Naamans Creek
Flood Abatement Study

Final Report

December 1999

Prepared for:

The Naamans Creek Flood Abatement Committee

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Table of Contents

Table of Contents (continued)

Table of Contents (continued)

Table of Contents (continued)

Table of Contents (continued)

Appendices

List of Figures

Table of Contents (continued)

List of Figures (continued)

List of Tables

Table of Contents (continued)

Abbreviations

CMP – corrugated metal pipe
CNA – Critical Natural Area
CNs – curve numbers
CPOM – coarse particulate organic matter
DelDOT – Delaware Department of Transportation
DNREC – Delaware Department of Natural Resources and Environmental Control
FEMA – Federal Emergency Management Agency
FIRM – Flood Insurance Rate Maps
ft – feet
GIS – Geographic Information System
HEC-RAS – Hydraulic Engineering Center-River Analysis System
NAI – Natural Areas Inventory
NCCo – New Castle County
NCCD – New Castle Conservation District
NCCDLU – New Castle County Department of Land Use
NCFAC – Naamans Creek Flood Abatement Committee
NCFAS – Naamans Creek Flood Abatement Study
NPDES – National Pollution Discharge Elimination System
NRCS – Natural Resources Conservation Service
NRCW – National River Cleanup Week
RBP – Rapid Bioassessment Protocol
RCP – reinforced concrete pipe
sec – second
T_c – concentration time
TR-20 – Technical Release 20
UDC – Unified Development Code
USDA – United States Department of Agriculture
USEPA – United States Environmental Protection Agency
USGS – United States Geological Survey
WMS – Watershed Modeling System
WRA – Water Resources Agency
WSE – water surface elevation

Executive Summary

As a result of historical severe flooding and flood-related problems in the Naamans Creek and Perkins Run Watersheds, legislation (HCR 24) was passed to establish a flood abatement committee and fund a study of the problem. The purpose of the study was to characterize the nature of the watersheds, identify sources of heavy stormwater runoff, quantify flows throughout the watersheds, identify problem sites, propose and evaluate efficacy and feasibility of solutions at these sites, and identify and propose methods of restoring natural conditions within the watersheds. This report represents the culmination and presentation of the findings of that study.

The study area includes the entire area that drains surface water runoff to Perkins Run and the South Branch of Naamans Creek. The Naamans Creek and Perkins Run Watersheds are highly developed with most of the development occurring prior to the 1970s, before New Castle County and the State of Delaware required stormwater management for land development. Consequently, as impervious area increased due to development, unmanaged stormwater runoff flows increased proportionally. In addition, significant disturbances to the natural stream system, such as stream relocation, stream channelization and lining, and floodplain/riparian buffer encroachment, occurred. The combination of increased flows and stream disturbance eventually caused Naamans Creek, Perkins Run and their tributaries to exceed the capacity of their streambanks and historic floodplains during storm events, resulting in severe flooding, erosion, ecosystem degradation, and other flood-related problems throughout the watershed. A general in-field aquatic and water quality assessment indicated significantly degraded conditions within stream areas at the middle and lower end of the watersheds. A geomorphic evaluation of the evaluated streams indicates a similar regressive trend in the downstream direction. Essentially, the results of the general watershed characterization conducted as part of this study indicates that significant areas of the Naamans Creek and Perkins Run Watersheds are highly disturbed, degraded with respect to water quality and erosion, and prone to flooding.

The watersheds were hydrologically modeled using the National Resource Conservation Service TR-20 computer model to generate storm flows for the 2-, 5-, 10-, 50- and 100-year recurrence interval precipitation events. The results of this model were used to generally evaluate erosion and flooding conditions at roadway crossings of the creeks, homes in the vicinity of streambanks, and existing structural modifications to the creeks. Additionally, the relative efficacy of proposed improvement measures were evaluated by incorporation into the model and comparing the modeled improvement flows with existing conditions flows.

A fundamental task of the flood abatement study was to identify existing and historic flooding, water quality, and other flood-related problems in the Naamans Creek and Perkins Run Watersheds. In order to identify the improvement sites, the following tasks were conducted: collection and review of existing data, review of New Castle County and Delaware Department of Transportation problem areas, coordination of public workshops, analysis of existing studies, and detailed field reconnaissance. Information obtained from citizen comments on the Naamans Creek web site was also used as a source of problem site identification.

On the basis of the data-collection, a tabular summary was developed listing seventy-nine (79) problem/potential improvement sites which were been identified as having a flood-related problem or potential for use to mitigate flood-related problems. These sites were evaluated and prioritized by the project team in cooperation with the flood abatement committee and thirty (30) sites were selected for detailed evaluation. The sites that were not specifically addressed by the study, where possible, were referred to an appropriate federal, state or local agency (i.e., Federal Emergency Management Agency, New Castle Conservation District) for further action.

Site-specific improvement measures were developed for each of the thirty (30) sites based upon the identification of specific flood-related problems by the residents of the Naamans Creek and Perkins Run Watersheds. These measures were categorized as follows:

- General Drainage Improvements that relate to surface water conveyance modifications,
- Floodproofing Improvements that protect structures from floodwaters by physical means,
- Streambank Stabilizations that focus on restoring and protecting eroding streambanks,
- Culvert Improvements that involve enlargement of existing culverts to enhance conveyance of water during flooding events,
- Stormwater Management Improvements that enlarge or otherwise modify existing stormwater management facilities to provide additional quantitative and qualitative treatment of runoff, and
- Flow Attenuation Facilities that consist of new, large-scale stormwater management facilities.

A detailed site assessment, which included a conceptual design and a feasibility assessment, was performed for each of the thirty (30) sites to evaluate the feasibility of the proposed improvements, develop preliminary design features to be incorporated into the final design, and eliminate the need for additional planning-level studies. They also facilitate prioritization for future implementation and furnish cost estimates which can be used for obtaining implementation funding. Preliminary design information packages summarizing the analysis for each potential improvement were developed and are presented as an appendix to the report.

General recommendations were made to address watershed-wide flooding issues and begin to address the causes of flooding in the Naamans Creek and Perkins Run Watersheds. The recommendations include the modification of existing stormwater management regulations to minimize and seek to infiltrate stormwater runoff, the maintenance of predevelopment groundwater recharge rates, use of conservation design techniques and protection of stream channels. In addition, it was recommended that a watershed coordinator be appointed to "champion" efforts to improve the Naamans Creek and Perkins Run Watersheds, a Water Resources Management Plan be developed, riparian buffer areas be developed on endangered, critical planting areas be developed.

A final task of the watershed study was to research funding sources to be used to fund the improvement measures recommended in this report. Appropriate federal, state, and local funding alternatives are identified and discussed herein.

This report is a tool for the Naamans Creek Flood Abatement Committee and other subsequent committees and planning efforts to use in implementing measures to improve the flooding and water quality conditions in the Naamans Creek and Perkins Run Watersheds. A summary of all the site-specific recommended improvements, their relative rankings and estimated costs is presented in Table 9.1. It is recommended that these projects be considered on the basis of the ranking set forth in this table and the availability of funds.

In addition, a list of recommended watershed-wide improvements is presented in Table 9.2. Implementation of these improvements will require the cooperation of federal, state and local government agencies.

1.0 Introduction

1.1 Background

Historically, the Naamans Creek and Perkins Run Watersheds have experienced severe flooding and other flood-related problems as a result of increased streamflows during intense precipitation events. Concerns about land development and its effect on the quantity and quality of water in these watersheds have driven an effort to identify existing conditions and problem areas through a watershed flood abatement study.

Local State legislators and New Castle County officials responded to concerns about the flooding problems and the quality of water in the Naamans Creek and Perkins Run Watersheds by passing House Resolution HCR 24. This legislation, sponsored by Representatives Wayne Smith and Senator Myrna Bair, established the Naamans Creek Flood Abatement Committee (NCFAC). Funded by State (75%) and County (25%) monies, the Committee contracted with Duffield Associates, Inc. in association with McCrone, Inc. (herein referred to as the project team) to perform the Naamans Creek Flood Abatement Study (NCFAS). The project team was to perform an evaluation of watershed characteristics and the effects of flooding on properties in the Naamans Creek and Perkins Run Watersheds. Members of the Naamans Creek Flood Abatement Committee are as follows:

- Representative Wayne Smith, Co-Chair
- Senator Myrna Bair, Co-Chair
- Councilman Robert Weiner, New Castle County
- Richard Baccino, New Castle County
- Dariel Rakestraw, New Castle Conservation District
- Richard Smith / John Hughes, Delaware Department of Natural Resources and Environmental Control
- Gerald Kauffman, University of Delaware Water Resources Agency
- Robert McCleary, Delaware Department of Transportation
- Marianne Cinaglia, Citizen
- Nathan Cloud, Citizen

1.2 Purpose and Goals

The purpose of the Naamans Creek Flood Abatement Study as defined by the NCFAC is to seek to address the present condition of a highly urbanized watershed and to propose means to mitigate damage to structures and natural features of the land and to restore, to the extent possible, the physical, hydrologic, biological, and ecological characteristics of the watershed.

The goals of the Naamans Creek Flood Abatement Study as defined by the NCFAC are to:

A. Identify sources of heavy stormwater runoff, impact of flooding, water flow and stormwater runoff on Naamans Creek, Perkins Run, and its tributaries.

   A1. Prepare a watershed model that the public can understand and that will summarize the impacts to the entire watershed (Naamans Creek, Perkins Run, their major tributaries), during/after the 2-year, 5-year, 10-year, 50-year, and 100-year storm.

   A2. Include hydrologically significant points of entry of estimated runoff.

B. Seek measures to eliminate stormwater damage.

   B1. Identify and propose solutions to existing stream and stormwater related flooding problems to residences, businesses and infrastructure.

   B2. Qualitatively assess the effectiveness of stormwater management techniques to correct current structural damage.

   B3. Stabilize streambanks where high stream velocities have eroded the banks.

   B4. Improve culvert capacity to prevent flooding.

   B5. Examine stormwater management systems to determine which areas may be expanded or designed for improved stormwater management.

   B6. Propose locations for embankment and/or wetland construction to attenuate water flow and hence reduce flooding.

   B7. Minimize soil erosion and sediment deposition along corridors.

   B8. Determine by preliminary design analysis, the estimate of probable cost, flood reduction benefits, and constructability of each site.

   B9. Preserve and enhance stream corridors, floodplains and wetlands.

C. Seek means to restore a more natural base flow and aquatic habitat to the Naamans Creek.

   C1. Propose conservation and acquisition of critical open space along stream corridors, floodplains and wetlands.

   C2. Examine stormwater management systems to determine which areas may be expanded or designed for improved stormwater management.

   C3. Propose locations for embankment and/or wetland construction to attenuate water flow and hence reduce flooding.

   C4. Propose methods to minimize soil erosion and sediment deposition along corridors.

   C5. Propose methods to establish and maintain water quality controls to safeguard streams, wetlands, and wildlife habitat.

C6. Propose methods to preserve and enhance stream corridors, floodplains and wetlands.

D. Prepare a community awareness campaign to heighten awareness of the public to the problems of urban runoff.

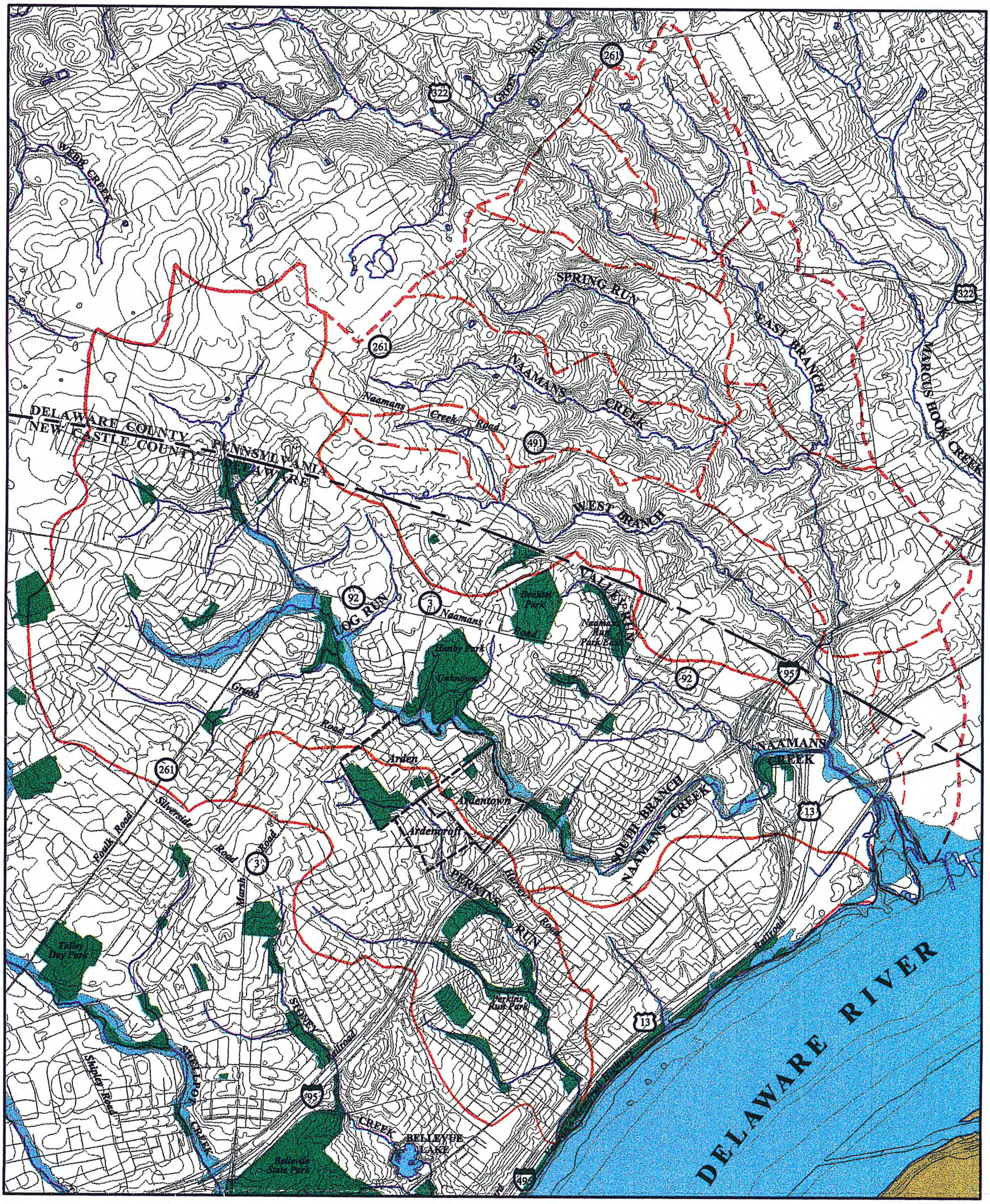
E. Suggest state/county, legislative/regulatory changes to accommodate future development without denigrating the watershed.

To accomplish these goals, the NCFAS addresses site-specific problems as identified by the residents of the Naamans Creek and Perkins Run Watersheds (Figure 1.1). These problems include, but are not limited to, flooding, erosion, drainage, and water quality. This report recommends specific improvements that will serve to solve or mitigate the most significant of these problems.

In addition, the NCFAS identifies and makes recommendations to address watershed-wide flood-related and water quality concerns. This initiative will recommend long-term, innovative methods and techniques to improve the general health of the watershed such as retrofitting existing stormwater management basins, developing or enhancing riparian buffers, utilizing bioengineering technologies, and preserving open spaces, among others.

The following sections of this report provide a general characterization of the watersheds and describe the hydrologic model for each watershed. Next, the report delineates the method of problem identification and the processes for improvement site selection and assessment that were followed in this study. Finally, the report describes site-specific and general recommendations, projected costs, and funding alternatives as well as providing an overall prioritization of the sites and a recommended plan for implementing the suggested improvements.

Figure 1.1 Naamans Creek and Perkins Run Watersheds



NOT TO SCALE

*Adapted from Naamans Creek Watershed and Open Space, University of Delaware, Institute for Public Administration, May 1997.

Legend:

- Parks and Open Space
- 100 Year Flood Plain
- Hydrology
- Naamans Creek Flood Abatement Study Watershed Boundaries
- Non-Study Watershed Boundaries
- Municipal Boundaries

SOURCES OF DATA:

Roads:
Delaware Department of Transportation centerline file (1996)
Data developed from orthophoto quad sheets (1992).

Land Use:
Delaware:
Department of Natural Resources and Environmental Control (DNREC, 1996)
Data developed from orthophoto quarter quad sheets (1992).
Pennsylvania:
Delaware Valley Regional Planning Commision.
Data developed from aerial photography (April, November, 1990).

Updated by Bethel and Upper Chichester Townshipo Engineers, 1997.
Modified with data provided by citizens drive-by field check.

Stream Network and Roads:
Delaware Department of Transportation (1994).
Pennsylvania Department of Transportation (1994).

Floodplains:
Floodplain data was extracted from digital files supplied by the Federal Emergency Management Agency (FEMA), Washington, D.C. 1993.

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2.0 General Characterization of the Watersheds

2.1 General Watershed Description

The NCFAS area includes the entire area that drains surface water runoff to Perkins Run and the South Branch of Naamans Creek, as shown in Figure 1.1. The South Branch of Naamans Creek Watershed begins in Bethel Township, Pennsylvania and flows through New Castle County, Delaware, as well as portions of Delaware County, Pennsylvania and eventually discharges into the Delaware River. Perkins Run Watershed is located entirely in New Castle County, traveling generally southwesterly from northwest of Marsh Road and discharging into the Delaware River.

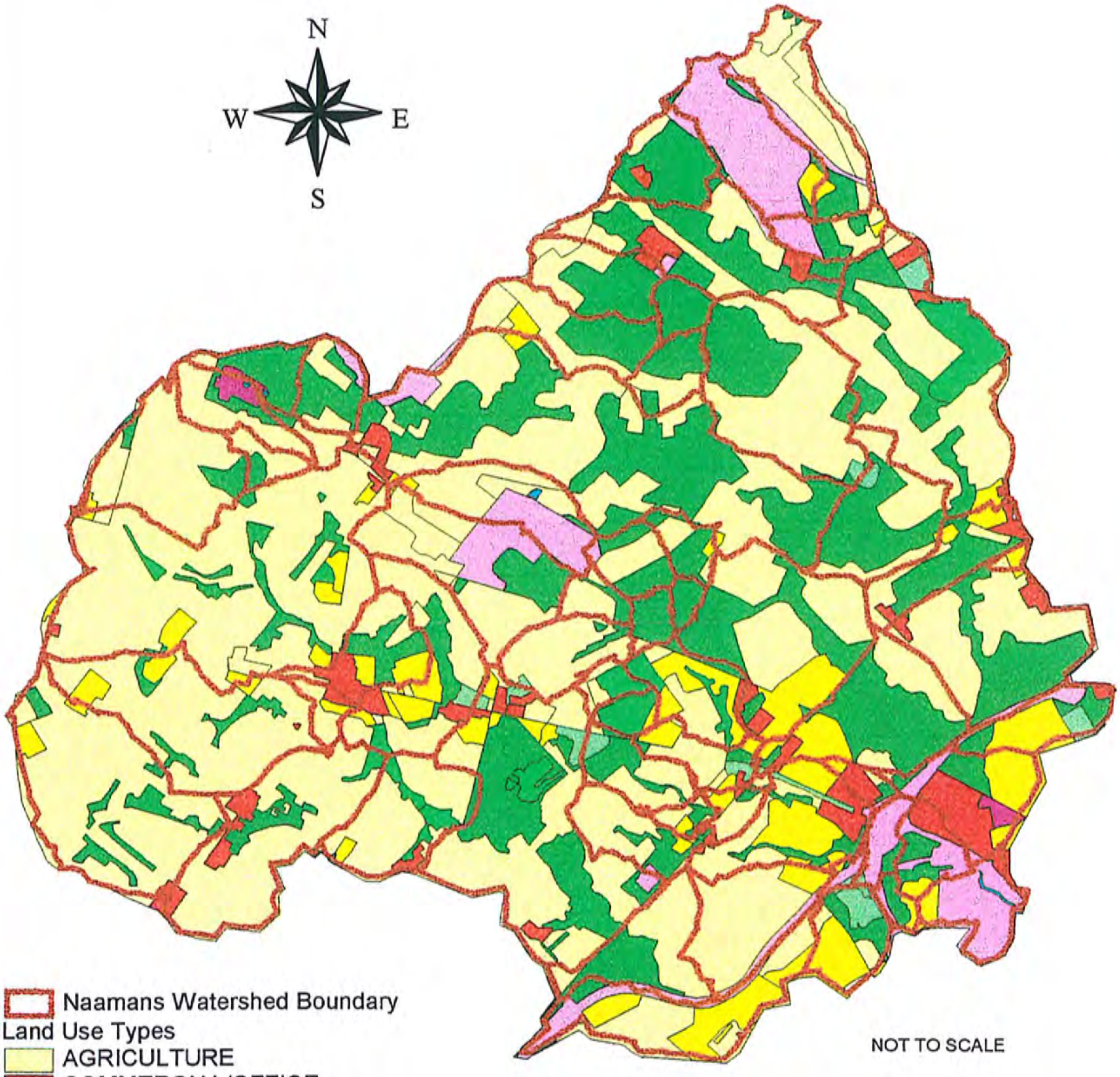
As shown in the Figure 2.1 and 2.2 Land Use Maps, the Naamans Creek and Perkins Run Watersheds are highly developed. Most of the development occurred prior to the 1970s, before New Castle County and the State of Delaware required stormwater management for land development. Consequently, as impervious area increased due to development, unmanaged stormwater runoff flows increased proportionally. In addition, significant disturbances to the natural stream system, such as stream relocation, stream channelization and lining, and floodplain/riparian buffer encroachment, occurred. The combination of increased flows and stream disturbance eventually caused Naamans Creek, Perkins Run and their tributaries to exceed the capacity of their streambanks and historic floodplains during storm events, resulting in severe flooding, erosion, ecosystem degradation, and other flood-related problems throughout the watershed. The increased impervious area also reduced natural infiltration of precipitation resulting in a reduction of stream base flow volumes.

2.2 Geology

The Naamans Creek and Perkins Run Watersheds are located in the Piedmont Physiographic Province of the Piedmont Basin. The geology of the Piedmont Province consists mostly of a thick mass of highly deformed metamorphic and igneous rocks (Woodcuff and Plank 1995). The predominant rock type in the NCFAS study area is the Wilmington Complex. The Wilmington Complex Formation typically is resistant to chemical and physical weathering and is generally characterized by relatively gentle slopes and moderately incised valleys. The rocks in this complex are generally massive, do not readily transmit or store groundwater, and consequently, they do not make good aquifers.

Naamans Creek and Perkins Run receive water from precipitation and from groundwater through the geologic formation with which they are in contact. However, because the Wilmington Complex Formation does not transmit groundwater well, only limited groundwater contributions are made to the study area streams and tributaries.

Figure 2.1 Naamans Creek - Land Use



Naamans Watershed Boundary

Land Use Types

- AGRICULTURE
- COMMERCIAL/OFFICE
- COMMERCIAL/SERVICES
- COMMUNITY SERVICE
- INDUSTRIAL
- INSTITUTIONAL
- MANUFACTURING
- MULTI-FAMILY
- PUBLIC/PRIVATE OPEN
- RECREATION
- RESIDENTIAL (HIGH)
- RESIDENTIAL (LOW/MED)
- SINGLE FAMILY (DETACHED)
- TRANSPORTATION
- TRANSPORTATION/UTILITY
- UTILITY
- VACANT
- WATER
- WOODED

*Adapted from University of Delaware, Institute for Public Administration, November 1995

Sources of Land Use Data:

Delaware:
Department of Natural Resources and Environmental Control (DNREC, 1996)
Data developed from orthophoto quad sheets (1992).

Pennsylvania:
Delaware Valley Regional Planning Commision. Data developed from aerial photography (April, November, 1990) and updated by Bethel and Upper Chichester Township Engineers, 1997.

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Figure 2.2 Perkins Run - Land Use

*Adapted from University of Delaware, Institute for Public Administration, November 1995

Sources of Land Use Data:

Delaware:
Department of Natural Resources and Environmental Control (DNREC, 1996) Data developed from orthophoto quad sheets (1992).

Pennsylvania:
Delaware Valley Regional Planning Commision. Data developed from aerial photography (April, November, 1990) and updated by Bethel and Upper Chichester Township Engineers, 1997.

Perkins Run Watershed Boundary

Land Use Types

- COMMERCIAL/OFFICE
- INSTITUTIONAL
- PUBLIC/PRIVATE OPEN
- RESIDENTIAL (HIGH)
- RESIDENTIAL (LOW/MED)
- TRANSPORTATION/UTILITY
- VACANT
- WOODED

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2.3 Groundwater

Groundwater is found throughout the NCFAS area at relatively shallow depths. Due to the low transmissivity of the Wilmington Complex Formation, the potential to yield groundwater in the Naamans Creek and Perkins Run Watersheds is low. Although there are a number of private domestic water supply wells, there is only one documented shallow public water supply well which exists in the upper part of the basin.

Existing groundwater quality information is limited in the NCFAS study area. However, most potential point sources of groundwater contamination in the Naamans Creek and Perkins Run Watersheds are located in the more industrialized parts of the watersheds between the Delaware River and Interstate 95 (DNREC, 1999).

Information on potential non-point sources of groundwater contamination are limited, but include primarily urban runoff but also may include agriculture and on-site wastewater disposal ("septic") systems.

2.4 Soils

The Neshaminy-Talleyville-Urban Land, Neshaminy-Aldino-Watchung, and to a lesser extent, the Aldino-Keyport-Mattapax-Urban Land soils associations dominate the soil groups in the NCFAS watersheds. A soils association is a landscape that has a distinctive proportional pattern of soils. It normally consists of one or more major soils and one minor soil, and is named for the major soils. Most of the soils in the associations identified above, exhibit high erodibility and have slow permeabilities due to moderately fine and fine-textural subsoils. Figures 2.3 and 2.4 show individual soil types for the NCFAS area, in the Naamans Creek and Perkins Run Watersheds. Typically, the stream substrate in Naamans Creek, Perkins Run, and their tributaries consists of boulders, cobbles, and pebbles with little sand.

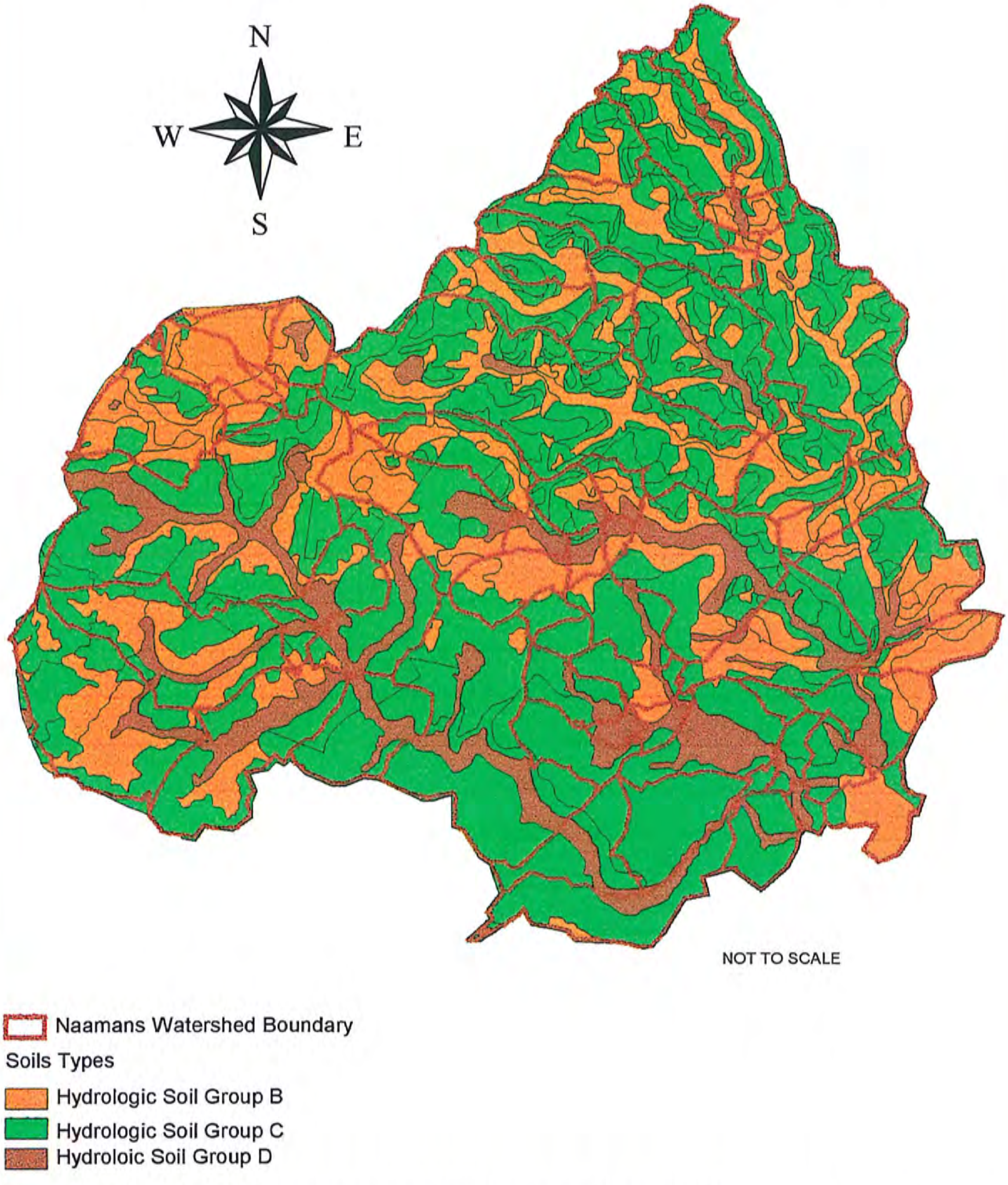
2.5 Surface Water

Surface water quality in the NCFAS study area is impacted by point source and non-point source discharges. Point source (end-of-pipe) discharges are, in many instances, regulated through issuance of National Pollution Discharge Elimination System (NPDES) permits. These permits regulate the type, concentration and load of pollutants that can be discharged from a facility to a watercourse. In addition, these permits require monitoring and reporting to be performed by the discharging facility.

Non-point source discharges are more difficult to define, but can generally result from surface water runoff and to a lesser extent percolation, groundwater discharge, and atmospheric deposition.

Three monitoring stations are used by DNREC to assess surface water quality in the Naamans Creek Watershed: one behind Phoenix Steel, one at Naamans Road, and one approximately equidistant from the other two on the South Branch of Naamans Creek.

Figure 2.3 Naamans Creek - Soil Types



*Adapted from University of Delaware, Institute for Public Administration, November 1995
Sources of Soil Data:

Delaware:
Soil Survey New Castle County, Delaware, United States Department of Agriculture, October 1970.

Pennsylvania:
Soil Survey for Chester and Delaware Counties, Pennsylvania, United States Department of Agriculture May 1963.

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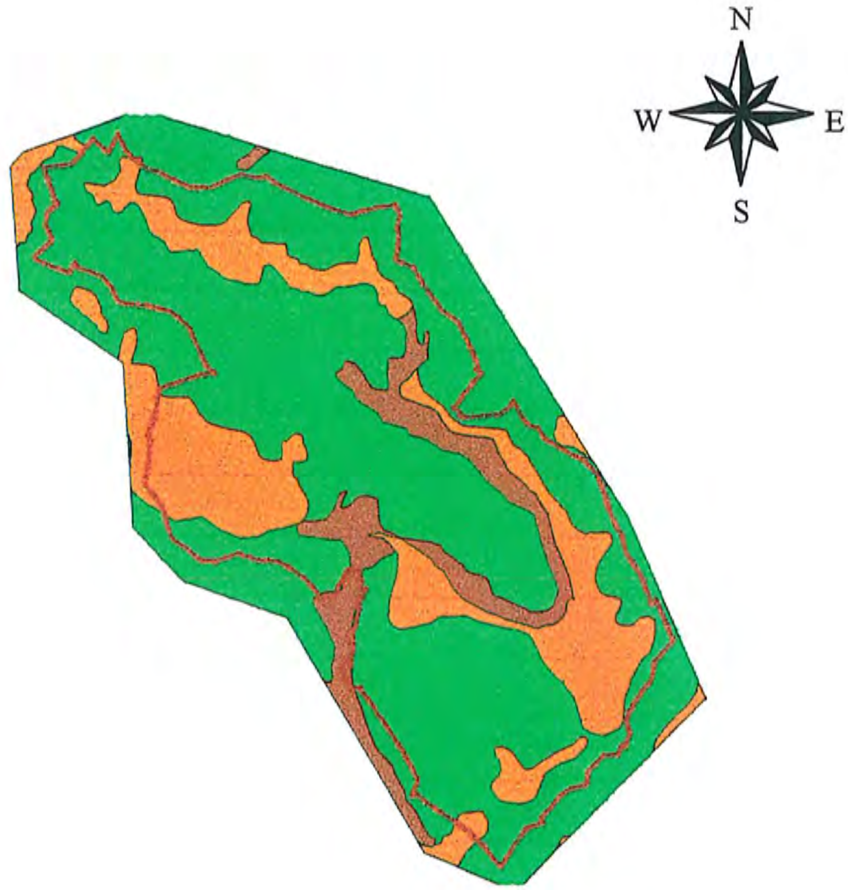
Figure 2.4 Perkins Run - Soil Types



NOT TO SCALE

Perkins Run Watershed Boundary

Soils Types

Hydrologic Soil Group B
Hydrologic Soil Group C
Hydrologic Soil Group D

*Adapted from University of Delaware, Institute for Public Administration, November 1995

Sources of Soil Data:
Delaware:
Soil Survey New Castle County, Delaware, United States Department of Agriculture, October 1970.

