledge Borough, Upper Dublin, Upper Moreland Township, Upper Southampton Township, and Warminster Township.

The research outputs herein are believed to be reliable. All the opinions and research outputs are the judgments of the research team. The draft floodplain modeling and mapping are currently under review of FEMA.

Executive Summary

The water system of any community is a key concern of its residents. People expect a safe and adequate water supply, options to swim and fish in the waterways, and of course protection from floods. The residents of the Pennypack Creek Watershed of southeastern Pennsylvania have similar expectations. However, they have been exposed to a number of critical issues related to their watershed, caused by natural and man-made reasons.

The Pennypack Creek Watershed covers 56 square miles of twelve municipalities and includes a population of more than 300,000 people (2000 Census). Over the past thirty years, the watershed has undergone considerable development and suburbanization. This has led to a number of problems, including increased incidence of flooding and ecological degradation. The key issues identified in this watershed are unplanned land development, poor stormwater management, impaired water quality, and outdated floodplain maps.

The purpose of the *Pennypack Creek Watershed Study* was to initiate a comprehensive study focusing on these key issues. The study was undertaken by a multi-disciplinary research team of the Center for Sustainable Communities (CSC) of Temple University. The study consisted of the following major components:

- hydrologic modeling to determine new floodplain boundaries;
- geographic information system (GIS) mapping and data inventory creation;
- water quality studies;
- evaluation of existing stormwater facilities;
- assessment of open space and corridor alternatives; and
- recommendations.

Hydrologic Modeling

One of the major focuses of this study was to update the existing Flood Insurance Rate Maps (FIRMs) by delineation of new floodplain boundaries that result from two hypothetical (design) storms: 100-year and 500-year storms. The existing FIRMs for the Pennypack Watershed were developed based on pre-1970 hydrologic conditions and coarse contour data. New maps have taken advantage of more accurate data and improved technologies for identifying flood hazards.

The Pennypack Watershed was divided into ten sub-basins. The hydrologic model was calibrated to twelve historic storms that occurred over the watershed area. In comparison with prior studies, new floodplains emerged due to improved modeling and the high accuracy of topography data used in this study. However, there was no systematic difference. In other words, the extent of the new floodplains was not always larger or smaller than prior studies; it is worth mentioning, however, that the difference was sometimes as large as 400 feet. Overall, the study delineates 3.4 square miles of 100-year floodplain areas, compared to 2.74 square miles in the existing maps.

Floodplain Mapping and GIS Data Inventory

The CSC created a GIS data inventory that helped assess the watershed and delineate new floodplains. It also allowed computational analyses and selection of building footprints inside the floodplains. These data sets were later used to create new floodplain maps for the municipalities throughout the watershed.

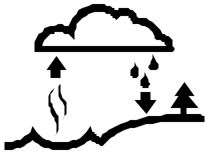
The key focus of the GIS-based data inventory was to create 2 ft resolution elevation data, including Digital Elevation Model (DEM), Triangulated Irregular Network (TIN), and contour intervals. Other data sets include 2003 digital ortho-photographs (1 ft pixel resolution), updated stream network, flow-paths, bridges and culverts, dams, and building foot prints. The CSC has collected and edited a number of GIS data layers from different sources which include political and hydrologic boundaries, soil, geology, land cover, streets, transportation facilities, parcels, land use, trails, and parks and open space. The CSC has also converted a number of paper maps to GIS data layers, including the zoning maps. A complete list of data layers used in this project is included in Section 3.

Water Quality Studies

The goal of the water quality monitoring program was to examine the human impact on stream water quality and identify potential factors to mitigate some of these impacts in the Pennypack Watershed. This study did not attempt to measure the overall water quality of the Pennypack Creek. Instead, this program examined several problems on a small scale where human activity has the potential to alter water quality.

Observations from the small scale studies include:

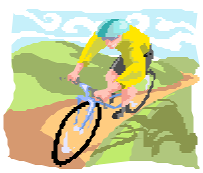
- rapid rise in water level after storms shows the importance of overland flow;
- similarity in conductivity and nutrients at storm pipes and buffer zones also shows the importance of overland flow;
- temperatures were warmer in upstream ponds, but rapidly dissipated downstream;
- water downstream of the Upper Moreland – Hatboro Wastewater Treatment Plant had higher nitrate, conductivity, and temperature; and
- urban discharge had generally higher conductivity and more variability than the non-urban discharge monitored at the same site; the variability could not be predicted by land use patterns but was influenced by a combination of source terms and local hydrology.



Stormwater Management

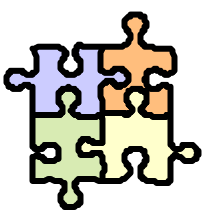
Based on a field assessment of the entire Pennypack Creek Watershed, the CSC research team evaluated the condition and functionality of existing stormwater facilities, assessed the potential for retrofitting such facilities so as to improve both their environmental and flood control performance, and sought locations for recommended new stormwater Best Management Practices (BMPs).

Opportunities that municipalities can take advantage of immediately are those which they can implement on publicly owned lands, such as municipal administration buildings and schools. Each municipality owns and/or manages sites that could be potentially "retrofitted" with some form of BMPs. The municipalities can also create stormwater management districts to provide a source of funding to retrofit sites on both public and private lands. The research team has identified priority sites within each sub-basin where BMPs can have a significant and cost-effective impact on controlling stormwater runoff.



Open Space and Corridor Alternatives

This study also has found that many of the municipalities within the watershed have initiated new open space plans or updated existing ones. While each municipality has taken a slightly different approach, it is encouraging to see that municipalities have conducted in-depth analyses of their open space inventory. However, it is likely that some but not all of the municipalities have looked outside of their boundaries in order to identify potential synergies and linkages. It is critical that municipalities look beyond their political jurisdiction in order to make recommendations for preservation of valuable open space linkages.



Recommendations

Based on the evaluations of the study components, the CSC research team has developed the following recommendations:

Floodplain Management – Each municipality in the watershed regulates development within the floodplain to varying degrees. It is imperative that these regulations be more rigorously enforced. The CSC recommends that once the new 100-year floodplain maps have been approved by FEMA, they should be enacted by the municipalities as their official floodplain maps. The CSC also recommends that the municipalities consider updating their existing ordinances to enable them to more rigorously enforce the new floodplain boundaries.

Model Stormwater Management Ordinance –The communities within the watershed should adopt more progressive and rigorous stormwater management ordinances, and strive for consistency watershed-wide. The CSC has developed a draft model stormwater management ordinance that is consistent with the new stormwater regulations recently adopted by the City of Philadelphia on January 1st, 2006. These regulations were modeled after the ordinance developed through the Pennsylvania Act 167 Stormwater Management Planning process in Delaware County for the Darby and Cobbs Creek Watershed.

BMPs and Retrofit Priorities – The comprehensive control of stormwater runoff for the entire Pennypack Watershed can be achieved through stormwater management in each of its ten sub-basins. Retrofitting existing stormwater facilities as well as areas developed prior to the implementation of any stormwater management controls with BMPs is the key to reducing water quality and quantity problems within the Pennypack Watershed. The CSC researchers recommend that each municipality create a stormwater management utility to provide sufficient revenues to fund such retrofits. Furthermore, each municipality should concentrate initial resources on implementing retrofits at the priority sites within each sub-basin where BMPs can have a significant and cost-effective impact on controlling stormwater runoff.

Wastewater Treatment Plant Upgrades – The Upper Moreland-Hatboro Wastewater Treatment Plant discharges high concentrations of nutrients to Pennypack Creek. As noted in Section 4, observed nitrate concentrations range from 10 to 22 mg/L and phosphorus levels are also well above recommended limits. The research team recommends that the Upper Moreland-Hatboro Joint Sewer Authority conduct a feasibility study to evaluate possible upgrades to improve the plant's performance to significantly reduce nutrient levels in its effluent. Possible treatment options include biological removal (BNR) or chemical additives. Although the team's recommendations on new, improved, or preserved stormwater BMPs focus mainly on the goal of reducing peak discharge and/or runoff volumes, most, if not all, of the recommended practices would have significant beneficial impacts on water quality as well.

Open Space Planning and Preservation – The research team has developed recommendations for open space in the watershed. The team assessed a proposed trail configuration and made recommendations concerning its implementation. An unused railroad right-of-way owned by the South Eastern Pennsylvania Transportation Authority (SEPTA) appears to be the best choice for the location of the Pennypack Trail. The Montgomery County Planning Commission (MCPA) has included the Pennypack Trail and this right-of-way in its County Open Space Plan. Given its regional interest and extent, the MCPC, in consultation with the Bucks County Planning Commission, should initiate discussions with SEPTA and seek the resources necessary to implement the trail.

ACRONYMS

BMP	Best Management Practice
CSC	Center for Sustainable Communities
CTP	Cooperating Technical Partner
DEM	Digital Elevation Model
DEP	Department of Environmental Protection
DRBC	Delaware River Basin Commission
DVRPC	Delaware Valley Regional Planning Commission
FEMA	Federal Emergency Management Agency
FHM	Flood Hazard Map
FIRM	Flood Insurance Rate Map
GIS	Geographic Information Systems
MCPC	Montgomery County Planning Commission
NFIP	National Flood Insurance Program
NOAA	National Oceanic and Atmospheric Administration
PA DEP	Pennsylvania Department of Environmental Protection
PERT	Pennypack Ecological Restoration Trust
PWD	Philadelphia Water Department
SEPTA	South Eastern Pennsylvania Transportation Authority
TIN	Triangulated Irregular Network
USGS	U.S. Geological Survey
WTP	Upper Moreland – Hatboro Wastewater Treatment Plant

1 INTRODUCTION

The Center for Sustainable Communities (CSC) at Temple University Ambler College embarked on a research study of the Pennypack Creek Watershed in June of 2002. The goal of the study was to assist communities within the watershed in reducing flooding, improving water quality, and better managing future development.

The CSC was established in July of 2000 with a goal of promoting effective, holistic approaches to land use planning and management, sustainable development, ecological restoration, and community revitalization. The mission of the CSC is to offer educational programs, conduct interdisciplinary research, and serve as a regional resource to address issues of the environment and sustainability. The CSC's approach brings together municipal officials, nonprofit organizations, homeowners, agency leaders, and other interested parties to address regional concerns collaboratively.

Recognizing that the development of sound land use policies and promotion of environmental awareness have become priority concerns for public officials – both regionally and nationwide, the CSC has begun to take on research and demonstration projects that will help to establish good examples of land use and environmental planning here in southeastern Pennsylvania.

The *Pennypack Creek Watershed study* is one such demonstration project, which utilized the most updated data and advanced technological resources available, while also striving to lay the groundwork for a forum of communication and collaboration between multiple jurisdictions within this watershed that shall continue far beyond the completion of this study. The study consisted of the following major components:

- hydrologic modeling to determine new floodplain boundaries;
- geographic information system (GIS) mapping and data inventory creation;
- water quality studies;
- evaluation of existing stormwater facilities;
- assessment of open space and corridor alternatives; and
- recommendations.

Figure 1: Pennypack Watershed municipalities

The CSC has created a website on which the draft report and the draft floodplain maps produced by this study have been posted to be shared with the watershed municipalities and the public: http://www.csc.temple.edu/pennypack.

Ultimately, communities will be able to benefit from this study by having more accurate, detailed information on which to base their future development plans and ordinances. Communities shall be educated about planning alternatives, and residents and municipal officials will be better equipped to anticipate problems and seek proactive solutions more readily.

Partners

Municipalities: Each of the eleven municipalities outside of Philadelphia County whose jurisdictions fall either partially or wholly within the Pennypack Creek Watershed committed to participating in this study. The municipalities located wholly or partially in the watershed include: Abington Township, Bryn Athyn Borough, Hatboro Borough, Horsham Township, Jenkintown Borough, Lower Moreland Township, Rockledge Borough, Upper Dublin, Upper Moreland Township, Upper Southampton Township, and Warminster Township.

Federal Emergency Management Agency (FEMA): Through the Map Modernization process, FEMA is now working to respond to the National Flood Insurance Program (NFIP) requirements and customer demand for more accurate and updated floodplain maps nationwide. FEMA has developed a 5-year plan called the Multi-Year Flood Hazard Identification Plan (MHIP) for updating the Nation's flood hazard data with the help of its mapping partners and other stakeholders.

According to the FEMA web site, there are over 20,000 communities in the NFIP. The Cooperating Technical Partners (CTP) Program of FEMA has been initiated to create partnerships between FEMA and participating NFIP communities and agencies that can actively participate in the FEMA Flood Hazard Mapping Program. The CSC has become a CTP of FEMA to collaborate in maintaining up-to-date flood maps and other flood hazard information.

William Penn Foundation: The William Penn Foundation, founded in 1945 by Otto and Phoebe Haas, is dedicated to improving the quality of life in the Greater Philadelphia region through efforts that foster rich cultural expression, strengthen children's futures, and deepen connections to nature and community. In partnership with others, the Foundation works to advance a vital, just, and caring community.

