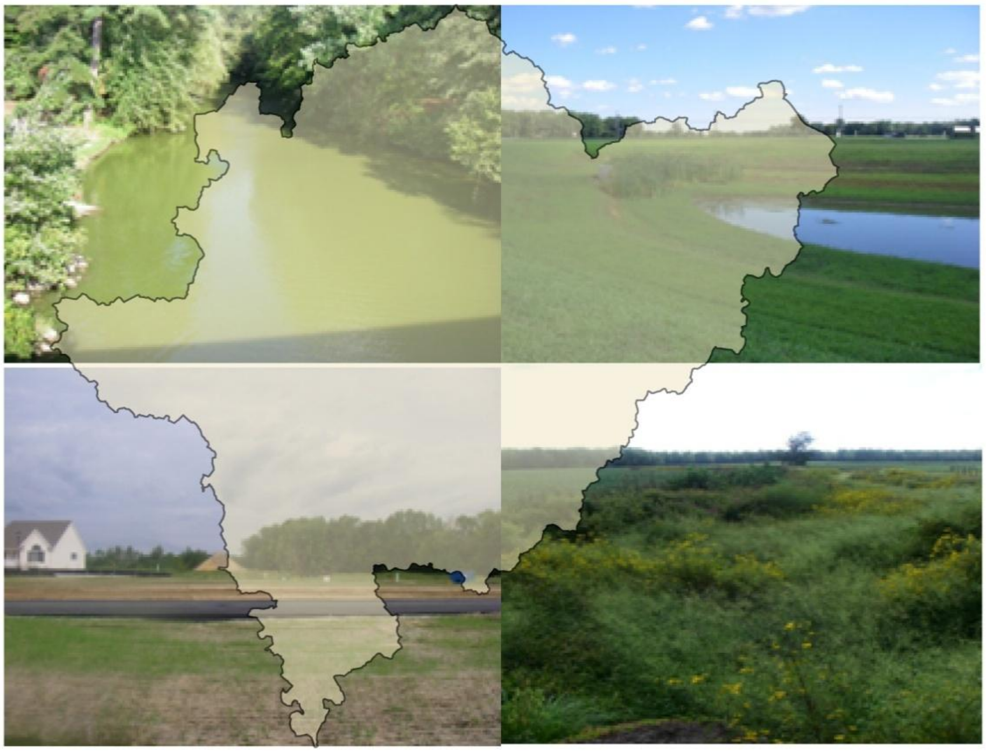
MURDERKILL WATERSHED MANAGEMENT PLAN



The Delaware Department of
Natural Resources and
Environmental Control

July 2014

URS Corporation
12420 Milestone Center Drive, Suite 150
Germantown, Maryland 20876

MURDERKILL WATERSHED MANAGEMENT PLAN

Prepared for

Delaware Department of Natural Resources and Environmental Control
Sediment and Stormwater Program
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Dover, DE 19901

July 2014

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AFO	Animal Feeding Operations
ARS	Agricultural Research Service
BEHI	Bank Erodibility Hazard Index
BMP	Best Management Practice
CAFO	Concentrated Animal Feeding Operations
$CBOD_5$	Oxygen-consuming compounds
CN	Curve Number
CRWR	Center for Research in Water Resources
CWP	Center for Watershed Protection
DelDOT	Delaware Department of Transportation
DEM	Digital Elevation Model
DGS	Delaware Geological Survey
DNREC	Delaware Department of Natural Resources and Environmental Control
EPA	Environmental Protection Agency
ESD	Environmental Site Design
ESRI	Economic and Social Research Institute
FEMA	Federal Emergency Management Agency
FIS	Flood Insurance Study
GIS	Geographic Information System
HEC	Hydrologic Engineering Center
HSG	Hydrologic Soil Group
LID	Low Impact Development
LiDAR	Light Detection and Ranging
LULC	Land Use/Land Code
NHD	National Hydrography Dataset
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
OWTDS	On-site wastewater treatment and disposal system
RAC	Regulatory Advisory Committee
SSURGO	Soil Survey Geographic database
SVAP	Stream Visual Assessment Protocol
SWAPP	Source Water Assessment and Protection Program
TMDL	Total Maximum Daily Load
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
URS	URS Corporation
WIP	Watershed Implementation Plan

The Murderkill Watershed Management Plan focuses on assessing the stormwater quality and quantity problems and provides recommendations for improving conditions in the watershed. This report builds on efforts identified in the technical memorandum "Prioritization of Murderkill Subwatersheds" developed by the Center for Watershed Protection (CWP). Watershed conditions were evaluated using existing and future land use, soils and geology, hydrology, source water protection program information, existing stormwater management facilities, and drainage complaints. The following analyses were performed:

- Hydrologic analysis was conducted to understand the hydrologic characteristics of the watershed and to provide basis for the development of what-if scenario models. Further, the flows from the hydrology model were used to evaluate the conveyance capacity of road crossings and to support the development of updated Flood Insurance Rate Map information (performed under separate contract).
- Hydraulic computations were conducted for 82 culverts to determine their conveyance capacity for design storm for existing and future conditions. The evaluated culverts were categorized as green (passes the design storm with one foot of freeboard), yellow (passes the design storm with less than one foot of freeboard), and red (does not pass the design storm). Improvement measures were proposed for undersized crossings.
- Six segments of streams were selected in the watershed to conduct a detailed stream assessment. The streams assessed were Double Run, Hudson Branch, Pratt Branch, Upper Murderkill River, Middle Murderkill River and Tributary to McCauley Pond.

Based on the above analyses, an assessment was performed to qualitatively rank the subwatersheds. Subwatersheds ranked as good (Lower Murderkill, Spring Creek, McCauley Pond, Middle Murderkill) were generally located in the southern and downstream reaches of the Murderkill Watershed. Swamp Creek and Beaverdam Branch subwatersheds, located in the upstream end of the watershed, received a fair ranking. Browns Branch and Pratt Branch each received poor ratings, and Hudson Branch and Double Run received very poor ratings. These four subwatersheds are generally located in the developed portions of the corridor of the Murderkill Watershed. Section 7 summarizes the conditions of each subwatershed and Section 9 and 11 identify appropriate restoration strategies.

The watersheds that were ranked Poor or Very Poor were selected to develop what-if scenario models to assist Deleware Department of Natural Resources and Environmental Control (DNREC) in development of appropriate stormwater management regulations/strategies. The most appropriate strategy appears to be considering an effective imperviousness of zero percent.

This Watershed Management Plan recommends improvement measures including structural projects (e.g., riparian buffer improvements, stream restoration, BMP/LID projects, new stormwater ponds/wetlands, stormwater pond retrofits, and road crossing improvements) as well as management strategies and action items. The recommended projects were prioritized based on their potential for improving the watershed. Implementation of these recommendations will help DNREC meet their goals of reducing flooding and improving the water quality conditions in the Murderkill Watershed.

Section 1 Introduction

1.1 PROJECT PURPOSE

The Murderkill Watershed Management Plan was developed as a part of the professional engineering and environmental services provided by URS Corporation (URS) to the Delaware Department of Natural Resources and Environmental Control (DNREC) for the Murderkill Watershed. The services provided for the Murderkill Watershed, which are being conducted under separate contracts, include: (1) A floodplain study to support the DNREC's involvement in the National Flood Insurance Program, and (2) This watershed management plan.

The Department of Natural Resources and Environmental Conservation (DNREC) is faced with the challenge of urbanization in many parts of the state. In order to minimize the water quantity and quality problems in these developing areas, DNREC is in the process of changing their Sediment and Stormwater Regulations. Murderkill Watershed is identified to be one of the primary target areas for development and hence as a part of its effort to restore the natural conditions in the watershed, DNREC has undertaken this watershed study. The primary goal of this study is to provide flood control/protective measures throughout the watershed along with providing water quality improvement recommendations wherever feasible.

The Murderkill Watershed Management Plan characterizes the watershed through a review of existing data, field reconnaissance, and hydrologic modeling to address flooding and water quality concerns in the watershed. A subwatershed assessment, detailed stream assessment, and development of a "what-if" scenario model were used to develop watershed recommendations to restore and maintain watershed quality. The plan identifies and evaluates potential opportunities for flood protection measures, culvert improvement projects, new or retrofit stormwater management facilities, Best Management Practices (BMPs), Low Impact Development (LID) techniques, habitat improvements, stream restoration, and non-structural management strategies.

1.2 AREA OF STUDY

The Murderkill Watershed is located in southeastern Kent County, Delaware. A vicinity map is provided as **Figure 1.1**. The watershed includes the Murderkill River as the main stem and several significant tributaries, including Spring Creek, Pratt Branch, Hudson Branch, Double Run Branch, and Browns Branch. Significant water bodies include McGinnis Pond, McCauley Pond, Killens Pond, Coursey Pond, and Andrews Lake. The Murderkill Watershed drains 102.6 square miles in an easterly direction and discharges to the Delaware Bay at the Murderkill River's confluence at Bowers Beach. The Murderkill River is tidally influenced from the Delaware Bay to approximately the confluences of Spring Creek and Browns Branch with the Murderkill River.

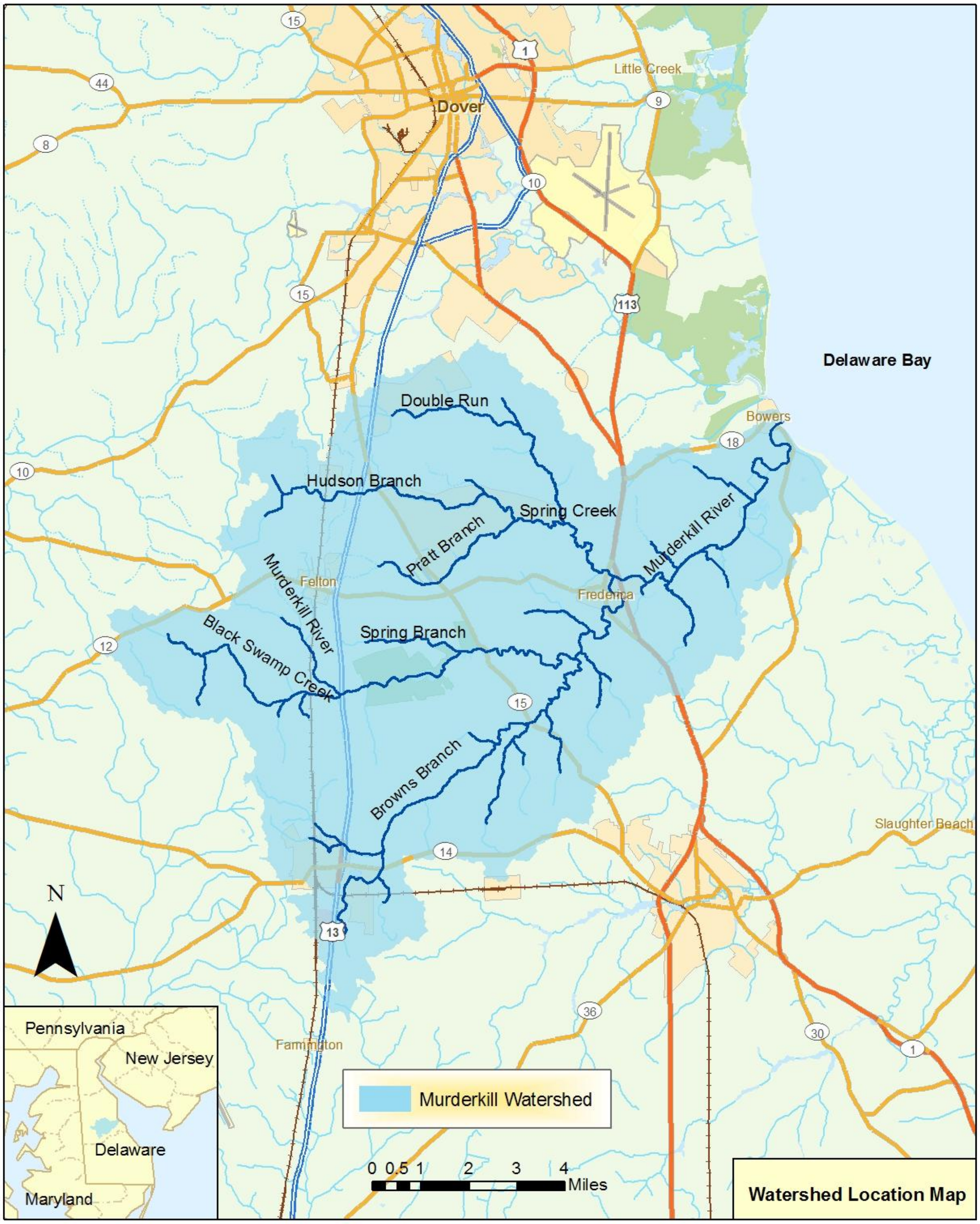


Figure 1.1: Murderkill Watershed Location

Section 2 Data Collection, Review, and Analysis

2.1 PREVIOUS STUDIES

The purpose of this task was to collect and review existing data on the Murderkill Watershed. Extensive water quality data have already been collected and documented in previous studies. To avoid duplicating efforts, URS used the results from previous studies as a basis for the watershed management plan.

URS obtained previous studies, maps, aerial photographs, and geographic information system (GIS) data for the Murderkill Watershed. The sources for the existing studies and data include DNREC, Kent Conservation District, watershed groups, the Environmental Protection Agency (EPA), the Delaware Department of Transportation (DelDOT), and consultants. To understand the baseline conditions of the watershed, URS studied the results of previous watershed assessments (e.g., potential improvement measures, watershed conditions); comprehensive county, local, town, and city plans; and digital data, such as land use, soils cover, BMPs, and drainage boundaries, that were used for the hydrologic modeling effort. A list of documents reviewed is provided in Section 12.

While numerous reports were reviewed and evaluated, data from the report *Prioritization of Murderkill Subwatersheds* has significantly contributed to this study. The most recent assessment of the Murderkill Watershed was conducted by the Center for Watershed Protection (CWP) in August 1, 2005. CWP published a Technical Memorandum entitled *Prioritization of Murderkill Subwatersheds*. This memorandum described the general watershed conditions, presented a review of existing water quality monitoring data and a land cover analysis, and prioritized subwatersheds for future analysis. This memorandum served as a key document for URS' watershed assessment. URS also reviewed the potential restoration measures identified in this memorandum for consistency when recommending the proposed improvement measures for the watershed in this plan. Additionally, for consistency, URS maintained the general subwatershed delineation for the watershed used in the memorandum.

2.2 GIS DATA

The development of the Murderkill Watershed Management Plan relies extensively on available GIS data. As part of this task, URS reviewed existing GIS data from DNREC and Kent County. Data were reviewed to identify existing stormwater management facilities, areas with no stormwater management controls, existing outfalls and drainage areas, and potential restoration project areas. Table 2.1 below lists the data acquired.

Table 2.1: Summary of Acquired GIS Data

GIS Coverage	Source
2-foot contours, 2007	DNREC
Aerial photographs, 2007	U.S. Department of Agriculture Farm Service Agency (USDA-FSA) Aerial Photography Field Office
Annual rainfall data	National Oceanic and Atmospheric Administration (NOAA)
BMPs	DNREC

GIS Coverage	Source
Community boundaries	Kent County
Digital Elevation Model (DEM) (statewide)	Delaware Geological Survey
Development status	Kent County
Existing land use (2008)	Delaware DataMIL
Future land use (zoning based on 2007 Comprehensive Plan)	Kent County
Geology	Delaware Geological Survey
Growth zone based on Kent County Growth Plan	Kent County
Impervious surface	DNREC
Light Detecting and Ranging (LiDAR) data	DNREC
National Hydrography Dataset flow lines	U.S. Geological Survey (USGS)
Parcels	Kent County
Private, municipal, and county stormwater facilities in Kent County	DNREC
Railroads	DelDOT
Recharge potential maps	Kent County
Roads	Economic and Social Research Institute (ESRI)
Sewer, water, and storm drain data layers	Kent County or DNREC
Soils	Natural Resources Conservation Service
Wetlands	Kent County

2.3 FIELD RECONNAISSANCE

Field reconnaissance was conducted by URS engineers to obtain general information on the watershed and road crossing information, and to supplement and update the existing GIS data. The field reconnaissance consisted of two parts: (1) Watershed overview and (2) Evaluation of road crossings and obstructions.

(1) **Watershed overview:** The watershed reconnaissance was conducted with an emphasis on identifying sources of pollution, observing general conditions, and identifying potential restoration opportunities in the watershed. Prior to the field visit, URS identified target areas for field assessment based on a desktop review of GIS data, which included aerial imagery, BMP databases, storm drain systems, transportation layers, and contours. To obtain data on watershed conditions, URS conducted 5 days of watershed reconnaissance. Since the field reconnaissance was limited to 5 days by the scope/services for this project, the entire 102.6 square mile watershed could not be assessed in detail; therefore the field reconnaissance targeted 17 specific areas in the watershed that included developed areas, undeveloped areas, and known problem areas. Criteria used for selecting the target areas included:

- Land use (e.g., open space)
- Property ownership (e.g., public/private)
- Stream buffers
- Areas of uncontrolled/controlled stormwater runoff

Photographs and notes were taken at each target site, and sample field assessment forms are included in Appendix A. Potential restoration sites identified in the field reconnaissance are described in Section 9 of this report.

(2) **Field evaluation of road crossings:** Field evaluations of road and rail crossings having an opening of 36 inches or larger were conducted as a part of hydraulic analysis of road crossings/obstructions to determine their capacity for approximate return periods. A total of 82 crossings were evaluated in the field. Detailed information on the procedure adopted for this evaluation is described in Section 5 of this report.

2.4 ESTABLISHMENT OF STUDY SUBWATERSHEDS

URS used the subwatershed boundaries defined by the CWP as the basis for this watershed study. The delineation of the subwatersheds was based on major tributary drainage courses, similar land use, and point of interest. Eleven major subwatersheds were delineated for the Murderkill Watershed. The subwatershed boundaries were redefined more accurately using a higher resolution topographic dataset which was used for the detailed hydrologic analysis of the watershed. The establishment of the subwatersheds also aided in the detailed investigation and characterization of the watershed in order to focus proposed improvement measures and strategies and to determine their cumulative benefits on a subwatershed level. Figure 2.1 displays the 11 major study subwatersheds. An assessment of the study subwatersheds is provided in Section 7 of this report.

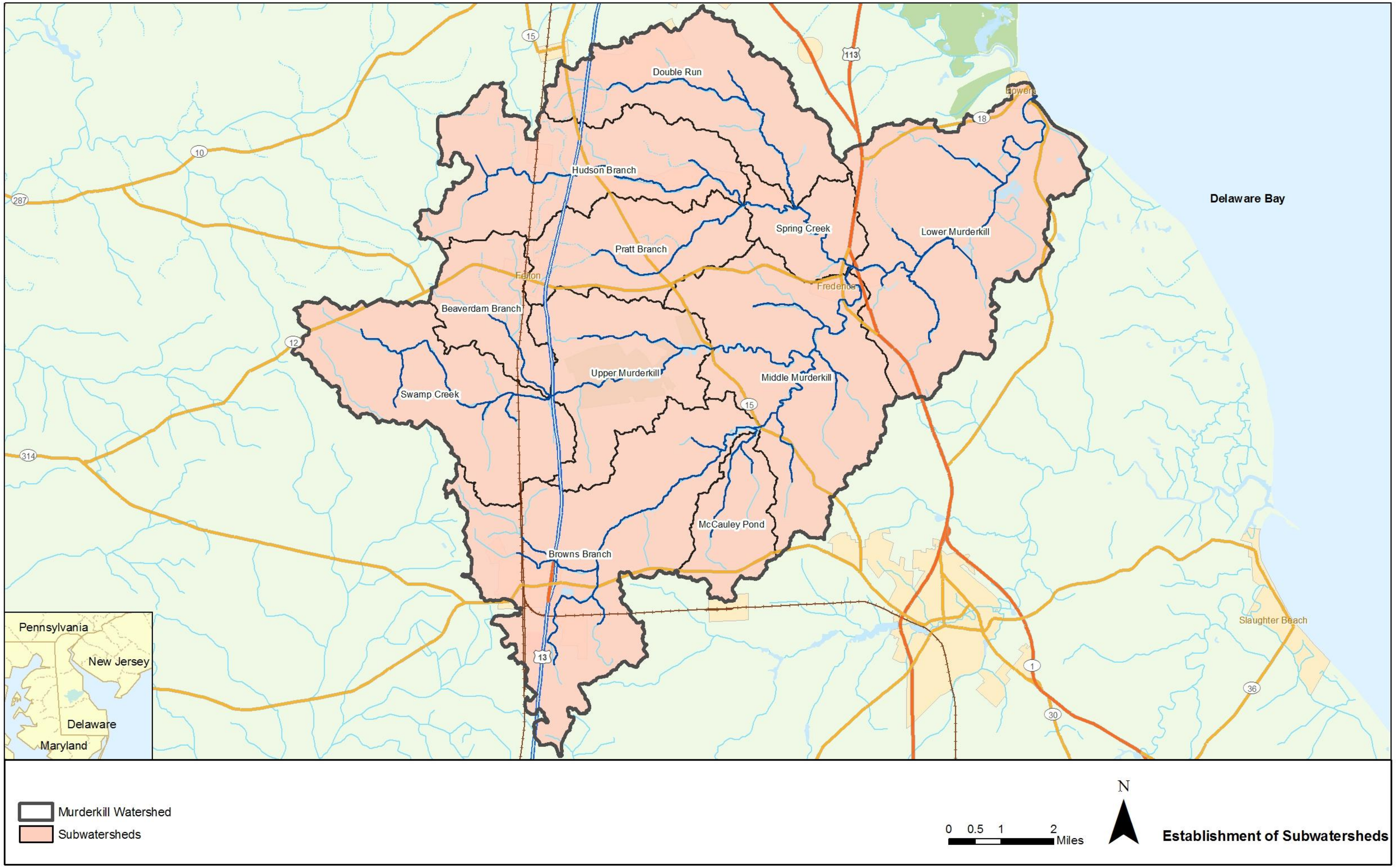


Figure 2.1: Major Subwatersheds in the Murderkill Watershed

Section 3 Watershed Conditions

To better understand the conditions of the watershed, a baseline assessment of the watershed was performed. The assessment included analyzing the existing and future land use, natural features and community features. A description of the results of the analysis is described in the sections below.

3.1 LAND USE

Existing conditions land use maps show that the watershed is primarily rural with agricultural land use occupying more than half of the watershed. Wetlands and forested areas occupy 17% of the watershed. The impervious development in the watershed is distributed primarily in the municipalities of Bowers Beach, Felton, Frederica, Harrington, Houston, and Viola, and in the census-designated places of Woodside East and Riverview. The Kent County Comprehensive Plan (2007) indicates that the area between the two major highways (US 113 and US 13) is recognized as a growth zone, and about 69% of the total development in the county has occurred in the growth zone in last 5 years (from 2002-2007). Table 3.1, Figure 3.1, and Figure 3.2 show the distribution of land use in the watershed for existing and future conditions.