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Evaluation of historical and current data showed that enterococcus bacteria concentrations have consistently exceeded the state surface water quality standard. Dissolved oxygen, pH, iron, and phosphorus concentrations were in compliance with state water quality criteria; however, dissolved oxygen has been decreasing steadily over the last 15 to 25 years.

Total suspended solids have decreased in the last 26 years, but sediment deposition continues to be a problem throughout the watershed. Soil erosion, the principal source of sedimentation, is a natural process, and some amount of sediment transport is necessary to maintain stream stability. However, land development and uncontrolled surface water runoff has greatly accelerated the erosion process. Pollutants attached to sediment particles in addition to sediment deposition have had a negative impact on water quality.

Members of a group called Stream Watch provide additional monitoring in the Naamans Creek and Perkins Run Watersheds. Stream Watch was established in 1985 by the Delaware Nature Society in cooperation with DNREC. Volunteers choose locations to monitor local waterways and report their data to a DNREC coordinator for compilation. Currently, Stream Watch monitors 7 locations on the South Branch of Naamans Creek Watershed and 5 locations in the Perkins Run Watershed. The visual survey performed by volunteers includes an assessment of pollution, including the presence of excess algae, water color or odor, and the identification of potential pollutant sources. The chemical/physical survey includes measurement of air and surface temperature, pH, and dissolved oxygen. Additionally, macroinvertebrate indicators of pollution are collected from rocks, vegetation, and/or bottom sediments, and are identified.

2.6 Land Use

Data provided by the University of Delaware Water Resources Agency (WRA), indicates that the land use in the South Branch of Naamans Creek and Perkins Run Watersheds has been characterized as highly developed (Figures 2.1 and 2.2). Most of the land has been developed for residential use with supporting commercial, institutional, transportation and utility uses. Additional land use categories include agricultural, community-service, industrial, wooded, and vacant areas. A summary of the overall land use and total impervious cover areas for the North Branch and South Branch of Naamans Creek and Perkins Run Watersheds is presented in Table 2.1.

Table 2.1: Naamans Creek and Perkins Run Watersheds Land Use[1]

Land Use	South Branch of Naamans Creek Watershed Total Area[2]	South Branch Imper. Area	North Branch of Naamans Creek Watershed Total Area	North Branch Imper. Area	Total Naamans Creek Watershed Total Area	Total Naamans Imper. Area	Perkins Run Watershed Total Area	Perkins Run Imper. Area
Drainage Area	3808		4838		8646		1152	
Single Family Residential	2163	649	1659	498	3822	1147	654	196
Multi-family Residential	20	11	64	35	84	46	60	33
Office	0	0	0	0	0	0	0	0
Industrial	191	137	64	46	255	184	58	42
Transport/Utility	200	180	184	166	384	345	60	54
Commercial	200	170	208	176	407	346	60	51
Institutional	167	92	151	83	318	175	50	28
Public/Private Open Space	162	0	22	0	184	0	49	0
Wooded	404	0	2006	0	2410	0	122	0
Agricultural	29	0	37	0	67	0	9	0
Mining	0	0	0	0	0	0	0	0
Water	18	18	3	3	21	21	3	3
Vacant	30	0	116	0	146	0	9	0
Total Impervious		1257		1007		2264		407
Percent Impervious[3]		33%		21%		26%		35%
Total Land Developed	2941		2330		5270		942	
Percent of Land Developed	77%		48%		61%		82%	

[1] Data provided by University of Delaware Water Resources Agency
[2] drainage areas in acres
[3] 10 - 15% is the threshold above which watersheds become degraded (WRA)

The North Branch of Naamans Creek, which is primarily located in southeastern Pennsylvania, is substantially less developed than the Delaware portions of the Naamans Creek Watershed. Based on the data provided by the WRA, it is estimated that approximately 77% of the total South Branch of Naamans Creek Watershed is developed and 33% of that area is impervious. The North Branch of Naamans Creek is only 48% developed, having a total impervious cover of 21%. Of the watersheds evaluated in this report, Perkins Run Watershed is the most developed with 82% developed land and 35% impervious cover.

2.7 General Aquatic Habitat Assessment

2.7.1 Introduction

The project team performed a general assessment of the aquatic habitat and overall health of the aquatic biological community of the Naamans Creek Watershed as part of the NCFAS. The assessment was comprised of a water quality based model that determined the effects of urban runoff on the local benthic (bottom dwelling) macroinvertebrate populations located throughout the watershed.

Biological communities, such as the local benthic macroinvertebrate populations, integrate the effects of stressors (pollution, siltation, etc.) over time, and provide an ecological measure of varying environmental conditions. Especially in the case of non-point source pollution, biological communities can be the most obvious indicators of habitat degradation or environmental stress in highly variable conditions.

Benthic macroinvertebrate communities are good indicators of localized conditions because their migration is very limited. Macroinvertebrate communities also respond relatively quickly to stress, and are fairly easily identified. Data on pollution-tolerant and intolerant species is readily available, so a rapid assessment using simple sampling techniques and quick sampling/processing turn-around can give significant information about the aquatic environment.

Biological impairment of the aquatic community may be assessed by use of metrics that relate to community, population, and functional aspects of the community. Species (or taxa) richness is a metric that was used in this assessment to measure the health of the community by identifying the total number of families of invertebrates present in a sample. Taxa richness generally increases with increasing water quality, habitat diversity, and/or habitat suitability (USEPA, 1990).

Another metric utilized in this assessment was the identification of each collected macroinvertebrate's functional feeding group, or categorization of each macroinvertebrate by the technique it uses to gather food and the particle size of food ingested. Taxa may either be specialists that are restricted to the utilization of a specific food resource, or facultative and able to exploit a broader range of food resources (USEPA, 1990). Generalists, which can tolerate disturbance to aquatic habitats, appeared as the dominant group in collected samples taken from disturbed communities.

2.7.2 Methods

This section describes the methods utilized in selecting sampling stations, collecting samples and performing infield assessments and characterizations.

2.7.2.1 Station Selection

Stations were selected based on generally comparable habitats to ensure that community differences resulting from water quality or habitat degradation could be distinguished from community differences due to natural physical or structural change in habitat. The chosen stations all had the same degree of canopy coverage and substrate type. Stream width within stations varied from 8.0 feet to 46.0 feet from bank to bank. Water depth within stations varied between 3.0 inches and 12.0 inches.

Four sampling stations were selected in Pennsylvania and four sampling stations were selected in Delaware in order to cover a broad range of conditions throughout the Naamans Creek Watershed. Figure 2.5 depicts each station location on the USGS topographic quadrangle maps.

Two control stations were selected in the upper reaches of Naamans Creek in Pennsylvania. Control Station 1 (Station PEB2) was located on the East Branch of Naamans Creek in the westernmost section of Upper Chichester Township, Pennsylvania. Control Station 2 (Station PSB8) was located on the South Branch of Naamans Creek in Bethel Township, Pennsylvania. ThesFAS areal stations represent the "best attainable" conditions within the local residential/commercial context of the watershed, and are by no means considered undisturbed. The control stations were selected based on their location within areas that are less densely populated and that contain less impervious surface than the portion of the watershed in New Castle County, Delaware.

Data collected from sampling stations throughout the watershed of Naamans Creek were compared to results obtained from control station conditions considered the best attainable for the watershed. A network of stations (DSB3, DSB4 and DSB5) were located at points of increasing distance along the South Branch of Naamans Creek from Control Station 1 at the Delaware/Pennsylvania state line, west to the I-495/I-95 Interchange near the Delaware River in Claymont, Delaware. In addition, two other stations in Pennsylvania (PMB1 and PWB5) and one station in Delaware (DUT7) were located at representative areas along different branches in the watershed.

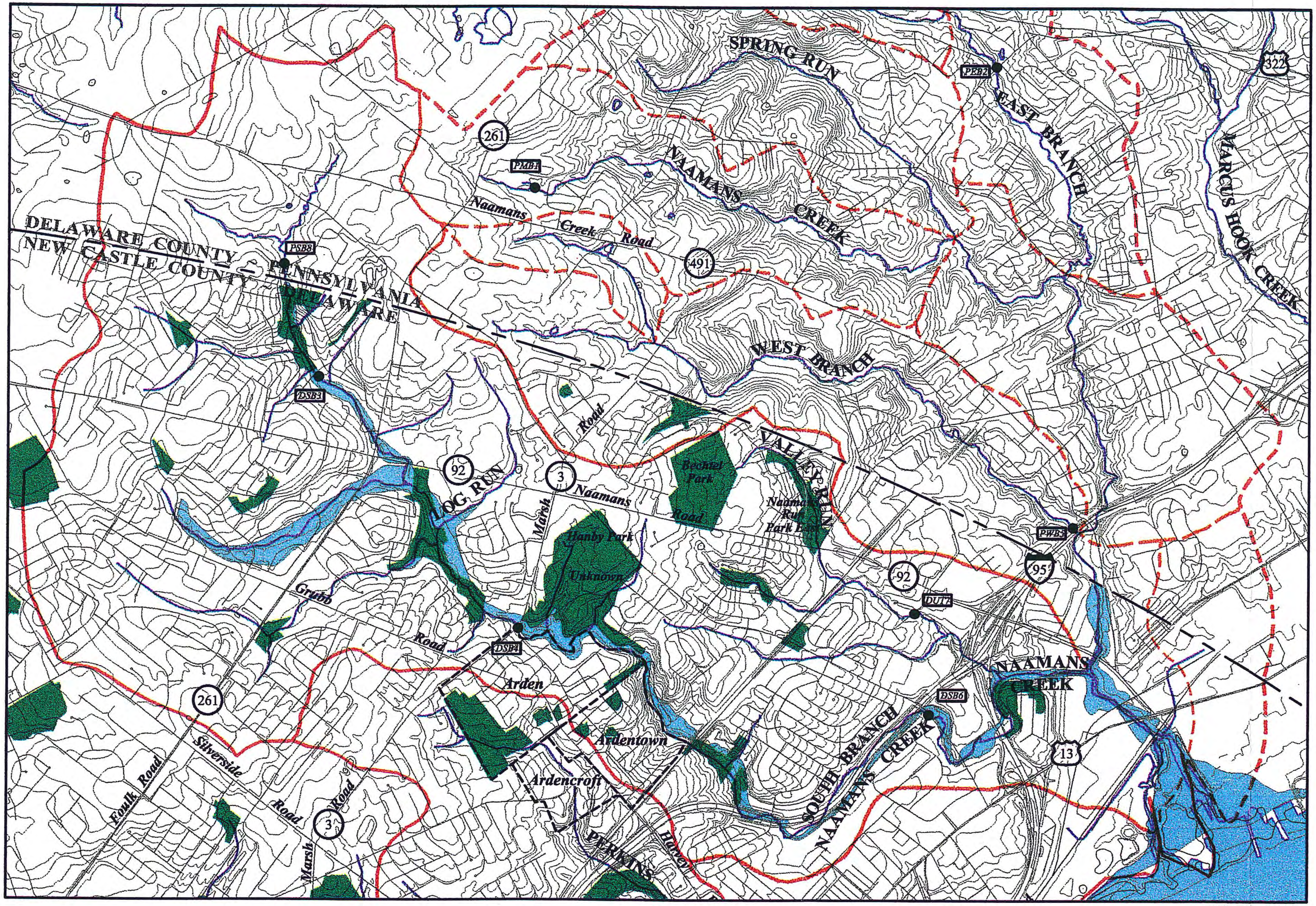
2.7.2.2 Macroinvertebrate Sampling

The U.S. Environmental Protection Agency's Rapid Bioassessment Protocol I (RBP I) was utilized as the basis of this aquatic assessment. RBP I is used to discriminate obviously impacted and non-impacted areas from potentially affected areas requiring further investigation (USEPA, 1989).

RBP I focuses on qualitative sampling of benthic macroinvertebrates supplemented by a cursory field examination of other aquatic biota such as periphyton, macrophytes, slimes and fish. All available habitats are sampled by using dip nets, or kick nets, or by hand (USEPA, 1989).

For the purposes of this study, qualitative benthic samples were collected from riffle/run and pool sections of stream using a 1 square meter kick net. Benthic macroinvertebrate taxonomic orders and families collected were listed on the Biosurvey Field Data Sheet with an estimate of relative abundance (absent, rare, abundant, dominant). Lower levels of identification were made when possible, along with relative abundance of other aquatic biota.

Figure 2.5 Aquatic Habitat Assessment Sampling Locations



*Adapted from Naamans Creek Watershed and Open Space, University of Delaware, Institute for Public Administration, May 1997.

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2.7.2.2.1 Riffle/Run Sample

Two riffle or run (the portion of current between riffles and pools) samples were collected using a 1 square meter kick net at each station: one from an area of fast current velocity and one from an area of slow current velocity. The two samples were composited for processing. The composite sample was field-sorted in a small pan with a light-colored bottom. All organisms collected were identified to family (or lower), and classified according to functional feeding group.

2.7.2.2.2 Pool Sample

A 1 square meter kick net sample was taken in depositional areas where coarse particulate organic matter (CPOM) accumulates. CPOM exists as plant debris (leaves, needles, twigs, and bark). Benthic macroinvertebrates that eat this material are classified in the functional feeding group called shredders. Shredders are fairly sensitive to toxic pollutants that adsorb to CPOM. The absence of shredders is characteristic of unstable, poorly retentive headwater streams in disturbed watersheds (USEPA, 1989).

CPOM was collected with the sample and field-sorted in a small pan with a light-colored bottom. Qualitative samples of individuals collected in this sample were recorded on the Biosurvey Field Data Sheet.

2.7.2.2.3 Habitat Assessment

General characteristics of the macroinvertebrate habitat were evaluated and recorded. General characteristics that were investigated include channel modification, bottom substrate/available cover, degree of substrate embeddedness, riffle quality, frequency of riffles, sediment deposition, channel velocity/depth, bank stability, bank vegetation type, degree of shading, and riparian zone width.

Each characteristic ranged in degree from excellent to poor, with assigned scores for each range. A score was generated for each station as a means of identifying and evaluating habitat quality at each station. The habitat assessment evaluation was used to determine the extent that habitat may be a limiting factor in the health of the aquatic community.

2.7.2.2.4 Physical Characterization/Water Quality

The physical properties of each station in terms of water quality were also determined and recorded. Any notable odors, surface spills, stream depth and width, water temperature, pH, conductivity, and inorganic and organic substrate classification were recorded.

2.7.2.2.5 Biological Impairment Detection

The detection of biological impairment was made for each station based on the presence of a list of impairment indicators, as defined by the United States Environmental Protection Agency (USEPA) (USEPA, 1989). Impairment indicators include: absence of stoneflies, mayflies, and caddisflies (pollution-intolerant species); dominance of pollution-tolerant groups of macroinvertebrates; low benthic abundance; low taxa richness; absence of other aquatic communities such as periphyton, macrophytes or fish; or the overabundance of some communities such as filamentous algae or slimes. Impairment was detected on the basis of observations made on habitat, water quality, physical characteristics, and the qualitative biosurvey (USEPA, 1989). The degree of impairment was not quantified, but an estimation of the probable cause of the impairment was provided.

2.7.3 Results

The results of the data collected are summarized below for each station, listed by reach, in order from upstream to downstream location. Refer to Table 2.2 (Habitat Parameters Identified for Naamans Creek Sampling Stations) and Table 2.3 (Qualitative Abundance of Benthic Macroinvertebrate Taxa Collected from Naamans Creek) to compare data collected from all stations throughout the watershed. The Aquatic Habitat Assessment Data Sheets are attached as Appendix A. The habitat parameters and their ratings are also described in Appendix A.

Table 2.2: Habitat Parameters Identified for Naamans Creek Sampling Stations

Habitat Parameter	Station							
	PMB1	**PEB2**	**DSB3**	**DSB4**	**PWB5**	**DSB6**	**DUT7**	**PSB8**
Dominant substrate type	boulder /cobble	cobble /gravel	cobble /gravel	boulder /cobble	cobble /gravel	cobble /gravel /silt	cobble /gravel	Cobble /gravel
Velocity (ft/sec)	stagnant	0.67	0.50	0.33	0.33	0.50	0.25	0.25
Avg. stream width (feet)	8 to 10	10	26	46	23	34	10	8
Avg. stream depth (inches)	3 to 4	6	6	8 to 12	5	6 to 8	6	4 to 6
Surrounding land use	residential /forested	residential	residential	residential /forested	commer. /forested	commer. /forested	commer. /forested	residential / forested
Evidence of sour at bends	undercut banks	undercut, exposed roots	undermined roots	heavy bank undercutting	heavy bank undercutting	slight undercutting	undermined roots	none
Canopy cover	open to partly open	partly shaded	partly open	partly open	partly shaded	partly shaded	partly open	partly open
Temperature (°C)	9.7	10.1	11.7	8.2	8.5	9.5	10.2	9.3
pH	6.74	7.32	7.24	7.11	7.12	6.99	7.16	5.71
Conductivity (u)	0.313	0.425	0.206	0.241	0.245	0.261	0.374	0.236
Habitat Assessment Score	102.50	119.50	17.50	121.50	118.25	103.00	85.00	149.50
Impairment Detected?	Yes	No*	Yes	Yes	Yes	Yes	Yes	No

* Detection of minor erosion by silt/gravel deposition and undercut roots.

Table 2.3: Qualitative Abundance of Benthic Macroinvertebrate Taxa Collected from Naamans Creek

	Station							
Taxon	**PMB1**	**PEB2***	**DSB3**	**DSB4**	**PWB5**	**DSB6**	**DUT7**	**PSB8***
Oligochaeta		2	2	1				
Gastropoda	4		3			4	1	3
Ephemeroptera		1						1
Unidentified					3			
Heptageniidae								
Stenonema		2						
Other		1			1			
Decapoda								
Amphipoda								
Gammarus	1	3			3			
Hemiptera								
Veliidae			1					
Anisoptera								2
Aeshnidae								
Gomphidae	1							
Lanthus		1						
Zygoptera								
Coenagrionidae	1							1
Plecoptera								
Pteronarcyidae								
Pteronarcys		1						
Tricoptera								
Hydropsychidae			3	3	3	2	1	1
Phryganeidae								
Ptilostomis	1							
Coleoptera								
Elimidae		1						
Haliplidae					1			1
Psephenidae					1			
Unidentified		1						1
Diptera								
Tipulidae		1	2			1		2
Chironomidae							1	2
Total Taxa	5	11	5	2	6	3	3	9
Overall Abundance	>100	72	32	39	64	62	4	25

*Control Stations, 1 = Rare, 2 = Common, 3 = Abundant, 4 = Dominant

2.7.3.1 Main Branch of Naamans Creek

The Main Branch of Naamans Creek originates in Bethel Township, Pennsylvania just east of Foulk Road (Pa Route 261), near Booth's Corner. Surrounding land use along most of this branch consists of residential development.

Station PMB1

Station PMB1 was located at the headwaters of the Main Branch of Naamans Creek, approximately 200 feet upstream of the crossing of Robin's Road in Bethel Township, Pennsylvania. The sampling station was located at the treeline between two residential houses. The drainage area upstream from the station is predominantly forested. A discharge pipe leading from one of the houses had been directed into the stream at the sampling station.

The Main Branch of Naamans Creek at this point in the watershed had been severely affected by channelization and by blockage of flow by grass-clipping and leaf-debris deposits. There was no noticeable velocity of flow at the time of sampling. This station had a low amount of canopy coverage in comparison to the other stations sampled, allowing a high degree of macrophytes to dominate the aquatic community.

Benthic Macroinvertebrate Community

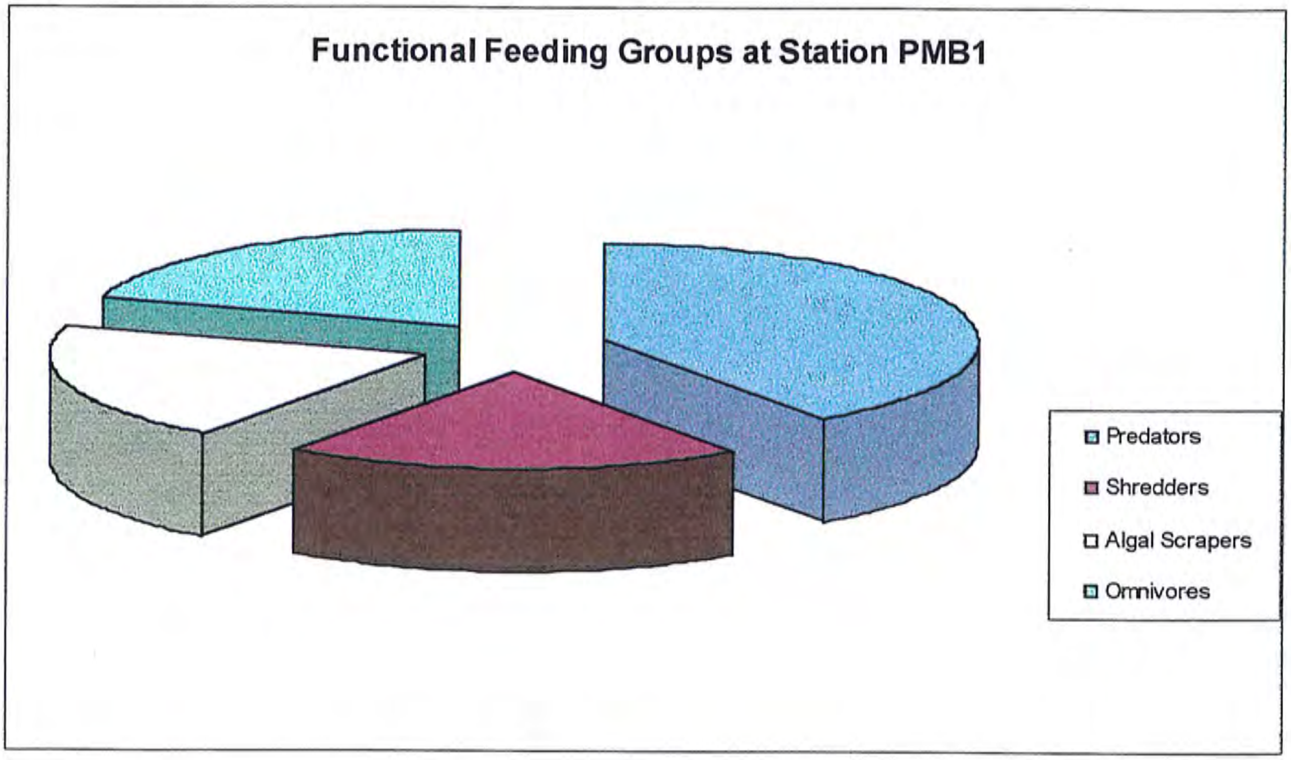
As Table 2.3 shows, taxa richness consisted of five taxa. More than 100 organisms were collected at this station, but only seven of these were insects. Gastropods (or snails) predominated in this sample, indicating a high density of algae. As shown on the data for Station PMB1 in Appendix A, fish and tadpoles were common.

Four orders and five families of benthic macroinvertebrates were represented in the data collected from Station PMB1 (Figure 2.6). Two types of pollution-intolerant indicator species were collected (Phryganeidae and Gomphidae).

Four types of functional feeding groups were present in the sample (Figure 2.6). The dominant group was the predators, represented by two types of odonates (Dragonflies and Damselflies).

Habitat Assessment

Figure 2.7 indicates that the habitat-assessment score for Station PMB1 at 102.5 was below the average for all stations. This low score was due to the restriction of baseflow caused by the overburden of debris deposited in-stream, as well as the



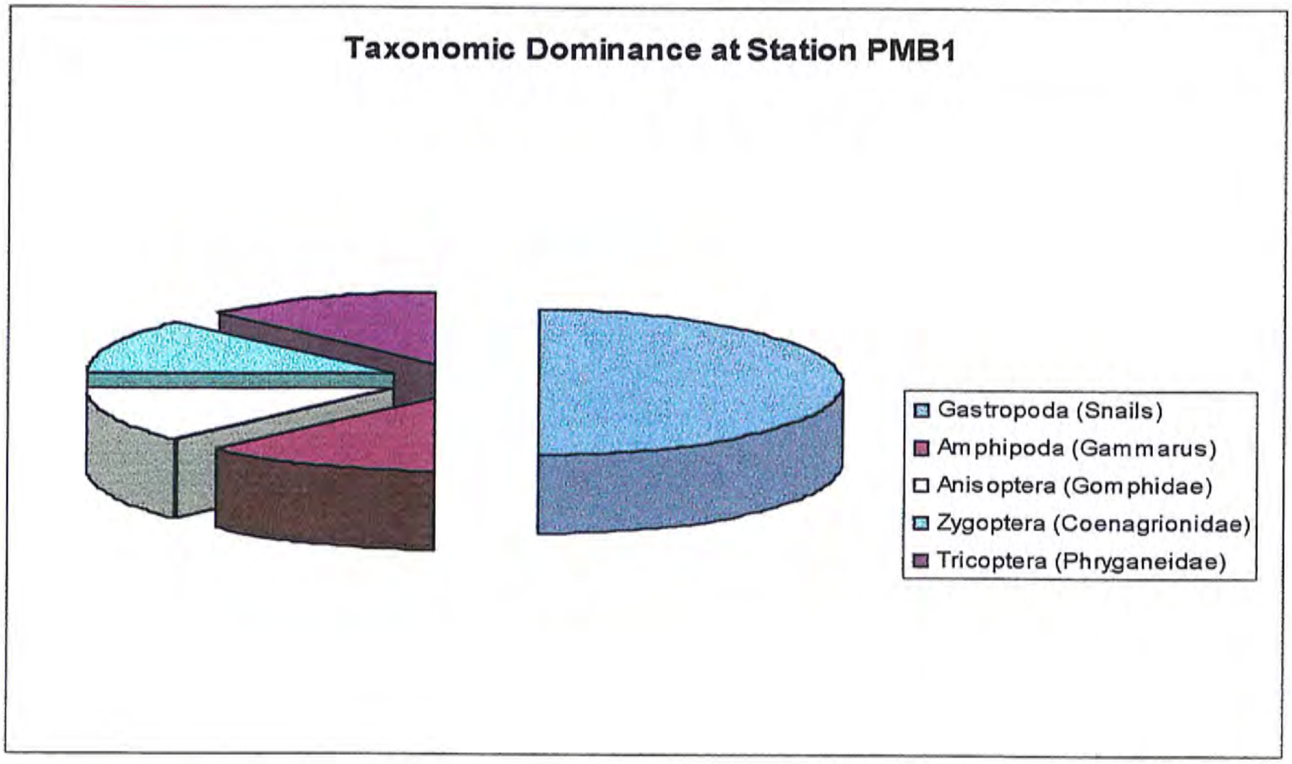


Figure 2.6: Benthic Macroinvertibrate Community of Stations PMB1

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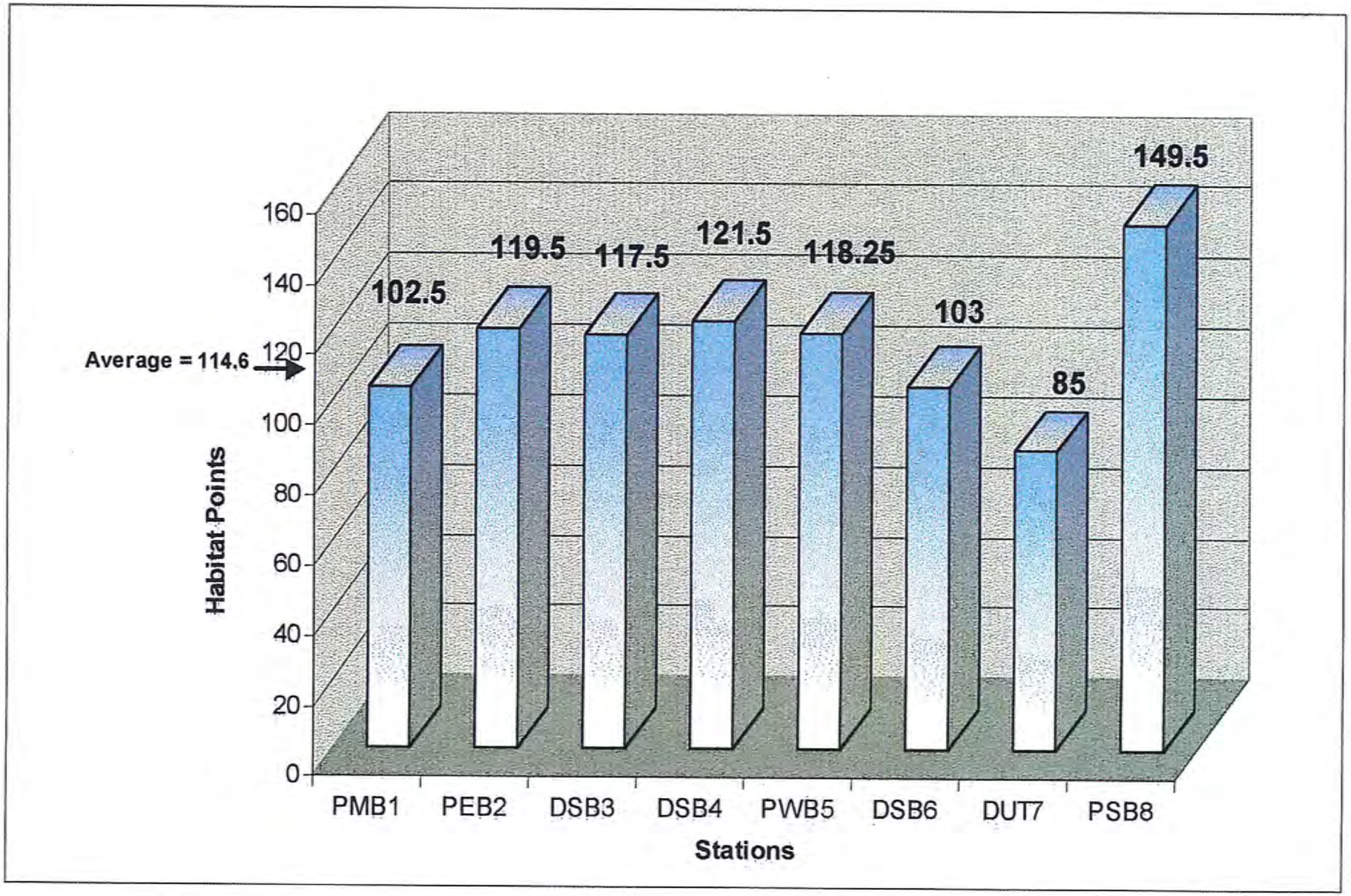

Figure 2.7: Habitat Assessment Summary

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unstable banks and linear channelization of the stream. Moreover, heavy silt deposition appeared on the stream substrate.

Physical Characterization/Water Quality

The temperature, pH, and conductivity recorded at this station were all within normal ranges. No noticeable pollution or odors were observed at this station.

Biological Impairment Detection

This section of the Main Branch of Naamans Creek was impaired by erosion indicated by a heavy silt deposit on the substrate. This section of stream also was impaired by the low flow conditions caused by debris choking the channel, and possibly by nutrients deposited into the stream from human activities, as indicated by the high levels of algae and snails.

2.7.3.2 <u>East Branch of Naamans Creek</u>

The East Branch of Naamans Creek consists primarily of forest/open land in the upper watershed, and moderately dense residential land use in the lower watershed within Upper Chichester Township, Pennsylvania. The East Branch originates in the vicinity of Route 322 and Foulk Road (Pa Route 261).

Station PEB2

Station PEB2 was located near the intersection of Larkin Road and Woodstream Road, just downstream of a large residential development called Willowbrook. The East Branch of Naamans Creek maintains a riparian corridor of approximately 300 feet in width, which runs through Willowbrook, continues through the sampling station, and extends downstream past the Glen Estates and Timber Creek residential develop-ments. Station PEB2 was approximately 1.6 miles downstream of the headwaters of the East Branch of Naamans Creek. Station PEB2 was a control station for this aquatic habitat assessment.

Benthic Macroinvertebrate Community

Station PEB2 consisted of eleven taxa as indicated in Table 2.3, which was the highest amount of taxa collected from any station in Naamans Creek.

Nine taxonomic orders of invertebrates were represented, including one family of stonefly called Pteronarcyidae, which has a very low tolerance to pollution

(Hilsenhoff, 1988), as well as two types of mayflies (Figure 2.8). The abundance of organisms collected was relatively high. Six types of functional feeding groups were present in the sample, which indicates a healthy food web with a wide range of food materials (Figure 2.8).

Habitat Assessment

Figure 2.7 indicates that the habitat-assessment score for Station PEB2, at 119.5, was above average for all sampled stations. Good to fair scores were assessed for most habitat parameters; however, some indications of erosion in the form of root undercutting and exposed roots were observed. Silt and gravel deposits were also noted covering the substrate. It appeared that silt deposition was not yet limiting the habitat quality for pollution-intolerant species such as mayflies, stoneflies, and caddisflies, as all were commonly present in the sample.