Philadelphia Water Department (PWD): The Philadelphia Water Department's Office of Watersheds is working to achieve viable and measurable improvements to the region's waterways by implementing planning and management strategies that foster good science, public involvement, and fiscal responsibility. The PWD's goal is to meet regulatory requirements while enhancing the health and aesthetics of our environment. The Office of Watersheds has been charged with the mission of integrating traditionally separate tasked programs, including Philadelphia's Combined Sewer Overflow (CSO) program, the Stormwater Management Program, and its Source Water Protection Program, to maximize the resources allocated to these programs and to ensure the comprehensive achievement of their goals.

The Office of Watersheds initiated the River Conservation Planning process in the Pennypack Creek Watershed at the time that the CSC study had begun. This simultaneous planning initiative created the opportunity for additional collaboration and data sharing.

The Pennypack Ecological Restoration Trust (PERT): The mission of PERT and its membership is to protect, restore, and preserve the lands of the central Pennypack Creek Valley so they:

- remain an enhancement to the quality of visitors' lives;
- remain a vibrant and diverse natural landscape supporting native plant and animal life; and
- become the standard of excellence for innovative restoration and stewardship practices to be shared with other individuals and organizations joined in common commitment to the environment.

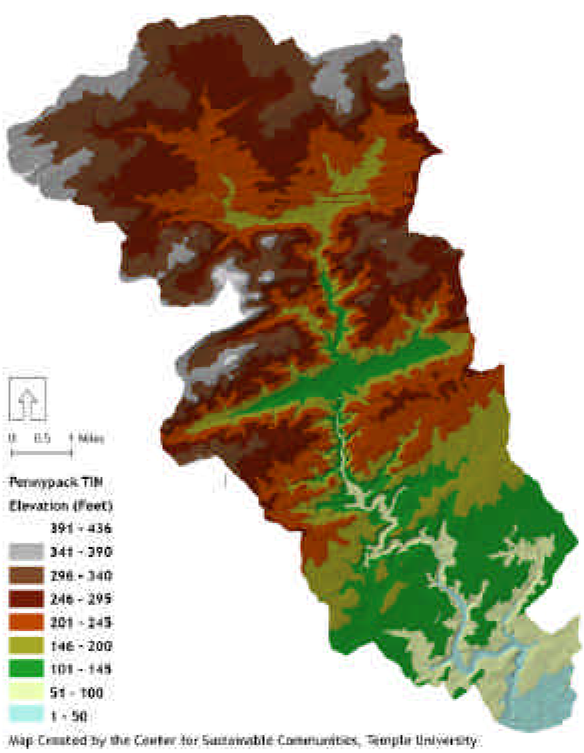


Figure 2: Pennypack Watershed elevation

As PERT was in the process of updating its master plan, the CSC committed to an ongoing collaboration in order to support this update.

Funding

The *Pennypack Creek Watershed Study* has illustrated the synergy created when multiple groups work together toward a common goal. Initially, the watershed municipalities committed a total of $100,000. The CSC was subsequently the recipient of a very generous $330,000 grant from the William Penn Foundation. FEMA then contributed $192,500 to the effort. The CSC added $95,000.

Study Area

The Pennypack Creek Watershed is located in southeastern Pennsylvania. It covers 56 square miles and includes a population of approximately 300,000 people (2000 census). The watershed includes the 1,334 acre Pennypack Park, part of the Fairmount Park system; Lorimer Park in Montgomery County; the Pennypack Ecological Restoration Trust, which protects 720 acres of land in Montgomery County; as well as many additional suburban "pocket" parks and preserves. The watershed lies within the lower Delaware River Basin and discharges to the Delaware River in the City of Philadelphia. Most of the watershed is located in Montgomery County, with additional small portions in Bucks and Philadelphia Counties (Figure 1).

The topography of the watershed is characterized by gently rolling hills in the headwaters, moderately sloping valley in the central part of the watershed, and tidal flats in the lower portion draining to the Delaware River. The elevations over the whole watershed range from 436 feet to less than 10 feet above mean sea-level (Figure 2).

The flow regimen in Pennypack Creek and the interrelationships between surface and groundwater within its watershed are complicated not only by development and other human activities within the basin, but also by its complex environmental character. In particular, the bedrock geology is highly diverse and the geologic history spans more than 600 million years. There are great differences in the physical characteristics of the many different rock types within the watershed. Their textures, mineral compositions, hardnesses, permeabilities; the differences in the ways in which they weather and decompose, and the resulting differences in the soils and terrains developed on them; all these factors influence the ways in which water moves over, into, and through them.

Figure 3: A railroad bridge crossing the main stem of the Pennypack Creek

Consequently, the hydrologic regimen of the Pennypack Creek and its tributaries varies greatly from place to place within the larger watershed. Floodplain and stormwater management planning in the watershed must take all these factors into account.

Figure 4: Pennypack main stem

The study area for the project did not include the Philadelphia portion of the watershed. This reduced the scope of the study area to 43 square miles, about 77 percent of the whole watershed, which includes only the 11 suburban municipalities.

2 CHARACTERIZATION OF PROBLEM

Over the past thirty years, the Pennypack Creek Watershed has undergone considerable development and suburbanization. This has led to a number of problems, including increased incidence of flooding, impaired water quality, and ecological degradation.

Figure 5: Flooding in Pennypack Watershed
Source: Bucks County Courier Times

The incidence of flooding in the watershed has particularly increased as this suburban development has sprawled within the upstream portions of the watershed. Of paramount concern is the increase in the amount of impervious cover (i.e. roads, rooftops, turf grass), which has contributed to the escalation of runoff and flood levels. “Land development is now recognized as one of the major causes of stormwater quality and quantity problems.” (PA DEP, 2006).

As federal, state, and local agencies regularly reimburse homeowners for flood-related losses, it is in everyone’s best interest that floodplains be properly managed and protected. The greater incidences of events such as Hurricane Floyd and Tropical Storm Alison have highlighted the need for a re-evaluation of the management strategy of floodplains in this watershed. Municipalities and other emergency management agencies can potentially save a great deal on insurance and buy-out costs if they can better prevent flood losses.

As a result of the devastating effects of Hurricane Floyd, local communities faced millions of dollars worth of damage. “During Hurricane Floyd, eight people were killed along the banks of the Pennypack when heavy rainstorms caused flooding,” (The Temple News, 2005). Residents of the Huntingdon Valley Club condominiums were forced to move elsewhere after flooding from Hurricane Floyd in 1999 and the remnants of Tropical Storm Allison in 2001 rendered their homes uninhabitable.

Additionally, due to Tropical Storm Allison, the Village Green Apartment complex in Upper Moreland Township was the site where six people were killed in an explosion when a clothing dryer became disconnected from the wall triggering a gas leak – believed to be the result of the flooding. The dryer became disconnected when the room had become inundated with over 2 feet of water; the dryer had been lifted up and floated across the room tearing the gas line from the wall. The Old Mill Inn in Hatboro Borough sits at the bank of the creek and sustained an estimated $18,000 to $20,000 in damages in the summer of 2001 when the first floor of the restaurant filled with over 20 inches of water.

According to author Paul DeBarry, “comprehensive watershed management requires an interdisciplinary approach to solve complex problems.” (DeBarry, 2004). In the following paragraphs, the complexity of such problems in the Pennypack Watershed have been analyzed.

Unplanned Land Development

Much of the Pennypack Creek Watershed area was developed as a part of the "inner ring suburbs" of Philadelphia in the 1950s through the 1980s. The land development process dramatically alters the hydrology of a site and has far reaching effects throughout the watershed. Prior to development, precipitation was able to soak into the ground or was returned to the atmosphere by evapotranspiration. The post-development conditions of buildings, parking lots, turf grass, and other forms of impervious cover reduce

Figure 6a and 6b: According to the existing FIRMs, over 800 buildings in the watershed are inside 500-year floodplains, among which 149 are inside the floodways and 577 are inside 100-year floodplains.

infiltration and evapotranspiration and consequently decrease groundwater storage and stream baseflow, but increase the amount of surface runoff.

"Significant development within a floodplain results in significant losses in water resources, ecological resources, and human resources that may easily outweigh the property value of the floodplain" (Bedient and Huber, 2002). In addition, the impervious surfaces, resulting from unplanned land development, have the following effects on water resources: (1) rapid runoff, (2) non-point source pollution, (3) decreased groundwater recharge, and (4) increased stream temperatures, all of which result in increased flooding, increased stream bank erosion, impaired water quality, and decreased aquatic diversity (DeBarry, 2004).

Poor Stormwater Management

The increase in stormwater runoff has a major impact on the hydrology, biology, chemistry, and other physical features of a watershed, because it is a major component of the hydrologic cycle (DeBarry, 2004). Much of the worsened flooding is a direct result of an ever-increasing volume of stormwater runoff being discharged throughout the watershed. These increased volumes of runoff are not only the result of increases in the aforementioned impervious surfaces, but also from the substantial areas of natural landscape being converted to lawns on highly compacted soil. The "manicured" vast green lawns of turf grass observed as a critical component of the suburban "American Dream" home can contribute to stormwater runoff almost as much as a paved parking lot can. Furthermore, resulting stormwater runoff is now subject to many pollutants such as nutrients (in fertilizers), pesticides, and bacteria that it encounters as it makes its way to the nearest waterbody.

Figure 7: On average about 30% of the Pennypack Watershed is covered by impervious surface (based on 2000 data – map showing impervious coverage in brighter color)

Development in many of the watershed municipalities took place long before stormwater management plans and ordinances were ever adopted. As with many of the largely developed suburbs surrounding Philadelphia, ordinances that were in place during the suburban growth period did not adequately manage the increased stormwater runoff resulting from the increase in impervious cover. It was not until the 1970s that municipalities began to recognize the need to get involved with this type of regulatory oversight. Before that there was never any effort made to determine if houses or structures were within the floodplains.

Figure 8: Riparian buffer in poor condition

Impaired Water Quality

Maintaining and improving surface water quality is an essential component of any watershed management plan. Surface water quality can be deteriorated because of the lack of stormwater runoff management and non-point source pollution control (DeBarry, 2004). Stormwater runoff from parking lots or other types of impervious surfaces increases stream temperatures and contributes to the non-point source pollution. Pollutants come from automobile emissions, lawn and garden chemicals, and litter (DeBarry, 2004).

Increasing urbanization in Pennypack Watershed has also led to the destruction of riparian buffers, which has created additional pollution problems stemming from overland runoff into the watershed's streams, both the main stem Pennypack Creek and its tributaries.

The destruction of riparian buffers also has increased sediment loadings in the Pennypack Creek. It has led to the widespread loss of habitat for both aquatic and terrestrial species. The modification of the stream corridors to suburban landscapes also has resulted in the introduction of many invasive, non-native plant species and provided a venue for deer and geese, which have overpopulated the region and made ecological restoration activities and water quality improvement problematic. This "non-point" problem, combined with other "point" source problems stemming primarily from wastewater treatment plant discharges, has contributed to the degradation of water quality. Of particular concern are significant infiltration and inflow problems occurring at plants during storm events.

Figure 9: Stream bank erosion

Outdated Floodplain Maps

Currently, all municipalities within the watershed area regulate development within the 100-year floodplain, to varying degrees. See Appendix E for a table describing municipal floodplain ordinances. However, this will do nothing to address the development that took place prior to this land development regulation. There are already a large number of structures located within the floodplain in need of attention.

Meanwhile, as municipalities attempt to at the very least protect the 100-year floodplain area from certain types of development; it is clear that their planning and zoning efforts are based on what might be severely inaccurate geographic representations of the existing Flood Insurance Rate Maps (FIRMs). These maps were prepared for FEMA in the early 1970s, based upon data and development patterns of the 1960s. Site-specific updates have been prepared, but they are still based on these old data, in particular hydrologic data.

These maps are no longer of the level of accuracy necessary for the safe management of the floodplains. Not only has the geographic area of the floodplain evolved over time with the changes in the upstream development patterns, but with the technological advances in stormwater runoff modeling and hydraulic and hydrologic modeling, it is possible to create significantly more accurate representations of the flood zones. Identifying how water moves over, into, and through the watershed's naturally complex geography is hampered by reliance on these outdated maps.

Figure 10: The residence of Lynda Thomas (shown in yellow circle) is not within the existing floodplain boundary (shown in red), although she has experienced occasional flooding in the last 27 years

3 HYDROLOGIC MODELING AND FLOODPLAIN MAPPING

A floodplain can be defined as low lands adjoining a channel of a river, stream, or other waterbodies that have been or may be inundated by floodwater. According to FEMA, "Flood hazard conditions are dynamic, and many (floodplain) maps may not reflect recent development and/or natural changes in the environment." One of the major focuses of this study was to replace the existing FIRMs by delineation of new floodplain boundaries that result from two hypothetical (design) storms: 100-year and 500-year storms.