Table 3.1: Existing and Future Conditions Land Use Distribution

Land Use	Existing Conditions	Future Conditions
Clear-cut	0.2%	0.2%
Commercial	0.5%	0.7%
Confined Feeding Operations/Feedlots/Holding	0.3%	0.2%
Deciduous Forest	1.8%	0.7%
Emergent Wetland - Tidal and Non-tidal	4.7%	4.4%
Evergreen Forest	0.7%	0.4%
Extraction and Transitional	1.5%	0.6%
Farms, Pasture and Cropland	50.5%	26.5%
Farmsteads	1.0%	0.6%
Forested Wetland - Tidal and Non-tidal	10.0%	5.4%
High Density	0.0%	0.1%
Impervious	4.8%	4.8%
Industrial	0.1%	0.5%
Institutional/Governmental	0.2%	0.2%
Low Density	0.0%	40.0%
Man-made Reservoirs and Impoundments	0.7%	0.3%
Medium Density	0.0%	1.1%
Mixed Forest	8.4%	4.4%
Mixed Urban or Built-up Land	0.2%	0.1%
Mobile Home Parks/Courts	0.3%	0.1%
Multi Family Dwellings	0.0%	0.0%

Land Use	Existing Conditions	Future Conditions
Open Water	1.0%	0.6%
Orchards/Nurseries/Horticulture	0.2%	0.0%
Rangeland	0.1%	3.2%
Recreational	0.5%	0.1%
Sandy Areas and Shoreline	0.0%	0.0%
Scrub/Shrub Wetland - Tidal and Non-tidal	0.7%	0.4%
Shrub/Brush Rangeland	0.5%	0.3%
Single Family Dwellings	10.9%	3.8%
Transportation/Communication/Utilities	0.3%	0.2%

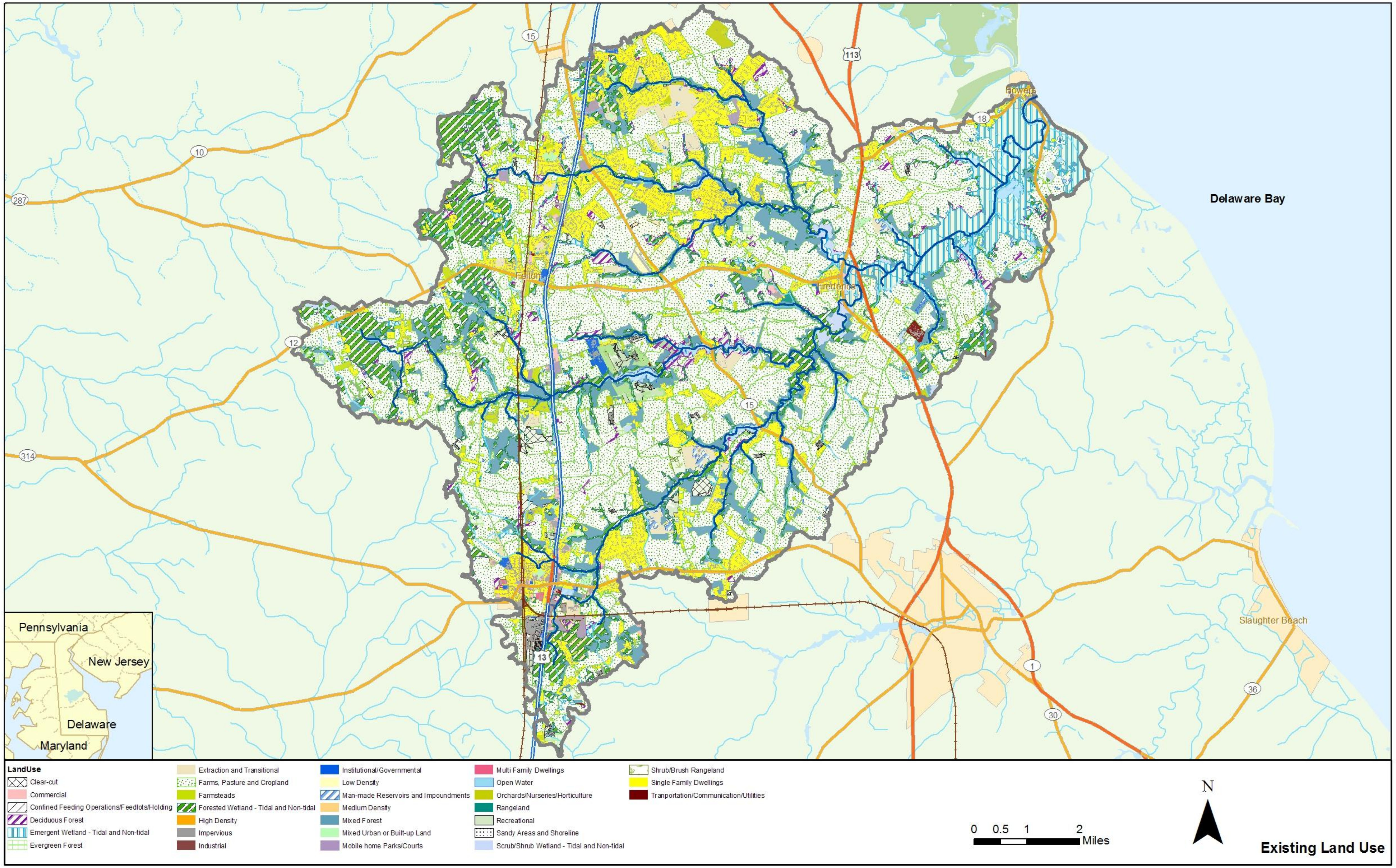


Figure 3.1: Murderkill Watershed Existing Conditions Land Use Map

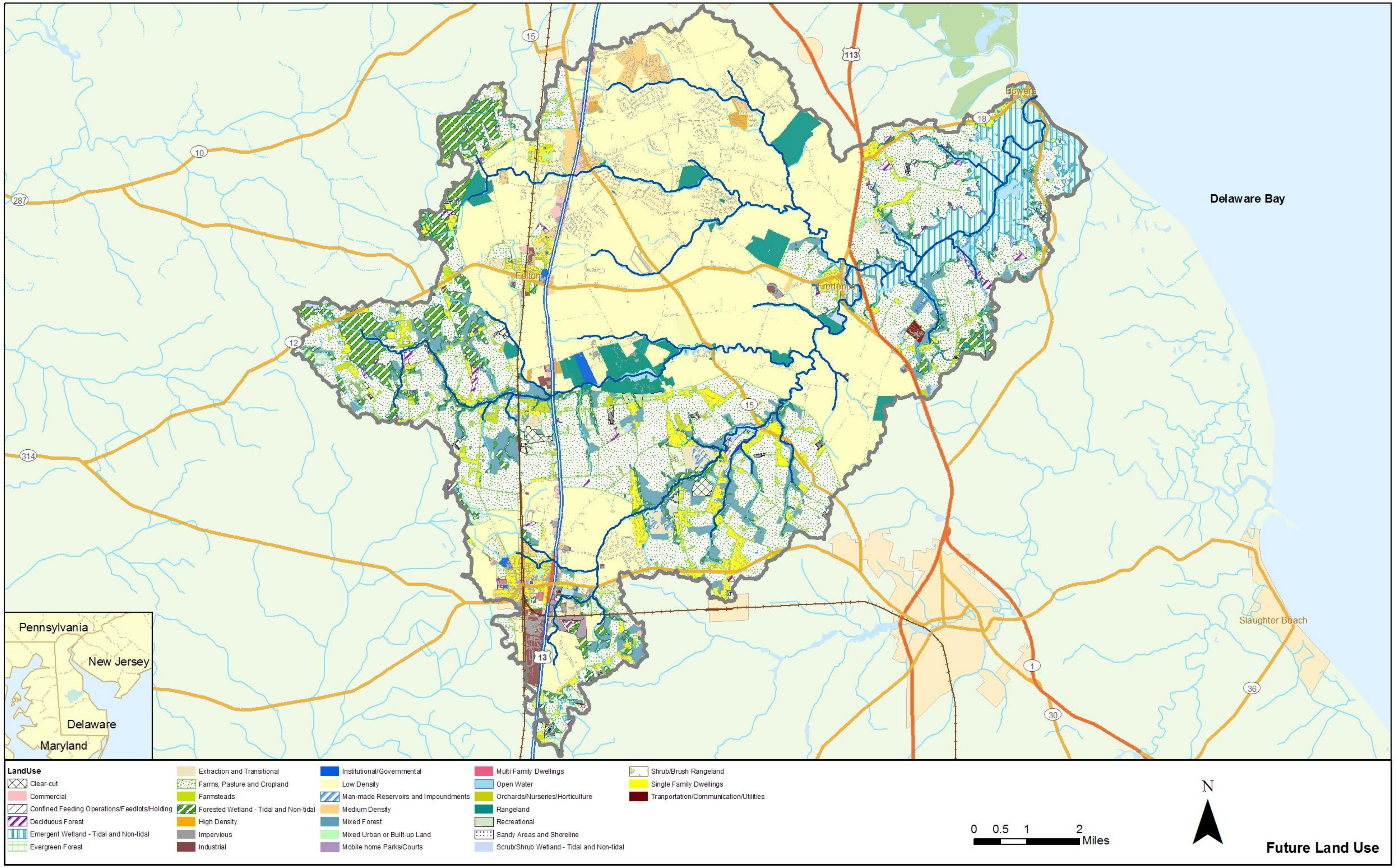


Figure 3.2: Murderkill Watershed Future Conditions Land Use Map (Developed from Future Zoning in 2007 Kent County Comprehensive Plan)

3.2 SOILS AND GEOLOGY

Hydrologic soil group type B (silt loam or loam) with moderate infiltration rates occupies approximately 49% of the watershed. Hydrologic soil group type D (silty clay loam, sandy clay, clay) with high runoff coefficients covers 28% of the watershed. Hydrologic soil group type A (sand, loamy sand) with highest infiltration rate and group C (sandy clay loam) with low infiltration rates occupy 14% and 6% of the watershed, respectively. The distribution of the hydrologic soil group was used in the development of the hydrologic model for the watershed.

The watershed lies entirely on the Atlantic coastal plain, which is primarily made up of sediments, silt, sand, and gravel that have eroded off the Piedmont and adjacent Appalachian Mountains. Geologically, the watershed can be divided into 8 distinct areas classified as:

- Beaverdam Foundation
- Carolina Bay Deposits
- Columbia Formation
- Lynch Heights
- Scotts Corners Formation
- Marsh Deposits
- Shoreline Deposits
- Swamp Deposits

Distribution of hydrologic soil groups and geological units in the Murderkill Watershed is shown in Figure 3.3.

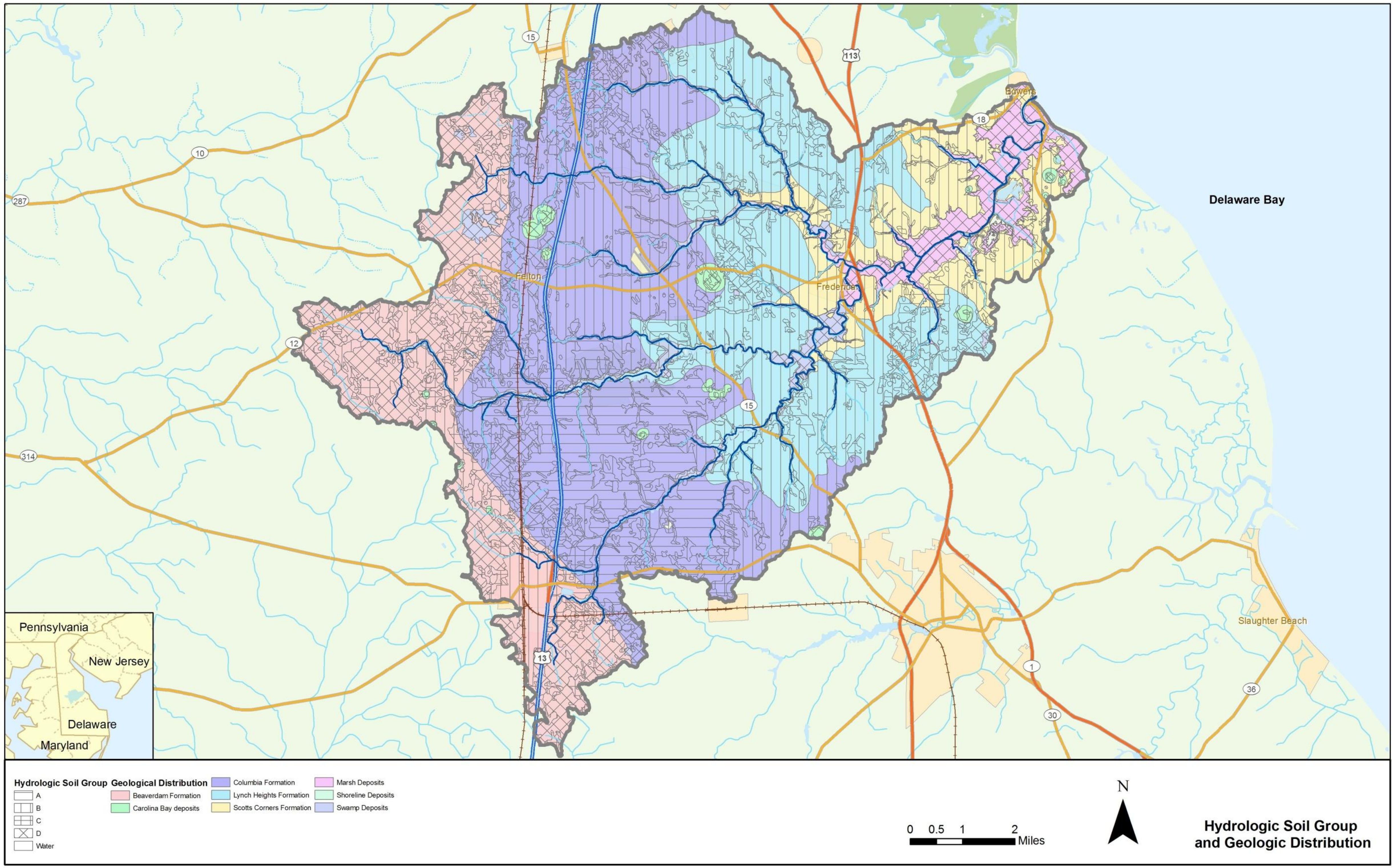


Figure 3.3: Hydrologic Soil Group and Geologic Distribution

3.3 HYDROLOGY

The watershed contains approximately 231 miles of stream network, with Murderkill River as the mainstem, and Spring Creek, Pratt Branch, Hudson Branch, Double Run Branch, and Browns Branch as the major tributaries. Approximately 0.78 square mile of the watershed is occupied by lakes and ponds. Significant lakes in the watershed include McGinnis Pond, McCauley Pond, Killens Pond, Coursey Pond, and Andrews Lake. These facilities are state-owned, and the dam embankments and hazard classification for these facilities have recently been evaluated by DNREC. Information on location of the dams and their hazard classification is listed in Table 3.2. This information aided in the development of the hydrologic model which is described in Section 4.

Figure 3.4 shows the stream network and location of lakes and ponds with the dams in the watershed.

Table 3.2: Dams in Murderkill Watershed

Pond/Lake	Owner	Dam Class	Location	Hazard Classification
McGinnis Pond	DNREC Division of Fish and Wildlife	B	McGinnis Pond Road	High
Andrews Lake	DelDOT	A	Andrews Lake Road	Significant
Coursey Pond	DelDOT	B	Canterbury Road	High
Killens Pond	DNREC Division of Parks and Recreation	B	Killens Pond Road	Low
McCauley Pond	DNREC Division of Fish and Wildlife	B	Canterbury Road	High

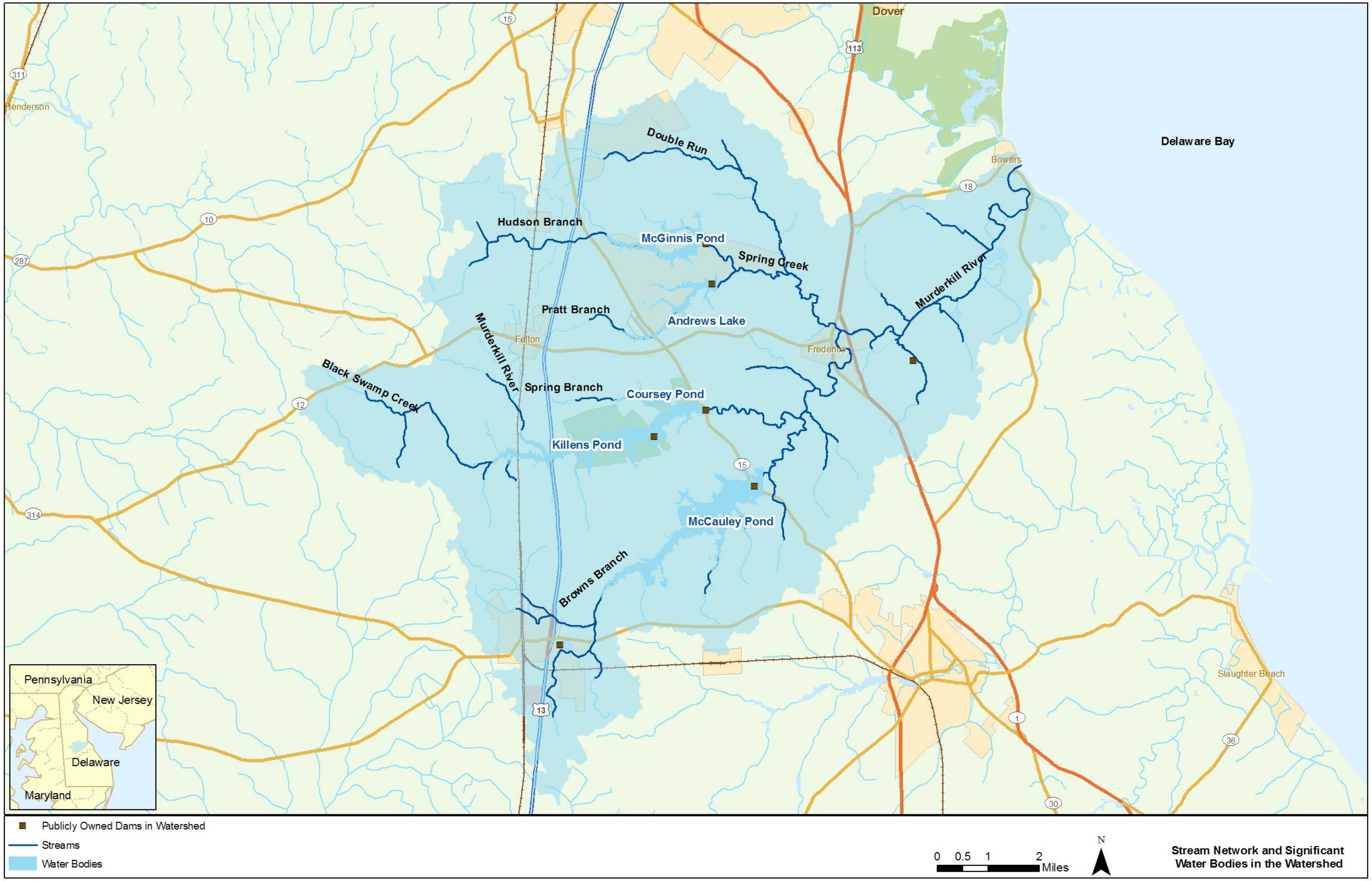


Figure 3.4: Stream Network and Location of Significant Water Bodies

3.4 SOURCE WATER PROTECTION PROGRAM

The Delaware Water Resources Agency along with the Delaware Division of Public Health promotes the protection of waters in streams and aquifers in the state of Delaware through their "Source Water Assessment and Protection Program (SWAPP)." In their April 2007 publication, "Protecting the Sources of Your Drinking Water," DNREC stated that all of Kent County relies solely on ground water for drinking water supplies and that it is important to protect these areas from ground water contamination. According to SWAPP, the source water protection areas are classified as follows:

- Well head areas
- Excellent ground water recharge potential areas
- Surface water supply areas

Kent County has the highest percent of "Excellent Ground Water Recharge Potential Areas" in the state of Delaware. Ground water is recharged by infiltration of rainfall through land surface; therefore, changes in land use distribution would affect the quality of runoff infiltrating, which in turn affects the ground water quality. Hence, it is critical to protect these ground water recharge areas from development/activities that cause detrimental effects on the quality of ground water. Recommendations regarding protection of excellent ground water recharge potential areas are presented in Section 11 of this report.

Table 3.3 gives the distribution of the recharge potential areas in Murderkill Watershed, and Figure 3.5 shows the distribution of potential ground water recharge areas.

Table 3.3: Distribution of Recharge Potential Areas in Murderkill Watershed

Recharge Potential	Percent of Watershed
Excellent	26.9%
Fair	26.8%
Good	35.6%
Poor	2.6%

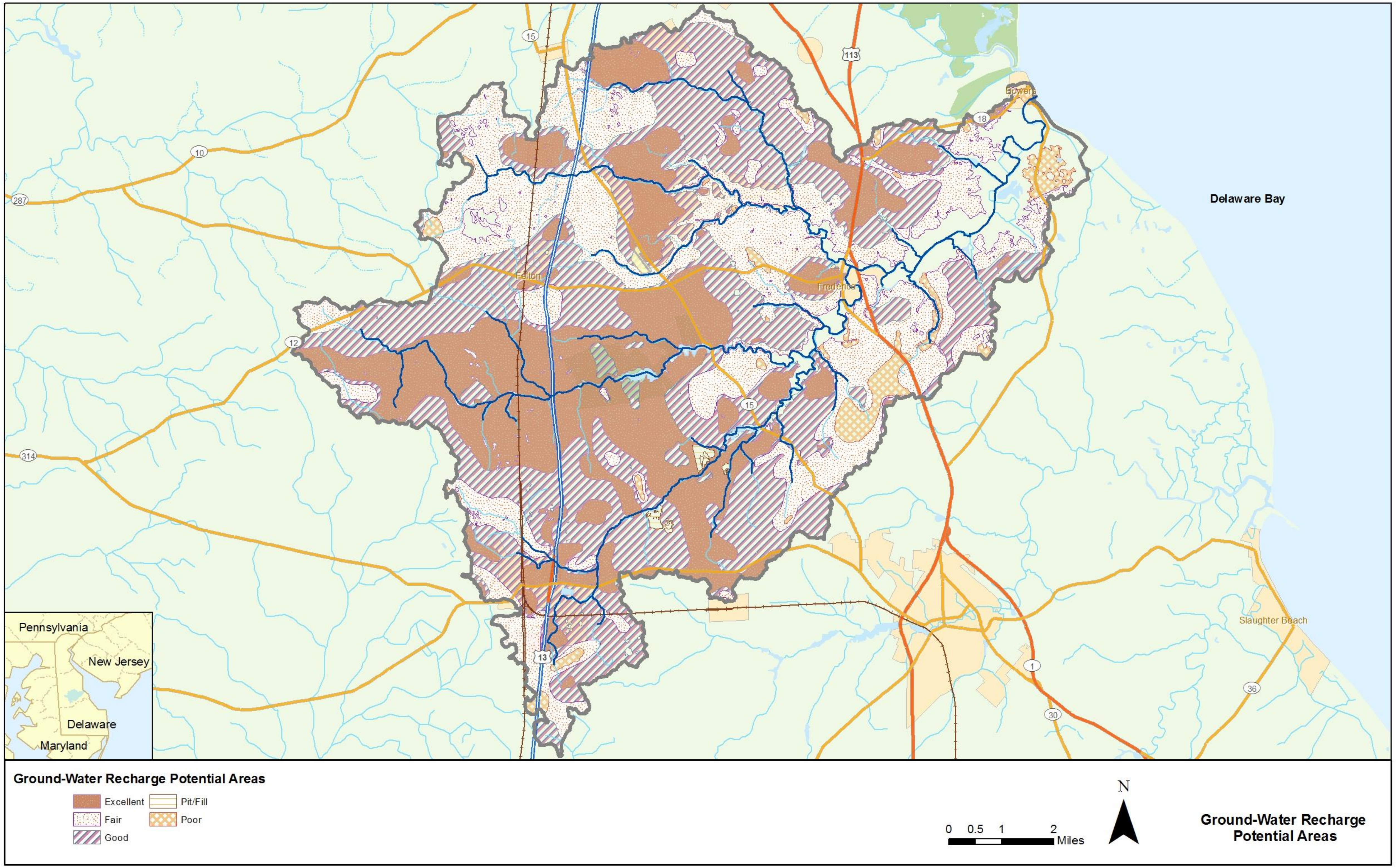


Figure 3.5: Distribution of Ground Water Recharge Potential Areas

3.5 WATER QUALITY

The Murderkill Watershed's most significant environmental concerns are high nutrient loading and low dissolved oxygen. A water quality assessment performed by DNREC determined that, to meet Delaware's Water Quality Standards in the Murderkill River Watershed, "the point and non-point source loads of nutrients (nitrogen and phosphorus) and oxygen-consuming compounds ($CBOD_5$) within the watershed should be reduced" (DNREC, 2005). $CBOD_{5}$ is carbonaceous biochemical oxygen demand. As a result, the Total Maximum Daily Loads (TMDLs) that were published in 2001 were amended in 2005 to include nutrients and $CBOD_5$ within the Murderkill Watershed.

(1) **Point Sources:** The major point sources that contribute to the pollution in the watershed are from wastewater treatment plants. Five wastewater treatment facilities are located in the watershed. Names of the facilities and streams receiving treated wastewaters are listed in Table 3.4.

Table 3.4: Wastewater Treatment Facilities in the Watershed

Facility Name	Receiving Stream
City of Harrington STP	Browns Branch
Kent County Facility	Lower Murderkill
Canterbury Crossing MHP	Double Run
Southwood Acres MHP	Double Run
West Farm, Inc.	Middle Murderkill

STP – Sewage Treatment Plant
MHP – Mobile Home Park

Three point sources are regulated by DNREC through the National Pollutant Discharge Elimination System (NPDES) Permit Program: City of Harrington Sewage Treatment Plant, the Kent County Facility, and the Canterbury Crossing Mobile Home Park. As NPDES permits require discharge monitoring reports, the concentrations of point sources were used by EPA to develop the TMDLs. The Southwood Acres MHP and West Farm Inc. no longer discharge to the Murderkill River and hence are not included in the NPDES permit program.

(2) **Non-point Sources:** Non-point sources of pollution in the watershed include surface runoff from agricultural and other land use activities, septic tanks, and ground water discharges loaded with nutrients, especially nitrogen (EPA, 2005). The major non-point sources of pollutant discharges in the Murderkill River Watershed are surface runoff from agricultural and urban areas and leakage from septic systems.

3.6 STORMWATER MANAGEMENT

In general, development results in an increase in impervious cover and an increase in the peak flow and total volume of runoff. Development also impacts the water quality of the runoff entering the streams, as it contains pollutants such as nutrients, pathogens, and sediments. Stormwater management facilities play an important role in reducing the volume of runoff and amount of pollutants entering the streams. Stormwater management facilities provide water quality treatment, volume reduction, or both, depending on the type of facility.

Based on existing land use conditions, 21.2 square miles in Murderkill Watershed is developed. A review of existing data provided by DNREC indicates that there are 183 stormwater management facilities in the Murderkill Watershed that treat stormwater runoff from approximately 5 square miles of developed area which is only 24% of the developed area of the watershed. Table 3.5 lists the types of stormwater management facilities in the watershed and the total area treated by each type. Figure 3.6 shows the distribution of the facilities in the watershed.

Appendix B lists all the stormwater management facilities located in the watershed.

