ALTERNATIVE FUTURES FOR HEADWATER STREAM AND WETLAND LANDSCAPES IN THE UPPER DELAWARE BASIN, NEW YORK, USA

BY

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THESIS

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ABSTRACT

From September 2004 to June 2006, flood events of national significance (federally and state declared disaster areas requiring millions of dollars in federal and state flood aid) occurred within the Upper Delaware Basin of New York (Delaware River Basin Commission, 2007a). The lower portion of the watershed is approximately 120 miles northwest of New York City. In particular, Sullivan and Delaware counties of New York experienced property damage, loss of life, streamside erosion, and degraded water quality, which affected downstream river and estuary areas. It is predicted that flooding will continue to occur frequently within the watershed (Delaware County, 2006). Flood events may have adverse impacts on the New York City's municipal water supply watersheds, which are in the same geographic area as the Upper Delaware Basin. Degradation of stream resources may also limit recreational uses such as fishing.

In addition to flood events, future urban growth is expected for the Upper Delaware Basin, particularly in Sullivan County. Existing and future urban growth management needs to consider ecosystem services of the watershed, specifically to identify and evaluate existing flood storage and water quality maintenance, and preserve and enhance these functions. Ecosystem services also need to be identified for probable future landscape conditions and whether or not there will be sufficient levels of the services for human based needs. Headwater streams and wetlands are important in providing the aforementioned ecosystem services.

To understand the existing levels of ecosystem services provided by wetlands and headwater streams within the watershed, a landscape analysis of flood storage capacity and water quality maintenance contributions of wetlands and streams for the Upper Delaware Basin was completed. Analyses included: 1) identification of aggregated headwater stream networks, 2) watershed-based preliminary assessment of wetland functions (W-PAWF), 3) stream corridor condition assessment, using a GIS-based Streamside Health Model (Meixler, 2003), and 4) wetland storage capacity derived from stormwater monitoring of New York City Department of Environmental Protection

reference wetlands and stormwater modeling using the Natural Resources Conservation Service's (NRCS) TR-55 and TR-20 models.

Baseline stream analysis included headwater streams (1st and 2nd order) and basins from the NHDPlus (1:100 K) dataset. Combined USGS National Hydrography Dataset (NHD) and NYCDEP 1:24 K flowlines characterized 81% (1,745.4 stream miles) of the total stream network as headwater reaches. The results of the wetland assessment prioritized US Fish and Wildlife Service National Wetland Inventory wetlands for conservation, preservation, and protection based on predicted high or moderate performance values for surface water detention, nutrient transformation, and nutrient and particulate retention. Most NWI wetlands were predicted to have moderate or high values. Streamside condition results prioritized degradation potential of NHD 1:24 K headwater streams using adjacent land-cover types ranging in the degree of human induced disturbance. Seventy six percent of headwater stream reaches are predicted to be in excellent or good condition. The remaining 24% of stream corridors are predicted to be in fair to poor conditions. Estimates of stormwater storage capacity of NWI wetlands within a typical rural and urban headwater catchment were derived for a one year (prior dry conditions) and a one hundred year (prior wet conditions) storm event. Results show that there is an estimated deficit of flood storage capacity from existing wetland resources.

In addition to baseline ecological and hydrologic conditions, alternative future scenarios were analyzed and proposed based on selected ecosystem services of headwater streams and wetlands. The SLEUTH (slope, land-cover, exclusion, urbanization, transportation, and hill-shade) urban growth model, calibrated for the Upper Delaware Basin was used to project future urban development growth scenarios for 2030 (Jantz, 2008). The baseline scenario looked at the protection of all existing NWI wetlands and New York State Department of Environmental Conservation freshwater regulatory wetlands. Under existing development trends, from 2005 – 2030 Sullivan County is predicted to have a 108% increase in total impervious surface cover, which is likely to negatively impact stream and wetland resources.

Ecological, hydrologic, and urban growth analyses provided necessary information for selecting appropriate conservation designs for stormwater best management practices (BMPs); including buffered and restored wetlands and riparian corridors, natural stream channel design, bioswales, resized culverts, pervious surface technologies, and compact development. The economic costs of surface water detention provided by existing wetlands within typical urban and rural headwater catchments were derived from the predicted monetary costs of constructing new stormwater storage capacity with stormwater BMP retrofits. The costs of existing surface water detention ranged from approximately $12.7 – $151.4 million dollars. Federal monetary aid provided for flood damages and losses was compared to the predicted costs of existing surface water detention services provided by wetlands within headwater catchments.

In conclusion, the analyses of baseline conditions of ecological and hydrological functions from this study informed appropriate selection of conservation design-based stormwater BMPs for possible flood and water quality management strategies for an urbanizing Upper Delaware Basin. Actual results for the Upper Delaware Basin may be most applicable to the Catskill Mountains region. The approach used in this study may be applicable to watersheds across the United States of America and the world in need of finding solutions for managing more frequent intense floods and increases in urban development.

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CHAPTER 1
INTRODUCTION

1.1 IMPORTANCE OF WETLANDS AND HEADWATER STREAMS IN THE UPPER DELAWARE BASIN

1.1.1 Wetland Definitions and Functions

Wetlands greatly contribute to the integrity of ecological and hydrological functions in New York's Upper Delaware Basin. Important ecological functions provided by wetlands include stream water quality protection, and mitigation of flood dynamics. Parts of the watershed, a source to the New York City municipal water supply system, are prone to flooding. Negative water quality impacts associated with past flooding events were stream-bank erosion, sediment accumulation, and degraded water quality associated with flood-damaged structures, such as road and building infrastructure (Delaware River Basin Flood Mitigation Task Force, 2007). Other negative impacts from the flood events included loss of human life and extensive loss of property and cropland (Delaware River Basin Flood Mitigation Task Force, 2007). To avoid diminished water quality and flood related damages, wetland resources of the Upper Delaware Basin need to be protected. Assessing existing baseline ecological services provided by wetlands will help facilitate flood management, water quality protection, and smart urban development within the watershed.

For regulatory purposes, wetlands are defined differently by various state and federal governmental authorities. For this study area, wetlands are regulated by definitions used by the New York State Department of Environmental Conservation (NYSDEC), the US EPA, and the US Army Corps of Engineers. The NYSDEC uses the definitions within the Clean Water Act (jointly issued by US EPA and US Army Corps of Engineers regulations), which apply to all federal regulation of waters.

According to the NYSDEC wetlands are areas saturated by ground or surface water that support vegetation adapted to saturated soil conditions (New York State DEC, 2008). The US EPA and the US Army Corps of Engineers have a common definition for wetlands, "Those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas (US Army Corps of Engineers, 2006)."

Wetlands found within the Upper Delaware Basin are inland freshwater wetlands (**Figure 1**). Such wetlands are commonly found on floodplains adjacent to streams and rivers (riparian wetlands); isolated depressions surrounded by dry land (basins); and bordering the side banks of lakes and ponds (US EPA, 2006). Vegetation common within inland freshwater wetlands include: herbaceous plants in wet meadows and marshes, shrubs in swamps, and trees and herbaceous vegetation in woodland swamps (US EPA, 2006).

Figure 1: *Upper Delaware Basin Lotic Freshwater Wetland.*

Within a watershed, wetlands upstream of flood-prone areas store floodwater and release it slowly, thus desynchronizing flood peaks, lowering hydrologic discharge energy, and lessening the severity of flooding events (Meyer et al., 2007, Schumacher, 2003b and Tiner, 2003). In addition, wetlands may retain sediment and serve as sediment sinks, which alters channel-forming hydrodynamics and may stabilize stream configurations (Meyer et al., 2007, Schumacher, 2003b and Tiner, 2003).

Wetlands in the Upper Delaware Basin provide important ecological and hydrologic functions, affecting water quality and flood management. The steep topography of the Upper Delaware Basin creates surface water connections between wetlands and headwater streams. Wetlands commonly have hydrologic connections to other wetlands via groundwater pathways (Meyer et al., 2007, Schumacher, 2003b and Tiner, 2003). This study focuses on flood and water quality protection functions provided by wetlands within the watershed, including flood mitigation and protection of downstream water quality. Some of the most relevant wetland functions to this study include: nutrient transformation, stream flow maintenance, surface water detention, sediment and particulate retention, inland shoreline stabilization, and diverse wildlife habitats (**Table 1**).

Table 1: Selected Wetland Water Quality and Flood Protection Functions
(Tiner, 2003)

Wetland Function	**Description**
Nutrient transformation	• Retain sediments and adsorbed nutrients. Periodically flooded and seasonally saturated wetlands perform this function. • Denitrification ($N0_3$ to N_2 gas). • Nitrogen fixation via microbial-based reduction (N_2 gas to NH_3). • Phosphorus removal via algae and vegetative assimilation (dependent on accumulation of organic matter over time as organisms decompose, in addition to soil and water chemistry).
Stream flow maintenance	• Source of groundwater that may sustain stream flow. • Headwater wetlands provide stream flow. • Floodplain wetlands detain water as bank storage and later release it as stream flow.
Surface water detention	• Reduces flood heights and downstream flooding. • Wetlands with woody vegetation have higher functional levels than emergent wetlands. • Emergent wetlands along streams provide flood storage.

Table 1 (cont.)

Wetland Function	Description
Sediment and particulate retention	• Capture and retain high amounts of particulates and sediments. Vegetated wetlands function at a greater rate than non-vegetated wetlands. • Depressional wetlands will likely capture sediments.
Inland shoreline stabilization	• Vegetated wetlands stabilize soil or substrate and reduce erosion.

1.1.2 Headwater Stream Definitions and Functions

Wetlands are commonly located near or adjacent to headwater streams within a drainage area. Although, wetland resources may be located away from headwater stream reaches. Wetlands commonly have hydrologic connections to headwater stream networks via groundwater pathways (Meyer et al., 2007, Schumacher, 2003b and Tiner, 2003). Delineating headwater stream networks may facilitate identifying probable locations of nearby wetlands. Many of the ecological services provided by wetlands are also provided by headwater streams because of the commonly shared hydrologic connection between the two water body systems. Headwater streams provide many important ecological and hydrological functions within a watershed important to this study. These functions include water quality maintenance and flood protection. Therefore it is important to assess the true spatial extent of the headwater stream network of the Upper Delaware Basin to understand contributions of ecological and hydrological functions of headwater streams and wetlands.

Headwater streams located within the upper portion of a watershed regulate many aspects of downstream waters, including water quality and quantity, flow velocity, and landscape connections to wetlands and riparian zones. The aggregation of all first and second order streams, which amounts to over two thirds of total stream length, defines headwater reaches within a river network (Freeman et al., 2007). Before a distinct stream channel forms, shallow swales, also called “zero-order streams” act as conduits for water flowing to first order streams. Zero order streams may be considered part of a headwater system, but are not readily identifiable with GIS technology (Meyer et al., 2007). The first appearance of a defined channel within a stream corridor is considered a first order stream.

Streams may be further defined by their temporal flow of water. Ephemeral streams contain flowing water after major precipitation or for short time periods. Intermittent streams flow during wet time periods, such as during the spring or after snow-melts. Finally, perennial streams have continuous annually flowing water (Schumacher, 2003a and Meyer et al., 2007). A headwater stream segment may be defined by any of the aforementioned temporal flow categories based on site specific characteristics (Meyer et al., 2007). First order streams are commonly defined as intermittent or perennial without upstream tributaries; where a second order stream forms below the confluence of two first order streams (Freeman et al., 2007).

Analysis of the National Hydrography Dataset medium resolution data (1:100,000) revealed approximately 53%, 2,900,000 km (1,801,976 miles), of total stream length in the lower 48 United States, excluding Alaska is composed of headwater streams (Nadeau and Rains, 2007). Ephemeral and intermittent streams comprise 50 %, 1,460,000 km (907,202 miles), of total headwater stream length in the United States, not including Alaska. In New York, ephemeral and intermittent streams make up 11% or 11,900 km (7,394 miles), of total stream length (Nadeau and Rains, 2007).

The spatial extent of headwater streams is based on the resolution of the data analyzed. Regional or more local analysis of headwater stream networks may require higher resolution data than analyses performed for headwater streams for the entire contiguous United States of America. Higher resolution data of headwater stream networks may reveal greater spatial extents than more coarse resolution datasets. An example of a regional analysis of a headwater stream network (1:72,000 resolution) within the Catskill Mountains of Greene County, New York was conducted for the Batavia Kill watershed, a sub-basin within the Schoharie Reservoir watershed (**Figure 2**). Greene County borders the northeast side of Delaware County (*see* **Figure 9**). Within the sub-basin the aggregated lengths of headwater stream reaches include about 73% of the total stream network's length. Typical headwater streams in the Upper Delaware Basin may have intact forested corridors (**Figure 3**).

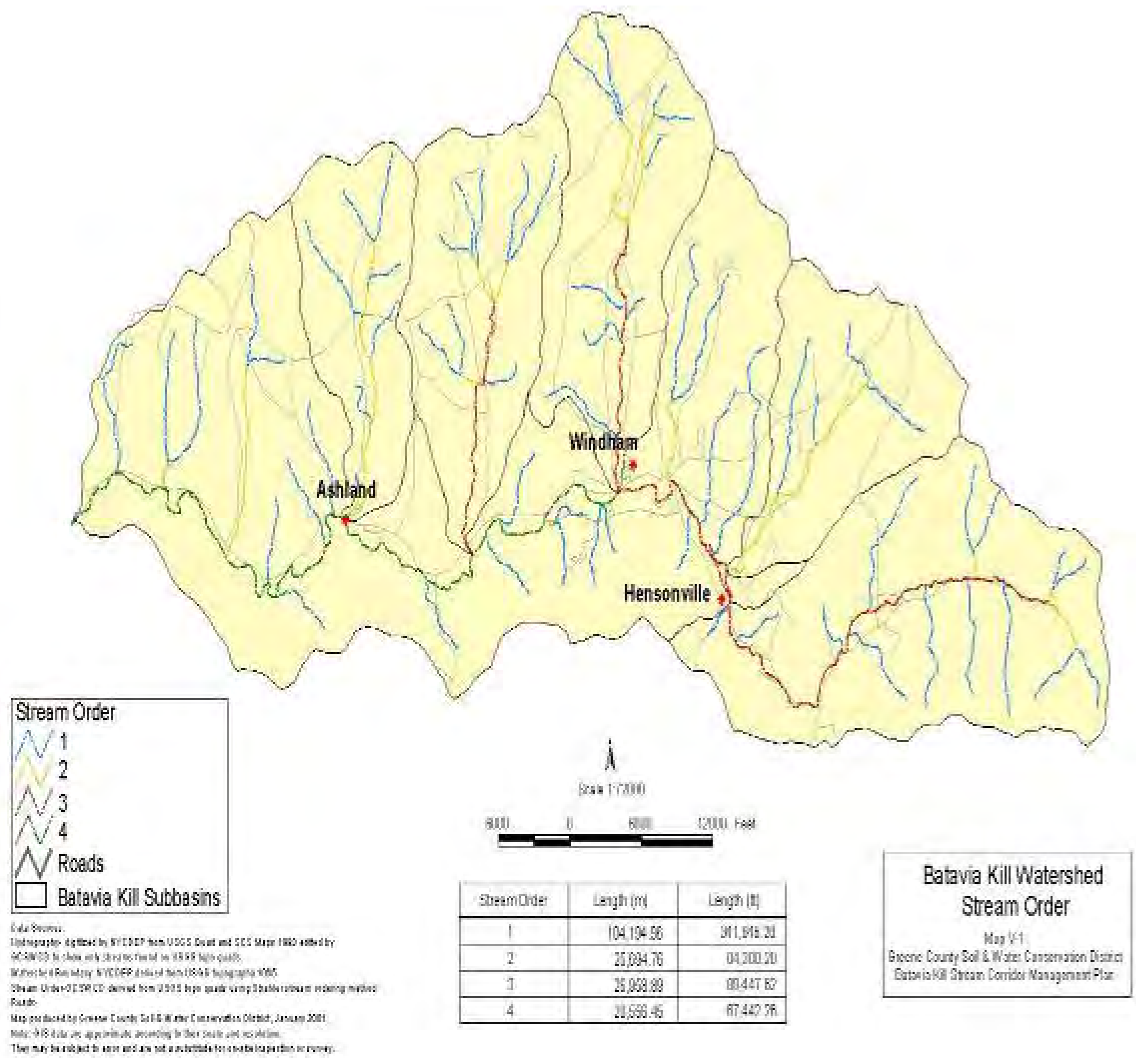


Figure 2: *Batavia Kill Watershed Stream Order Map, Greene County, NY* (Greene County Soil and Water Conservation District, 2003).

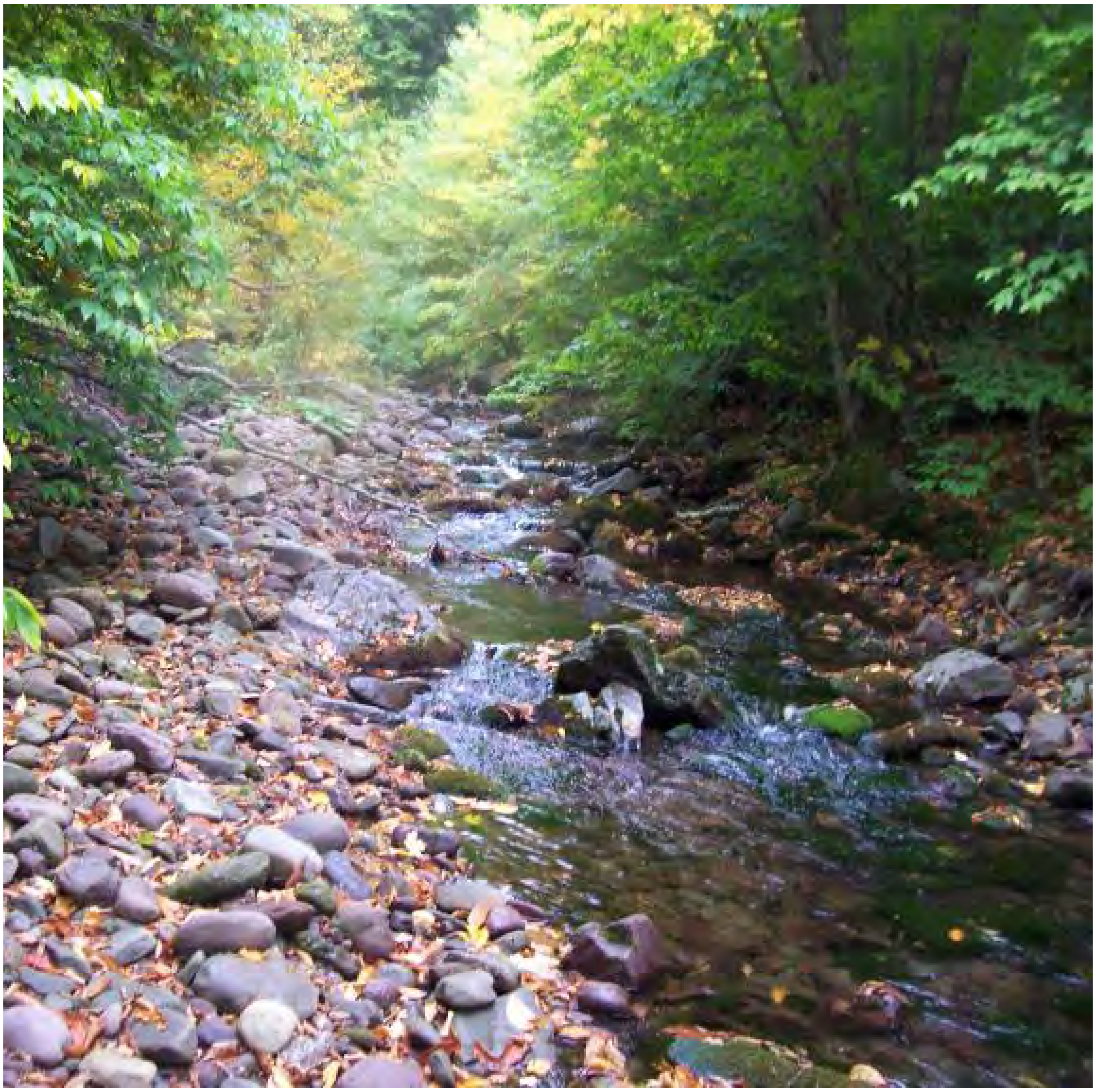


Figure 3: *Typical Forested Headwater Stream Corridor Within the Upper Delaware Basin.*

The ecological and hydrological watershed functions that headwater streams provide of interest to this study include: mitigating flood frequency and intensity; storage and recharge of groundwater resources; retention of sediments and pollution; maintenance of water quality and quantity; recycling of nutrients; and diverse habitats for flora and fauna (**Table 2**) (Meyer et al., 2003).

Table 2: Selected Headwater Stream System Functions:
(Meyer et al., 2007)

Headwater Stream Function	**Description**
Flood frequency and intensity mitigation	• Control the flow rate of water to larger downstream streams. • Absorb large amounts of rainwater, runoff, and snowmelt. • Natural/unaltered streambeds (gravel, rocks, and debris dams) provide rough surfaces creating friction to slow down the flow of water. Slow moving water is more likely to infiltrate streambeds and adjacent channels. Intact headwater streams may also reduce channel soil erosion. • Reduce local and downstream flooding (Schumacher, 2003b).
Groundwater storage and recharge	• Provide largest surface area of soils within a stream system, allowing for groundwater recharge and storage. • High water table of headwater stream allows water to infiltrate soils and rocks and flow to groundwater.
Capture sediment and pollution	• Sediment deposition occurs in channel pools (The Federal Interagency Stream Restoration Working Group, 2001). • Reduce nutrients flowing to downstream reaches (Schumacher, 2003b). • Riparian vegetation reduces sediment loads to streams (Schumacher, 2003b).
Maintenance water quality and quantity	• Moderate high flow (flood) and maintain low flow (dry/drought) volumes. Base flow regulates groundwater flow to stream channel during dry periods.
Nutrient recycling	• Aquatic organisms assimilate dissolved and particulate inorganic nitrogen (N). N is released when these organisms decompose. • Sediments adsorb phosphorus (P) removing it from the water column. Aquatic plants assimilate P and convert it to organic P. Detritivores and grazers may consume the plant material; some of the organic P is excreted and taken up by plants (The Federal Interagency Stream Restoration Working Group, 2001). • Microorganisms transform organic matter into food for other aquatic organisms. • Headwater streams act as sources of dissolved organic carbon (from in-channel (autochthonous) and out of channel (allochthonous) sources) (Nadeau and Rains, 2007).

Table 2 (cont.)

Headwater Stream Function	Description
Habitat: diverse terrestrial and aquatic areas	• Environmental surroundings vary throughout stream network. Headwater streams in wet areas create wider channels and deep pools. • Typical headwater stream supports hundreds to thousands of organisms, including: algae, bacteria, fungi, aquatic and terrestrial plants, invertebrates, fish, amphibians, birds, and mammals.

1.2 ALTERATIONS OF HEADWATER STREAMS AND ASSOCIATED IMPACTS

Urban development occurring in landscapes containing headwater streams, wetlands, and riparian areas alters localized and downstream hydrologic and ecologic characteristics. The most probable headwater stream modifications that have occurred in Delaware and Sullivan counties are: piped discharges, hard surfacing, streambed disturbance, streambank armoring, and channelization (Issacs, 2007b). Existing and future urban development is commonly associated with storm and waste water infrastructure and impervious surfaces. Roof-tops, sidewalks, parking lots, and roads are common impervious surfaces that direct stormwater at greater velocities and shorter time periods into nearby streams. Streambank armoring is used to stabilize banks and prevent soil erosion. Stream channelization, a common practice in urbanizing landscapes, shortens or removes meanders to reduce the time span it takes for water to runoff from specific watershed locations. According to the NYSDEC, streambed sediment removal is performed to facilitate the efficient movement of water through the stream (Issacs, 2007b). Unfortunately, this action only causes more sediment to return to the streambed over time and exacerbates the problem by further disturbing streambed integrity. All of the aforementioned stream modifications have direct negative effects on stream functions; some also affect wetland functions.