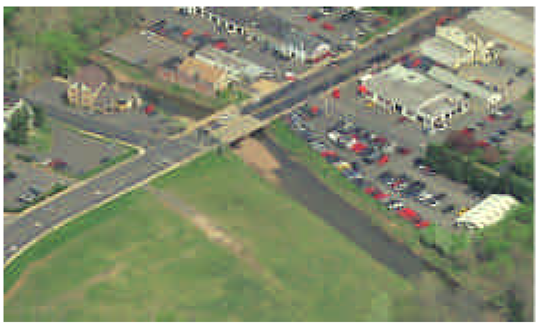


Figure 11: Rapid urbanization in the floodplains is common throughout the Pennypack Watershed

The existing FIRMs for the Pennypack Watershed were developed in the 1970s. According to Federal Register (Vol. 66 No. 228, p.59166), "Historically, flood hazard information presented on NFIP flood maps has been based on the existing conditions of the floodplain and watershed. When the mapping of flood hazards was initiated under the NFIP, the intent was to reassess each community's flood hazards periodically and, if needed, revise the revise the flood map for that community. Flood hazards may change significantly in areas experiencing urban growth."

The FEMA has a portion of its website dedicated to the modernization of Flood Hazard Maps (FHMs) nationwide. FEMA describes how this modernization process must be undertaken through a collaborative process, under which data is shared amongst partners of all levels of government. These new maps are to take advantages of revised data and improved technologies.

Need for Updated Floodplain Maps

Topography plays a vital role in the distribution and flux of water and energy in a watershed. The United States Geological Survey (USGS) has prepared 7½° quadrangle topographic maps at a scale of 1:24,000 for most of the country, and a common contour interval is 10 ft. This scale is generally considered the minimum scale in hydrologic modeling and a tighter interval is preferred for accurate and detailed studies. According to FEMA, "new maps can take advantage of revised data and improved technologies for identifying flood hazards. Up-to-date maps support a flood insurance program that is more closely aligned with actual risk, encouraging wise floodplain management and increase in the public's flood hazard awareness."

Although GIS has been used since the 1970s, the extensive application of GIS to hydraulic and hydrologic modeling and floodplain mapping and management did not begin until the early 1990s because of the following reasons: (1) lack of suitable hydrologic data; (2) lack of funding to acquire GIS software and hardware; (3) lack of GIS knowledge in the engineering community; and (4) lack of hydrologic modeling knowledge in the GIS community. Now GIS is commonly used for watershed delineation, runoff estimation, hydrologic modeling, and floodplain mapping. For example, the U.S. Army Corps of Engineers (ACOE) software HEC-RAS can import GIS-generated stream networks and cross sections, analyze the data in 3-D perspectives, and export the outputs including floodplain boundaries as a set of polygons.

Figure 12: Example of inaccuracy in available stream data in the watershed. Here the blue line represents the accurate stream network, consistent with the ortho-photo. Other available stream files do not match the actual stream location.

Research has indicated that the precipitation values (from the U.S. Weather Bureau's Technical Paper-40, or TP-40, which was published in 1961) widely used in previous studies are no longer valid. These values were used in the creation of existing Pennypack FIRMs as well. The CSC researchers believe that it has been well established that TP-40 systematically underestimated the extreme precipitation events. This was due to a number of factors: the short average duration of the precipitation records analyzed; the relatively small number of weather stations; and the statistical distribution used to analyze the data. The Temple researchers requested and have received permission from FEMA to use more recent data from the National Oceanic and Atmospheric Administration (NOAA) Atlas 14, which can be accessed at: http://hdsc.nws.noaa.gov/hdsc/pfds/orb/pa_pfds.html.

This makes a very significant difference in the inputs to the hydrologic and hydraulic models employed in the redelineation of the floodplains in the watershed. For instance, according to TP-40, the precipitation from the 100-year, 24-hour storm in our study area was expected to be 7.2 inches, and this number has been codified in virtually all local stormwater management ordinances. The more recent data indicates that the 100-year, 24-hour event is 8.75 inches, a difference of more than 20%.

The CSC has initiated a flood map modernization process utilizing the latest data and software available in order to create new maps with a high level of accuracy. The software used in this study are ArcGIS, HEC-RAS, HEC-GeoRAS, Hec-HMS, WMS, and AutoCAD.

Creation of GIS-Based Data Inventory

Researchers agree that GIS is an excellent tool for creating and analyzing geographic data related to a watershed. According to gis.com, "GIS is a collection of computer hardware, software, and geographic data for capturing, managing, analyzing, and displaying all forms of geographically referenced information." Geographic data are also known as spatial data, and include the locations and descriptions of geographic features of the world, such as rivers, mountains, trees, roads, buildings, and more. Geographic data are a composite of both spatial data and descriptive data. Spatial data are data that have spatial location in the world, such as a house. Descriptive data are data that do not have any spatial location, such as a house owner name or parcel number. Geographically referenced information means any information that can be referred to any certain location on the earth.

Since 2002, the CSC has developed a GIS-based data inventory for the study area. Messrs. A.S.M. Abdul Bari and Md Mahbubur Rabb Meenar, CSC's Senior GIS Design Specialists, have directed this aspect of the study. A number of Temple University students were involved in the process of data conversion, data editing, and data creation. This GIS inventory helped assess the watershed and delineate new floodplains; and it also allowed computational analyses and selection of building footprints inside the floodplains. These data sets were later used to create new floodplain maps for the municipalities throughout the watershed.

The key focus of the GIS-based data inventory was to create higher quality or higher resolution Digital Elevation Model (DEM) data, which allows more detailed terrain representation and analysis. Newly created GIS datasets include 2003 digital ortho-photographs (1 ft pixel resolution), 2 ft resolution elevation data such as DEM, Triangulated Irregular Network (TIN), and contour intervals, updated stream networks, flow-paths, bridges and culverts, dams, and building foot prints. The CSC has collected and edited a number of GIS data layers from different sources that include political and hydrologic boundaries, soil, geology, base flow, land cover, streets, transportation facilities, parcels, land use, trails, and parks and open space. The CSC has also converted a number of paper maps to

Figure 13: Bridges and other constrictions were mapped for hydrologic modeling

GIS data layers, including the zoning maps.

The consultant Aero2 Inc. created the digital ortho-photography and high resolution elevation data. The aerial mapping was done in non-growing season, when foliage was off the trees. Aero 2 has undertaken the following steps:

- Aerial Photography at 1"=660' negative scale using Airborne GPS technology flight;
- Ground Control Survey, performed by licensed land surveyor;
- Analytical Aerotriangulation, which performs image measurements to achieve interior and exterior image parameters; and
- Stereo compilation and creation of new data.

A complete list of GIS data inventory is provided in Table 1.

Data	Source	Year
Biological Data		
Fish	Philadelphia Water Department	2002
Habitat	Philadelphia Water Department	2002
Microinvertebrate	Philadelphia Water Department	2002
Water Related Data		
Pennypack Watershed Boundary	Philadelphia Water Department	1999
Pennypack Watershed Sub-basins	Center for Sustainable Communities	2004
Wetlands	Delaware Valley Regional Planning Commission	1981
Bridges & Culverts	Center for Sustainable Communities	2005
Dams	Philadelphia Water Department	1999
Riparian Buffers	Heritage Conservancy	2002
Effluent Concentration	Philadelphia Water Department	2003
Discharges & Withdrawals	Delaware River Basin Commission	1996
Streams	Center for Sustainable Communities	2004
Banks	Center for Sustainable Communities	2004
Flow-Paths	Center for Sustainable Communities	2006
Floodplains	Center for Sustainable Communities	2006
Geological Data		
Bed Rock Geology	Delaware River Basin Commission	1998
Soil	Delaware River Basin Commission	Unknown
Base Flows	Philadelphia Water Department	1998
Demographic Data		
Household Density	US Census Bureau	1990/2000
Median Household Income	US Census Bureau	1990/2000
Population Density	US Census Bureau	1990/2000
Land Features Data		
Land Use	Delaware Valley Regional Planning Commission	1990/1995/2000
Land Cover	United States Geological Survey	2001
Parcel (partial)	Center for Sustainable Communities	2004
Building Footprints (inside floodplains)	Center for Sustainable Communities	2006
Zoning (partial)	Center for Sustainable Communities	2004
Trails	Delaware Valley Regional Planning Commission	2002
Tree Canopy Density	United States Geological Survey	2001
Impervious Surfaces	Pennsylvania State University, Dr. Toby Carlson	1985/2000
2 ft Contours	Center for Sustainable Communities	2004
2 ft Digital Elevation Model	Center for Sustainable Communities	2004
Triangulated Irregular Network	Center for Sustainable Communities	2004
Hillshade	Center for Sustainable Communities	2004
Slope	Center for Sustainable Communities	2004
Road Density	Center for Sustainable Communities	2005
Forest Fragmentation	Center for Sustainable Communities	2005

Table 1: GIS Data Inventory

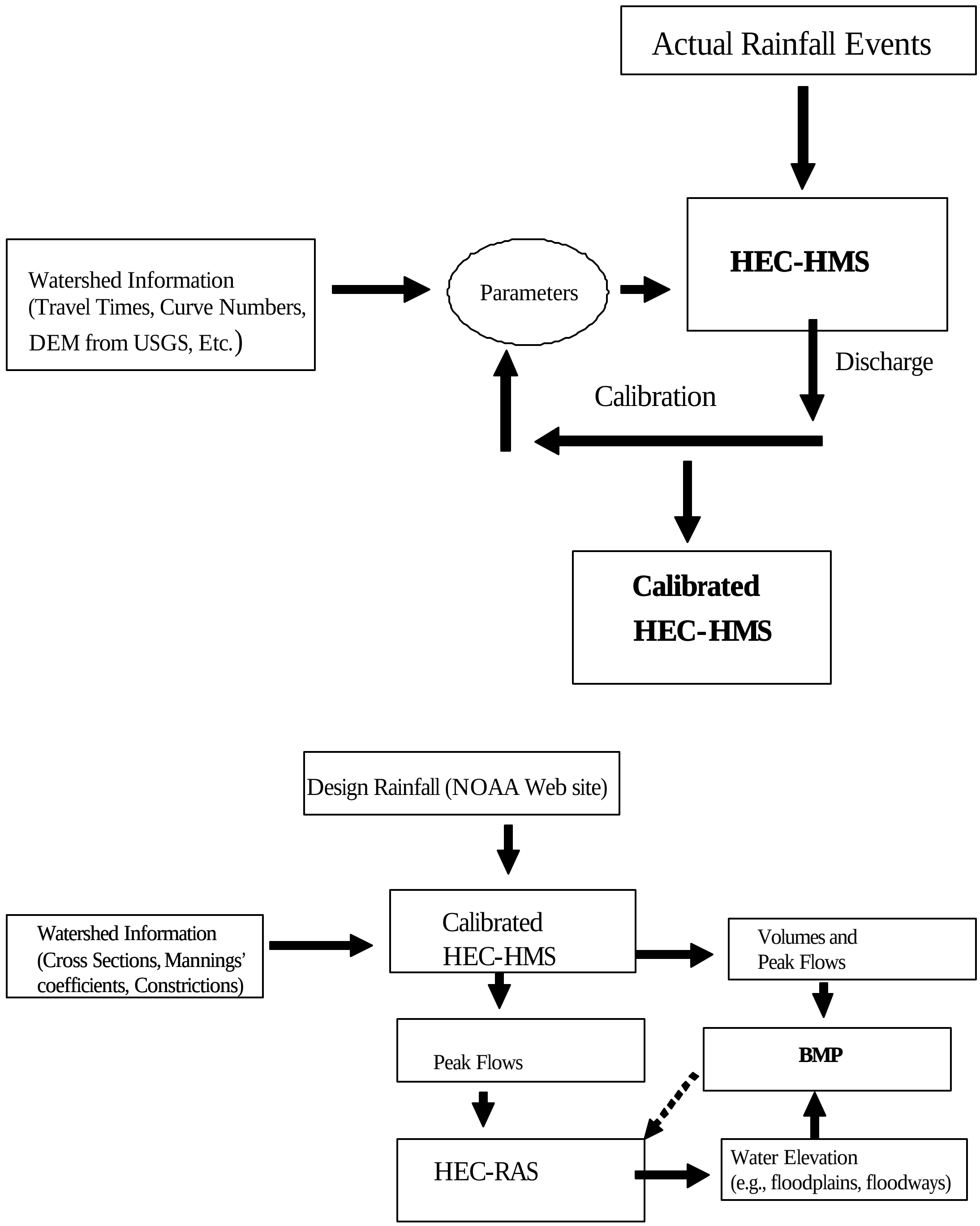


Figure 14: Flow Diagram of the Hydrologic Model

The Hydrologic Modeling

Integration of GIS and hydrologic modeling connects geospatial data with hydrologic process models describing how water moves through the environment.

The Pennypack Watershed study has used GIS extensively in the hydrologic modeling. Dr. Michel Boufadel led this aspect of the study.