Table 3.5: Stormwater Management Facilities in the Watershed

Type of Facility	No. of Facilities in Watershed	No. of Acres Treated by the facility (Acres)
Bioretention	1	1.4
Bio-Swale	28	148
Dry Pond	44	446
Infiltration	27	261
Other	3	103
Wet Pond	80	2,201

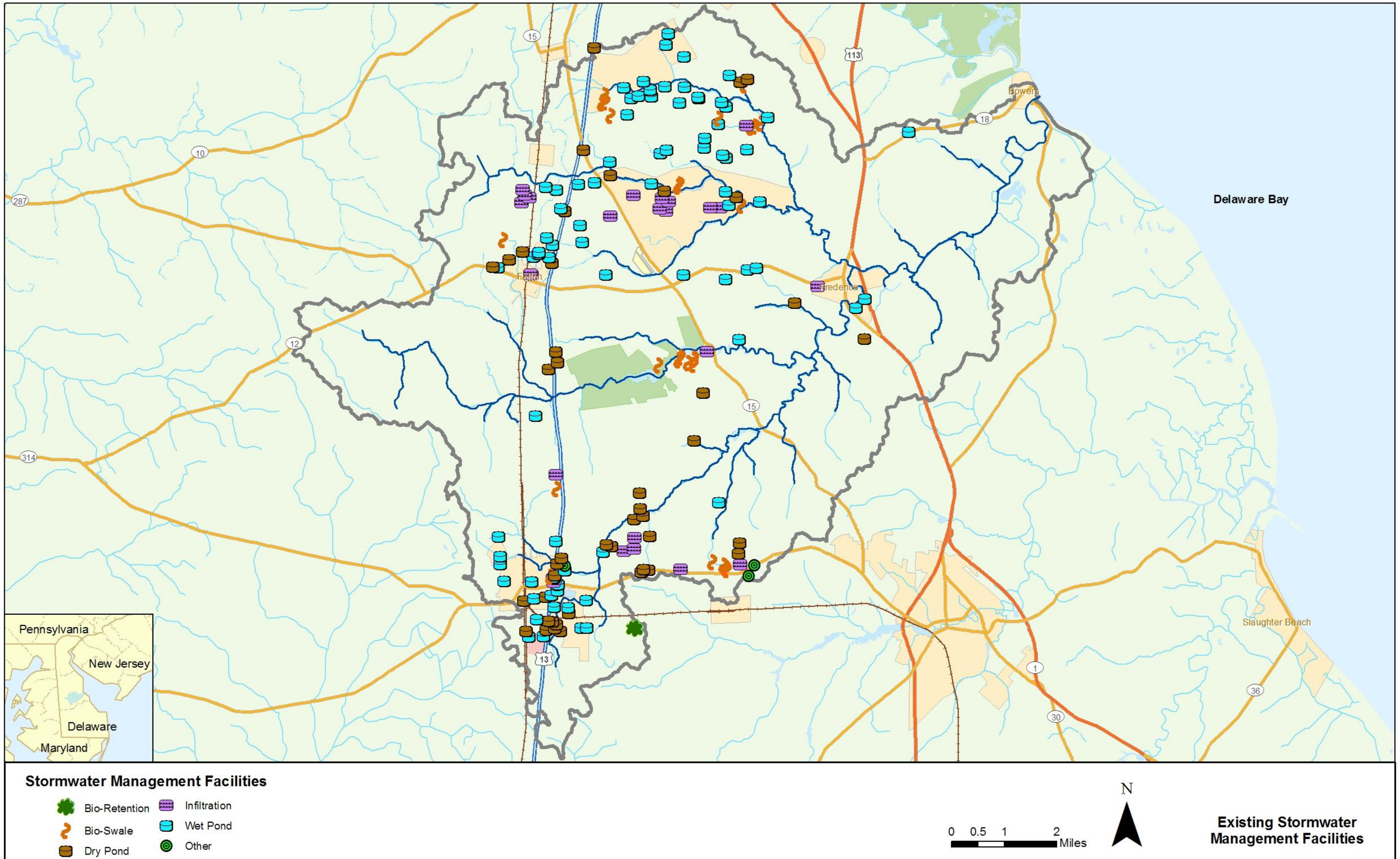


Figure 3.6: Location of Stormwater Management Facilities in Murderkill Watershed

3.7 FEMA FLOOD STUDY

Kent County currently has a published County-wide Digital Flood Insurance Rate Map (DFIRM) that delineates areas subject to flooding. Some of the streams in the County are studied by detailed methodology and the maps depict the 100-year and 500-year flood zones with Base Flood Elevations (BFE) shown for the 100-year event (i.e., Zone AE). However, numerous streams in the watershed were studied by "approximate" methodologies (i.e., Zone A) which are generally less accurate. To support DNREC’s involvement in the National Flood Insurance Program, URS is performing an updated study of 35 miles of streams in the Murderkill watershed to update Zone A areas to Zone AE with Base Flood Elevations.

3.8 DRAINAGE COMPLAINTS DATABASE

Flooding is a major concern in the Murderkill Watershed. Rapid urbanization along with aging stormwater management facilities and undersized culverts have caused an increase of flooding in the Murderkill Watershed. DNREC maintains a Drainage Complaint Database that compiles complaints received regarding drainage issues. These complaints are generally made by residential property owners. A total of 91 drainage complaints were recorded since 2007, of which, 55 were categorized under Private Drainage Concern, 21 under Sediment and Stormwater Concern, and the remaining 15 complaints were miscellaneous relating to other categories. According to the drainage complaints database provided by DNREC, 49 of the 91 complaints appear to be resolved. A table with the list of these complaints is provided in Appendix B of this report.

Figure 3.7 provides the distribution of drainage complaints throughout the watershed.

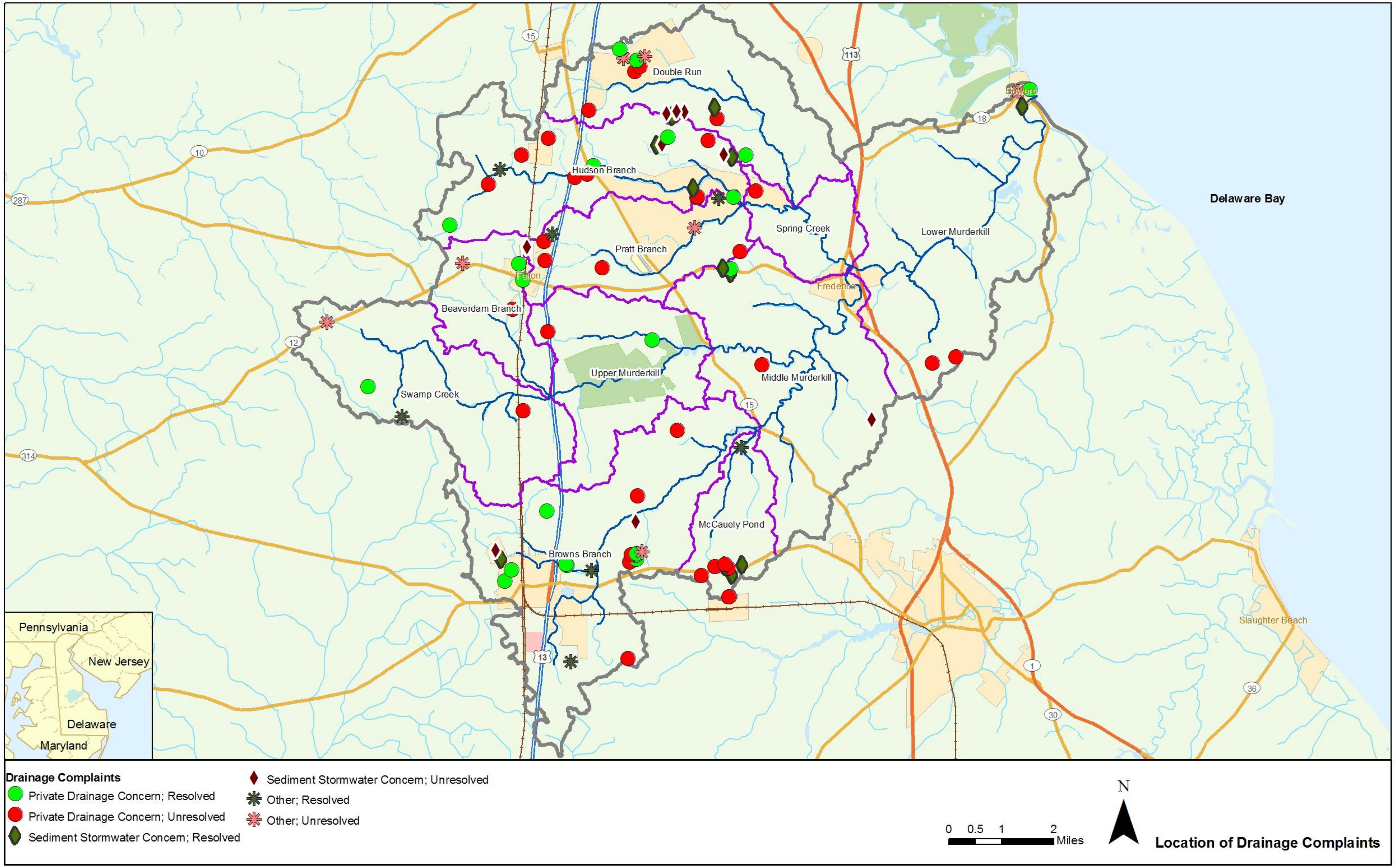


Figure 3.7: Distribution of Drainage Complaints in the Watershed

Section 4 Hydrologic Analysis

A hydrologic analysis of the Murderkill Watershed was performed as a part of the watershed study to better understand the watershed's hydrologic characteristics and aid in the development of a what-if scenario model for providing recommendations for the restoration of the watershed. In addition, the hydrologic analysis supports the Murderkill Flood Study that URS is conducting for DNREC under a separate contract.

The hydrologic model was developed using GIS mapping tools and the U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center's Hydrologic Modeling System: HEC-HMS (Version 3.3), ArcGIS 9.2 based (ESRI, 2006), ArcHydro (CRWR, 2007), and HEC-GeoHMS (USACE, 2003) models. The hydrologic model was developed using data obtained from previous studies as well as data gathered from field reconnaissance of Delaware dams and current GIS datasets, NOAA Atlas 14 precipitation data (NOAA, 2009), and USGS gage stream flow data (USGS, 2009).

The study involved developing the model for two scenarios:

(1) Existing conditions: the existing conditions land use information was obtained from the State of Delaware DataMIL (Delaware, 2008).

(2) Future conditions: the future conditions land use information was developed by merging the existing land use data with the future zoning data provided in the Kent County Comprehensive Plan of 2007.

The Soil Survey Geographic (SSURGO) database available at http://SoilDataMart.nrcs.usda.gov/ was used to obtain the GIS coverage of soils for the watershed. Data for dams at Andrews Lake, Coursey Pond, Killens Pond, McCauley Pond, and McGinnis Pond (surveyed by URS under a separate contract) were included in the model. In addition to the survey data, the dam storage information in the form of bathymetry data was obtained from Hydroqual (Thuman, 2009).

A total of 67 subwatersheds were delineated using 3-meter DEM data. The model was run for the 24-hour, and 1-, 2-, 5-, 10-, 25-, 50-, 100-, and 500-year recurrence interval rainfall events to estimate the flood magnitudes for the respective events. In addition to these, a 2-inch event, which is defined as the "water quality event" by DNREC, was also simulated in the hydrologic model.

Calibration of the model was conducted using the instantaneous discharge data available at three USGS stations: Murderkill River at Felton (USGS Gage 01484000), Pratt Branch (USGS Gage 01484050), and Browns Branch (USGS Gage 01484018), along with precipitation data to model a selected storm event. The results obtained from the hydrologic analysis were compared to the effective discharges in the Federal Emergency Management Agency's (FEMA's) Flood Insurance Study (FIS) for Kent County, Delaware, GISHydro, and also with the discharges obtained from the StreamStats website (USGS, 2009), which uses calculations derived from the most recent regression equations developed by Ries et al. Detailed descriptions of the model development along with the results are included in Appendix C (Hydrologic Analysis) of this report.

The hydrologic analysis was approved by DNREC, and more detail on this analysis is included in Appendix C. This model has also been reviewed and approved by FEMA for use in the

Murderkill Flood Study. The flows from the hydrologic model were used to analyze the conveyance capacity of the road crossings (Section 5),and in the development of “What-if Scenarios” Models (Section 8).

Section 5 Hydraulic Analyses of Road Crossings

Streams that flow under a road or railroad are conveyed by engineered structures such as culverts or bridges. Depending on the road's level of service, such as high-capacity arterial or local residential, the structures are usually designed for storms with recurrence periods of 50, 25, or 10 years plus one foot of freeboard. Table 5.1 summarizes the Delaware classification of roads and the recurrence period storm they should be designed for.

Table 5.1: Classification of Roads and Design Storm Event

Type of Road	Design Recurrence Period Storm Event
Collector	50 -Year
Arterial	50 -Year
Local	25 -Year
Rural Collector	25 -Year

Overtopping, significant damage to roads, and traffic interruption occur during a flood event if there is a deficiency in the conveyance capacity of the structure. Structures with deficient capacities also decrease the stability of the stream channel, thereby causing erosion and sedimentation which affects aquatic life.

URS performed hydraulic analysis of the stream crossings in the watershed to identify their conveyance capacities and deficiencies. Eighty-two structures with an opening larger than 36 inches were analyzed. Procedures adopted in performing the analysis are described in the following sections.

5.1 FIELD EVALUATION OF ROAD CROSSINGS

The first part in the hydraulic analysis of the structures consisted of field evaluation of the crossings. Prior to conducting the field evaluation, URS obtained available crossing information from the DelDOT bridge maintenance group. URS then conducted field visits to road and railroad crossings that have openings of 36 inches or larger to collect the following data:

- Crossing opening data (e.g., type, culvert size, culvert material, headwall material/configuration, culvert skew)
- Distance from the top of the opening to the minimum overtopping elevation
- Configuration of downstream channel (to compute outlet control discharges)
- Distance from the downstream invert to the low-flow elevation below the culvert (to determine whether a blockage to fish passage exists; other downstream conditions such as bank erosion, over-widening, and bed degradation will be noted)
- Digital photographs
- GPS location of upstream and downstream culvert at ends
- Potential for conveyance improvements

- Other pertinent data necessary for hydraulic computations

For the purposes of this planning level study, the information was obtained using a tape measure and field observation rather than a detailed field survey. Field assessment sheets were developed to ensure consistent data collection. Completed field forms are included in Appendix A.

5.2 EVALUATION OF THE HYDRAULIC CAPACITY

After obtaining the measurements of the structures in the field, the capacities of the structures were evaluated. The HDS-5 (Hydraulic Design of Highway Culvert) approach was adopted and Microsoft Excel was used to conduct the analysis. Culvert capacities for all the structures were computed for inlet control and outlet control scenarios. The maximum capacity of the culvert under inlet control conditions was calculated from the field observations using equation 4.1:

$$Q = [(A*D^{0.5})/K_u]* [((HW_i/D)-Y+0.5*S^2))/C]^{0.5} \text{------------------------} (4.1)$$

Where,

Q = Discharge, cubic feet per second (cfs)
A = Full cross-sectional area of culvert barrel, square feet (ft^2)
D = Interior height of culvert barrel, ft
HW_i = Headwater depth above inlet control section invert, feet (ft)
S = Culvert barrel slope, feet per foot (ft/ft)
K_u, M, C, Y = Constants for inlet control design equations (obtained from Table 9 of the Hydraulic Design of Highway Culverts manual, USDOT, May 2005)

The maximum flow, Q, obtained from equation 4.1 was then used to determine the critical depth (d_c) of the culvert using the nomographs. The obtained critical depth in turn was used to determine the capacity of the culvert with outlet control condition using equation 4.2:

$$Q= A*[(2*H*g)/(1+K_e+(29*n^2*L)/R^{1.33})]^{1/2} \text{-------------------------} (4.2)$$

Where,

Q = Discharge, cfs
A = Full cross-sectional area of culvert barrel, ft^2
L = Length of the culvert barrel, ft
H = Headloss computed from outlet control equation, ft
n = Pipe (culvert) Manning's coefficient
g = Acceleration due to gravity, 32.2 ft/sec^2
R = Wetted perimeter, ft
K_e = Entrance loss coefficients (obtained from Table 12 of the Hydraulic Design of Highway Culverts manual, USDOT, May 2005)

A worst-case assumption for tailwater equal to bankfull condition was used. The discharges for both inlets and outlets were compared, and the lowest discharge was selected to determine the flow regime of the structure.

Culvert capacity was estimated for two scenarios:

1. With 0 foot of freeboard to the top of road
2. With 1 foot of freeboard to the top of road

The subbasins containing the culverts were identified, and the peak flows for storm events were obtained from the existing and future conditions hydrology model. A raster analysis was performed in GIS using the Flow Direction Grid and Flow Accumulation Grid to determine the area draining to each crossing. The flows at each crossing were obtained using drainage area ratio estimates (equation 4.3):

$$Q_c = [A_c/A]^b * Q \text{---} \quad (4.3)$$

Where,

Q_c= Estimated flow at the crossing, cfs
A_c= Drainage area of the crossing, acres (ac)
Q = Subbasin flow from hydrology model, cfs
A = Drainage area of subbasin, ac
b = Exponent of drainage area

Based on the report "Magnitude and Frequency of Floods on Nontidal Streams in Delaware" (USGS, 2006), it can be inferred that a value of 0.6 is used for the exponent of drainage area, "b", in the Piedmont and a value of 0.7 is used in the coastal plain in the state of Delaware. Since the Murderkill Watershed is located entirely in the coastal plain, a value of 0.7 was used as the exponent of drainage area. For crossings located higher in the subbasins, flows were estimated using the upstream subbasin.

URS considered the DelDOT road classification to determine the design storm. Roads categorized as Local and Rural Collector roads were assigned 25-year design storm and Collectors & Arterials were assigned 50-year design storm. Roads that were not in the DelDOT system were classified as local roads and assumed to have a 25-year design storm. The results of the analyses are categorized as follows:

- Green: Culvert passes the design storm with 1 foot of freeboard
- Yellow: Culvert passes the design storm with less than one foot of freeboard
- Red: Culvert does not pass the design storm

The conveyance capacity of the crossings was analyzed for existing and predicted future condition flows. Figure 5.1 and 5.2 summarizes the results of the analyses. Table 5.2 through Table 5.4 show the summary of the hydraulic analysis and capacity of the structures expressed in terms of percent design flow conveyed through the structure. The results are also summarized by subwatershed in Section 7.

Table 5.2: Summary of Culvert Analysis

	Green	Yellow	Red
Existing	54.9%	13.4%	31.7%
Future	51.2%	12.2%	36.6%

Table 5.3: Culvert Capacity for Existing Conditions

Crossing ID	Location	Subwatershed	Design Storm (Year)	Capacity with 1' freeboard	Capacity with 0' freeboard	Classification
031A	Irish Hill Road	Double Run	50	100%	100%	
033A	Canterbury Road	Pratt Branch	50	81%	92%	
033B	Canterbury Road	Hudson Branch	50	100%	100%	
035C	Carpenter Bridge Road	Middle Murderkill	50	100%	100%	
105A	Peachtree Road	Double Run	50	64%	77%	
106A	Woodlytown Road	Double Run	50	48%	56%	
239A	Firetown Road	Hudson Branch	25	84%	100%	
281A	Hopkins Cemetery Road	Swamp Creek	25	36%	61%	
282A	Marshyhope Road	Swamp Creek	25	100%	100%	
282B	Marshyhope Road	Beaverdam Branch	25	85%	95%	
286A	Reeves Crossing	Beaverdam Branch	25	100%	100%	
287A	Paradise Alley Road	Swamp Creek	25	100%	100%	
290A	Pea Hill Road	Browns Branch	25	84%	100%	
290B	Pea Hill Road	Browns Branch	25	25%	100%	
371A	Barratts Chapel Road	Double Run	50	100%	100%	
371B	Barratts Chapel Road	Hudson Branch	50	64%	74%	
371C	Barratts Chapel Road	Hudson Branch	50	100%	100%	
381A	Fox Chase Road	Hudson Branch	25	100%	100%	
384C	Killens Pond Road	Browns Branch	25	100%	100%	
386A	Scrap Tavern Road	Upper Murderkill	25	100%	100%	
388C	Canterbury Road	Middle Murderkill	50	100%	100%	
390A	Fork Landing Road	Middle Murderkill	25	100%	100%	
394A	McCauley Pond Road	McCauley Pond	25	100%	100%	
398A	Sandbox Road	McCauley Pond	25	100%	100%	
429A	Jackson Ditch Road	Browns Branch	25	100%	100%	
432A	Messicks Road	Browns Branch	25	100%	100%	
433A	Corn Crib Road	Browns Branch	25	100%	100%	
78A	Little Mastens Corner Road	Browns Branch	25	100%	100%	
URS1	Barratts Chapel Road	Hudson Branch	50	100%	100%	
URS10	Paradise Alley Road	Swamp Creek	25	49%	56%	
URS11	Little Mastens Corner Road	Swamp Creek	25	100%	100%	
URS12	Lombard Street	Beaverdam Branch	25	94%	100%	
URS13	Marshyhope Road	Beaverdam Branch	25	100%	100%	
URS14	Plymouth Road	Hudson Branch	25	65%	82%	
URS15	Under railroad track near Turkey Point Road	Hudson Branch	50	100%	100%	
URS16	Turkey Point Road	Hudson Branch	50	100%	100%	
URS17	Barney Jenkins Road	Double Run	25	71%	81%	
URS2	Robbins Road	Pratt Branch	25	100%	100%	
URS20	West. Evens Road	Hudson Branch	25	36%	53%	
URS21	West. Evens Road	Hudson Branch	25	58%	74%	
URS22	Friedel Road	Hudson Branch	25	78%	100%	
URS23	Evens Road	Hudson Branch	50	84%	89%	

Crossing ID	Location	Subwatershed	Design Storm (Year)	Capacity with 1' freeboard	Capacity with 0' freeboard	Classification
URS24	Ruritan Lane	Hudson Branch	25	100%	100%	
URS25	Berrytown Road	Hudson Branch	25	100%	100%	
URS28	Black Swamp Road	Swamp Creek	25	28%	53%	
URS29	Burnite Mill Road	Swamp Creek	50	44%	63%	
URS3	Lake Drive	Pratt Branch	25	56%	68%	
URS30	Mayor Lane	Pratt Branch	25	100%	100%	
URS31	Erin Avenue	Pratt Branch	25	100%	100%	
URS32	Little Mastens Corner Road	Browns Branch	25	50%	84%	
URS33	Bowers Beach Road	Lower Murderkill	25	82%	100%	
URS34	Anderson Road	Double Run	25	58%	74%	
URS35	Woodlytown Road	Double Run	50	22%	26%	
URS36	Millchop Lane	Double Run	25	75%	97%	
URS37	Barratts Chapel Road	Hudson Branch	50	100%	100%	
URS38	Midstate Road	Middle Murderkill	50	100%	100%	
URS39	Midstate Road	Middle Murderkill	50	100%	100%	
URS4	Indian Point Road	Pratt Branch	25	100%	100%	
URS40	Midstate Road	Middle Murderkill	50	100%	100%	
URS41	Cams Fortune Road	McCauley Pond	25	100%	100%	
URS42	Bloomfield Drive	McCauley Pond	25	95%	100%	
URS43	Gun Road and Club Road	Browns Branch	25	62%	79%	
URS44	Central Park Drive	Browns Branch	25	41%	59%	
URS45	Blue Jay Lane	Middle Murderkill	25	100%	100%	
URS46	Holleger	Middle Murderkill	25	100%	100%	
URS47	Fork Landing Road	Middle Murderkill	25	93%	100%	
URS48	Weiner Avenue	Browns Branch	25	75%	100%	
URS49	Little Mastens Corner Road	Browns Branch	25	100%	100%	
URS5	Chimney Hill Road	Upper Murderkill	25	100%	100%	
URS50	Park Brown Road	Browns Branch	25	100%	100%	
URS51	Park Brown Road	Browns Branch	25	100%	100%	
URS52	Milford Neck Road	Lower Murderkill	25	70%	89%	
URS54	Under railroad track near Messicks Road	Browns Branch	25	100%	100%	
URS55	Under railroad near Corn Crib Road	Browns Branch	25	100%	100%	
URS56	Railroad Avenue	Browns Branch	25	14%	37%	
URS57	Under railroad track near Railroad Avenue	Browns Branch	25	76%	84%	
URS58	Second Avenue	Browns Branch	25	82%	100%	
URS59	Harrington Avenue	Browns Branch	25	69%	100%	
URS6	Chimney Hill Road	Pratt Branch	25	100%	100%	
URS7	Chimney Hill Road	Pratt Branch	25	100%	100%	
URS8	Paradise Alley Road	Upper Murderkill	25	80%	97%	
URS9	Paradise Alley Road	Swamp Creek	25	58%	67%	