The aforementioned stream alterations usually occur in the Upper Delaware Basin on small land or stream parcels that focus on problems of individual landowners. Currently there is not a collective watershed management approach for avoiding or mitigating negative effects of flood events (Issacs, 2007a). Successful long term stormwater management (improved water quality and reduced peak surface flow) in urbanized and rural areas may require in-channel structural modifications in combination with additional floodplain storage capacity (detention areas) (Bernhardt and Palmer, 2007).

In the *Appendix* the probable effects of some human-induced stream modifications are summarized (**Table A.1**). Generally channel modifications caused by humans have negative effects on a stream corridor system, most commonly through increasing the intensity and frequency of flood events. It is important to mitigate or alleviate these negative effects on the stream corridor system for long term sustainable stream and floodplain management.

From a national perspective, protecting headwater streams and wetlands from human induced alterations has always been an important issue, but recent Supreme Court rulings related to the Clean Water Act (CWA) have highlighted the issue by limiting federal protection for these systems. These cases include: *Solid Waste Agency of Northern Cook County v. U.S. Army Corps of Engineers, SWANCC* (2001), and 2006: *Rapanos v. United States* and *Carabell v. Army Corps of Engineers*. These court rulings have removed or diminished federal jurisdiction over certain types of wetlands and headwater streams under the Clean Water Act. Loss of legal protection for these waters could mean that all of the ecological services that such waters provide to downstream areas could be lost within a given watershed.

The 2006 *Rapanos v. United States* and *Carabell v. Army Corps of Engineers* split court ruling requires that CWA jurisdiction be based on a “significant nexus” existing between upstream and navigable-in-fact waters (Alexander et al., 2007). Proving a “nexus” exists may involve providing evidence that the alteration, degradation, or destruction of headwater streams produces similar deleterious consequences in downstream navigable waters and associated tributaries (Alexander et al., 2007).

1.3 HISTORY OF FLOODING AND URBAN DEVELOPMENT IN THE UPPER DELAWARE BASIN

Between September 2004 and June 2006 intense flood events occurred in Sullivan and Delaware counties of New York (Delaware River Basin Flood Mitigation Task Force, 2007). These counties lie within the upper Delaware River Basin at the southern end of the Catskill Mountains. Negative impacts resulting from the floods included loss of human life, extensive loss of property and cropland, stream-bank erosion, sediment accumulation, and degraded water quality associated with flood-damaged structures and aquatic habitat (Delaware River Basin Flood Mitigation Task Force, 2007). Such impacts have not occurred in the region since the flood of 1955 (Delaware River Basin Flood Mitigation Task Force, 2007).

Over 10,000 people within the region were affected by impacts of the floods, with thousands of damaged structures (Delaware River Basin Flood Mitigation Task Force, 2007). Many historic population centers of Delaware and Sullivan counties are at risk to frequent and flash flooding, because they are located in narrow mountainous valleys, along the sides of streams and reservoirs (Delaware County, 2006).

According to the National Oceanic and Atmospheric Administration, 48 significant flood events have occurred within Delaware County between January 1950 and February 2005 (Delaware County, 2006). Flash floods, which cause severe flood damage, occur frequently within Delaware County, where urban development and public infrastructure are commonly located in the 100 and 500 year floodplains of the Upper Delaware Basin (Delaware County, 2006).

The spatial extent of flood related claims and projects within the Upper Delaware Basin were recorded by FEMA for 2005 and 2006 (**Figure 4**). Flooding that occurred in June 2006 affected urban development areas (**Figures 5 – 6**). As would be expected, much of the urban development was located in narrow mountainous floodplains. Public infrastructure, such as bridges, roads, and power lines were all affected by flood waters (**Figure 5**). Residential development spread out across the narrow floodplain is flooded out in Cochecton, NY (**Figure 6**). These photos illustrate typical conditions of urban development affected by severe flood events in the Upper Delaware Basin.

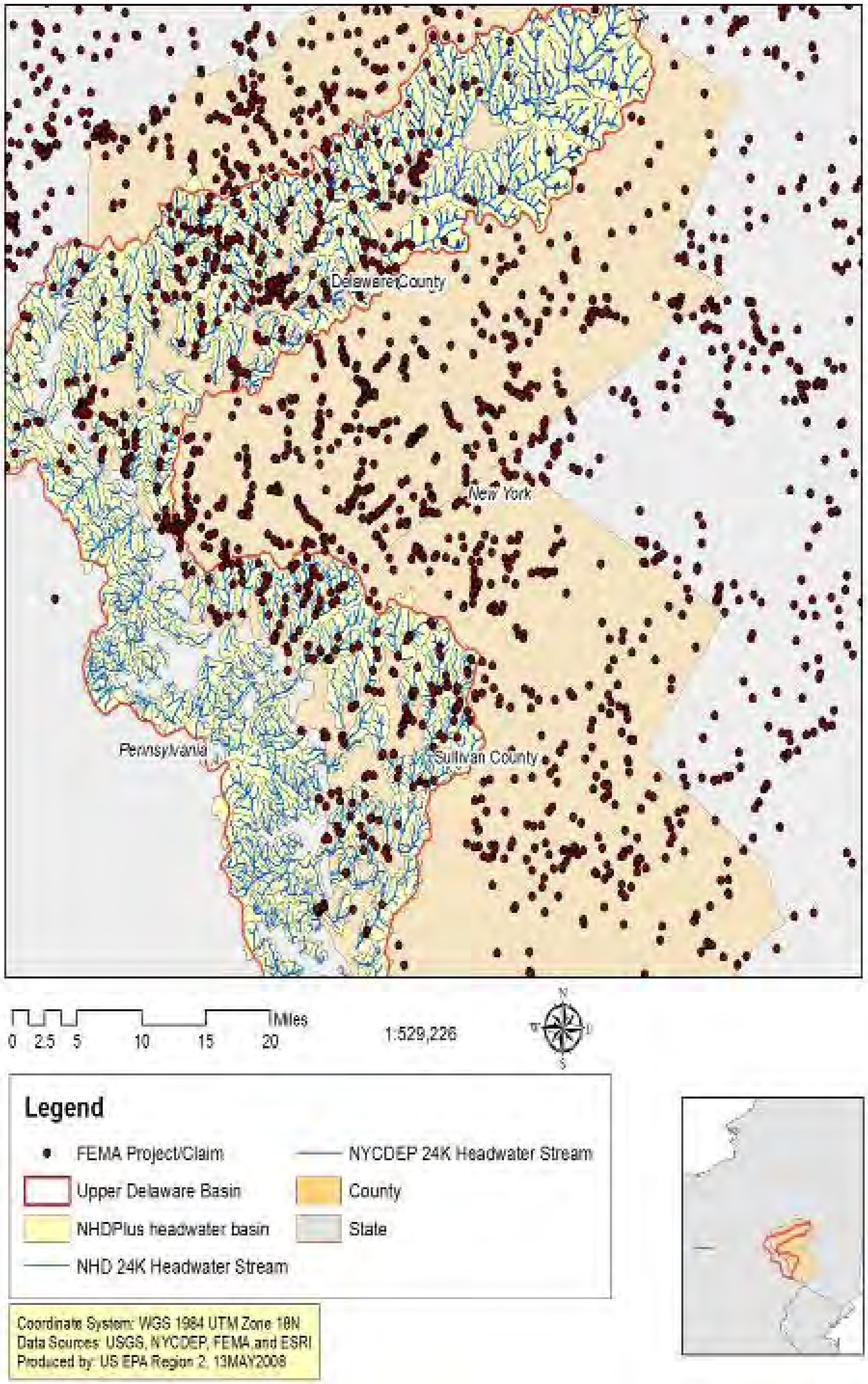


Figure 4: *Upper Delaware Basin: FEMA 2005 and 2006 Projects/Claims.*

Figure 5: *6/28/06, Downtown Callicoon, NY Flooded by Callicoon Creek Flood Waters* (MacLean, Photo courtesy of the Times Herald-Record, 2006).

Figure 6: *6/28/06, Cochecton, NY Inundated by Delaware River Flooding Event* (Goulding, Photo courtesy of the Times Herald-Record, 2006).

Man-made factors that exacerbate flooding events and associated negative impacts in the watershed include: reservoir management; increases in the percent of impervious surfaces as a result of increased urban development; channelization of tributaries or drainage ditches; loss of riparian vegetation and other natural infiltration areas; and the installation or retrofitting of conventional stormwater pipes discharging into the Delaware River (Delaware River Basin Flood Mitigation Task Force, 2007).

The primary reason for the flood events was unusually large amounts of rainfall and snowmelt during and prior to the floods, with rapid surface water runoff and little infiltration due to shallow glacial soils. Over a seven-day time span during the June 2006 flood, certain areas in the northern and western parts of the basin received more than 15 inches of precipitation (Delaware River Basin Flood Mitigation Task Force, 2007). Circumstances were similar with the April 2-3 2005 flood in the Neversink River Basin, part of the New York City municipal water supply system, where precipitation during March was above normal (Suro and Firda, 2006). During the 2005 and 2006 flood events the stream reaches and soils were very likely to be completely saturated with little capacity to store additional water.

The three New York City reservoirs within the Delaware Basin, Cannonsville, Neversink, and the Pepacton were at storage capacity prior to the three flood events which occurred between September 2004 and June 2006 (Delaware River Basin Commission, 2007b). The three reservoirs experienced uncontrolled spills during the three flooding events between September 2004 and June 2006 (Delaware River Basin Commission, 2007b). For the 2005 peak flood event, it was predicted that the crest levels of the Delaware River would have been 1 – 2.5 feet higher without reservoirs present within the Delaware River Basin (Ahnert, 2006). The Neversink River Basin attenuated peak discharge from the 2005 flood event, where peak inflow to the basin was 23,100 cubic feet per second (CFS) and the peak discharge was 12,300 CFS (Delaware River Basin Commission, 2007b). The peak inflow to the basin represented what the peak discharge rate would have been without the presence of the reservoir. Flood attenuation functionality of a reservoir is based on its surface area, spillway length, and available storage (Delaware River Basin Commission, 2007b).

From 1904 to 2006 seven of the ten worst floods (highest stream crest levels) along the main stem of the Delaware River Basin occurred in the absence of the reservoirs or the absence of spills from the reservoirs (Delaware River Basin Commission, 2007b). This indicates the majority of the worst floods from 1904 – 2006 occurred when the reservoirs did not exist to attenuate peak stream discharges; and when the reservoirs were in place they did not spill over for the majority of the worst flood events. During the record flood of 1955 (highest stream crest level on record) only the Neversink and Pepacton reservoirs of the New York City Delaware Basin were built; neither of these reservoirs spilled during the flood (Delaware River Basin Commission, 2007b).

The New York City water supply reservoirs are managed to reach full capacity in late spring (Delaware River Basin Commission, 2007b). In the past several years flood mitigation has been implemented by releasing water from the reservoirs during winter months to mitigate the potential for future spills (Delaware River Basin Commission, 2007b).

Stormwater runoff from urban areas with impervious surfaces affects flood management efforts. Vegetation loss and soil compaction following development results in reduced infiltration of flood waters, increased soil erosion, and increased frequencies of flash flood events. Some projected future urban development in Sullivan County involves the construction of a Native American casino (New York State, 2007). Construction of this facility would create hard surfacing from additional parking lots, sidewalks, roads, and spur significant growth of secondary urban development. Other areas in Sullivan County are experiencing uncontrolled growth of urban development from people investing in second homes (Sullivan County, Department of Planning and Community Development, 2007).

Stormwater management efforts within the New York City municipal water supply system focus on managing the first hour of moderate to high intensity storm events, called first-flush (New York City Department of Environmental Protection (DEP), 2008a). A stormwater retrofit program funded by New York City is administered by the Catskill Watershed Corporation (New York City DEP, 2008a). The stormwater retrofit program provides support with design, construction, and maintenance of stormwater best management practices (BMPs) for small and large businesses and private property owners (New York City DEP, 2008a). Typical projects funded by the retrofit program include enhanced collection and conveyance systems, primary screening and sedimentation, and inactive pool sedimentation (New York City DEP, 2008a).

Not all existing stormwater management practices implemented within the watershed are considered BMPs. For example, some of the municipalities within the watershed have existing stormwater pipes that are too small to handle stormwater surface runoff from certain storm events. These stormwater pipes should be retrofitted to accommodate greater amounts of surface water flow associated with storm and flood events.

The public is concerned that human induced modifications of the watershed, such as land development, reservoir management, and other floodplain encroachment will exacerbate the devastating effects of future flood events, similar to those of 2004 – 2006 (Delaware River Basin Flood Mitigation Task Force, 2007). Federal funding has been and is being provided to flood victims, and flood protection measures are being identified as part of the recovery process. Community stakeholders and property owners affected by the flood events have resorted to various emergency solutions to restore damaged properties or stream reaches. According to the NYSDEC the most common solutions for fixing local streams in the watershed include stream bank stabilization with rip-rap or sediment removal from small streambed reaches (Issacs, 2007b) (**Figures 7 – 8**). These stream projects are permissible under a permit issued by the NYSDEC, but many projects are conducted illegally without permits.

Figure 7: *Steel Sheet Pile Wall Protecting Private Property From Stream* (New York City DEP, 2008b).

Figure 8: *Large Rocks Protecting and Stabilizing Stream Bank Adjacent to Road Infrastructure* (New York City DEP, 2008b).

Other common human induced stream modifications include: channelization and diversions for efficient flow conveyance; and floodwalls and levees for controlling flood heights in narrow corridors (The Federal Interagency Stream Restoration Working Group, 2001). In headwater streams, common alterations include enclosure with storm drains and channelization or rip-rap with heavy stone materials (The Federal Interagency Stream Restoration Working Group, 2001). Hardening of the stream bank prevents natural lateral stream migration within the floodplain and forces high-energy laden waters downstream (Bernhardt and Palmer, 2007). Resultant down-cutting or channel incision causes large amounts of sediment removal, lateral erosion, and possible lowering of the water-table. Adjacent riparian areas may be disconnected from the stream channel, reducing water filtration and evapotranspiration functions of stream waters (Bernhardt and Palmer, 2007).

The types of stream restoration practices used by property owners and community stakeholders within the Upper Delaware Basin need to address long-term flood management and water quality protection needs. The commonly used stream repair practices used after a severe flood event occurs within the watershed may exacerbate negative effects of downstream flooding and water quality degradation.

1.4 PURPOSE OF STUDY

The purpose of this study was to develop procedures to enhance stream and flood management in the Upper Delaware Basin. County and stream management plans dealing with water quality protection and flood management were reviewed for management needs. To understand how to contribute to the needs of these management plans, relevant management plans were reviewed. Issues focusing on water quality protection and flood management within the plans were highlighted as potential topic areas that could be of interest to this EPA-sponsored study. A list of county and stream management plans and common areas of interest with this study includes the following:

- **Delaware County Action Plan**:
  Assists county stakeholders, such as residents, farmers, businesses, and communities in meeting water quality objectives and parameters without losing opportunities for economic vitality (Delaware County, 2002).
  Common areas of interest shared between the Delaware County Action Plan and this study include:

    1. Identifying and assessing community stormwater management needs and opportunities.
    2. Assessing and applying landscape designs to help businesses and communities develop stormwater/flood management projects.
    3. Creation of recommendations for stormwater management practices for critical roadways and stormwater structures; and a highway management plan for future road and stormwater infrastructure needs.
    4. Studying impacts of impervious surface coverage on quantity and quality of stormwater runoff and floodwaters.
    5. Assessing Best Management Practices (BMPs) for mitigating floodwaters and associated contaminants.

- **Sullivan County 2020 Toolbox**:
  A county planning document, which focuses on open space and natural resources management, water resources management, farmland protection and forestry, and open space (Sullivan County, 2005). Common areas of interest shared between the Sullivan County 2020 Toolbox and this study include:

  1. Balance urban development with water resource issues.
  2. Analysis of water resources.
  3. Water Resource Management Plan Critical Areas:
     - Water quality and quantity
     - Drinking water supply and wastewater treatment
     - Aesthetics and recreation
     - Stormwater and floodplain management
     - Ecosystem needs
     - Minimize water quality impacts from site design

  West Branch of the Delaware River Stream Corridor Management Plan:
  Provides a plan for local stakeholders, municipalities, organizations, and governmental agencies to enhance the stewardship of the West Branch of the Delaware River and its tributaries (Delaware County Soil and Water Conservation District, 2004). Common areas of interest shared between the West Branch of the Delaware River Stream Corridor Management Plan and this study include:

  1. Consider stream functions with stream restoration or mitigation projects: floodplain ecology, sediment transport, and water quality.
  2. Have a better understanding of stream processes.
  3. Encourage riparian landowners and managers to understand potential causes of flood damages, probable effects from mitigation activities, and seek technical guidance when needed.

The three management plans all seek answers to water quality protection and flood management related issues that are addressed in this study, with a focus on wetlands and headwater streams within the Upper Delaware Basin. Analyses and results from this study may be incorporated into existing county and stream management plans, dealing with water quality protection and flood management. It is important that this study be readily accessible to those responsible for implementing the various county and stream management plans. Having an understanding of existing ecological services provided by wetlands and headwater streams may assist with water resources management needs within the watershed.

1.5 STATING THE NEED FOR PROACTIVE FLOODPLAIN AND STREAM MANAGEMENT

The Delaware River Mitigation Task Force and various agencies/organizations involved with reducing flood losses admit there is a need to end the traditional reactionary "fix and rebuild" solutions employed with flood events within the Upper Delaware Basin (Delaware River Basin Flood Mitigation Task Force, 2007). For this to occur, various studies, plans, and funds will be necessary to allow people to understand how best to live or to avoid living in floodplain areas prone to frequent and/or intense flooding. Floods are common events and it is essential that people learn to coexist with annual flood events (Delaware River Basin Flood Mitigation Task Force, 2007).

Existing stream, county, and municipal plans in the Upper Delaware Basin do not focus on the ecological services provided by wetlands and headwater streams. Future successful floodplain management requires considerations of the ecological and hydrological functions of headwater streams and wetlands. An understanding of baseline conditions, including ecological services provided by wetlands and headwater streams will provide important information for existing and future stormwater management and urban planning needs.

Protecting and regulating ecological services provided by wetlands and headwater streams is important for effective floodplain management, smart urban growth planning, and water quality protection efforts within the Upper Delaware Basin. Identification of wetlands and headwater streams within the watershed, and classification of those waters for downstream services provided, particularly downstream flood mitigation and water quality protection, will allow prioritization and protection of such areas as part of a future comprehensive flood management plan.

Identification of existing and future land use practices that degrade headwater tributaries and wetlands will allow areas of the watershed to be targeted for remediation. This will allow future BMPs facilitating stormwater management to be identified, avoiding downstream degradation and loss of existing flood mitigation features within the watershed.

1.6 MAIN RESEARCH QUESTIONS

1) The primary questions asked by this study include: What are the existing baseline conditions of the landscape? What existing features of the landscape cause flooding and degrade water quality? What existing features of the landscape mitigate flooding and protect water quality? Do existing conditions provide sufficient levels of service for water quality protection and flood attenuation management needs? To evaluate this, existing baseline ecological services, focusing on water quality protection and flood attenuation functions were assessed at the watershed scale.

Some of the resources used to address the aforementioned questions include: location of wetlands; true length of headwater stream networks; USGS stream gauge records; an impervious surface model (Zielinski, 2002); TR-55 model (NRCS); watershed-based preliminary assessment of wetland functions (W-PAWF) (Tiner, 2003); and an existing stream-side conditions assessment model (Meixler, 2003).

2) What is the existing capacity of wetlands within the Upper Delaware Basin to detain surface water? How do existing wetland resources manage stormwater in both rural and urban headwater catchments? Does the existing stormwater storage capacity of wetlands within the watershed provide sufficient levels of storage for stormwater management needs? Resources used to address these questions included: stormwater monitoring data from New York City DEP (NYCDEP) reference wetlands and TR-55 and TR-20 models (NRCS).

3) How do existing urban development and land use trends affect the delivery of baseline ecological services; and do existing land use trends conflict with flood and water quality protection management needs? These questions were addressed using wetland resource surveys and inventories; residential building permit activities of Sullivan County; and the SLEUTH urban growth model (Jantz, 2008).

4) If there is a conflict of interest between existing development trends and delivery of sufficient ecological services, what alternative future scenarios could be proposed? Resources used to answer this question include: SLEUTH urban growth model (Jantz, 2008); US Army Corps of Engineers 404 permit records; and alternative watershed-based residential development patterns.

5) What best management practices (BMPs) could be used as design templates for supporting development needs and appropriate levels of ecological services within the watershed? Resources used to answer this question include: the New York State Stormwater Management Design Manual; stream restoration projects conducted by the Greene County Soil and Water Conservation District and the NYCDEP; the National Engineering Handbook: Part 654 Stream Restoration Design by the NRCS; and technical stormwater management reports from the Center for Watershed Protection.

6) Could proactive planning to improve and enhance ecological services provided by wetlands and headwater streams reduce future federal aid money allocated for flood related damages and losses within the watershed? The resources used to address this question include: National Flood Insurance Program claims; federal aid records of repairing public infrastructure; and technical stormwater management reports from the Center for Watershed Protection.

CHAPTER 2
METHODS

2.1 SITE DESCRIPTION

2.1.1 Location

The Upper Delaware Basin is classified by the USGS as an eight digit hydrologic unit code (HUC-8), cataloging unit, or a watershed. An eight digit hydrologic unit represents a distinct hydrologic feature, including drainage basins within a specific geographic area (USGS, 2008). The Upper Delaware Basin USGS HUC-8 GIS based polygon boundary is composed of 762,842 acres and is located northwest of New York City. The village of Stamford, located at the top of the watershed is about 160 miles from New York City. Close to the bottom of the watershed is the hamlet of Narrowsburg, located about 120 miles from New York City (**Figure 9**).

Part of the New York City municipal water supply system is located in/or adjacent to the Upper Delaware Basin (**Figure 9**). Multiple reservoir basins make up the total area or watershed of the New York City municipal water supply system, located in the Catskill Mountains region (**Figure 10**). Protecting drinking water quality within the New York City municipal water supply system watershed is of utmost importance to stakeholders in New York City and the NYCDEP. The Cannonsville Reservoir is the only New York City reservoir located within the Upper Delaware Basin. Other New York City reservoirs are located within basins adjacent to the Upper Delaware Basin. The Upper Delaware Basin also supports local and regional economies through its world class trout fishery.