Physical Characterization/Water Quality

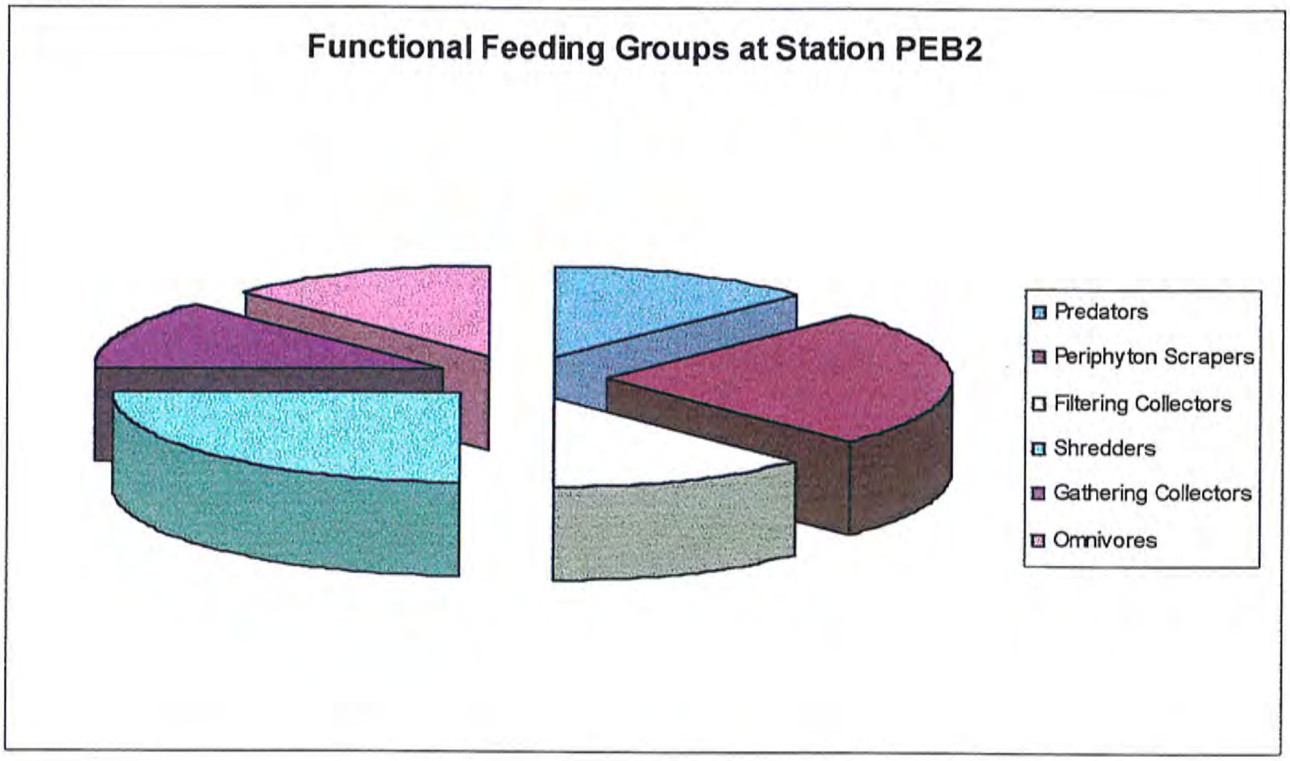
The temperature, pH, and conductivity recorded at this station were all within normal ranges. This station had the highest conductivity of all stations sampled. A slight odor of petroleum was detected at this station.

Biological Impairment Detection

The presence of pollution-intolerant species, the high abundance of collected organisms, and the high taxa richness indicated that this section of the East Branch of Naamans Creek was not impaired. There appeared to be minor erosion at and upstream from Station PEB2, but the data collected indicated that the aquatic community has not been influenced significantly by silt deposition.

2.7.3.3 <u>West Branch of Naamans Creek</u>

The West Branch of Naamans Creek originates southeast of the South Branch of Naamans Creek and meanders along the Pennsylvania/Delaware border, where it joins the East Branch of Naamans Creek at I-95 in Lower Chichester Township, Pennsylvania. The upper half of the West Branch of Naamans Creek is primarily forested/undeveloped land, and the bottom half is residential.



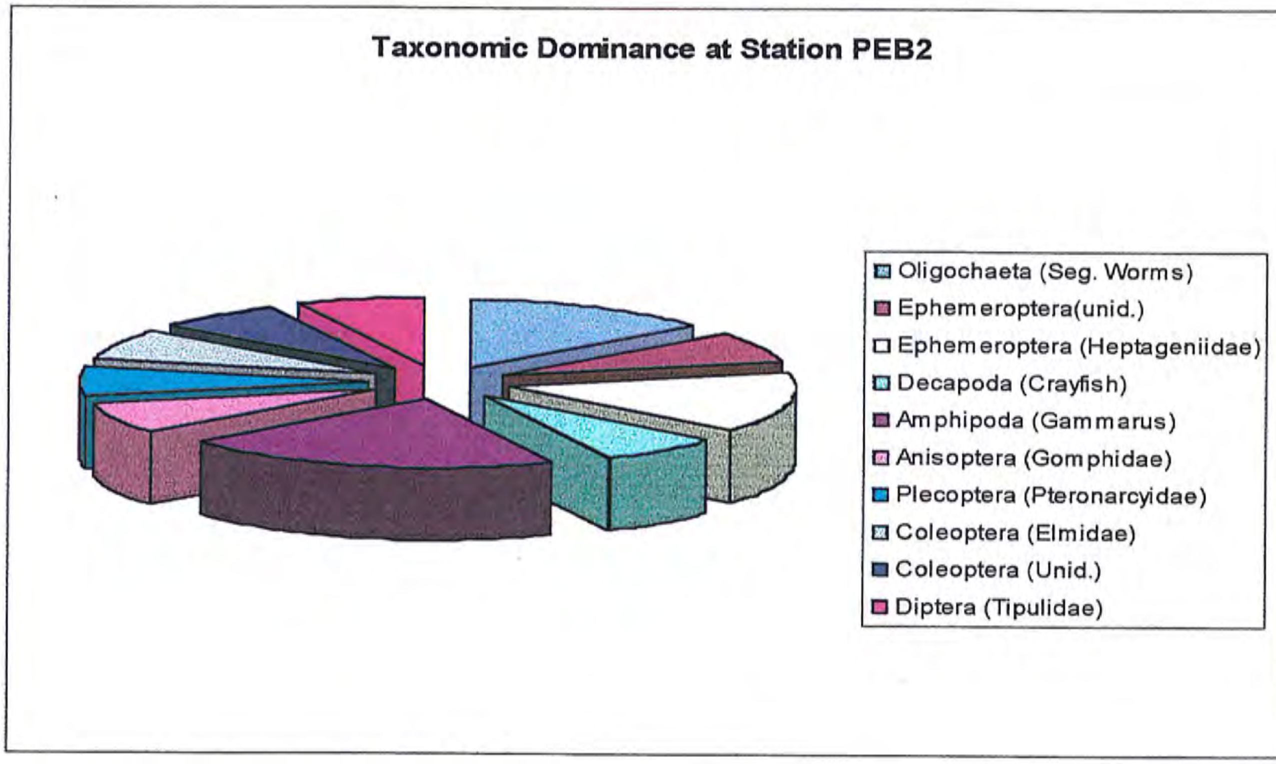


Figure 2.8: Benthic Macroinvertibrate Community of Stations PEB2

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Station PWB5

Station PWB5 was located near the confluence of the West Branch and East Branch of Naamans Creek, just 250 feet upstream from the I-95 bridge at the Peppermill Inn on Pennsylvania Route 491 (Naamans Creek Road).

Benthic Macroinvertebrate Community

Table 2.3 indicates that six taxa were present in samples collected from Station PWB5. Overall, the abundance of organisms collected was comparatively high. As shown in Figure 2.9, six families of benthic macroinvertebrates were represented in the sample, most of which are considered somewhat pollution-tolerant (Hilsenhoff, 1988).

Five functional feeding groups were present in the sample. However, it appeared that predators and shredders had dropped out of the community, and filtering/gathering collectors and omnivores had become dominant (Figure 2.9). Such a sampling might be indicative of a normal mid-sized reach stream, where collector-scraper communities dominate over the shredder dominated headwater sized streams (Williams and Feltmate, 1992).

Habitat Assessment

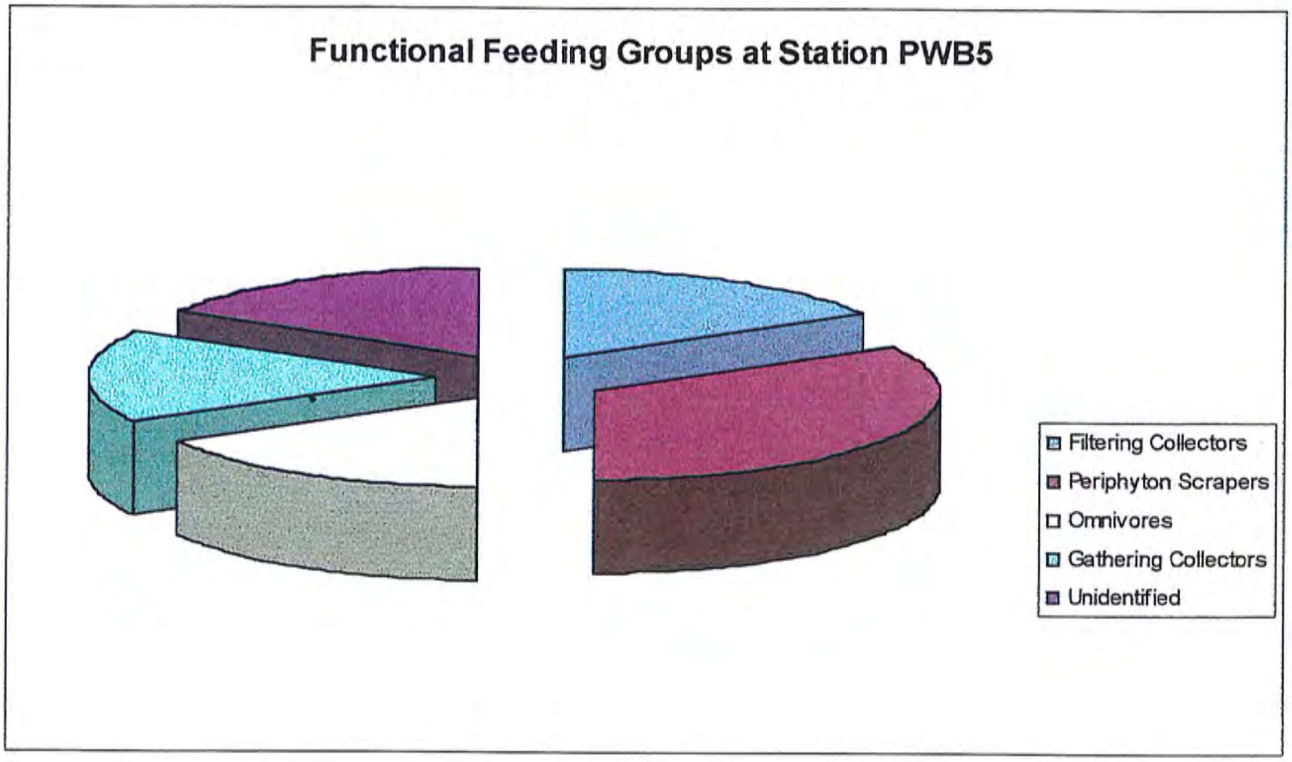
Figure 2.7 indicates that the habitat assessment score for Station PWB5, at 118.25, was above the average for all sampled stations. Observations of sediment deposition and lack of riffle habitat in this portion of stream limited the available habitat for aquatic organisms.

Physical Characterization/Water Quality

The temperature, pH, and conductivity recorded at this station were all within normal ranges. No noticeable pollution or odors were observed.

Biological Impairment Detection

This section of the West Branch of Naamans Creek was determined to be impaired due to heavy siltation and low taxa richness. The presence of pollution-intolerant mayflies and a wide range of functional feeding group types may indicate that the impairment is not severe. Further investigation is needed to determine the degree of impairment and the overall health of this aquatic community.



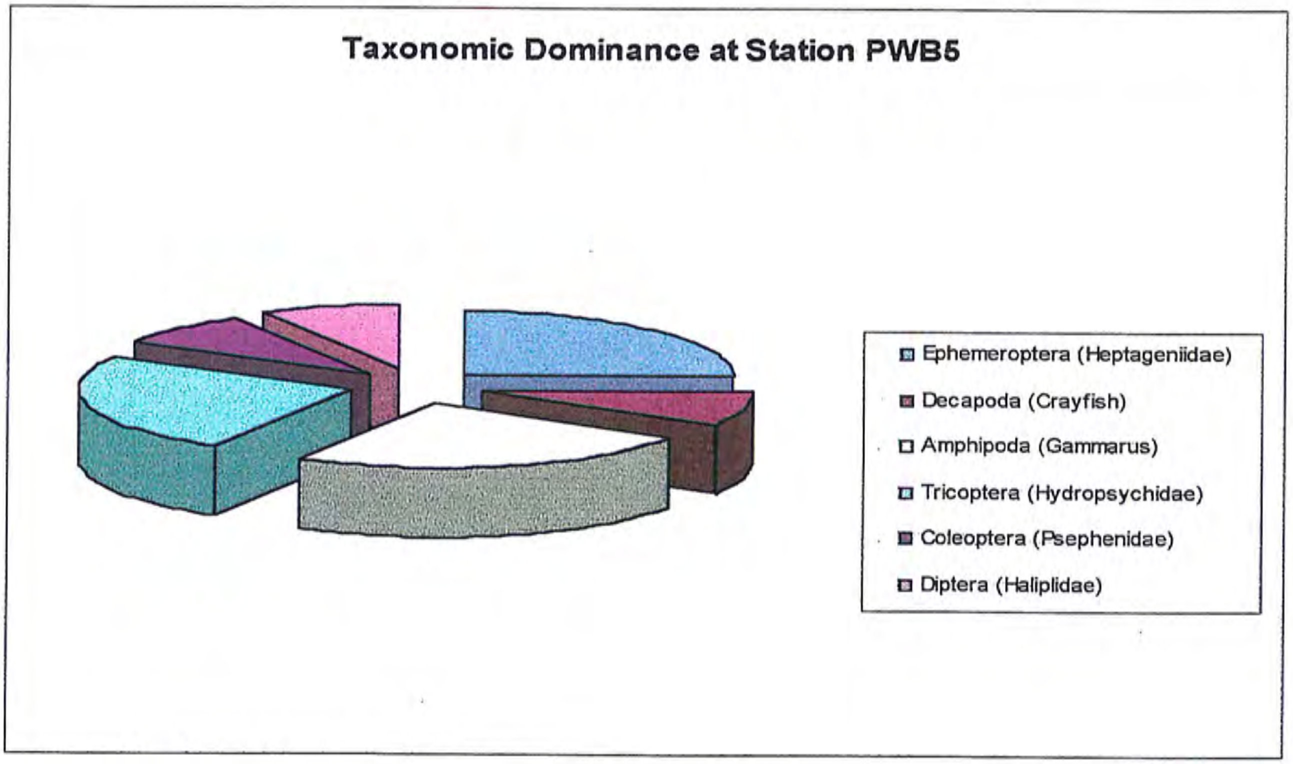


Figure 2.9: Benthic Macroinvertibrate Community of Stations PWB5

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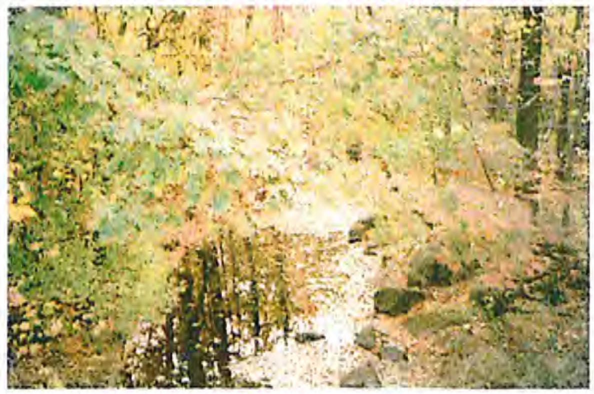
2.7.3.4 South Branch of Naamans Creek

The South Branch of Naamans Creek originates between Zebley Road and Naamans Creek Road in Bethel Township, Pennsylvania, and extends southeast through New Castle County, Delaware until it reaches the Delaware River in Claymont, Delaware. This branch of Naamans Creek travels through the most densely populated portion of the watershed.

Station PSB8



Station PSB8 was located on Sharon Drive in the residential development of Sharon, at the Pennsylvania/Delaware boundary. The station was positioned in the headwaters within a wide riparian corridor just downstream from a man-made wetland/detention facility adjacent to the stream. Station PSB8 was a control station for this aquatic habitat assessment.

Benthic Macroinvertebrate Community

Table 2.3 indicates that Station PSB8 consisted of nine taxa, although only twenty-five (25) individuals were collected in the sample. Included in the sample was one Odonate species (damselfly) that is considered pollution-intolerant (Aeshnidae) (Hilsenhoff, 1989). Nine families of benthic macroinvertebrates were represented in the sample (Figure 2.10).

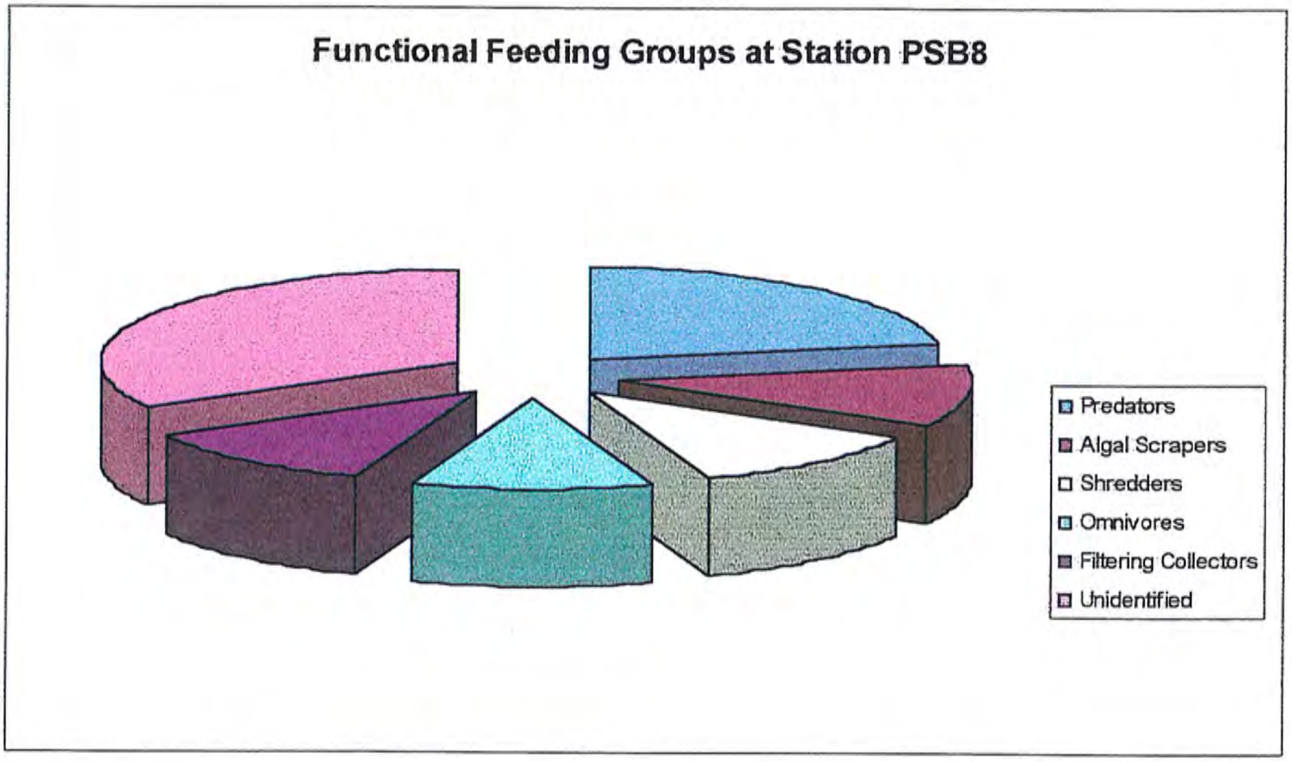
Six functional feeding groups were identified, ranging from predators to filtering collectors (Figure 2.10). Despite low abundance, the aquatic population appeared to be balanced and healthy in this section of the South Branch of Naamans Creek.

Habitat Assessment

Station PSB8 scored the highest out of all stations sampled, at 149.5. The high score was due primarily to lack of erosion along the bed and banks of the stream, and the absence of sediment on stream substrate (except at the road crossing). Stream banks appeared very stable, with a combination of understory shrubs and trees. Total riparian zone width was approximately 200 feet wide surrounded by residential land.

Physical Characterization/Water Quality

The pH measured at Station PWB8 was slightly lower than other stations, which perhaps is a reflection of the groundwater characteristics of this headwater reach. All other water quality measurements appeared normal.



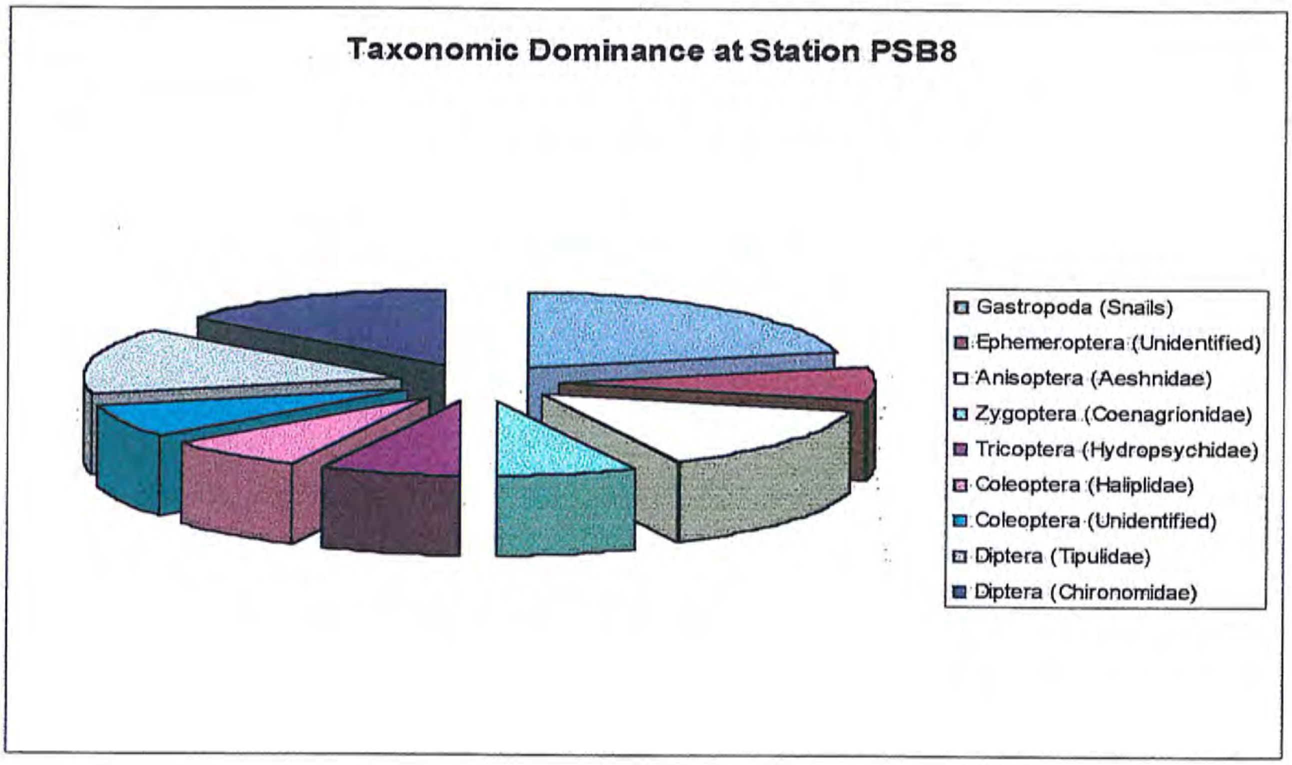


Figure 2.10: Benthic Macroinvertibrate Community of Stations PSB8

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Biological Impairment Detection

The presence of pollution-intolerant species, a high taxa richness, and a stable bed and banks indicated that this section of the South Branch of Naamans Creek was not impaired.

Station DSB3

Station DSB3 was located on Stone Crop Road in the residential development of Channin, in Delaware. Station DSB3 was approximately 2,400 feet downstream of Station PSB8. Like PSB8, a forested corridor of approximately 200 feet in width surrounded Station DSB3.

Benthic Macroinvertebrate Community

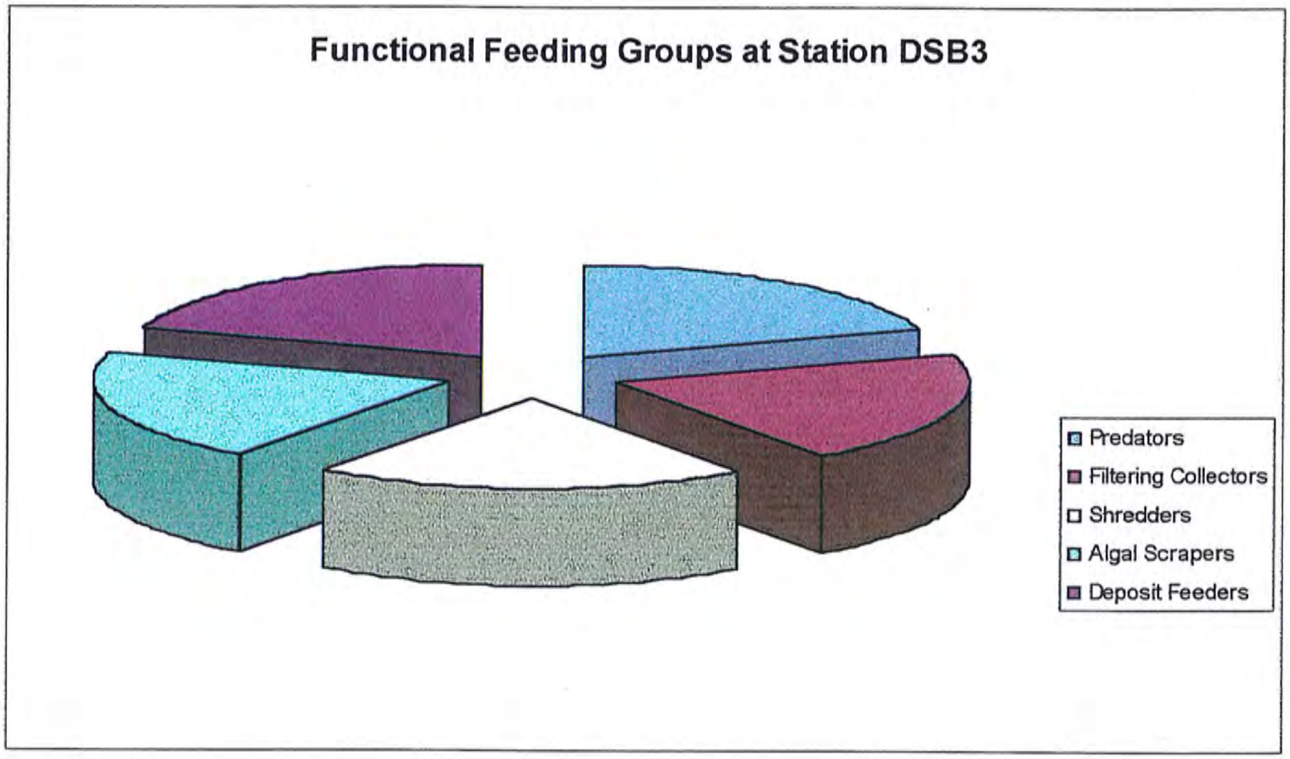
Taxa richness in Station DSB3 totaled five representative orders and five families, with an overall abundance of 32 individuals (Table 2.3). This sampling represented an overall decrease by six taxa from Station PSB8 to Station DSB3. The dominant taxa collected at Station DSB3 were filtering collectors (Hydropsychidae) and snails; however, five different functional feeding groups were collected (Figure 2.11). Pollution-intolerant species such as mayflies were noticeably absent at Station DSB3. The dominant presence of the caddisfly Hydropsychidae, which is considered somewhat pollution-intolerant, indicates that some organic pollution was probable (Hilsenhoff, 1988).

Habitat Assessment

Station DSB3, at 117.5, scored above the average of all sampled stations. Good and fair score values were received for most habitat parameters. However, Station DSB3 received fair and poor scores for bank stability and velocity/depth categories. The dominant habitat type in Station DSB3 consisted of shallow riffles of moderate velocity with thick gravel deposits, evidencing high erosional impact to the aquatic habitat in this section of Naamans Creek.

Physical Characterization/Water Quality

The temperature, pH, and conductivity recorded at this station were all within normal ranges. No noticeable pollution or odors were observed.



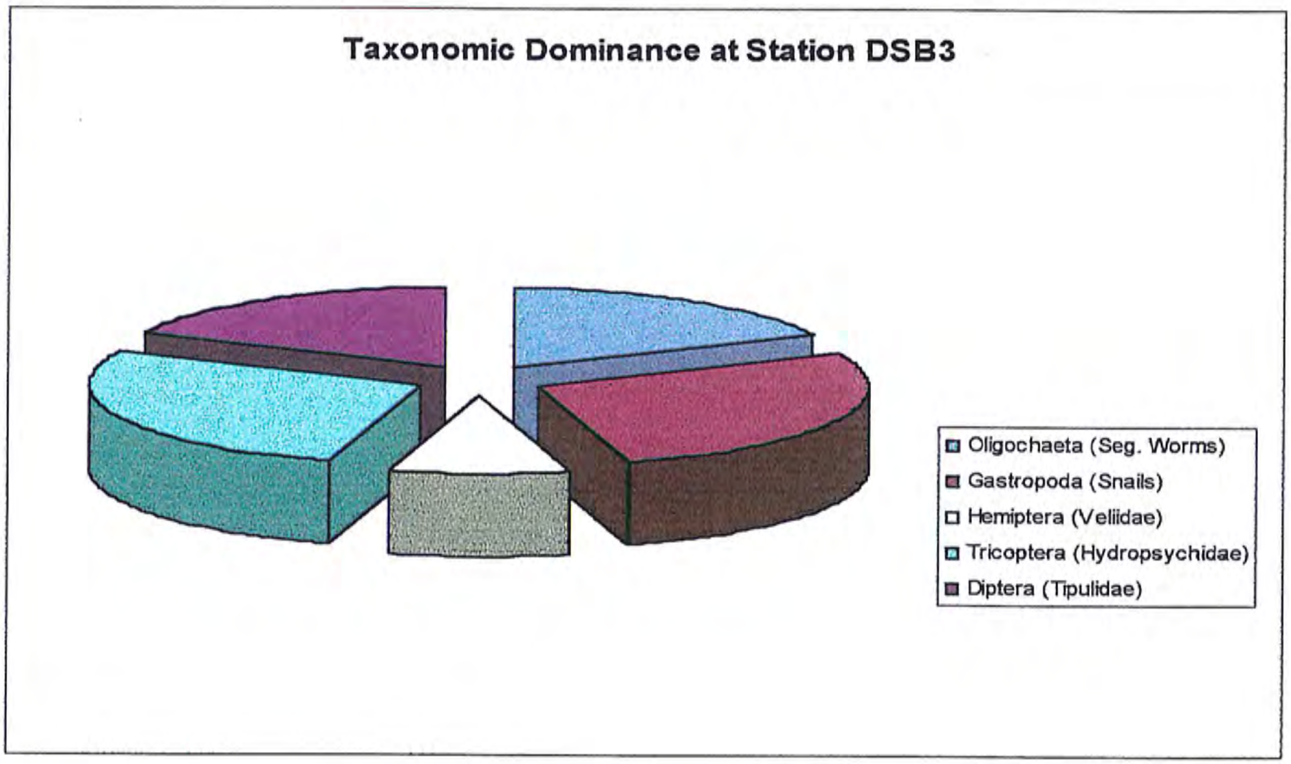


Figure 2.11: Benthic Macroinvertibrate Community of Stations DSB3

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Biological Impairment Detection

This section of the South Branch of Naamans Creek was determined to be impaired due to heavy erosion, as evidenced by thick gravel deposition. The obvious decline in macroinvertebrate taxa in this station, and the shift in functional feeding groups also indicated impairment. Further investigation is needed to determine the degree of impairment and the overall health of this aquatic community.

Station DSB4

Station DSB4, which was located 400 feet downstream of Marsh Road (RD 3) in Arden, Delaware, was approximately 1.45 miles downstream of Station DSB3. A very wide band of undisturbed forested habitat surrounded station DSB4 on both banks. A residence and a large concrete bridge structure were located 400 feet upstream of this station. The forested corridor associated with Hanby Park continued downstream of the station.