Table 5.4: Culvert Capacity for Future Conditions

Crossing ID	Location	Subwatershed	Design Storm (Year)	Capacity with 1' freeboard	Capacity with 0' freeboard	Classification
031A	Irish Hill Road	Double Run	50	100%	100%	
033A	Canterbury Road	Pratt Branch	50	76%	86%	
033B	Canterbury Road	Hudson Branch	50	100%	100%	
035C	Carpenter Bridge Road	Middle Murderkill	50	100%	100%	
105A	Peachtree Road	Double Run	50	57%	69%	
106A	Woodlytown Road	Double Run	50	43%	50%	
239A	Firetown Road	Hudson Branch	25	74%	100%	
281A	Hopkins Cemetary Road	Swamp Creek	25	36%	61%	
282A	Marshyhope Road	Swamp Creek	25	100%	100%	
282B	Marshyhope Road	Beaverdam Branch	25	75%	84%	
286A	Reeves Crossing	Beaverdam Branch	25	100%	100%	
287A	Paradise Alley Road	Swamp Creek	25	100%	100%	
290A	Pea Hill Road	Browns Branch	25	78%	100%	
290B	Pea Hill Road	Browns Branch	25	23%	100%	
371A	Barratts Chapel Road	Double Run	50	100%	100%	
371B	Barratts Chapel Road	Hudson Branch	50	58%	67%	
371C	Barratts Chapel Road	Hudson Branch	50	100%	100%	
381A	Fox Chase Road	Hudson Branch	25	100%	100%	
384C	Killens Pond Road	Browns Branch	25	100%	100%	
386A	Scrap Tavern Road	Upper Murderkill	25	89%	100%	
388C	Canterbury Road	Middle Murderkill	50	100%	100%	
390A	Fork Landing Road	Middle Murderkill	25	100%	100%	
394A	McCauley Pond Road	McCauley Pond	25	100%	100%	
398A	Sandbox Road	McCauley Pond	25	100%	100%	
429A	Jackson Ditch Road	Browns Branch	25	100%	100%	
432A	Messicks Road	Browns Branch	25	100%	100%	
433A	Corn Crib Road	Browns Branch	25	100%	100%	
78A	Little Mastens Corner Road	Browns Branch	25	98%	100%	
URS1	Barratts Chapel Road	Hudson Branch	50	100%	100%	
URS10	Paradise Alley Road	Swamp Creek	25	49%	56%	
URS11	Little Mastens Corner Road	Swamp Creek	25	100%	100%	
URS12	Lombard Street	Beaverdam Branch	25	87%	97%	
URS13	Marshyhope Road	Beaverdam Branch	25	100%	100%	
URS14	Plymouth Road	Hudson Branch	25	59%	74%	
URS15	Under railroad track near Turkey Point Road	Hudson Branch	50	100%	100%	
URS16	Turkey Point Road	Hudson Branch	50	100%	100%	
URS17	Barney Jenkins Road	Double Run	25	63%	72%	
URS2	Robbins Road	Pratt Branch	25	100%	100%	
URS20	West. Evens Road	Hudson Branch	25	36%	53%	
URS21	West. Evens Road	Hudson Branch	25	52%	67%	
URS22	Friedel Road	Hudson Branch	25	70%	95%	
URS23	Evens Road	Hudson Branch	50	77%	82%	

Crossing ID	Location	Subwatershed	Design Storm (Year)	Capacity with 1' freeboard	Capacity with 0' freeboard	Classification
URS24	Ruritan Lane	Hudson Branch	25	100%	100%	
URS25	Berrytown Road	Hudson Branch	25	100%	100%	
URS28	Black Swamp Road	Swamp Creek	25	28%	53%	
URS29	Burnite Mill Road	Swamp Creek	50	44%	63%	
URS3	Lake Drive	Pratt Branch	25	51%	63%	
URS30	Mayor Lane	Pratt Branch	25	100%	100%	
URS31	Erin Avenue	Pratt Branch	25	100%	100%	
URS32	Little Mastens Corner Road	Browns Branch	25	47%	78%	
URS33	Bowers Beach Road	Lower Murderkill	25	80%	100%	
URS34	Anderson Road	Double Run	25	52%	67%	
URS35	Woodlytown Road	Double Run	50	19%	22%	
URS36	Millchop Lane	Double Run	25	66%	86%	
URS37	Barratts Chapel Road	Hudson Branch	50	100%	100%	
URS38	Midstate Road	Middle Murderkill	50	100%	100%	
URS39	Midstate Road	Middle Murderkill	50	100%	100%	
URS4	Indian Point Road	Pratt Branch	25	100%	100%	
URS40	Midstate Road	Middle Murderkill	50	100%	100%	
URS41	Cams Fortune Road	McCauley Pond	25	100%	100%	
URS42	Bloomfield Drive	McCauley Pond	25	95%	100%	
URS43	Gun Road and Club Road	Browns Branch	25	56%	72%	
URS44	Central Park Drive	Browns Branch	25	39%	57%	
URS45	Blue Jay Lane	Middle Murderkill	25	100%	100%	
URS46	Holleger	Middle Murderkill	25	100%	100%	
URS47	Fork Landing Road	Middle Murderkill	25	83%	95%	
URS48	Weiner Avenue	Browns Branch	25	72%	100%	
URS49	Little Mastens Corner Road	Browns Branch	25	100%	100%	
URS5	Chimney Hill Road	Upper Murderkill	25	100%	100%	
URS50	Park Brown Road	Browns Branch	25	97%	100%	
URS51	Park Brown Road	Browns Branch	25	100%	100%	
URS52	Milford Neck Road	Lower Murderkill	25	70%	89%	
URS54	Under railroad track near Messicks Road	Browns Branch	25	100%	100%	
URS55	Under railroad track near Corn Crib Road	Browns Branch	25	100%	100%	
URS56	Railroad Avenue	Browns Branch	25	14%	36%	
URS57	Under railroad track near Railroad Avenue	Browns Branch	25	73%	81%	
URS58	Second Avenue	Browns Branch	25	78%	100%	
URS59	Harrington Avenue	Browns Branch	25	66%	98%	
URS6	Chimney Hill Road	Pratt Branch	25	100%	100%	
URS7	Chimney Hill Road	Pratt Branch	25	100%	100%	
URS8	Paradise Alley Road	Upper Murderkill	25	65%	78%	
URS9	Paradise Alley Road	Swamp Creek	25	58%	67%	

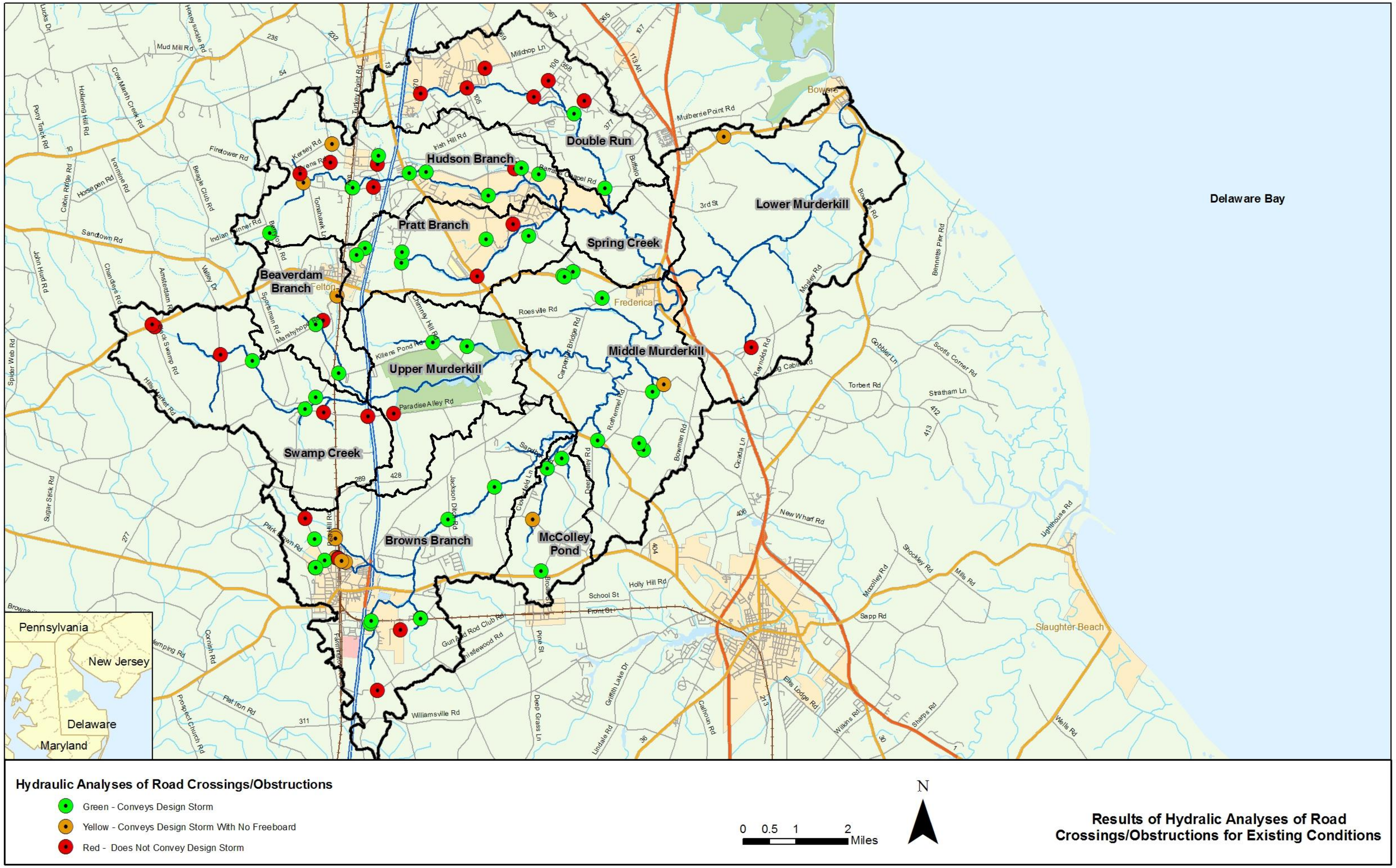


Figure 5.1: Results of Hydraulic Analyses of Road Crossings and Obstructions for Existing Conditions

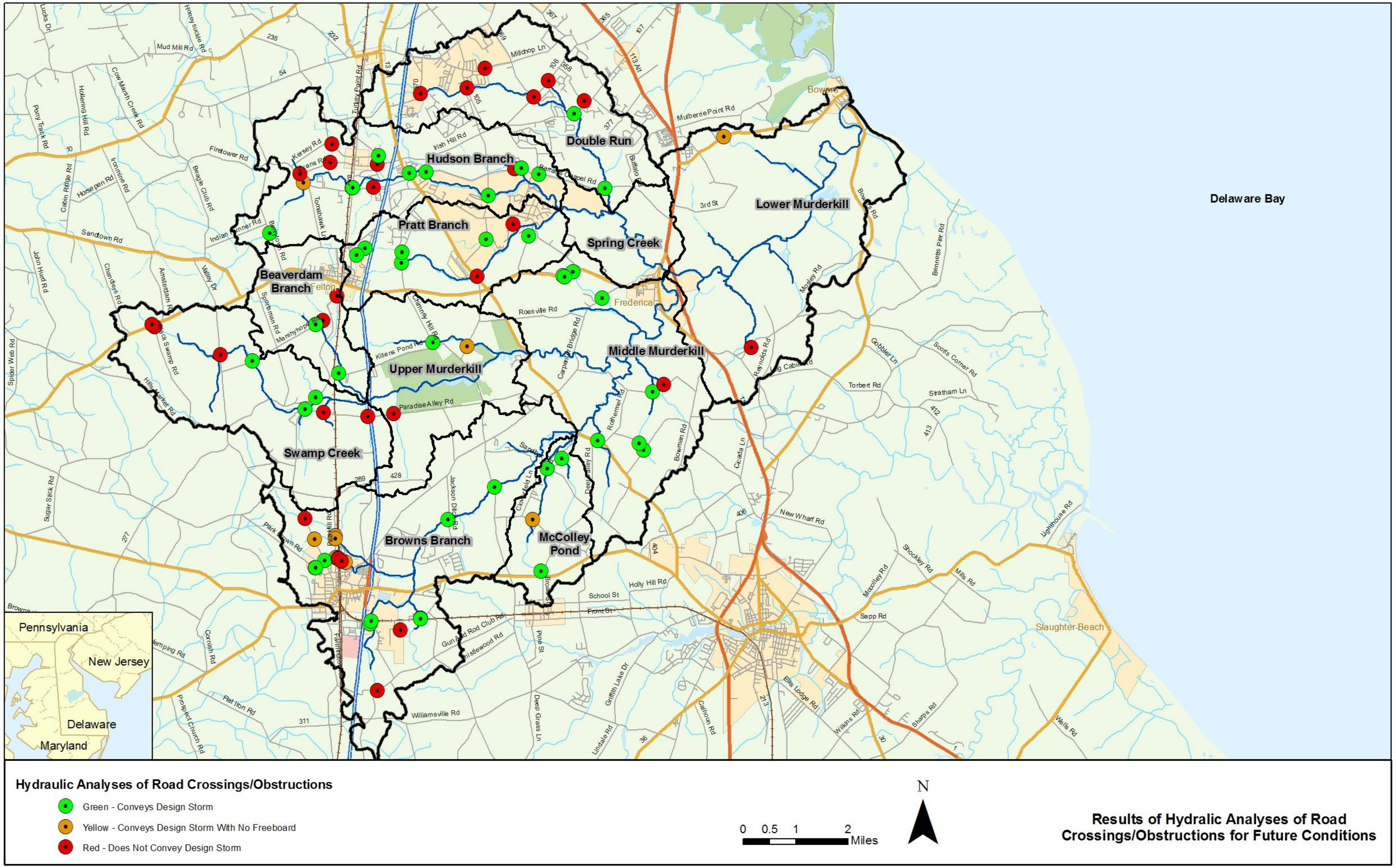


Figure 5.2: Results of Hydraulic Analyses of Road Crossings and Obstructions for Future Conditions

Section 6 Stream Assessment

URS conducted stream assessments for selected reaches along Murderkill River and its tributaries as a part of the watershed management plan to characterize the stream conditions throughout the watershed. Field assessments were performed to:

(1) Conduct geomorphic assessment to classify the streams based on Rosgen classification

(2) Estimate the bankfull discharge and bankfull geometry based on field measurements for the channel for successful design of restoration of projects

(3) Assess the stream stability, water clarity, habitat conditions, and other physical conditions of selected stream segments and conduct a Stream Assessment Visual Protocol (SVAP) evaluation

(4) Estimate the Bank Erodibility Hazard Index (BEHI) for streams with high and steep banks

(5) Identify potential restoration measures that could be adopted in future watershed management decisions

A list of potential sites for future restoration projects was identified by DNREC staff and URS from:

1. The CWP's Technical Memorandum, *Prioritization of Murderkill Subwatersheds*, 2005
2. Sites that were defined as problem areas in the previous studies

Six sites with different stream health conditions in both developed and rural areas were selected by the project team. Three of the six sites were identified as highest priority in the CWP's (2005) Technical Memorandum. Three thousand feet of streams were assessed in total as a part of this watershed study.

The selected sites were assessed to observe existing conditions with regard to stream stability, condition of riparian zone, aquatic habitat, fish blockages, infrastructure conflicts, water clarity, and trash. Field assessments for the sites also included measurement of stream profiles and cross sections using a laser level and surveyor's rod. The assessed streams were then assigned Rosgen classifications based on the hydrogeomorphology of the stream. Measurements were obtained for all the sites except for Middle Murderkill River because this river was not wadeable. These measurements were used to estimate bankfull geometry and bankfull discharge, and these estimates were compared to the published U.S. Fish and Wildlife Service (USFWS) regional equations, which are developed with drainage area as the only independent variable.

The second part of the stream assessment included an SVAP evaluation of the stream site to assess the physical conditions in the stream segment for 15 different physical elements as listed below in Table 6.1.

Since the entire stream segments were fresh water bodies, salinity was not assessed as a part of SVAP evaluation. Observed macroinvertebrates in the stream was not considered an important parameter in characterizing the health and stability of the stream, so sampling and identification of macroinvertebrates was not included in the scope of this project.

Table 6.1: SVAP Evaluation Categories

SVAP Element	Evaluated (Y/N)	SVAP Element	Evaluated (Y/N)	SVAP Element	Evaluated (Y/N)
Channel	Y	Nutrient enrichment	Y	Canopy cover	Y
Hydrologic alteration	Y	Barriers to fish movement	Y	Manure presence	Y
Riparian zone (buffers)	Y	Instream fish cover	Y	Salinity	N
Bank Stability	Y	Pools	Y	Riffle embeddedness	Y
Water Appearance	Y	Invertebrate habitat	Y	Macroinvertebrates	N

In addition, the BEHI was calculated for two sites, Site 1 at Double Run and Site 2 at Hudson Branch, because field assessments indicated that these two sites contained high and steep banks. The BEHI was calculated for these two sites to estimate the stream bank's ability to resist erosion.

Information on the location of the site, drainage area, Rosgen classifications, and SVAP scores are provided in Table 6.2.

Table 6.2: List of Stream Assessment Sites

Site No	Name	Location	Drainage Area (sq. mi)	Rosgen Classification	SVAP Score	BEHI Rating
Site 1	Double Run (W640)	US 13 along Irish Hill Rd	6.3	F5	6.5-Fair	High-Left Bank Moderate-Right Bank
Site 2	Hudson Branch (W680)	Along Canterbury Rd between Dailey Rd and Barratts Chapel Rd	3.0	F5	4.75-Poor	Moderate-Left Bank Moderate to High-Right Bank
Site 3	Pratt Branch (W1170)	Along Canterbury Rd near Felton	3.6	C5	8.3-Good (upstream); 5.9-Poor (downstream)	N/A
Site 4	Upper Murderkill River (W1220)	Along US 13, south of Reeves Crossing Rd	14.5	C5	7.8-Good	N/A
Site 5	Middle Murderkill River (W1260)	Along Canterbury Rd, south of Rossville Rd below Coursey Pond Dam	22.4	-	5.7-Poor	N/A
Site 6	Tributary to McCauley Pond (W1060)	North of US 13/Milford Harrington Hwy	1.4	C5	6.75-Fair	N/A

A detailed description of the field procedures adopted, analyses performed and proposed recommendations is provided in Appendix D (Stream Assessment) of this report.

Section 7 Assessment of Subwatersheds

This section provides an overview of the conditions of the major subwatersheds in the Murderkill Watershed. The Murderkill Watershed was delineated into 11 subwatersheds to evaluate specific watershed characteristics. As part of the hydrologic analyses (Section 4), the subwatersheds were further divided into smaller “basins” to provide more detail about the subwatersheds.

The goal of the subwatershed assessment is to examine the extent of issues in the subwatersheds and to identify the target areas for the implementation of the proposed management projects. The watershed assessment was also used to determine subwatersheds for the “what-if” scenario modeling; the subwatersheds that were ranked Poor and Very Poor were selected as the candidates to run the what-if scenarios.

Based on available data, discussions with DNREC, Kent County, and the Kent Conservation District, and the field and stream assessments and analyses discussed previously in this watershed plan, the URS team developed a qualitative approach to evaluate the subwatersheds. Subwatersheds were qualitatively ranked as Good, Fair, Poor, or Very Poor. The characterization was evaluated with respect to numerous factors such as:

- Hydrologic and hydraulic analysis results
- Field reconnaissance observations
- Stream assessment results
- Subwatershed conditions from the CWP Technical Memorandum
- Existing stormwater management facilities
- Ground water recharge potential areas
- Percent of streams with inadequate forested buffer
- Percent existing impervious cover of subwatershed area
- Percent existing forest cover
- Future development potential

Table 7.1 and Figure 7.1 summarize the results of the subwatershed assessment. The section below summarizes the assessment of each subwatershed.

Table 7.1: Qualitative Subwatershed Assessment

Subwatershed	Area mi^2 (HEC-HMS)	Percent Impervious (2007)	Percent Forest Cover (2007 land use)	Percent Developable (CWP Technical Memo, 2005)	Percent Likely to be developed (CWP Technical Memo, August, 2005)	Percent Growth Zone (CWP Technical Memo, August, 2005)	Percent of streams with inadequate forested buffer (CWP Technical Memo, August, 2005)	CWP Prioritization	Bank Height Ratio Analysis	SVAP Classification	Total Number of Overtopping Culverts	Percent Excellent Ground Water Recharge Potential	Percent Developed Area Treated by Stormwater Management Facilities	Main Observed Issues	Overall Assessment
Beaverdam Branch	4.4	5.1	12.0	46	0	60	66	2	N/A	N/A	2 of 4	39.9	7.2	Stormwater runoff, drainage issues, erosion, new development	Fair
Browns Branch	16.3	8.4	12.0	58	2.7	53	74	2	N/A	N/A	10 of 20	27.4	14.2	Inadequate forested buffer	Poor
Double Run	9.5	7.0	11.3	61	7.2	96	54	1	High vertical instability	Fair	6 of 8	16.6	51.0	New development	Very Poor
Hudson Branch	10.7	6.2	6.2	55	7.9	80	80	1	High vertical instability	Poor	7 of 16	19.0	22.5	New development, stormwater runoff, erosion	Very Poor
Lower Murderkill	16.4	2.1	7.6	42	1.1	3	18	3	N/A	N/A	1 of 2	8.0	7.2	Inadequate forested buffer	Good
McCauley Pond	3.6	4.3	17.0	73	3.1	0	48	3	Vertical stability	Fair	1 of 4	46.2	44.0	New development	Good
Middle Murderkill	13.4	2.6	9.2	75	6.8	73	27	2	Vertical stability	Good	1 of 9	14.3	17.8	Inadequate forested buffer, new development	Good
Pratt Branch	6.5	7.4	9.3	74	10.2	100	52	1	Vertical stability	Poor	2 of 8	21.9	23.3	New development	Poor
Spring Creek	3.3	2.3	20.5	75	9.6	94	21	3	N/A	N/A	N/A	13.0	8.3	New development	Good
Swamp Creek	10.5	2.8	12.4	61	0	0	60	3	N/A	N/A	5 of 8	56.9	7.2	Inadequate forested buffer, erosion	Fair
Upper Murderkill	8.0	3.3	16.2	59	0.6	69	50	2	Vertical stability	Good	1 of 3	63.2	10.6	Inadequate forested buffer, erosion, poor water quality in lakes	Good

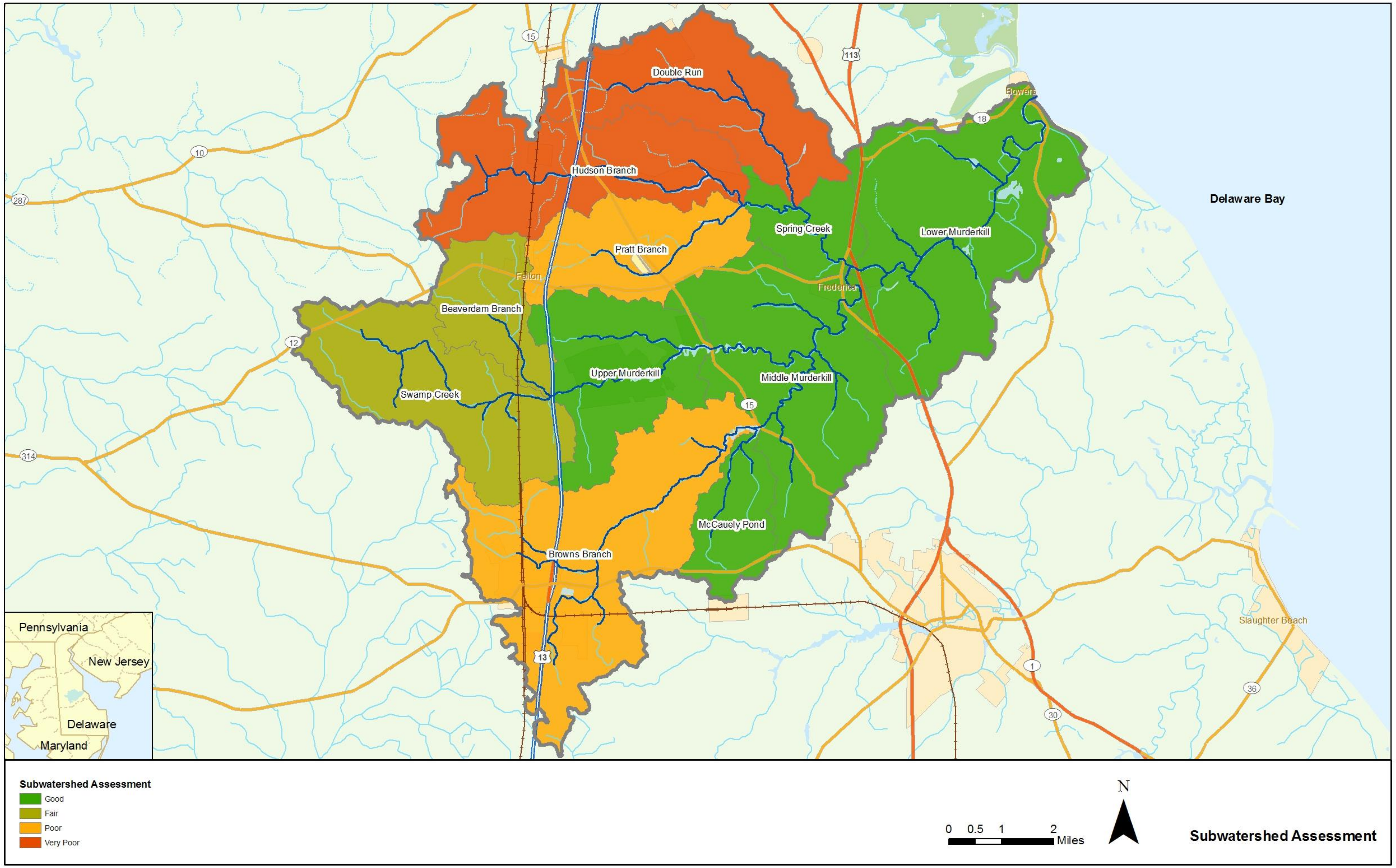
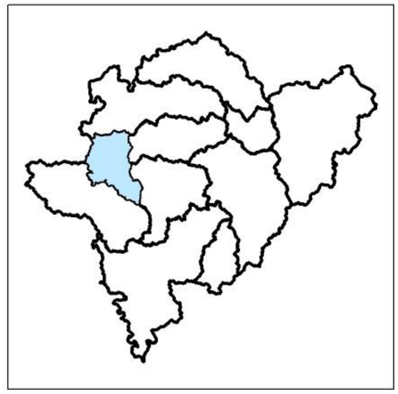


Figure 7.1: Results of Subwatershed Assessment

Beaverdam Branch Subwatershed:

Subwatershed conditions:

- Drainage area – 4.4 sq. miles
- Existing impervious area – 5.1%
- Percent of developed area treated by stormwater management facilities – 7.2%
- Existing Forest Cover – 12.0%
- Number of overtopping structures – 2
- SVAP Score – N/A
- Overall URS assessment – Fair



Existing land use distribution and future development: Farms, pastures, and cropland occupy a major part (45.6%) of the land use distribution in Beaverdam Branch Subwatershed. It has an existing impervious cover of 5.1%, which ranks it fifth highest among the 11 subwatersheds. The subwatershed has an existing forest cover of 12.0%. Only 12.0% of the subwatershed is occupied by residential land use. Sixty percent of the subwatershed is located in the Kent County Growth Zone; however, based on CWP's Technical Memorandum, the subwatershed has a very low likelihood of being developed.