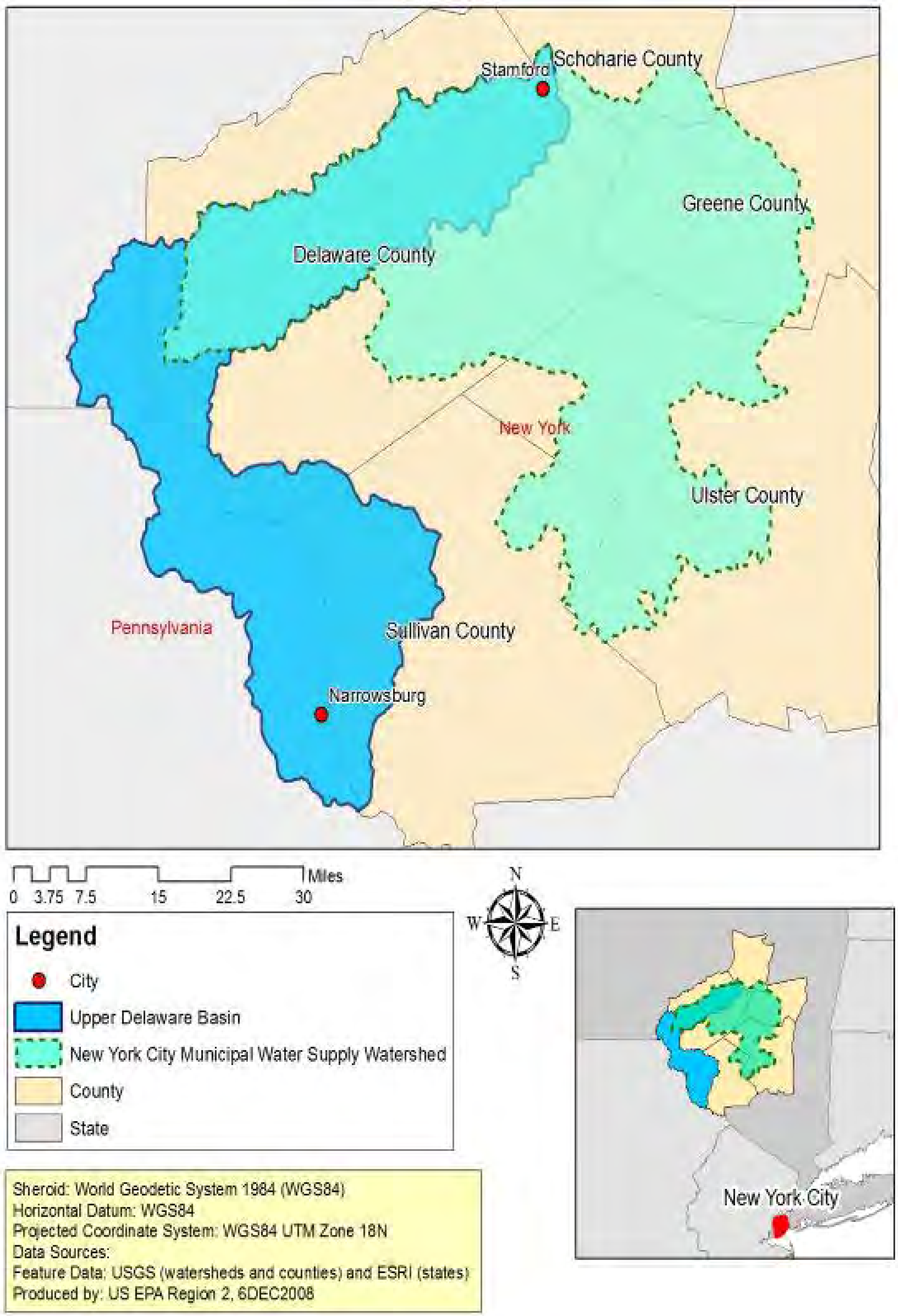


Figure 9: *Upper Delaware Basin: Watersheds and Counties.*

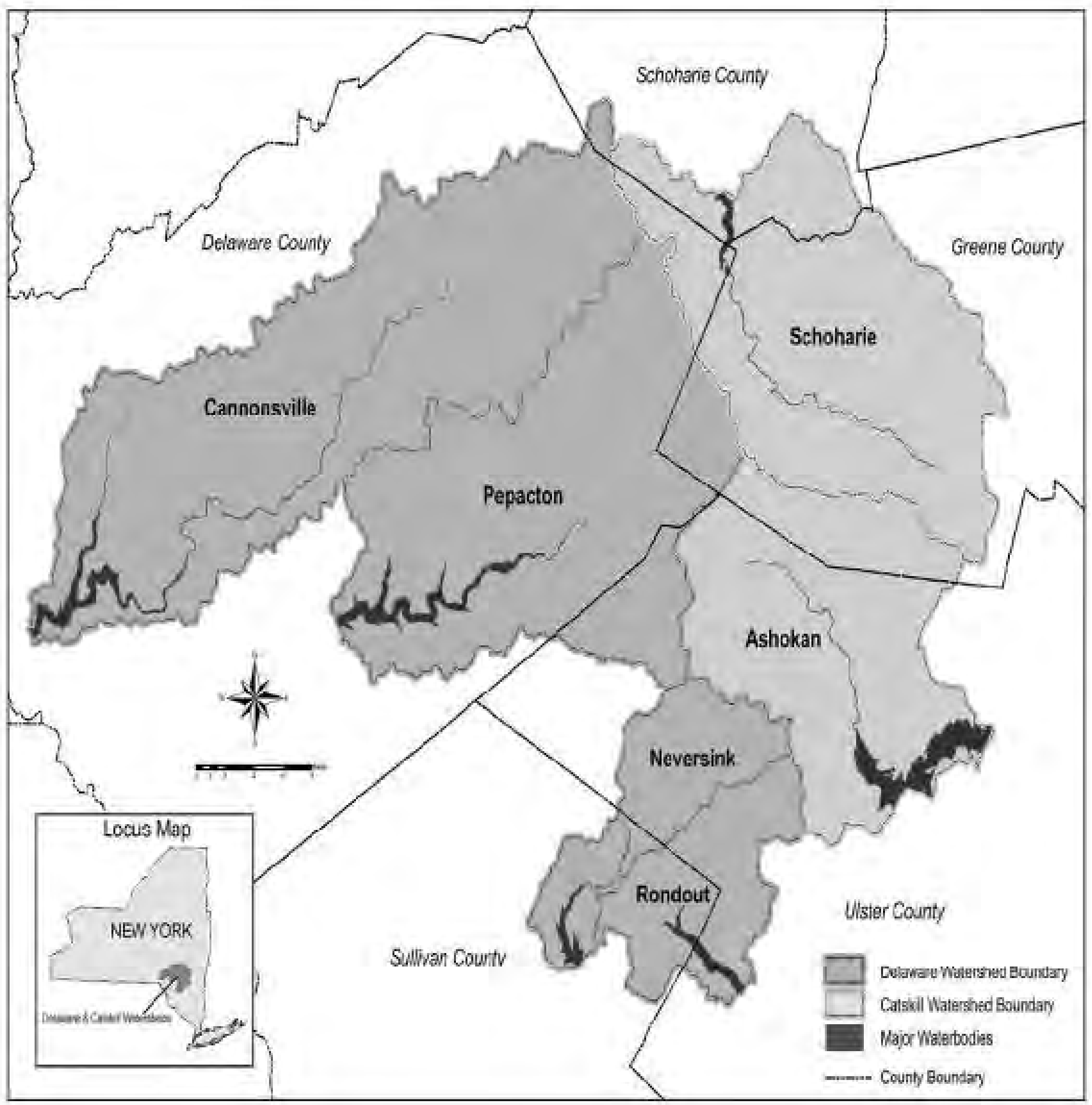


Figure 10: *New York City Reservoir Basins* (Tiner et al., 2005).

2.1.2 Topography, Soils, and Ecoregions

The Upper Delaware Basin is located in the eastern part area of the Allegheny Plateau, the northern portion of the Appalachian Plateaus (Delaware County Soil and Water Conservation District, 2004). There are three Omernik Level III ecoregions located within the Upper Delaware Basin, including the Northern Appalachian Plateau and Uplands, the Northeastern Highlands, and the North Central Appalachians (**Figure 11**). An ecoregion is delineated based on similar biotic and abiotic characteristics, such as physiography, geology, soils, hydrology, vegetation, wildlife, and land-use.

Surface water flow throughout the landscape divides the Upper Delaware Basin into various sub-basins. The Upper Delaware Basin is broken into the West and East branches of the Delaware River. The headwaters of the West Branch Delaware River are located within the Upper Delaware Basin (**Figure 12**).

Central Delaware County is drained by the West Branch, with the river flowing southwest to the Cannonsville Reservoir. Headwater stream reaches occur in narrow valleys which intersect the West Branch at right angles. Many of the peaks and ridges within the West Branch watershed have elevations greater than 2,000 feet. For example, the elevation of the high-water mark at the Cannonsville Reservoir is 1,150 feet (Delaware County Soil and Water Conservation District, 2004). The existing landscape of hills and valleys has been carved out by rivers and tributaries cutting the plateau from the southeast to the northwest. From the west the Upper Delaware Basin's main drainage path is the West Branch of the Delaware River, where water drains a narrow and flat valley floor from the northeast to southwest (Delaware County Soil and Water Conservation District, 2004). An elevation model of the Upper Delaware Basin (**Figure 13**) depicts a minimum elevation of 747.2 feet and a maximum of 3,089.1 feet. The total topographic relief of the watershed is approximately 2,341.9 feet (**Figure 13**).

The existing topography of the watershed was formed by recent glaciations. The parent material is primarily composed of glacial till deposits in the uplands. The layer of till is commonly thin and stony, with an average depth of 40 inches. Underneath the permeable glacial till commonly resides a low permeable subsoil layer. In valley floors and at their margins, sandy and gravelly materials are found. In urban areas, such as villages gravelly loam soils are found. Infrequently "fluvaquents" are found in frequently flooded soils along narrow stream channels (Delaware County Soil and Water Conservation District, 2004). Typical streams often flow through the mountainous topography in the Catskill Mountain region (**Figure 14**).

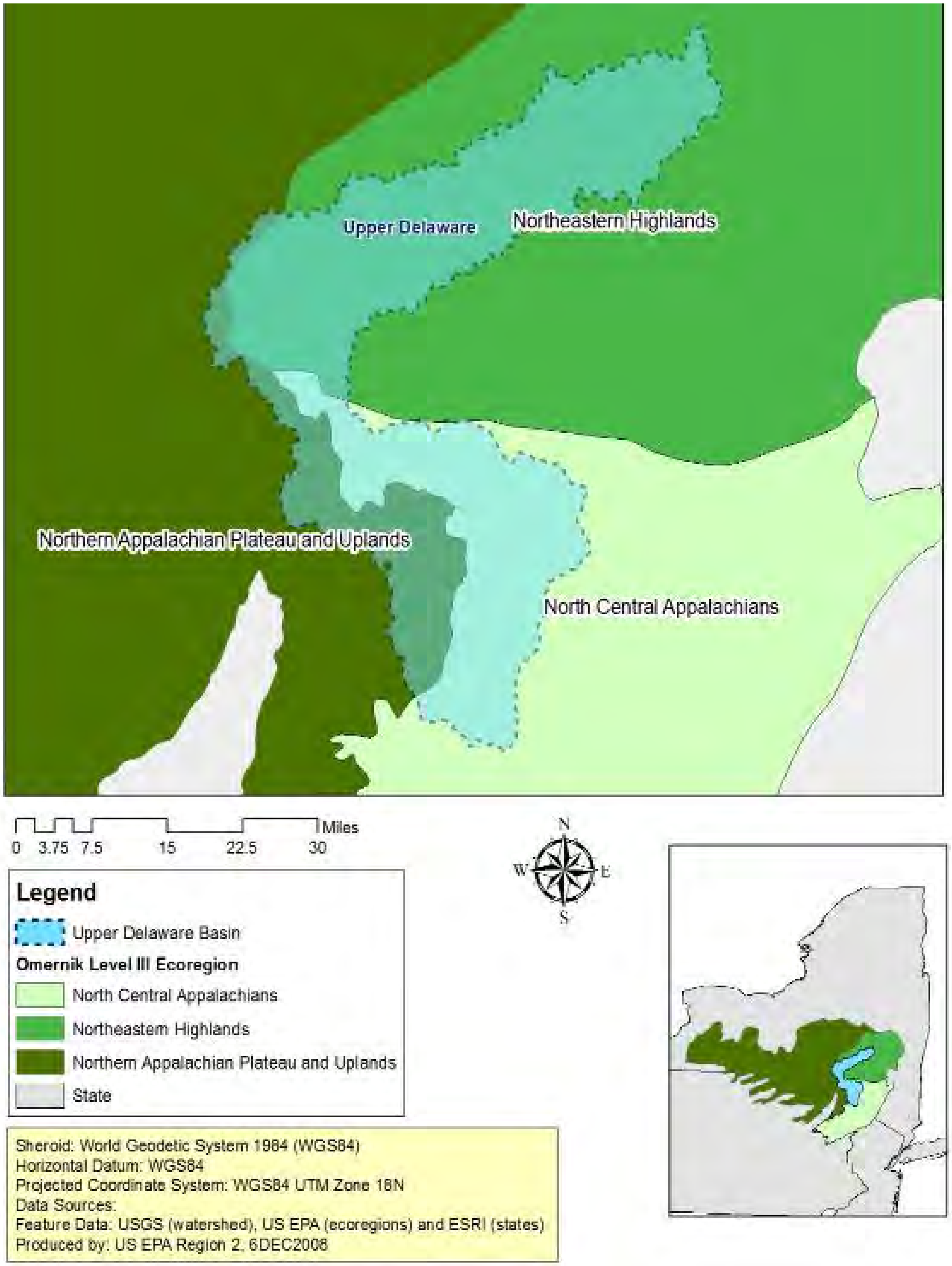


Figure 11: *Upper Delaware Basin: Omernik Level III Ecoregions.*

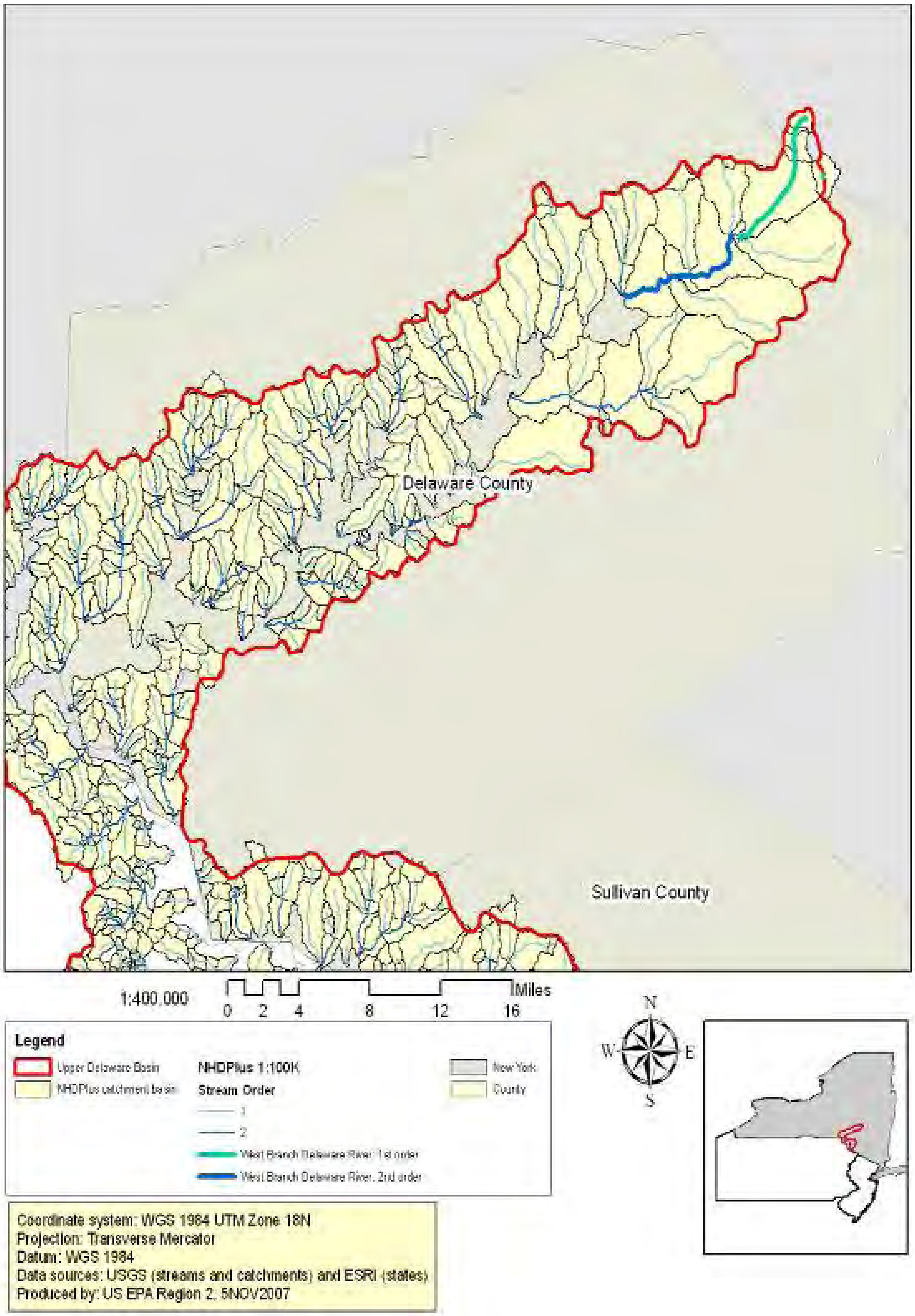


Figure 12: *Upper Delaware Basin: Headwater Streams and Catchment Basins: West Branch Delaware River:* stream reaches are located within northeastern Delaware County.

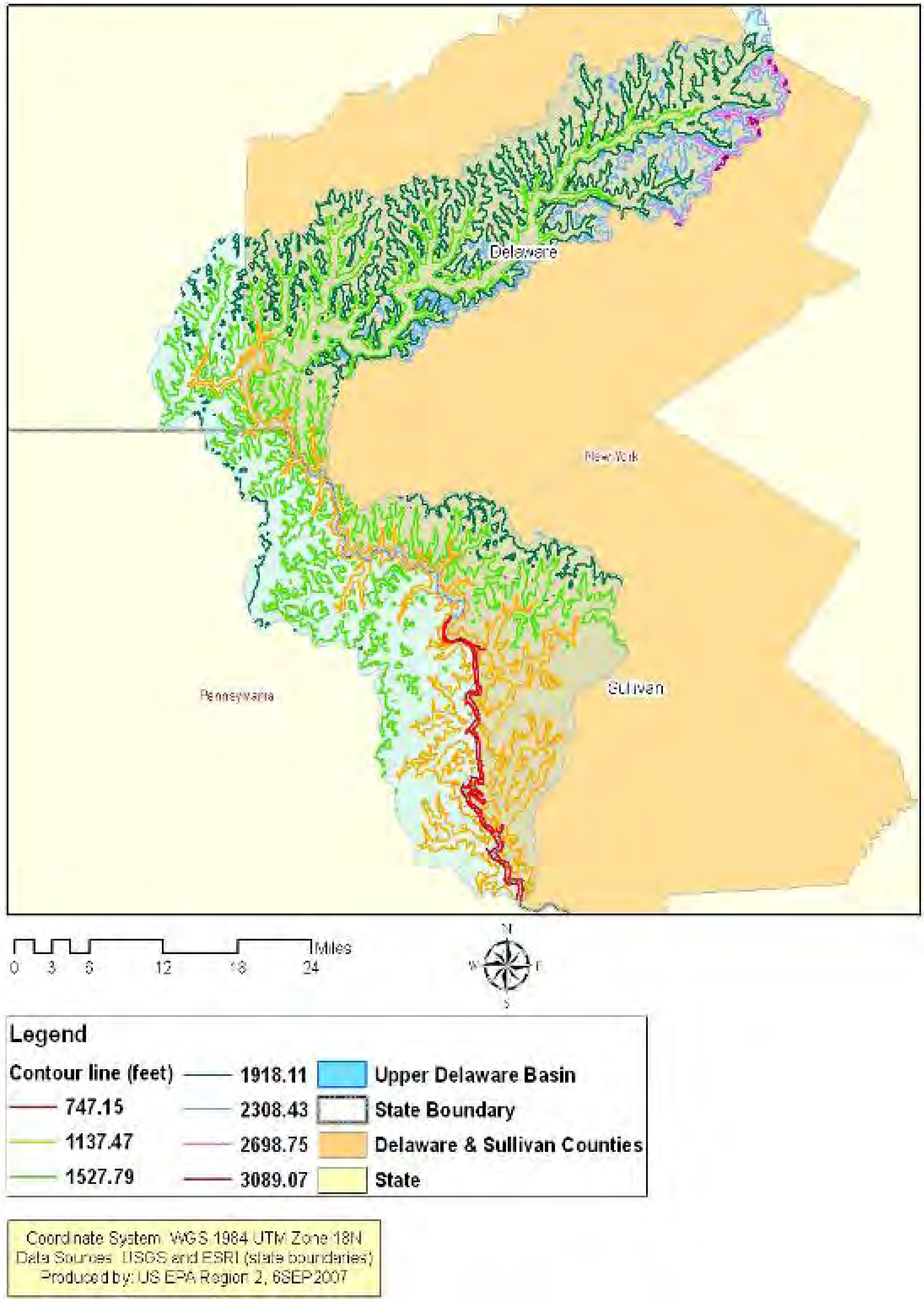


Figure 13: *Upper Delaware Basin: Elevation Model (30 meter DEM).*

Figure 14: *Typical Catskill Mountain Region Stream, Greene County, NY*

2.1.3 Land Use and Land-Cover

In the upland region of the Upper Delaware Basin deciduous forest is the dominant vegetative coverage within the West Branch Basin, also known as the Cannonsville Reservoir Basin; including ash, birch, beech, cherry, maples, and oaks. Conifers are present on some north facing slopes, including mainly eastern hemlock and some white pine. Land use/land-cover along streams, tributaries, and hillsides include agriculturally-based uses; these include grass, shrubs, alfalfa, and corn. Tree species along the main West Branch include the aforementioned species and butternut, sycamore, and willows (Delaware County Soil and Water Conservation District, 2004).

Urban land-cover only makes up a small fraction of the West Branch Basin at about 0.1% (Delaware County Soil and Water Conservation District, 2004). Dairy farming and forestry are the most dominant and pervasive land uses within the West Branch Basin include (Delaware County Soil and Water Conservation District, 2004). Urban land-cover, including various impervious surfaces, is commonly located in floodplain regions, creating the potential for flood events to negatively impact peoples' lives. The National Land Cover Data 2001 dataset was analyzed, focusing on the Upper Delaware Basin. The dominant land-cover types of the Upper Delaware Basin include: deciduous forest, mixed forest, and pasture/hay (**Figure 15**).

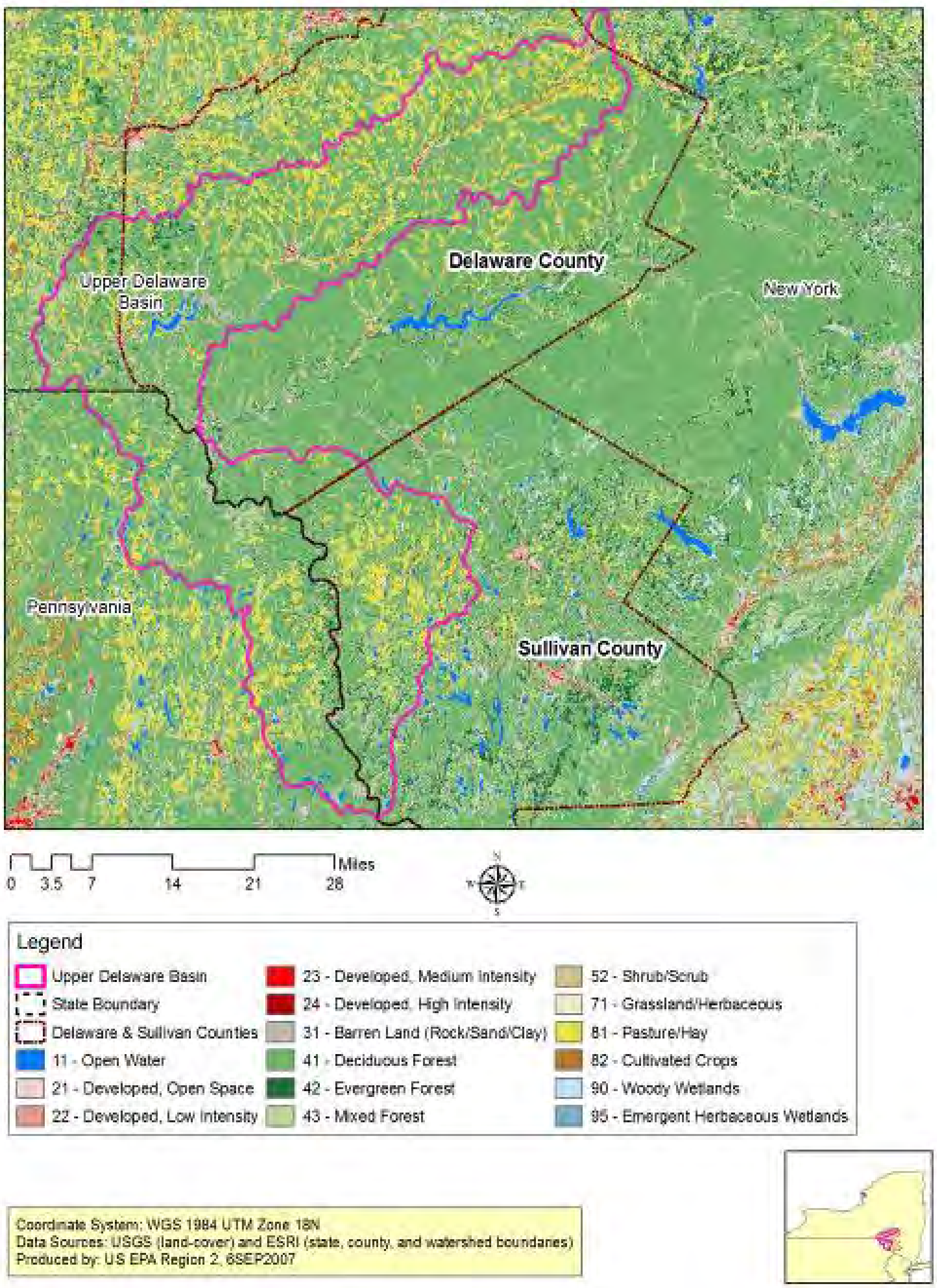


Figure 15: *Upper Delaware Basin: 2001 National Land Cover Data.*

2.1.4 Climate Data

From 1952 – 2005 the Catskill Mountains region, including the Upper Delaware Basin experienced general patterns of increased precipitation, runoff, potential evapotranspiration (PET), and warmer air temperatures. The regional rate of precipitation increased by 136 mm over the 53 year period (Burns et al., 2007). A smaller increase of 19 mm for PET over the 53 year period resulted in increased surface water runoff (Burns et al., 2007). Peak snowmelt shifted from early April in 1952 to late March in 2005 (Burns et al., 2007). Regional annual mean air temperature increased by 6 °C over the 53 year period (Burns et al., 2007). Earlier snowmelt could result from warmer air temperatures, which would contribute to increases in surface water runoff and PET (Burns et al., 2007). The overall increases in rates of precipitation and warmer air temperatures could cause reservoir basins, streams, ponds, and wetlands to reach their corresponding surface water detention capacities more quickly. Potential effects are more frequent flood events within the watershed.