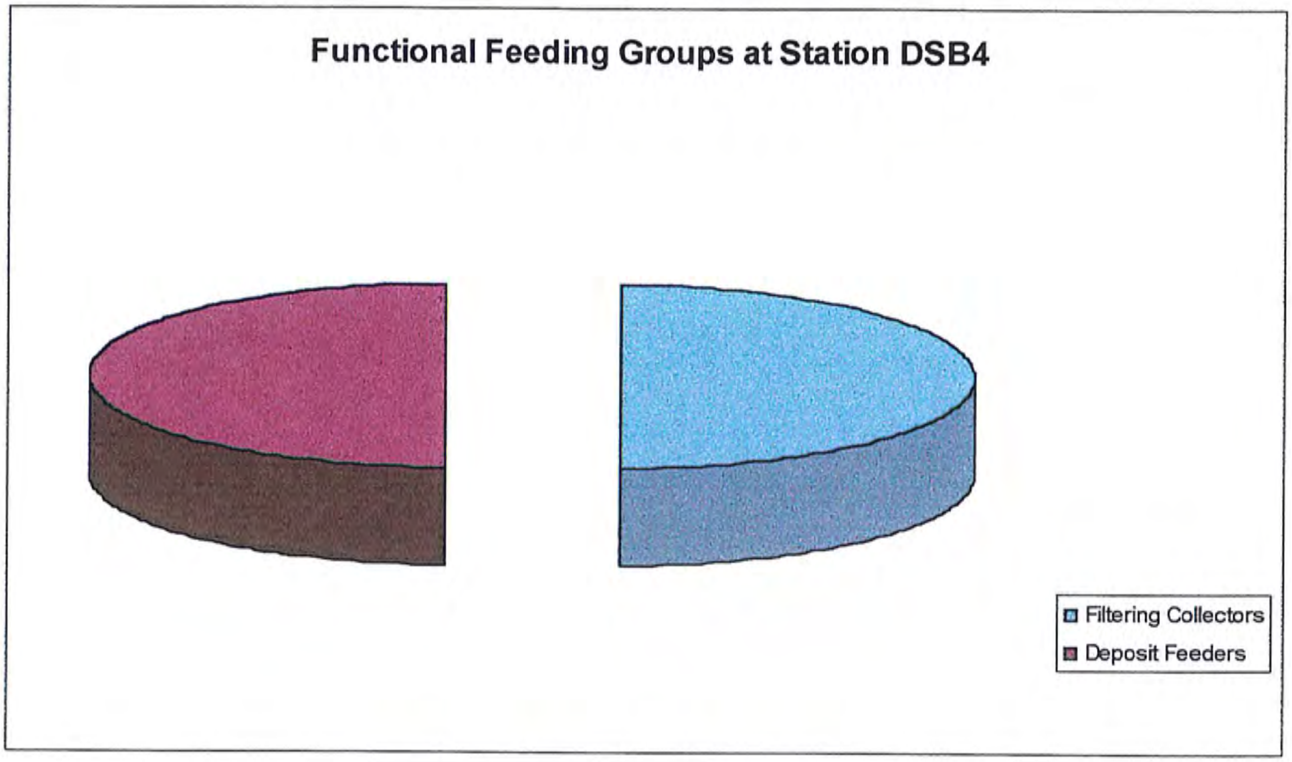
Benthic Macroinvertebrate Community

Station DSB4 only had two taxa collected from the sample, neither of which was considered pollution-intolerant (Table 2.3). The dominant taxa collected was the caddisfly Hydropsychidae, which, as stated previously, indicates some organic pollution (Figure 2.12).

The decrease in taxa represented a significant decline in species richness from Station PSB8, which had eleven different taxa represented in the sample. Only two functional feeding groups were identified (Figure 2.12). This decline indicated a severe restriction in food source, habitat availability, and an imbalance in the aquatic community.

Habitat Assessment

Station DSB4, at 121.5, had the second-highest score for habitat of all sampled stations. This section of the South Branch of Naamans Creek flows through wooded parkland and continues through the village of Arden, which maintains a high degree of pervious surface and forested canopy cover. It would be expected that the entire stretch of this portion of stream would provide very suitable habitat for benthic macroinvertebrates. The limiting factor to the aquatic community in this case is the documented severe flooding and erosion that occurs at regular intervals throughout this corridor. Heavy siltation and extreme bank erosion were noted during the sampling event. Any habitat available to aquatic organisms becomes inaccessible due to thick silt deposits and severe scour during storm events.



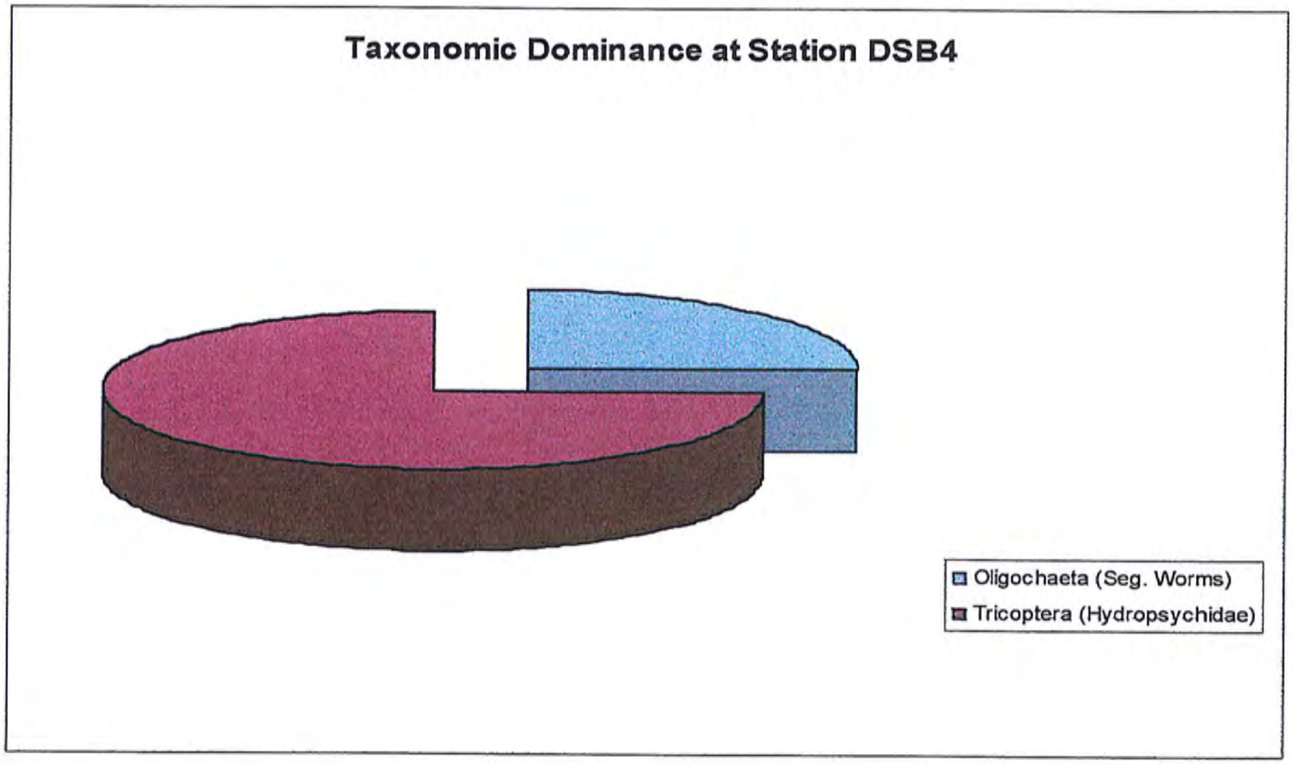


Figure 2.12: Benthic Macroinvertibrate Community of Stations DSB4

DUFFIELD ASSOCIATES

Physical Characterization/Water Quality

The temperature, pH, and conductivity recorded at this station were all within normal ranges. No noticeable pollution or odors were observed.

Biological Impairment Detection

This section of the South Branch of Naamans Creek was determined to be impaired due to heavy scour and siltation caused by severe flooding events. The reduced number of taxa collected, the dominance of one functional feeding group, and the lack of pollution-intolerant organisms indicated an impaired aquatic community. Further investigation is needed to determine the degree of impairment and the overall health of this aquatic community.

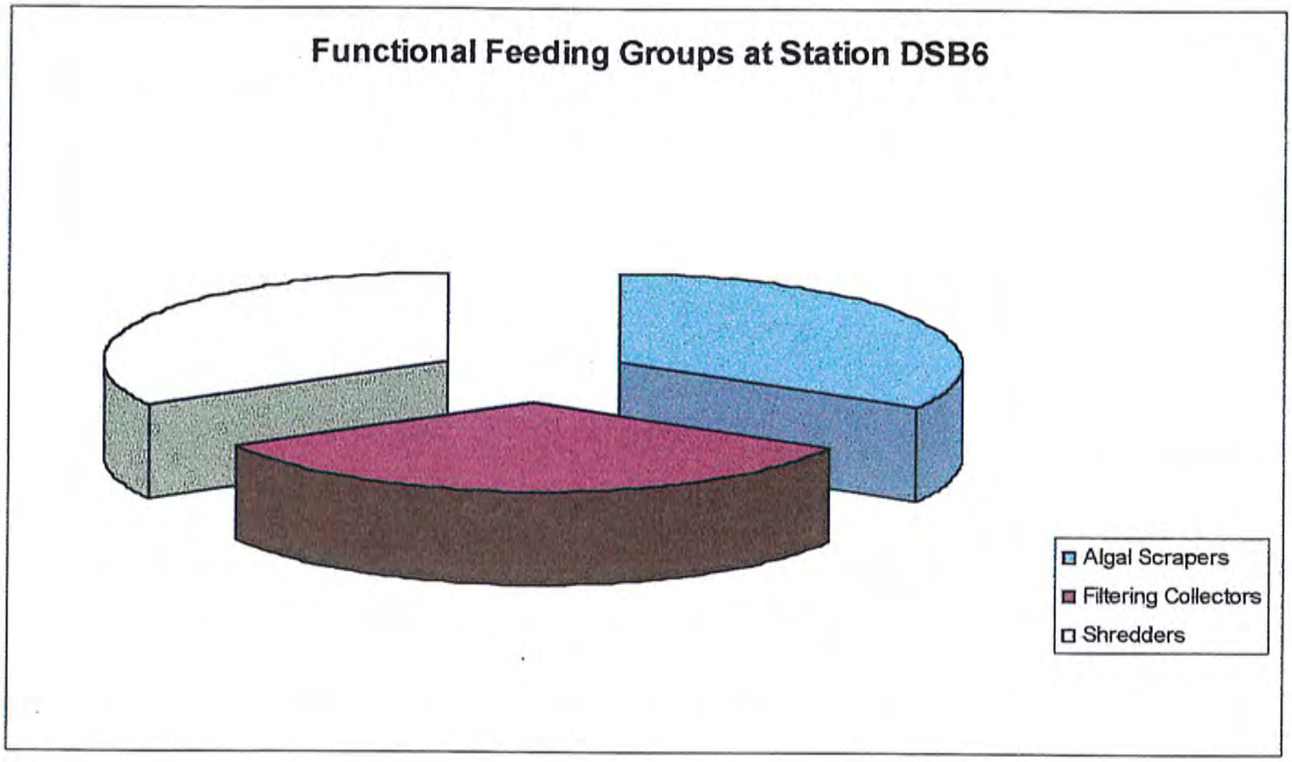
Station DSB6

Station DSB6 was located on Darley Road downstream of I-95 in Claymont, Delaware. Station DSB6 was approximately 2.75 miles downstream of Station DSB4. A large concrete culvert was noted extending from the bank approximately 400 feet upstream from the station. A sanitary sewer manhole was located on the stream bank directly adjacent to the station.

Benthic Macroinvertebrate Community

Station DSB6 only had three taxa collected from the sample, and no pollution-intolerant species were collected (Table 2.3). The dominant taxa collected were Gastropods (snails), which indicates an overabundance of algae generated from high nutrient levels in the water (Figure 2.13). Slimes were abundant at this station, which is another indicator of pollution.

The decreased number of representative taxa and functional feeding groups was comparable to the previous station, Station DSB4, and indicated a continuing trend in stream impairment throughout the South Branch of Naamans Creek. The data suggested that the benthic macroinvertebrate community in this section of stream was impaired by pollution more than any other station sampled.



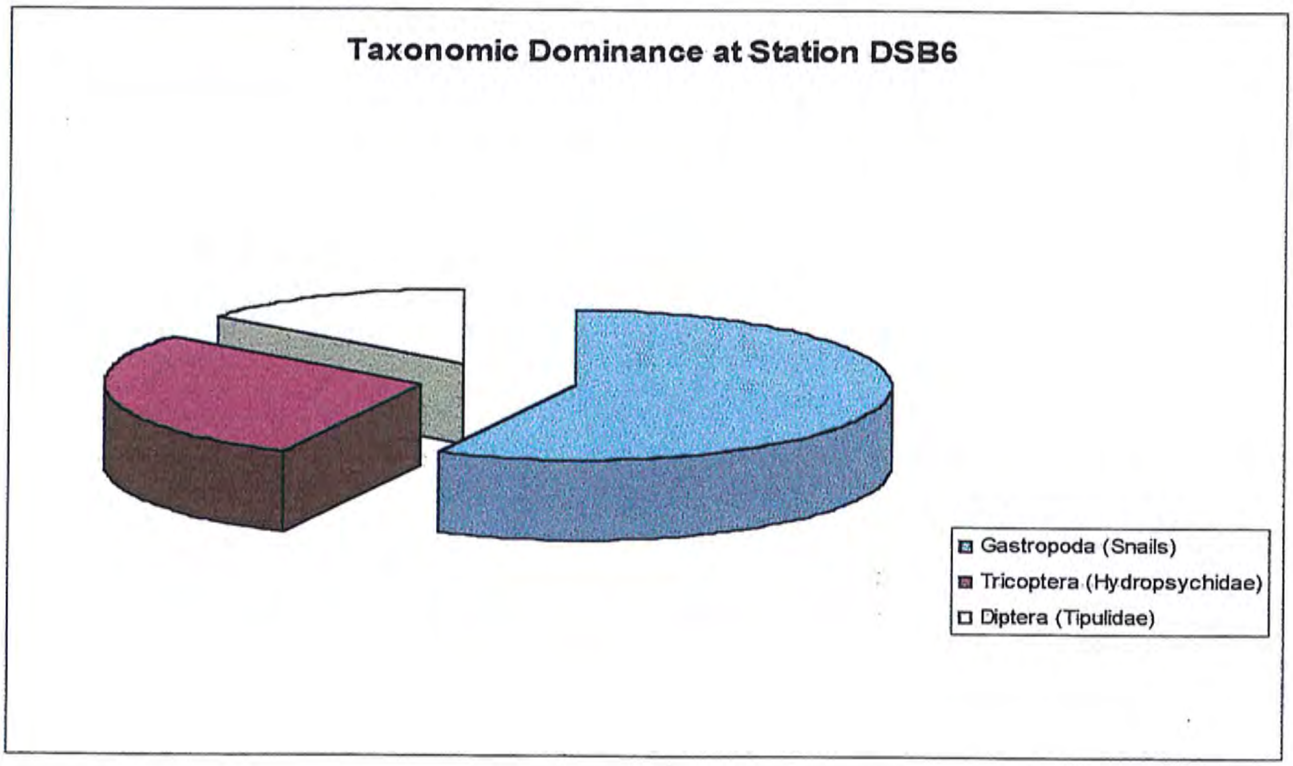


Figure 2.13: Benthic Macroinvertibrate Community of Stations DSB6

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Habitat Assessment

Station DSB6 received a score of 103, which was below the average for all stations sampled. Overall scores at this station were considered fair due to infrequent riffles, heavy sediment deposit, lack of stable habitat, and evidence of human activity. Although siltation and erosion limited the habitat in this portion of Naamans Creek, organic pollution also had a significant role in the reduction of suitable living conditions for aquatic organisms.

Physical Characterization/Water Quality

Conductivity and pH taken from samples at Station DSB6 appeared normal. However, the smell of sewage was noted in the stream sediment.

Biological Impairment Detection

This section of the South Branch of Naamans Creek was determined to be impaired based on the scour and siltation caused by severe flooding events, as well as the evidence of organic pollution. The reduced number of taxa collected and the lack of pollution-intolerant organisms indicated an impaired aquatic community. Further investigation is needed to determine the degree of impairment and the overall health of this aquatic community.

2.7.3.5 Unnamed Tributary to Naamans Creek

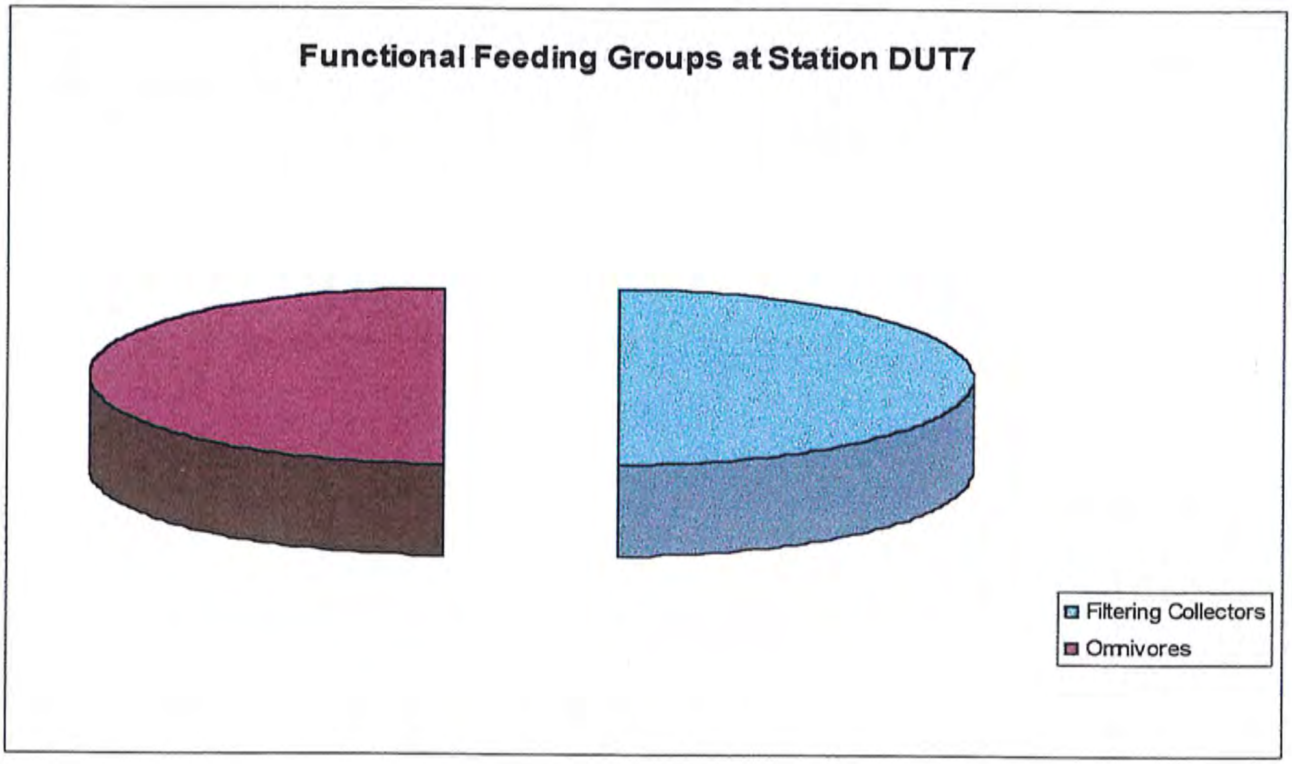
An unnamed tributary to Naamans Creek originates behind Bechtel School Park at the Pennsylvania/Delaware border, and extends through densely populated residential developments such as The Timbers, Ramble Wood, Valley Run, Longview Farms, and Greentree until it joins the South Branch of Naamans Creek southeast of I-95 in Claymont, Delaware. This tributary has been significantly altered from its original state by installation of culverts, rechannelization, loss of riparian vegetation, and increase in impervious surfaces.

Station DUT7

Station DUT7 was located along Peachtree Drive in GreenTree. Just upstream from Station DUT7 was a concrete culvert elevated 1.0 to 2.0 feet above the streambed.

Benthic Macroinvertebrate Community

Station DUT7 only had three taxa collected from the sample, and no pollution-intolerant species were collected (Table 2.3 and Figure 2.14). Only four individual



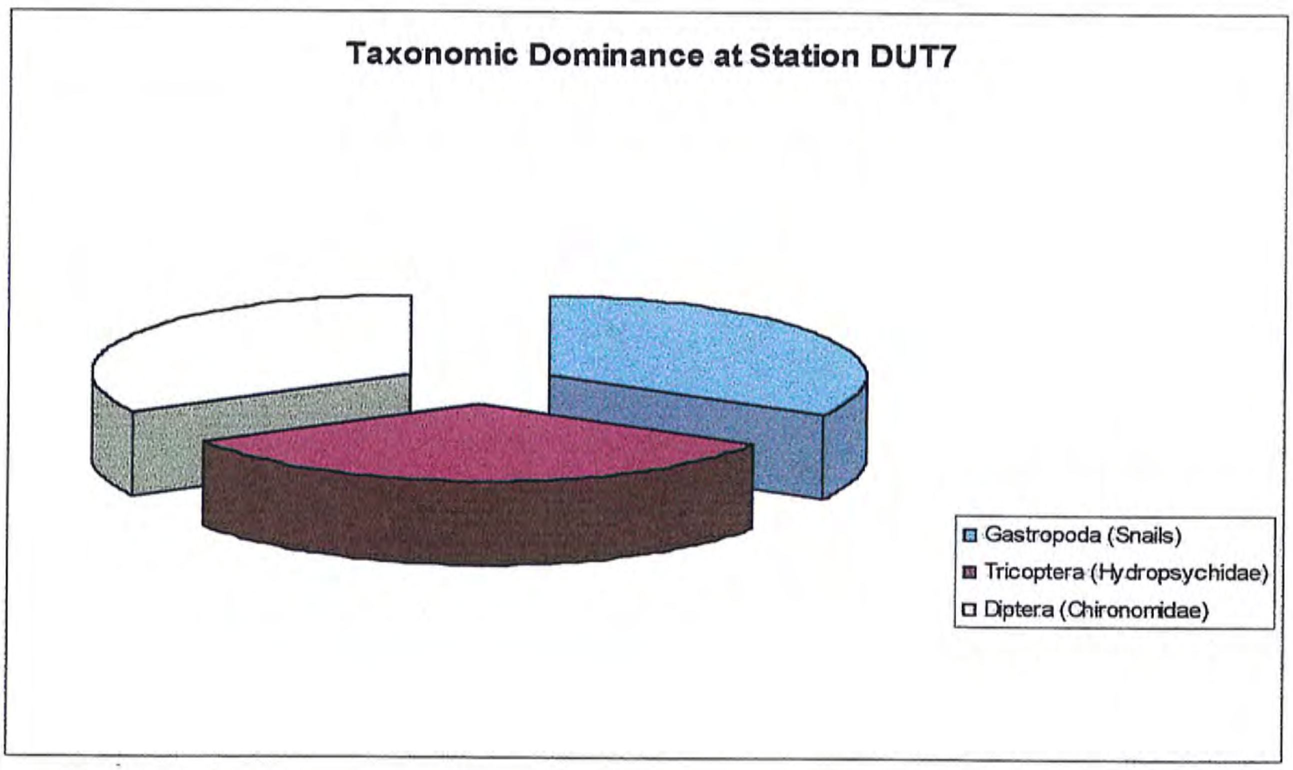


Figure 2.14: Benthic Macroinvertibrate Community of Stations DUT7

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organisms were collected, which represented the lowest overall abundance of all stations sampled.

The low abundance suggested that this section of the Unnamed Tributary to Naamans Creek was only temporarily inundated. This section of stream may have been modified to such a degree that it now flows intermittently.

Habitat Assessment

Station DUT7 scored the lowest out of all stations sampled, at 85. The presence of root undermining along the banks, and thick in-stream deposits of gravel and sand indicate the flashy and turbulent nature of floodflow through this section of stream. Scores for most habitat parameters were fair due to bank instability, lack of varying depth/substrate type, and evidence of human activity. The riparian corridor extended only 20 feet wide, and apartment complexes and roadways along both banks surrounded the stream.

Physical Characterization/Water Quality

The temperature, pH, and conductivity recorded at this station were all within normal ranges. No noticeable pollution or odors were observed. Trash was present within and along the stream corridor.

Biological Impairment Detection

This section of the Unnamed Tributary to Naamans Creek was determined to be impaired because of erosion and siltation caused by severe flooding, as well as from modification by human activity.

The reduced number of taxa, the low abundance of individuals collected, and the lack of pollution-intolerant organisms indicated an impaired aquatic community. Further investigation is needed to determine the degree of impairment and the overall health of this aquatic community.

2.7.4 Discussion

2.7.4.1 Benthic Macroinvertebrates

Figures 2.6 and 2.8 through 2.14 depict the taxonomic dominance of aquatic macroinvertebrates collected for each station. Figures 2.10 through 2.13 show a decrease in the amount of taxa present along the South Branch of Naamans Creek. The control station at the most upstream point (Figure 2.10: Station PSB8) had a total of nine orders and eleven families represented in the collected sample. The station furthest downstream on the South Branch of Naamans Creek (Figure 2.13: Station DSB6) had a total of three orders and three families represented in the sample.

Data collected from stream sampling indicates a trend in decreasing abundance of aquatic macroinvertebrate taxa as well as a decreasing trend in taxa richness from upstream to downstream stations.

The data also suggests a decrease in pollution-intolerant species of mayflies, stoneflies and caddisflies, and an increase in pollution-tolerant and generalist species moving from upstream to downstream stations.

The number of functional feeding groups also declined from upstream stations to downstream stations. Along the South Branch of Naamans Creek, representative functional feeding groups decreased from six in Station PSB8, to five in Station DSB3, to two and three in Station DSB4 and DSB6. Only generalist feeders such as omnivores, deposit feeders, and the filtering collector Hydrophychid caddisflies remained dominant in the downstream stations.

Comparison to Controls

Both control stations had the highest taxa richness, and the highest number of functional feeding groups in comparison to other stations sampled within Naamans Creek Watershed. Stations with higher overall abundance than the control stations tended to be dominated by large numbers of snails, which indicates high algae growth, and thus high nutrient levels brought about by pollution. In general, the higher the taxa richness and the number of representative functional feeding groups, the greater the habitat diversity, and the better the water quality.

2.7.4.2 Habitat Assessment

The habitat assessment performed for the Naamans Creek Watershed indicates that physical aquatic habitat sampled in all stations was relatively comparable. As seen in the photographs of each station, conditions vary slightly from station to station. Only two stations, Station PMB1 and DUT7, were drastically limited by lack of water flow and by human disturbance.

Two major effects of urbanization on aquatic systems and insects are post-storm increases in the discharge of streams and rivers downstream from developments, and the increase in sediment load from bankside erosion as streams enlarge to accommodate higher discharges (Williams and Feltmate, 1992).

Higher levels of sediment can affect aquatic insects as a pollutant by altering biochemical conditions, food resources, and respiratory diffusion gradients (Williams and Feltmate, 1992). However, higher sediment loads can also degrade habitat by blanketing substrate and filling interstitial space between stones, which limits inhabitable space. It is suggested that no other physical factor influences aquatic insects more than substrate composition (Williams and Feltmate, 1992).

Other ecological effects caused by suspended solids are mechanical or abrasive action; loss of light penetration, which restricts algae and protozoic growth that could throw off the balance of the entire food chain in an aquatic environment; adsorption and/or absorption of various chemicals; and change in temperature fluctuations (Hart and Fuller, 1974). Therefore, sediment loading not only affects aquatic organisms directly by limiting their available habitat, but it alters the entire structure of the community.

All stations except one control station (Station PSB8) indicated silt deposition in varying degrees. The degree to which sediment loading is affecting the Naamans Creek Watershed can only be determined by more detailed investigations involving quantitative data techniques such as RBPII and RBPIII protocols (or others), in combination with complete water quality analysis including fecal coliform, heavy metals, nutrient, and organic carbon testing.

2.7.4.3 Physical Characterization/Water Quality

The parameters used for water quality in this assessment included temperature, conductivity, and pH, which along with the general characterization of the physical components of stream substrate and habitat features, were used to identify any obvious changes or problems throughout the watershed, such as point-source pollution or major disturbance to the stream.

Generally, the only observations that indicated any change from upstream to downstream stations were the detection of odors and the presence of point discharges. These water quality parameters were not designed to detect non-point discharge pollution, or identify toxicity levels in the water column.

As indicated above, a detailed water quality investigation would be appropriate to determine the degree of impairment to Naamans Creek, and would provide accompanying information relating to the aquatic community health.

2.7.4.4 Biological Impairment Detection

All stations were detected to be impaired except stations PEB2 and PSB8. Stations PMB1, DSB3, DSB4, PWB5, PEB2, DSB6, and DUT7 indicated erosion and sedimentation problems that were affecting the health of the aquatic communities in and around these stations. Slight sedimentation impairment was detected in Station PEB2, but the impairment did not appear to influence the overall health of the aquatic community at this station. The majority of the South Branch of Naamans Creek, from Station DSB3 down through Station DSB8, appears to be impaired by heavy deposition of silt, sand, and gravel, and by erosional undercutting/undermining of banks.

The degree of impairment appears to range from slight to severe throughout the watershed. As stated previously, the degree of impairment can only be more accurately characterized through quantitative analyses of aquatic macroinvertebrate sampling and water quality analysis, in combination with streamflow modeling and loading matrices.

2.8 Geomorphic Classification

2.8.1 General

The stream types in the Naamans Creek and Perkins Run Watersheds were generally characterized using the stream classification method developed by Dave Rosgen. This method classifies streams on the basis of channel morphology. The objectives of classifying streams with this method is to:

- Predict a stream or river's behavior,
- Develop specific hydraulic and sediment relationships for a given stream type and state,
- Provide a mechanism to extrapolate site-specific data to stream reaches having similar characteristics, and
- Provide a consistent frame of reference for communicating stream morphology and condition among a variety of disciplines and interested parties (Rosgen, 1996).

The stream classification system is used primarily as the basis for stream restoration design.

The Rosgen method classifies streams at four levels:

- Level I - Geomorphic Classification
- Level II - Morphological Description
- Level III - Stream State or Condition
- Level IV - Validation

Level I describes the geomorphic characteristics of a river based on a stream's dimension pattern and profile. Stream channel dimension describes the stream's cross section in terms of width and depth. Channel widths generally increase downstream as drainage area and discharge increase. Channel depth typically varies greatly for reaches of streams with similar discharges. Stream channel pattern refers to a stream's sinuosity or meander pattern. Streams are typically more straight on a steeper slope and increase in sinuosity with decreasing slope. Stream channel profile describes gradient or slope. Generally, channel gradient decreases in a downstream direction with increases in stream flow. Level I classification can be performed using topographic and landform maps. The general classification developed in this report was performed at Level I, focusing primarily on dimension, pattern, and profile.

Level II is a more detailed morphological description based on field-determined information. At this level, channel entrenchment, dimensions, patterns, profiles and materials (i.e., rock, gravel, silt, sand, etc.) are quantified through field measurement.

Level III describes the existing state or condition of the stream as it relates to stability, response potential, and function (Rosgen, 1996). Additional parameters are evaluated at this level including riparian vegetation, sediment supply, flow regime, debris occurrence, depositional features, channel stability, bank erodibility and direct channel disturbances.

Finally, Level IV is the level at which measurements are taken to verify process relationships inferred from preceding analysis.

2.8.2 Geomorphic Characterization of Streams on the Naamans Creek and Perkins Run Watersheds

Most of the streams and tributaries in the Naamans Creek and Perkins Run Watersheds can be generally classified into two stream types: those that exist in moderate gradient areas ("B" type streams); and those that exist in lower gradient areas ("C" type streams). Some streams may be classified as gullies ("G" type streams).

2.8.2.1 "B" Stream Types

The "B" stream types found exist on gently sloped (2%) to moderately steep (4%) terrain. These streams generally are moderately entrenched, have a high width/depth ratio (greater than 12), low sinuosity, and have riffle dominated channels with infrequently spaced pools. These streams indicate relatively stable plan and profile, and relatively stable streambanks. In these types of streams, streambank erosion rates and channel aggradation/degradation process rates are generally low (Rosgen, 1996).

2.8.2.2 "C" Stream Types

The "C' stream types found exist in lower gradient areas (less than 2%), exhibit a higher sinuosity and are characterized by a regular riffle/pool configuration. The primary morphological characteristics of "C" stream types are the sinuous, low relief channel and characteristic "point bars" on the inside bends of active channels. The channel aggradation (sediment deposition)/degradation (erosion) and lateral extension processes have been accelerated in these streams in the study area. These processes are directly related to the existing upstream watershed conditions and flow and sediment regime. These streams are significantly degraded and eroded resulting in unstable streambanks.

2.8.2.3 "G" Stream Types

The "G" or gully type streams found exist on moderate gradient (2% to 4% slope) and are characterized by entrenched channels and low width/depth ratios. These stream channels are highly eroded and typically have high sediment transport rates. The "G" stream type was not as evident in the watershed as the "B" and "C" stream types.

2.9 Groundwater Recharge/Base Flow Evaluation

A climatic water balance evaluation was performed as an assessment of groundwater recharge potentials within the approximately 1,150 acre Perkins Run and the approximately 3,800 acre of the South Branch of Naamans Creek Watershed areas as depicted on Figure 1.1. The evaluation was performed in general accordance with the methods outlined in the "Instructions And Tables For Computing Potential Evapotranspiration And The Water Balance" by C.W. Thornthwaite and J.R. Mather (1957).

The climatic water balance, which is attached as Appendix B, provides an estimate of groundwater recharge potential by accounting for water input, in this case precipitation, and water losses, such as evapotranspiration, soil moisture retention and runoff. The difference or "surplus" is assumed to be recharge to the groundwater-table.

- Monthly average precipitation amounts were calculated for a 30-year period (1963-1992) as reported for the New Castle County Airport.
- Runoff was estimated by the SCS curve-number procedure, using Table 2-26 of TR-55 manual (1986), based on soil and vegetation type.
- Root zone soil moisture retention was estimated, using Table 10 of Thornthwaite and Mather (1957), based on soil and vegetation type.
- As noted above, runoff curve number and root zone soil moisture retention potential are primarily functions of soil texture and vegetation growth.
- Based on mapping, published by the Soil Conservation Service, (SCS, October 1970, "Soil Survey, New Castle County"), the soils within the watershed areas are rated as either hydrologic group B (i.e., moderately well to well-drained soils having moderate infiltration rates) or hydrologic group C (i.e., soils having low infiltration rates and layers which impede downward movement of water).
- Land use within the watershed areas is characterized as "grass-good condition," "woods-good condition" or "impervious cover" with runoff curve numbers and soil moisture retention as follows:

	Group B		**Group C**	
Land Use	**Curve Number**	**Soil Moisture (inches)**	**Curve Number**	**Soil Moisture (inches)**
Grass-good	61	8	74	8
Woods-good	55	16	70	16
Impervious	98	0	98	0

Based on the area ratio of the various land use types, as discussed above, the watershed modeling system (WMS) computed weight average curve number for the watersheds as follows:

Naamans - South Branch:	78.34
Perkins Run:	78.77

Similarly, weighted average soil moisture retention values were estimated as follows:

Naamans - South Branch	6.21 inches
Perkins Run	6.02 inches

Based on this approach the climatic water balance estimates for the watershed are as follows:

Table 2.4: Hydrologic Budget Estimates for the Naamans Creek Watershed

	South Branch Naamans Creek	Perkins Run
Precipitation (inches)	43.27	43.27
Evapotranspiration (inches)	27.37	27.33
Overland Runoff (inches)	4.22	4.39
Recharge (inches)	11.68	11.55

Evapotranspiration represents that portion of the incident precipitation within the watershed, which is returned to the atmosphere either by direct evaporation or plant transpiration. Overland runoff represents the portion discharged to surface water as stormwater runoff. Recharge is that portion, which passes through the root zone to the groundwater-table. Since groundwater use within the watersheds is limited, Cressfield being the only reported public system well, the recharge water will in the long-term also discharge to the area stream system. Stream flows in both the South Branch of Naamans Creek and Perkins Run represent the time weighted, composite averages of the stormwater runoff and groundwater recharge within the respective watershed areas.