Field reconnaissance and stream assessment: Beaverdam Branch has approximately 14.3 miles of stream network. The CWP assessed 13.0 miles for buffer and concluded that 66% of the stream network lacks stream buffer, which ranks it third lowest among the subwatersheds in that category. A stream assessment was not performed for the subwatershed as a part of this study.

Ground water recharge potential areas: According to SWAP Program of DNREC the subwatershed area can be categorized as:

- 39.3% - Excellent ground water recharge potential
- 45.0% - Good-ground water recharge potential
- 14.9% - Fair- ground water recharge potential

Existing stormwater management facilities: Beaverdam Branch Subwatershed has seven existing stormwater management facilities that treat 44.2 acres of developed area. The facilities include dry and wet ponds and a bio-swale.

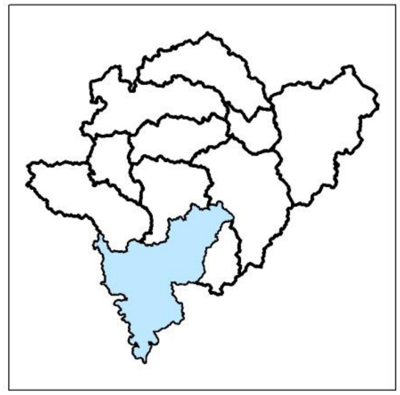
Overtopping structures: Four crossings were analyzed to estimate their conveyance capacity for the design storm. Two of the four crossings convey the design storms; one crossing conveys the storm with 0 freeboard and one crossing does not pass the design storm.

Subwatershed assessment summary: The CWP's Technical Memorandum indicates that the Beaverdam Branch Subwatershed is 0% likely to be developed even though 60% of the subwatershed falls in the Kent County Growth Zone. The Beaverdam Branch Subwatershed ranks in the middle (fifth) when compared to all the subwatersheds in the areas of percent impervious, percent forest cover. Based on these observations, an overall rating of "Fair" was assigned to the subwatershed. With 66% of the streams having inadequate buffer, this subwatershed ranks third lowest in that area; and improving the riparian buffers would help restore the health of the subwatershed. Half of the road crossings analyzed overtopped for the design storm. Improving the hydraulically deficient structures would increase their conveyance capacity during storm events. Beaverdam Branch Subwatershed has 612 acres of developed area, of which runoff from only 44.2 acres is provided with treatment by stormwater management facilities. Constructing stormwater management facilities that would treat the runoff for water quality/quantity is recommended in the developed areas.

Browns Branch Subwatershed:

Subwatershed conditions:

- Drainage area – 16.3 sq. miles
- Existing impervious area – 8.4%
- Existing forest cover – 12.0%
- Percent of developed area treated by stormwater management facilities – 14.2%
- Number of overtopping structures – 10
- SVAP Score – N/A
- Overall URS assessment – Poor



Existing land use distribution and future development: Browns Branch Subwatershed has the highest imperviousness (8.4%) among all the subwatersheds. However, farms, pastures, and croplands are the major land use type (42.7%) in the subwatershed. Approximately 13% of the land use in the subwatershed is residential. Per the CWP Technical Memorandum, the subwatershed has a 2.7% likelihood of being developed.

Field reconnaissance and stream assessment: Browns Branch Subwatershed has approximately 30.2 miles of stream network. The CWP assessed 29.3 miles for buffer and concluded that 74% of the stream network has inadequate stream buffer, which ranks it second lowest among the 11 subwatersheds. Browns Branch was not included as a part of the stream assessment performed by URS and thus no SVAP scores were provided for this stream.

Ground water recharge potential areas: According to SWAP Program of DNREC the subwatershed area can be categorized as:

- 27.4% - Excellent ground water recharge potential
- 49.8% - Good ground water recharge potential
- 18.1% - Fair ground water recharge potential

Existing stormwater management facilities: Browns Branch Subwatershed has 58 existing stormwater management facilities that treat 475.8 acres of residential, commercial, and institutional land uses. The facilities include dry and wet ponds, bioretention ponds, bio-swales, and infiltration trenches.

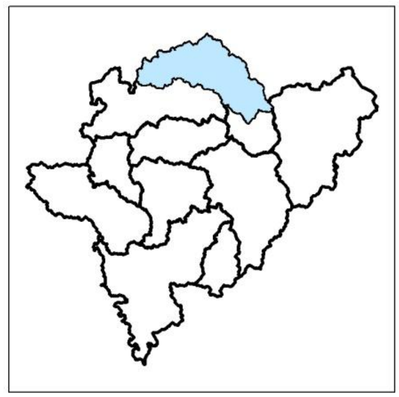
Overtopping structures: Twenty crossings were analyzed to estimate their conveyance capacity for the design storm. Ten of the 20 crossings convey the design storms, five crossings convey the storm with no freeboard, and five crossing do not pass the design storm. Browns Branch Subwatershed has the second highest number of crossings that overtop the design flows.

Subwatershed assessment summary: Browns Branch has the highest impervious (8.4%) cover of all the subwatersheds. With a forest cover of 12%, this subwatershed ranks fifth among the subwatersheds. Fifty-three percent of the subwatershed is in the Kent County Growth Zone, and according to the CWP's Technical Memorandum, there is 2.7% likelihood that the subwatershed would be developed. The subwatershed ranks second lowest, with 74% of the streams lacking forested buffers. Half of the road crossings were analyzed to estimate the conveyance capacity overtopped for the design flows. The subwatershed has approximately 3,360 acres of developed area, but runoff from only 14.2% of the developed area is treated by stormwater management facilities. Based on these parameters, an overall rating of "Poor" was assigned to the subwatershed. Recommendations to restore the quality of the subwatershed include: improving the conveyance capacity of the hydraulically deficient structures, constructing stormwater management facilities to treat the runoff from the developed areas, and improving the riparian buffers for the streams that have inadequate buffers.

Double Branch Subwatershed:

Subwatershed conditions:

- Drainage area – 9.5 sq. miles
- Existing impervious area – 7.0%
- Existing forest cover – 11.3%
- Percent of developed area treated by stormwater management facilities – 51.0%
- Number of overtopping structures – 6
- SVAP Score – 6.5 (Fair)
- Overall URS assessment – Very Poor



Existing land use distribution and future development: Farms, pastures, and croplands (40.0%) and single-family dwellings (24.6%) occupy most of the land use distribution in the Double Branch Subwatershed. It has an existing imperviousness of 7.0%, which ranks it third highest in the Murderkill Watershed. About 96% of the subwatershed is in the Kent County Growth Zone, and based on the CWP Technical Memorandum, it has a 7.2% likelihood of being developed in the future.

Field reconnaissance and stream assessment: Double Run Subwatershed has 17.0 miles of stream network. The CWP assessed 13.7 miles of stream for buffer and concluded that 54% of the stream network has inadequate stream buffer. URS conducted an assessment of this reach in the field and concluded that the channel is affected by sediment and high storm flows, and that the stream is not providing diverse stable habitat except at the lower end of the reach. An overall SVAP rating of "Fair" was assigned to the reach. A bank height ratio analysis performed by URS concluded that the stream is deeply incised with high vertical instability.

Ground water recharge potential areas: Based on the classification provided by the SWAP Program of DNREC, the subwatershed area can be classified as:

- 16.6% - Excellent ground water recharge potential

- 58.5% - Good ground water recharge potential
- 22.4% - Fair ground water recharge potential

Existing stormwater management facilities: Double Branch Subwatershed has 33 existing stormwater management facilities that treat 1,196.6 acres of residential and commercial land. The facilities include dry and wet ponds, bio-swales, and infiltration trenches.

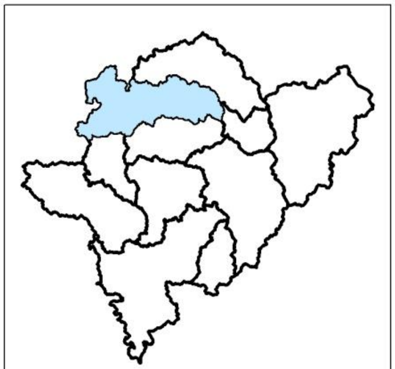
Overtopping structures: Eight crossings were analyzed to estimate their conveyance capacity for the design storm. Two of the eight crossings convey the design storm, and the remaining six do not pass the design storm. Double Branch Subwatershed has the highest number of crossings that overtop the design flows.

Subwatershed assessment summary: An overall assessment score of "Very Poor" was assigned to Double Branch Subwatershed. With an impervious cover of 7%, the subwatershed ranks third highest, and with a forest cover of 11.3%, it ranks sixth highest among the other subwatersheds. The CWP's assessment of the streams indicates that 54% of the streams in the subwatershed lack forested buffers; therefore, projects that improve the riparian buffers are recommended. Bank height ratio analysis of Double Branch concluded that the stream has high vertical instability, hence grade control measures are recommended to provide stability. Double Branch Subwatershed has the highest number of crossings (75%) that overtop the design storms. Improvements that increase the conveyance capacity of the crossings are recommended. Stormwater management facilities that would treat the runoff from new development are recommended.

Hudson Branch Subwatershed:

Subwatershed conditions:

- Drainage area – 10.7 sq. miles
- Existing impervious area – 6.2%
- Percent of developed area treated by stormwater management facilities – 22.5%
- Existing forest cover – 6.2%
- Number of overtopping structures – 7
- SVAP Score – 4.75 (Poor)
- Overall URS assessment – Very Poor



Existing land use distribution and future development: Farms, pastures, and croplands (38.8%) and tidal and non-tidal forested wetland (21.3%) are the two major land use distributions in the Hudson Branch Subwatershed. Single-family dwellings, which occupy 19.8% of the subwatershed, ranks third in the land use distribution. The subwatershed has an existing imperviousness of 6.2% and ranks fourth in high imperviousness among the 11 subwatersheds. Approximately 80% of the subwatershed is in the Kent County Growth Zone, and based on the CWP's Technical Memorandum, the subwatershed has a 7.9% likelihood of being developed in the future.

Field reconnaissance and stream assessment: Hudson Branch Subwatershed has approximately 24.6 miles of stream network. The CWP assessed 20.4 miles of stream for buffer and concluded that 80% of the stream network has inadequate stream buffer. URS conducted an assessment of this reach and concluded that the stream lacks instream habitat, has excess sediment supply, inadequate natural riparian buffer, and unstable channel banks. An overall SVAP rating of "Poor" was assigned to the reach.

Ground water recharge potential areas: Based on the classification provided by the SWAP Program of DNREC the subwatershed area can be classified as:

- 19.0% - Excellent ground water recharge potential
- 23.0% - Good ground water recharge potential
- 52.2% - Fair ground water recharge potential

Existing stormwater management facilities: A total of 497.7 acres of residential and commercial land uses in the Hudson Branch Subwatershed are treated by 28 stormwater management facilities that include dry and wet ponds, bio-swales, and infiltration trenches.

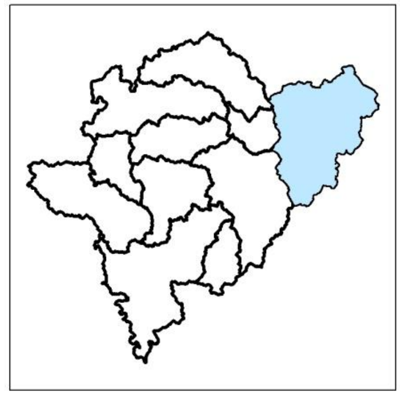
Overtopping structures: Sixteen crossings were analyzed to estimate their conveyance capacity for the design storm in Hudson Branch Subwatershed. Nine of the sixteen crossings convey the design storms; two of them convey the design storm with no freeboard, and the other five do not pass the design storm.

Subwatershed assessment summary: The CWP's Technical Memorandum says that the Hudson Branch Subwatershed is 7.9% likely to be developed, which ranks it third highest among all the Murderkill subwatersheds. The subwatershed has the least forest cover (6.2%) compared to the other Murderkill subwatersheds. The subwatershed ranks fourth among all the subwatersheds in the areas of percent impervious cover (6.2%) and area in the Kent County Growth Zone (80%). The subwatershed has the least forested buffer cover along the streams, with 80% of the streams having inadequate zones. Seven of 16 road crossings are predicted to be overtopped during the design storms. The subwatershed has 2,215 acres of developed area, of which only 22.5% has stormwater treatment facilities. The stream assessment of the Hudson Branch concludes that the stream has excess sediment supply, lacks instream habitat, and has high vertical instability, and as a result, URS assigned a rating of "Very Poor" to the Hudson Branch Subwatershed. Some of the improvement measures to restore the health of the subwatershed include: improving the conveyance capacity of the culverts to convey the design storms, constructing new stormwater management facilities to treat the runoff from existing and future development, providing grade control for streams to prevent further bed degradation, and implementing effective stormwater management regulations along with a tree planting initiative to minimize the effect of urbanization on the health of the subwatershed.

Lower Murderkill Subwatershed:

Subwatershed conditions:

- Drainage area – 16.4 sq. miles
- Existing impervious area – 2.1%
- Existing forest cover – 7.6%
- Percent of developed area treated by stormwater management facilities – 7.2%
- Number of overtopping structures – 2
- SVAP Score – N/A
- Overall URS assessment – Good



Existing land use distribution and future development: Farms, pastures, and cropland (49.0%) and emergent wetland-tidal and non-tidal (26.0%) are the major land use type distributions in the Lower Murderkill Subwatershed. The subwatershed has only 2.1% impervious cover, the lowest impervious cover of all the subwatersheds. Only 3% of the subwatershed is in the Kent County Growth Zone and it has a very low likelihood of being developed in the future.

Field reconnaissance and stream assessment: Lower Murderkill Subwatershed has approximately 82 miles of stream network. The CWP assessed 77.9 miles of stream for buffer and concluded that only 18% of the stream network has inadequate stream buffer. No stream assessments were conducted for this subwatershed

Ground water recharge potential areas: Based on the classification provided by the SWAP Program of DNREC the subwatershed area can be classified as:

- 8.0% - Excellent ground water recharge potential
- 22.7% - Good ground water recharge potential
- 30.9% - Fair ground water recharge potential

Existing stormwater management facilities: Lower Murderkill Subwatershed has only one existing wet pond that treats 70.5 acres of the Bowers Landing residential area.

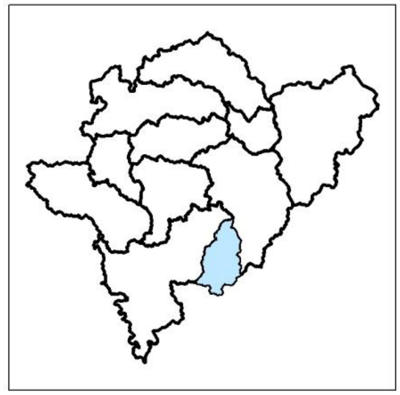
Overtopping structures: Two crossings were analyzed in the subwatershed to estimate their conveyance capacity. One of them conveys the design flows with no freeboard and the remaining one does not pass the design flow.

Subwatershed assessment summary: Lower Murderkill Subwatershed is the largest among all the Murderkill Subwatersheds and the least developed, with an impervious cover of only 2.1%. Only 3% of the subwatershed is in the Kent County Growth Zone, and according to the CWP's Technical Memorandum, the subwatershed has a 1.1% likelihood of being developed in the future. The subwatershed has the highest forested buffer cover, with 82% of the streams having good riparian buffer. All of the crossings analyzed for conveyance capacity overtopped the design storms; therefore, improving the conveyance capacity of the crossings should be considered. Only 8.7% of the developed area in the subwatershed is treated by stormwater management facilities; therefore, implementing stormwater management in developed areas is recommended. Based on these observations, an overall rating of “Good” was assigned to the subwatershed.

McCauley Pond Subwatershed:

Subwatershed conditions:

- Drainage area – 3.6 sq. miles
- Existing impervious area – 4.3%
- Existing forest cover – 17.0%
- Percent of developed area treated by stormwater management facilities – 44.0%
- Number of overtopping structures – 1
- SVAP Score – 6.75 (Fair)
- Overall URS assessment – Good



Existing land use distribution and future development: McCauley Pond Subwatershed, which is located outside the Kent County Growth Zone, has the second highest forest cover in the Murderkill Watershed. Farms, pastures, and cropland (55.8%), mixed forest (16.1%), and single-family dwellings (15.1%) are the three major land use distributions in the watershed. The subwatershed has a 3.1% likelihood of future development.

Field reconnaissance and stream assessment: McCauley Pond Subwatershed has approximately 5.9 miles of stream network. The CWP assessed 4.2 miles of stream for buffer and concluded that 48% of the stream network has inadequate stream buffer. URS conducted an assessment of the tributary to McCauley Pond, and an overall SVAP rating of “Fair” was assigned to the reach. Channel aggradation and less than optimal instream habitat were listed as the main factors in assigning the score for the reach.

Ground water recharge potential areas: Based on the classification provided by the SWAP Program of DNREC the subwatershed area can be classified as:

- 46.2% - Excellent ground water recharge potential
- 50.8% - Good ground water recharge potential
- 2.1% - Fair ground water recharge potential

Existing stormwater management facilities: The McCauley Pond Subwatershed has 11 existing stormwater management facilities that treat 234.8 acres of residential area in the watershed. The types of facilities include dry/wet pond and bio-swales.

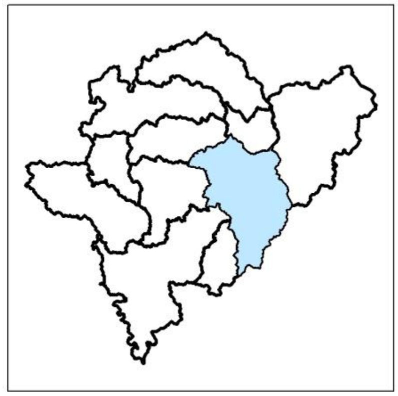
Overtopping structures: Four crossings were analyzed in the subwatershed, of which three convey the design flows and one conveys the design flows with no freeboard.

Subwatershed assessment summary: McCauley Pond Subwatershed was assigned an overall assessment rating of “Good.” The subwatershed has the second highest forest cover of 17%. The subwatershed is completely outside the Kent County Growth Zone, and according to CWP’s Technical Memorandum, it has a 3.1% likelihood of being developed. Twenty-five percent of crossings that were analyzed in the subwatershed overtopped for the design storm, hence improvements that increase the conveyance capacity of the crossings are recommended. Assessments of the streams indicate they have stable vertical banks but excess sediment, and that 48% of the streams lack buffer around them. Stream restoration projects that reduce the sediment loads in the stream and improve the riparian buffers are recommended to be implemented. Stormwater in approximately 44% of the developed area in McCauley Pond Subwatershed is treated by various facilities. Continuing to provide stormwater management for existing and future development areas is recommended. McCauley Pond Subwatershed has the third highest percentage of excellent ground water recharge potential areas; therefore, it is recommended that these areas be protected.

Middle Murderkill Subwatershed:

Subwatershed conditions:

- Drainage area – 13.4 sq. miles
- Existing impervious area – 2.6%
- Existing forest cover – 9.2%
- Percent of developed area treated by stormwater management facilities – 17.8%
- Number of overtopping structures – 1
- SVAP Score – 5.7 (Poor)
- Overall URS assessment – Good



Existing land use distribution and future development: Middle Murderkill Subwatershed is relatively less developed, with farms, pastures, and cropland occupying more than half (67.1%) of the land use distribution in the watershed. The subwatershed has a forest cover of 9.2%, which ranks it third highest among the 11 subwatersheds. However, 73% of the subwatershed is located in the Kent County Growth Zone and has a 6.8% likelihood of being developed in the future.

Field reconnaissance and stream assessment: Middle Murderkill Subwatershed has 22.6 miles of stream network. The CWP assessed 24.4 miles of buffer and concluded that 27% of the stream network has inadequate stream buffer. URS conducted an assessment of this reach in the field and concluded that the channel has an intact riparian zone with stable banks and abundant deep pools. However, an overall SVAP rating of “Poor” was assigned to the reach primarily due to the murky appearance of water, presence of a dam, and the break in canopy cover at the dam.

Ground water recharge potential areas: Based on the classification provided by the SWAP Program of DNREC the subwatershed area can be classified as:

- 14.3% - Excellent ground water recharge potential
- 31.6% - Good ground water recharge potential
- 37.5% - Fair ground water recharge potential

Existing stormwater management facilities: There are nine existing stormwater management facilities in the Middle Murderkill Subwatershed that treat 169.9 acres of residential and commercial areas. The types of facilities include dry and wet ponds and an infiltration trench.

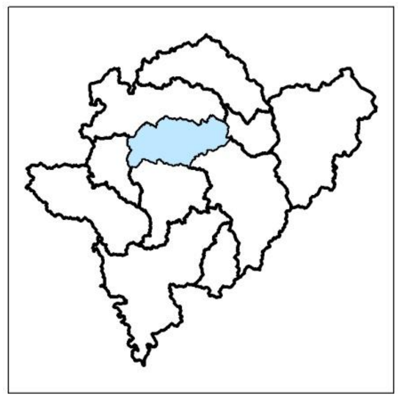
Overtopping structures: Nine crossings were analyzed in this subwatershed, and all except one convey the design flows.

Subwatershed assessment summary: Middle Murderkill Subwatershed, with an impervious cover of 2.6%, has the third lowest impervious cover of the Murderkill subwatersheds. The subwatershed also ranks third lowest for forest cover (9.2%). Seventy-three percent of the subwatershed is located in the Kent County Growth Zone, and according to the CWP's Technical Memorandum, there is a 6.8% likelihood that the subwatershed would be developed, ranking it among the highest developable subwatersheds. Assessment of Middle Murderkill River concluded that the stream banks have good vertical stability, and that 73% of the streams in subwatershed have adequate stream buffer; therefore, projects that would restore the buffers along the remaining 27% of the streams should be implemented. Only one of the nine road crossings analyzed to estimate the conveyance capacity overtopped for the design flows. Measures to improve the conveyance capacity of the inadequate crossing should be considered. The subwatershed has approximately 955.7 acres of developed area, of which runoff from 17.8% of the development are treated by existing stormwater management facilities. Based on these parameters, an overall rating of "Good" was assigned to this subwatershed.

Pratt Branch Subwatershed:

Subwatershed conditions:

- Drainage area – 6.5 sq. miles
- Existing impervious area – 7.4%
- Existing forest cover – 9.3%
- Percent of developed area treated by stormwater management facilities – 23.3%
- Number of overtopping structures – 2
- SVAP Score – 8.3 (Upstream-Good); 5.9 (Downstream-Poor)
- Overall URS assessment – Poor



Existing land use distribution and future development: Farms, pasture, and cropland (52.9%) and single-family dwellings (18.9%) are the major land use types in the Pratt Branch Subwatershed. The subwatershed has an impervious cover of 7.4%, which ranks it second highest among the 11 subwatersheds. The entire subwatershed is located in the Kent County Growth Zone and it has the highest likelihood (10.2%) for future development.

Field reconnaissance and stream assessment: Pratt Branch Subwatershed has 10.4 miles of stream network. The CWP assessed 7.8 miles of buffer and concluded that 52% of the stream network has inadequate stream buffer. URS conducted an assessment of this reach in the field and assigned an overall SVAP rating of "Good" to the upstream section of the reach due to the presence of ample instream habitat, forest cover, riparian buffer, and stable banks. The downstream section of the stream has a braided channel and sand deposition running through it, and as a result, this section was assigned an SVAP rating of "Poor."

Ground water recharge potential areas: Based on the classification provided by the SWAP Program of DNREC, the subwatershed area can be classified:

- 21.9% - Excellent ground water recharge potential
- 36.0% - Good ground water recharge potential
- 40.7% - Fair ground water recharge potential

Existing stormwater management facilities: The Pratt Branch Subwatershed has 22 facilities in the watershed that treat 301.6 acres of residential and commercial areas in the subwatershed. Wet and dry ponds, infiltration trenches, and bio-swales are the types of existing stormwater management facilities that treat primarily residential and commercial areas.

Overtopping structures: Eight crossings were analyzed in the watershed. Six of the eight crossings convey the design flows. Two crossings do not pass the design flows.

Subwatershed assessment summary: Pratt Branch has the second highest impervious cover (7.4%) compared to the other subwatersheds. The subwatershed, with a forest cover of 9.3%, ranks fourth lowest among the subwatersheds. The entire subwatershed is located in the Kent County Growth Zone, and according to the CWP's Technical Memorandum, there is a 10.2% likelihood that the subwatershed would be developed, ranking it the highest among all the subwatersheds. Fifty-two percent of the streams in subwatershed lack stream buffer. Twenty-five percent of the road crossings analyzed to estimate the conveyance capacity overtopped for the design flows. The subwatershed has approximately 1,294 acres of developed area, runoff from 23.3% of which is treated by stormwater management facilities. Assessment of Pratt Branch indicates that the stream banks have good vertical stability and that there is excess sediment supply that has resulted in channel aggradation and braiding. Based on these parameters, an overall rating of "Poor" was assigned to the subwatershed. Recommendations to restore the quality of the subwatershed include: improving the conveyance capacity of the hydraulically deficient structures, constructing stormwater management facilities to treat the runoff from the developed areas, improving the riparian buffers for the streams that have inadequate buffers, and implementing stream restoration projects to reduce the sediment loads and improve the habitat.