For stormwater management purposes, the predicted precipitation rates for the 100-year, 24-hour storm event in New York for the years 1993 and 2003 were analyzed (**Figure 16**). The maps are based on data available up to 1993 and 2003. Predicted precipitation rates in the Upper Delaware Basin in 1993 ranged from 5 – 7.5 inches (**Figure 16**). In 2003 the range was 5.5 – 7.5 inches of predicted precipitation. The main precipitation classes of the Upper Delaware Basin in 1993 were 5.5, 6, 6.5, and 7 inches (**Figure 16**). In 2003 the major precipitation classes were 6, 6.5, and 7 inches (**Figure 16**). From 1993 to 2003 the predicted precipitation rates for the 100-year, 24-hour storm event in the Upper Delaware Basin became less varied, with an overall increase in areas predicted to have higher precipitation rates. It is worth noting that the Upper Delaware Basin is located adjacent to the area in New York which is predicted to have the greatest amount of predicted precipitation for a 100-year, 24-hour storm event (**Figure 16**). This area is mainly located in Greene County, adjacent to Delaware County. Note that the spatial extent of the peak predicted precipitation rate of 10 inches in Greene County increased in area from 1993 to 2003 (**Figure 16**).

Although there appears to be changes in the trends of the 1993 and 2003 100-year, 24-hour storm event maps (**Figure 16**), temporal variability in extreme precipitation rates throughout the United States may be caused by natural variability (Kunkel et al., 2003). For example, the magnitude of 1-day storm event duration frequencies from 1895 – 1905 is comparable to the magnitudes from the 1980s and 1990s (Kunkel et al., 2003).

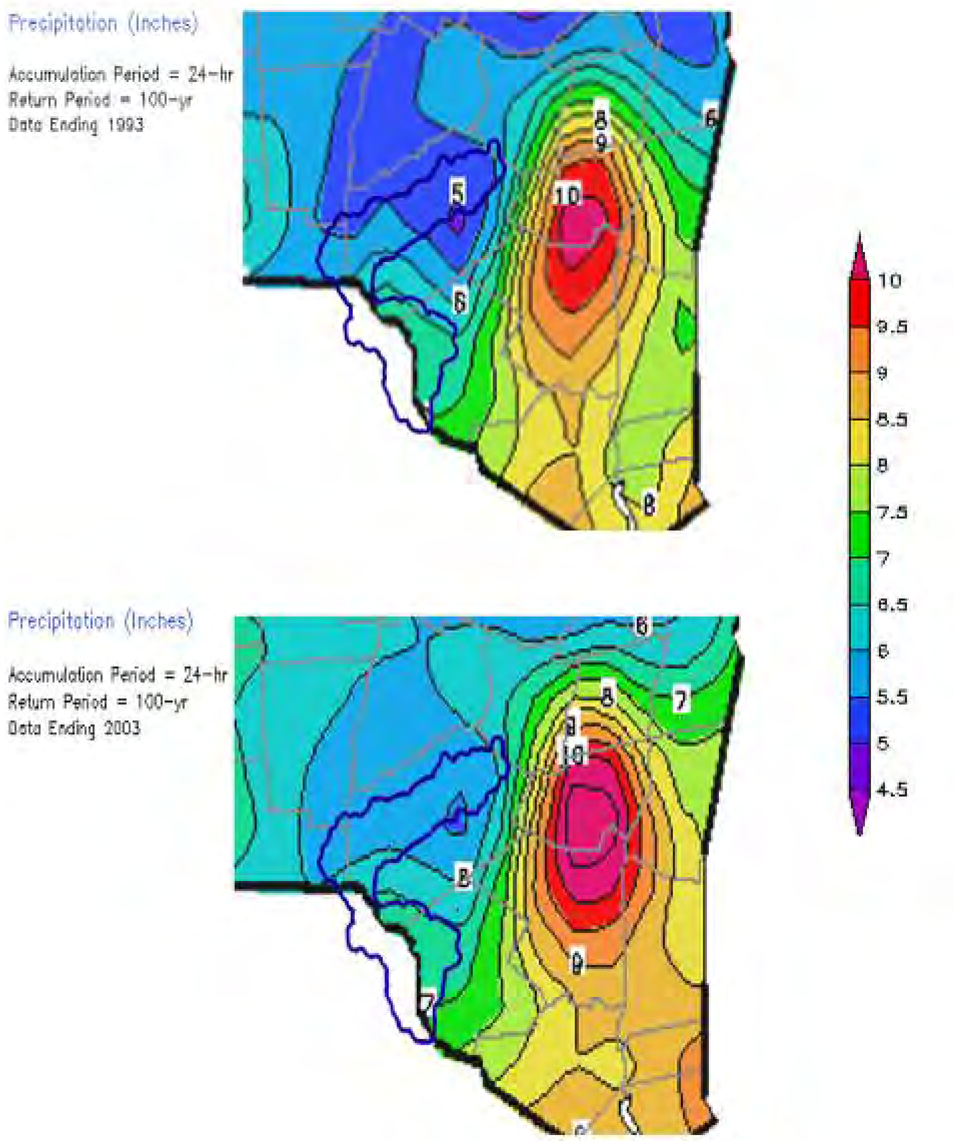


Figure 16: *New York State 24-Hour, 100-Year Storm Event Precipitation 1993 and 2003 Comparison* (Northeast Regional Climate Center, 2008). The Upper Delaware Basin is outlined in blue.

To understand how long term precipitation rates in New York and the Upper Delaware Basin relate to the rest of the continental United States, a 72 month (2003 – 2008) standardized precipitation index (SPI) through the end of February 2008, standardized against long term average precipitation from 1895 to the end of February 2008 was assessed. The SPI designates a single numerical value to precipitation quantities which are compared amongst regions with similar and dissimilar climates (Western Regional Climate Center, 2008a). The Upper Delaware Basin region is classified as exceptionally to extremely wet compared to its long term average and other areas within the continental United States (**Figure 17**). From 2003 to 2008 New York and the northeastern states were generally classified as being wetter than most other areas within the continental United States based on these data (**Figure 17**).

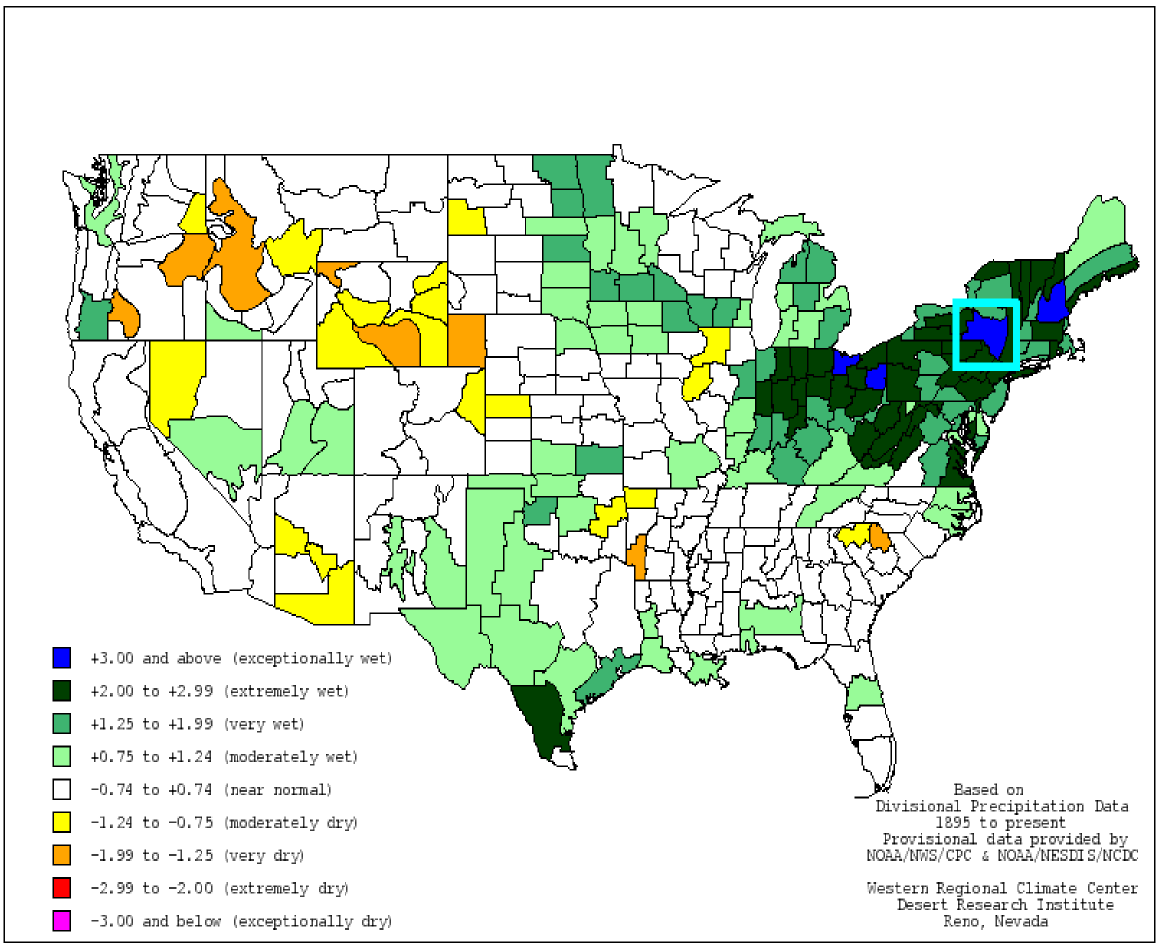


Figure 17: *72-month Standardized Precipitation Index through the end of February 2008* (Western Regional Climate Center, 2008b). The Upper Delaware Basin is generally outlined by the light blue box.

2.1.5 Existing Wetland Resources

The Upper Delaware Basin has a variety of wetlands, ranging in size, vegetation, and hydrologic regime (**Table 3**). A portion of the watershed, 105,453.3 acres or 14%, currently does not have digital NWI data available. The NYSDEC does have digitally mapped wetlands for areas missing digital NWI data, which totals to 3,926.2 acres. The total wetland acreage for the watershed, including digital data from NWI and the NYSDEC is 25,586.8 acres, or 3% of the watershed. Most analyses completed in this study relied mainly on digital NWI data for matters of consistency (**Figure 18**). Field identification of non-digitally available NWI wetlands was conducted in the fall of 2007.

Table 3: Upper Delaware Basin Wetland Types (NWI, 1997)

Wetland Type	**Total (acres)**	**Percent of Total Wetlands**
Freshwater Emergent Wetland	3,019.3	14
Freshwater Forested/Shrub Wetland	5,670.0	26
Freshwater Pond	2,808.6	13
Lake	8,273.2	38
Other	13.2	0
Riverine	1,876.3	9
Total Wetlands	21,660.6	100

Note: this chart only accounts for currently available NWI digital data. A portion of the Upper Delaware Basin currently does not have digital NWI data (see **Figure 18**).

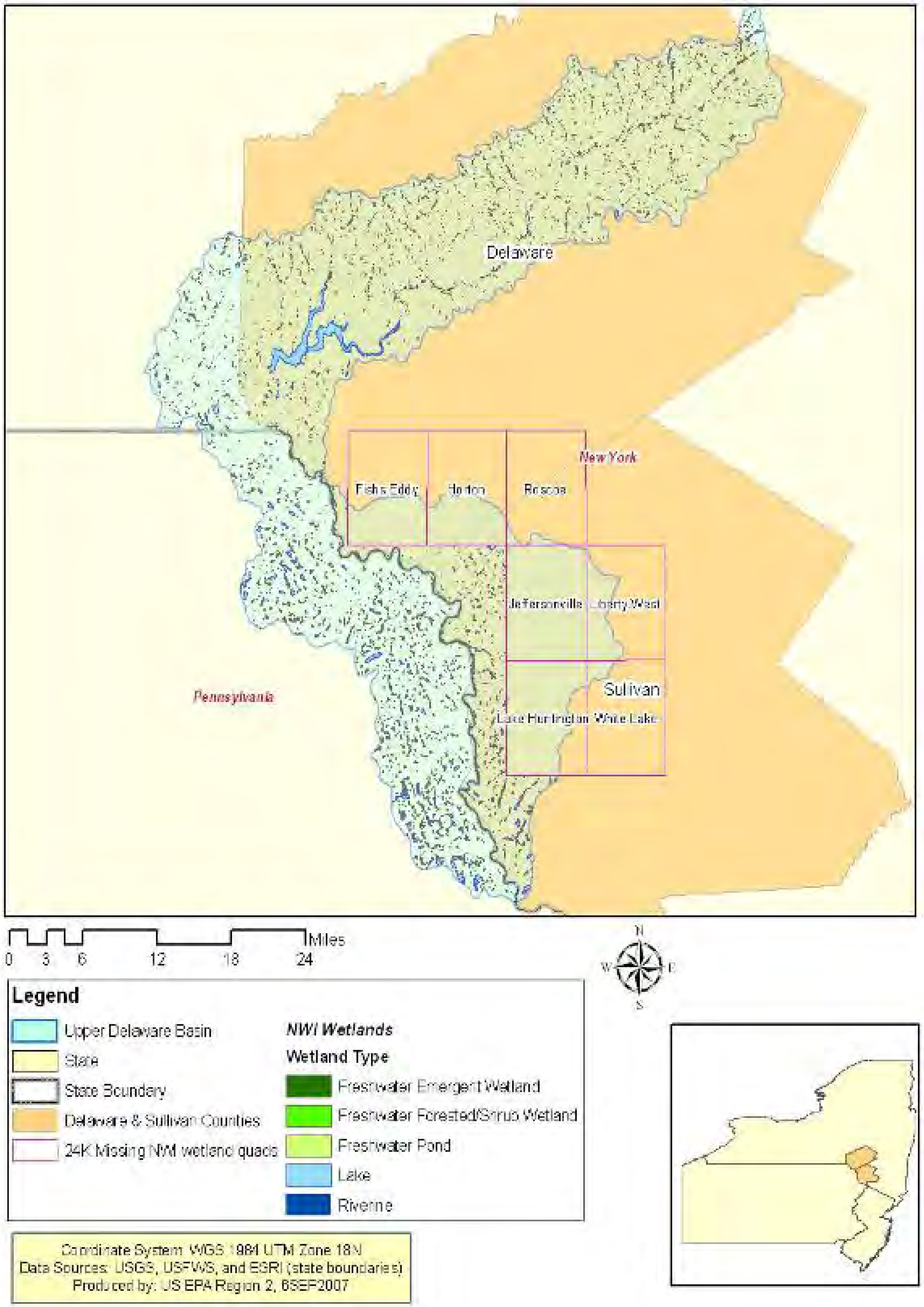


Figure 18: *Upper Delaware Basin: NWI Wetlands.*

2.2 HEADWATER STREAM DELINEATION

To create a headwater stream network using GIS resources, three different data sources were compiled for analysis. These included NHDPlus (1:100K resolution), National Hydrography Dataset high resolution (1:24K), and NYCDEP 1:24K flowlines. The NHDPlus dataset was used as the initial base-map for 1st order streams, their associated catchments, and 2nd order streams. To increase the resolution of the headwater stream network from the base-map, 1:24K stream reaches were added to the map. The NHDPlus headwater catchments were used to clip all 1:24K stream reaches falling within the catchment boundaries. Spatial analyses were conducted to assess total headwater stream network length at both the 1:100K and 1:24K resolutions. The NYCDEP flowline dataset only covered portions of the Upper Delaware Basin that lie within the New York City municipal water supply system watershed (Cannonsville Reservoir Basin). Data were extrapolated from the NYCDEP headwater streams to the entire Upper Delaware Basin to represent the overall potential increase in headwater stream length. Comparisons were made between different headwater stream resolution datasets; also the overall contribution of headwater streams to the entire stream network within the watershed was analyzed.

2.3 HYDROLOGIC ANALYSES

2.3.1 USGS Stream Gauge Data

Long term monitoring of annual peak discharges rates from streams within the watershed were evaluated for trends in relation to the recent flood events. Multiple USGS stream gauges were identified and located within the watershed using a GIS dataset. A small portion of the stream gauge locations had monitoring records for 30 or more years. Two stream gauges with monitoring data records greater than 30 years were used.

USGS stream gauge 01434000 Delaware River at Port Jervis, NY is located just outside of the Upper Delaware River Basin in northwestern Orange County. The monitoring period for the Port Jervis stream gauge was from 1904 to 2006 (102 years). The southern most USGS stream gauge located within the Upper Delaware Basin is USGS stream gauge 01428500 Delaware River above Lackawaxen River near Barryville, NY. This second stream gauge had monitoring data available from 1964 to 2006 (42 years). The Lackawaxen River stream gauge and all other USGS stream gauges located in the watershed along 1:100 K headwater streams were identified and located (**Figure 19**).

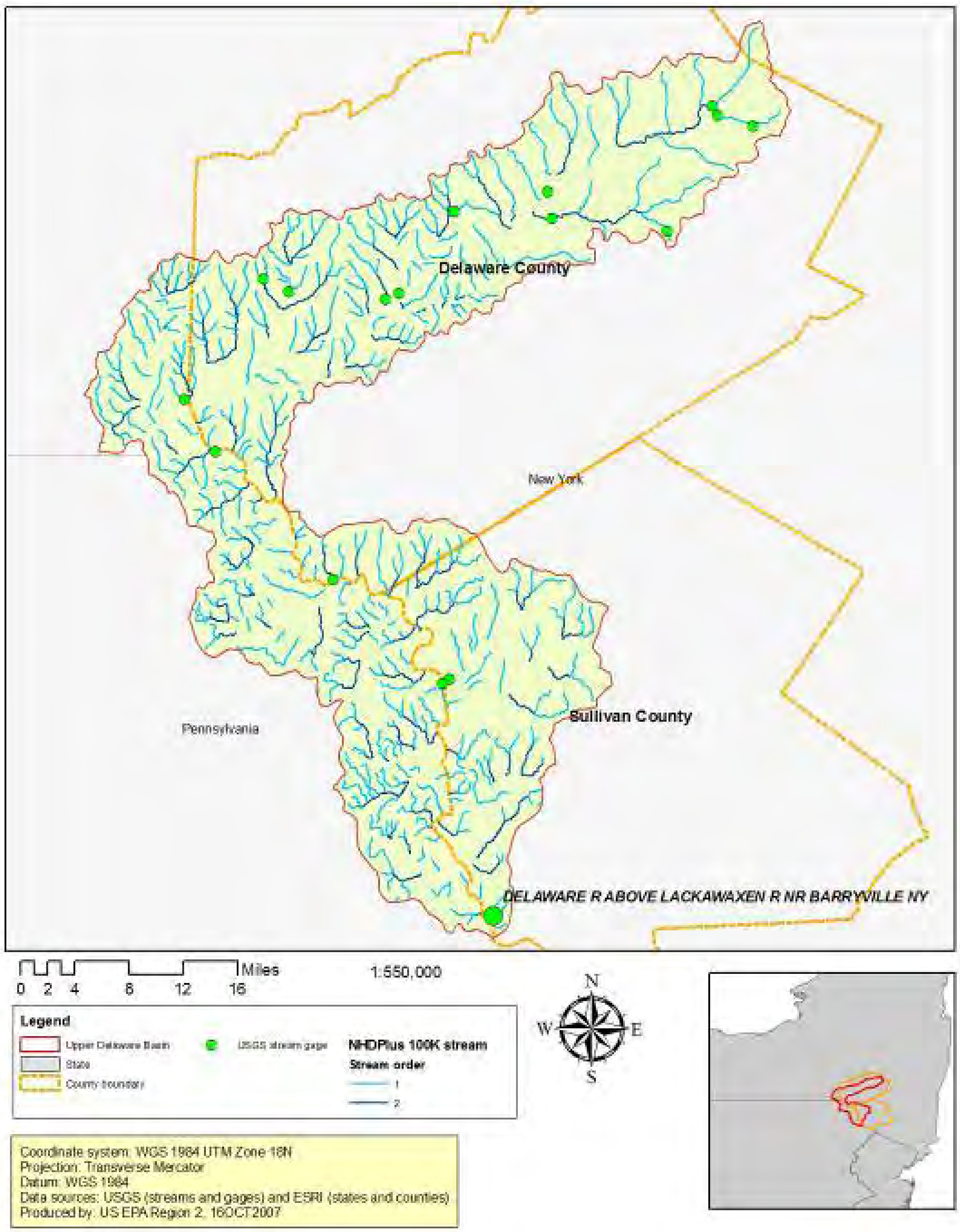


Figure 19: *Upper Delaware Basin Stream Gauge (USGS stream gauge 01428500):Delaware River above Lackawaxen River near Barryville, NY.*
Note: headwater streams are directly adjacent to the Lackawaxen River stream gauge.

2.3.2 Impervious Surface Model: Upper Delaware Basin Assessment

Once the larger scale hydrologic trends were completed an "impervious surface model" developed by Zielinski, 2002 was applied to selected headwater catchments. The impervious surface model assumes certain amounts of impervious surface cover in a given catchment will impact the integrity, stability, and functionality of stream resources (Zielinski, 2002). When there is an increase in the amount of impervious surface in a given catchment stormwater runoff rates increase. Predicted impacts on streams within catchments having 11% to 25% impervious surface coverage include degraded water quality, physical instability, and altered geometry (Zielinski, 2002). In the Upper Delaware Basin many man-made impervious surfaces, such as roads, parking lots, and buildings are located close to stream reaches. The proximity of impervious surfaces to streams in urban or rural catchments makes the "impervious surface model" applicable to the Upper Delaware Basin. The impervious surface model considers the sub-watershed scale (0.5 – 30 square miles) the appropriate use of the model for stream management. The NHDPlus catchments within the watershed are the same size as the sub-watersheds mentioned by Zielinski, 2002.

To prioritize catchments for use with the impervious surface model, an analysis of existing land-cover types was conducted. The National Land Cover Data 2001 (NLCD), the most current national land-cover dataset at the time of study was used to estimate existing land-cover types within the watershed. This assessment facilitated the identification and selection of urban catchments for later analysis with the impervious surface model.

After the land-cover assessment was conducted for the watershed, GIS resources were applied more directly for use with the impervious surface model. Using GIS data, including impervious surface cover, NHDPlus catchments, urban areas, and public roads, the "impervious surface threshold" of 11% to 25% was used to analyze headwater catchments with urban areas. The impervious surface model was applied to two pilot headwater catchments, Walton and the Stamford-Hobart catchments. The two catchments are different in many ways, including: size, location within the watershed, and amount of impervious surface coverage.