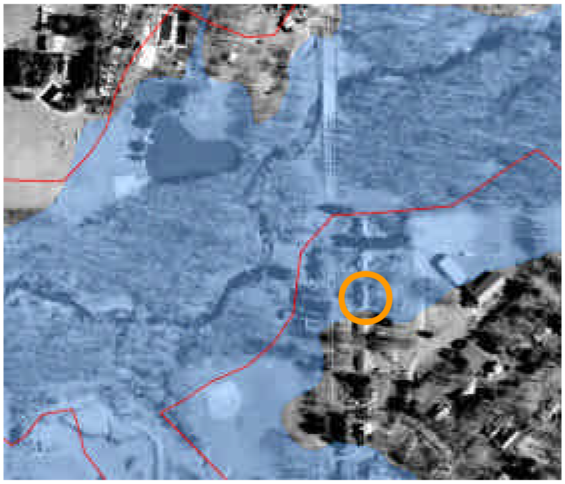


Figure 15: The residence of Lynda Thomas (in yellow circle) is now within the updated 100-year floodplain (shown in blue), although it was not so on the existing FIRM (in red boundary, as also shown in Figure 10)

As mentioned before, the goal of hydrologic modeling was to delineate new floodplains in the Pennypack Watershed that result from 100-year and 500-year hypothetical design storms. Delineating new floodplain boundaries depends on the accurate prediction of stormwater runoff and stream flows, which require three essential parameters: drainage area, times of concentration, and an infiltration/runoff parameter typically based upon soil and land use. The drainage area or sub-basin of a watershed is an area from which the runoff contributes to a "point of interest," such as the outlet of the stream or a stream gage. The Pennypack Watershed was divided into ten sub-basins before performing the hydrologic modeling. However, following the study boundary, floodplains were delineated only for the seven suburban sub-basins.

The hydrologic modeling process entails developing an actual or hypothetical design storm and then calculating the runoff and peak discharge for the selected event. The Pennypack hydrologic model was calibrated to twelve historic storms that occurred over the watershed area. The calibration required the input of land use data along with rainfall and runoff data. The latest land use data (based on year 2000 aerial mapping by the DVRPC) were incorporated in the analysis. High resolution (1 km x 1 km) radar rainfall data were used. Nine storms were used to estimate values of hydrologic parameters. The results indicated that these values are capable of accurately predicting the runoff occurring in the remaining three storms. For this reason, the estimated parameter values were used to predict the runoff resulting from the 100-year storm.

As mentioned previously, in predicting the runoff resulting from the 100-year storm, the depth of rainfall estimated by the NOAA Atlas 14 (8.75 inches) was used instead of the older TP-40 study. This greater rainfall depth along with the new land use data resulted in runoff peak values and volumes that are larger than those predicted in prior studies in the Pennypack Watershed.

Figure 16: Comparison of 100-year floodplains. Existing boundary is shown in red dotted line and new boundaries are shown as blue areas

Delineation of the floodplains for the study area was conducted using the (new) two-feet resolution topographic data prepared for the study area. In comparison with prior studies, new floodplains emerged due to the high accuracy of topography used in this study. In addition, use of HEC-RAS software provided the ability to automatically generate interpolated cross sections. However, there was no systematic difference. In other words, the extent of the new floodplains was not always larger or smaller than prior studies; it is worth mentioning, however, that the difference was sometimes as large as 400 feet. Overall, the modeling delineates 3.4 square miles of 100-year floodplain areas, compared to 2.74 square miles in the existing maps.

Temple University faculty and students provided field data on constrictions in the watershed to support the hydrologic modeling. As constrictions can significantly divert flood flows locally, this step was necessary to fine tune the modeling and floodplain maps. The detailed methodology of hydrologic modeling has been included as Appendix A.

Figure 17a and 17b: Collection of field data on constrictions in the watershed

Floodplain Mapping

The CSC GIS Studio has created the draft floodplain maps based upon the data outputs obtained from the hydraulic and hydrologic modeling. After the floodways and 100-year and 500-year floodplains were generated, the studio digitized the building footprints of all the structures within the floodplain boundaries based on the 2003 Ortho-photos. Following a spatial GIS query, the number of buildings intersected by floodplains was calculated. Table 2 shows the number of such buildings in each municipality of Pennypack Watershed. Figure 18 shows an example of the three dimensional simulation of the structures in the floodplains.

The CSC has delivered two sets of draft floodplain maps to each municipality. One map shows the newly delineated floodways, 100-year, and 500-year floodplains; and the other map compares the existing FEMA 100-year floodplain boundaries with the new ones. The new floodway and 100-year and 500-year floodplains are displayed in Maps 1 through 5. Other floodplain maps are attached in the Compact Disk in pdf format.

Web Site Creation

The CSC has created a website on which the draft report and the draft floodplain maps produced by this study have been posted to be shared with the watershed municipalities and the public: http://www.csc.temple.edu/pennypack.

In addition, the web site includes the project details, a number of visual contents including pictures, maps, and video clips. It also offers a list of online resources for further studies.

Municipality	New Floodplains			FEMA Floodplains		
	Floodway	100 year	500 year	Floodway	100 year	500 year
Warminster	4	26	44	5	15	52
Upper Southampton	14	73	126	0	65	70
Horsham	16	112	132	49	138	200
Hatboro	10	70	87	21	59	59
Upper Moreland	26	197	236	39	140	209
Lower Moreland	41	118	147	27	93	114
Upper Dublin	6	18	22	0	4	4
Bryn Athyn	0	7	7	3	51	65
Abington	23	87	99	5	12	29
Total	**140**	**708**	**900**	**149**	**577**	**802**

Table 2: Buildings in floodplains – comparison between existing and new maps
Note: There are no 100-year or 500-year floodplains in Jenkintown and Rockledge. Building footprint information is based on 2003 ortho-photo.

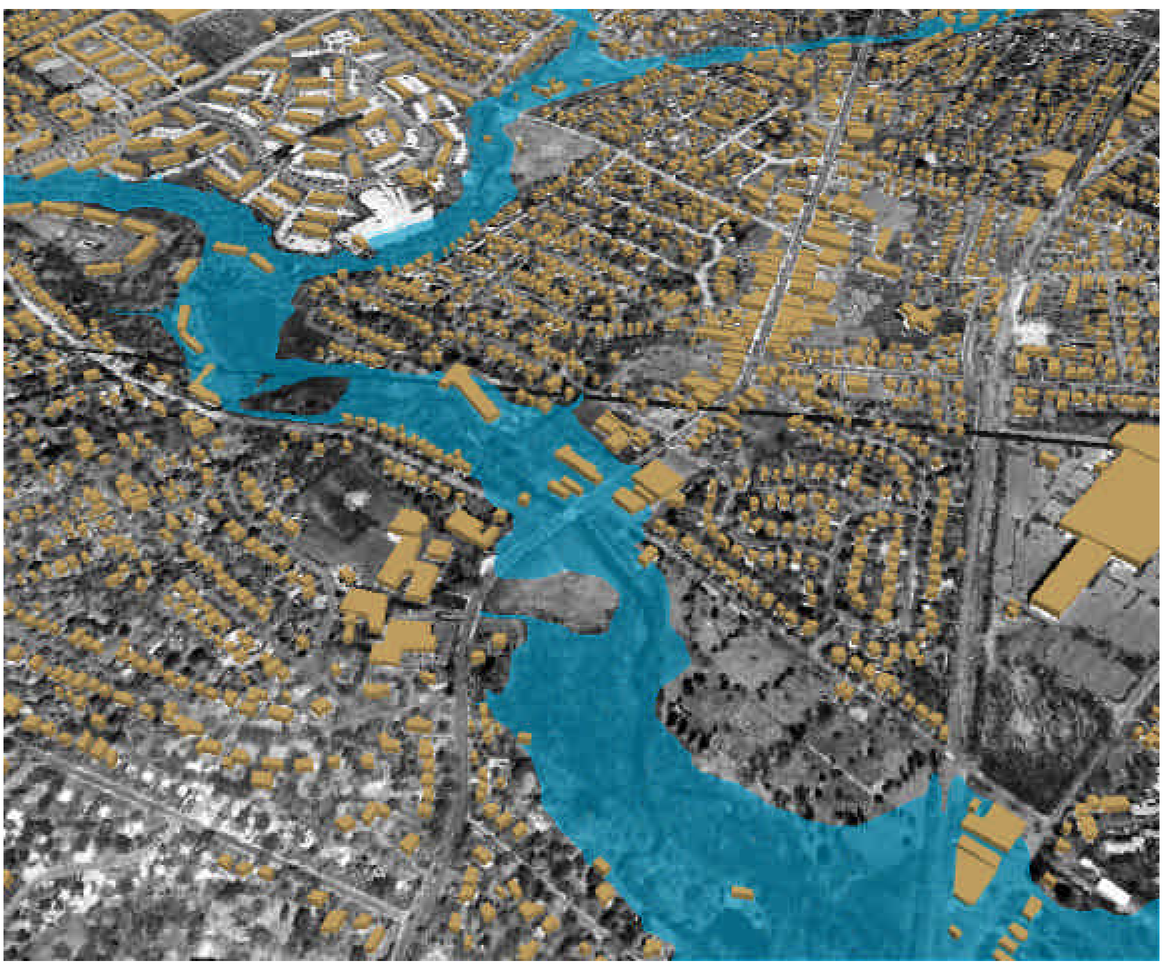
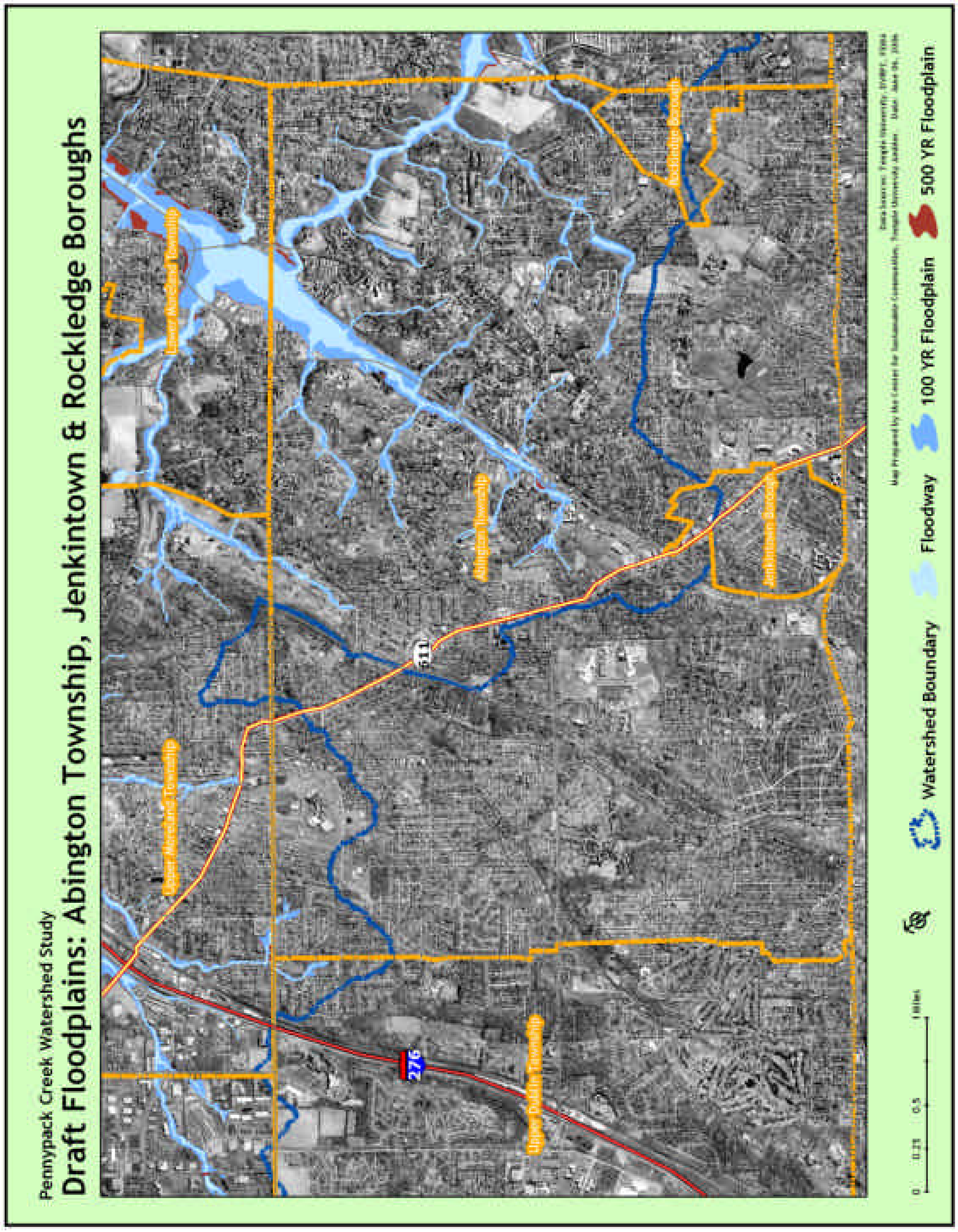
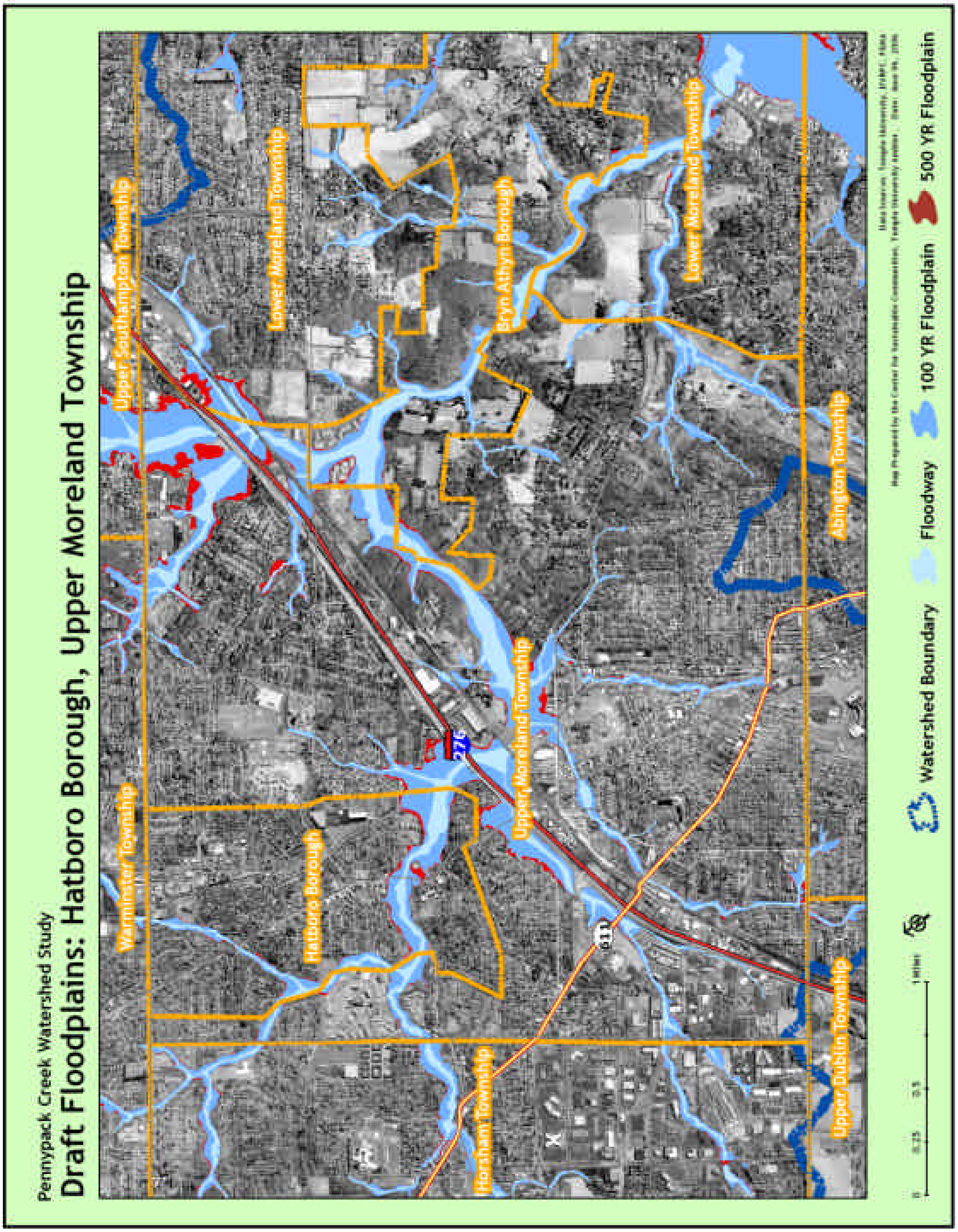