Spring Creek Subwatershed:

Subwatershed conditions:

- Drainage area – 3.3 sq. miles
- Existing impervious area – 2.3%
- Existing forest cover – 20.5%
- Percent of developed area treated by stormwater management facilities – 8.3%
- Number of overtopping structures – N/A
- SVAP Score – N/A
- Overall URS assessment – Good

Existing land use distribution and future development: Spring Creek Subwatershed is relatively undeveloped compared to the other subwatersheds. This subwatershed has the highest tree cover, with 20.5% of the watershed occupied by forest. The other predominant land use in the watershed includes farms, pasture, and cropland. Approximately 94% of the watershed is in the Kent County Growth Zone, and according to CWP's Technical Memorandum, the subwatershed ranks second highest in terms of likelihood of future development.

Field reconnaissance and stream assessment: Spring Creek Subwatershed has approximately 8.6 miles of stream network. The CWP assessed 7.9 miles of stream for buffer and concluded that 21% of the stream network has inadequate stream buffer. The stream appeared to be in good condition, and hence stream assessment was not conducted for Spring Creek Subwatershed.

Ground water recharge potential areas: Based on the classification provided by the SWAP Program of DNREC the subwatershed area can be classified as:

- 13% - Excellent ground water recharge potential
- 16.9% - Good ground water recharge potential
- 56.9% - Fair ground water recharge potential

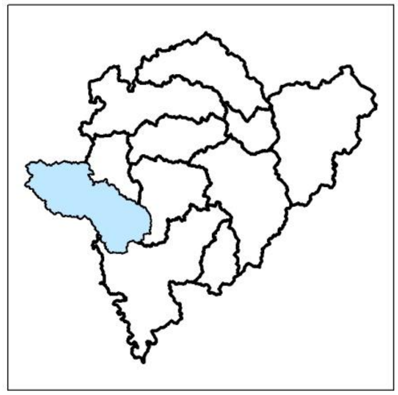
Existing stormwater management facilities: The Spring Creek Subwatershed has one existing stormwater management facility that treats runoff from 15.1 acres of the Otter Run residential area.

Overtopping Structures: No crossings were analyzed in this subwatershed.

Subwatershed assessment summary: An overall assessment score of "Good" was assigned to Spring Creek Subwatershed. With an impervious cover of 3.3%, the subwatershed is second least developed and has the highest forest cover (20.5%). Ninety-four percent of the subwatershed is in the Kent County Growth Zone, with a 9.6% of likelihood of being developed. Approximately 79% of the streams in the subwatershed have good riparian buffer; therefore, projects that maintain existing buffers and implement additional buffers along the streams that lack buffers are recommended.Approximately 8.3% of the developed area in the subwatershed is treated by various stormwater management facilities. Additional stormwater management facilities that would treat the runoff from existing and future developed areas are recommended.

Swamp Creek Subwatershed:

Subwatershed conditions:
- Drainage area – 10.5 sq. miles
- Existing impervious area – 2.8%
- Existing forest cover – 12.4%
- Percent of developed area treated by stormwater management facilities – 7.2%
- Number of overtopping structures – 5
- SVAP Score – N/A
- Overall URS assessment – Fair



Existing land use distribution and future development: Swamp Creek Subwatershed has approximately 2.8% impervious cover, with farms, crops, and pastures occupying 56.0% of the subwatershed. The subwatershed has a small amount of residential cover, with single-family dwellings occupying 5.0% of the watershed. The subwatershed is located completely outside the Growth Zone, and according to the CWP's Technical Memorandum, it has a 0% likelihood of future development.

Field reconnaissance and stream assessment: Swamp Creek Subwatershed has approximately 24.5 miles of stream network. The CWP assessed 23.3 miles of stream for buffer and concluded that 60% of the stream network has inadequate stream buffer. Swamp Creek was not included as a part of the stream assessment performed by URS, and thus no SVAP scores are provided for this stream.

Ground water recharge potential areas: Based on the classification provided by the SWAP Program of DNREC the subwatershed area can be classified as:

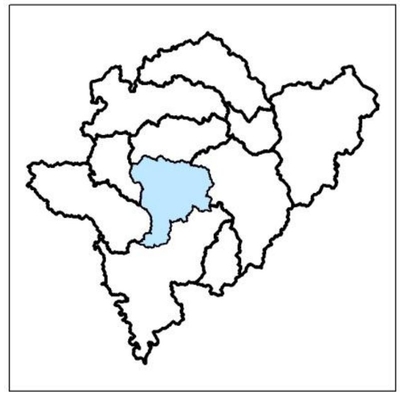
- 56.9% Excellent ground water recharge potential
- 33.6% Good ground water recharge potential
- 8.7% Fair ground water recharge potential

Existing stormwater management facilities: There are two existing stormwater management facilities in the subwatershed that treat 63.3 acres of the residential and commercial areas.

Overtopping structures: Eight crossings were analyzed in the subwatershed. Five of the eight crossings do not pass the design flows and the remaining three convey the design flows.

Subwatershed assessment summary: The CWP's Technical Memorandum says that the Swamp Creek Subwatershed is 0% likely to be developed. The subwatershed is located outside the Kent County Growth Zone. The subwatershed ranks as the eighth lowest and fourth highest compared to the subwatersheds in the areas of percent impervious and percent forest cover, respectively. With 60% of the streams having inadequate buffer, the subwatershed ranks eighth compared to other subwatersheds. Based on these observations, an overall rating of "Fair" was assigned to the subwatershed. Sixty-three percent of the road crossings analyzed to estimate the conveyance capacity overtopped for the design flows. Improvement measures for the hydraulically deficient structures are recommended to increase their conveyance capacity during storm events. Swamp Creek Subwatershed has 878.2 acres of developed area, of which only 63.2 acres is treated for runoff. Constructing stormwater management facilities that would treat the runoff for water quality/quantity is recommended in the developed areas. Swamp Creek Subwatershed has 56.9% of the area classified as having excellent ground water recharge potential. It is recommended that these areas be protected.

Upper Murderkill Subwatershed:



Subwatershed conditions:

- Drainage area – 8.0 sq. miles
- Existing impervious area – 3.3%
- Existing forest cover – 16.2%
- Percent of developed area treated by stormwater management facilities – 10.6%
- Number of overtopping structures – 1
- SVAP Score – 7.8 (Good)
- Overall URS assessment – Good

Existing land use distribution and future development: Upper Murderkill Subwatershed has a relatively low percent imperviousness and high percent forest cover. While 69% of the subwatershed lies within the Growth Zone, only 0.6% of the watershed is likely to be developed. The major land use distribution in the subwatershed includes farms, pastures, and croplands, which occupy 58.8% of the subwatershed.

Field reconnaissance and stream assessment: Upper Murderkill Subwatershed has 12.5 miles of stream network. The CWP assessed 10.7 miles of buffer and concluded that 50% of the stream network has inadequate stream buffer. URS conducted an assessment of this reach in the field and assigned an overall SVAP rating of "Good," primarily due to the channel condition, intact riparian zone, bank stability, water clarity, and instream habitat diversity.

Ground water recharge potential areas: Based on the classification provided by the SWAP Program of DNREC, the subwatershed area can be classified as:

- 63.2% - Excellent ground water recharge potential
- 26.9% - Good ground water recharge potential
- 6.5% - Fair ground water recharge potential

Existing stormwater management facilities: The Upper Murderkill Subwatershed has 11 facilities in the watershed that treat 91.0 acres of residential and commercial areas in the subwatershed. The types of stormwater management facilities in the subwatershed include dry ponds, infiltration trenches, and bio-swales.

Overtopping structures: Three crossings were analyzed in the subwatersheds to estimate their conveyance capacity. Two of the three crossings successfully convey the design storm.

Subwatershed assessment summary: An overall assessment score of "Good" was assigned to Upper Murderkill Subwatershed. With an impervious cover of 3.3%, the subwatershed ranks fifth lowest, and with a forest cover of 16.2% it ranks third highest among the other Murderkill subwatersheds. Sixty-nine percent of the subwatershed is located in the Kent County Growth Zone; however, according to the CWP's Technical Memorandum, there is only a 0.6% likelihood that the area would be developed. The CWP's assessment of the streams indicates that half the streams in the subwatershed lack forested buffers; therefore, projects that improve the riparian buffers are recommended. Assessment of Upper Murderkill Subwatershed concluded that the stream has good vertical stability and instream habitat; hence, continual management of these natural features is recommended. One out of three crossings does not convey the design storms. Improvements that increase the conveyance capacity of the crossing are proposed. Runoff from approximately 10.6% of the developed area in the subwatershed is treated by various stormwater management facilities. Additional stormwater management facilities that would treat the runoff from existing and future developed area are recommended. The Upper Murderkill Subwatershed has the highest percent (63%) of excellent ground water recharge potential areas. It is recommended that these areas be protected.

Section 8 What-If Scenario Models

Based on discussions with DNREC, the URS team developed "what-if" scenario models as part of the Murderkill Watershed Management Plan. These models were developed to assist DNREC and other stakeholders in making watershed management decisions. The scenarios were described in a memo dated January 18, 2011, and approved by DNREC in discussions on February 22, 2011. In total, 16 different "what-if" scenarios were evaluated for the Murderkill Watershed. Each "what-if" scenario modeled a stormwater management measure to estimate the resulting reduction in flow rate or pollutant loads due to that measure. Some of the "what-if" scenarios were used to illustrate the result of enforcing post-construction stormwater management measures described in the *Working Draft Sediment and Stormwater Regulations*, DNREC, 2010. These scenarios were modeled to evaluate the impact of various stormwater management options on current and future subwatershed conditions. The scenarios that were modeled based on DNREC's recommendations include:

- Scenarios 1 through 4: this scenario evaluated the effectiveness of determining the allowable peak discharge for the 10-year event based on standard unit peak discharge for forested areas within the subwatershed.
- Scenarios 5 through 8: this scenario evaluated the effectiveness of determining the allowable peak discharge for the 100-year event based on standard unit peak discharge for forested areas within the subwatershed.
- Scenarios 9 through 12: this scenario evaluated the benefits that could be achieved by the implementation of runoff reduction practices that mimic predevelopment conditions in the developed areas.
- Scenarios 13 through 16: this scenario evaluated the effectiveness of adding 100 foot riparian buffers to reduce pollutants removal and peak flows.

Four of the 11 subwatersheds were selected for the "what-if" scenarios: Double Run, Hudson Branch, Pratt Branch, and Spring Branch. These subwatersheds were chosen based on their high growth potential and Poor or Very Poor subwatershed condition assessment (as discussed in Section 7).

8.1 SCENARIOS 1 THROUGH 4: STANDARDS-BASED UNIT DISCHARGE APPROACH – 10-YEAR

Based on the criteria proposed in the *Working Draft Sediment and Stormwater Regulations*, (DNREC 2010) the allowable peak discharge from the 10-year, 24-hour conveyance event was calculated by determining the total area of three land use/soil categories in the subwatershed and applying a pre-determined unit discharge rate to the total area of each category. The categories and their associated 10-year unit discharge rates are:

- Wooded/Forested area based on 2007 Land Use/Land Code (LULC) and Hydrologic Soil Group (HSG) A: 0 cfs/ac
- Wooded/Forested area based on 2007 LULC and HSG B, C, and D: 0.375 cfs/ac
- Non-Wooded/Forested area based on 2007 LULC: 0.75 cfs/ac

This standards-based approach was used to apply a unit discharge rate to each subwatershed for both existing and future conditions. The unit discharge results were initially obtained for the four selected subwatersheds by determining the total area of the three land use/soil categories in each subwatershed and applying the unit discharge, which resulted in a large difference from the HEC-HMS discharge values. This large difference was most likely due to the unit discharge method being solely a function of area, and intended to be applied at a site-scale level, instead of an area as large as the selected subwatersheds. The time for flow to travel through the subwatershed was not accounted for.

To account for the large difference in discharges that was initially obtained from applying the unit-discharge to the entire subwatershed area, a time factor coefficient was obtained by using the ratio of the HEC-HMS discharge results from both existing and future conditions and the discharge obtained from applying the unit-discharge rate to each total area of land use/soil category within the subwatershed based on the existing conditions. A time factor coefficient was obtained for each subwatershed for both existing and future conditions. The average ratio from the four selected subwatersheds, as well as results from applying this ratio for subwatersheds in a similar DNREC study being conducted in the Nanticoke River watershed, was used to obtain an average time factor coefficient that could be applied to other similarly sized subwatersheds. The calculated average time factor coefficients are listed in Table 8.1. By applying these time factor coefficients, the discharge results from applying the unit discharge method were more consistent with the results of the HMS model. These coefficients were applied to the initial unit discharge results to obtain the values in Table 8-1.

Table 8.1: Time Factor Coefficient Used for Unit Discharge Results

Time Factor Coefficient	
Existing Conditions Discharge	0.165
Future Conditions Discharge	0.215

The result of applying the 10-year unit discharge with a time factor coefficient was compared with the existing and future conditions discharge results from the HEC-HMS model for each subwatershed. These results are shown in Table 8-2.

Table 8.2: Results from Applying Unit Discharge for 10-Year, 24-Hour Conveyance Event

	Double Branch (6,081 ac)	Hudson Branch (6,862 ac)	Pratt Branch (4,169 ac)	Spring Creek (2,111 ac)
Unit Discharge Result: Existing Conditions (cfs)	708.86	818.72	489.09	223.18
Unit Discharge Result: Future Conditions (cfs)	925.06	1,068.43	638.26	291.25
HEC-HMS Discharge (cfs) Existing Conditions	829.00	631.70	385.10	262.20

	Double Branch (6,081 ac)	Hudson Branch (6,862 ac)	Pratt Branch (4,169 ac)	Spring Creek (2,111 ac)
HEC-HMS Discharge (cfs) Future Conditions	977.65	939.50	435.50	306.80

A standards-based approach of applying a unit discharge to a select subwatershed in order to set maximum allowable peak discharges for the subwatershed can be used if a few adjustments are made. Applying the unit discharges provided in the *Draft Stormwater and Sediment Regulations* (DNREC, 2010) to large subwatershed areas produces results that are much higher than results produced from HEC-HMS modeling. However, when the unit discharge method was applied to a smaller area, the results were similar to the discharges obtained from the HEC-HMS model. If the standards-based unit discharge method will be used in the regulations, there should be a limit on the area that it is applied to. Further investigation is needed to determine the maximum drainage area that the current method should be limited to. Otherwise, a more reasonable flow rate can be obtained for setting allowable peak discharges by using a time factor coefficient.

8.2 SCENARIOS 5 THROUGH 8: STANDARDS-BASED UNIT DISCHARGE APPROACH – 100-YEAR

Scenarios 5 through 8 are very similar to Scenarios 1 through 4. However, for Scenarios 5 through 8, the unit discharge analysis was completed for the flooding event (100-year, 24-hour). The allowable 100-year peak discharge for the selected subwatersheds was determined using the following categories and associated unit discharges:

- Wooded/Forested area based on 2007 LULC and HSG A: 0.25 cfs/ac
- Wooded/Forested area based on 2007 LULC and HSG B, C, and D: 1.25 cfs/ac
- Non-Wooded/Forested area based on 2007 LULC: 2.25 cfs/ac

The results of applying the 100-year unit discharge for each subwatershed was compared with the existing and future conditions discharge results from the HEC-HMS model. These results are shown in the Table 8-3.

Table 8.3: Unit Discharge Results for the 100-Year, 24-Hour Conveyance Event

	Double Branch (6,081 ac)	Hudson Branch (6,862 ac)	Pratt Branch (4,169 ac)	Spring Creek (2,111 ac)
Unit Discharge Result: Existing Conditions (cfs)	2,546.90	2,933.71	1,755.97	811.51
Unit Discharge Result: Future Conditions (cfs)	2,847.72	3,280.21	1,963.37	907.35
HEC-HMS Discharge (cfs) Existing Conditions	2,670.70	2,601.30	1,416.20	909.90
HEC-HMS Discharge (cfs) Future Conditions	2,938.70	2,792.40	1,516.60	995.90

The unit discharge results were obtained the same way for Scenarios 5 through 8 as for Scenarios 1 through 4 and a time factor coefficient was obtained in a similar manner.

The conclusions regarding scenarios 5 through 8 are the same as for scenarios 1 through 4, in that the applicability to large watersheds is not appropriate. Further, investigation is needed to determine the minimum drainage area this method should be limited to.

8.3 SCENARIOS 9 THROUGH 12: EFFECTIVE IMPERVIOUSNESS OF 0%

The Regulatory Advisor Committee (RAC) proposed another new performance criterion in the *Draft Sediment and Stormwater Regulations* (DNREC, 2010), which focuses on implementing runoff reduction practices for post-development areas to achieve an effective imperviousness of 0%. These criterion were based on the 1-year, 24-hour storm event. The purpose of proposing these regulations was to mimic pre-development conditions as closely as possible in developing watersheds. This scenario model was completed by converting land use marked as a growth area in the Kent County Comprehensive plan to open space. As a result, the Curve Number (CN) values for each subwatershed were adjusted based on the conversion of growth areas to open space. The CN is a parameter used to predict runoff and infiltration during a rain event. For more information on CNs and their selection, refer to Appendix C. The future conditions hydrologic model was run with new CN values obtained from the conversion of land use to open space.

For the basis of comparison, the future conditions hydrologic model was also run for 50% of land indicated to be a growth area converted to open space, and 50% left as a growth area. To determine the CN values for this portion, the average of the future and “what-if” CN value was used. This method was chosen because there were no definitive specifications from the Kent County Comprehensive Plan or DNREC on land that would or would not be developed. Land with development potential was simply included in the growth area. The 1-year recurrence interval storm was computed in the model. The results of this are shown in Table 8-4.

Table 8.4: Results for Future Conditions Hydrologic Model with Growth Zone Converted to Open Space

What-If Subwatershed	1-Year Discharge: Existing (cfs)	1-Year Discharge: Future (cfs)	1-Year Discharge: What-If (cfs)	1-Year Discharge: What-If 50/50 (cfs)
Double Run	110.1	153.8	97.8	123.6
Hudson Branch	119.5	157.1	103.1	128.7
Pratt Branch	35.8	46.5	54.1	49.6
Spring Creek	28.5	39.1	31.1	34.9

These values show the hydrologic impact that development could have on each of the selected subwatersheds. Furthermore, the comparison of discharges shows the effect of implementing stormwater management practices that reduce imperviousness from future development in potential growth areas. In general, the flow rates are reduced as a result of converting land use marked as growth areas to open space. For the Pratt Branch Subwatershed, the resulting discharges increased as a result of the land use conversion. This is due to the large amount of forested and wetland area that was located in the growth area. This CN value increased as a result of the land use conversion to open space.

The criterion of implementing stormwater management features to achieve 0% effective imperviousness seems to be an effective regulation. This could be an effective tool for enforcing land use regulations in developing areas in the watershed. By requiring the post-development hydrology to mimic conditions for open space land use, flow rates could be reduced in developing subwatersheds.

8.4 SCENARIOS 13 THROUGH 16: ADDING 100-FOOT RIPARIAN BUFFERS

Another "what-if" scenario that was investigated was how adding a 100-foot riparian buffer to all streams in the four selected subwatersheds would affect land and hydrology in the watershed. The riparian buffer area would serve as a transition between a stream and the land adjacent to the stream. These riparian buffer areas improve water quality and quantity by allowing runoff to be absorbed or infiltrated into the ground before it reaches the stream. The following was determined from the analysis of Scenarios 13 through 16:

- The amount of land area that would be affected
- The number of trees that would be planted in the buffer areas
- The area of land planned for future development that would be replaced with trees
- The impact on the percent imperviousness
- The estimated pollutant load reduction based on readily available data
- The impact on existing and future conditions hydrologic model results

GIS analysis was performed for the "what-if" subwatershed scenarios and yielded the results shown in Table 8.5 based on existing and future land use.

Table 8.5: Results from GIS Analysis of the Addition of Buffers to All Streams in the "What-If" Subwatersheds

Subwatershed	Area of Buffer (ac)	Possible Number of Trees Planted (320 per ac)	Future Development Area Impacted (ac)	Impervious Surface Area Impacted (ac)
Double Run (6,081 ac)	213.8	68,416	194.9	7.3
Hudson Branch (6,862 ac)	360.2	115,264	292.4	8.1
Pratt Branch (4,169 ac)	185.1	59,232	185.1	5.9
Spring Creek (2,111 ac)	89.8	28,736	89.8	0.3

A few assumptions were made to complete the hydrologic analysis. The land use of the riparian buffer was assumed to be Forested Wetland. Furthermore, the HSG was assumed to be "B." To be consistent with the existing and future hydrologic model, the CN values were reduced based on the method used previously for the hydrologic analysis. The Manning's n values for the overbanks were increased from between 0.12 and 0.15 to 0.25 to account for the forested area, and for channels they were increased from 0.05 to 0.06 to account for storage due to the addition of buffers. Also, the percentage of imperviousness was reduced in the model by the percent of impervious surface affected by the addition of riparian buffer. Based on the assumptions used to model the riparian buffers, there does not appear to be a significant reduction in discharges by adding the buffers, as seen in Tables 8-6 and 8-7.

Table 8.6: Discharge Results with the Addition of Buffers for Existing Conditions

What-If Subwatershed	Existing Conditions HEC-HMS Discharge (cfs)	Existing Conditions What-If Discharge with Buffer (cfs)	Percent Decrease
Double Run	2,670.70	2,611.5	2.27
Hudson Branch	2,601.30	2,542.6	2.31
Pratt Branch	1,416.20	1,391.6	1.77
Spring Creek	909.90	891.6	2.05

Table 8.7: Discharge Results with the Addition of Buffers for Future Conditions

What-If Subwatershed	Future Conditions HEC-HMS Discharge (cfs)	Future Conditions What-If Discharge with Buffer (cfs)	Percent Decrease
Double Run	2,938.6	2,867.4	2.48
Hudson Branch	2,792.4	2,725.1	2.47
Pratt Branch	1,516.6	1,487.5	1.96
Spring Creek	995.8	973.6	2.28

Although adding buffer areas to streams does not markedly reduce flows, the potential for pollutant reduction is high. The estimated pollutant load reduction that would result from adding a riparian buffer to all streams would be:

- 65% reduction in ground water nitrogen
- 60% reduction in surface water nitrogen
- 70% reduction in surface water phosphorus

This pollutant load reduction is based on the study *Riparian Buffers in the Murderkill Watershed*, DNREC, 2002, which attempted to replicate the effect of installing riparian buffers on natural waterways. Buffer effectiveness rates from a Maryland Lower Eastern Shore agricultural study were used along with calculated nutrient loading rates to determine the percentage of pollutant load reduction. This study was based on the buffer length being 100 feet. The actual pollutant load reduction from installing buffers in the selected subwatersheds could potentially be lower than the estimated percentages from the DNREC 2002 study because it is unrealistic to convert 100 percent of the area that is 100 feet on each side of each stream into riparian buffer area.

8.5 CONCLUSIONS

Based on the results of the "what-if" scenario analyses, the regulation criteria modeled for Scenarios 9 through 12 seem to be the most appropriate. By substituting open space land use into growth zone areas, or even portions of the growth zone areas, the future conditions discharge would be closer to the existing conditions flow rates. This criterion could be modeled more accurately once it is determined what specific parcels within the subwatersheds are planned for development.

Though not recommended as the most appropriate criteria, the standards-based unit discharge approaches analyzed in Scenarios 1 through 8 could be used for subwatershed analysis as long as a time factor coefficient is applied to the unit discharge flow rates. The standards-based methodology proposed in the *Draft Sediment and Stormwater Regulations* (DNREC, 2010) is more applicable at the site-specific level. Further investigation should be performed to determine the maximum applicable drainage area for applying the unit discharge directly without a time factor coefficient.

Applying a 100-foot buffer area to streams in the subwatersheds did not result in a significant reduction of flow. To achieve a greater reduction in flow, the addition of buffer areas could be used in conjunction with additional stormwater management measures that provide storage (discussed in Sections 9 and 10). By adding riparian buffer areas to streams in the watershed, there would most likely be a significant reduction in pollutants from runoff.