This climatic water balance can be used as a tool to estimate the total volume of rainfall that is allowed to percolate, enter the groundwater system and eventually enter the streams of the Naamans Creek and Perkins Run Watersheds. To more completely evaluate the existing base flow to Naamans Creek, it is recommended that a detailed water budget be performed. This analysis would consider all factors influencing base flow including, but not limited to, impervious/pervious area, rainfall, wells, septic systems, french drain interception/discharge, and sump pump discharge.

Using the above numbers for groundwater recharge, average base flows in Naamans Creek and Perkins Run would be expected to be on the order of 0.85 cubic feet per second per square mile of drainage area. Given that drainage areas contributing to Naamans Creek vary from approximately 0.25 square miles at the upper reaches of the watershed to 13.51 square miles at the lower reaches of the watershed, average base flows would be expected to be within the range of approximately 0.2 cfs near headwaters to 12 cfs at the downstream end of the watershed. The average base flow in Perkins Run would be expected to be between 0.2 and 1.5 cubic feet per second.

The impacts of increased impervious area on base flows can be also evaluated through the climatic water balance method. Although not requested as part of the scope of the NCFAS a number of questions were raised on this issue. Accordingly, base flow changes were estimated by adjusting the curve numbers for both the Naamans Creek and Perkins Run watersheds to represent both undeveloped conditions and an increase in 10 percent impervious over existing conditions. The results of these approximations are given in Table 2.5 below. As shown in the table, increasing impervious cover by 10 percent is expected to result in a decrease in base flow on the order of approximately one percent in both Naamans Creek and Perkins Run watersheds.

Table 2.5: Estimated Changes in Base Flow Due to Development

Condition	Naamans Creek CN	Naamans Creek Base Flow (cfs/sq. mile)	Naamans Creek Reduction	Perkins Run CN	Perkins Run Base Flow (cfs/sq. mile)	Perkins Run Reduction
Undeveloped	71.37	0.919	-	68.26	0.933	-
Existing	78.34	0.860	6.4%	78.77	0.851	8.8%
10% Increase in Impervious	79.04	0.852	7.3%	79.82	0.838	10.2%

3.0 Hydrologic Model

3.1 General Description

The model used in this watershed study was Watershed Modeling System (WMS). WMS utilizes digital terrain data to delineate watershed and sub-basin boundaries to compute geometric parameters used in hydrologic modeling. WMS includes tools that aid in the creation of both rural and urban watersheds with interfaces to hydrologic modeling software. Sub-basins of the watershed can be created by adding any number of additional outlet points along the stream network. Besides the sub-basin boundaries, WMS automatically creates a topologic representation of the watershed that is later used in the defining model, Technical Release 20 (TR-20).

The hydrologic program TR-20 is used to model the rainfall runoff process. The TR-20 model was developed by the Hydrology Branch of the Soil Conservation Service (now known as the National Resource Conservation Service) and is generally recognized as the engineering standard for computing direct runoff resulting from rainfall. WMS merges information obtained from terrain models and the Geographic Information System (GIS) to create geometric attributes such as areas, slopes, and runoff distances. Through this program, outlets are added to the stream network, and composite curve numbers and times of concentration are computed automatically.

3.2 Watershed and Subwatershed Delineation

A watershed or subwatershed is defined as the land area that will topographically drain to a point of interest. Generally, the point of interest is taken as the confluence of two streams, a road culvert, or some arbitrary point along a stream for which it is desired to compute runoff flows. The United States Geological Survey (USGS) 7.5 Minute Quadrangle maps (Wilmington North-DEL-PA-1993 and Marcus Hook-PA-NJ-DEL-1993) were utilized as base maps for topography and roadway locations.

The boundaries of Naamans Creek, including the East Branch, Main Branch, West Branch, South Branch, and Perkins Run Watersheds were delineated using WMS. These primary watersheds were then divided into subwatersheds based on the existence of hydrologically significant features, including structures associated with significant upstream flood storage (such as bridges and culverts), valley slope, stream confluences, and potential improvement locations. A map of these delineations is included in Figure 1.1.

3.3 Curve Number Generation

Curve numbers (CNs) describe the portion of the rainfall that will be converted into runoff. CNs are a function of soil type, saturation, ground slope, and land use cover type. Soil type is based on the United States Department of Agriculture (USDA) Soils Maps and is classified into four hydrologic soil groups (A, B, C and D, with A being the most pervious and D the least pervious). Soil maps for the Naamans Creek and Perkins Run Watersheds were provided by the University of Delaware Water Resources Agency. Hydrologic soils groups were interpreted on the soils maps and then electronically digitized. Average soil moisture conditions were assumed for the study. Areas of similar land use and ground slope were taken from Water Resource Agency mapping (Naamans Creek Watershed – Land Use, Water Resources Agency for New Castle County, November 1995) and digitized. Mapping showing the soils and land use for the Naamans Creek Watershed is included in Figures 2.1 through 2.4.

As defined within the SCS methods, a CN value exists for each unique set of land use and soil conditions. It is necessary, therefore, to subdivide each subwatershed into areas that have a single land use and soil condition and to assign the appropriate CN value to each area. Subwatershed CN values are then computed as an area-weighted composite of these subdivided area CN values. In order to facilitate this calculation in this study, WMS was utilized. Subwatershed, soils, and land-use layers were overlaid and "dissolved" into polygons having single values for each parameter (subwatershed ID, soils classification, and land use category). A CN value was assigned to each polygon and the product of CN times polygon area was calculated for each subwatershed. These products were then divided by the subwatershed areas to compute the composite CN value. Final CN values and associated calculations are presented in the TR-20 model documentation in Appendix C.

3.4 Calculation of Concentration Times

Concentration time (T_c) is a measure of how quickly overland runoff will reach a point of interest within a given subwatershed. This parameter, in conjunction with the CN value and specified rainfall, is sufficient for the generation of runoff hydrographs for unique drainage areas (subwatersheds) in the TR-20 model. Using SCS methods, T_c values were computed by WMS as a function of ground slope and roughness, flow length, and, in cases where flow is concentrated, channel geometry. All T_c calculations and final values are presented in the TR-20 model documentation in Appendix C.

3.5 Impoundment Storage Routing

In areas of flow constriction along a stream reach, storage of runoff will occur upstream of the constriction. If the combination of the available storage volume and the constriction is significant, downstream flow attenuation will occur. These situations typically arise at roadway and railroad culverts, stormwater facilities, impoundments, and dams. In cases where impoundment storage was deemed to be significant within the Naamans Creek and Perkins Run Watersheds, the impoundments were chosen as the points of interest for delineated subwatersheds. Within the TR-20 method, the attenuation effects due to impoundments are accounted for by the performance of level pool flood routing. This method requires values of flow through the constriction and upstream stored volume for each specified value of elevation over which flow may occur at the constriction. Volumes were computed using estimated topographic information from USGS Quadrangle Maps. Flow through constrictions was estimated using a variety of methods including FHWA culvert methods, weir flow, the Army Corps of Engineers HEC2 Model, and other methods. All volumetric calculations, constriction flow calculations, and flow impoundment calculations are presented in the TR-20 model documentation in Appendix C.

3.6 Modeling Approach and General Results

A TR-20 model was developed using the input data for subwatersheds, reaches, and impoundments, as described above. In accordance with this method, upper watersheds and reaches were connected to lower reaches, and flows were computed by the program from upstream to downstream. A schematic showing input data and connectivity information for watersheds, reaches, and impoundments is given in the TR-20 model documentation in Appendix C.

Statistically, the 2-, 5-, 10-, 50- and 100-year rainfall events were used to generate runoff for the study. A rainfall event is defined as the magnitude of precipitation from a storm event measured in probability of occurrence (e.g., 50-year storm) and duration (e.g., 24 hours). The 2-year storm was chosen as an indicator of high frequency (more frequent) storm events and the 100-year storm was chosen as indicator of extreme (less frequent) events.

The model was used as a tool to address the issues discussed in the remainder of this report. These issues include the evaluation of whether proposed storage of streamflows would be effective in a particular location, whether increasing storage would flood upstream structures, which roads are overtopped in various storm events, and generally, whether cost-effective solutions exist for channel improvements, culvert enlargements, off-stream detention, and other improvements.

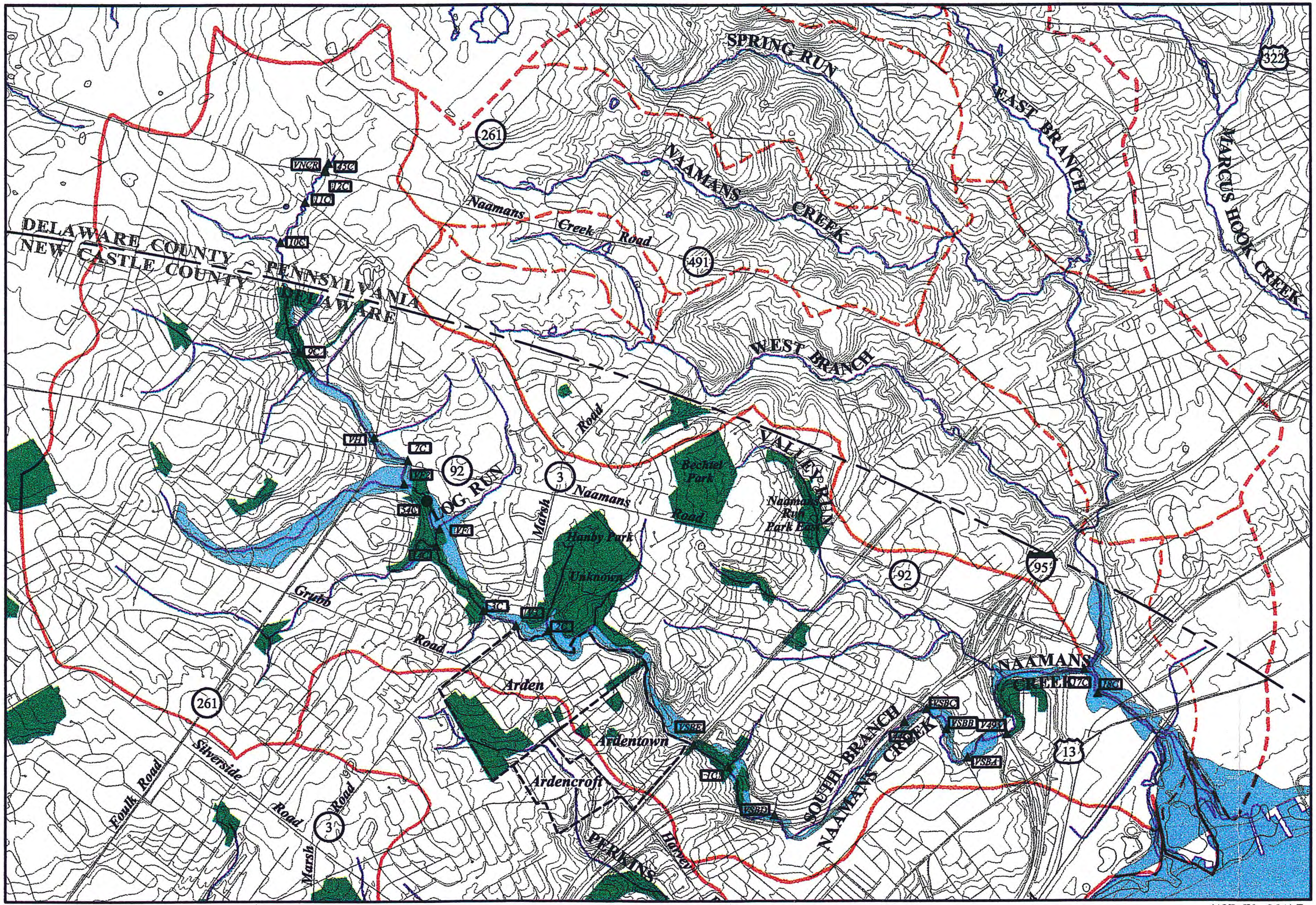
Computed streamflows for the 2-, 5-, 10-, 50- and 100-year storm events in the South Branch of Naamans Creek and Perkins Run Watersheds are shown in Table 3.1 and 3.2. Flow measurement locations were selected based on the hydrologic significance in the watershed. Figure 3.1 and 3.2 indicate the flow measurement locations.

3.7 Calibration

Several methods of calibration were considered during the development of the model. The best method is to compare data to measured stream flows. Since there is not a stream gauge on Naamans Creek, this was not an alternative for calibration. A regression model was also considered, but it did not account for reservoir or reach routing. Therefore, this method was deemed inconsistent with the TR-20 model. A translation of flow data from a stream gauge on the nearby Shellpot Creek was also considered. Because of differences in watershed characteristics between the Naamans Creek and Shellpot Creek Watersheds, this approach was deemed inappropriate. Therefore, it was decided to use historical flood levels.

Based on data provided by the residents of 2300 Inwood Road, during the July 5, 1989 and September 16, 1999 storms, approximately 2 feet of water was present in their yard and adjacent to their home. Also, discussions with the residents of 2304 Inwood Road indicated

Figure 3.1
South Branch Naamans Creek Flow Measurement Locations



*Adapted from Naamans Creek Watershed and Open Space, University of Delaware, Institute for Public Administration, May 1997.

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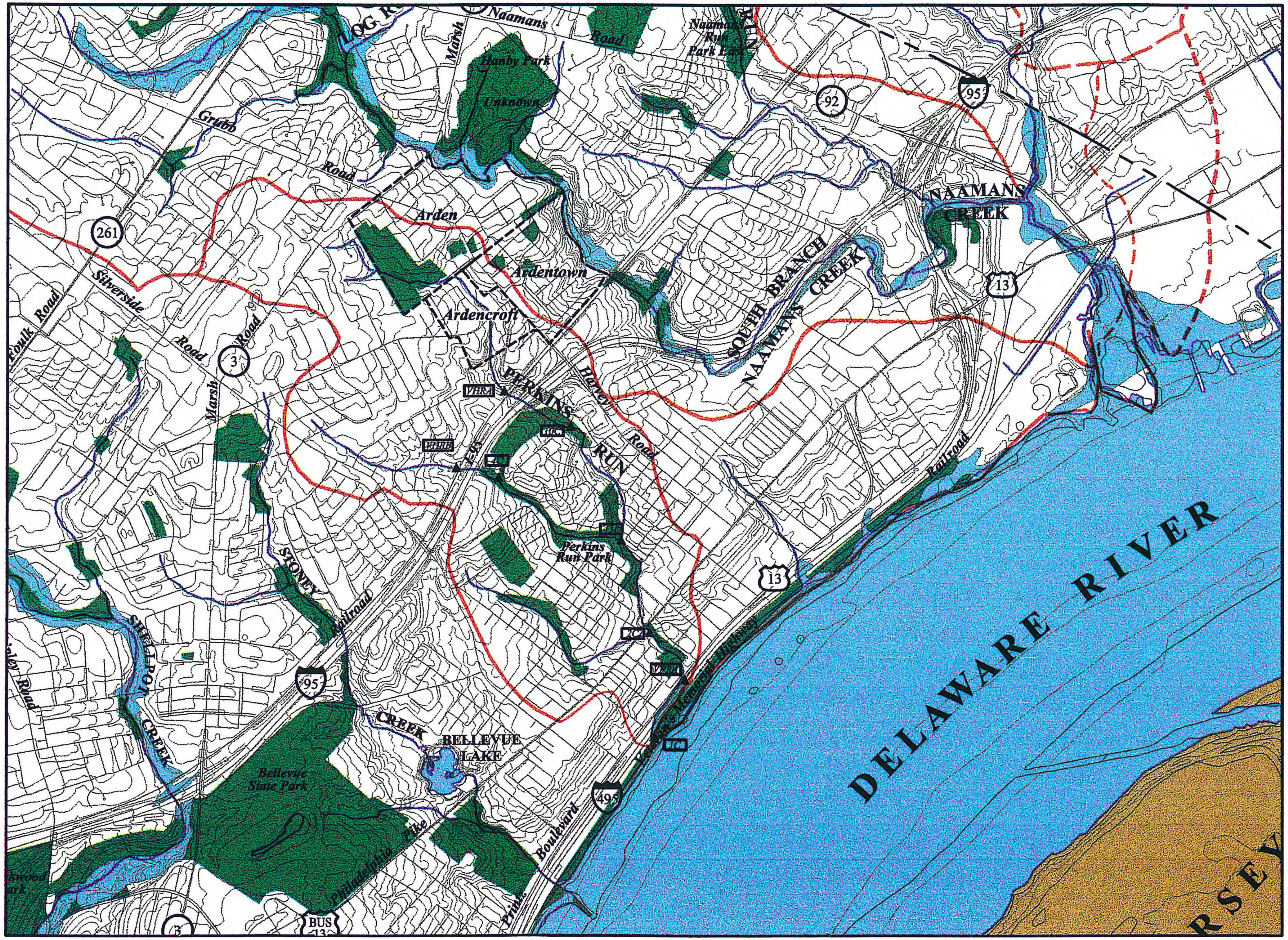
Figure 3.2
Perkins Run Flow Measurement Locations



Legend:

- Parks and Open Space
- 100 Year Flood Plain
- Hydrology
- Perkins Run Watershed Boundary
- Non-Study Watershed Boundaries
- Municipal Boundaries
- Flow Measurement Location

*Adapted from Naamans Creek Watershed and Open Space, University of Delaware, Institute for Public Administration, May 1997.

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that approximately 6 to 12 inches of water was present near the rear of their home during the same storms. These storms are generally accepted as closely conforming to the 100-year storm event in New Castle County. The 100-year storm event for the TR-20 model developed for this study shows the same amount of standing water, 6 to 12 inches, on the overbank of Naamans Creek at these locations. Therefore, it is our opinion that the TR-20 model enables an accurate simulation given the land use, soils and topographic data used.

Table 3.1: Computed Flows in the South Branch of Naamans Creek

Location ID	Approximate Location	2 Year Storm	5 Year Storm	10 Year Storm	50 Year Storm	100 Year Storm
45C	Naamans Creek Road, Woodland Acres, PA	75	152	217	331	404
VNCR	Naamans Creek Road, Woodland Acres, PA	72	104	134	189	217
11C	Zebly Road, Sharon, PA	144	228	292	405	478
10C	Sharon Drive, Sharon, PA	360	585	758	1053	1239
9C	Tonbridge Drive, Northminister Park, DE	933	1528	1988	2761	3247
VH	Foulk Road, Wilmington, DE	936	1526	1994	2753	3253
7C	Naamans Road, Wilmington, DE	1311	2149	2804	3870	4610
VF2	F & N Shopping Center, Wilmington, DE	298	493	643	892	1055
54C	Harvey Mill Park, Wilmington, DE	389	645	842	1168	1371
VF	Harvey Mill Park, Wilmington, DE	351	645	845	1171	1372
4C	Harvey Mill Park, Wilmington, DE	676	1115	1454	2016	2376
3C	Jamaica Drive, Wilmington, DE	2133	3513	4574	6333	7507
V3	Marsh Road, Wilmington, DE	2132	3497	4610	6327	7455
2C	Hanby Park, Hillside Road, Wilmington, DE	2466	4095	5416	7487	8840
VSBE	B & O Railroad, Wilmington, DE	2209	3345	4131	5275	6006
1C	Woodgreen Court, Radnor Green Park, Wilmington, DE	2278	3463	4287	5477	6241
VSBD	Interstate 95, Wilmington, DE	2267	3440	4261	5423	6192
44C	East Avon Drive, Wilmington, DE	2499	3809	4731	6052	6919
VSBC	Interstate 95, Wilmington, DE	2487	3804	4727	6075	6916
VSBB	Darley Road, Wilmington, DE	2517	3807	4761	6092	6944
VSBA	Darley Road, Wilmington, DE	2525	3855	4780	6142	7012
V495	Interstate 495, Wilmington, DE	2251	3474	4401	6208	7146
17C	Naamans Road, Tristate Mall, DE	2728	4102	5151	7475	8836
18C	Naamans Road, Ridge Road, Tristate Mall, DE	3766	5969	7733	11434	13550

Note: all flows reported in cubic feet per second.

Table 3.2: Computed Flows in Perkins Run

Location ID	Approximate Location	2 Year Storm	5 Year Storm	10 Year Storm	50 Year Storm	100 Year Storm
VHRA	B & O Railroad	362	603	790	1104	1302
10C	Dustin Drive	390	646	843	1176	1385
VPRB	B & O Railroad, Interstate 95	141	248	328	446	504
4C	Parkside Boulevard, Wilmington, DE	146	254	335	455	517
11C	Perkins Run Park, Wilmingtont, DE	465	771	1002	1391	1615
2C	Philadelphia Pike, Wilmington, DE	1003	1659	2148	2962	3458
VPRA	Philadelphia Pike, Wilmington, DE	1008	1591	2080	3132	3402
1C	Fox Point Park	1242	1943	2503	3778	4168

Note: all flows reported in cubic feet per second.

4.0 Problem Identification

4.1 General

A fundamental task of the flood abatement study was to identify existing and historic flooding, water quality, and other flood-related problems in the Naamans Creek and Perkins Run Watersheds. The goal was to identify problem sites and propose potential improvement measures for each site. In order to identify the improvement sites, the project team conducted the following tasks: collection and review of existing data, review of New Castle County (NCCo) and Delaware Department of Transportation (DelDOT) problem areas, coordination of public workshops, analysis of existing studies, and detailed field reconnaissance. As discussed in the following sections, information obtained from citizen comments on the Naamans Creek web site was also used as a source of problem site identification.

4.2 Collection and Review of Available Data

One of the goals of the flood abatement study was to make maximum use of available data from studies and evaluations that have already been performed in the Naamans Creek Watershed to identify problem sites. Maps containing land use and topography aided in the understanding of the dynamics of the watershed and helped identify water quality and quantity problems within it. Soils and zoning maps were used to show how the watershed reacts to rainfall and runoff and to show existing wooded areas and open space. This information and other available data gathered from NCCo and DelDOT were used to identify and evaluate potential problem and improvement sites. The following list summarizes the primary sources of data that were reviewed for applicability to this project:

- Open File Report No. 31 – The Storm of July 5, 1989: Hydrologic Conditions, Delaware Geological Survey, October 1989
- NCCo and DelDOT Complaints, (New Castle County, Department of Special Services, DelDOT)
- FEMA Flood Insurance Rate Maps, New Castle County, Delaware, 1996
- Naamans Creek/Perkins Run Watershed – Land Use and Soils Data (WRA)
- United States Geological Survey (USGS), 7.5 Minute Series (Topographic) Maps, Wilmington North Quadrangle and Marcus Hook Quadrangle
- Soil Survey, New Castle County, Delaware, October 1970 (USDA, Soil Conservation Service)
- Engineering Study for Storm Drainage, New Castle County, Delaware, July 1968 (Edward H. Richardson Associates, Inc.)
- Engineering Update for Storm Drainage, New Castle County, Delaware, 1990 (Landmark Engineering, Inc. in association with Duffield Associates, Inc. and VanDemark & Lynch, Inc., March 1990)

- Naamans Creek Storm Drainage Study for Northern Section of the South Branch of Naamans Creek Branch "B" and Presently Developed Related Spurs, (Mann-Talley Engineers, Inc., 1971)

During the initial information-gathering stage of the project, existing data were reviewed. To develop a list of problem sites that had been previously identified and to locate potential regional stormwater management sites, members of the project team reviewed existing hydrologic and drainage reports, maps, and other existing watershed data. In addition, team members met with representatives of New Castle County's Department of Special Services, DelDOT's Stormwater Management Section, and the New Castle Conservation District.

4.2.1 Review of Existing Reports

The primary sources of previously identified flood-related issues and proposed solutions used by the project team were "Engineering Study for Storm Drainage, New Castle County, Delaware, 1968," the "Engineering Update For Storm Drainage, New Castle County, Delaware, 1990" and "Open File Report No. 31 - The Storm of July 5, 1989: Hydrologic Conditions, 1989." These reports identified problem/improvement sites for numerous drainage basins in New Castle County, Delaware (including the Naamans Creek Watershed) and developed preliminary recommendations for the mitigation of flooding conditions. Improvement sites listed in these reports that previously had not been addressed were evaluated as potential improvement sites for this study.

4.2.2 Review of NCCo and DelDOT Problem/Improvement Sites

In addition to the review of existing reports, members of the project team met with representatives from New Castle County's Department of Special Services, Drainage Section group, and DelDOT's Stormwater Management Section. The purpose of these meetings was to discuss and identify historical and existing flooding problem/improvement sites that these agencies had identified in the watershed. Flooding or drainage improvements that had previously been implemented in the watershed were discussed at this time. Sites that were not previously addressed by these agencies were evaluated as potential improvement sites for this study.

4.2.3 Review of Existing Watershed Data

As shown in Figures 2.1 and 2.2, the Naamans Creek and Perkins Run Watersheds are highly developed and leave few available open-space sites for regional or semi-regional stormwater management or flood control. Of those open space areas available for stormwater management, potential improvement sites were evaluated based on the presence of flooding and water quality problems, location in the watershed, land use, existing topography, hydrogeologic conditions, and the drainage area to the site. The topography, soils, and land use sources listed previously were used in combination with these evaluations to identify potential stormwater management sites to be used to mitigate flooding conditions in the watersheds.

4.3 Public Workshops

A public workshop was conducted on January 11, 1999 during the data-collection phase of the study. The purpose of the workshop was to present an overview of the Naamans Creek Flood Abatement Study and to solicit input from residents regarding problem areas in the watershed. Prior to the workshop, a project informational bulletin (Appendix D) was developed and mailed to the watershed residents. The bulletin was developed to announce the commencement of the Naamans Creek Flood Abatement Study, provide background information, briefly discuss the goals of the study, identify the study area, and invite members of the public to the workshop to discuss and identify problem/improvement sites. The workshop was conducted in the evening to accommodate the largest number of participants possible. Maps and other study information were provided to aid the residents in identifying problem areas. Senior technical members of the project team led the workshop and representatives from other agencies (DNREC, WRA, and DelDOT) and the Flood Abatement Committee were invited to attend the workshop in order to provide information and education.

During the workshop, residents identified problem sites in the watershed by meeting individually with project team members and completing questionnaires. Copies of the workshop questionnaires are included in Appendix E. These worksheets identified the name, address, and phone number of the complainant, the comment or problem, and the magnitude and the duration of the problem. The questionnaires were then used to list potential problem and improvement sites to be evaluated in the field reconnaissance and site-assessment phase of the study.

The final workshop was held on September 15, 1999 to present the recommendations of this report to the residents of the Naamans Creek and Perkins Run watersheds. At this workshop, the members of the project team met individually with residents to discuss the site-specific and general watershed improvement recommendations.

4.4 Web Site

A Naamans Creek web site located on the World Wide Web at www.naamanscreek.com was developed at the time of project kick-off as an additional method of information dissemination and data collection. The web site also served to give updates of the flood abatement study progress, to provide general information about watershed management, and to enable residents to communicate with the project team. A hard copy of the web site home page is included in Appendix F.

4.5 Field Reconnaissance

Following the data-collection phase of the study, a tabular summary was developed listing seventy-nine (79) problem/potential improvement sites. A problem/potential improvement site is a site that had been identified as having a flood-related problem or a potential to mitigate flood-related problems. Table 4.1 summarizes these seventy-nine (79) identified sites.

The scope of work for the flood abatement study specified that, as part of the design phase, preliminary design packages would be developed for up to 30 sites. Initially, all sites shown in Table 4.1 were evaluated by project team engineers and scientists to determine whether those sites should be recommended to be carried through to the design phase. A typical identified site which might be carried through the preliminary design phase could include stabilization of a streambank that is experiencing severe erosion leading to loss of land or it could be a location where flooding is occurring along the creek and which is causing property damage or a public safety risk.

The project team performed an initial screening to identify those sites that would not be included under the scope of work for the NCFAS. For instance, several residents were concerned with the location of the Federal Emergency Management Agency's (FEMA) 100-year floodplain boundary in relation to their properties. Because delineation of the 100-year floodplain boundary and evaluation of FEMA flood insurance requirements were not part of the project scope, these sites did not receive further consideration. During the public workshops, however, members of the project team and DNREC worked with residents to identify flood elevations near individual homes based on the FEMA Flood Insurance Rate Maps. These sites were either referred to FEMA directly or to DNREC's FEMA representative. Also, several identified problem sites were located outside of the study area and, therefore, were dropped from further consideration. Finally, some residents indicated that they did not have a site-specific problem but were generally concerned about flooding and water quality in the watershed. Other participating citizens indicated that they had not experienced flood-related or water quality problems. The sites that were not specifically addressed by the NCFAS were, where possible, referred to an appropriate federal, state or local agency (i.e., FEMA, New Castle Conservation District) for further action.

For the remaining sites that potentially required some form of remediation or could be improved to mitigate flood-related problems, the project team performed a field reconnaissance in the spring and summer of 1999 to identify and assess potential improvement measures. To document the information gathered during the site visits, the team utilized field data sheets. These data sheets, as presented in Appendix G, provided the means to obtain uniform and consistent data for all sites.

When possible, the project team met with residents on-site to obtain a better understanding of the identified problem and the specific location of the problem. This information was noted on the field data sheets along with a sketch of the site. In addition, photographs were taken to document the problem and ownership, utility, topographic or other related information was noted.

Table 4.1: Problem/Potential Improvement Sites

Site ID	Address/Location	Problem/Review	Source
101	2 Wistar Avenue	Insufficient storm drainage	Workshop [1]
102	2326 Walnut Lane	Insufficient storm drainage	Workshop [1]
(A1) 103	2401 Brae Road	Surface water drainage	Workshop [1]
104	102 Milford Avenue	Groundwater seepage	Workshop [1]
104	107 Milford Avenue	Insufficient storm drainage	Workshop [1]
105	2642 Longwood Drive	Insufficient storm drainage	Workshop [1]
106	200 Maple Avenue	None	Workshop [1]
107	702 Parkside Boulevard	Insufficient storm drainage	Workshop [1]
(C1) 108	4, 6 & 8 Broadbent Road	Streambank erosion	Workshop [1]
(A2) 109	1804 Walnut Street	Surface water drainage	Workshop [1]
111	Grubb Landing Road	None	Previous Report [2]
201	2723 Grubb Road	Groundwater seepage	Workshop [1]
202	120 Hilldale Court	Groundwater seepage	Workshop [1]
203	2203 Lancashire Drive	Groundwater seepage	Workshop [1]
301	733 Plumtree	Insufficient storm drainage	Workshop [1]
(D1) 302	2300 Marsh Road	Culvert capacity	Workshop [1]
303	2317 Jamaica Drive	Surface water drainage	Workshop [1]
(B1) 304	7 Garrett Road	Flooding	Workshop [1]
(B1) 304	9 Garrett Road	Flooding	Workshop [1]
(A3) 305	1500 Upsan Downs Lane	Surface water drainage	Workshop [1]
306	2213 Patwynn Road	None	Workshop [1]
307	2315 Jamaica Drive	Surface water drainage	Workshop [1]
(B2) 308	2300 Inwood Road	Flooding	Workshop [1]
(B2) 308	2302 Inwood Road	Flooding	Workshop [1]
(B2) 308	2304 Inwood Road	Flooding	Workshop [1]
309	2305 Forestwood Drive	None	Workshop [1]
(C2) 310	911 Darley Road	Streambank erosion	Workshop [1]
(C3) 311	211 Woodgreen Court	Streambank erosion	Workshop [1]
(C4) 312	50 Chestnut Street	Streambank erosion	Workshop [1]
313	108 Broadent Road	None	Workshop [1]
314	Indian Hills/Asburn Hills		Field Review
(A4) 314	1907 Millers Road	Surface water drainage	Workshop [1]
315	Woodland Road	None	Previous Report [2]
(E1) 317	Foulk Road & Naamans Creek	Stormwater management	Field Review [4]
(C5) 318	2221 Patwynn Road	Streambank erosion	Workshop [1]
(B3) 319	2204 Valley Avenue	Streambank erosion	Workshop [1]
320	101 Garrett Road	Groundwater seepage	Workshop [1]
(E2) 322	Harvey Mill Park	Stormwater management	Field Review [4]

Table 4.1: Problem/Potential Improvement Sites (continued)

Site ID	Address/Location	Problem/Review	Source
(C6) 401	2607 Pennington Drive	Streambank erosion	Workshop [1]
402	2547 Deepwood Drive	Streambank erosion	Workshop [1]
(C7) 403	130 Hilldale Court	Streambank erosion	Workshop [1]
(C8) 404	2003 Marsh Road	Streambank erosion	Workshop [1]
405	2308 East Mall	Insufficient storm drainage	Workshop [1]
407	1510 Lower Greenbriar Road	Streambank erosion	Workshop [1]
(C9) 408	1997 Kershaw Lane	Streambank erosion	Workshop [1]
501	2404 Valley Avenue	Streambank erosion	Workshop [1]
502	1908 Sherwood Road		Workshop [1]
503	2223 Old Orchard Road		Workshop
(F4) 601	107 Delview Drive	Flow attenuation	Workshop [1]
602	2218 Lincoln Avenue	Insufficient storm drainage	Workshop [1]
(D2) 701	1920 Zebley Road	Culvert capacity	Workshop [1]
702	2119 Dunhill Drive		Workshop [1]
703	2319 Wynnwood Road	Insufficient storm drainage	Workshop [1]
704	Arden & Marsh Road		Field Review [4]
706	S. 1-95 & N. Linden St.		Field Review [4]
707	Grubb Road & Branch B	Insufficient storm drainage	Previous Study [2]
(D3) 709	2300 Inwood Road	Culvert capacity	Workshop [1]
(D3) 709	2302 Inwood Road	Culvert capacity	Workshop [1]
(D3) 709	2304 Inwood Road	Culvert capacity	Workshop [1]
(E3) 801	Naamans & Smith Roads	Stormwater management	Field Review [4]
802	Naamans & Channin Roads	Stormwater management	Field Review [4]
(E4) 803	Naamans & Mousley Place	Stormwater management	Field Review [4]
804	Naamans & Fox Oak Roads	Stormwater management	Field Review [4]
(E5) 805	Northminister	Stormwater management	Field Review [4]
(E5) 806	Naamans & Carpenter Roads	Stormwater management	Field Review [4]
(F1) 902	Bechtel Park	Flow attenuation	Field Review [4]
(F2) 904	Radnor Green	Flow attenuation	Field Review [4]
(F3) 905	Behind Montessori School	Flow attenuation	Field Review [4]
(F4) 906	Windybush	Flow attenuation	Field Review [4]
(F5) 907	Sherwood Forest	Flow attenuation	Field Review [4]
908	Bethel Township	Stormwater management	Field Review [4]
909	Penn Del Archers	Stormwater management	Field Review [4]
	1705 Talley Road	Flooding	Workshop [1]
	2644 Bellows Drive	Insufficient storm drainage	Workshop [1]
	7 Burnett Drive	Culvert capacity	Workshop [1]
	2113 Meadow Lane	None	Workshop [1]
	1908 Sherwood Road	None	Workshop [1]

Table 4.1: Problem/Potential Improvement Sites (continued)

Site ID	Address/Location	Problem/Review	Source
	2306 Taggart Court	None	Workshop [1]
	3626 Naamans Drive	None	Workshop [1]
	2021 Longcome Drive	None	Workshop [1]
	1807 Pond Road	None	Workshop [1]
	19 Dustin Drive	None	Workshop [1]

1. Naamans Creek Flood Abatement Study workshops held on January 11, 1999.
2. Engineering Update for the Storm Drainage, New Castle County, Delaware, 1990.
3. Naamans Creek Flood Abatement Study Committee
4. Field reconnaissance and evaluation of potential problem/improvement sites by the project team.