2.3.3 Stormwater Modeling

After the impervious surface model was applied, a more detailed analysis of stormwater runoff rates was conducted using the Natural Resources Conservation Service (NRCS) TR-55 and TR-20 models for small urban watersheds. To properly manage stormwater events there has to be an understanding of stormwater runoff occurring in both urban and rural catchments. The NHDPlus catchment acts as a boundary for managing stormwater entering headwater streams. Using rural and urban headwater catchments the NRCS TR-55 and TR-20 stormwater runoff models for small urban watersheds were applied to one urban and one rural catchment in the watershed. These models use a 24-hour single rain event to estimate stormwater runoff from drainage areas. These include peak discharge estimates for 1, 2, 10, 20, 50, and 100-year storm events within a selected drainage area. The recommended size of a wooded watershed using the TR-55 and TR-20 models is between twenty acres (0.031 square mile) and sixteen thousand acres (25 square miles). Using the TR-55 model for wooded watersheds or catchments outside this spatial range may over predict stormwater runoff rates (O'Connor, 2008, Fennessey et al., 2001, and WinTR-55 Workgroup, 2002). The two catchments used for this study fall within the applicable spatial range for small wooded watersheds. Model analyses were compared to actual USGS recorded peak flow discharges and precipitation rates for drainage areas of similar size and associated storm event return intervals.

2.4 FUNCTIONAL ASSESSMENTS

2.4.1 Watershed-Based Preliminary Assessment of Wetland Functions: Upper Delaware Basin Assessment

A functional assessment of NWI wetlands within the Upper Delaware Basin was conducted using the US Fish & Wildlife Service's "Watershed-based Preliminary Assessment of Wetland Functions (W-PAWF) (Tiner, 2003). The US Fish and Wildlife Service adopted the hydrogeomorphic approach developed by Dr. Mark Brinson to assess functions of NWI wetlands (Tiner, 2003). With the W-PAWF, all NWI 1979 Cowardian classified wetlands were assigned "landscape position, landform, water flow path, and waterbody (LLWW)" descriptors. Based on the combination of LLWW descriptors different ecological functions have been predicted for each NWI wetland. Ecological functions associated with different LLWW codes are ranked as moderate or high; wetlands without LLWW codes associated with moderate or high functional values are predicted not to perform certain ecological functions. The general types of LLWW descriptors used in this study were summarized (**Table 4**). From this assessment predicted ecological functions were determined, including surface water detention, sediment retention, nutrient transformation, shoreline stabilization, and stream flow maintenance. These ecological functions were chosen for the assessment because they focused on water quality and floodplain management functions.

GIS technology and datasets were used to complete the wetland functional assessment. The basis for the assessment came from joining and supplementing data from the W-PAWF used for the West of the Hudson Watersheds study (Tiner et al., 2002) and applying it to the entire Upper Delaware Basin. The tabular joins were based on the NWI 1979 Cowardian classifications from the Upper Delaware Basin datasets and the West of the Hudson Watersheds dataset. Overall the tabular joins were successful, but some wetlands were left without "landscape position, landform, water flow path, and waterbody (LLWW)" descriptors. All NWI wetlands without LLWW descriptors within Sullivan and Delaware counties were manually assigned LLWW descriptors. A tabular join from the Sullivan and Delaware County classifications was later applied to the entire watershed. This last tabular join accounted for 95.52% of all digitally mapped NWI wetlands within the Upper Delaware Basin. A portion of the southeastern side of the basin does not currently have digital NWI data. The NYSDEC has digitally mapped wetlands for this portion of the Upper Delaware. The W-PAWF assessment was not applied to the NYSDEC wetlands because they did not include the NWI Cowardian classifications. NYSDEC wetlands account for 9.92% (2,384.09 acres) of total wetland coverage in the watershed.

Table 4: Landscape Position, Landform, Water Flow Path, and Waterbody Type (LLWW) Descriptors (Tiner, 2003)

Landscape	Landform	Water Flow Path	Waterbody Type
Lotic	Floodplain Basin Fringe Island	Throughflow Throughflow-intermittent Throughflow-entrenched Bidirectional-nontidal	River (Gradients: Dammed, High, Middle, Low, and Intermittent) Streams (Gradients: Dammed, High, Middle, Low, and Intermittent)
Lentic	Fringe Basin Flat Island	Bidirectional-nontidal Throughflow	Natural Lake (Main Body and Open and Semi-enclosed Embayment) Dammed River Valley Lake (Reservoir) Dammed River Valley Lake (Hydropower) Dammed River Valley Lake (Other) Other Dammed Lake (Former Natural Lake) Other Dammed Lake (Artificial)
Terrene	Fringe (pond) Basin Basin (former floodplain) Flat Flat (former floodplain) Interfluve Slope	Outflow Outflow-artificial Inflow Throughflow Throughflow-artificial Throughflow-entrenched Isolated Paludified	Pond (Natural, Dammed/Impounded, Excavated, Beaver, and Other Artificial)

2.4.2 Streamside Health Model: Upper Delaware Basin Assessment

Stream functions are affected by adjacent land-cover and land uses. To assess the probable functionality of headwater stream reaches a “streamside health model” analysis was completed for all NHD 1:24 K headwater streams within the Upper Delaware Basin. To understand the overall ecological health of streamside habitats of the watershed, a GIS-based model developed by Meixler, 2003 was employed. The model predicts “ecological health or condition” of streamside habitats by predicting the likelihood of stream habitats to perform desired ecological functions, such as water quality protection and flood attenuation. The model assumes that natural intact or the least human disturbed riparian buffers have the greatest potential for highly rated streamside health. Riparian buffers with land-cover types highly modified by humans are predicted to have the lowest rating for streamside health.

The model uses various GIS datasets and analysis techniques to complete the assessment. Two GIS data layers were used for this model: NHD high resolution headwater stream flowlines (1:24K) and the National Land Cover Data (NLCD) 2001. The first step of the model requires a 30 m buffer around all stream flowlines. A 30 m buffer is the USDA recommended 100 ft streamside buffer for water filtration (Meixler, 2003). The next step involves converting the stream vector-based stream buffer into a vector-based grid. The cell size of the stream buffer was made equal to the NLCD layer, which was 26.9 m^2. Once the streamside buffer was in a grid format, the grid was used as a mask for the land-cover grid. The mask clips out the land-cover types within the streamside buffer.

Land-cover types within the streamside buffer were ranked based on their likelihood to support ecological-based streamside functions. Natural or undisturbed habitats generally support the highest level of ecological functions. Conversely, habitats disturbed by low to high degrees of human-based activities are predicted to have lower performing ecological functions. The relationship between streamside health model classification of streamside conditions and the NLCD 2001 land-cover types was compiled (**Table 5**).

Table 5: Streamside Health Model Classification System

Streamside Condition	**Land-cover Type**
Excellent	Open Water
	Deciduous Forest
	Evergreen Forest
	Mixed Forest
	Grassland Herbaceous
	Woody Wetland
	Emergent Herbaceous Wetland
Good	Scrub Shrub
Fair	Pasture Hay

Table 5 (cont.)

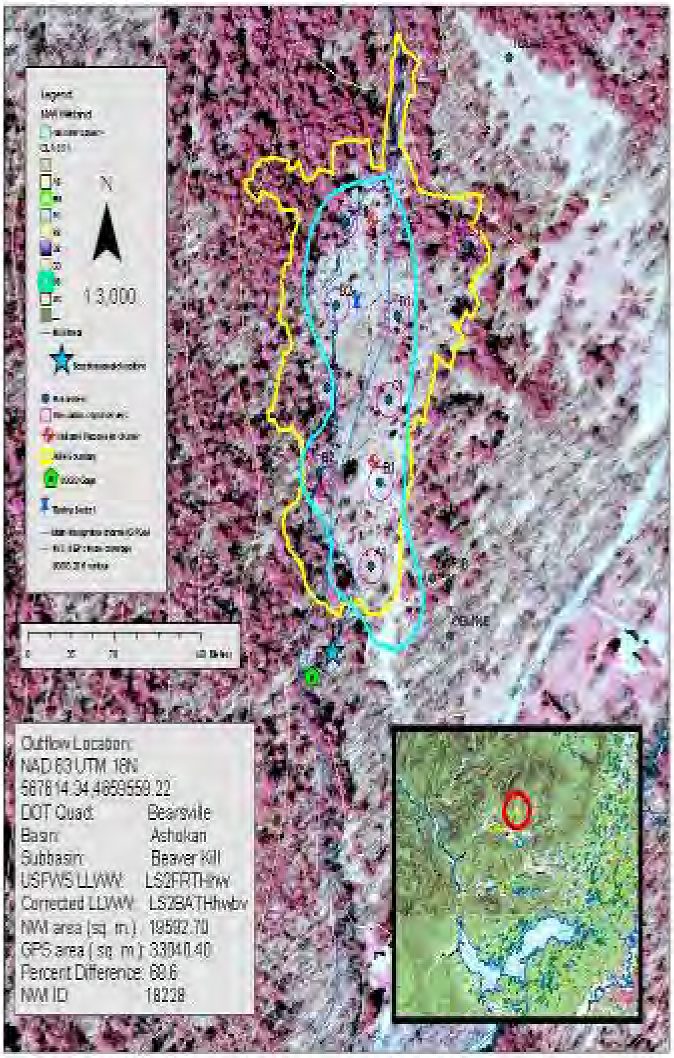
Streamside Condition	Land-cover Type
Poor	Developed Open Space
	Cultivated Crops
Very Poor	Developed Medium Intensity
	Developed High Intensity
	Barren Land

2.5 FLOOD STORAGE ASSESSMENT

2.5.1 Wetland Stormwater Monitoring and Storage Capacity

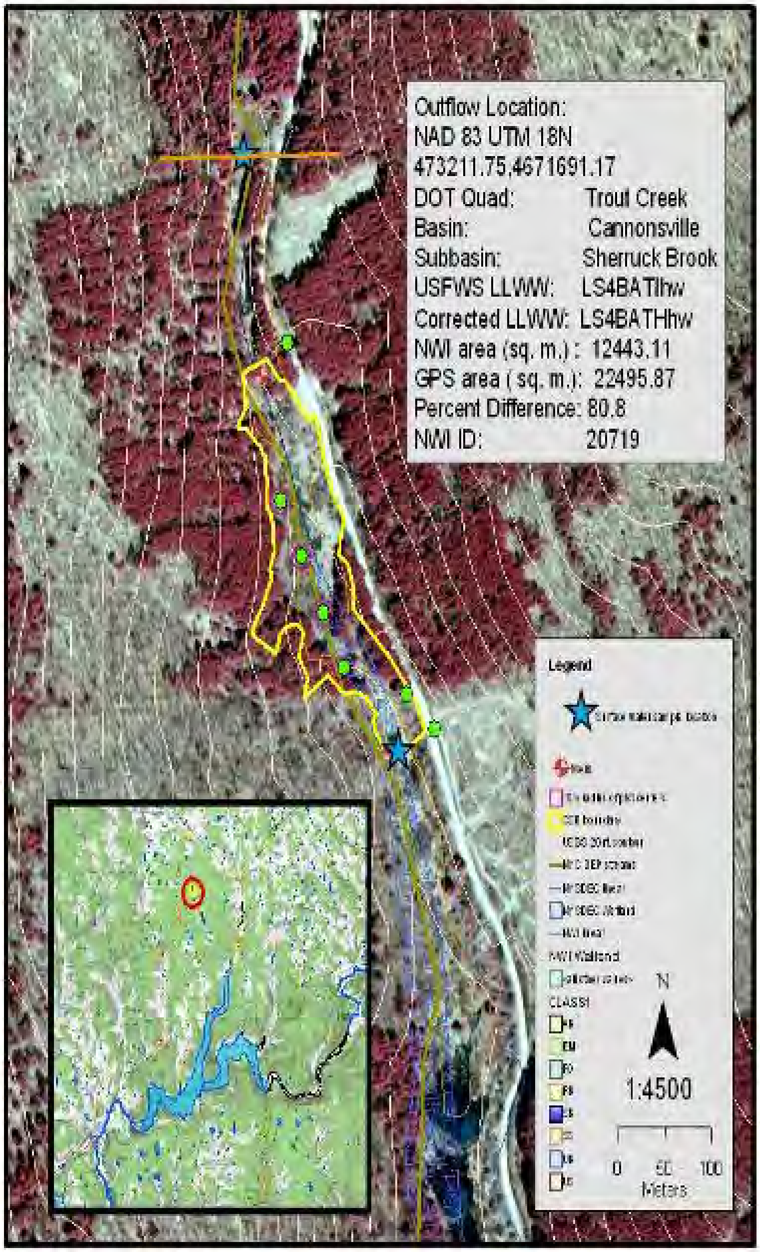
Stormwater monitoring data from two NYCDEP reference wetlands were used to estimate the flood storage capacity of NWI wetlands within the Upper Delaware Basin with high to moderate surface water detention functionality based on the results from the Watershed-based Preliminary Assessment of Wetland Functions (W-PAWF) of the Upper Delaware Basin. From September 2004 to October 2005, stormwater monitoring data were recorded for surface water inputs and outputs of two NYCDEP reference wetlands with predicted high performing surface water detention capabilities, located in different areas within the New York City municipal water supply system (Cirmo, 2006). Stormwater data from the reference wetlands, indicating positive net storages of stormwater were used to predict the storage capacity of all NWI wetlands with predicted moderate to high performance functionality (W-PAWF assessment) under ideal circumstances within the watershed. The locations of the NYCDEP reference wetlands used to predict stormwater storage capacity for the watershed were identified and located (**Figures 20 – 21**).

Certain types of freshwater wetlands have moderate to high surface water detention functions, primarily based on their landscape position, landform, water flow path, and water body type. Surface water detention functionality was analyzed at various temporal and spatial scales: 1) the entire Upper Delaware Basin; 2) typical rural and urban headwater catchments for a 1-year storm event (prior wet conditions) and a 100-year (prior dry conditions) storm event; and 3) storm event hydrographs for both the rural and urban (Stamford-Hobart) headwater catchments. The analyses also allowed for predicting existing deficits in wetland stormwater storage capacity for typical urban and rural headwater catchments. All flood storage assessments conducted used a combination of the NRCS TR-55 and TR-20 model results and from the NYCDEP reference wetlands stormwater data.



NYC DEP The boundary depicted represents the WOH Reference Wetland Monitoring Program study site, not a delineation of adjacent wetlands. The percent difference of NWI and GPS areas represents the difference between the GPSed study site area and the area of immediately corresponding NWI polygon areas.

Figure 20: *NYCDEP Reference Wetland, AMH Mink Hollow, Mink Hollow Road, Lake Hill, NY*: located in the Ashokan Basin. Its corrected LLWW classification is “lotic stream, middle gradient, basin, through-flow, headwater, beaver-induced (NYCDEP, 2006).”



NYC DEP The boundary depicted represents the WOH Reference Wetland Monitoring Program study site, not a delineation of adjacent wetlands. The percent difference of NWI and GPS areas represents the difference between the GPSed study site area and the area of immediately corresponding NWI polygon areas between the inflow and outflow used in the study.

Figure 21: *NYCDEP Reference Wetland, CSB Mormon Hollow Road, Tompkins, NY*: located in the Cannonsville Reservoir Basin. Its corrected LLWW classification is “lotic stream, intermittent gradient, basin, through-flow, headwater (NYCDEP, 2006).”

2.6 URBAN TREND AND LAND-COVER CHANGE ANALYSES

2.6.1 SLEUTH Urban Growth Model Analysis: Upper Delaware Basin

Growth of urban development in the Upper Delaware Basin is a concern of many stakeholders, including county planners, the National Park Service, Delaware River Basin Commission, water resource managers, state and federal agencies, and a regional university (Jantz and Goetz, 2007). To understand how urban development has occurred in the past and is likely to occur in the future, an urban growth model called SLEUTH was implemented. SLEUTH stands for: slope, land use, exclusion, urban extent, transportation, and hill shade (Woods Hole Research Center, 2008).

Using historical impervious surface maps (representing urban development) from 1986 to 2006, SLEUTH was trained and calibrated to simulate historic development patterns into the future (Jantz and Goetz, 2007). The SLEUTH model was applied to four counties within the Upper Delaware Basin, including Delaware and Sullivan counties of NY and Wayne and Pike counties of PA. Collectively the SLEUTH model results from the counties provide a watershed-based perspective of impacts from urban development.

An existing development trend scenario, based on current land use policies and development rates was established to assess potential impacts on natural resources (Jantz and Goetz, 2007). The baseline or existing conditions scenario was used to conceptualize alternative development scenarios focused on protecting and conserving ecological services provided by existing wetland and headwater stream resources. Sullivan County was the major focus of wetland impacts from existing development trends. Analyses looked at future increases in impervious surface area and associated wetland losses. SLEUTH model results for wetland losses were compared to actual US Army Corps of Engineers 404 permitted wetland losses within Sullivan, Delaware, Pike (PA), and Wayne (PA) counties. Existing and alternative future development scenarios were analyzed and proposed to plan out delivery of critical ecological services.

2.7 GIS DATABASE

Most of the assessments and analyses carried out for this project involved the use of geographic information systems (GIS) data and software. The majority of the GIS datasets were collected and organized before most of the analyses were conducted. All of the datasets were accessed for no-charge from publicly available sources. The EPA Region 2 GIS server provided a portion of the datasets used, while other online sources supplemented desired data needs. The primary GIS software resource was ArcGIS 9.2, including ArcMap and ArcCatalog. Other ArcMap extension tools employed included XTools Pro Version 5.0.0 and DigitalGlobe Image Server.

Once the GIS data were collected, it was cataloged and organized according to federal and EPA based geospatial metadata standards. These standards were used to provide future users of the datasets appropriate background information about the data. Metadata is commonly produced in association with GIS datasets to describe their content, quality, condition, and other relevant data characteristics (Federal Geographic Data Committee, 2000). Cataloging of metadata was conducted using the US EPA Metadata Editor, which is an extension tool for ArcGIS (US EPA, 2007). Use of the US EPA Metadata Editor allowed for metadata to be created in accordance with EPA-based geospatial metadata standards. The EPA has implemented its metadata standards by adopting and supplementing the Federal Geographic Data Committee's Content Standard for Digital Geospatial Metadata (**Table 6**).

Table 6: US EPA Geospatial Metadata Requirements
(US EPA, 2007)

Metadata Section	**Description**
Identification Information	Basic information about the data.
Data Quality	General quality assessment of the data.
Spatial Data Organization *(Optional)*	Mechanism used to represent spatial information of the data.
Spatial Reference Information	Description of reference frame to encode coordinates of the data.

Table 6 (cont.)

Metadata Section	Description
Entity and Attribute Information *(Optional)*	Details of content information of the data: entity types, attributes, and domains from which attributes may be assigned.
Distribution Information	Information about the distributor and ways of obtaining the data.
Metadata Reference Information	Date of metadata information and the party responsible for it.

2.8 SELECTION OF BEST MANAGEMENT PRACTICES (BMPS) FROM EXISTING DESIGN PRECEDENTS

Based on results from the various assessments and analyses, including: headwater stream network delineation; ecological and hydrological functions of wetlands; conditional assessment of headwater stream corridors; climatic data; stormwater monitoring; urban and wetland land-cover change; and predicted future urban development, best management practices (BMPs) were selected. Conservation, preservation, protection, and enhancement of existing and future ecological services from wetland and headwater stream resources guided the appropriate selection of various BMPs for different scales and contexts within the Upper Delaware Basin. This collection of selected BMPs acts as a toolbox to use for stormwater management. BMPs currently used within the New York City municipal water supply system watershed and New York state formed the basis of BMP design precedents and selections. Sources of BMP designs came from Greene County Soil and Water Conservation District, NYCDEP, NYSDEC, the Center for Watershed Protection, and the Natural Resources Conservation Service (NRCS).

The first criteria for selecting BMPs started with managing for design storm events which would provide overbank flood protection and stable conveyance of stormwater. Design storm events were chosen based on recommendations from the New York State Stormwater Management Design Manual (New York State DEC, 2003). The second criteria was based on the ability of a BMP to perform high levels of flood attenuation and/or water quality protection as it related to protection, preservation, restoration, and creation of wetland and stream resources.

Different BMPs provide varying amounts of beneficial ecological services based on the type of headwater catchment, rural or urban, they are located within. Prioritizing headwater catchments for BMPs was based on the amount of existing and expected urban development (impervious surface cover) and predicted deficits in surface water detention. Rural catchments with headwater stream corridors in fair to very poor conditions were also prioritized for evaluation of BMPs.

The scale of selected BMPs ranged from residential developments, roadways, sidewalks, parking lots, individual housing parcels, and residential backyards. The various spatial scales and contexts within the Upper Delaware Basin require a different suite of BMPs for any given site or catchment. This toolbox of BMPs briefly showcases where, when, why, and how to use the BMPs.

2.9 ECONOMIC VALUATION OF ECOLOGICAL FUNCTIONS

The ecological functions provided by wetlands and headwater streams may be assigned various economic values. Providing an economic valuation of the ecological functions allows society to understand approximate costs associated with functions of wetlands and headwater streams. Within the context of this study, flood attenuation and water quality protection are the primary functions of interest. An estimate of the economic value of surface water predicted to be detained by existing wetlands within the watershed was calculated by estimating the construction costs of building new stormwater BMPs to detain surface water already stored by existing wetlands.

Some of the negative economic losses caused by flood events are preventable with proper stormwater management and planning. The existing landscape and environmental conditions of the Upper Delaware Basin require increases in flood attenuation and water quality protection. Analyses of potentially avoidable costs from recent flood events within the watershed were connected to existing deficits of desirable ecological and hydrologic functions.

Records of economic costs from the recent flood events (2004 – 2007) were obtained from a local newspaper (the Times Herald-Record), the Delaware River Basin Commission, and the Federal Emergency Management Agency (FEMA). The main argument is that a portion of these economic losses could potentially be avoided with future investments that improve and enhance ecological functions of wetlands and headwater stream resources.

CHAPTER 3
RESULTS

3.1 HEADWATER STREAM DELINEATION

The lengths of streams in the whole watershed (1:100K resolution) and headwater streams and associated catchment basins were summarized (**Table 7)**. A base-map of 1:100K resolution headwater streams within the watershed was created (**Figure 22**). The percentage of total headwater catchment stream network length is compared to the total Upper Delaware Basin stream network length (**Table 7)**. At the 1:100 K scale 77.62% of the total stream network length within the Upper Delaware Basin is classified as "headwater streams."

Defining headwater streams based on stream order is dependent upon the scale or resolution of the stream data. NHD fine resolution has a 1:24K scale, which depicts more stream miles than the NHDPlus medium (1:100K) resolution data. Within the Upper Delaware Basin NHDPlus headwater catchments contain a total of 963.6 headwater stream miles. Analyses of these same catchments at the 1:24K scale contain 1,745.4 headwater stream miles (**Table 8**). Base-maps of the 1:24 K headwater stream networks were created (**Figures 23 – 24**). There is a difference of 781.8 headwater stream miles between the 1:100K and 1:24K datasets. A "zoomed-in" view of **Figure 24** highlights the difference in stream miles between the medium and high resolution stream data (**Figure 25**).

Table 7: Stream Length Statistics: Upper Delaware Basin Headwater Streams and Catchment Basins (NHDPlus medium resolution (1:100K) flowlines)

Water Boundary	**Stream Category**	**Total Length of Stream System** (miles)	**Percent of Total Stream System** (miles)
Upper Delaware Basin	All stream segments	1,241.4	100%
Headwater catchment basins	First order streams	740.2	60%
	Second order streams	223.4	18%
	Summation of first and second order streams	963.6	78%

Note: headwater stream segments based on USGS NHDPlus 1:100K flowline data.