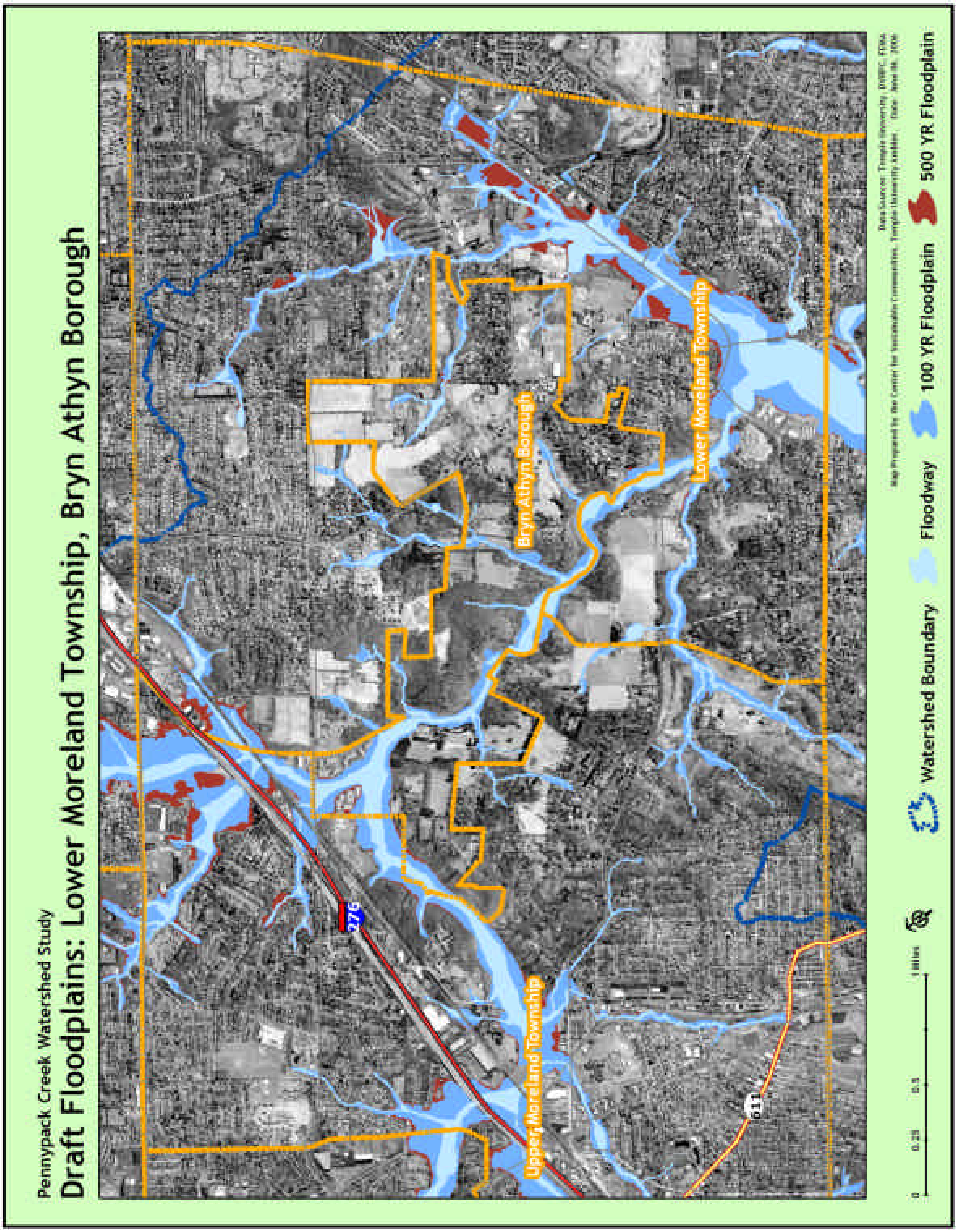
Figure 18: Three dimensional simulation of the structures in the 100-year floodplains



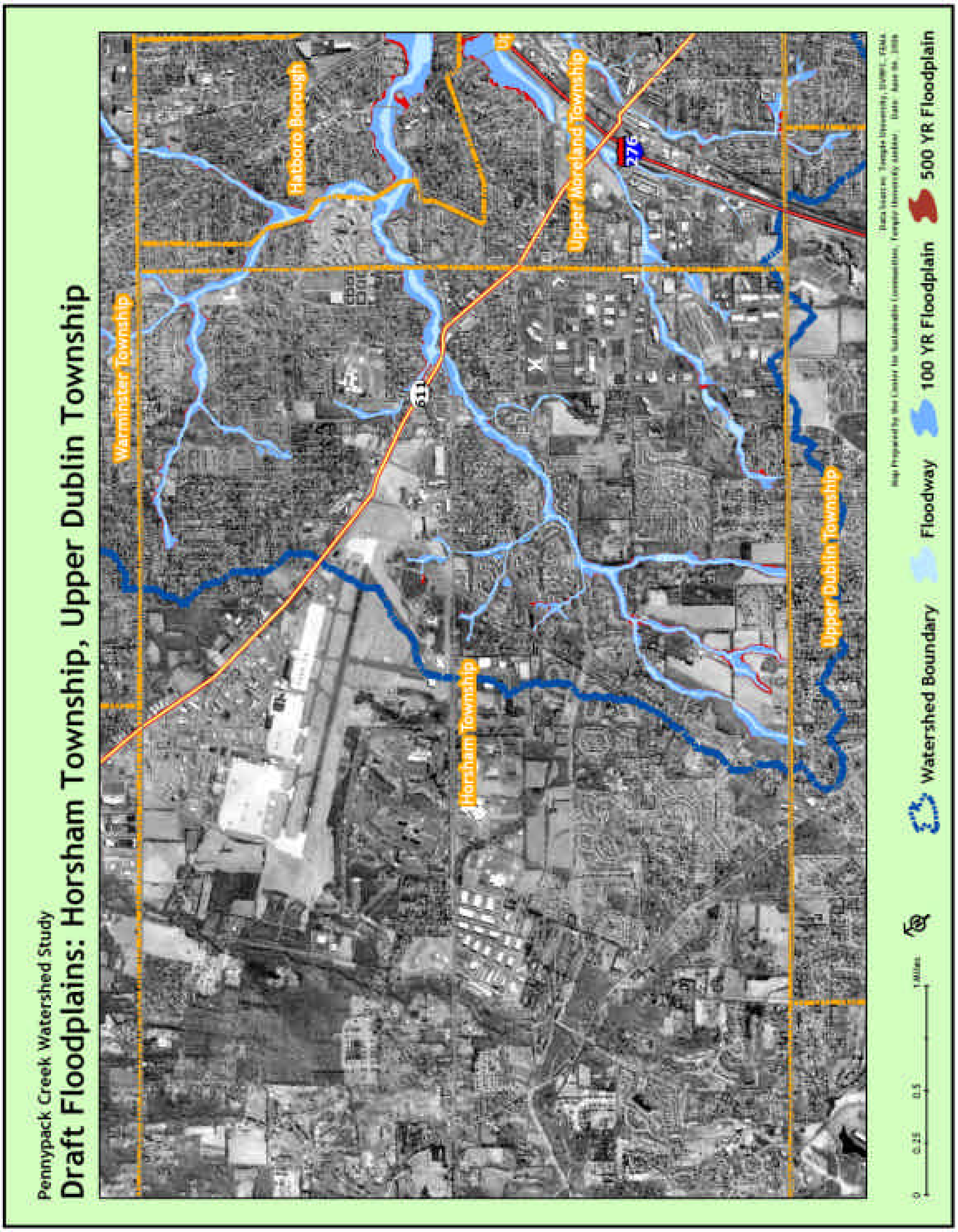
Map 1: Draft floodways and 100-year and 500-year floodplains in Abington Township, Jenkintown Borough, and Rockledge Borough