5.0 Improvement Site Selection and Assessment

5.1 Site Selection

Following the field reconnaissance, the sites for which preliminary design packages would be developed were identified. The candidate sites that were dropped from further consideration either after the initial screening or following the field reconnaissance were added to a referral file that is discussed in Section 5.4. These sites that are not directly addressed in this report, have been referred to an appropriate federal, state or local agency (i.e., DNREC, New Castle Conservation District) with recommendations on how to address the identified problem.

The intent of the site selection process was to be as responsive as possible to the numerous and varied problems identified by the residents throughout the Naamans Creek and Perkins Run Watersheds. The sites were initially divided into five problem/potential improvement categories: general drainage, floodproofing, streambank stabilization, culvert improvements, stormwater management facilities and flow attenuation. Information gathered during the field reconnaissance phase of the study was used to recommend sites to the NCFAS for development of preliminary design packages. Recommendations for each site were made based on the potential to protect an individual or a group's property, reduce flooding, enhance stream conveyance, restore stable stream conditions and/or improve water quality.

The selection process resulted in the identification of thirty (30) sites that would benefit directly from an improvement measure or create a flood relief or water quality benefit downstream as a result of an improvement at that location.

Representative sites were selected from each of the problem/potential improvement categories. These sites were presented to the Naamans Creek Flood Abatement Committee and approved for consideration under the preliminary design package development phase of the study.

5.2 Problem/Potential Improvement Categories

5.2.1 General Drainage

This discussion of general drainage improvements addresses areas in the watershed that were identified as experiencing localized flooding or ponding of water from surface water runoff. These problems typically arise due to a site's location (i.e., at the bottom of a hill) or inadequate surface water drainage. Improvement measures to address the problems consist of providing a means to collect and convey surface water away from the area of concern. Surface water collection and conveyance measures recommended include grading of drainage swales and/or construction of structural facilities such as catch basins, gutters and storm drains.

5.2.2 Floodproofing

Floodproofing improvements were recommended where existing homes are located in the floodplain and have experienced property damage as a result of flooding of Naamans Creek, Perkins Run or their tributaries. Proposed floodproofing improvements include the use of earthen berms or embankments or structural floodwalls to prevent encroachment of floodwater and physically floodproofing a structure by the installation of watertight windows and flood shields on doors to prevent inflow of flood waters.

Pursuant to FEMA guidelines, floodproofing was only recommended where removal of structures from the floodplain and reduction of flow through stormwater management upstream was evaluated and determined not to be feasible.

5.2.3 Streambank Stabilization

Streambank stabilization was recommended where erosion of streambanks has occurred resulting in significant loss of property. Streambank erosion in the Naamans Creek and Perkins Run Watersheds is an indication of stream instability resulting from increased flows and alterations of the stream channels and floodplains.

Streambank stabilization techniques were selected based on the characteristics of the creek (i.e., its dimension, pattern and profile), streamflow velocities and the existence of tree canopy. Where possible less invasive and less structural techniques were selected such as the use of rock flow vanes, root wad protection and bioengineering techniques. Rock flow vanes (Figures 5.1 and 5.2) consist of rocks that are placed in the stream to redirect the erosive force of floodwaters away from the streambank toward the middle of the creek. J-hook flow vanes provide enhancement of fish habitat as well as bank stabilization by creating small deep pools behind the vane for fish and other aquatic habitat. The redirection of flow maintains non-turbulent water near the streambanks allowing vegetation to grow and stabilize the banks. Vegetation is either allowed to establish itself or can be established through planting of native plant species.

In appropriate conditions, root wad stabilization (Figure 5.3 and 5.4) can be used in place of more traditional methods such as riprap to protect streambanks from the erosive forces of floodwaters. As trees are removed from eroded streambanks, the root wads are kept intact and placed along the regraded streambed facing the direction of impinging flow. Native species vegetation is established behind the root wad to provide a stable root mat on the bank. In addition to streambank stabilization, root wads provide enhanced aquatic habitat through shading of the outside edge of the stream channel.

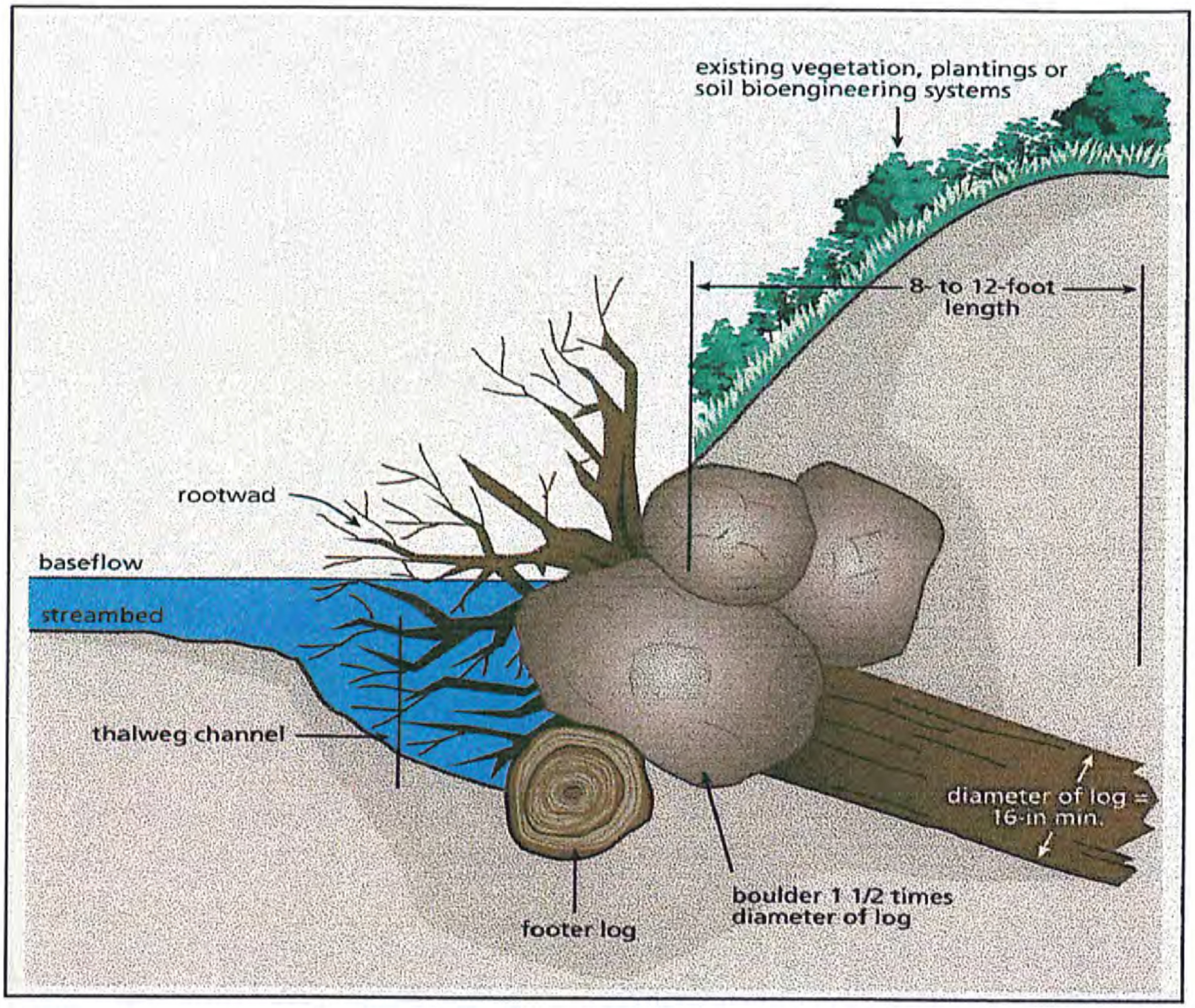
Biostabilization is also recommended for streambank stabilization either by itself or in conjunction with other techniques. Biostabilization consists of planting of native species plants to provide a stable root mat on streambanks. The plantings are typically done through biodegradable bio-logs or erosion control blankets to provide additional streambanks protection while the plant becomes established. The bio-logs and erosion control blankets typically consist of coconut fiber and straw held with nylon netting. The

Figure 5.1: Rock Flow Vane

DUFFIELD ASSOCIATES

Figure 5.2: J-Hook Rock Flow Vane

DUFFIELD ASSOCIATES



***Adapted from Stream Corridor Restoration: Principles, Processes, and Practices - October 1998, The Federal Interagency Stream Restoration Working Group.**

Figure 5.3: Root Wad Stabilization Diagram

DUFFIELD ASSOCIATES

Figure 5.4: Root Wad Stabilization

DUFFIELD ASSOCIATES

coconut fiber and straw protect the new plants and eventually biodegrade leaving the mature plant with well established root mats.

Biostabilization is only recommended where streamflow velocities and impinging flow can be controlled, groundwater seepage through the banks does not exist and sunlight will reach the plantings. These conditions, if present, have the potential to adversely impact plant growth.

Finally, riprap stabilization is recommended when the previously mentioned techniques cannot be used (i.e., in entrenched channels with extensive tree canopy cover). Riprap is placed to protect the streambank from erosive flow forces during flooding events. Where recommended, riprap should be placed only in the lower part of the stream channel where actual erosive forces are concentrated. Biostabilization or native species planting, where feasible, should be placed on the upper parts of the streambank that are exposed to less erosive forces.

It should be noted that streambank erosion and channel degradation is evident throughout much of the Naamans Creek and Perkins Run Watersheds. Recommendations for specific sites were made based on these sites identified by the residents of the watershed. Evaluation of all of the streams and tributaries was not included in the scope of work of this study but should be considered in the future. A discussion of issues and guidelines related to this work is included in Section 6.

5.2.4 Culvert Improvements

Culvert improvement recommendations include the enlargement and/or modification of existing road culverts or drainage systems to increase capacity and improve conveyance. These improvements are based upon specific location problems as identified by residents. Evaluation of all culverts and other flow restricting structures in the study area was not included in this scope, however, should be considered in the future. A discussion of issues and guidelines related to this proposal are included in Section 6.

5.2.5 Stormwater Management

Recommendations were made to retrofit existing and construct new stormwater management or wetlands to reduce streamflow and/or improve water quality during precipitation events. Existing DelDOT stormwater management facilities basins along Naamans Road were evaluated to determine if they could be retrofitted to provide additional reduction in peak stormwater runoff rates. The evaluation of these basins found that, in most cases, the existing facilities were already over designed, that is, were designed to reduce peak runoff to less than pre-road development conditions. The facilities selected for improvement were chosen based on the availability of land adjacent to the existing basin that could be used for expansion. More volume added to these basins results in an additional, significant reduction in peak stormwater runoff rates resulting in reduced base flood elevations downstream of the basins. Due to the small drainage areas contributing to these basins and their relatively small size, the reduction in peak flow to the stream is limited to the area directly downstream of the individual basin. As the drainage area increases with downstream distance, the mitigating impact of the enlarged basin decreases.

Several sites were also recommended for creation of stormwater fed wetlands to improve water quality during rainfall events by directing stormwater runoff through the wetland. In addition to providing quality treatment of runoff through filtration and plant uptake, wetlands will also provide a more diversified habitat.

5.2.6 Flow Attenuation

The flow attenuation facilities recommended consist of embankment and/or excavation created ponds or basins designed to reduce peak flows in the Naamans Creek and Perkins Run Watersheds. The reasons used for recommending the expansion of the existing stormwater management facilities discussed above are the same rationale for the recommendations for these attenuation facilities. The goal is to create a facility to temporarily attenuate water during precipitation events and release the water at a controlled rate. Ideally, the facilities should be located at the source of increased runoff and seek to infiltrate the runoff such as on individual lots of a housing development. If this goal can not be accomplished, runoff should be conveyed and controlled at a local stormwater management facility. However, because the majority of the study area is already developed with uncontrolled runoff and limited space available for construction of new or for expansion of existing stormwater management basins, which alternatives would provide limited impact. The remaining areas available for flow attenuation in the study area are undeveloped lands. These remaining undeveloped lands are mostly wooded and would require partial removal of wooded areas or grading modification to construct the proposed flow attenuation facilities. While these proposed facilities present potential environmental impact and safety issues, they will however, also provide a significant reduction in streamflows, ranging from one-third to one-half of downstream flows during major storm events. This reduction in flow will result in significantly reduced base flood elevations, reduced flooding of bridges/culverts and less streambank erosion. Reduction in base flood elevations should result in the removal of homes from the 100-year floodplain. For these reasons, four (4) flow attenuation facilities were recommended for consideration.

While construction of these attenuation facilities will result in some near term loss of tree cover, as part of their construction, reforestation can be accomplished to minimize long term environmental impacts. The safety concerns posed by the storage of high flow for short periods (usually 24 hours or less) need to be weighed against similar and/or greater risks posed by the downstream flooding which they are designed to relieve.

5.3 Site Assessment

A detailed site assessment, which included a conceptual design and a feasibility assessment, was performed for each of the thirty (30) sites presented in Tables 6.1 through 6.6. The assessments were performed to evaluate the feasibility of the proposed improvements, develop preliminary design issues to be incorporated into the final design, and eliminate the need for additional planning-level studies. They also facilitate prioritization for future implementation and furnish estimates of probable cost which can be used for developing implementation funding. Preliminary design information packages summarizing the analysis for each potential improvement are provided in Appendix H. These packages include a summary of the existing site conditions, analysis of the proposed improvements, and a feasibility assessment. The packages also include a site plan and an estimate of probable cost for each recommended improvement measures.

5.3.1 Preliminary Design Information Packages

Preliminary designs were developed for each of the identified problem/potential improvement sites. As discussed in Section 5.2, the proposed improvements included general drainage improvements, floodproofing, streambank stabilization, culvert improvements, stormwater management, wetlands creation and flow attenuation. Standard engineering methodologies and innovation design techniques were used when appropriate for the preliminary designs, as discussed below.

Available data were used to perform the preliminary design. Most topographic data was taken from USGS quadrangle maps. Supplemental design data were obtained for drainage, conveyance structures (i.e., culverts and bridges) by field surveys performed as part of this study. Flood Insurance Rate Maps (FIRM) of New Castle County, Delaware (FEMA, 1996) were also used.

Streamflows generated at specific improvement sites by the TR-20 hydrologic model were used for floodproofing, streambank stabilization, culvert improvement, and flow attenuation sites. In addition, flow attenuation sites were evaluated for their potential to reduce downstream peak streamflows during various rainfall events using the TR-20 model.

Drainage conveyance structure improvement computations were performed using field survey data. Headwater elevations for the culvert improvements and the bridges and culverts included in the TR-20 model were computed using the U.S. Army Corps of Engineers HEC-RAS program and Federal Highway Bureau nomographs, respectively.

Preliminary stormwater management and flow attenuation computations were performed using estimated surface (headwater) elevations and appropriate weir and orifice equations.

Streambank stabilization computations were performed using Natural Stream Restoration techniques developed by Dave Rosgen and others, bioengineering techniques and parameters set forth by the Pennsylvania Sediment and Erosion Regulations, Chapter 4 - Recommended Engineering Methods and Procedures for Design of Bank Stabilization.

5.3.2 Feasibility Assessment

The feasibility of a proposed improvement measure was analyzed based on the factors discussed below. The feasibility assessment for each of the thirty (30) selected improvement sites are presented in the preliminary design packages in Appendix H.

5.3.2.1 Effectiveness

Effectiveness of a proposed improvement measure was defined as the capability to reduce flooding, improve stream conveyance, stabilize a streambank or channel, improve water quality or protect structures or property. Effectiveness is based on the drainage area, predicted reductions in discharges and water surface elevations, and other assessment factors.

5.3.2.2 Ownership

When possible, a preliminary determination was made whether the improvement site is located on public or private property. Permission and/or the right to use public or private lands must be acquired prior to implementation of any of the proposed improvement measures recommended in this study. Facilities located on multiple private properties are likely to be more difficult to implement due to easement and/or right-of-way acquisition considerations.

DelDOT-owned lands in the Naamans Road project area, which are being considered for improvement sites should not pose ownership issues since DelDOT has committed to participate in the Naamans Creek Flood Abatement Study effort.

5.3.2.3 Utility Conflicts

During field visits, the presence and approximate locations of readily identifiable utilities and overhead power lines were noted. During final design, a detailed utility location plan must be developed.

5.3.2.4 Environmental Issues

The assessment of the proposed improvements considered potential wetland and woodland habitat impacts. In several cases, wetland plantings are recommended to be incorporated into the proposed improvement design to mitigate the impact on stream systems. For most of the proposed improvements, wetland and stream system disturbance is minimal. However, the flow attenuation facilities will have a measurable short term impact on the aquatic and terrestrial (woodland) habitats in the vicinity of the proposed embankments and/or excavations. There is limited wooded and highly vegetated land remaining in the Naamans Creek and Perkins Run Watersheds. Most of these remaining wooded areas do provide for a biologically diverse system of native flora and fauna. For this reason, potential environmental impacts resulting from the construction of the proposed flow attenuation facilities must be weighed against the flow reduction benefits.

5.3.2.5 New Castle County Unified Development Code Issues

Implementation of the proposed improvements will need to comply with the provisions of New Castle County, Delaware's Unified Development Code. Issues related to County floodplain, wetland, woodland, and other environmental or construction regulations were considered during the feasibility assessment.

5.3.2.6 Permit Acquisition

The permits expected to be required for construction of the proposed improvement measures were identified, and anticipated permitting issues were noted in the preliminary design packages. Typical potential permits for proposed remedial measures include: Subaqueous Lands (DNREC, Division of Water Resources, Subaqueous Section), Wetlands (U.S. Army Corps of Engineers), Floodplain (FEMA and NCCDLU), and Grading, Site Review and Sediment and Erosion Control (NCCDLU).

5.3.3 Cost Estimates

Estimates of probable design and construction costs were developed for each potential site. Design costs include estimates for engineering, permitting, and topographic surveys. Estimated construction costs include items such as grading, excavation, embankments, structural components, stabilization/restoration, and sediment and erosion control costs. Unit cost data from the Delaware Department of Transportation's Division of Highways and cost estimates developed by the project team were utilized to determine the design and construction costs. Costs reflect 1999 conditions and should be adjusted for construction in future years. Land acquisition costs are not included in the cost estimates, but the availability of requisite easements and rights-of-way, as well as acquisition or easement costs, should be considered prior to proceeding with final design.

5.4 Site Referral

As discussed in Section 4.5, the project team performed an initial screening to identify those sites that would not be included under the scope of work for the NCFAS. We recommend that many of these sites be referred to DNREC, DelDOT, or New Castle Conservation District for further action. The sites for referral to one of these agencies are listed in Table 5.1 and draft letters to these agencies are in Appendix I

Table 5.1: Sites Referred to Agencies

Site ID	Location	Problem	Recommendation	Referred Agency
	2664 Bellows Drive	Localized flooding	Drainage improvements	NCCD[2]
	102 Milford Avenue	Clogged culverts	Improve road drainage system/maintenance	DelDOT[1]
	7 Burnett Drive	Clogged culverts	Review culvert capacity/maintenance	DelDOT[1]
	1705 Talley Road	FEMA floodplain	Contact DNREC's FEMA coordinator	DNREC[3]
101	2 Wistar Street	Localized flooding	Drainage swale	NCCD[2]
104	107 Milford Avenue	Localized flooding	Underdrains	NCCD[2]
106	200 Maple Avenue	Localized flooding	Drainage improvements	NCCD[2]
107	702 Parkside Blvd.	Culvert repair	Review culvert capacity	DelDOT[1]
301	733 Plumtree Road	Insufficient storm drainage	Improve road drainage system	DelDOT[1]
303	2317 Jamaica Drive	Localized flooding	Drainage improvements	NCCD[2]
309	2305 Forestwood Dr.	Street flooding	Review drainage/culvert capacity	DelDOT[1]
402	2547 Deepwood Dr.	Street drain worsens stream water quality	Review culvert capacity	DelDOT[1]
407	1510 Greenbriar Road	Localized flooding	Drainage improvements	NCCD[2]
501	2404 Valley Avenue	Clogged culverts	Maintenance	DelDOT[1]
503	2223 Old Orchard Road	Sediment blocking stream	Remove sediment	NCCD[2]
602	2218 Lincoln Ave.	Clogged culverts	Review culvert capacity/maintenance	DelDOT[3]

1. DelDOT refers to the Delaware Department of Transportation.
2. NCCD refers to New Castle Conservation District.
3. DNREC refers to the Delaware Department of Natural Resources and Environmental Control.

6.0 Site-Specific Improvement Recommendations

This report recommends the design and implementation of site-specific and general or watershed-wide improvement measures for the NCFAS area. The site-specific improvement measures were developed based upon the identification of specific flood-related problems by the residents of the Naamans Creek and Perkins Run Watersheds. With the exception of the flow attenuation sites, these measures will generally improve conditions (i.e., reduce flows, stabilize streambanks, etc.) in the immediate vicinity of the improvements. The watershed-wide improvement measures recommended in this report address the causes of the flood-related problems and seek to address them on a watershed-wide basis. The watershed-wide improvement recommendations will be discussed in detail in Section 7.0. Site-specific improvement recommendations are summarized in the following subsections. A combination of both site-specific and watershed-wide improvement measures are recommended to achieve the greatest benefit to the Naamans Creek and Perkins Run Watersheds.

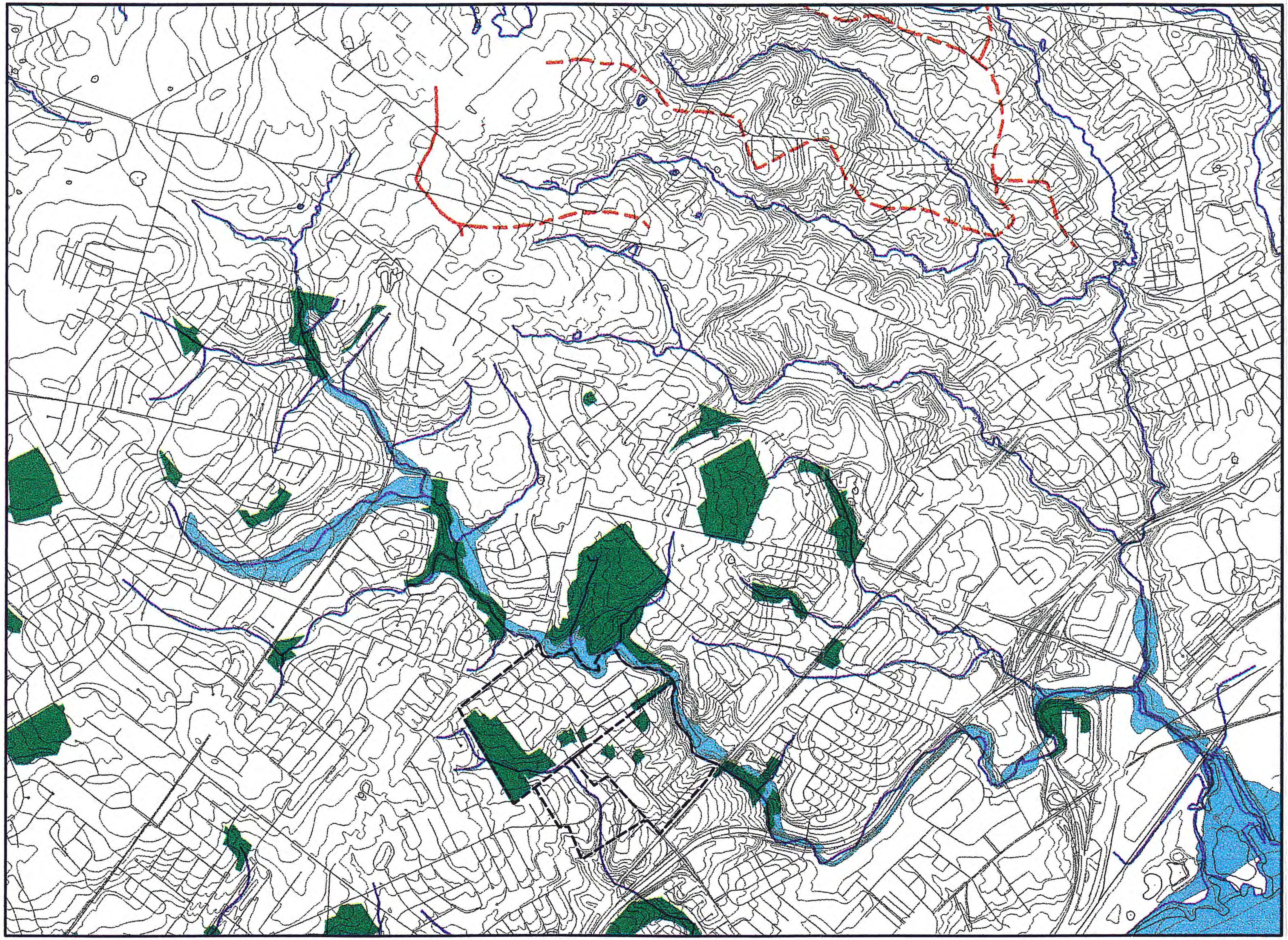
The report recommends implementation of thirty (30) site-specific mitigation measures to reduce flooding, enhance physical stream condition and improve conveyance of surface water runoff and water quality. As discussed in Section 5, these measures are categorized as follows:

- General Drainage Improvements that relate to surface water conveyance modifications,
- Floodproofing Improvements that protect structures from floodwaters by physical means,
- Streambank Stabilizations that focus on restoring and protecting eroding streambanks,
- Culvert Improvements that involve enlargement of existing culverts to enhance conveyance of water and reduce flooding during flooding events,
- Stormwater Management Improvements that enlarge or otherwise modify existing stormwater management facilities to provide additional quantitative and qualitative treatment of runoff, and
- Flow Attenuation Facilities that consist of new, large-scale stormwater management facilities to provide downstream flood mitigation.

The subsections below provide a brief summary of the site-specific improvement measures recommended in this report. Detailed site-specific preliminary design packages are included in Appendix H.

It is important to note that none of the proposed improvements summarized in the following sections can be implemented without the expressed cooperation of the land owners. The stated intent of the NCFAC is to identify and implement improvements without exercising condemnation authority.

Figure 6.1
South Branch Naamans Creek Problem/Potential Improvement Sites



NOT TO SCALE

*Adapted from Naamans Creek Watershed and Open Space, University of Delaware, Institute for Public Administration, May 1997.

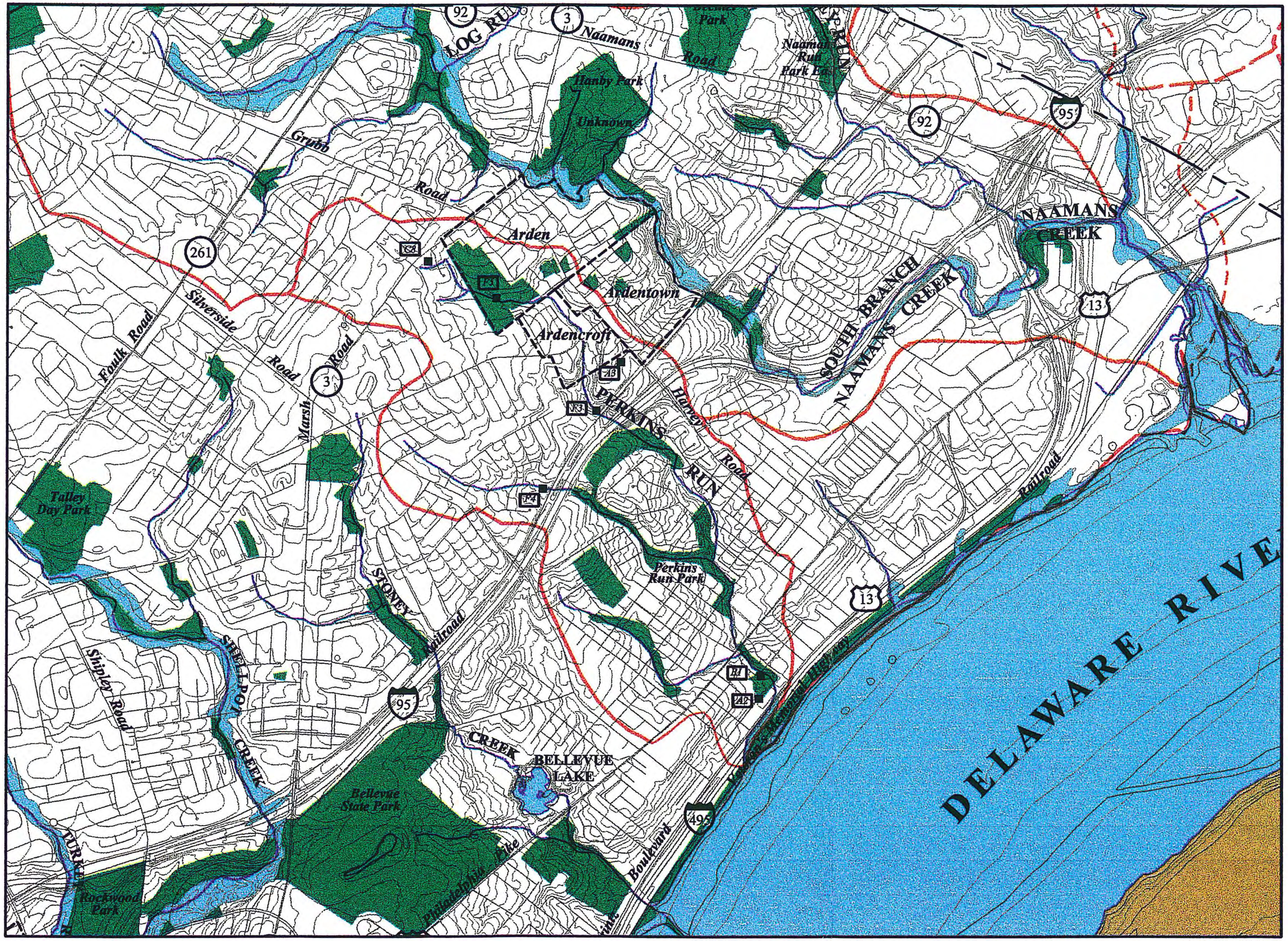
Legend:

- Parks and Open Space
- 100 Year Flood Plain
- Hydrology
- South Branch Naamans Creek Watershed Boundary
- Non-Study Watershed Boundaries
- Municipal Boundaries
- F3 Problem/Potential Improvement Site

DUFFIELD ASSOCIATES

Figure 6.2

Perkins Run Problem/Potential Improvement Sites



*Adapted from Naamans Creek Watershed and Open Space, University of Delaware, Institute for Public Administration, May 1997.

Legend:

- Parks and Open Space
- 100 Year Flood Plain
- Hydrology
- Perkins Run Watershed Boundary
- Non-Study Watershed Boundaries
- Municipal Boundaries
- Problem/Potential Improvement Site

DUFFIELD ASSOCIATES

6.1 General Drainage Improvements

General drainage improvements are recommended for five (5) sites (Table 6.1).