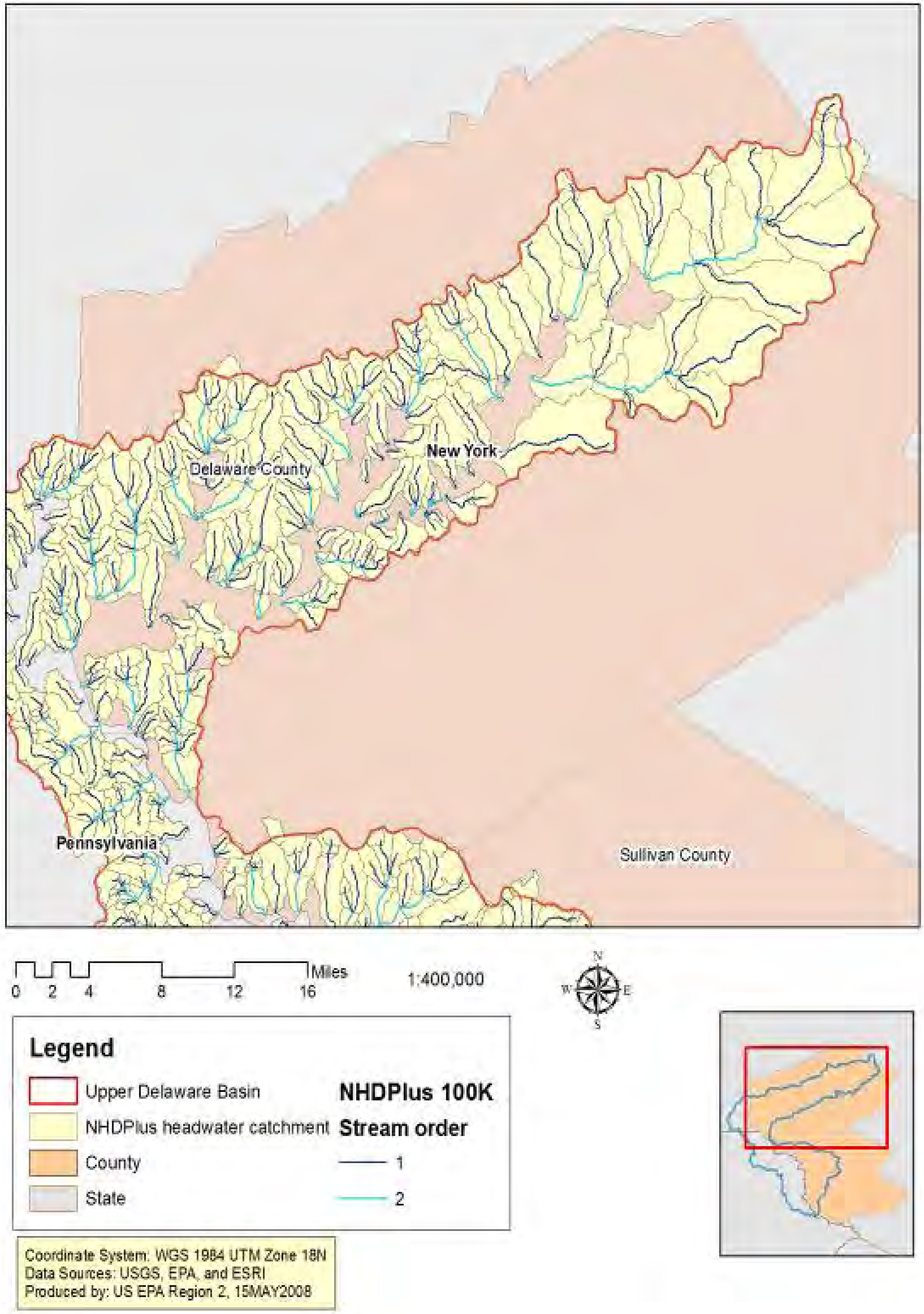


Figure: 22 *Upper Delaware Basin:1:100 K Headwater Stream Network Base-Map.*

Table 8: Stream Length Statistics: Upper Delaware Basin Headwater Streams and Basins (1:24K flowlines)

Water Boundary	**Stream Category**	**Total Length of Stream System** (miles)	**Percent of Total Stream System** (miles)
Upper Delaware Basin	All stream segments 1:24 K	2,149.3	100%
Headwater catchments	NHD 1:24 K headwater stream	1,695.4	79%
	NYCDEP (limited basins) headwater stream	50.0	2% (additional stream miles)
	Summation of NHD and NYCDEP streams	1,745.4	81%

The NYCDEP stream dataset covers portions of the New York City municipal water supply system watershed within the Upper Delaware Basin. NYCDEP streams only cover 39.1% of the surface area of all headwater basins within the Upper Delaware Basin. From the NYCDEP stream dataset there are 667.2 stream miles within the Upper Delaware Basin.

Comparisons between the headwater stream networks from the 1:100 K and 1:24 K datasets reveal that higher resolution data greatly increases total stream network length. The change in percentage of headwater stream miles from the 1:100 K data to the 1:24 K data was +81%. The NYCDEP stream dataset increased the total length of the 1:24 K headwater stream network by 7%. It is predicted that if NYCDEP dataset represented the whole Upper Delaware Basin there would be 1,822.4 headwater stream miles (127 additional miles).

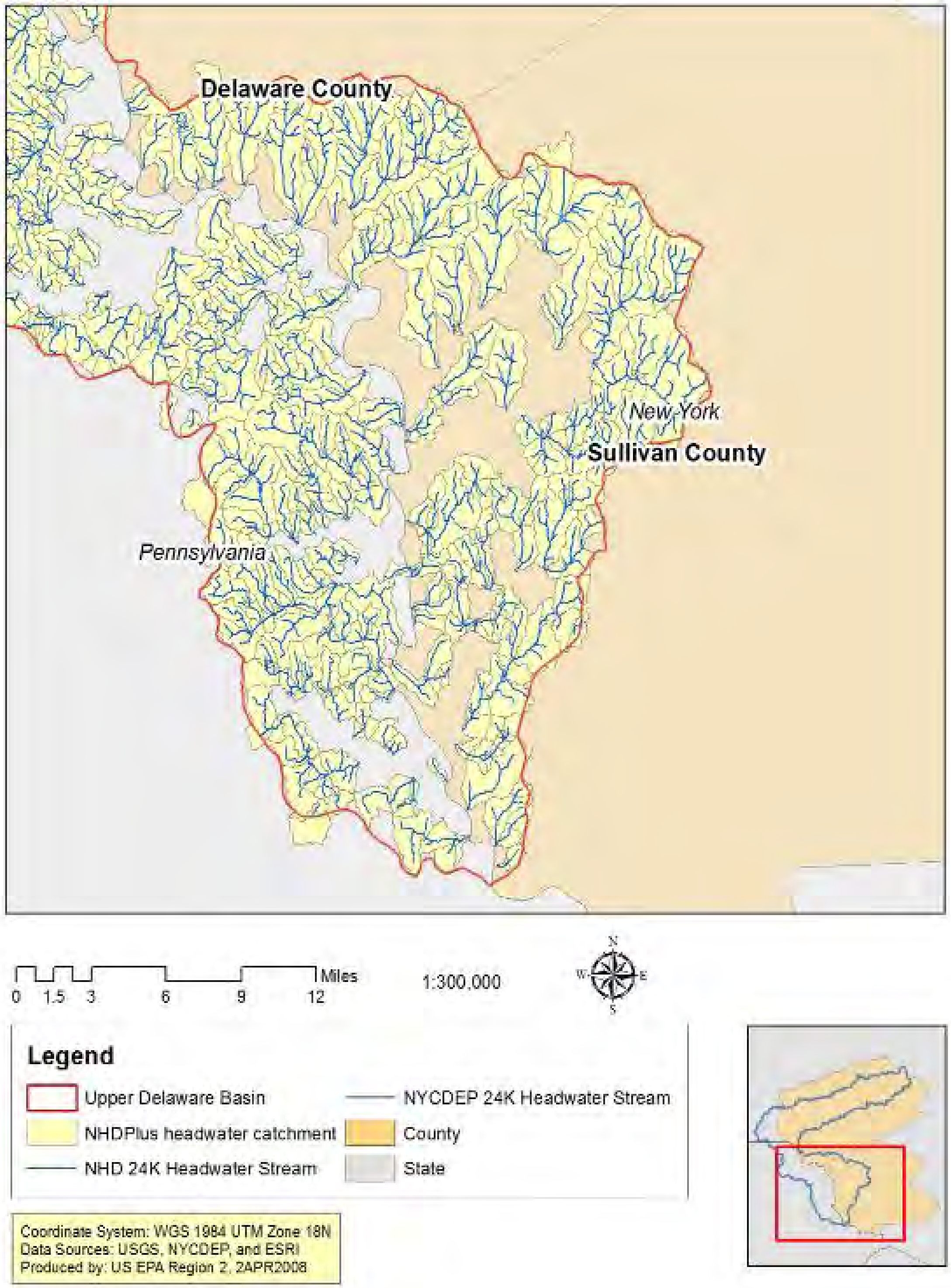


Figure 23: *Upper Delaware Basin: 1:24 K Headwater Stream Network of Sullivan County, NY.*

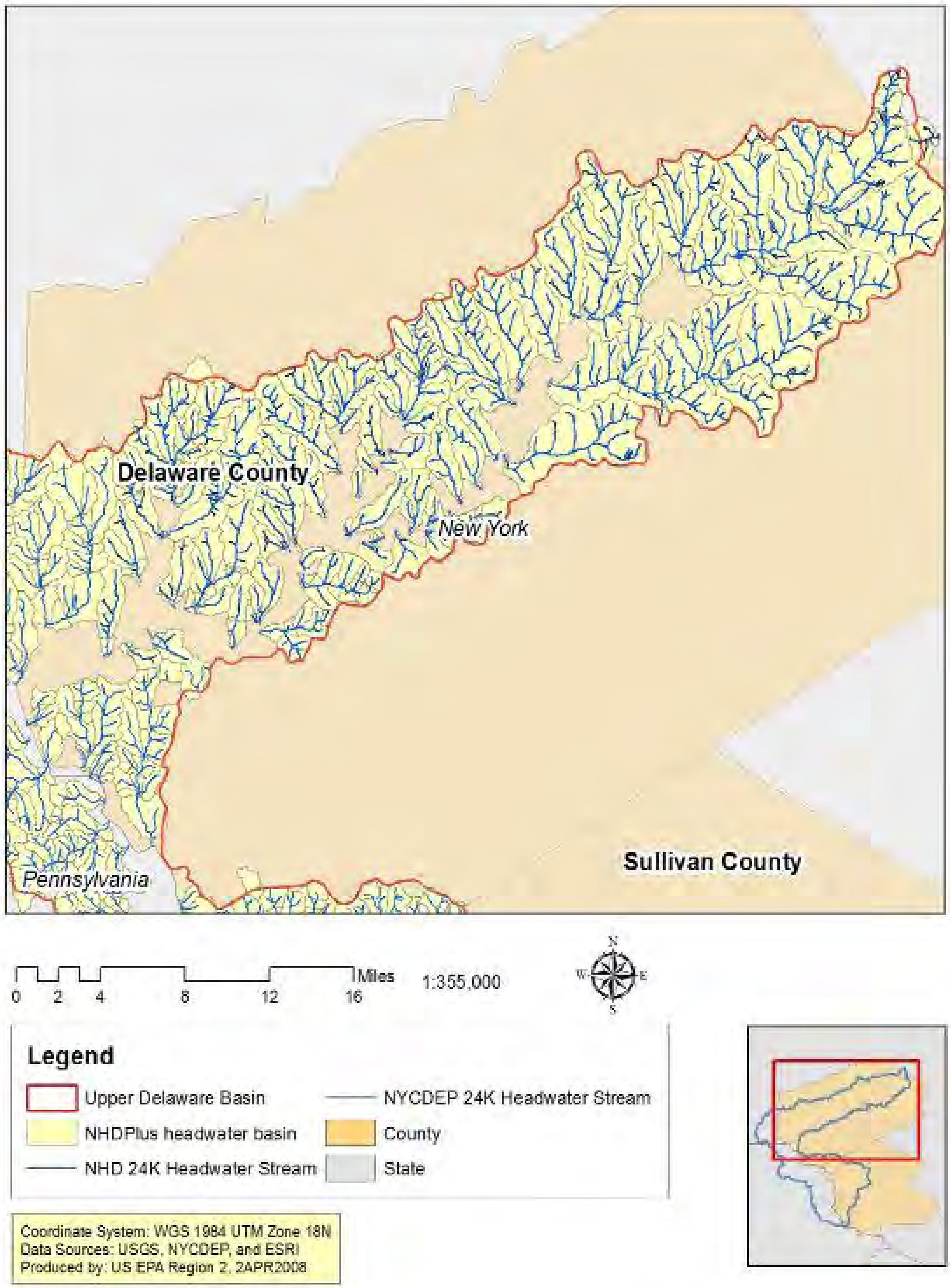


Figure 24: *Upper Delaware Basin: 1:24 K Headwater Stream Network of Delaware County, NY.*

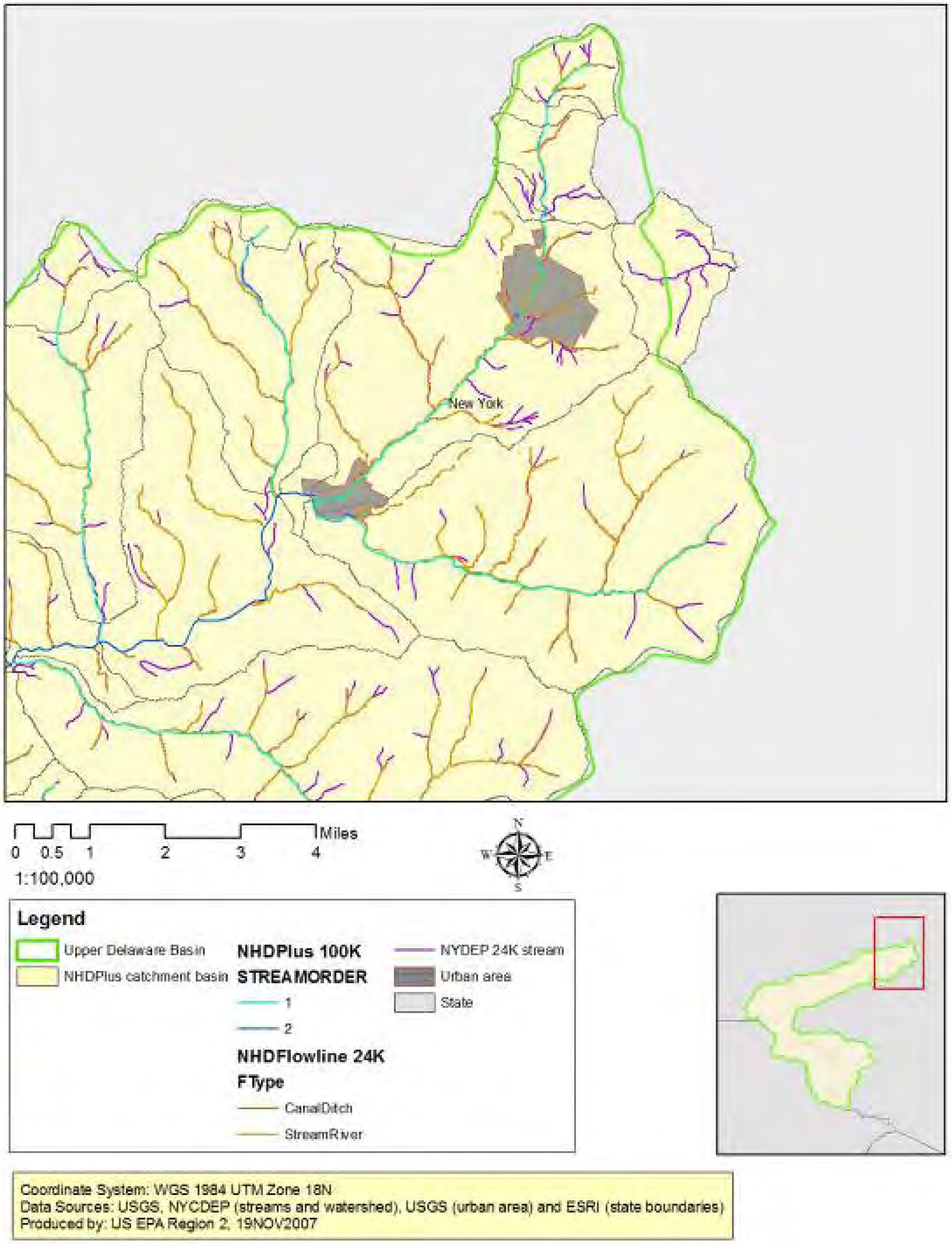


Figure 25: *Upper Delaware Basin: Close-Up View of Headwater Streams, Delaware County, NY:* view of the northeast portion of the watershed. Note the difference in the number of stream flowlines between the 1:100K and 1:24K stream networks.

3.2 HYDROLOGIC ANALYSES

3.2.1 USGS Stream Gauge Data

The annual peak stream flow measurements (maximum daily average) of the USGS stream gauge 01434000 Delaware River at Port Jervis from 1904 until 2006 were identified (**Figure 26**). Port Jervis is located just outside of the Upper Delaware Basin in northwestern Orange County. The drainage area for this stream gauge is 3,070 mi^2 (Brooks, 2005). In 1904, 1955, and from 2004 to 2006 there were record peak annual stream flow events that exceeded 150,000 ft^3/sec. The peak flow event of 2004 had a 90-year recurrence interval, based on peak flow events from 1964 to 2004 (Brooks, 2005). The recurrence interval of a peak flow event is the reciprocal of the probability that a certain event will occur in a given year. So a 90-year event has a 1.1 percent chance of occurring in a given year. From 2005 to 2006 there have been two peak flow events greater in magnitude than the 90-year storm event from 2004.

The southernmost USGS stream gauge within the Upper Delaware Basin is USGS stream gauge 01428500 Delaware River above Lackawaxen River near Barryville, NY (**Figure 27**). The annual peak stream flow measurements of USGS stream gauge 01428500, dating from 1964 to 2006 were identified (**Figure 27**). The drainage area for this stream gauge is 2,020 mi^2 (Brooks, 2005). In 2004 the annual peak stream flow event was a 90-year event (Brooks, 2005). At this stream gauge, from 2005 to 2006 the annual peak stream flow events had greater magnitudes than the 90-year storm event of 2004. The spatial locations of USGS stream gauges at Port Jervis and near Barryville, NY were identified (**Figure 28**).

In 2004 – 2006 the annual peak stream flow records for both stream gauges were caused by specific climatic conditions. In September 2004 the flood was associated with remnants of Hurricane Ivan. Subsequently the April 2005 flood event was caused by a weather frontal system and associated snowmelt. Lastly, the June 2006 flood event was the result of a stalled weather frontal system (Firda, 2008).

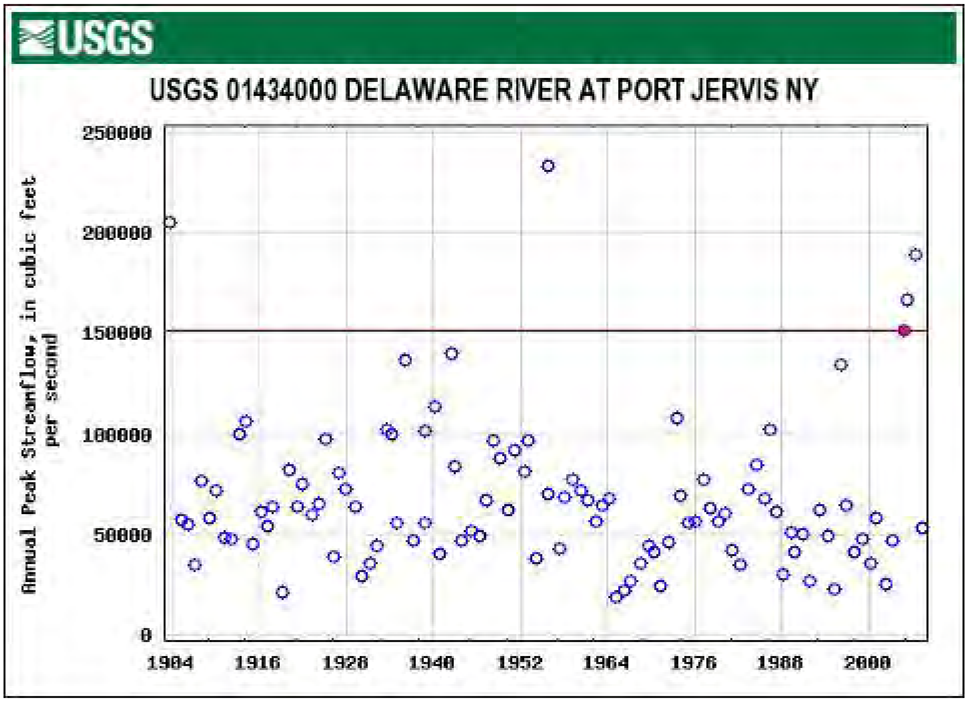


Figure 26: *USGS 01434000 Delaware River at Port Jervis NY*: peak annual stream flow at Port Jervis, NY (USGS, 2008). The read dot and line indicate the 90-year recurrence interval of the peak flow event of 2004 (Brooks, 2005).

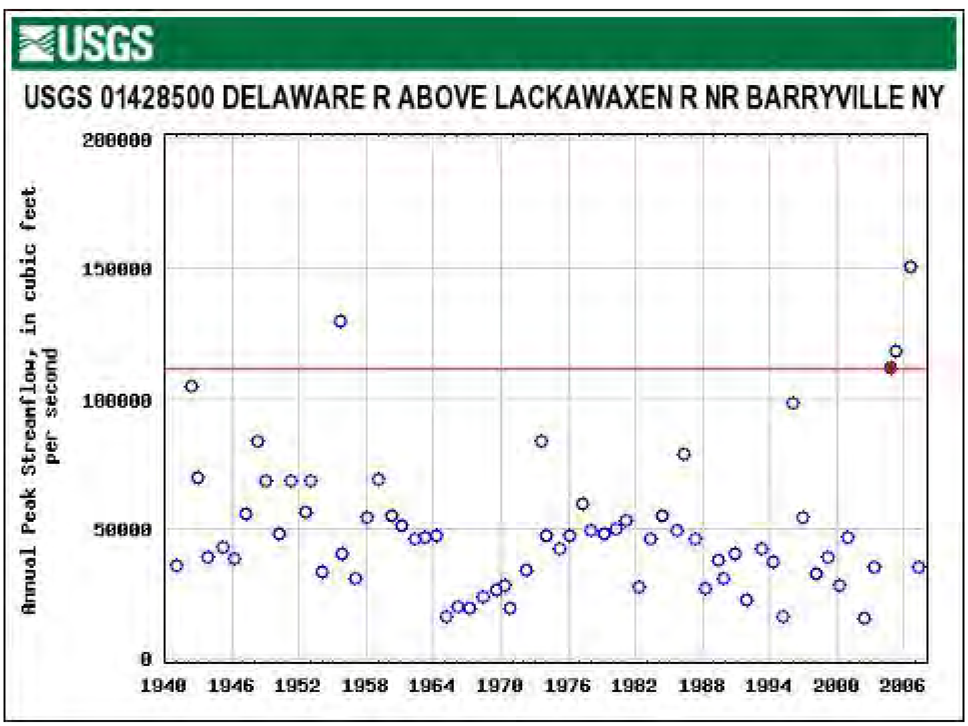


Figure 27: *USGS 01428500 Delaware River above Lackawaxen R NR, Barryville, NY (Sullivan County)*: peak annual stream flow near Barryville, NY (USGS, 2008). The read dot and line indicate the 90-year recurrence interval of the peak flow event of 2004 (Brooks, 2005).