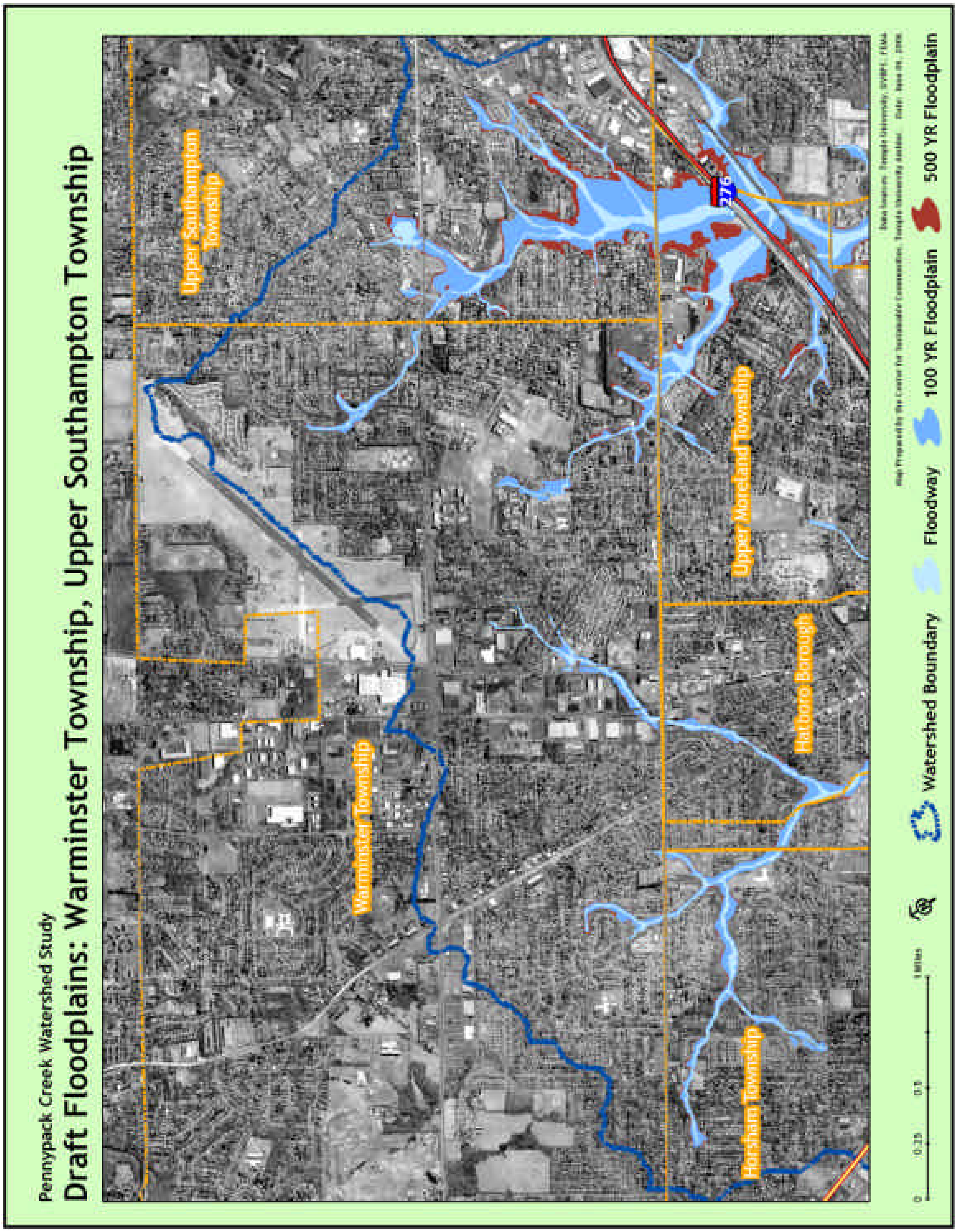
Map 2: Draft floodways and 100-year and 500-year floodplains in Upper Moreland Township and Hatboro Borough



Map 3: Draft floodways and 100-year and 500-year floodplains in Lower Moreland Township and Bryn Athyn Borough



Map 4: Draft floodways and 100-year and 500-year floodplains in Horsham and Upper Dublin Townships



Map 5: Draft floodways and 100-year and 500-year floodplains in Warminster and Upper Southampton Townships

4 WATER QUALITY STUDIES

The goal of the water quality monitoring program was to examine the human impact on stream water quality and identify potential factors to mitigate some of these impacts. Dr. Laura Toran conducted this aspect of the project.

This study did not attempt to measure the overall water quality of the Pennypack Creek, which has been addressed by previous stream assessments (e.g., Philadelphia Water Department (PWD), 2003). Instead, this program examined several problems on a small scale where human activity has the potential to alter water quality. Specifically, the program included four small-scale water quality studies in the spring/summer of 2003 and 2004. The details of the methods and results are described in Appendix B.

The first study examined how water quality changes traveling from a storm pipe through a buffer zone to Pennypack Creek. The second study evaluated the effects of upstream ponds on temperature in tributaries and Pennypack Creek. The third study measured daily nitrate concentrations upstream and downstream of the Upper Moreland – Hatboro Wastewater Treatment Plant (WTP), a significant source of point discharge in the basin. The fourth project was a comparison of urban and non-urban drainages that discharge in the same location. In each of the studies, continuous monitoring was conducted so that the water quality response to storm events as well as baseflow was measured over time. Several large data sets were generated; only a small portion of the data (example responses) is shown in Appendix B.

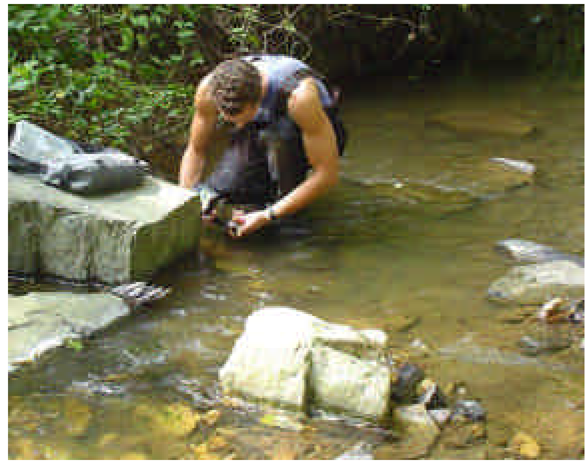


Figure 19: Collection of water quality data in the Pennypack Creek

One theme that emerged from these small scale studies is that overland flow is a major contributor to stream water quality. When the research team monitored both in the stream and at the point source of several stressors, such as storm pipes and upstream ponds, they found that the downstream water quality was homogenized. In other words, overland flow contributes nutrients, chloride, and warmer waters, all of which impact the overall water quality rather uniformly. One exception is that downstream of the WTP, the water quality (e.g. nitrate) was distinctly higher than upstream (increasing from 1 mg/L to 10-20 mg/L NO_3-N).

Observations from the small scale studies include:

- rapid rises in water levels after storms show the importance of overland flow;
- similarity in conductivity and nutrients at the storm pipe and in the buffer zone also shows the importance of overland flow;
- temperatures were warmer in upstream ponds, but rapidly dissipated downstream;

- water downstream of the WTP had higher nitrate, conductivity, and temperature; and
- urban discharge had generally higher conductivity and more variability than the non-urban discharge monitored at the same site; the variability could not be predicted by land use patterns but was influenced by a combination of source terms and local hydrology.

An implication of this work is that effective BMPs include those that increase infiltration (reduce overland flow). For example, infiltration galleries and wetlands would have more effect on water quality than small scale stream restoration such as bank stabilization. Section 5 evaluates existing stormwater facilities and management in the watershed and recommendations for BMPs are set forth in Section 7. The research team has identified 96 sites for new or retrofitted BMPs, of which 57 are rated "Highest priority."

Nonetheless, regulation of large point sources (such as the WTP) continues to be critically important. Of the four dischargers located in the watershed, three are small "package" plants that do not have significant adverse impacts on water quality. The fourth plant, the WTP is authorized by the Department of Environmental Protection (DEP) and Delaware River Basin Commission (DRBC) to discharge more than seven million gallons a day of treated effluent. As noted in Appendix B, nitrate concentrations upstream from the plant during the period of observation were steady at 1-2 mg/L. Downstream from the plant, concentrations were much higher, typically over 10 mg/L, and up to 22 mg/L. Given that the samples were diluted by existing streamflow, this indicates that effluent concentrations are much higher. The EPA has suggested a level of around 3 mg/L as a standard for aquatic life. While such a standard has not been promulgated as part of any regulation, the fact that our observation values are much higher is of concern to the research team.

Figure 20: A water quality monitoring station in Lorimer Park

Phosphorus (P) is another nutrient of concern downstream of the WTP. The PWD has noted that P concentrations are typically small above the plant and high below the plant, typically 1.5 mg/L. These concentrations have been confirmed by the CSC research team. Concentrations exceeding 0.3 mg/L are considered problematic. Both high phosphate and nitrate levels cause excessive plant and algae growth, which cause eutrophication. Nuisance algal blooms are common below the plant. Nutrient removal would improve the performance of the plant. This is discussed in Section 7. See appendix B for the full report.

5 STORMWATER MANAGEMENT

In the summer of 2004 through spring of 2005, a visual assessment of the entire Pennypack Creek Watershed was performed. This reconnaissance was conducted mainly on foot by M. Richard Nalbandian, a CSC Research Fellow, in order to get a full picture of what was actually happening on the ground within the creek's watershed and its surrounding riparian corridors. As mentioned above, the reconnaissance was conducted mostly on foot, but often had to resort to "windshield survey" methods, especially in areas such as residential subdivisions or industrial properties where access was severely limited or completely prohibited.

This assessment evaluated the condition and functionality of existing stormwater facilities, assessed the potential for retrofitting such facilities so as to improve both their environmental and flood control performance, and sought locations for recommended new stormwater BMPs.

Figure 21: The ten sub-basins of the Pennypack Creek Watershed

Field observations were made at a total of 421 locations within the seven suburban sub-basins into which the entire watershed study area was divided for hydrologic and hydraulic modeling purposes. There were 87 such locations in sub-basin 1B, 103 in 2B, 74 in 3B, 33 in 4B, 30 in 5B, 42 in 6B, and 53 in 7B. Six maps showing all 421 locations are included in the attached Compact Disk, and the notes describing those observations are in Appendix C.

The locations were in some instances a single point (e.g. a detention basin, culvert, bridge, outfall, or inlet structure), in other cases a line (e.g. the boundary or edge of a playing field, a parking lot, or a certain stretch of stream), and in still other instances, a bounded area or polygon (e.g. an entire school campus, apartment complex, shopping center, industrial/commercial property, or a currently open or undeveloped field or woodland).

Failing Stormwater Management

It was not until the 1970s that requirements for controlling the quantity or quality of runoff coming from a developed site were a consideration. Water was routed from a site to the nearest stream in the most expedient manner. This increased volume of water accelerates erosion and sedimentation and destroys stream habitat. From the 1970s until recently, stormwater management relied primarily on the use of detention basins to manage stormwater. While these basins controlled the peak flows of water, they did not reduce the overall volumes of runoff and did nothing to address or improve the water quality of runoff.

Today we know better. Stormwater BMPs and regulatory requirements are improving stormwater management in new developments. However, these actions do little to address the sins of the past. Water quality and quantity issues in older developments will require the retrofitting of existing stormwater facilities or the installation of stormwater controls where none exist in order to reduce the runoff volumes.

Many existing stormwater management facilities in the watershed have become completely or partially dysfunctional because of poor or no maintenance, ineffective design, or a combination of such factors. Some of these were obviously constructed many years ago, as evidenced by their filling by sediments and debris and the abundant tree growth within them. However, many have been constructed in recent years, and some have been observed that are quite new, but which are already evidencing poor performance.

Whatever their age, many such dysfunctional or poorly functioning facilities, whether with respect to management of discharge rates, volumes, or water quality, have been identified on the abovementioned maps as having the recommended “Highest Priority” or “High Priority” for renovation, redesign, and/or retrofitting.

Among the 421 observation locations, the CSC has identified that only 73 locations have some form of stormwater management facilities. However, 48 of these existing facilities are, in the judgment of the study team, either completely dysfunctional or performing poorly.

Opportunities

One strategy being employed in urbanized watersheds is to retrofit existing stormwater structures to better control stormwater volume and to improve water quality. However, public perception and acceptance of stormwater retrofits cannot be taken for granted. The recent spread of West Nile virus has raised public concern regarding perceived mosquito breeding sites; basin naturalization and changes in basin/site hydrology tend to tap into this anxiety despite abundant evidence that facilities such as wet ponds or constructed wetlands can provide habitat for insect predators and are actually less likely to harbor such disease vectors. New stormwater management approaches need to be carefully explained and

Figure 22: High water marks were noted in the field observations

resident concerns must be addressed.

The need for education and demonstration of successful stormwater retrofits is essential to illustrating the effectiveness of such BMPs and alleviating these public misconceptions, all while improving the conditions within these urbanized watersheds.

Opportunities that municipalities can take advantage of immediately are those which they can implement on publicly owned lands. Each municipality owns and/or manages sites that could be potentially "retrofitted" with some form of BMPs. These sites would not only reduce stormwater impacts, but also serve as model sites within the region.
The Urban Storm Water Workgroup of the Chesapeake Bay Program compiled data on the pollutant removal efficiencies of urban storm water management BMPs. While the actual performance of specific BMP installations varies, the Workgroup found that practices that could be used in parking areas such as porous pavement, bioretention areas and infiltration trenches had pollutant removal efficiencies for Total Suspended Solids (TSS) of 85 to 90% and for Total Nitrogen (TN) and Total Phosphorous (TP) of 40 to 70%. Conventional detention basins have pollutant removal efficiencies for TSS of only 10% and for TN and TP of 5 to 10%. In contrast, practices that might be used to replace or retrofit dry detention basins had significantly higher pollutant removal efficiencies. For example, a dry extended detention basin had a pollutant removal efficiency of 60% for TSS, 20% for TN and 30% for TP. A wet pond had an efficiency of 80% for TSS, 30% for TN and 50% for TP.