Table 6.1: General Drainage Improvements

Site ID	Location	Water Quality/ Flooding Evaluation	Recommended Improvement Measures	Number of Stormwater Management Facilities Upstream
(A1) 103	2401 Brae Road	Surface water and residential flooding	Install collection structure and diversions	11
(A2) 109	1804 Walnut Street	Surface water and residential flooding	Install diversions and swales	15
(A3) 305	1500 Upsan Downs Lane	Erosion of Town Path adjacent to residence	Install swale and grading	8
(A4) 314	1907 Millers Road	Surface water and residential flooding	Install swales and trench drain	11
(A5) 321	2401 Foulk Road and Valley Road	Surface water and residential flooding	Install diversions and swale	4

6.1.1 Site A1 - 2401 Brae Road

A grassed drainage swale that collects and conveys surface water runoff from upgradient roads and a path is currently eroding at this location. In addition, residents at this site have experienced basement flooding during high intensity rainfall events.

To stabilize the drainage swale, plunge pool energy dissipation structures are proposed at the discharge points of the concrete spillway and driveway culvert that discharges to the swale. The plunge pools consists of small, excavated areas serving to reduce the velocity and energy of the runoff as it enters the swale. In addition, the swale would be stabilized with an erosion control mat supporting grass or other non-woody vegetation.

To reduce basement flooding, it is recommended that the residents redirect water discharging from their roof gutters and downspouts away from their home.

6.1.2 Site A2 - 1804 Walnut Avenue

Surface water runoff primarily from Walnut and Penn Avenues and inadequate yard drainage has caused flooding of a garage and basement at this location resulting in property damage. A drainage swale in the front and side yards of this property is recommended to convey surface water away from the house, which should reduce surface ponding and subsequent infiltration. In addition, a paved berm, similar to a speed bump, is proposed on the driveway, at the entrance to the garage to prevent inflow of surface water.

6.1.3 Site A3 - Upsan Downs Lane

Surface water runoff from Upsan Downs is causing erosion of the town path and adjacent drainage swale at this location. Construction of a grassed swale and improvements to the existing riprap swale is proposed to stabilize this site.

6.1.4 Site A4 - 1907 Millers Road

Surface water runoff has resulted in flooding and surface ponding at this location due to its location at the base of a hill and inadequate yard drainage. Construction of an open-grated gutter or slotted drain across the driveway combined with a drainage swale on the upgradient part of the property is proposed to collect and convey surface water through the yard and away from the existing house.

6.1.5 Site A5 - 2401 Foulk Road and Valley Road

Surface water runoff has resulted in yard and basement flooding at this site due to its location at the base of a hill and inadequate surface drainage. A grassed swale and catch basin are proposed along the rear property line at this location to convey runoff away from the existing homes.

6.2 Floodproofing

Floodproofing is recommended for three (3) sites (Table 6.2) that are located in the floodplain. Floodproofing alternatives were selected only after property acquisition and reduction of flows through retrofitting of existing upstream stormwater management facilities were deemed infeasible.

Table 6.2: Floodproofing

Site ID	Location	Water Quality/ Flooding Evaluation	Recommended Improvement Measures	Number of Stormwater Management Facilities Upstream
(B1) 304	Garrett Road	Stream flooding/ streambank erosion	Flood proofing, streambank stabilization	15
(B2) 308	2300, 2302 & 2304 Inwood Road, Lancashire	Surface water and residential flooding	Flood proofing	10
(B3) 319	2204 Valley Avenue	Erosion and stream flooding	Flood proofing	4

6.2.1 Site B1 - 7 and 9 Garrett Road

Due to their location directly adjacent to Perkins Run, the properties at 7 and 9 Garrett Road have experienced basement flooding as a result of the creek exceeding its streambanks during high intensity precipitation events. Removal of the existing basement doors and construction of watertight walls in their place is recommended to prevent inflow of floodwaters and reduce property damage at both 7 and 9 Garrett Road. If residents are not receptive to these changes, an alternative would be to extend an existing berm adjacent to Perkins Run along both properties to contain floodwaters. In addition, streambank stabilization is recommended to stabilize the severely eroded banks of Perkins Run downstream of Garrett Road.

6.2.2 Site B2 - 2300, 2302 and 2304 Inwood Road

Due to their location at the confluence of the South Branch of Naamans Creek and Log Run, the homes located at 2300, 2302 and 2304 Inwood Road experience flooding during high intensity rainfall events often resulting in basement damage. Installation of watertight windows and flood shields on the doors of the homes at this location, to prevent inflow of floodwaters, is recommended.

6.2.3 Site B3 - 2204 Valley Avenue

Due to its location adjacent to Spur G of the South Branch of Naamans Creek, this site floods during high intensity rainfall events resulting in property damage. Installation of watertight windows, where applicable, and floodsheilds on the doors is recommended to prevent inflow of floodwaters.

6.3 Streambank Stabilization

Streambank stabilization is recommended for eight (8) sites (Table 6.3).

Table 6.3: Streambank Stabilization

Site ID	Location	Water Quality/ Flooding Evaluation	Recommended Improvement Measures	Number of Stormwater Management Facilities Upstream
(C1) 108	4, 6 & 8 Broadbent Road	Yard flooding, creek overflows, stream bank erosion	Streambank stabilization	1
(C2) 310	911 Darley Road	Surface water, residential flooding, streambank erosion	Streambank stabilization	0
(C4) 312	50 Chestnut Street/ Ardentown	Streambank erosion, surface water, residential flooding	Stream restoration	11
(C5) 318	2221 Patwynn Road	Streambank erosion	Streambank stabilization	1
(C6) 401	2607 Pennington Drive	Streambank erosion	Streambank stabilization	4
(C7) 403	Sunnyside Tract	Streambank erosion from railroad culvert	Streambank stabilization	11
(C8) 404	2003 Marsh Road	Streambank erosion	Streambank stabilization	0
(C9) 408	1997 Kershaw Lane	Streambank erosion	Streambank stabilization	0

6.3.1 Site C1 – 4, 6, and 8 Broadbent Road

The streambanks of the South Branch of Naamans Creek bordering 4, 6, and 8 Broadbent Road are eroding resulting in streambank and channel degradation. A combination of root wads, native species plantings (bioengineering) and riprap, where necessary, are recommended to stabilize the streambank at this location. Bioengineering alone is not suitable at this site due to the extensive tree canopy cover, resulting in lack of sunlight needed to support plant growth.

6.3.2 Site C2 – 911 Darley Road

Significant bank erosion along a tributary to the South Branch of Naamans Creek is encroaching on the property of 911 Darley Road. Replacement of an existing, undercut vertical wall and a new gabion or mechanically stabilized earth wall is proposed for this site to reduce property damage. A combination of root wads, native species plantings (bioengineering) and riprap is recommended to stabilize the streambank in other eroded locations at this site.

6.3.3 Site C4 – 50 Chestnut Street

The streambanks and channel along the South Branch of Naamans Creek are unstable for approximately 1,500 lineal feet downstream of Marsh Road. A comprehensive stream restoration design is recommended for this reach to stabilize the channel and improve conveyance.

6.3.4 Site C5 – 2221 Patwynn Road

Streambank erosion at this site has resulted in the loss of land and has increased sediment load and deposition downstream. A combination of riprap and biostabilization is recommended to stabilize the eroded and undercut streambank.

6.3.5 Site C6 – 2607 Pennington Drive

Potential loss of a portion of an existing fence adjacent to a tributary to Naamans Creek is occurring at this site. Streambank erosion is causing sediment deposition downstream and property loss. A combination of riprap and biostabilization of the eroded and undercut streambank is proposed to reduce property loss and protect the existing fence, while providing water quality benefits downstream.

6.3.6 Site C7 – Sunnyside Tract

Significant undercutting and sloughing occurs along the streambank downstream of the B&O Railroad crossing of the South Branch of Naamans Creek. The proposed streambank stabilization will consist of a combination of riprap and biostabilization techniques. Riprap will be used in the lower, more erosive part of the stream channel and biostabilization in the form of native species plantings reinforced with erosion control matting will be used on the upper slopes.

6.3.7 Site C8 – 2003 Marsh Road

The streambanks along a tributary to Naamans Creek behind the residence of 2003 Marsh Roads are undercut and eroding. The erosion has resulted in property loss and an increased sediment load downstream. The proposed stabilization will consist of riprap and biostabilization. Riprap will be used in the lower, more erosive portion of the stream channel and biostabilization consisting of native species plantings reinforced with erosion control matting will be used on the upper slopes.

6.3.8 Site C9 – 1997 Kershaw Lane

The existing gabions lining the banks of the South Branch of Naamans Creek near 1997 Kershaw Lane have deteriorated to the point of no longer being functional. Consequently, significant streambank erosion is occurring. Continued deterioration of the gabions will result in further destabilization of the streambanks, ultimately causing additional streambank erosion, property loss, and increased sediment load downstream. Replacement of the existing gabions with a new gabion structure or a mechanically stabilized earth wall in approximately the same location along the streambank is recommended for this site.

6.4 Culvert Improvements

Culvert improvements are recommended for three (3) sites (Table 6.4).

Table 6.4: Culvert Improvements

Site ID	Location	Water Quality/ Flooding Evaluation	Recommended Improvement Measures	Number of Stormwater Management Facilities Upstream
(D1) 302	2300 Marsh Road	Stream flooding	Improve culvert capacity/ Flood proofing/ Acquisition	10
(D2) 701	1920 Zebley Road	Roadway flooding	Roadway drainage improvement, culvert development	0
(D3) 709	Log Run & Inwood Road	Roadway flooding	Increase culvert capacity, Bank stabilization	10

6.4.1 Site D1 – 2300 Marsh Road

The culvert system under Marsh Road at the intersection of the South Branch of Naamans Creek is overtopped during significant rainfall events. Residential structures are flooded during these rainfall events. Three improvement options were considered. One option is to floodproof the homes that are floodprone. A second option is to acquire the property or properties that continue to flood. Due to area constraints, additional culverts are not recommended.

6.4.2 Site D2 – 1920 Zebley Road

Roadside flooding at 1920 Zebley Road occurs due to inadequate roadside conveyance. During and following most rainfall events, stormwater runoff ponding and road flooding occurs at this site. A grassed swale and culvert system is proposed to facilitate conveyance of stormwater runoff. The majority of the proposed system will be a grassed swale, however, culverts will be utilized at driveway crossings.

6.4.3 Site D3 – Inwood Road

Residents on Inwood Road near the intersection of Log Run experience occasional flooding. The two existing culverts under Inwood Road are inadequate to convey most high intensity precipitation events. There are three options to reduce property flooding at this site. The first option is to shorten the existing culverts. The second option is to add a third culvert of the same size and length as the existing culverts. The third option is to add a third culvert and shorten the existing culverts. All three options will lower the water surface elevation during storms at the stream crossing.

6.5 Stormwater Management

Stormwater management improvements are recommended for six (6) sites (Table 6.5).

Table 6.5: Stormwater Management Facilities

Site ID	Location	Water Quality/ Flooding Evaluation	Recommended Improvement Measures	Number of Stormwater Management Facilities Upstream
(E1) 317	Foulk & Naamans Road, Chin Wu Property	Potential stormwater management facility and/or wetland creation	Potential stormwater management facility and/or wetland creation	1
(E2) 322	Harvey Mill Park	Floodplain park	Wetland creation	10
(E3) 801	Naamans Road and Smith Lane	Existing DelDOT stormwater detention basin	Stormwater management basin expansion	4
(E4) 803	Naamans Road & Mousely Place	Existing DelDOT stormwater detention basin	Stormwater management basin expansion	1
(E5) 805	Birch Knoll Road & Pine Cliff Drive	Existing stormwater detention basin	Redesign or reconstruct basin	1
(E6) 806	Naamans & Carpenter Road	Vacant lot adjacent to stream	Design or construct stormwater basin & wetland	0

6.5.1 Site E1 – Foulk & Naamans Roads

Based upon requests from members of the NCFAC, an offline stormwater management pond is proposed for the South Branch of Naamans Creek at the northeast intersection of Foulk and Naamans Roads. The excavated pond at this location would require the newly built Genuardi's shopping center and other existing businesses to be abandoned and removed. A wetland is proposed for the adjacent Chin Wu property and would be created by regrading the site to collect surface water runoff and by adding wetland vegetation of provide quality treatment and a diversified habitat. These facilities will not significantly reduce flooding downstream, but will provide water quality improvements.

6.5.2 Site E2 – Harvey Mill Park

Flooding and water quality problems occur downstream of Harvey Mill Park. An offline wooded wetland area is proposed for the open space adjoining the South Branch of Naamans Creek at this location. The wetland facility would create an extended floodplain that would provide temporary storage of floodwaters. Wooded wetlands would be created in the excavated area between Naamans Creek and Wynwood to provide aquatic and terrestrial habitat and water quality benefits.

6.5.3 Site E3 – Naamans Road & Smith Lane

Residential flooding and water quality issues occur downstream of an existing DelDOT stormwater management basin adjacent to the Dartmouth Woods II subdivision. A series of improvements are proposed for this site. The first improvement includes a volume expansion of the existing DelDOT basin to lower the peak water level elevation downstream. The second improvement is to further excavate the existing Dartmouth Woods II basin to provide extended stormwater detention. The third improvement is to improve the conveyance of the receiving ditch between Dartmouth Woods Road and Channin Drive. A combination of all three improvements would provide the greatest benefits for reducing downstream residential flooding.

6.5.4 Site E4 – Naamans Road & Mousely Place

This site is an existing DelDOT stormwater management basin located at the intersection of Naamans Road and Mousely Place. Residential flooding and water quality problems occur downstream of this location. Enlarging the existing basin within the DelDOT right of way will provide a reduction in peak runoff discharges and improved water quality benefits.

6.5.5 Site E5 – Birch Knoll Road & Pine Cliff Drive

This site is an existing residential stormwater management facility located near the intersection of Birch Knoll Road and Pine Cliff Drive. Due to existing grading and stormwater collection conditions, the existing basin does not function adequately as designed. A redesign and construction of the existing stormwater management facility in the form of a shallow marsh will improve stormwater quality and quantity treatment.

6.5.6 Site E6 – Naamans and Carpenter Roads

This site is an existing DelDOT conservation easement located northeast of the intersection of Naamans and Carpenter Roads. Proposed improvements for this site include excavation to provide temporary storage of surface water runoff and establishment of a wooded wetland. A wooded area would be created in the excavated area to provide aquatic and terrestrial habitat and water quality benefits. The improvement will have minimal impact on downstream flood elevations.

6.6 Flow Attenuation

Flow attenuation is recommended for five (5) sites (Table 6.6).

Table 6.6: Flow Attenuation

Site ID	Location	Water Quality/ Flooding Evaluation	Recommended Improvement Measures	Number of Stormwater Management Facilities Upstream
(F1) 902	Bechtel Park	Downstream flooding problems, possible location for flood storage, and streambank erosion	On-line flood storage	0
(F2, C3) 904	Radnor Green	Downstream flooding, streambank erosion, and concrete channel	Channel Improvement	11
(F3) 905	Behind Montessori School	Downstream flooding, and streambank erosion	On-line flood storage	8
(F4) 906/601	Windybush	Downstream flooding, and streambank erosion	On-line flood storage	5
(F5) 907	Sherwood Forest	Downstream flooding, and streambank erosion	On-line flood storage	2

6.6.1 Site F1 – Bechtel Park

This site is located on a tributary of the West Branch of Naamans Creek upstream from the intersection of Valley Place Road and Valley Run Drive within Bechtel School Park. An on-line storage facility is proposed at this location to reduce downstream flooding and bank erosion.

6.6.2 Site F2, C3 – Radnor Green

This site is located along Naamans Creek upstream of Glenrock Road and between I-95 and Woodgreen Court. The concrete channel at this location provides no stream habitat and habitat improvements such as the installation of J-Hook rock flow vanes and rock weir structures is recommended.

6.6.3 Site F3 – Behind Montessori School

This site is located on Perkins Run directly upstream of I-95 and the B&O Railroad stream crossing. Residential flooding occurs downstream of this site. A proposed earth berm at this location will provide significant temporary stormwater runoff storage to reduce both the peak discharge and the peak water surface elevation downstream.

6.6.4 Site F4 – Windybush

This site is located northeast of Chatham Place along a tributary of Perkins Run. A stormwater management facility with a shallow marsh is proposed for this site. The proposed shallow marsh facility would provide significant water quality benefits and quantity control and will reduce flood elevations downstream.

6.6.5 Site F5 – Sherwood Forest

This site is located on Perkins Run, in the wooded area known as Sherwood Forest, northeast of Buckingham Greene. Residential flooding occurs downstream of this site. A proposed earth berm at this location will provide quality and quantity stormwater management and reduce both the peak discharge and the peak water surface elevations downstream.

6.7 Ranking Matrix

A qualitative ranking matrix was developed by the project team to assist the Naamans Creek Flood Abatement Committee (NCFAC) and subsequent planning committees in prioritizing implementation of the potential improvement measures recommended in this report. Each of

TABLE 6.7
RANKING MATRIX

Effectiveness:	Hydraulic Impact:	Environmental Impact:	Constructability:	Permit Feasibility:	Probable Cost:	Overall Ranking
✔✔✔ Highly Effective	✔✔✔ High Impact	✔✔✔ Few Impacts	✔✔✔ Few Constraints	✔✔✔ High Feasibility	✔✔✔ Low Cost	✔✔✔ Good
✔✔ Moderately Effective	✔✔ Moderate Impact	✔✔ Some Impacts	✔✔ Some Constraints	✔✔ Moderate Feasibility	✔✔ Moderate Cost	✔✔ Moderate
✔ Minimally Effective	✔ Low impact	✔ Numerous Impacts	✔ Numerous Constraints	✔ Low Feasibility	✔ High Cost	✔ Poor

Site No.	Location	Effectiveness	Hydraulic Impacts	Environmental Impact	Constructability	Permit Feasibility	Probable Cost	Rank
A1 (103)	2401 Brae Road	✔✔✔	✔	✔✔	✔✔✔	✔✔✔	✔✔✔	✔✔✔
A2 (109)	1804 Walnut Street	✔✔✔	✔	✔✔✔	✔✔✔	✔✔✔	✔✔✔	✔✔✔
A3 (305)	1500 Upsan Downs	✔✔✔	✔	✔✔✔	✔✔✔	✔✔✔	✔✔✔	✔✔✔
A4 (314)	1907 Millers Road	✔✔✔	✔	✔✔	✔✔✔	✔✔✔	✔✔✔	✔✔✔
A5 (321)	2401 Foulk Road	✔✔✔	✔	✔✔✔	✔✔✔	✔✔✔	✔✔✔	✔✔✔
B1 (304)	Garrett Rd Alternative A	✔✔✔	✔	✔✔✔	✔✔✔	✔✔✔	✔✔✔	✔✔✔
B1 (304)	Garrett Rd Alternative B	✔✔✔	✔	✔✔✔	✔✔✔	✔✔✔	✔✔✔	✔✔✔
B2 (308)	2302 & 2304 Inwood Road	✔✔✔	✔	✔✔✔	✔✔✔	✔✔✔	✔✔✔	✔✔✔
B3 (319)	2204 Valley Ave	✔✔✔	✔	✔✔✔	✔✔✔	✔✔✔	✔✔✔	✔✔✔

TABLE 6.7 (CONTINUED)
RANKING MATRIX

Effectiveness:	Hydraulic Impact:	Environmental Impact:	Constructability:	Permit Feasibility:	Probable Cost:	Overall Ranking
✓✓✓ Highly Effective	✓✓✓ High Impact	✓✓✓ Few Impacts	✓✓✓ Few Constraints	✓✓✓ High Feasibility	✓✓✓ Low Cost	✓✓✓ Good
✓✓ Moderately Effective	✓✓ Moderate Impact	✓✓ Some Impacts	✓✓ Some Constraints	✓✓ Moderate Feasibility	✓✓ Moderate Cost	✓✓ Moderate
✓ Minimally Effective	✓ Low impact	✓ Numerous Impacts	✓ Numerous Constraints	✓ Low Feasibility	✓ High Cost	✓ Poor

Site No.	Location	Effectiveness	Hydraulic Impacts	Environmental Impacts	Constructability	Permit Feasibility	Probable Cost	Rank
C1 (108)	4, 6 & 8 Broadbent Road	✓✓✓	✓	✓✓	✓✓	✓✓	✓✓	✓✓
C2 (310)	911 Darley Road	✓✓✓	✓	✓✓	✓✓	✓✓	✓✓	✓✓
C4 (312)	50 Chestnut Street	✓✓✓	✓	✓✓	✓✓	✓✓	✓✓	✓✓
C5 (318)	2221 Patwynn Road	✓✓✓	✓	✓✓	✓✓	✓✓	✓✓	✓✓
C6 (401)	2607 Pennington Drive	✓✓✓	✓	✓✓	✓✓✓	✓✓	✓✓✓	✓✓
C7 (403)	Sunnyside Tract	✓✓✓	✓	✓	✓✓	✓✓	✓✓	✓✓
C8 (404)	2003 Marsh Road	✓✓✓	✓	✓✓	✓✓	✓✓	✓✓	✓✓
C9 (408)	1997 Kershaw Lane	✓✓✓	✓	✓✓	✓✓	✓✓	✓✓	✓✓
D1 (302)	2300 Marsh Road Option 2	✓✓✓	✓✓✓	✓✓✓	✓✓✓	✓✓✓	✓✓✓	✓✓✓
D1 (302)	2300 Marsh Road Option 3	✓✓✓	✓	✓✓✓	✓✓✓	✓✓✓	✓	✓✓
D2 (701)	1920 Zebley Road	✓✓✓	✓	✓✓✓	✓✓✓	✓✓	✓✓✓	✓✓✓
D3 (709)	Log Run & Inwood Road Option 1	✓✓✓	✓	✓✓	✓✓✓	✓✓	✓✓	✓✓
D3 (709)	Log Run & Inwood Road Option 3	✓✓✓	✓	✓✓	✓✓	✓✓	✓✓	✓✓

Table 6.7 (Continued)
Ranking Matrix

Effectiveness:	Hydraulic Impact:	Environmental Impact:	Constructability:	Permit Feasibility:	Probable Cost:	Overall Ranking
✔✔✔ Highly Effective	✔✔✔ High Impact	✔✔✔ Few Impacts	✔✔✔ Few Constraints	✔✔✔ High Feasibility	✔✔✔ Low Cost	✔✔✔ Good
✔✔ Moderately Effective	✔✔ Moderate Impact	✔✔ Some Impacts	✔✔ Some Constraints	✔✔ Moderate Feasibility	✔✔ Moderate Cost	✔✔ Moderate
✔ Minimally Effective	✔ Low impact	✔ Numerous Impacts	✔ Numerous Constraints	✔ Low Feasibility	✔ High Cost	✔ Poor

Site No.	Location	Effectiveness	Hydraulic Impacts	Environmental Impacts	Constructability	Permit Feasibility	Probable Cost	Rank
E1 (317)	Foulk & Naamans Road	✔	✔	✔✔	✔	✔✔	✔	✔
E2 (322)	Harvey Mill Park	✔✔✔	✔✔	✔✔	✔✔	✔✔✔	✔✔	✔✔
E3 (801)	Naamans Road & Smith Lane	✔✔✔	✔✔✔	✔✔	✔✔✔	✔✔✔	✔✔	✔✔✔
E4 (803)	Naamans Road & Mousely Place	✔✔✔	✔✔✔	✔✔	✔✔✔	✔✔✔	✔✔	✔✔✔
E5 (805)	Birch Knoll Road & Pine Cliff Drive	✔✔	✔	✔✔	✔✔	✔✔	✔✔	✔✔
E6 (806)	Naamans & Carpenter Road	✔✔✔	✔	✔✔	✔✔	✔✔	✔✔	✔✔
F1 (902)	Bechtel Park	✔✔✔	✔✔✔	✔	✔✔	✔	✔	✔✔
F2, C3 (904)	Radnor Green	✔✔	✔	✔✔✔	✔✔	✔✔	✔✔	✔✔
F3 (905)	Behind Montessori School	✔✔✔	✔✔✔	✔	✔✔	✔	✔	✔✔
F4 (906/601)	Windybush	✔✔✔	✔✔✔	✔	✔✔	✔	✔	✔✔
F5 (907)	Sherwood Forest	✔✔✔	✔✔✔	✔	✔✔	✔	✔	✔✔

the thirty (30) sites proposed for improvements was qualitatively ranked based primarily on the feasibility criteria discussed in section 5. Probable cost was also included as a ranking criteria. Each of the sites was evaluated with respect to:

- Effectiveness,
- Hydraulic Impact,
- Environmental Impact,
- Constructability,
- Permit Feasibility, and
- Probable Cost.

Table 6.7 presents the ranking of individual sites for each parameter and provides an overall ranking of the sites. The ranking table allows the NCFAC to compare the relative effectiveness and cost of each proposed improvements versus the potential impacts or constraints.

6.8 Site Referrals

It is recommended that the problem/potential improvement sites not directly addressed in this report be referred to an appropriate agency for further action. For instance, general drainage sites should be referred to the New Castle Conservation District and road drainage sites should be referred to DelDOT. Letters have been drafted for the NCFAC summarizing the problem or concern related to each site and addressed to the appropriate agency. A copy of the questionnaire from the workshop and a field data sheet, if available, are attached to the draft letters. The draft letters are attached in Appendix I.

7.0 General Watershed Improvement Recommendations

This section discusses watershed-wide improvement measures that will reduce stream flooding, improve stream water quality and generally reduce the impacts associated with urban development of the watersheds.

7.1 Hydrologic Impacts of Urban Development

Urban development has had a heavy influence on the quality of the watercourses in the Naamans Creek and Perkins Run Watersheds. The hydrology of an area is changed when vegetation such as trees and grass, which previously intercepted and/or absorbed rainfall, are removed. Likewise, the removal of natural depressions, which provide temporary storage for stormwater runoff, alters an area's hydrology. Cleared areas can no longer "slow down" surface water to the point at which the water can naturally infiltrate. As impervious surface area is increased with the construction of rooftops, roads, driveways, parking lots, and other similar surfaces, natural infiltration of rainfall is further reduced. The overall consequence of these activities in the Naamans Creek and Perkins Run Watersheds is the rapid conversion of most rainfall into stormwater runoff. As a result, the stream systems through these watersheds have been severely impacted in the following manners:

- declining surface-water quality;
- diminishing groundwater recharge and quality;
- diminishment in stream base flows;
- degradation of stream channels;
- increased overbank flooding; and
- floodplain expansion.

7.1.1 Declining Water Quality

Impervious surfaces in the study area tend to collect contaminants that have been produced from specific land uses (e.g., industry, housing, commercial development); leaked from vehicles, settled from the atmosphere, or deposited from adjacent areas. During rainfall events, these contaminants are collected in stormwater runoff and conveyed into surface waters or infiltrated to groundwater. Some common pollutants found in urban stormwater include:

- suspended solids;
- nutrients;
- bacteria;
- hydrocarbons;
- trace metals;
- pesticides;
- chlorides (in the winter);
- thermal impacts; and
- trash and debris.

7.1.2 Diminishing Groundwater Recharge and Quality

The infiltration of rainfall through the soil profile is necessary for the replenishment of groundwater. The Natural Resources Conservation Service (NRCS) has estimated groundwater recharge volumes for the hydrologic soils groups. (Table 7.1)

Table 7.1: NRCS Estimates of Annual Recharge Rates, Based on Soil Type

Hydrologic Soils Group	Average Annual Recharge
"A" Soils	18 inches/year
"B" Soils	12 inches/year
"C" Soils	6 inches/year
"D" Soils	3 inches/year

Groundwater sustains flows in streams during periods of dry weather. As impervious area has been increased with an increase in development, rainfall infiltration and groundwater recharge have decreased. Consequently, some perennial streams have run dry during dry-weather periods. For a further discussion regarding the impact of development on base flow, see Section 2.9.

Many urban land uses also impact the quality of groundwater if stormwater runoff is allowed to infiltrate without proper treatment. In those areas known to generate potential contamination, treatment of runoff is essential.

7.1.3 Degradation of Stream Channels

Due to uncontrolled stormwater runoff resulting from urban development, the frequency and magnitude of stormflows have increased in the Naamans Creek and Perkins Run Watersheds with increasing development. This is especially true since much of the development in the basin occurred prior to the enactment of stormwater quality and quantity management regulations. As a result, the stream channels and banks are exposed to erosive stream flows at a higher frequency and for a longer duration. These erosive forces have caused stream instability, which is evidenced by channel widening, increased streambank and channel erosion, increased sediment deposition and embedding of substrate (resulting in a decline in stream substrate quality), loss of pool/riffle structure, and degradation of aquatic habitat.

Lower frequency precipitation events, in the range of a two-year frequency, typically result in the most erosion in stream channels. The State of Delaware's current stormwater management regulations require that post-development two-year storm discharge rates do not exceed pre-development two-year storm discharge rates. However, recent research and experience shows that criterion for a two-year peak discharge is not adequate to protect downstream channels from erosion. (Maryland DEP, 1999). In some cases, maintaining two-year storm peak flows may actually accelerate streambank erosion because of the extended exposure to the erosive streamflows.

Delaware's Sediment and Stormwater Regulations do require that the first inch of stormwater runoff be released over a 24-hour period. This extended detention does provide a measure of control for stormwater runoff for rainfall events of greater frequency than the 2-year storm.

7.1.4 Increased Flooding

Flooding occurs when streamflows exceed the capacity of the stream channel and overflow into the adjacent floodplains. Flooding in the Naamans Creek and Perkins Run Watersheds has resulted in damage to property (private homes) and downstream drainage structures (bridges and culverts).

Uncontrolled stormwater runoff from urban development has resulted in an increase in the frequency of flooding events in the watersheds. Consequently, flood damage has also increased proportionally. The goal of the State of Delaware's Sediment and Stormwater Regulations has been to maintain pre-development peak stormwater runoff discharge rates for the 2-, 10-, and 100-year storm events after development, keeping the level and frequency of flooding the same over time. However, most of the development in the Naamans Creek and Perkins Run Watersheds occurred prior to the implementation of these more restrictive regulations.

7.1.5 Floodplain Expansion

Floodplains are natural flood storage areas and help attenuate downstream flooding. Floodplains are important habitat areas that typically include riparian forests, wetlands and wildlife corridors. As development has increased, the peak discharge for the 100-year discharge has increased proportionately. In addition, natural floodplains have been altered and encroached upon during development. Consequently, the elevation of a stream's 100-year floodplain becomes higher and the boundaries of the floodplain get wider.

7.2 Stormwater Management

Stormwater management in the State of Delaware and New Castle County has historically focused on local structural facilities, primarily stormwater management ponds, designed to control runoff from an entire development site or section of a site. More recently, a Conservation Design for Stormwater Management Manual has been developed that is designed to provide incentives for land developers to retain and incorporate natural site features into the site development process and thereby reduce or eliminate the need for structural stormwater management controls.

The following paragraphs outline several suggested changes to current stormwater management regulatory programs for consideration by the State and New Castle County. The changes are based on stormwater management regulations in the states of Maryland and Pennsylvania and are designed to address the impacts of urban development described above. The proposed changes are suggested for consideration for new development and redevelopment projects to improve watershed conditions.

The Delaware Sediment and Stormwater Regulations were designed to establish minimum guidelines that are to be applied statewide. There are provisions in these regulations that allow locally delegated sediment and stormwater programs to establish more stringent requirements than the State. DNREC has indicated that they are prepared to discuss alternate stormwater strategies with the NCFAC and New Castle County, Department of Land Use or other appropriate delegated agencies.

As an alternative, the NCFAC, New Castle County or New Castle Conservation District could propose to DNREC that the Naamans Creek and Perkins Run watersheds be named "Designated Watersheds." As a "Designated Watershed," DNREC may establish additional sediment and stormwater requirements due to existing water quantity or quality problems.

A recommended hierarchy of stormwater management practices is suggested below:

- Minimize Stormwater Runoff
- Maintain or Augment Groundwater Recharge Rates
- General Stormwater Management Design
  - Attenuate at source
  - Achieve Quality Improvement During Conveyance
- Stormwater Management Controls
  - Size for water quality volume
  - Size for recharge volume
  - Size for stream channel protection volume
  - Size for flood protection

7.2.1 Minimize Stormwater Runoff

For new construction and development activities, minimization of stormwater runoff should be addressed to reduce the need for large scale structural stormwater management controls. This can be accomplished through conservation design techniques including, but not limited to, smaller road size, shared driveways, smaller lots with more open space and use of open channel stormwater conveyance versus piped systems.

In addition, elimination of waivers from stormwater quality control for redevelopment sites based on existing impervious coverage should be considered.

7.2.2 Maintain Groundwater Recharge Rates

It is recommended that requiring the volume of groundwater recharge on all development sites be maintained at pre-development levels to assure that there is no reduction of the annual recharge to the groundwater reservoir resulting in a lowering of the base flow of streams be considered. This can be accomplished with natural recharge areas or supplemental recharge facilities. While much of the watershed has fine grained surficial soils, recharge is possible.

7.2.3 General Stormwater Management Design

Where stormwater runoff minimization techniques are not feasible, flow attenuation at the source of runoff should be considered. This can be accomplished through the use of natural depressions or small man-made retention areas designed to maximize infiltration.

If runoff must be conveyed to a central control structure, an attempt should be made to achieve water quality improvement during conveyance through such techniques as dispersed flows and naturally vegetated shallow flow channels.

7.2.4 Stormwater Management Controls

Management of stormwater should be based on optimizing the existing landscape and adapting methods to mimic nature's processes. Stormwater management practices that utilize techniques that minimize runoff, increase infiltration, remove pollutants, and preserve the chemical, biological, thermal and hydraulic regimes of streams are called "Best Management Practices" or BMPs. BMPs are designed on a watershed-wide basis and consider attenuation of runoff at the source, runoff conveyance to management facilities and pre-treatment, and mitigation of secondary impacts such as warming (thermal pollution). Standards to be adopted for BMPs should promote the incorporation of safe and functional systems that are visual assets to the development project. Ideally, BMPs will include multiple components in functional order to form a linked management system to control and treat runoff discharge to obtain the desired effect.