Section 9 Proposed Improvement Measures

As a part of this project, site-specific structural management alternatives are recommended to improve, restore, and enhance the natural resources of the Murderkill Watershed. The potential improvement measures were identified based on hydraulic analysis of crossings (Section 5), stream assessment (Section 6), and subwatershed assessments (Section 7). A cursory assessment of each measure was performed based on the following factors:

- Relative effectiveness or level of improvement
- Environmental impacts
- Cost considerations
- Constructability

Figure 9.1 shows the location of proposed improvement projects. The proposed structural projects were divided into two categories:

1. Water quality improvement projects
2. Crossings improvement projects

9.1 WATER QUALITY IMPROVEMENT PROJECTS

Water quality improvement projects would improve the water quality in the vicinity of the project area by reducing the total nitrogen, phosphorous, and sediment levels in the runoff, thereby benefiting the Murderkill Watershed. Due to the large size of the watershed and the scope of effort for this study, the proposed water quality improvement measures proposed in this section do not represent an exhaustive list of potential measures. Future targeted studies could be conducted to identify additional potential water quality improvements. Types of water quality projects recommended in the watershed include:

1. Improvements to riparian buffers
2. Stream improvements/restoration
3. New BMP/LID projects
4. New stormwater ponds/wetlands, stormwater pond retrofits, and lake management plans

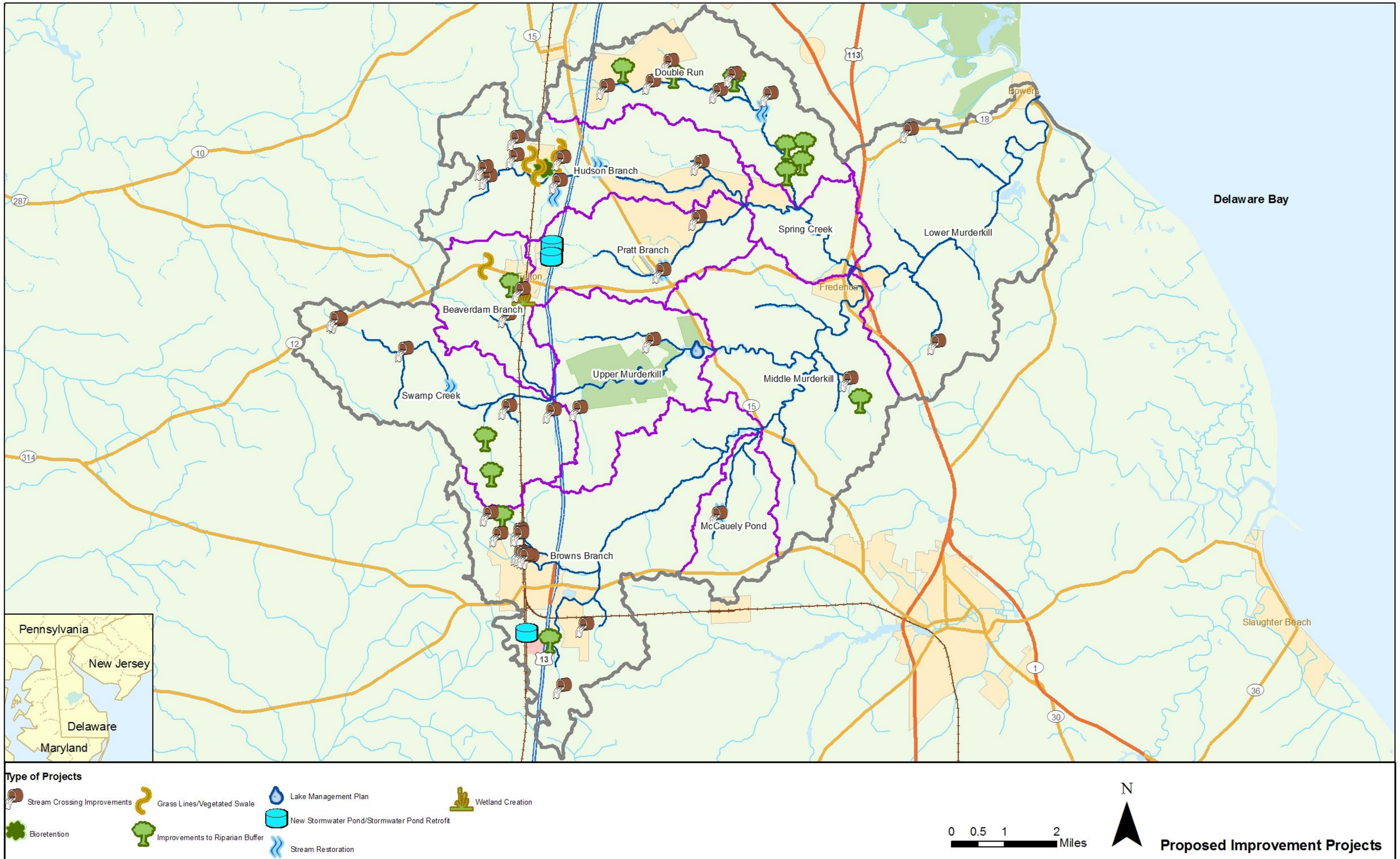


Figure 9.1: Location of Proposed Structural Improvement Projects

Improvements to riparian buffers: Based on the subwatershed assessment (Section 7), streams with inadequate buffers were identified and projects that would improve/restore the riparian buffers were proposed. Addition of riparian buffers to the selected project sites would reduce pollutant loads from the upstream land uses, thereby improving the water quality. Implementation requires minimum design efforts, and thus relatively low costs are anticipated for these projects. Thirteen sites for buffer improvements were identified throughout the Murderkill Watershed. All project sites except for two (Project ID 20 and 21) are located on privately owned land; therefore, easement/property acquisition will be required during project implementation. Project ID 20 is proposed on State Fair property, and Project ID 21 is proposed in an existing right-of-way; therefore, no ownership constraints are anticipated for those two sites. All project sites can be accessed from adjacent roads. Table 9.1 summarizes the proposed buffer improvement projects in the watershed.

Stream improvements/restoration: Based on the stream assessment (Section 6) and subwatershed assessment (Section 7), six stream segments were identified for potential stream restoration projects. Table 9.2 summarizes the proposed stream restoration projects in the watershed.

BMP/LID projects: BMP/LID projects would improve the water quality of the runoff from the upstream land uses in the drainage area by filtering pollutants such as nutrients and sediment before water reaches the stream system. Two types of BMP/LID projects are proposed for the watershed:

- Bioretention areas
- Grass-lined/vegetated swales with underdrain

Moderate costs are anticipated for the implementation of these projects, as they incorporate design elements and require engineering design. Environmental impacts/permit requirements are not anticipated for these projects. All the project sites are primarily located on private property; therefore, easement/property acquisition will be required for project implementation. Inclusion of check dams to control erosive velocities should be considered during the design of grass-lined/vegetated swales to ensure that the flow velocities are not erosive. Table 9.3 summarizes the proposed BMP/LID projects in the watershed.

New stormwater ponds/wetlands, stormwater pond retrofits, and lake management plans: Three stormwater pond retrofit projects and two new stormwater ponds/wetlands are proposed based on the subwatershed assessment (Section 7). Lake management plans for Coursey and Killens Ponds are also proposed to improve their water quality. Information on the proposed projects is provided in Table 9.4.

Table 9.1: Proposed Riparian Buffer Improvement Projects

Project ID	Subwatershed	Drainage Area and Land Use	Proposed Project Location and Description
1	Double Run	684 Acres; Agricultural, Deciduous Forest, Non-tidal forested wetland, Residential.	Improvements to 4,800 linear feet of riparian buffers for Thorndyke Branch from Millchop Lane to Woodlytown Road.
2	Double Run	344 Acres; Cropland, Residential, Non-tidal Forested Wetlands.	Improvements to 5,600 linear feet of riparian buffer for Tributary of Double Branch from Walnut Shade Road to Cherry Drive.
3	Double Run	110 Acres; Cropland, Single-family dwellings, Non-tidal forested wetlands.	Improvements to approximately 3,300 linear feet of riparian buffer for Tributary of Double Branch near Sophers Row.
4	Double Run	152 Acres; Cropland, Mixed Forest	Improvements to riparian buffers for the Tributary of Double Branch. The project extends 1,700 linear feet upstream and 2,100 linear feet downstream of Evidence Road.
5	Double Run	94 Acres; Cropland	Improvements to approximately 2,700 linear feet of riparian buffer for Tributary of Double Run north of Barratts Chapel Road.
6	Double Run	208 Acres; Cropland, Residential, Non-tidal forested wetlands.	Improvements to approximately 1,500 linear feet of riparian buffer for the Tributary of Double Branch west of Buffalo Road.
7	Double Run	60 Acres; Residential	Improvements to approximately 2,700 linear feet of riparian buffer for Tributary of Double Run from CR-30 to Flint Drive.
20	Browns Branch	N/A; Recreational, Agricultural, Residential	Improvements to approximately 13,800 linear feet of riparian buffer for State Fair Property and surrounding area between Farmington Road and Corn Crib Road.
21	Browns Branch	N/A; Agricultural	Improvements to approximately 7,200 linear feet of riparian buffers for the unnamed stream crossing Little Mastens Road.
22	Swamp Creek	N/A; Agricultural	Improvements to approximately 7,100 linear feet of riparian buffers for Tributary of Swamp Creek crossing Hopkins Cemetery Road.
23	Beaverdam Branch	N/A; Agricultural, Residential	Improvements to approximately 8,700 linear feet of riparian buffers for Fan Tax Ditch from Peach Basket Road to Lombard Street.
29	Swamp Creek	N/A; Agricultural, Residential	Improvements to approximately 6,700 linear feet of riparian buffer for Black Swamp Creek along Little Mastens Corner Road until Paradise Alley Road.
30	Middle Murderkill	N/A; Agricultural	Improvements to approximately 6,200 feet of riparian buffer for Tributary to Middle Murderkill River at West farm from Blue Jay Lane to Fork Landing Road.

Table 9.2: Proposed Stream Restoration Projects

Project ID	Subwatershed	Drainage Area and Land Use	Project Location and Description	Cursory Project Assessment
8	Hudson Branch	406 Acres; Cropland, Residential, Transitional	Restoration of approximately 7,200 linear feet of Tributary to Hudson Branch between Tomahawk Lane and US13. Project includes erosion control methods along banks and removal of excess vegetation.	This project will help reduce the sediment loads in the streams and stabilize the channel banks, thereby improving the instream water quality and habitat. Some of the sections of the stream are buffered by forests, so some trees may be affected during project implementation. The project site can be accessed from Plymouth Road or Turkey Point Road. Majority of the project site is on private property; therefore, easement/property acquisition will be required. Relatively high cost is anticipated for project implementation.
28	Swamp Creek	N/A; Agricultural	Restoration of approximately 13,500 linear feet of Black Swamp Creek from Hopkins Cemetery Road to Little Mastens Corner Road. Project includes providing erosion control and bank stabilization.	Implementation of this project will help reduce the sediment transportation in the channel, thereby providing stable habitat along restored banks and improving overall instream water quality and habitat. The project site can be accessed from either Hopkins Cemetery road at the upstream end or from Little Mastens Corner Road from the downstream end. The stream is buffered by forests, so some trees may be affected during project implementation. High implementation cost is anticipated for the project. The entire project area is on private land; therefore, coordination with owners will be required for easement/property acquisition.
31	Double Run	4038 Acres Residential, Agricultural	Restoration of 500 linear feet of the Double Branch River from downstream of culvert under Irish Hill Road. Project includes addition of grade control measures by installing cross vanes, constructed riffles, rock sills, and/or rock winding for the high vertical, unstable banks.	Implementation of this project would prevent bed degradation and improve aquatic habitat through the development of alternating riffles and pools. The stream is buffered by forests, so grading of existing channel will require some tree removal. Relatively high implementation costs are anticipated for this project. The project site can be accessed from Irish Hill Road. Some parts of the project site are located on private property; therefore, easement/property acquisition will be required.
32	Hudson Branch	1920 Acres; Residential	Restoration of 500 linear feet of Hudson Branch from downstream of culvert under Canterbury Road. Project includes implementation of grade control measures by installing cross vanes, constructed riffles, rock sills, and/or rock winding for the high vertical, unstable banks.	Implementation of this project would prevent bed degradation and improve aquatic habitat through the development of alternating riffles and pools. The stream is buffered by forests, so grading of existing channel will require some tree removal. Relatively high costs are anticipated for the implementation of this project. The project site can be accessed from Canterbury Road. The entire project area is located on private land; therefore, coordination with owners will be required for easement/property acquisition.

Project ID	Subwatershed	Drainage Area and Land Use	Project Location and Description	Cursory Project Assessment
33	Pratt Branch	2,304 Acres; Residential, Agricultural, Non-tidal forested	Restoration of 500 linear feet of Pratt Branch from downstream of culvert under Canterbury Road near Felton. Project; includes identification of upstream sediment sources and addition of possible BMPs in the riparian buffers to control the flow of sediment loads into the stream.	This project would improve the overall health of the stream and instream habitat. Moderate implementation costs are anticipated. The project site can be accessed from Canterbury Road. Easement/property acquisition will be required, as the project area is entirely on private property.
34	McCauley Pond	896 Acres; Residential, Agricultural, Non-tidal forested	Restoration of 500 feet of Tributary to McCauley Pond from downstream of culvert under Bloomfield Drive. Project includes identification of upstream sediment sources and implementation of potential BMPs in the riparian buffers to control the flow of sediment loads into the stream.	This project would improve the overall health of the stream and instream habitat. . Moderate implementation costs are anticipated. The project site can be accessed from Bloomfield Drive. Easement/property acquisition will be required, as most of the project area is on private property.

Table 9.3: Proposed BMP/LID Projects

Project ID	BMP/LID Type	Subwatershed	Drainage Area and Land Use	Project Description and Location	Accessibility to Project Site
9	Grass-Lined/Vegetated Swale	Hudson Branch	44 Acres; Farmstead, Residential, Commercial	1,800 linear feet of vegetated swale is recommended in the open area between Fence Post Lane and Howard Street.	The project site has good access from Howard Street.
10	Grass-Lined/Vegetated Swale	Hudson Branch	1.5 Acres; Residential	300 linear feet of vegetated swale is recommended north of Evens Road.	The project site has good access from Evens Road.
11	Grass-Lined/Vegetated Swale	Hudson Branch	1.5 Acres; Residential	300 linear feet of vegetated swale is recommended south of Evens Road.	The project site has good access from Evens Road.
12	Grass-Lined/Vegetated Swale	Hudson Branch	36 Acres; Other urban or built-up land, Residential	830 linear feet of grass swale along Evens Road is recommended.	The project site has good access from Evens Road.
13	Bioretention Areas	Hudson Branch	11 Acres; Residential	776 linear feet of bioretention areas west of King Lane are proposed to capture runoff from residential areas.	The project site has good access from King Lane.
14	Bioretention Areas	Hudson Branch	11 Acres; Residential	776 linear feet of bioretention areas east of King Lane are proposed to capture runoff from residential areas.	The project site has good access from King Lane.
15	Grass-Lined/Vegetated Swale	Hudson Branch	31 Acres; Residential	2,170 linear feet grass swale along Turkey Point Road is recommended to capture stormwater from residential areas.	The project site has good access from Turkey Point Road.
25	Grass-Lined/Vegetated Swale	Beaverdam Branch	N/A; Residential	2,600 linear feet of grass swale along SR-12 is recommended to capture stormwater from residential areas in downtown Felton.	The project site has good access from SR-12.

Table 9.4: Proposed Stormwater Pond and Lake Management Projects

Project ID	Project Type	Subwatershed	Drainage Area and Land Use	Project Description and Location	Cursory Project Assessment
16	Stormwater Pond Retrofit/ Improvements	Pratt Branch	18 Acres; Residential	Retrofit of the stormwater pond located along Burchneal Court is recommended. The proposed recommendations include excavation of the pond to increase the storage volume and addition of BMPs such as forebays to treat the runoff for water quality. Installation of a multi-stage PVC riser structure is also recommended to improve the management of peak flows.	Retrofitting the pond with a multi-stage PVC riser would reduce peakflows, thereby reducing flooding. Constructing pre-treatment basins would significantly improve the intake of nutrients from the runoff. The site is easily accessed from Burchneal Court. An existing wooded area next to the pond may be impacted during project implementation. Moderate cost is anticipated for this project.
17	Stormwater Pond Retrofit/ Improvements	Pratt Branch	10 Acres; Residential	Existing stormwater pond west of US13 is recommended to be expanded to increase the storage volume.	Retrofitting the pond would provide water quality treatment and quantity management for the runoff. The facility can be accessed from Jubilee Court. Even though the project site is located on private property, no major ownership constraints are anticipated because there is already an existing facility at the project site. Moderate implementation cost is anticipated for this project.
18	Stormwater Pond Retrofit	Pratt Branch	4.7 Acres; Transitional	The existing facility behind US13 is proposed to be retrofitted/converted to a wetland.	The proposed project would provide water quality treatment and quantity management for the runoff from residential areas. Expanding the existing pond and creating a wetland would be of relatively high cost. Even though the project site is located on private property, no major ownership constraints are anticipated because there is already an existing facility at the project site.
19	New Stormwater Pond	Browns Branch	N/A; Recreational (State Fair Property)	Possible opportunities for implementation of stormwater management facilities to treat the runoff from the State Fair property.	Depending on the type of stormwater management facility constructed, the proposed project would provide water quality treatment and quantity control for the runoff from the State Fair property. Implementation cost of the project would be relatively high because it would include soil removal and engineering techniques. As the property is publicly owned, no ownership constraints are anticipated during project implementation. The project site can be accessed from Fairgrounds Road.

Project ID	Project Type	Subwatershed	Drainage Area and Land Use	Project Description and Location	Cursory Project Assessment
24	Wetland Creation	Beaverdam Branch	N/A; Gravel site	The gravel site behind Lombard Street is proposed to be converted to a wetland.	Implementation of wetland would treat the runoff and manage flooding in this area of Felton. Due to significant engineering construction costs, implementation cost of this project would be relatively high. The project site has easy access from Lombard Street/Little Mastens Corner Road. No ownership constrains anticipated for project implementation as the project site is publicly owned.
26	Lake Management Plan	Upper Murderkill	N/A; Agricultural, Residential	Proposed project includes development of a lake management plan for Coursey Pond by including management of conservation areas, buffer networks, and maintenance of stormwater practices, septic systems, and sewer networks.	A lake management plan would improve the water quality of the pond. As no major engineering activities are expected, implementation of this project would be relatively inexpensive. No ownership constraints are anticipated, as the project area is publicly owned. The project site can be accessed from SR-15.
27	Lake Management Plan	Upper Murderkill	N/A; Agricultural, Residential, Recreational (Killens Pond State Park)	Proposed project includes development of a lake management plan for Killens Pond by including management of conservation areas, buffer networks, and maintenance of stormwater practices, septic systems, and sewer networks.	A lake management plan would improve the water quality of the pond. As no major engineering activities are expected, implementation of this project would be relatively inexpensive. No ownership constraints are anticipated, as the project area is publicly owned. The project site can be accessed from Killens Pond Road.

9.2 CROSSING IMPROVEMENT PROJECTS

The hydraulic analysis for the crossings identified the culverts and the bridges that were overtopped for the road's design storms (25-year or 50-year, depending on the road classification) for existing and future conditions (Section 5). Improvement measures were recommended for all overtopped structures to address the structures' deficiency in conveyance capacity. Forty overtopped structures were identified from hydraulic analysis. However, improvements were recommended for only 38 structures because one of the crossings (URS50) conveys 97% of the future conditions flow and 100% of existing conditions flow with 1 foot of freeboard, and the other crossing (URS56) is a 105-foot-long pipe on private property.

These 38 crossings selected for improvements were categorized as follows:

(1) Crossings that pass the design storm with no freeboard, but do not have capacity to pass the design flow under both existing and future conditions with 1 foot of freeboard. (Yellow category)

(2) Crossings that overtop the road under either existing and/or future conditions (Red Category)

Table 9.5 and Table 9.6 illustrate the proposed improvements recommended for each crossing for Yellow and Red categories.

Table 9.5: Proposed Culvert Improvements (Yellow Category)

Crossing ID	Field Observations of the Crossing	Conveys design storm with 1' freeboard		Recommended Improvement Measures
		Existing Conditions	Future Conditions	
239A	Twin 60”x84” elliptical corrugated metal pipes under Firetown Road.	No	No	The proposed recommendation is to install an additional pipe of the same size (60”x84”) to increase the conveyance capacity.
290A	A 42”x72” elliptical corrugated metal pipe under Pea Hill Road. Home appliances and trash observed at the downstream end of the culvert.	No	No	The proposed recommendation is to install an additional pipe of the same size (42”x72”) to increase the conveyance capacity. Removal of trash and debris at the downstream end is also recommended.
290B	Twin 54” corrugated metal pipes circular culvert under Pea Hill Road.	No	No	The culvert would be replaced with a twin 60”x120” reinforced concrete box culverts with 35^{o} to 75^{o} wingwall flares to the barrel.
386A	Twin 48”x72” elliptical corrugated metal pipes under Scrap Tavern Road	Yes	No	The existing culvert would be replaced with twin 48”x76” elliptical reinforced concrete pipes and a square edge with headwall ends should be installed to convey the future conditions flow.
78A	Two circular reinforced concrete pipes of 36” and 30” diameter under Little Mastens Corner Road	Yes	No	A reinforced concrete pipe of 36” diameter should be added to the existing pipes to convey the future conditions flows.
URS33	Twin 36” diameter circular reinforced concrete pipes under Bowers Beach Road. Evidence of beaver dam at the downstream side of the culvert.	No	No	A reinforced concrete pipe of 36” diameter should be added to the existing pipes to convey the future conditions flows. Removal of the beaver dam is also recommended to avoid potential culvert blockage.
URS42	A 42”x72” elliptical corrugated metal pipe under Bloomfield Drive.	No	No	The proposed recommendations include addition of another pipe of the same dimensions as the existing pipe (42”x72”) to increase the conveyance capacity. Residential areas at the upstream end of the crossing must be considered during project implementation for any ownership constraints.
URS48	Twin 48”x72” elliptical corrugated metal pipes under Weiner Avenue.	No	No	The proposed recommendation includes addition of another pipe of the same dimensions as the existing pipe (48”x72”) to increase the conveyance capacity.
URS58	Twin 54” diameter circular, corrugated metal pipes under Second Avenue.	No	No	The proposed improvements include addition of another pipe with same dimensions as the existing pipe (54”) and installation of headwalls to stabilize the soil conditions around the inlet and outlet areas.

Table 9.6: Proposed Culvert Improvements (Red Category)

Crossing ID	Current Conditions	Conveys design storm with no freeboard		Recommended Improvement Measures
		Existing Conditions	Future Conditions	
033A	Three elliptical corrugated metal pipes of size 54”x66” under Canterbury Road.	No	No	The existing culvert would be replaced by three reinforced concrete elliptical pipes of 58”x91” dimensions; headwall installation is proposed to stabilize the soil conditions around inlet and outlet areas.
105A	Twin 72” diameter circular corrugated metal pipes under Peachtree Road.	No	No	Proposed improvement measures include replacing the culvert with three 72” diameter circular reinforced concrete pipes and installing headwalls to stabilize the soil conditions around inlet and outlet areas.
106A	Twin 72” diameter circular corrugated metal pipes under Woodlytown Road.	No	No	The crossing would be replaced by three 72’’x84’’ reinforced concrete box culverts with 35^{o} to 75^{o} wingwall flares to the barrel.
281A	Twin 48”x72” corrugated metal pipes under Hopkins Cemetery Road.	No	No	The culvert would be replaced by twin 54’’x96’’ reinforced concrete box culverts with 35^{o} to 75^{o} wingwall flares to the barrel.
282B	Twin 36” diameter circular reinforced concrete pipes under Marshyhope Road.	No	No	Another 36” diameter pipe would be added to the existing pipe to increase the conveyance capacity of the crossing.
371B	A 72” diameter circular corrugated metal pipe under Barratts Chapel Road.	No	No	The proposed recommendations include addition of another pipe of the same dimension (72”) to increase the conveyance capacity.
URS10	A 36” diameter circular reinforced concrete pipe under Paradise Alley Road.	No	No	The existing crossing would be replaced by twin 36’’x72’’ reinforced concrete box culverts to convey the design flows.
URS12	A 48” diameter circular reinforced concrete pipe under Lombard Street.	Yes	No	The deck height of 3.47 feet was observed in the field. Increasing the diameter of the pipe by 1 foot (60" pipe) would convey the existing and future conditions flows. Implementation of proposed improvements would involve disturbing the existing concrete headwall.
URS14	A 42" diameter circular reinforced concrete pipe under Plymouth Road. Downstream end of the culvert is filled with organic debris.	No	No	Another 42" diameter pipe would be added to the existing pipe to increase the conveyance capacity of the crossing.
URS17	A 48” diameter circular reinforced concrete pipe under Barney Jenkins Road. Evidence of beaver dam at the downstream side of the culvert.	No	No	The proposed recommendation includes addition of another pipe of the same size (48") to increase the conveyance capacity. Removal of the beaver dam is also recommended to avoid potential culvert blockage.
URS20	A 30"x48" reinforced concrete box culvert under W. Evens Road.	No	No	The span of the box culvert would be increased by 12.” Residential areas upstream of the culvert should be considered during the implementation of the project for any space constraints.
URS21	A 36” diameter circular reinforced concrete pipe under W. Evens Road.	No	No	Another 36" diameter pipe would be added to the existing culvert to increase the conveyance capacity of the crossing.