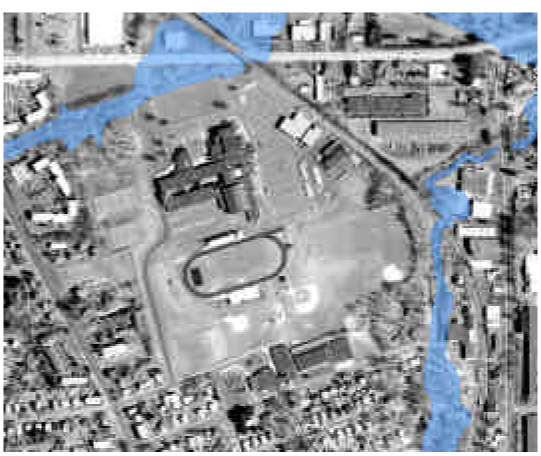


Figure 23: School campuses, such as this, can be ideal candidates for implementing new BMPs

Municipal Administration Buildings: Municipal administration buildings are wonderful opportunities for model BMP implementation, as developers, planners, engineers, and other municipal stakeholders would have the opportunity to see such practices in action, perhaps alleviating concerns that may surround the misconceptions that tend to surround the unknown.

Schools: Schools present tremendous opportunities for the implementation of stormwater BMPs. Projects on school properties would serve as demonstrations for both the schools and the surrounding communities to learn about watershed protection and stormwater management and would serve to educate a broad audience about the problems of stormwater run-off and ways to address them. However, school maintenance staff would need to be educated about environmentally friendly methods of taking care of school property. School districts, in the Pennypack Watershed and elsewhere, offer a unique opportunity for enhancing and retrofitting stormwater management facilities. In largely built out communities, they may own some of the largest tracts of open space available for innovative stormwater practices. As the educational focal points of their communities, they also offer the ability to teach students and their parents about stormwater issues through demonstration projects that are integrated into academic programs and the implementation of descriptive public signage. Unfortunately, no stormwater BMPs were observed at any of the schools in the watershed visited by CSC researchers.

Based upon the Pennsylvania Department of Education's new School Construction Reimbursement Criteria, Reimbursable Acres are calculated as follows for each school building located on the site: 1 acre for every 100 full-time equivalent (FTE) plus 10 acres for an elementary school, 20 acres for a middle school or 35 acres for a secondary or comprehensive vocational building or 15 acres for a part-time vocational building. The Department does not actually have acreage requirements for schools. But architects promoting the need for spacious new school grounds point to the aforementioned "optimum" guidelines in the school code.

The resulting school campuses are excessively large and surrounded by acres of closely manicured turf grass. This land is then subjected to the practice of endless "recreational mowing" for space that is often underutilized.

Rather than continuing the trend of large schools with extensive maintenance costs, consider alternative uses of this land. Allowing for meadows to grow on portions of the campus could present a means for saving money and producing stormwater benefits.

The first step in the planning process is to develop a facility inventory for all schools in the watershed. As a part of this inventory, site information for each school would be collected from the school districts and municipalities. The site information should include items such as parcel size, footprint area of impervious surfaces, and area of recreation and athletic spaces. A matrix could then be developed from this data and included in a final plan in order prioritize future potential retrofit sites.

Recognizing that each site will present different challenges and opportunities; information would be collected in the initial site analysis to evaluate potential suitable BMP retrofits for each identified high priority school. Potential BMPs should be applied in coordination with future building and maintenance plans and selection criteria should be developed to provide maximum water quality and quantity benefits. BMPs should be selected to repair existing damages caused by inadequate stormwater measures and to improve inefficient measures already in place.

Shopping Centers/Big Box Retail: Redevelopment projects within the watershed present opportunity for BMP implementation to take place on already developed sites. The Pennypack Watershed is home to a large number of retail shopping centers, many of which are bought and sold, renovated and redeveloped. These projects present municipalities with the opportunity to make a difference in the amount of stormwater runoff generated by an existing site, while potentially helping to alleviate flooding downstream.

Golf Courses: By their very nature, golf courses provide significant open spaces and opportunities to provide needed wildlife habitat in increasingly urbanized communities across North America. However, at the same time they can add to environmental concerns related to the potential and actual impacts of water consumption, pesticide/fertilizer use on local water sources, and land management practices such as mowing right into the streambed.

Within the Pennypack Watershed there are a number of golf courses, both public and private, which present opportunities for water quality improvement and stormwater management implementation.

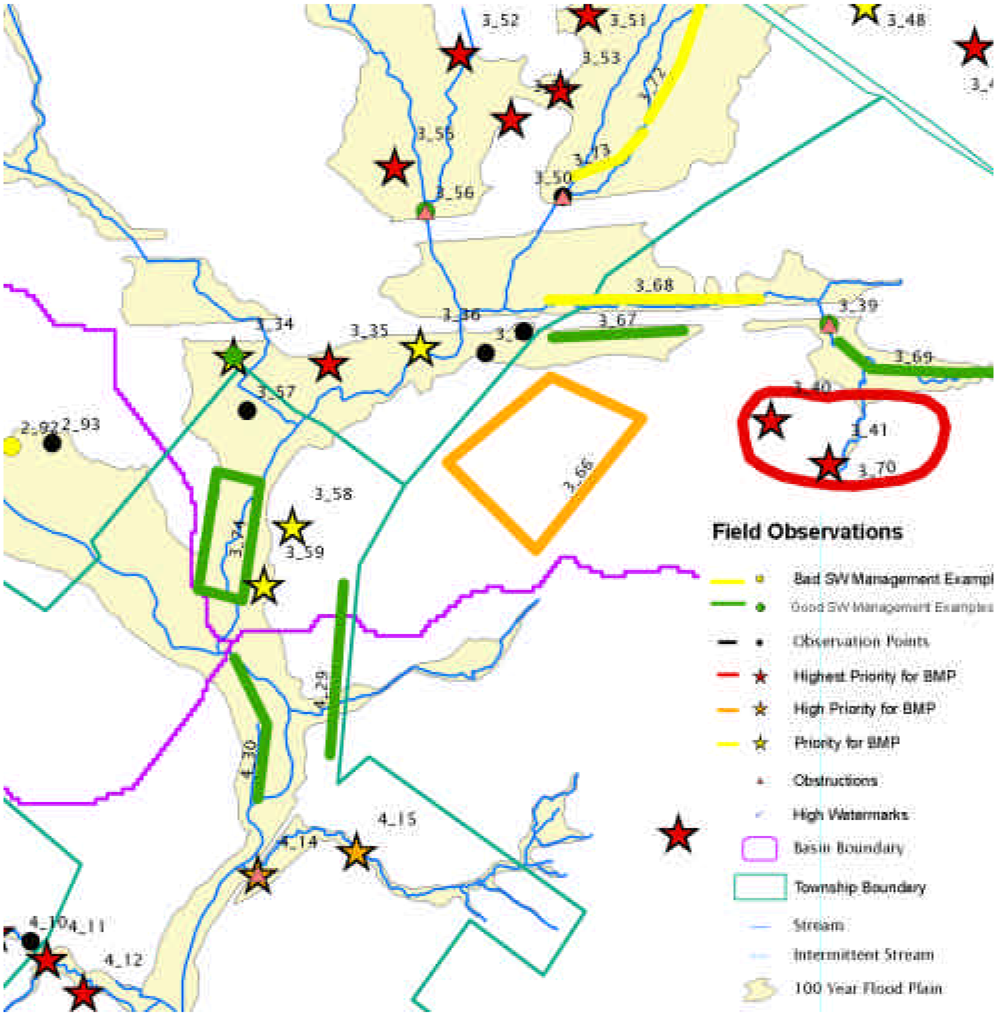


Figure 23: GIS mapping examples of field observations and recommendations

6 OPEN SPACE AND CORRIDOR ALTERNATIVES

Undeniably, open space makes a community a better place to live and work. Open spaces that have special significance associated with them such as historic places, scenic landscapes, and important natural resources, endow a community with an identity.

There exists an opportunity for municipalities to participate in the planning and preservation of natural open spaces and trails within the Pennypack Watershed. During the general election of November 2003, 78% of voters in Montgomery County responded yes to the following referendum question:

"Shall debt in the amount of One Hundred and Fifty Million Dollars, to be incurred over a ten year period, for the purpose of financing open space preservation, parks, recreation areas, recreation trails, shade trees, farmland preservation, protection and preservation of historic resources, natural habitats, and natural resources such as water, and the expenses of the debt, be authorized to be incurred by Montgomery County as debt approved by the electors?"

This referendum gave the county a clear mandate to begin the Green Fields/Green Towns open space program through the issuance of bonds to fund open space and green infrastructure projects. As part of the program, municipalities in the county are currently engaged in updating their open space plans in order to be eligible for a share of the $150M bond issue for open space preservation.

The Green Fields/Green Towns Program requires municipalities to coordinate with adjoining municipalities at critical points in the planning process. It stretches limited funds; Montgomery County provides more funds for multi-municipal projects (+15%). Multi-municipal projects are also likely to be received more favorably by funding sources when it can be demonstrated they benefit larger constituencies. It is environmentally sound; watersheds and ecosystems are not split by municipal boundaries. Connected open space provides a myriad of environmental benefits, not least of which is flood mitigation. Lastly, it is fiscally sound. Many studies show that quality of life resources are key factors in attracting and keeping businesses and homeowners.

Many of the municipalities within the Pennypack Watershed have taken advantage of this new open space planning funding source, and initiated the creation of open

Figure 24: Pennypack Ecological Restoration Trust

space plans or updates to existing ones. While each municipality has taken a slightly different approach, it is encouraging to see that municipalities have conducted in-depth analyses of their open space inventories. However, it is likely that some but not all of the municipalities have looked outside of their boundaries in order to identify potential synergies and linkages. It is critical that municipalities look beyond their political jurisdictions in order to make recommendations for preservation of valuable open space linkages. The CSC is proposing a Pennypack Trail that would provide a regional open space linkage.

From July to October 2004, the CSC consultant Andropogon Associates developed recommendations for open space in the Pennypack Creek Watershed, in particular trails and linkages to open

Figure 25a and 25b: A Pennypack Trail would provide a regional open space linkage

Figure 26: Newtown to Fox Chase line

space. This was accomplished through coordination with the planning commissions of Bucks and Montgomery Counties and the eleven municipalities within the watershed. As stated above the municipalities in Montgomery County are in the process of updating their open space plans. Andropogon concentrated on trail linkages in the watershed and the optimal location of a Pennypack Trail.

An unused railroad right-of-way owned by the South Eastern Pennsylvania Transportation Authority (SEPTA) appears to be the best choice for the trail. The rail line is ideally suited for usage as a public trail due to its location and its gentle grade. It could be used both to weave together the few remaining pieces of "natural" open space in the region and as a connector for public parks and sites of cultural interest. Much of the alignment is located in floodplain, which could provide opportunities for stormwater management interventions and public education about hydrologic systems. The team of landscape architects and planners reviewed and assessed the proposed trail configuration and made recommendations concerning its implementation.

See appendix D for the full report.

7 RECOMMENDATIONS

Based on the evaluations of the study components, the CSC research team has developed several recommendations.

Floodplain Management

The CSC recommends that once the new 100-year floodplain maps have been approved by FEMA, they should be enacted by the municipalities as their official floodplain maps. The CSC also recommends that the municipalities consider updating their existing ordinances to enable them to more rigorously enforce the new floodplain boundaries. One such approach might include regulating "Future-conditions floodplains."

According to Federal Register Vol. 66, No. 228, p. 59166, "from a floodplain management standpoint, future-conditions floodplains can be used, and are being used, by communities to enforce more stringent floodplain management policies than those required by FEMA. By displaying future-conditions floodplains on the FIRM, the community and FEMA are alerting the public that flood hazards may increase in the future due to urban development."

FEMA has created a reference document for communities interested in adopting future-conditions floodplains; "Modernizing FEMA's Flood Hazard Mapping Program: Recommendations for using future conditions Hydrology for the NFIP."

Key findings of this report are:

- The local community should determine the future-conditions land-use and hydrology
- If the community chooses to adopt a regulatory floodway based on future-conditions hydrology, the use of this floodway should be supported by local ordinances.
- If the community requests that FEMA do so, the future-conditions 1-percent-annual-chance (100-year) floodplain should be shown on the printed FIRM and be designated as Zone X with no base (1-percent-annual-chance) flood elevations (BFEs) shown.

Each municipality in the Pennypack Creek Watershed regulates development within the floodplain to varying degrees. See Appendix E for additional details regarding individual municipal floodplain ordinances.

Model Stormwater Management Ordinance

It is recommended that communities within the Pennypack Creek Watershed adopt more progressive and rigorous stormwater management ordinances, and strive for consistency watershed-wide. See Appendix F for a table describing the existing municipal stormwater ordinances.

The CSC has developed a draft model stormwater management ordinance that is consistent with the new stormwater regulations recently adopted by the City of Philadelphia on January 1st, 2006. These regulations were modeled after the ordinance developed through the Pennsylvania Act 167 Stormwater Management Planning process in Delaware County for the Darby and Cobbs Creek Watershed. This ordinance will be made available electronically to all municipalities in the watershed for evaluation. Watershed-wide adoption and enforcement of consistent stormwater management procedures will help to alleviate many of the water quality and quantity issues in the Pennypack Creek.