7.2.5 Quality Treatment

There are several proven methods available for improving water quality in Urban BMP design. To be considered an effective BMP, it is recommended that the design shall be capable of capturing and treating the full water quality volume, removing at least 80% of the annual total suspended solids (TSS) loading, having an acceptable longevity rate in the field, and removing at least 40% of the annual phosphorous load. A combination of structural and non-structural practices is normally required at most development sites to satisfy the above criteria. Recognized methods for improving the full water quality volume include certain classes of ponds, stormwater wetlands, filtering practices, and open channel practices designed to specifically capture and treat runoff.

Classes of ponds that have a combination of a permanent pool, extended detention or shallow marsh equivalent to the entire water quality volume include:

- Micropool extended detention ponds
- Wet ponds
- Wet extended detention ponds
- Multiple pond system
- "Pocket" Ponds

Management practices that include significant shallow marsh areas to treat urban stormwater and may also incorporate small permanent pools and/or extended detention storage to achieve the full water quality volume include:

- Shallow wetlands
- Extended detention shallow wetlands
- Pond and wetland system
- "Pocket" wetlands
- Submerged gravel wetlands

Practices that capture or temporarily store the water quality volume and then pass it to a filter bed are considered to be filtering practices. Filtered runoff may be collected and returned to the conveyance system. Types of filtering systems include:

- Surface sand filter
- Underground sand filter
- Perimeter sand filter
- "Rain Gardens"
- Organic filter
- Pocket sand filter
- Bioretention areas

Non structural BMPs are an integral component to the overall BMP strategy. In many cases, non-structural BMPs can be combined with structural BMPs to meet all stormwater requirements. The benefits of incorporating non-structural components into the BMP design include the reduction of runoff generation, which reduces the size of and cost of structural BMPs, and partial pollutant removal. Types of non-structural BMPs include:

- Conservation of natural areas
- Disconnection of rooftop runoff
- Disconnection of non-rooftop impervious areas
- Sheet flow discharge to stream buffers
- Use of open channels
- Reduction of impervious areas

7.2.6 Infiltration and Aquifer Recharge

The capacity for infiltration at any particular developed site is dependent on the underlying soil makeup and associated geology. Certain types of soils are predisposed to infiltrating significant quantities of water. These areas are usually comprised of localized deposits of fairly clean unconsolidated sands or limestone deposits. Past efforts have attempted to preserve the functionality of these special areas by limiting the amount of development, or impervious covered area within these protected zones, and by requiring the post-development recharge rates be equivalent to pre-development conditions. Typically, only stormwater runoff from rooftops or specially "cleaned" runoff is permitted to be infiltrated.

In conjunction with requiring the peak discharge rate from a developed watershed to be equivalent to the pre-developed condition, requirements for maintaining infiltration rates for the two-year storm event may be applicable also. Provided that the site soils are of the nature to permit effective infiltration, the size and location of these systems will be dependant on the volume of runoff to be infiltrated and the time period necessary to infiltrate. Frequently, large complex systems are constructed underneath large paved areas such as parking lots. Important issues relating to the design and construction of these systems include long-term maintenance and access for cleaning and repair, as clogging from sedimentation or biological activity may occur. Therefore, pre-treatment of runoff to be infiltrated is also an important consideration for planning and design. Recommended design criteria include the following:

- Infiltration devices shall be used as the stormwater management method of choice, where soil and site conditions allow. Such methods shall include vegetated surface berms, trenches and depressions, and sub-surface infiltration beds.
- The preferred method for infiltration shall be aboveground. Subsurface methods shall only be used when aboveground methods are infeasible. The order of preference for infiltration: shallow ground depressions, vegetated infiltration swales, infiltration basins with multi-level benches, combinations of the above and below-ground measures, followed by below-ground measures including, in no special order, porous pavement, seepage pits, trenches, and seepage beds.
- Absent site specific data for infiltration rates, infiltration systems should be sized to accommodate the ten-year storm and provide sufficient storage to fully infiltrate the two-year storm.
- Provisions for reducing the anticipated sediment loading and minimizing vegetative clogging shall be incorporated into the design.
- Provisions for maintenance and repair of the system shall be incorporated into the design.
- Infiltration systems shall be situated at least fifty feet from on-site wastewater systems or stream and shall be located down gradient from structures with basements.
- Infiltration systems shall be designed to provide positive overflow controls.

7.2.7 Stream Channel Protection

Increased frequency of bankfull flows experienced by a particular stream will result in bank erosion and overall degradation of the stream. Detention ponds historically maintained the peak discharge rate but released water at the peak rate over a longer duration to manage the greater volume of runoff resulting from increased development. To achieve stream channel protection, 24 hour extended detention of the 1-year, 24-hour storm is required. The rationale for this criterion, is that water will be released in a much more gradual manner such that critical erosive velocities will seldom be exceeded.

7.2.8 Flood Protection

Flood protection is provided by the existing stormwater management regulations which require maintaining post-development stormwater runoff rates at or below predevelopment runoff rates for the 2-year, 10-year and 100-year storm events. The goal is to prevent an increase in the frequency and magnitude of flooding events. It is recommended that stormwater management continue to address these storm events, but that stormwater be evaluated on a watershed basis. Typically, over-detention of stormwater runoff is recommended in the upper one-third of a watershed. Control of stormwater for the 2-, 10-, and 100-year storms at predevelopment rates is recommended for the middle third of a watershed, and no stormwater quantity management is recommended for approximately the lower third of the watershed. These guidelines vary based upon watershed characteristics. These guidelines do not apply to water quality management.

7.3 Stormwater Management Facility / Stormdrain Outfall Inventories

New Castle County government and the New Castle Conservation District have completed a partial inventory that identifies the locations and types of stormwater management facilities in New Castle County. The inventory was in draft form as of the writing of this report and was not available for inclusion. In addition, New Castle County and DelDOT have completed an inventory that identifies stormdrain outfalls constructed in New Castle County prior to 1992. According to New Castle County, the stormdrain outfall inventory will be updated to include outfalls constructed after 1992 as part of the NPDES stormwater permitting program. The stormdrain outfall inventory was not available from New Castle County or DelDOT as of the writing of this report.

It is recommended that the stormwater management facility and stormdrain outfall inventories be updated and finalized for each watershed in New Castle County. The inventory should include location, type of facility (e.g., permanent pool quantity/quality pond, sand filter, etc.) and capacity of the stormwater management facility or stormdrain.

This information could then be used to evaluate potential changes to existing stormwater management facilities or stormdrains to control the quantity and quality of stormwater runoff based upon the individual characteristics of the watershed in which it resides. This evaluation would be accomplished by modeling the specific performance of the various stormwater management facilities acting as a system within a watershed.

7.4 Watershed Coordinator

It is recommended that continuous coordination be maintained by implementing agencies (e.g., DNREC, New Castle County, DelDOT, New Castle Conservation District), in order to provide long-term management and attainment of the goals and programs outlined in this study for both the Naamans Creek and Perkins Run Watersheds. It is proposed that this coordination be accomplished by a designated coordinator to maintain organization of the efforts aimed at restoring these watersheds. The watershed coordinator would facilitate and track the implementation of the site-specific and general watershed improvements recommended in this report. In addition, the involved agencies should coordinate efforts to pursue and obtain funding from the various federal, state, and local government agencies as well as private organizations to be used for watershed improvements and public education/awareness efforts.

7.5 Water Resources Management Plan

It is recommended that development of a comprehensive Water Resources Management Plan be considered for the Naamans Creek and Perkins Run Watersheds, to identify methods for best management of all watershed issues. In addition to the flood-related data gathered in this report, detailed data on surface water, groundwater, water supply, wastewater treatment, stormwater control, and land use should be included in the comprehensive plan. Planning objectives for management of these water resources should be developed in this plan. At the plan completion, a linked, comprehensive database of watershed resources would exist.

The goal of watershed management is to plan and work toward an environmentally and economically healthy watershed that benefits all stakeholders. The main stage includes uncovering concerns, gathering and analyzing information and data, and documenting the data. It is recommended that the Water Resources Management Plan include at a minimum the following watershed information:

- Geologic data
- Soils data
- Surface water quantity and quality data
- Groundwater quantity and quality data
- Land use
- Assessment of potential water contaminant sources
- Assessment of hydrologic and hydraulic processes
- Assessment of geomorphic processes

- Physical and chemical characteristics
- Biological community characteristics
- Assessment of natural disturbances
- Assessment of human-induced disturbances

7.6 Riparian Buffer Enhancement

A riparian buffer is generally a linear corridor adjacent to a water body consisting of dense woody vegetation, such as trees and shrubs, that serves to filter stormwater runoff prior to entering the water body, provide thermal protection through shading, and provide a natural transition between the aquatic and terrestrial habitat. Additionally, root systems assist in anchoring the soil and consuming nitrogen. The creation of new riparian buffers and the enhancement of existing ones will improve water quality in the stream by controlling water temperature, contributing to habitat diversity, maintaining the stream channel's stability, and providing stormwater runoff quality management.

Section 10.330 of the UDC provides for a riparian buffer resource area and details design standards, including landscaping requirements, for riparian buffers. Greenways, a form of riparian buffer, are currently being implemented in several areas throughout the state. Acquisition of land for conservation easements may be necessary prior to the development of greenways. It is recommended that greenway development be considered in the Naamans Creek and Perkins Run Watersheds.

Riparian buffer development or enhancement is recommended throughout the Naamans Creek and Perkins Run Watersheds. Locations along Naamans Creek suitable for riparian buffer enhancement should be identified, and funding secured for development and improvement of these areas. State and/or County programs should be developed to administer and fund the riparian buffer enhancement programs and provide guidance to interested individuals or groups.

Much of the land adjacent to the creeks and streams in the study area is privately owned and developed. Consequently, these areas will likely be more difficult to develop as a riparian buffer. However, public awareness and education campaigns should be directed at educating the public to the benefits of these initiatives.

If appropriate trees and shrubs were made available from County or state sources, members of civic organizations or other groups in the watershed could participate in the planting effort under the supervision of a qualified professional. Arrangements for additional labor for stream enhancements may be explored with the State of Delaware and/or New Castle County Department of Special Services.

Recommended approach:

- Develop a riparian buffer team
- Secure a recurring source of moneys to fund the riparian buffer development/enhancement initiative
- Identify areas in the watershed that would benefit from riparian buffer development or enhancement
- Identify and notify the owners of these areas and obtain agreements to allow riparian buffer improvements
- Secure conservation easements, where possible, to preserve these areas
- Identify the appropriate plant species to be use based on new riparian buffer development or existing riparian buffer enhancement
- Enlist help from State, County and local officials (manpower, equipment, etc.)
- Develop planting schedules
- Organize community efforts (Riparian Buffer Development Days)

The DNREC Whole Basin management team is in the process of conducting a riparian corridor inventory project throughout the entire Piedmont Basin as of the writing of this report. The project involves an inventory of physical characteristics of streams identifies on USGS 7.5 Minute Series (topographic) maps throughout the Piedmont Region. On completion, it is recommended that the riparian corridor data from the Naamans Creek and Perkins Run Watersheds be attached to this report for reference and future riparian corridor/buffer enhancement projects.

7.7 Floodplain Management

Floodplains have been encroached upon or altered throughout the Naamans Creek and Perkins Run Watersheds. This is evident where lands have been filled and/or otherwise developed up to the edge of stream channels. The result of this encroachment has been the reduction in the function of the floodplain, including the storage and safe conveyance of floodwaters during high intensity precipitation events. Fill and placement of structures in the floodplain has resulted in restricted flows and raised flood elevations.

New Castle County's UDC includes a comprehensive set of rules to regulate development in the floodplain that should serve to protect these areas in the future. However, this does not address existing floodplain encroachment issues. It is recommended that, where possible throughout the Naamans Creek and Perkins Run Watersheds, floodplains be re-established to the maximum extent possible. This includes, when the opportunity arises, the removal of fill and structures that impede or restrict flood flows. Although somewhat controversial, removal of structures from the floodplain is recommended by FEMA, the State of Delaware and other federal and local agencies to enhance storm flow conveyance, reduce flood damage and protect against degradation.

7.8 Critical Planting Areas and Wetland Creation

Planting grasses, legumes, trees or shrubs on or adjacent to areas likely to produce contaminated runoff can greatly reduce the potential for impaired water quality. Permanent ground cover alleviates soil erosion and improves soil infiltration and aeration. Critical areas include those with steep slopes, poorly drained soils, or pesticide and nutrient use.

Where possible, grassed waterways should be used to direct concentrated flow runoff to more stable outlets. They can be used as outlets for terraces, to prevent gullies, or as filter areas for sediment. Some runoff reduction occurs for small rainfall events when water flows slowly through the waterway, allowing an increase of water to infiltrate.

The creation of wetlands can provide water quality benefits, improve and increase fish and wildlife habitat, reduce flooding, and provide educational and aesthetic benefits. Wetlands provide water quality benefits by filtering sediment and attached nutrients. They slow the flow of water to allow nutrients to be taken up by the plants and microorganisms. Leaching of nutrients into the groundwater is reduced through wetland creation by their slowly permeable soils.

It is recommended that, in addition to the specific wetland creations recommended in this study, available open space on State, County, or privately-owned land in the Naamans Creek and Perkins Run Watersheds should be considered for plantings or wetland creation, especially those areas adjacent to potential contaminant "hot spots".

Recommended approach:

- Identify areas in the watershed the would benefit from critical planting areas or wetlands creation
- Identify potential contamination "hot spots"
- Identify and notify the owners of these areas and obtain agreements to allow improvements
- Identify the appropriate plant species to be used based on the function of the plantings or wetlands
- Enlist help from State, County and local officials (manpower, equipment, etc.)
- Develop planting schedules
- Monitor creation efforts
- Perform maintenance activities as necessary

7.9 Stream Maintenance

Many localized flooding problems in the watershed are the result of deposited sediments and other debris, such as tree branches, clogging culverts and stream channels. Currently, both New Castle County and DelDOT have maintenance programs that periodically remove this debris to minimize the potential for clogged culverts. However, based upon comments at the

Naamans Creek Flood Abatement Study workshop and during field review of the streams in the watersheds, it is evident that numerous stream sections are not part of these maintenance programs or were not maintained with sufficient frequency. It is recommended that those areas identified during the workshops or during field reconnaissance that are not currently maintained be added to the routine maintenance programs of the appropriate agency. It is also recommended that sections of Naamans Creek and Perkins Run that are susceptible to flooding should be periodically walked to identify previously unknown sediment depositions or other blockages in the creek that may contribute to localized flooding. To that end, it is recommended that neighborhood stream watch groups be created to routinely walk Naamans Creek and Perkins Run. Under the guidance of the Watershed Coordinator, these groups could greatly assist New Castle County and DelDOT in identifying problem areas and subsequently reducing localized flooding.

Recommended approach:

- Identify locations in the creeks that continuously fill with sediment or clog to floating debris.
- Check to determine if these locations are on an existing stream maintenance plan.
- If on an existing maintenance schedule, check the inspection and maintenance frequency.
- Establish/monitor maintenance records to track the frequency of required maintenance.
- Increase the frequency of inspection and maintenance, if necessary.
- If not on an existing maintenance schedule, add the location to the routine inspection and maintenance plan

7.10 Public Education/Awareness

Educational programs designed to increase overall public awareness often result in the improvement to the water quality of a stream system. Pamphlets, flyers, educational workshops, and school programs are all tools that, when utilized properly, foster a sense of responsibility among the watershed residents. The focus of educational programs is not only to teach residents about the ecology and function of a watershed and its influence on each individual's quality of life, but also to maintain and protect the watershed after the initial effort of education has been made.

Programs such as the City of Wilmington's Project Turtle are excellent examples of the types of tools that can influence watershed residents and create a valuable legacy. Project Turtle is a public education program in which school children paint turtle symbols on catch basins to remind people of the ultimate destination of pollution: the river and its wildlife.

Several schools in the Brandywine School District have introduced a watershed education component into their curriculum at the 7th & 8th grade levels. We recommend expanding this program to include stream sampling and stream restoration projects in the Naamans Creek Watershed. An education module incorporating these components has been developed as part of this study. Additionally, school-business partnerships are being explored as a funding resource for this program. Development and dissemination of educational materials will facilitate understanding of watersheds and encourage stewardship.

It is recommended that the general public education program consist of:

- Placement of symbols, such as fish, or phrases, such as "Don't Dump—Naamans Creek Drainage," or as "Don't Dump—Perkins Run Drainage," stenciled or imprinted on all catch basins in the watershed to remind residents the water entering the stormwater collection system eventually makes its way to Naamans Creek and Perkins Run. The program is a great example of thinking globally and acting locally. The paints used for the stenciling should be environmentally safe and free of harmful contaminants
- Placement of signs on major roads at the watershed boundary to inform and remind the public that they are "Entering/Leaving the Naamans Creek or Perkins Run Watershed"
- "Protect Naamans Creek" or "Protect Perkins Run" signs at bridge crossings of the creek, and similar signs for tributaries identifying the watercourse and reminding residents to protect these resources
- Development of interpretive trails or enhancement of existing trails such as greenways along the banks of Naamans Creek, Perkins Run and surrounding park land identifying plant and animal species
- Development and distribution of pamphlets on the care and protection of the Naamans Creek and Perkins Run Watershed. The pamphlets and public education program could be developed with the cooperation of New Castle County, DNREC, the Delaware Nature Society, University of Delaware Water Resources Agency, and other private consultants. The public education program should be coordinated with New Castle County in areas that overlap with the NPDES program.
- Incorporate water quality education into the classroom. As part of environmental science education, schools near Naamans Creek or Perkins Run can conduct on-site investigations in the stream. Stream sampling, careful observation, accurate record keeping, and systematic measurements allow students to plot and monitor changing conditions of the stream. These efforts should be coordinated with DNREC to supplement their water quality monitoring program.
- Hold a watershed photo contest judging the best looking and most picturesque part of the Naamans Creek and Perkins Run Watersheds.
- Develop a wetland/stream walk program to give citizens of Naamans Creek and Perkins Run Watersheds the opportunity to learn about this valuable resource and at the same time collect information and data which will help identify trends in the watershed's health.
- Develop a team to organize residents to participate in National River Cleanup Week (NRCW), May 15-22. NRCW was originated in 1991 in response to recognition that America's streams and rivers are in need of cleaning due to the careless disposal of trash and other debris. Organization of all residents of the Naamans Creek and

Perkins Watersheds can be notified through a simple flier or newsletter. Participants walk the stream with trash bags to collect debris or garbage.

- Encourage participation in the River of Words Project. The River of Words Project is an international environmental poetry and art contest designed to nurture respect and understanding of the natural world by encouraging children to learn their ecological address and to describe through poetry and art their own place in space.
- Continue the web site created as part of this study to provide status updates, education, and a resident communication tool.

7.11 Additional Evaluations/Analysis

Due to the limited scope of this study it is likely that some problem areas were not identified or specifically addressed. It is therefore recommended that the following additional analysis be performed to identify those problem areas not included in this report.

7.11.1 Stream Restoration/Stabilization

It is recommended that the entire lengths of Naamans Creek and Perkins Run and their significant tributaries be walked to identify all areas of channel instability, including channel degradation and stream bank erosion. Based on the information collected during the stream walks, stream channel restoration plans can be developed to stabilize the stream corridor.

7.11.2 Base Flow Analysis

Diminishing base flow in the Naamans Creek and Perkins Run Watersheds continues to be a concern. An estimate of groundwater recharge and its relationship to base flow was developed as part of this report (Section 2.9), however, a detailed base flow analysis is recommended to fully evaluate the impact of decreased base flow on stream function and aquatic habitat.

7.11.3 Sanitary Sewer Evaluation

During the field reconnaissance and habitat assessment sewage odors were apparent at locations throughout the watershed. Much of the sanitary sewer system in this area is old and in need of maintenance. It is therefore recommended that an evaluation be performed to identify and propose repairs to leaking manholes and sanitary sewers. At the same time, unauthorized sewer outfalls could be identified and eliminated.

8.0 Funding Alternatives

A final task of the watershed study was to research funding sources to be used to fund the improvement measures recommended in this report. The following paragraphs summarize several federal, state, and local funding alternatives.

8.1 The Watershed Protection and Flood Prevention Act

The Watershed Protection and Flood Prevention Act is a Federal Law (Public Law 83-566) passed by Congress in 1954, in response to the damages sustained to the nation's streams and floodplains from erosion, sedimentation, and flooding. Public Law 83-566, referred to as PL-566, provides a mechanism for local organizations to receive technical and financial assistance from the Department of Agriculture for planning and carrying out watershed projects through cost-sharing. The goal of this program is to integrate conservation efforts by the individual landowner with overall watershed management. The scope of this program is limited to watershed areas of less than 250,000 acres in size. Discussions with personnel at the NRCS have determined that the PL-566 program is applicable to portions of the Naamans Creek and Perkins Run Watersheds.

Typical projects that are eligible for assistance through this program include:

- Projects dealing with preventing damage from erosion, floodwater, and sediment
- Projects that advance the conservation, development, utilization, and disposal of water
- Projects that promote land conservation

These are projects that address water resource problems that transcend the ability of an individual property owner to manage. Organizations eligible for assistance under this program must be legally organized under state law and have the authority to carry out, operate, and maintain the improvements. These projects must be sponsored by groups that collectively or individually have the power of eminent domain and the authority to draw from adequate funding sources to finance their share of the project costs (including all costs of operations and maintenance). Typically, project sponsors are soil and water conservation districts, counties, municipalities, state agencies, or other special purpose districts.

8.2 Flood Mitigation Assistance Program

The Flood Mitigation Assistance Program is a grant program administered by the Federal Emergency Management Agency (FEMA) that obtains project funding as an extension of their flood insurance program. The total grant program for the State of Delaware is limited to $125,000 per year. Funding for small projects is typically $10,000 to $20,000 per project. Typical projects supported by the grant program are those relating to insurable buildings, which include homes, businesses, and commercial structures.

Eligible projects typically involve insurable buildings that are repeatedly flooded or at high risk for flooding, based on flood history. This grant program will usually pay to elevate or relocate the at-risk structure if suitable property is nearby. The program may also include minor localized structural improvement projects such as erosion control and drainage improvements. Funding from this program may be applicable for smaller individual projects as a component to the overall watershed management strategy.

8.3 Suburban Streets Program

As part of a statewide program, each Delaware legislator receives an allowance to spend in his or her district for a roadway or roadway related drainage project identified by the legislator. This money is included in the State's annual budget and is incorporated into the Bond Bill. If accepted, the project is designed and bid by the Delaware Department of Transportation. This is a viable, albeit limited, funding source. Therefore, if implementation of proposed improvements is phased in over several years, funding from this program may provide for construction of smaller individual projects as a component of the overall watershed improvement plan.

8.4 Stormwater Utilities

Pursuant to Title 7, Chapter 40 of Delaware Code, Erosion and Sedimentation and Stormwater Management, conservation districts, counties, and municipalities have the authority to adopt a fee system to help implement a management program. In lieu of a fee system, conservation districts, counties, and municipalities have the authority to establish a stormwater utility. The utility may be developed for designated watersheds and may fund long-range watershed master planning, watershed retrofitting, and facility maintenance. Financial responsibility to the program must be reasonable and equitable, so that each contributor of runoff within a watershed (including State agencies) pays in accordance with the quantity and quality of runoff that is discharged to the designated watershed.

Furthermore, as established in the Delaware Sediment and Stormwater Regulations Section 7, the following are components required of a local utility ordinance to implement a stormwater utility:

- Financing of the utility with a user charge system. The use of county and municipal taxpayer rolls and accounting systems are allowed for the assessment and collection of fees.
- Clearly defined utility purpose, including programs to be funded by the utility. These include the preparation of long-range watershed master plans, annual inspections of private and public stormwater management facilities, implementing regular maintenance, reviewing stormwater management plans and inspecting sediment controls, and retrofitting designated watersheds to reduce existing flooding problems or to improve water quality.

- Designated utility boundaries, identified by the local governing body, creation of a management entity, method for determining utility charges, procedures for investment and reinvestment of collected funds, and an appeals or petition process.

Additional information is provided in Title 7, Chapter 40 of Delaware Code, Erosion and Sedimentation and Stormwater Management and the Delaware Sediment and Stormwater Regulations Section 7.

8.5 Army Corps of Engineers' Challenge 21 Program

At present, Congress is debating the final form of Challenge 21, a new initiative for stream habitat restoration. It is unlikely that this program will be available to fund proposed improvements in the Naamans Creek and Perkins Run Watersheds for some time.

8.6 Army Corps of Engineers' Continuing Authorities Program

The Continuing Authority Program establishes a process by which the Corps of Engineers can respond to a variety of water resource problems without the need to obtain specific congressional approval for each project. Under the Continuing Authorities Program, the Corps of Engineers is authorized to construct small projects within specific Federal funding limits, as part of a cost-sharing approach. The Federal cost limit for projects potentially applicable to the Naamans Creek and Perkins Run Watersheds may be as much as $5 million. There are four types of projects pertaining to the Naamans Creek and Perkins Run Watersheds covered by this program. They are:

8.6.1 Small Flood Control Projects (Section 205, Flood Control Act of 1948, as Amended)

Small flood control projects may be constructed, if advisable, as determined by the Chief of Engineers. The project must be a complete solution to the flood problem involved, and not require subsequent improvements to ensure effective results.

8.6.2 Emergency Streambank and Shoreline Protection Projects (Section 14, Flood Control Act of 1946, as Amended)

The Corps of Engineers may spend up to $500,000 in one locality in any fiscal year for the construction, repair, restoration, and modification of emergency streambank and shoreline protection works. These projects may be designed to prevent damage to highways, bridge approaches, and public works, as well as churches, hospitals, schools, and other non-profit services endangered by streambank or shoreline erosion.

8.6.3 Project Modifications for the Improvement of the Environment (Section 1135(B), Water Resources Development Act of 1986, as Amended)

The Corps of Engineers is authorized to investigate, study, modify, and construct projects for the restoration of fish and wildlife habitats where degradation is attributable to existing Federal water resource projects previously constructed by the Corps of Engineers. Both aquatic and terrestrial habitats can be improved.

8.6.4 Aquatic Habitat Restoration (Section 206 of the Water Resources Development Act of 1996)

The Corps of Engineers is authorized to investigate, study, modify, and construct projects for the restoration of aquatic habitats. Degradation does not need to be attributable to a previous Federal water resource project. Terrestrial habitats are not covered.

Projects eligible for assistance must meet the following criteria:

- The project must be complete within itself and not commit the Corps of Engineers to further construction. The project must solve a specific problem and not require a subsequent project to complete the solution.
- The project must be economically justified. The benefits from the project must exceed the cost of the project, including project operation and maintenance costs.
- The project must be environmentally acceptable.
- The project sponsor must be willing to assist with the project.

There is some flexibility to the types of projects that can be funded by each form of assistance. Typically, the cost sharing ranges from 65% to 75%.

8.7 Section 319 - Water Quality Environmental Protection Agency

There is a limited amount of funding provided by the U.S. Environmental Protection Agency (USEPA) for small projects focused on bioengineering or habitat enhancement projects. These projects usually are demonstration projects.

9.0 Summary and Recommended Implementation Plan

9.1 Summary

This report documents the activities and recommendations of the flood abatement study performed for the Naamans Creek and Perkins Run Watersheds. The flood-related problems identified in this study are typical of older (greater than 30 years), highly developed, mostly residential areas with largely uncontrolled surface water runoff. These problems include primarily flooding of properties and roadways, erosion and degradation of streambanks and channels, and degradation of water quality. As development increased, impervious surfaces (roads, parking lots, roofs, etc.) replaced land which was previously pervious. In addition, modifications were made to the stream corridor such as channelization and filling of natural floodplains. The ultimate result of the activities was the creation of an unstable stream system. As indicated in this report, this instability is evident not only in the physical changes to the stream corridor but also in the biological community of the stream corridor.

The site-specific and watershed-wide measures presented in this report were developed to address the immediate (site-specific) issues and problems in the watershed and also to develop long-term improvement guidelines that seek to improve conditions in the Naamans Creek and Perkins Run Watersheds, now and into the future.

9.2 Recommended Implementation Plan

This report is a tool for the NCFAC and other subsequent committees and planning efforts to use in implementing measures to improve the flooding and water quality conditions in the Naamans Creek and Perkins Run Watersheds. A summary of all the site-specific recommended improvements, their relative rankings and estimated probable costs is presented in Table 9.1. It is recommended that these projects be considered on the basis of the ranking set forth in this table and the availability of funds.

In addition, a list of recommended watershed-wide improvements is presented in Table 9.2. Implementation of these improvements will require the cooperation of federal, state and local government agencies.

Table 9.1: Recommended Improvement Sites

Site ID	Location	Ranking	Estimated Cost
(A1) 103	2401 Brae Road	✓✓✓	$7,500
(A2) 109	1804 Walnut Street	✓✓✓	$7,300
(A3) 305	1500 Upsan Downs Lane	✓✓✓	$6,900
(A4) 314	1907 Millers Road	✓✓✓	$12,000
(A5) 321	2401 Foulk Road and Valley Road	✓✓✓	$41,100
(B1) 304	Garrett Road		
	Floodproofing	✓✓✓	$10,000
	Streambank Stabilization	✓✓	$576,600
(B2) 308	2300, 2302 & 2304 Inwood Road, Lancashire	✓✓✓	$12,000
(B3) 319	2204 Valley Avenue	✓✓✓	$10,000
(C1) 108	4, 6 & 8 Broadbent Road	✓✓	$28,000
(C2) 310	911 Darley Road	✓✓	$95,000
(C4) 312	50 Chestnut Street/ Ardentown	✓✓	$550,000
(C5) 318	2221 Patwynn Road	✓✓	$53,000
(C6) 401	2607 Pennington Drive	✓✓	$33,000
(C7) 403	Sunnyside Tract	✓✓	$70,000
(C8) 404	2003 Marsh Road	✓✓	$17,000
(C9) 408	1997 Kershaw Lane	✓✓	$130,000
(D1) 302	2300 Marsh Road	✓✓✓ ✓✓	$14,000 Option 2 $1,500,000 Option 3
(D2) 701	1920 Zebley Road	✓✓✓	$26,000
(D3) 709	Log Run & Inwood Road	✓✓ ✓✓	$14,000 Option 1 $25,000 Option 3
(E1) 317	Foulk & Naamans Road, Genuardi's Shopping Center and Chin Wu Property		
	Alternative 1	✓	$2,800,000
	Alternative 2	✓✓	$330,000
(E2) 322	Harvey Mill Park	✓✓	$500,000
(E3) 801	Naamans Road and Smith Lane	✓✓✓	$275,000
(E4) 803	Naamans Road & Mousely Place	✓✓✓	$300,000
(E5) 805	Birch Knoll Road & Pine Cliff Drive	✓✓	$50,000
(E6) 806	Naamans & Carpenter Road	✓✓	$110,000
(F1) 902	Bechtel Park	✓✓	$530,000
(F2, C3) 904	Radnor Green	✓✓	$63,000
(F3) 905	Behind Montessori School	✓✓	$1,400,000
(F4) 906/601	Windybush	✓✓	$570,000
(F5) 907	Sherwood Forest	✓✓	$650,000

Table 9.1: Recommended Improvement Sites

Site ID	Location	Ranking	Estimated Cost
(A1) 103	2401 Brae Road	✔✔✔	$7,500
(A2) 109	1804 Walnut Street	✔✔✔	$7,300
(A3) 305	1500 Upsan Downs Lane	✔✔✔	$6,900
(A4) 314	1907 Millers Road	✔✔✔	$12,000
(A5) 321	2401 Foulk Road and Valley Road	✔✔✔	$41,100
(B1) 304	Garrett Road		
	Floodproofing	✔✔✔	$10,000
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(B2) 308	2300, 2302 & 2304 Inwood Road, Lancashire	✔✔✔	$12,000
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(E1) 317	Foulk & Naamans Road, Genuardi's Shopping Center and Chin Wu Property		
	Alternative 1	✔	$2,800,000
	Alternative 2	✔✔	$330,000
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(E3) 801	Naamans Road and Smith Lane	✔✔✔	$275,000
(E4) 803	Naamans Road & Mousely Place	✔✔✔	$300,000
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(F1) 902	Bechtel Park	✔✔	$530,000
(F2, C3) 904	Radnor Green	✔✔	$63,000
(F3) 905	Behind Montessori School	✔✔	$1,400,000
(F4) 906/601	Windybush	✔✔	$570,000
(F5) 907	Sherwood Forest	✔✔	$650,000

Table 9.2: Recommended Watershed-Wide Improvements

- Stormwater Management Regulatory Recommendations
  - Minimize Stormwater Runoff
  - Maintain Groundwater Recharge Rates
  - General Stormwater Management
    - Attenuate at Source
    - Achieve Quality Improvement During Conveyance
  - Stormwater Management Controls
    - Size for Stormwater Quality
    - Size for Recharge Volume
    - Size for Stream Channel Protection Volume
    - Size for Flood Protection Volume
- Watershed Coordinator
- Water Resources Management Plan
- Riparian Buffer Enhancement
- Floodplain Management
- Critical Planting Areas and Wetland Creation
- Public Awareness/Education

10.0 Limitations

This report is intended solely for the purpose stated within the report. Results of the analysis described herein or conclusions drawn in the report may not be useful in other situations and should not be used indiscriminately. Further, the evaluations contained in this report were based upon the information readily available to the project team at the time of the report as documented in the References. Finally, the methods and techniques employed herein were based on the state of the practice at the time of the report and our opinions are expressed to a reasonable degree of engineering certainty. No warranty, expressed or implied, is made.