Crossing ID	Current Conditions	Conveys design storm with no freeboard		Recommended Improvement Measures
		Existing Conditions	Future Conditions	
URS22	A 36” diameter circular reinforced concrete pipe under Friedel Road.	Yes	No	A deck height of 3.0 feet was observed in the field. Replacing the existing pipe by a 48" diameter pipe is proposed to accommodate the design flows.
URS23	A 42” diameter circular reinforced concrete pipe under Evens Road. Spalled concrete was observed at the upstream end of the pipe.	No	No	Another 42" diameter pipe would be added to the existing culvert to increase the conveyance capacity of the crossing.
URS28	A 42” diameter circular reinforced concrete pipe under Black Swamp Road.	No	No	The culvert would be replaced by twin 42"x78" reinforced concrete box culverts with 30° to 75° wingwall flares.
URS29	A 48” diameter circular reinforced concrete pipe under Burnite Mill Road	No	No	The crossing would be replaced by twin 4'x4' reinforced concrete box culverts with headwalls parallel to the embankment.
URS3	A 39” diameter circular reinforced concrete pipe under Lake Drive.	No	No	The crossing would be replaced by twin 42” diameter pipes to increase the conveyance capacity.
URS32	A 30”x66” elliptical corrugated metal pipe under Little Mastens Corner Road.	No	No	The crossing would be replaced by twin 38"x60" elliptical reinforced concrete pipes and a square edge with headwall would be installed at the ends.
URS34	A 36” diameter circular reinforced concrete pipe under Anderson Road.	No	No	Another 36" diameter pipe would be added to the existing culvert to increase the conveyance capacity of the crossing.
URS35	A 36” diameter circular reinforced concrete pipe under Woodlytown Road.	No	No	The existing culvert would be replaced by three 42"x60" reinforced concrete box culverts and 30° to 75° wingwall flares would be installed to stabilize soil at inlet and outlet areas.
URS36	A 48”x72” elliptical corrugated metal pipe under Millchop Lane.	No	No	The proposed recommendations include addition of another pipe of the same size (48"x72") to increase the conveyance capacity.
URS43	A 48” diameter circular corrugated metal pipe under the Gun And Rod Club Road.	No	No	The proposed recommendations include addition of another pipe of the same size (48") to increase the conveyance capacity. Implementation of the proposed project would involve disturbing the concrete bag headwall around the pipe.
URS44	A 42”x60” elliptical corrugated metal pipe under Central Park Drive	No	No	Proposed recommendations include replacing the existing crossing with twin 43"x68" elliptical reinforced concrete pipes and installing square edge headwalls at the inlets. Residential areas around the crossing must be considered during project implementation for ownership constraints.
URS47	A 60” diameter circular corrugated metal pipe under Fork Landing Road	Yes	No	Another 60" diameter pipe is proposed to be added to the existing culvert to increase the conveyance capacity of the crossing. Residential areas around the crossing must be considered during project implementation for ownership constraints.
URS52	Twin 24” diameter circular	No	No	Another 24" diameter RC pipe is proposed to be

Crossing ID	Current Conditions	Conveys design storm with no freeboard		Recommended Improvement Measures
		Existing Conditions	Future Conditions	
	reinforced concrete pipes under Milford Neck Road.			added to the existing pipes to convey the existing and future conditions flows.
URS57	A 48" diameter circular pipe. Field observations indicate the material of the pipe changes from corrugated metal pipe to cast iron/ductile iron. The crossing is under a railroad track. Trash and tires were observed at the upstream and downstream ends of the culvert.	No	No	Another 48" diameter pipe is proposed to be added to the existing culvert to increase the conveyance capacity of the crossing. Ownership constraints may arise during the implementation of the project because the railroad is privately owned by Norfolk Southern Railways.
URS59	A twin 42"x60" elliptical corrugated metal pipe under Harrington Avenue.	Yes	No	Proposed recommendations include replacing the existing crossing with twin 43"x68" elliptical reinforced concrete pipes and installing square edge headwalls at inlets and outlets.
URS8	A 36" diameter, circular reinforced concrete pipe under Paradise Alley Road. Fallen trees and organic debris observed at the downstream end of culvert.	No	No	The proposed recommendations include addition of another pipe of the same dimension (36") to increase the conveyance capacity. Removal of debris is also recommended.
URS9	A 36" diameter, circular reinforced concrete pipe under Paradise Alley Road.	No	No	The proposed recommendations include addition of another pipe of the same dimension (36") to increase the conveyance capacity.

Section 10 Management Strategies and Action Items

This section describes watershed-wide improvement measures and strategies that could be adopted for effective management of the watershed and to improve the quality of stormwater runoff. These are programmatic types of practices involving outreach activity, community education, policy changes, and economic instruments; they do not require traditional fixed permanent facilities. These improvement measures along with the structural management and LID projects represent a holistic approach to watershed management.

This section describes the watershed-wide management measures that are recommended for implementation in Murderkill Watershed.

- **Septic systems:** According to Delaware Phase I Watershed Implementation Plan (WIP, DNREC, 2010) septic tank nutrient leaching is one of the main sources of non-point source pollution in Murderkill Watershed. Approximately 5,000 individual septic tanks are identified in the watershed, with most of them being located in the Double Run and Hudson Branch Subwatersheds. Leakage of nitrogen from these systems poses a threat to ground water quality. Implementation of the following strategies would help reduce the impact on water quality through septic leaching:
  - **Regular cleanout of the septic system:** On-site wastewater treatment and disposal systems (OWTDSs) are required by permit conditions to have the septic tank pumped out once every 3 years. Regular cleanout of the septic system would help prevent the contamination of water quality due to seepage of septic effluent.
  - **Retrofitting existing septic system:** Existing septic systems that are failing contribute to the nitrogen leaching into the ground water system. Retrofitting the failing septic tanks with supplemental treatment would reduce impacts on ground water. Water bodies that have been impaired by failing septic systems should be identified, and septic systems close to the water bodies should be retrofitted to avoid further degradation of water quality.
  - **New septic system:** Installation of new septic systems should be certified by a professional who should perform a site assessment of ground water conditions and propose a suitable design for the new system. Installing an alternative supplemental treatment system to reduce pathogens and nutrientsis recommended.
  - **Centralized sewer service:** Implementation of a centralized sewer service that would convey household discharges to wastewater treatment plants could be an alternative to individual home septic systems. This would eliminate the expense of regular maintenance and pumping out of the septic tank and reduce septic leachate contamination of ground water.
- **Stormwater management:** The CWP's Technical Memorandum reports that the watershed will receive 35% of Kent County's growth, which would primarily be from low-density residential areas. Minimum commercial and industrial development is expected. Hudson Branch, Pratt Branch, and Double Run Subwatersheds are predicted to have the most development in the watershed. Residential development increases the impervious cover in the subwatershed, which results in increased surface runoff. The

following are some of the management strategies that would help reduce runoff and nutrient loads due to residential development:

- **Environmental Site Design:** ESD is a comprehensive approach of using small-scale stormwater management practices, nonstructural techniques, and better site planning to mimic natural hydrologic runoff characteristics and minimize the impact of land development on water resources. Adopting environmental site design principles in planning the layout for new development would provide more benefits with fewer impacts on natural resources.
- **Erosion and sediment control:** All new construction activities involve disturbing an area of earth. If proper erosion and sediment control measures are not adopted, sediment may be transported into the downstream conveyance system through surface runoff. Current Delaware erosion and sediment control regulations require an approved sediment and stormwater plan for any construction activity that disturbs 5000 square feet or more. More stringent measures have to be adopted by local municipalities, and effects of downstream conveyance systems must be analyzed before any new construction activity. Clustering any new development would also minimize the area of disturbance.
- **Storm drain stenciling programs:** A storm drain stenciling program involves marking storm drain inlets with information to avoid dumping of trash and pollutants into the drains by the public. Local municipalities could adopt this program in residential areas to educate the public on the consequences of illegal dumping and its effects on water quality.
- **Preserving source water protection areas by land conservation/acquisition program:** Land conservation programs for the preservation of areas identified as having “excellent ground water recharge potential” by the SWAP Program should be adopted. These protected areas could be converted to public parks, forested areas, or easements to conserve wildlife habitat and protect them from urban development.
- **Large land owners:** GIS analysis of the parcel database concluded that there are approximately 182 land owners who own parcel areas greater than 100 acres and about 59 owners who own parcels greater than 200 acres. The state and local authorities could work with large land owners in the watershed regarding the possible implementation of stormwater management facilities on their property by providing them with suitable incentives.
- **Street sweeping and catch basin cleanout:** Street sweeping programs involve sweeping roads, gutters, and parking lots to remove trash, debris, and dirt from the surface to prevent its washing off into the streams. The Delaware Phase I WIP (DNREC, 2010b) reports that the state currently does not have a record of street sweeping activities. DelDOT and the local governments could develop a comprehensive plan for street sweeping activities for the watershed that would involve keeping a log of the number of miles swept, frequency of sweeping, and amount of waste collected. If efficiently performed, street sweeping could be used as a primary treatment for the pollutants. Another alternative to street sweeping is catch basin cleanout, which involves periodic cleaning of storm drain inlets to remove accumulated materials that would clog the drain and reduce its efficiency. Regular

cleanout schedules for the storm drains could be established to retain their performance.

- **Community outreach and education:** Outreach and education programs educate the public on potential pollutants and how misusing them affects our water resources. These programs are intended to change pollutant-causing behaviors, thereby reducing pollutant loads in the watershed.
  - **Lawn care, turf management, and pet waste:** Proper lawn care practices help prevent nitrogen, phosphorous, insecticides, and herbicides from entering water bodies. Homeowners should be educated on practices like soil testing, fertilizer application, and pesticide use. Excess nutrients and harmful bacteria from pet waste enter streams through runoff. Outreach programs should include educating the public on the effects of pet waste on streams and lakes, posting signs, and installing publicly available disposable containers for pet waste. Even though the Murderkill Watershed is primarily an agricultural based watershed, these programs can be effectively implemented in the residential areas of the watershed and future residential areas.
  - **Impervious disconnections and rain garden/rain barrel programs:** These are practices that reduce runoff by decreasing impervious area with such methods as small-scale storage, infiltration, or redirection to pervious areas. Rain barrels, downspout disconnection, and rain gardens are some of the practices that could be adopted to achieve impervious disconnection. Programs could be established to educate the public on the effects of these programs on water quality and incentives could be awarded for homeowners for adopting these green technologies.
- **Forestry Management:** Murderkill Watershed is approximately 11% forested. It was concluded from the "what-if" modeling scenario that implementation of 100-foot buffers along streams would reduce 60 to 65% of nitrogen and 70% of phosphorous in ground water. Increasing forest or tree cover in the watershed would play a vital role in reducing the nutrient runoff into streams.
  - **Homeowner tree planting program:** This program would encourage converting turf area on a residential lot to tree cover. Programs could be developed that would encourage planting and preserving trees on private properties, both residential and rural.
  - **Timber management programs:** Delaware Forest Service currently keeps track of all timber harvesting done in the state. Permits are required for the conversion of forested area to development and agriculture. The Forest Service issues permits for all logging activity on more than 1 acre. Programs that address erosion and runoff issues due to forest harvesting should be implemented. Adopting a timber stand improvement program would promote diversity; maintain wild life corridors, stream sides, and buffer zones; and preserve natural ecosystems.
  - **Trees on public/state lands:** A cursory assessment of the existing tree cover on public/state owned land is recommended to be performed in order to recommend tree planting programs on these properties.

- **Agricultural and livestock operations:** Agriculture is the major land use type in Murderkill Watershed. Agricultural activities such as excessive application of pesticides and fertilizers, cultivation, and animal feeding operations contribute to the contamination of surface and ground waters. Pollutants like nutrients, sediment, and pesticides enter the streams through surface runoff and cause eutrophication. Listed below are some of the non-structural BMPs that could be implemented to improve the quality of agricultural runoff.
    - **Adopting a Nutrient Management Plan:** The state of Delaware currently has a Nutrient Management Law that limits the usage of phosphorous in agricultural applications. Further improvements that would emphasize the application procedures, amounts, and timing of fertilizer application could be made to the existing law.
    - **Soil testing:** Farmers should be encouraged to assess the fertility of soil by getting the soil tested in a laboratory. A soil test report indicates the composition of nutrients and pH, thus limiting the over application of nutrients leading to ground and surface water contamination. More research needs to be done in order to develop suitable programs that would include educating the farmers on the advantages of soil testing and provide that provide incentives for the participants of the program.
    - **Animal feeding operations:** DNREC oversees the National Pollutant Discharge Elimination System (NPDES) permits for concentrated animal feeding operations. The Delaware WIP (DNREC, 2010) for the Chesapeake Bay TMDL concluded that not all Concentrated Animal Feeding Operations (CAFOs) and Animal Feeding Operations (AFOs) throughout state of Delaware have been accounted for. A watershed-wide accurate assessment of the CAFOs and AFOs by DNREC is recommended to be conducted for implementation of suitable BMPs at these facilities.
    - **Erosion and sediment control practices:** Sediment enters streams and lakes through erosion and transports nutrients that are attached to it. Erosion and sediment control practices such as use of grass filter strips or buffer areas between agricultural lands and adjoining water bodies which help in reducing the transportation of nutrients through erosion should be recommended.
    - **Education program:** Local and state governments, along with soil conservation districts, should focus on outreach programs that would provide technical/financial assistance to the farmers by educating them on the implementation of agricultural BMPs such as cover crops, use of bio-fertilizers, and waste management programs.

Section 11 Implementation Recommendations

The recommendations for Murderkill Watershed are a compilation of numerous structural improvement projects and various management strategies. Specific recommendations are described in Section 9 (Proposed Improvement Measures) and Section 10 (Management Strategies and Action Items). These recommendations were identified by analyzing the current conditions of the subwatershed and considering possible future development conditions in each of them. The sections below discuss the implementation prioritization.

11.1 SUBWATERSHED PRIORITIZATION

Based on the subwatershed assessment, Double Run and Hudson Branch were assessed to be "Very Poor," and Pratt Branch and Browns Branch were assessed to be "Poor" in terms of overall health of the subwatershed. These subwatersheds also have a high potential for future development because they are in the Kent County Growth Zone. URS gave priority to these subwatersheds when we developed recommendations for projects that would help achieve a quantifiable improvement. Even though Spring Creek Branch was assessed as "Good," a high priority was given to this subwatershed because it has a high likelihood of being developed. The remaining subwatersheds were assessed as either "Fair" or "Good" but were also assessed for any water quality concerns, and suitable projects were proposed. The types of projects proposed and prioritization of the subwatersheds is provided in Table 11.11.

Table 11.1: Subwatershed Prioritization

Subwatershed	Priority	Type of Projects: Improvement of Riparian Buffers	Type of Projects: Improvement of Crossings/ Obstructions	Type of Projects: Implementation of Stormwater Management Facilities	Type of Projects: Implementation of Stream Restoration Projects	Comments on Prioritization
Beaverdam Branch	Medium	X	X	X		Low probability of future development, inadequate riparian buffers, overtopping crossings, and stormwater management.
Browns Branch	High	X	X	X		High impervious cover, uncontrolled stormwater runoff, and inadequate riparian buffers.
Double Run	High	X	X		X	Inadequate buffers, high probability of future development, streams with high unstable banks, and highest number of crossings that overtop the design storms.
Hudson Branch	High		X	X	X	Eroding streams with high unstable banks, high probability of future development and hydraulically deficient crossings that overtop the design storms.
Lower Murderkill	Low		X			Least developed subwatershed with a low likelihood of being developed, one overtopping structure.
McCauley Pond	Low		X		X	Highest forest cover, low potential for future development, one overtopping structure.
Middle Murderkill	Low	X	X			Low potential for future development, one overtopping structure.
Pratt Branch	High		X	X	X	High probability of future development, hydraulically deficient crossings, streams with high sediment loads.
Spring Creek	Medium					High probability of future development. (No proposed projects recommended in the subwatershed)
Swamp Creek	Medium	X	X		X	Inadequate buffers, eroded streams with high sediment loads, and hydraulically deficient crossings.
Upper Murderkill	Low		X	X		High forest cover, low probability of development, poor water quality in Coursey Pond and Killens Pond, and one hydraulically deficient crossing.

11.2 PRIORITIZATION OF ROAD CROSSING IMPROVEMENT PROJECTS

As discussed in Section 8, 82 crossings were hydraulically analyzed in the Murderkill Watershed to estimate their conveyance capacity for the design storm. Forty-two out of 82 crossings convey the design storms. Improvements were proposed to 38 of the 40 hydraulically deficient structures. Culverts that convey less than 60% of the design storm (with no freeboard under future conditions) should be prioritized during project implementation. Seven crossings have been identified under this category. All of these crossings are for roads owned by DelDOT; therefore, coordination with DelDOT is recommended to further analyze the capacity of the crossings and the feasibility of including them in the project. Table 11.2 lists the highest priority culverts in the Murderkill Watershed and their locations.

Table 11.2: Priority Road Crossing Improvement Projects

Crossing ID	Location	Subwatershed	Road Classification	Design Storm	Conveyance Capacity with 0' Freeboard (Future Conditions; %)
106A	Woodlytown Road	Double Run	Collector	50-year	50
URS10	Paradise Alley Road	Swamp Creek	Local	25-year	56
URS20	West Evens Road	Hudson Branch	Local	25-year	53
URS28	Black Swamp Road	Swamp Creek	Local	25 -year	53
URS35	Woodlytown Road	Double Run	Collector	50-year	22
URS44	Central Park Drive	Browns Branch	Local	25-year	57
URS56	Railroad Avenue	Browns Branch	Local	25-year	36

11.3 GROWTH AND DEVELOPMENT RECOMMENDATIONS

Based on the subwatershed assessment, Double Run, Hudson Branch, Pratt Branch, and Spring Creek Subwatersheds were identified as being in the Kent County Growth Zone and have the highest potential for future development. Therefore, these subwatersheds were selected to model the "what-if" scenarios. The "what-if" scenarios were used to illustrate the result of enforcing post-construction stormwater management regulations in these watersheds. Based on the results of "what-if" scenarios, URS concluded that implementation of new Delaware Sediment and Stormwater Regulation criteria that focus on enforcing runoff reduction practices for post-development areas to achieve an effective 0% imperviousness would be the most effective in maintaining the quality of the subwatershed for future development conditions.

The Double Run, Hudson Branch, Pratt Branch, and Spring Creek Subwatersheds have been identified as having high development potential based on CWP's Technical Memorandum. These subwatersheds have 10 to 25% of their area classified as "excellent ground water recharge potential" areas. Per the publication, "Protecting the Sources of Your Drinking Water", DNREC April 2007, these source water protection areas should be preserved as open space and parks by acquisition/conservation easements. According to the publication, if development occurs in the source water protection areas, it is recommended that the impervious cover of the new development be limited to 20% within the source water protection areas.

11.4 IMPLEMENTATION OF WATERSHED-WIDE MANAGEMENT STRATEGIES

Section 10 identifies the various management strategies that could be adopted to help achieve the water quality goals for the Murderkill Watershed. The management strategies target the areas of septic systems, stormwater management, community outreach and education, forestry management, and agricultural/livestock operations. They promote education, cooperation, and recreation to increase the awareness of the people who live in the watershed of how their participation in adopting these management strategies affects the health of the watershed. The management strategies and actions described in Section 10 can be implemented without major capital investments, as they do not involve any engineering practices. DNREC could implement these management strategies statewide by partnering with the counties, municipalities, and other agencies to improve their effectiveness.

11.5 OPPORTUNISTIC RECOMMENDATIONS

Sections 11.1 through 11.4 describe the various structural projects/management strategies that could be adopted based on the prioritization of the subwatersheds. Although a general priority of implementation is recommended in this watershed plan, we recommend that DNREC consider implementation of potential improvement projects other than the highest priority projects in conjunction with other activities in the watershed such as:

- Improving crossings as a part of road improvement/widening projects to accommodate higher flows that could result from future development.
- Addressing stormwater quality and quantity issues during the design of proposed transportation projects.
- State regulations currently require implementing stormwater management as part of new development. It is recommended that DNREC consider working with developers to provide additional stormwater controls for adjacent untreated existing impervious areas.
- If new development occurs in a subwatershed that would impact the streams and wetlands, prioritizing implementation of stream restoration/wetland mitigation projects to provide water quality benefits to the subwatershed.

11.6 CONCLUSIONS

Murderkill Watershed, which is primarily undeveloped, experienced rapid growth in recent years (i.e., 2002-2007) although this growth has significantly stalled since then. The conditions in the watershed vary on a subwatershed level. To enhance and preserve watershed conditions, projects that address flooding and water quality issues in the watershed for the effective management of stormwater runoff are identified in this report. Further, it is recommended that future development in the watershed be strategically planned by implementation of regulations and ordinances and by avoiding disruption of the sensitive areas in the watershed.

Section 12 References

Anderson, James R., Ernest E. Hardy, John T. Roach, and Richard E. Witmer, A Land Use and Land Cover Classification System for Use With Remote Sensor Data. U.S. Geological Survey Circular 671. 1976.

Center for Watershed Protection (CWP). Technical Memorandum Regarding Task 4.1.3: *Prioritization of Murderkill Subwatersheds*. CWP, Ellicott City, MD. August 1, 2005.

Delaware's Chesapeake Interagency Workgroup, Delaware's Phase I Chesapeake Watershed Implementation Plan, 29 November 2010.

DNREC, Division of Soil and Water Conservation, *Delaware Sediment and Stormwater Regulations*, Title 7 Natural Resources and Environmental Control, Delaware Administrative Code, 5101, Sediment and Stormwater Regulations. January 23, 1991, amended March 11, 1993, April 11, 2005. http://regulations.delaware.gov/AdminCode/title7/5000/5101.shtml.

DNREC, Division of Soil and Water Conservation, *Draft Sediment and Stormwater Regulations*, February 2009.

DNREC, *State of Delaware 2000 Watershed Assessment Report (305(b))*, April 1, 2000.

DNREC, Division of Water Resources, *Technical Analysis for the Murderkill River TMDLs.* December 2001, amended August 2005.

DNREC, Division of Water Resources, *Protecting the Sources of Your Drinking Water*, April 2007.

ESRI, *ArcGIS* Version 9.2. 2006, www.esri.com/.

Federal Emergency Management Agency (FEMA). *Flood Insurance Study for Kent County, Delaware and Incorporated Areas*, FEMA, May 5, 2003.

Kent County, *Comprehensive Plan 2007,* July 1, 2008.

Leopold Luna B., M. Gordon Wolman and John P. Miller. *Fluvial Processes in Geomorphology*. 1992. Dover Publications, Inc.

Leopold, Luna B. *Water, Rivers and Creeks.* 1997. University Science Books.

McCormick Taylor, *Safety Evaluation for Hearns Pond Dam and Williams Pond Dam*, April 2009.

Moglen, Glenn. GISHydro2000 Delaware Version. University of Maryland, College Park, 2007. http://www.gishydro.umd.edu/.

National Oceanic and Atmospheric Administration (NOAA), Atlas 14 Volume 2, Version 3 [Online] NOAA, Hydrometeorological Design Studies Center (HDSC), Precipitation Frequency Data Server (PFDS). 2009. http://dipper.nws.noaa.gov/hdsc/pfds/.

Natural Resources Conservation Science, *Stream Visual Assessment Protocol (SVAP),* National Water and Climate Center, Technical Note 99-1, 1998.

Rosgen, Dave. *Applied River Morphology.* Wildland Hydrology. Posoga Springs, Colorado. 1996.

Rosgen, Dave. *A Geomorphological Approach to Restoration of Incised Rivers.* Proceedings of the Conference on Management of Landscape Distributed by Channel Incision. 1997.

Sanborn, LiDAR data. 2007. http://datamil.delaware.gov/geonetwork/srv/en/metadata.show?currTab=simple&id=63.

State of Delaware, Office of Management and Budget, Delaware Geographic Data Committee, http://datamil.delaware.gov/.

State of Delaware, Office of Management and Budget, Delaware Geographic Data Committee, *2007 Delaware Land Use and Land Cover, Metadata*. May 18, 2008. http://datamil.delaware.gov/geonetwork/srv/en/metadata.show?currTab=simple&id=40.

Center for Research in Water Resources (CRWR), University of Texas at Austin, and the Environmental Systems Research Institute, Inc. (ESRI). *ArcHydro*. Version 1.2 for ArcGIS 9.2. 2007. www.crwr.utexas.edu/giswr/hydro/ArcHOSS/index.cfm.

Tiner, Ralph W., *Delaware's Wetlands Status and Recent Trends*, June 2007.

Thuman, Andy. *Excerpts from lake/pond bathymetry maps of Delaware's public ponds*. 1993. Hydroqual. Data obtained in an e-mail on September 2, 2009.

URS Corporation, 2007, *DNREC Dam Inventory*.

U.S. Army Corps of Engineers, Hydrologic Engineering Center. *Hydrologic Modeling System (HEC-HMS.)* Version 3.3. U.S. Army Corps of Engineers, Hydrologic Engineering Center, 2008. www.hec.usace.army.mil/software/hec-hms/.

U.S. Army Corps of Engineers, Hydrologic Engineering Center. *Geospatial Hydrologic Modeling Extension (HEC-GeoHMS).*Army U.S. Corps of Engineers, Hydrologic Engineering Center, 2003. www.hec.usace.army.mil/software/hec-geohms/.

U.S. Department of Agriculture, NRCS, Conservation Engineering Division, *Urban Hydrology for Small Watersheds*, Technical Release No. 55 (TR-55). USDA, Washington, DC. June 1986.

U.S. Department of Agriculture, Soil Conservation Service (now NRCS), *TR-20 Computer Program for Project Formulation Hydrology*, February 1992.

U.S. Department of Agriculture, NRCS, Soil Survey Geographic (SURGO) database, 2009 http://SoilDataMart.nrcs.usda.gov/

U.S. Department of the Interior, Geological Survey (USGS), *Guidelines for Determining Flood Flow Frequency, Bulletin #17B of the Hydrology Subcommittee*, revised September 1981 with editorial corrections March 1982.

U.S. Department of the Interior, U.S. Geological Survey (USGS), 2006A. *Magnitude and Frequency of Floods on Nontidal Streams in Delaware.* Reston Virginia: U.S. Geological Survey Scientific Investigations Report 2006-5146, 2006. Prepared by Ries, K.G., III and Dillow, J.J.A. in cooperation with the Delaware Department of Transportation and the Delaware Geological Survey. http://pubs.usgs.gov/sir/2006/5146/pdf/sir2006-5146.pdf.

U.S. Department of Interior, U.S. Geological Survey (USGS), 2006B, *User's Manual for Program PeakFQ, Annual Flood-Frequency Analysis Using Bulletin 17B Guidelines:* USGS, Techniques and Methods, Book 4, Chapter B4; 42 pgs. Prepared by Flynn, K.M.; W.H. Kirby; and P.R. Hummel, P.R.

http://pubs.usgs.gov/tm/2006/tm4b4/tm4b4.pdf

U.S. Department of Transportation, *Hydraulic Design of Highway Culverts*, revised May 2005

USGS StreamStats Version 2 [Online] USGS, 2009A, http://water.usgs.gov/osw/streamstats/.

USGS Surface Water Data. [Online] USGS, 2009B. http://waterdata.usgs.gov/usa/nwis/peak.