The draft model ordinance provides a modern and effective stormwater management program for municipalities in the Pennypack Creek Watershed. It requires that project designs follow a specific sequence in order to minimize stormwater impacts. Applicants seeking to develop or redevelop a site must:

- prepare an Existing Resource & Site Analysis Map; establish stream buffers;
- prepare a draft project layout;
- identify predevelopment hydrologic characteristics of the site;
- evaluate nonstructural stormwater management alternatives; and
- satisfy recharge objectives and provide for pretreatment before infiltration in order to protect groundwater quality and maintain and enhance stream base flows.

The draft ordinance includes the equations that must be used to calculate the infiltration requirements. Furthermore, the applicants must

- capture and treat the “water quality storage volume” calculated by using the equation provided in the ordinance;
- provide stream bank erosion protection by storing the volume of runoff from the post-development 2-year, 24-hour storm;
- maintain as much as possible predevelopment drainage areas and discharge points, i.e., maintain the natural hydrologic regimen to the extent possible; and
- control remaining runoff prior to discharge through detention, bioretention, or other structural controls so that peak runoff rates are significantly mitigated.

Calculation methodologies are presented in the draft. The model ordinance is attached as Appendix G.

BMPs and Retrofit Priorities

The overall watershed stormwater runoff can be controlled through the effective control of individual sub-basin stormwater runoff. It has been mentioned in a previous section that the Pennypack Watershed was divided into ten sub-basins for the purposes of the necessary hydrologic and hydraulic modeling. It must be noted that only sub-basins 1B through 7B are the subjects of the study, since sub-basins 8B through 10B lie within the City of Philadelphia. However, the comprehensive control of stormwater runoff for the entire Pennypack Watershed can be achieved only through stormwater management in all of its ten sub-basins.

Retrofitting existing stormwater facilities as well as areas developed prior to the implementation of any stormwater management controls with BMPs is the key to reducing water quality and quantity problems within the Pennypack Watershed. The CSC researchers recommend that each municipality create a stormwater management utility to provide sufficient revenues to fund such retrofits, to efficiently operate and maintain all stormwater facilities, and to ensure preservation of critical areas that perform vital stormwater management functions. Furthermore, each municipality should concentrate its initial efforts on implementing retrofits at the priority sites within each sub-basin where BMPs can have a significant and cost-effective impact on controlling stormwater runoff.

Within the Pennypack Watershed, if and when stormwater management measures were implemented in the development process, they have typically included just the standard detention or retention basins. The CSC is recommending a wide variety of both structural and non-structural BMPs in order to demonstrate a range of innovative stormwater management methods. Some types of structural BMPs to be considered include retrofitting existing detention basins to make them either extended detention or wet ponds, installation of porous pavement for parking and paths, installation of rain gardens, dry wells, infiltration trenches and galleries, and erosion stabilization techniques. Also, non-structural BMPs are recommended, such as incorporation of sustainable landscaping practices, reduced fertilization, and stormwater reuse for irrigation of playing fields and gardens.

Of the 421 observation locations mentioned in Section 5, 98 such locations (or groups of two or more related locations) were identified as potential sites for either new or retrofitted and improved stormwater management practices. However, the 98 locations include not only sites for recommended structural BMPs, but also sites or areas that should be preserved and even enhanced because of their high value for stormwater management due to their natural characteristics (e.g. critical floodplain areas, forests, swamps, wetlands, etc). Fifty nine of the 98 locations were identified as being of the “Highest Priority” (red stars, lines, or polygons on maps). The 39 locations identified as “High Priority” (orange stars, lines, or polygons on maps) are still regarded as having very significant but somewhat lesser potential for beneficial effects on stormwater management. The 98 locations are distributed as follows:

Sub-basin	Total Locations	Highest Priority	High Priority
1B	87	8	11
2B	103	9	7
3B	74	8	6
4B	33	8	2
5B	30	4	3
6B	41	7	5
7B	53	15	5
Total	**421**	**59**	**39**

Table 3: Prioritization of proposed BMPs

Finally, other locations, considered to be of somewhat lesser significance, but which are still recommended for new or retrofitted structural BMPs, or for preservation or enhancement of natural or non-structural BMPs are identified by yellow stars, lines, or polygons on maps.

Wastewater Treatment Plant Upgrades

The Upper Moreland-Hatboro Wastewater Treatment Plant discharges high concentrations of nutrients to Pennypack Creek. As noted in Section 4, observed nitrate concentrations range from 10 to 22 mg/L and phosphorus levels are also well above recommended limits. The research team recommends that the Upper Moreland-Hatboro Joint Sewer Authority conduct a feasibility study to evaluate possible upgrades to improve the plant's performance to significantly reduce nutrient levels in its effluent. Possible treatment options include biological removal (BNR) or chemical additives.

Although the team's recommendations on new, improved, or preserved stormwater BMPs focus mainly on the goal of reducing peak discharge and/or runoff volumes, most, if not all, of the recommended practices would have significant beneficial impacts on water quality as well. However, in one instance in particular, the research team has made a recommendation focused primarily on its water quality effects. At location 6-15 the team recommends a constructed wetland to treat the effluent from the "package" wastewater treatment plant that serves the Meadowbrook Apartment Complex.

Open Space Planning and Preservation

The research team has developed recommendations for open space in the watershed, in particular trails and linkages to open space. The team assessed a proposed trail configuration and made recommendations concerning its implementation. An unused railroad right-of-way owned by the SEPTA appears to be the best choice for the location of the Pennypack Trail.

Ideally, the municipalities within the watershed will not only be looking to maximize the total amount of open space preserved, but also carefully examining the location and function of each open space parcel and the potential for linkages between these parcels and the proposed Pennypack Trail.

The Montgomery County Planning Commission (MCPA) has included the Pennypack Trail and this right-of-way in its County Open Space Plan. Given its regional interest and extent, the MCPC, in consultation with the Bucks County Planning Commission, should initiate discussions with SEPTA and seek the resources necessary to implement the trail.

Figure 27: Pennypack Ecological Restoration Trust

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GLOSSARY OF TERMS

Basin – a large area of lower elevation than the surrounding areas. (www.dep.state.fl.us/geology/geologictopics/glossary.htm)

Best Management Practices (BMPs) – (1) a method, activity, maintenance procedure, or other management practice for reducing the amount of pollution entering a body of water (DeBarry); (2) A method for preventing or reducing the pollution resulting from an activity. The term originated from rules and regulation in Section 208 of the Clean Water Act. Specific BMPs are defined for each pollution source. (http://response.restoration.noaa.gov/cpr/watershed/calcasieu/calc_html/resources/glossary.html)

Links: Bryn Mawr College Wet Pond
http://egrfaculty.villanova.edu/public/Civil_Environmental/WREE/VUSP_Web_Folder/BC_web_folder/Wet_Pond-Bryn_Mawr_College.pdf

Contour – a line drawn on a map connecting points of equal height (http://wordnet.princeton.edu/perl/webwn)

Digital Elevation Model (DEM) – Digital Elevation Modeling is a representation of the topography of the Earth in digital format, that is, by coordinates and numerical descriptions of altitude (http:// eobglossary.gsfc.nasa.gov/Library/glossary.php3)

Erosion – the process whereby materials of the earth's crust are loosened, dissolved, or worn away and simultaneously moved from one place to another (http://ga.water.usgs.gov/edu/dictionary.html)

Floodplain – (1) the relatively level area of land bordering a stream channel and inundated during moderate to severe floods (DeBarry); (2) a low plain adjacent to a river that is formed chiefly of river sediment subject to flooding (http://wordnet.princeton.edu/perl/webwn)

The 100-year floodplain is defined as the outer boundary from a flood with a 1 percent chance of occurrence in any one year (DeBarry). The 500-year floodplain means 0.2 percent chance of occurrence.

Floodway – (1) the area near the center of the stream that has the greatest velocities and greatest discharge (DeBarry); (2) the channel of a river and the adjacent land areas that must be reserved in order to discharge the base flood without cumulatively increasing the water surface elevation more than a designated height (FEMA). This height is usually 1 foot, although some states are more restrictive.

Geographic Information Systems (GIS)— (1) a computer system for capturing, storing, checking, integrating, manipulating, analyzing and displaying data related to positions on the earth's surface (DeBarry); (2) a geographic information system is a system for management, analysis, and display of geographic knowledge, which is represented using a series of information sets. (http://www.esri.com/software/arcgis/concepts/overview.html)

Groundwater – water beneath the surface of the earth which saturates the pores and fractures of sand, gravel, and rock formations. (www.gem.msu.edu/gw/vocabulary/glossary.html)

Hydrology – (1) the science of dealing with the properties, distribution and circulation of water on the surface of the land, in the soil and underlying rocks, and in the atmosphere (DeBarry); (2) The science that treats the occurrence, circulation, and properties of the waters of the earth, and their reaction with the environment (http://web.em.doe.gov/wssrap/glossary.html)

Hydrologic Modeling – the use of physical or mathematical techniques to simulate the hydrologic cycle and its effects on a watershed (www.losl.org/gloss/gloss-e.html)

Impervious Surface – (1) a hard surface area that either prevents or retards the entry of water into the soil mantle or causes water to run off the surface in greater quantities or at an increased rate of flow. Common impervious surfaces include, but are not limited to, rooftops, walkways, patios, driveways, parking lots, storage areas, concrete or asphalt paving, and gravel roads. (http://www.epa.gov/indicators/roe/html/roeGlossI.htm); (2) land covering, such as concrete or asphalt, that does not allow water to pass through it into the ground (http://www.nps.gov/miss/programs/brj/brjresource/vocabulary.html)

Infiltration – (1) movement of water, typically downward, into soil or porous rock (DeBarry); (2) The movement of water into and through a soil (http://archive.ncsa.uiuc.edu/edu/RSE/RSEgreen/Glossary.html)

Non-point source (NPS) – (1) a pollution source that is distributed over an area rather than limited to an identifiable point (DeBarry); (2) a pollution source that cannot be defined as originating from discrete points such as pipe discharge. Areas of fertilizer and pesticide applications, atmospheric deposition, manure, and natural inputs from plants and trees are types of non-point source pollution (http://water.usgs.gov/pubs/circ/circ1144/nawqa91.11.html)

Riparian Buffer – (1) describes areas adjacent to rivers and streams with a high density, diversity and productivity of plant and animal species relative to nearby uplands (DeBarry); (2) beside or along the bank of a stream or river (http://www.chesapeakebay.net/awta/guide/home/glossary.html)

Runoff – (1) that part of the precipitation that flows toward the streams on the surface of the ground or within the ground. Runoff is composed of base flow and surface runoff (DeBarry); (2) Excess rainwater or snowmelt that is transported to streams by overland flow, tile drains, or ground water (http://water.usgs.gov/pubs/circ/circ1201/glossary.htm)

Stormwater – (1) runoff from rain, snow melt, surface water and other drainage (DeBarry); (2) Refers to rainwater, water from washing cars, overwatering lawns and other sources. Stormwater washes down storm drains and leads directly into lakes, rivers, and streams untreated. Stormwater can carry pollutants directly into our natural water resources (http://www.epa.gov/owow/estuaries/kids/glossary/)

Total maximum daily loads (TMDLs) – (1) a calculation of the maximum amount of a pollutant that a body of water can receive and still meet water quality standards; an allocation of that amount to the pollutant's sources (http://www.epa.gov/watertrain/cwa/glossary.htm); (2) under the Clean Water Act, a TMDL identifies the amount of a particular pollutant a stream can handle without violating water quality standards. States are required to distribute this allowable pollution load, the total maximum daily load of pollution, among polluters (http://www.nrdc.org/water/pollution/factor/gloss.asp)

Triangulated Irregular Network (TIN) – a vector based representation of the physical land surface, made up of irregularly distributed nodes and lines with three dimensional coordinates (x, y, and z) that are arranged in a network of nonoverlapping triangles. (http://en.wikipedia.org/wiki/Triangulated_irregular_network)

Watershed – (1) the region or land area that contributes to the drainage or catchment area above a specific point on a stream or river (DeBarry); (2) an area drained by a river (www.nwrc.usgs.gov/fringe/glossary.html); (3) the specific land area that drains water into a river system or other body of water. (http://www.unesco.org/education/tlsf/theme_c/mod13/www.worldbank.org/depweb/english/modules/glossary.htm)

Wetland – (1) ecosystems whose soil is saturated for long periods seasonally or continuously and supports hydrophytic vegetation (DeBarry); (2) land areas that are wet due to a close relationship to a body of water or groundwater, or land areas that are flooded regularly; they support vegetation adapted for life in saturated soil conditions (http://www.nwrc.usgs.gov/fringe/glossary.html)

APPENDICES

A: Hydrologic Modeling Methodology
B: Water Quality Studies Report
C: Field Observations
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E: Municipal Floodplain Ordinances Summary Table
F: Municipal Stormwater Ordinances Summary Table
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