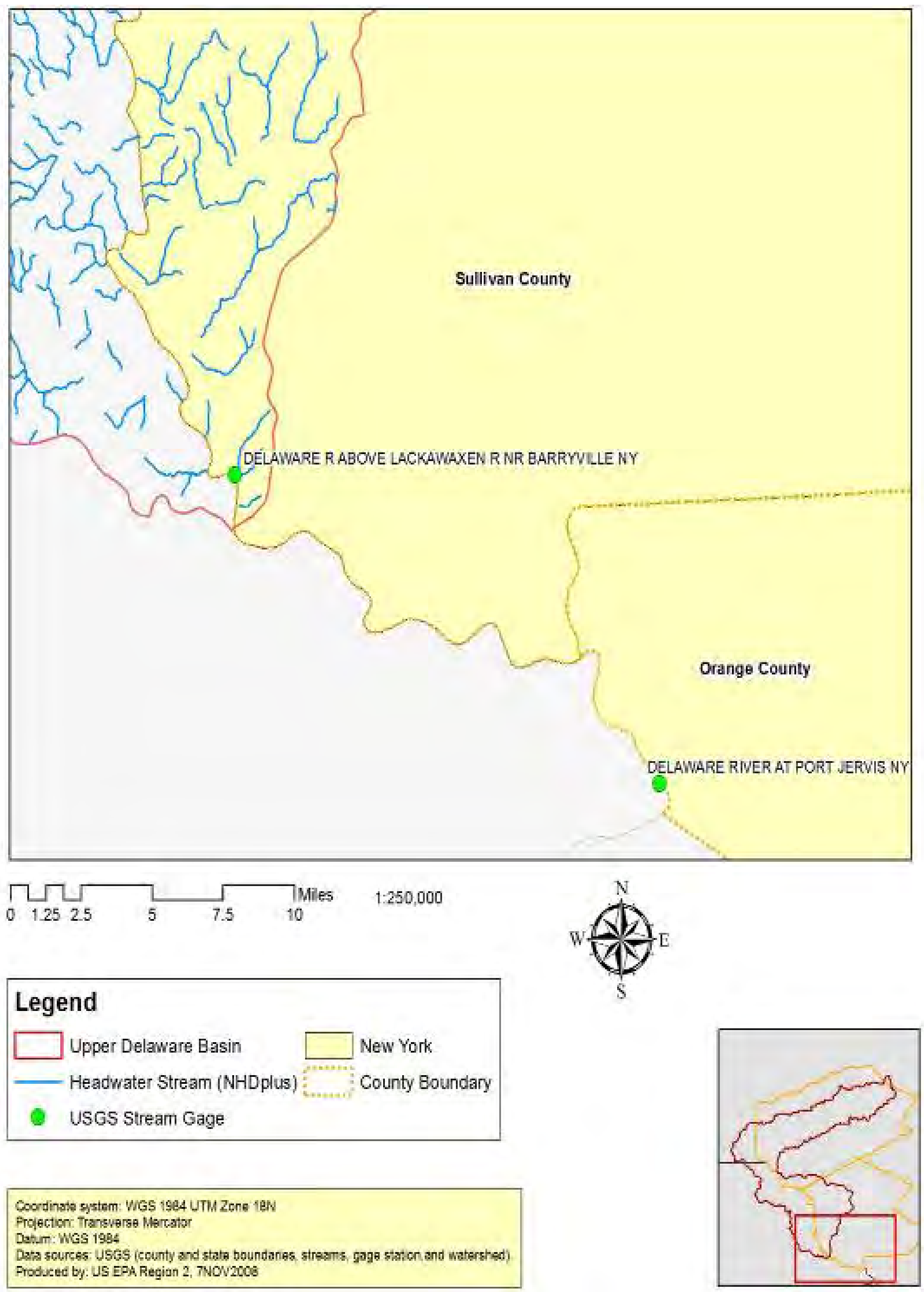


Figure 28: *Upper Delaware Basin USGS Stream Gauges: Delaware River above Lackawaxen R NR, Barryville, NY and Delaware River at Port Jervis, NY.*

3.2.2 Impervious Surface Model: Land-Cover Analysis and Prioritization of Urban Catchments

In order to prioritize urban and rural catchments, an analysis of existing land-cover types within the watershed was conducted. The National Land Cover Data (NLCD) 2001 was used for this analysis (**Figure 29**). Because of significant digits from the 30 meter by 30 meter resolution of the NLCD data the percentages of certain land-cover types are misleading. In the *Appendix* the acreage of each land-cover type is listed (**Table A.2**). Forest cover is the most dominant land-cover type within the Upper Delaware Basin. Agriculture is the most noticeable land-cover type based on human activity. This assessment made it clear that urban land development is currently not a large portion of land-cover types within the watershed.

The “impervious surface model” (Zielinski, 2002) was applied to two urban headwater catchments, Walton and Stamford-Hobart. The “percent impervious surface” of the Walton headwater catchment (**Figure 30**) was 3% impervious surface cover. The total area of 100 % impervious surface within the Walton headwater catchment was 28 acres. Total acreage within the Walton headwater catchment was 1,047.9 acres (1.6 sq. miles). The Walton catchment is predicted to good stream quality because it is below the 11 % impervious surface threshold for catchment basins (Zielinski, 2002). This includes good water quality, excellent habitat quality, diverse insect and fish communities, and stable stream channels (Zielinski, 2002).

The “percent impervious surface” of the Stamford-Hobart headwater catchment (**Figure 31**) was 1% (including additional road segments). The total area of 100% impervious surface within the Stamford-Hobart headwater catchment was 101.7 acres. Total acreage within the Stamford-Hobart headwater catchment was 7,563.8 acres (11.8 sq. miles). Stream quality of the Stamford-Hobart headwater catchment is predicted to be good.

As the Walton and Stamford-Hobart headwater catchments approach the 11 % “impervious threshold,” they should be properly managed for future increases in impervious surface cover. The municipalities of Walton, Stamford, and Hobart should manage their respective catchments’ pervious and impervious surfaces to protect headwater stream water quality, habitat, and fluvial geomorphic stability.

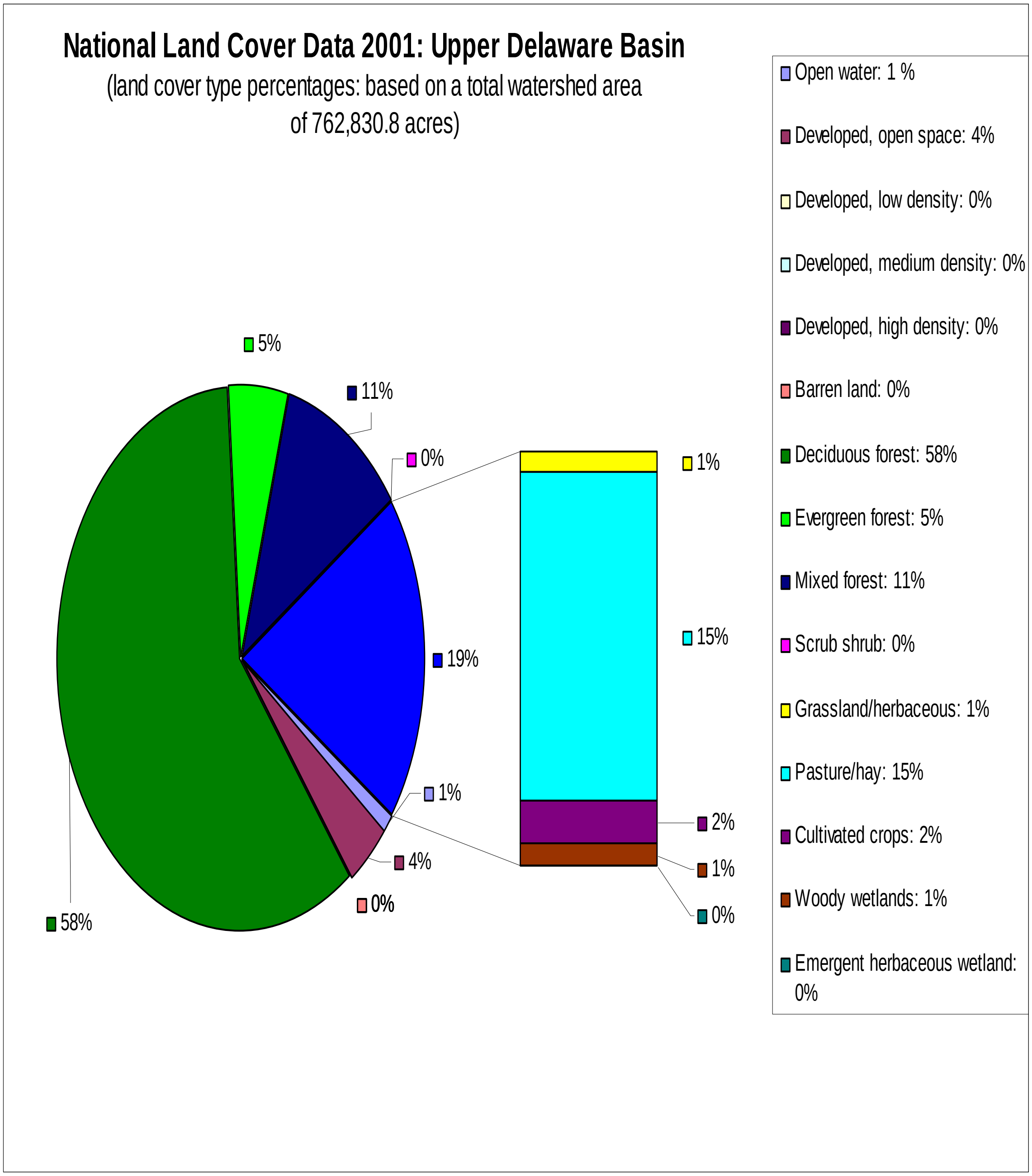


Figure 29: *National Land Cover Data 2001: Upper Delaware Basin.*

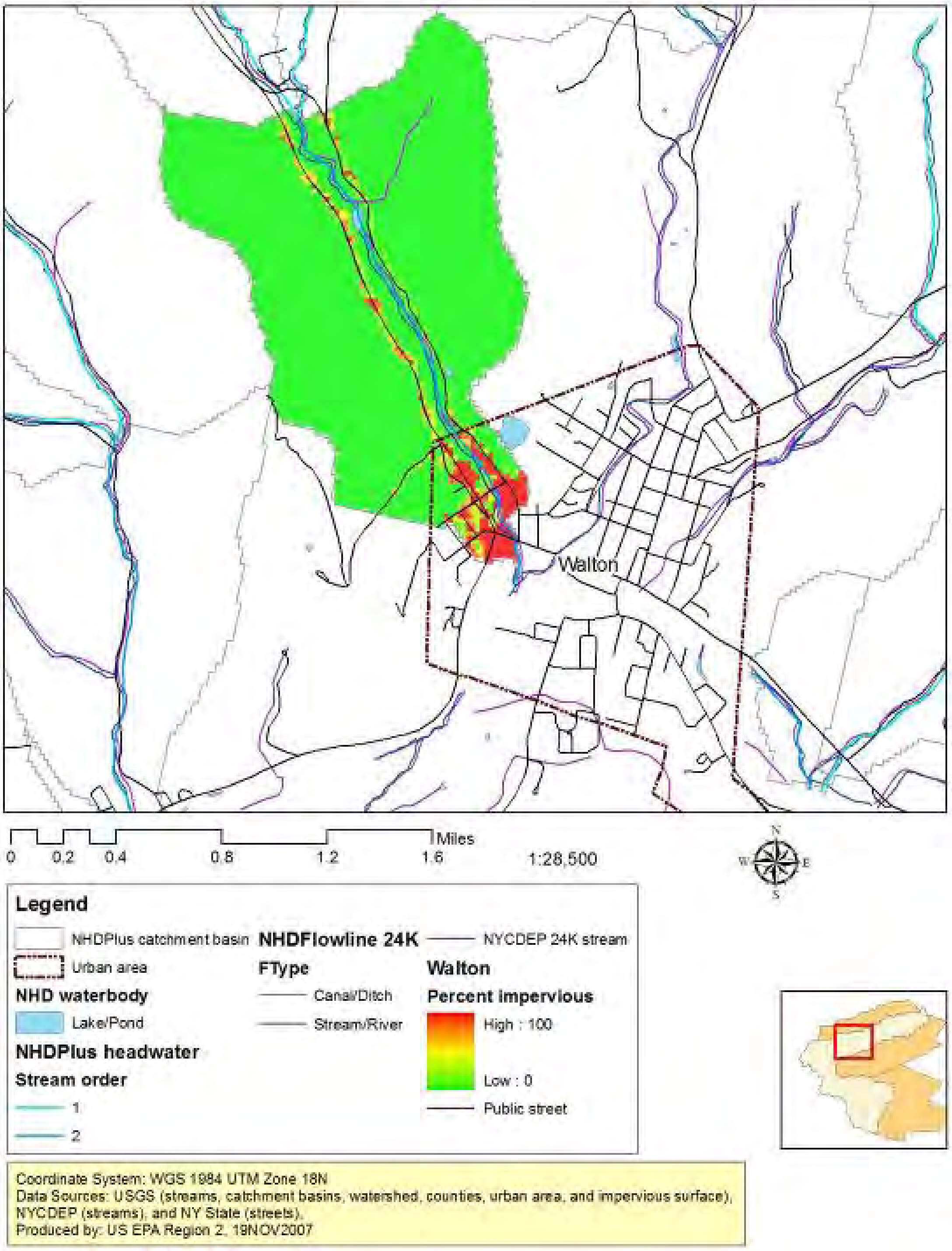


Figure 30: *Impervious Surface Model: Walton Headwater Catchment 2001*: the percent "red" in the Walton color-ramp indicates percent impervious surface cover (based on National Land Cover Data 2001).

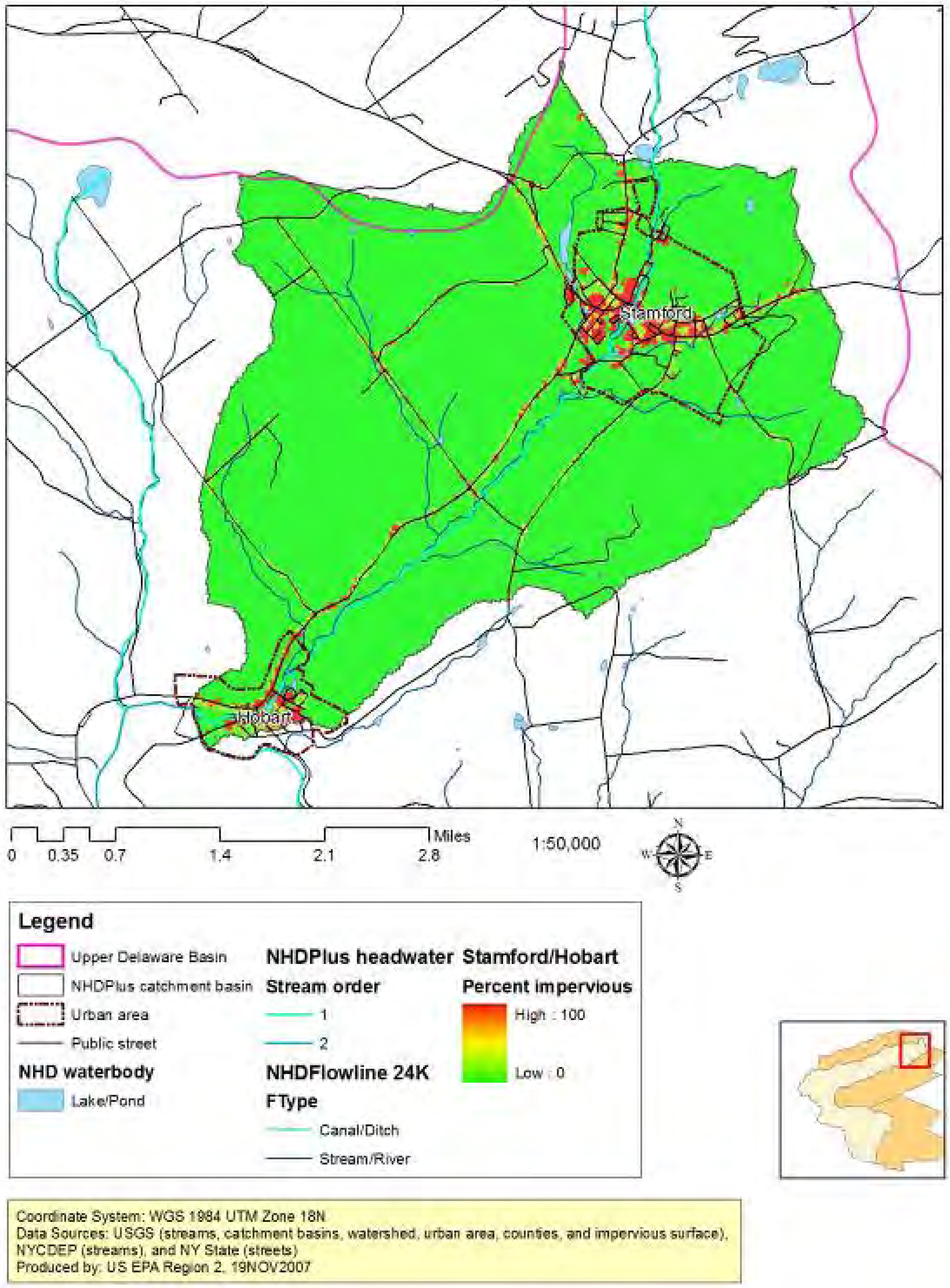


Figure 31: *Impervious Surface Model: Stamford-Hobart Headwater Catchment 2001:* the percent "red" in the Stamford-Hobart color-ramp indicates percent impervious surface cover (based on National Land Cover Data 2001).

3.2.3 TR-55 and TR-20 Analyses (Stormwater Runoff)

Two tables included in this section provide peak flow discharge rates for storm events applicable to the Upper Delaware Basin/Catskill region (**Tables 9 - 10**). The Brooks, 2005 report is for a storm event which occurred from September 18 – 19, 2004. This storm was part of the remnants of tropical depression Ivan (Brooks, 2005). The 24-hour total amounts of rainfall and their associated recurrence intervals for the Upper Delaware River Basin (Brooks, 2005 report) and county results from the TR-55 Model for Sullivan and Delaware counties were analyzed (**Table 9**). The recurrence intervals from the TR-55 Model and the Brooks, 2005 study fall within the same general range. The TR-55 Model precipitation recurrence intervals are based on 24-hour rainfall amounts for each county from NRCS rainfall distributions (WinTR-55 Workgroup, 2002).

USGS stream gauge flood summary data were collected for three headwater catchments with three dominant land use categories: rural, agricultural/urban, and urban/agricultural (**Table 10**). Each of these headwater catchments have USGS stream gauges located on a headwater stream reach. Direct comparisons between the different peak discharge rates of these headwater catchments cannot be made, because of the different drainage area sizes and lack of "recurrence interval" data. Although it is worth noting that both the headwater catchments with dominant urban and agricultural land uses had greater peak discharge rates than the rural catchment (**Table 10**). In general the larger the drainage area the greater the peak discharge rate. The agricultural/urban catchment had a greater peak discharge rate than the urban catchment, even though the urban catchment has a larger drainage area. This may mean that the mix of agricultural and urban land uses may cause greater amounts of stormwater runoff to occur than solely urban land uses in certain catchments.

Base-maps (**Figures 32 -34**) were created for each of the USGS stream gauges listed in **Table 10**. Data from **Table 10** was compared to baseline conditions from TR-55 analyses (**Table 11**), modeled for NHDPlus headwater catchments with either urban or rural/agricultural land use types in the Upper Delaware Basin of relatively similar drainage areas and locations within the New York City municipal water supply watershed. The surface area classified as “wetlands” is relatively similar for both the urban and rural NHDPlus catchments (**Figure 35**). Forest and agricultural land-cover types are in the rural catchment. Results from the TR-55 analyses give “recurrence intervals” for different storm events for each headwater catchment. Comparisons of the different catchments may be made with their common recurrence intervals and associated peak discharge rates.

The urbanized headwater catchment demonstrates higher peak discharge rates than the rural catchment (**Table 11**). This is likely due to the higher amount of impervious surface cover in the urbanized portions of the Stamford-Hobart catchment and the larger drainage area of the catchment. The rural catchment does not have a centralized urban area or municipality such as the urban catchment. Comparisons were made between the 24-hour peak discharge rates of the urban and rural headwater catchments, including discharge rates (cubic feet/second (CFS)) per square mile and per total drainage area (**Figures 36 – 37**). The peak discharge rates are noticeably greater for the urban headwater catchment (**Figures 36 – 37**). Relative comparisons were made between the TR-55-based hydrographs of the urban and rural catchments (**Figure 37**). Note that direct comparisons between the hydrographs of the catchments may not be made because of the different drainage area sizes; the urban catchment is 4.02 square miles larger than the rural catchment.

Direct comparisons of drainage per square foot may be made with data from the TR-55 analyses (**Figure 36**). For the 10-year, 24-hour storm event based on CFS/mi^2, the urban catchment had 1.5 times more surface runoff predicted than the rural catchment. Comparisons between the hydrographs of the two catchments show that a 25-year, 24-hour storm event in the rural catchment is relatively similar to the discharge between a 2-year and a 5-year, 24-hour storm event in the urban catchment. The urban catchment has approximately 1% more impervious surface cover than the rural catchment, which may partially account for higher peak stormwater runoff discharge curves for the urban catchment than the rural catchment. The larger drainage area of the urban catchment also accounts for the greater peak discharge rates compared to the rural catchment. In the Upper Delaware Basin the location of impervious surface strongly influences stormwater runoff rates; most impervious surfaces, such as roads and urban areas are located adjacent to streams in narrow mountainous valleys. A closer examination of the urban and rural catchment hydrographs is provided in the *Appendix* (**Figures A.1 – A.2**).

For rural and urban headwater catchments without stream gauge records peak flow discharge may also be estimated based on drainage area size and a given hydrologic region using regression equations created by the USGS (Lumia et al., 2006). Such equations may prove to be useful tools when managing stormwater runoff for different headwater catchments without stream gauge records. Located in the *Appendix*, are the hydrologic regions (based on physiographic and geologic features) of the USGS flood frequency and magnitude study for New York; the Upper Delaware Basin is located in both region 3 and region 4 (**Figure A.3**). USGS regression equations for estimating peak discharge (2, 10, and 25-year storm events) are based on the drainage size for the Upper Delaware Basin (**Table A.3**). While not completed in this report, these regression equations may be compared to hydrologic models, such as the TR-55 Model for stormwater management purposes. The USGS regression equations (Lumia et al., 2006) do not necessarily account for land-cover types, so calculated peak discharge rates may differ from results derived from stormwater models which account for land-cover types.

The New York State Stormwater Management Design Manual provides recommendations for detention of overbank flood waters for 10-year, 24-hour storm events. Alternative land-cover scenarios managing stormwater runoff in headwater catchments experiencing flooding problems should focus management efforts on the 10-year, 24-hour storm event (New York State DEC, 2003).

Table 9: Comparison of Upper Delaware River Basin (Brooks, 2005) and County (TR-55 Model) 24-Hour Storm Event Statistics

Location	**Amount of Rainfall During a 24-Hour Storm Event** (Inches)	**Recurrence Interval** (Years)
Upper Delaware River Basin	3.59 – 6.9 (Actual Range)	10 – 50 (General Range)
Delaware County	5.14	25 – 50
Sullivan County	5.48	10 – 25

Note: The recurrence intervals for Sullivan and Delaware counties (TR-55 Model) fall within the general range for the Upper Delaware River Basin (Brooks, 2005).

Table 10: Recent USGS Flood Report Summary Data for the Catskill Mountain Region (Sept. 18 – 19, 2004)

Location	**Date of recording**	**Context**	**Drainage Area** (mi^2)	**Peak Discharge previous maximum** (CFS)	**Peak Discharge** (CFS)	**$Ft^3/sec/mi^2$**
Sherruck Brook Trib. Near Trout Creek, NY	1997-2004	Rural	.49	89 *(6/13/03)*	104 *(9/18/04)*	82.5 *(9/18/04)*
Town BR SE of Hobart, NY	1998-2004	Agricultural/ Urban	14.30	4,400 *(7/4/99)*	1,840 *(9/18/04)*	128.7 *(9/18/04)*
West BR Delaware River at Hobart, NY	2000-2004	Urban/ Agricultural	15.5	480 *(4/9/01)*	738 *(9/18/04)*	47.6 *(9/18/04)*

(Brooks, 2005)

The short time periods of recorded peak discharge records for the three stream gauges do not allow for accurate predictions of “recurrence intervals” for the different peak discharge rates (**Table 10**). The rural catchment had the lowest peak discharge, while the agricultural/urban catchment had the highest peak discharge rate (Brooks, 2005). The actual rainfall amounts may have varied at the different locations of the stream gauges (**Table 10)**.

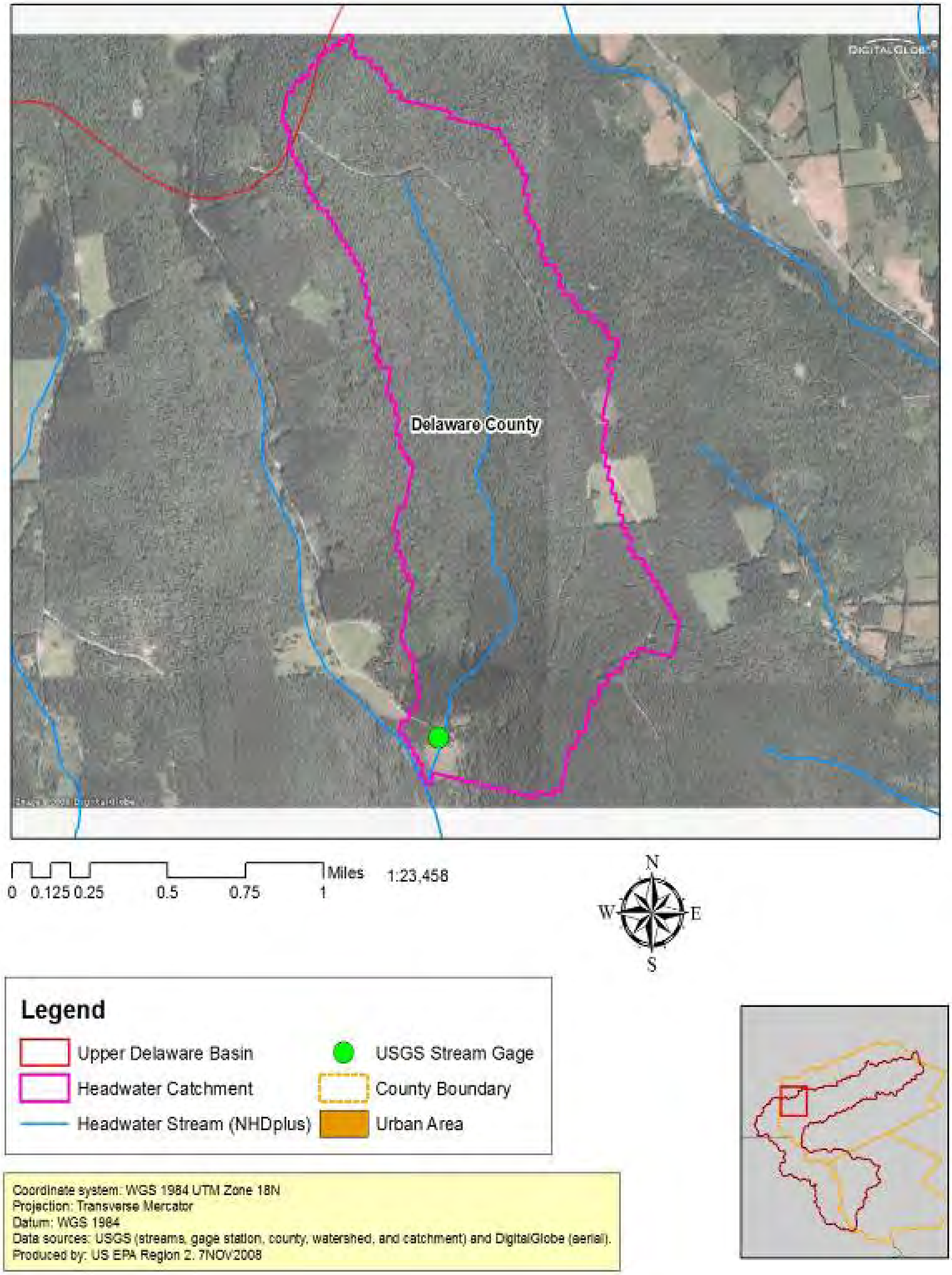


Figure 32: *Upper Delaware Basin USGS Stream Gauge: Sherruck Brook Tributary Near Trout Creek, NY.*

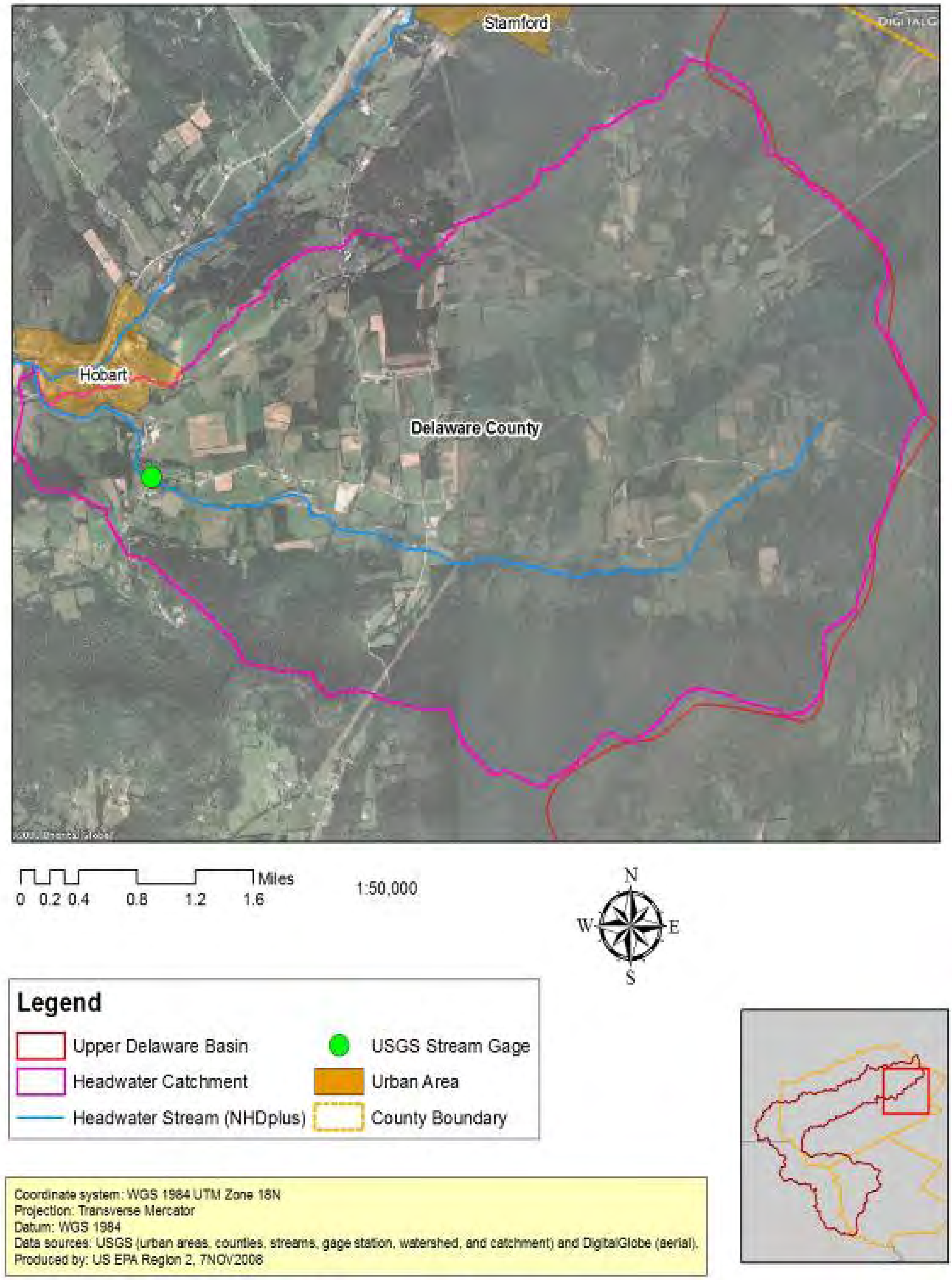


Figure 33: *Upper Delaware Basin USGS Stream Gauge: Town Brook SE of Hobart, NY.*

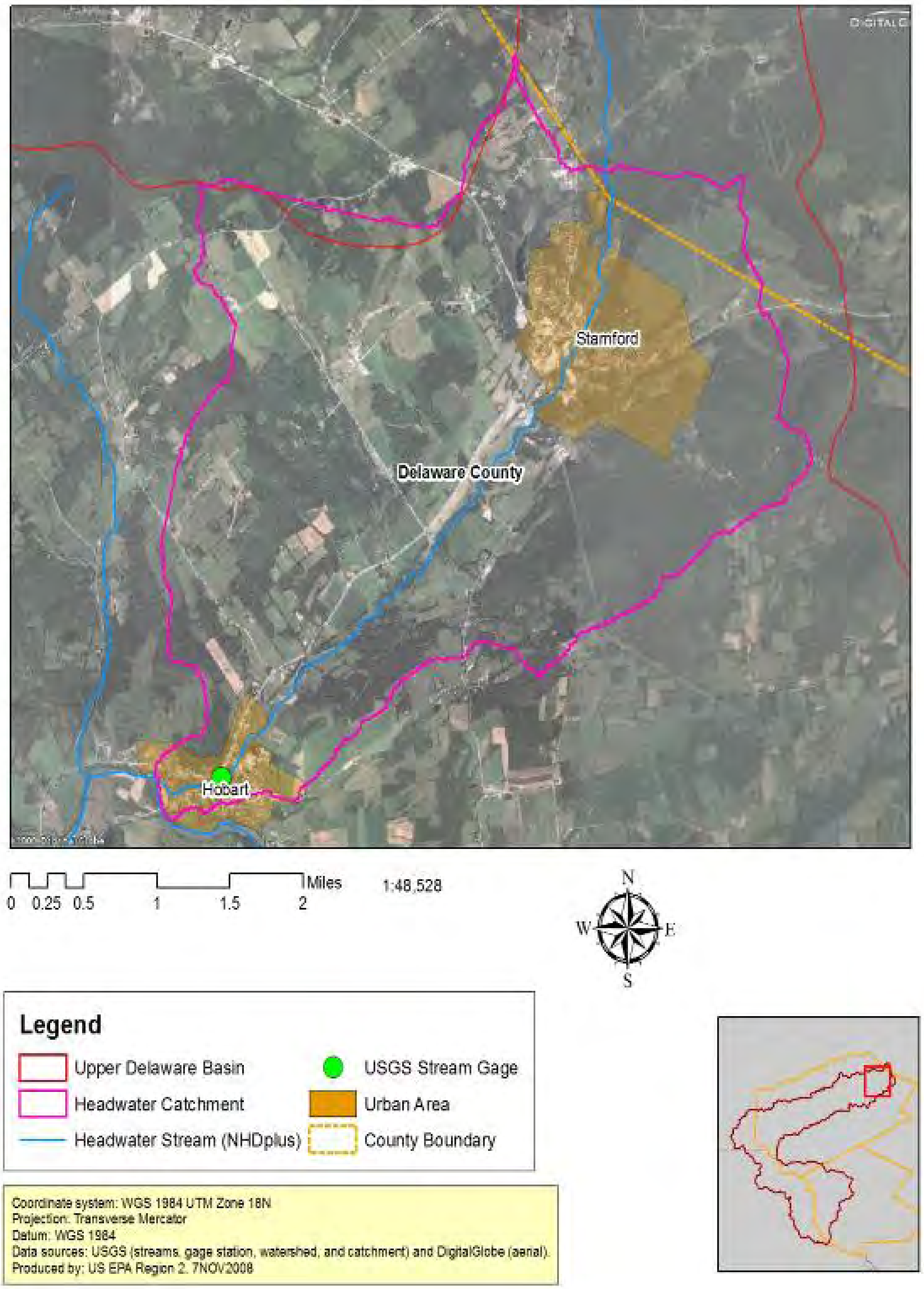


Figure 34: *Upper Delaware Basin USGS Stream Gauge: West Branch Delaware River at Hobart, NY.*

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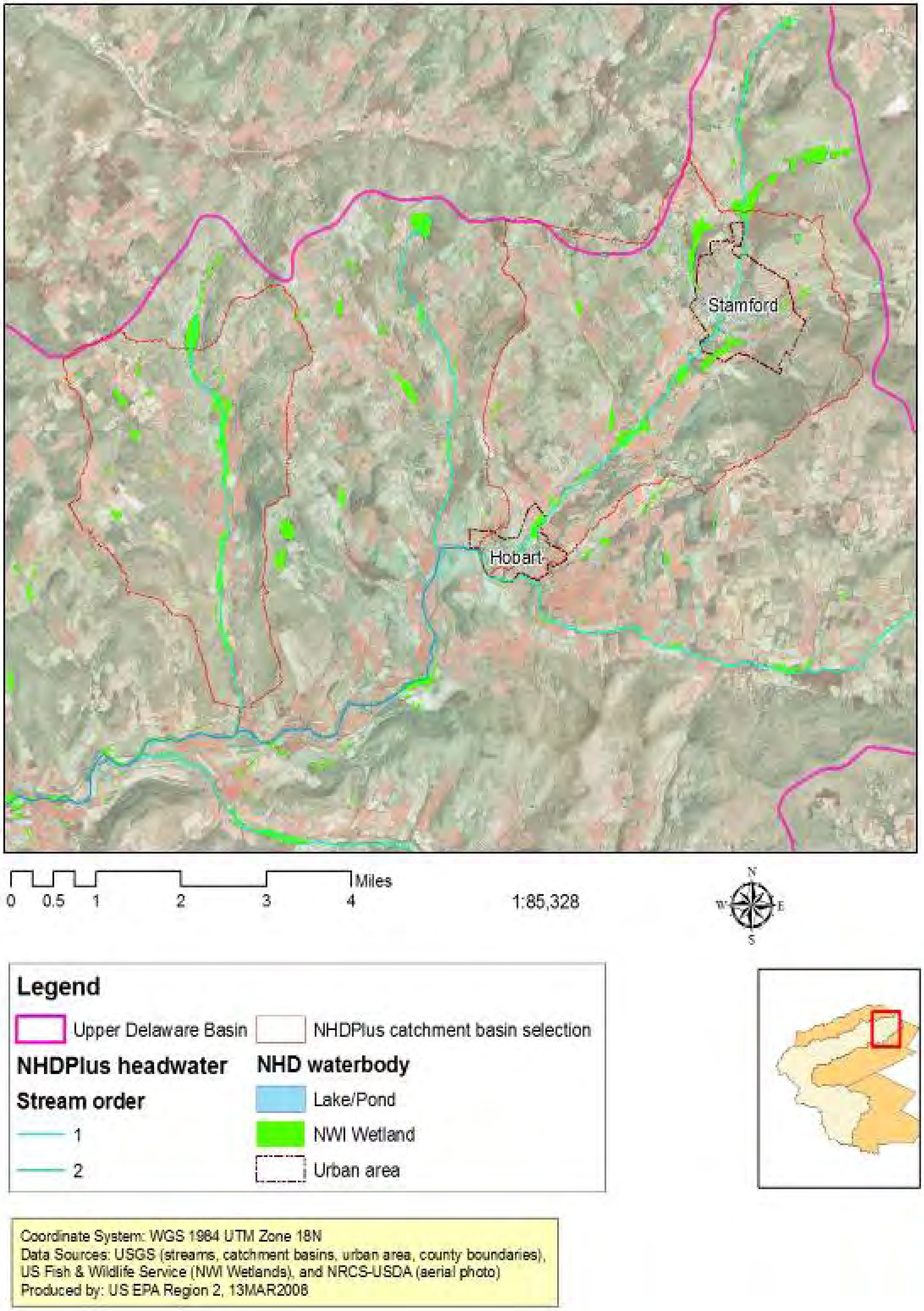

Figure 35: *Upper Delaware Basin: TR-55 Base-Map (Rural and Urban Headwater Catchments).* It should be noted that basins and catchments are used interchangeably.

Table 11: TR-55 Model Results: Existing Conditions for Typical (Urban and Rural) Headwater Catchments of the Upper Delaware Basin

NHDPlus Headwater Basin	**Context**	**Drainage Area** (mi^2)	**1-Year Peak Flow Event** (CFS) *(CFS/mi^2)	**10-Year Peak Flow Event** (CFS) *(CFS/mi^2)	**25-Year Peak Flow Event** (CFS) *(CFS/ mi^2)
Stamford-Hobart	Urban	11.75	737.61 *62.78	2,813.31 *239.43	3,435.09 *292.35
Rural basin W of Hobart	Rural	7.73	294.53 *38.10	1,264.11 *163.53	1,553.36 *200.95

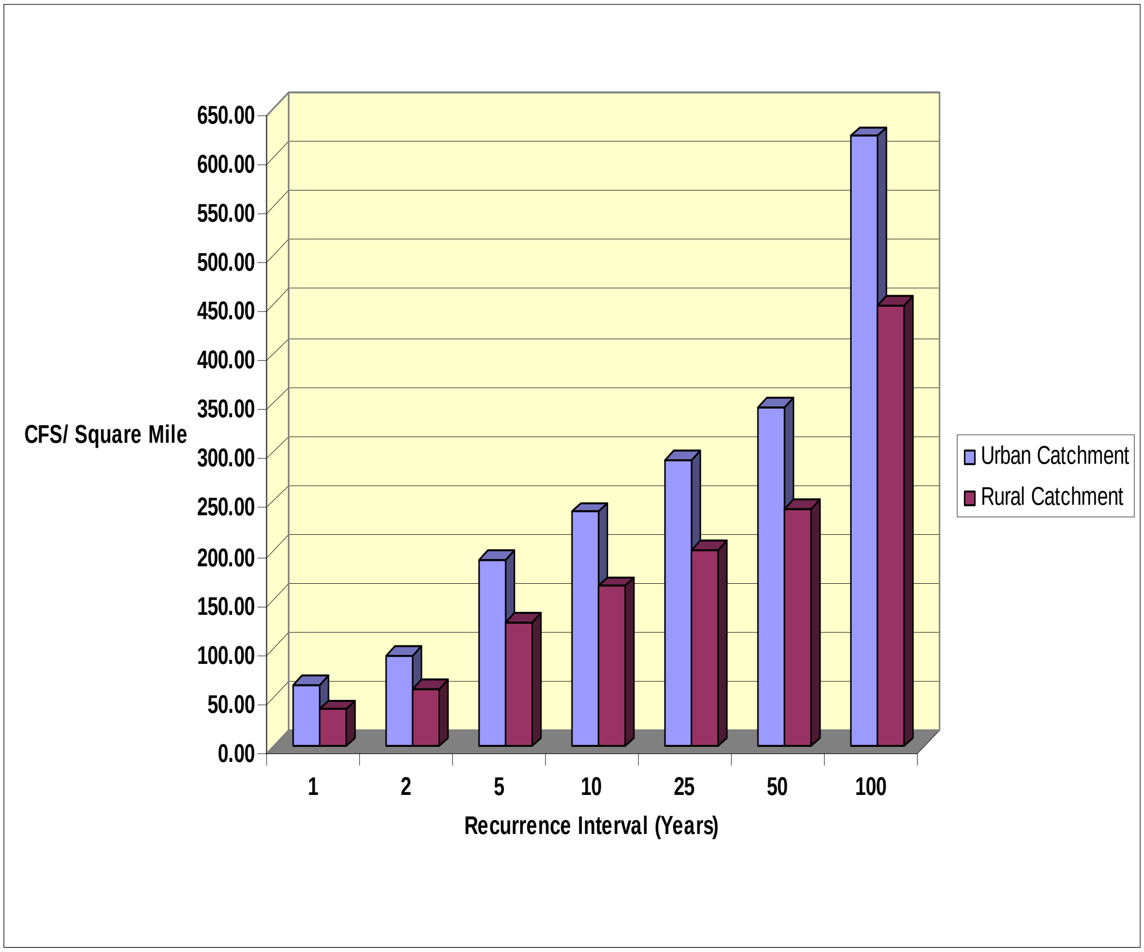

Figure 36: *TR-55 Model 24-Hour Peak Discharge Rates per Square Mile: Upper Delaware Basin Typical Urban and Rural Headwater Catchments.*

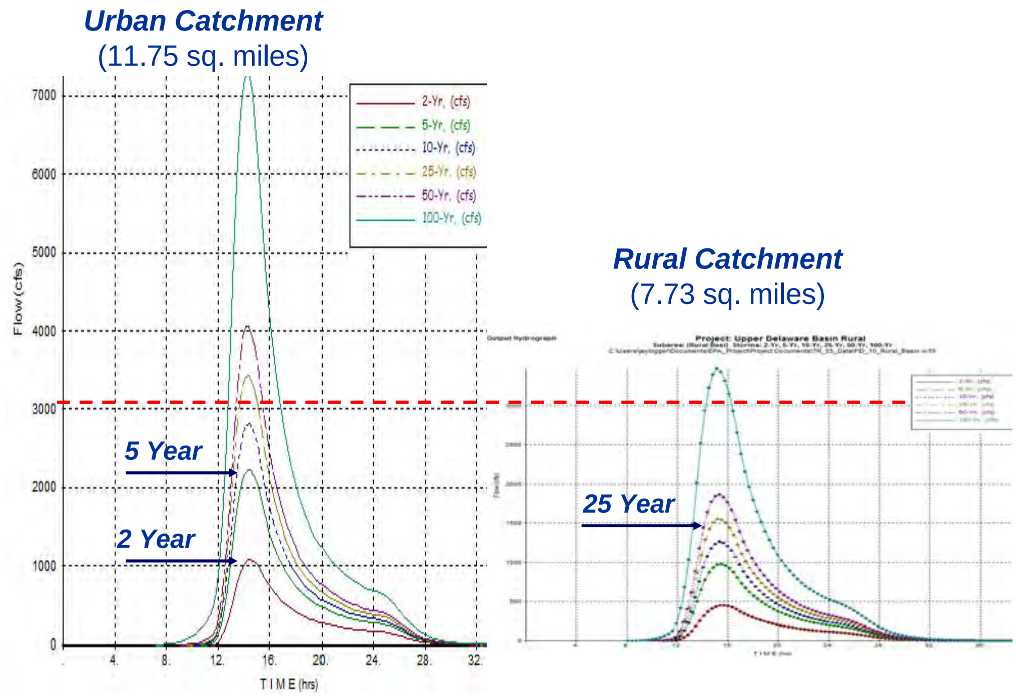

Figure 37: *TR-55 Model Existing Stormwater Peak Discharges: Typical Rural and Urban Headwater Catchments.* Note: the dashed red line indicates that the vertical axes from both hydrographs match up between 0 – 3,000 CFS.

3.3 FUNCTIONAL ASSESSMENTS

3.3.1 Watershed-Based Preliminary Assessment of Wetland Functions

Of all of the NWI wetlands within the Upper Delaware Basin, 70.74% of them were predicted to perform at least one of the ecological functions of interest. Many of the NWI wetlands which were assessed were found to perform more than one predicted function of interest to the study (**Figure 38**, **Table 12**). A portion of the southeastern side of the basin does not currently have digital NWI data and was not assessed using the W-PAWF.

In addition to the W-PAWF completed for the Upper Delaware Basin, an earlier project conducted by the NYCDEP (Machung, 2006) classified and monitored reference wetlands with the W-PAWF assessment methodology for wetlands located within the New York City municipal water supply system. A portion of the Upper Delaware Basin, the Cannonsville Reservoir Basin, is located within the New York City municipal water supply system (Tiner et al., 2005). The Cannonsville Reservoir Basin accounts for 2.98%

of the land area of the New York City municipal water supply system watershed (Tiner et al., 2005). Wetlands data from the NYCDEP study (Machung, 2006) provided monitoring results of actual ecological functions of reference wetlands. Reference wetlands included both terrene and lotic stream wetlands. These results may be associated with the functions predicted from the W-PAWF conducted for the entire Upper Delaware Basin.

Results from the NYCDEP study include the following (Machung, 2006)***:***

1) Wetland water quality is controlled by landscape position, anthropogenic inputs, and underlying geology.
2) Terrene (TE) wetlands have higher water table elevations (lower ranges) and lower dissolved organic carbon ([DOC]) concentrations than lotic headwater streams (LShw). Terrene wetlands have a higher amount of groundwater than stream influents.
3) TE wetlands have higher water tables and a greater time period of root zone saturation, likely facilitating accumulation and export of organic matter. Although TE wetlands have lower outflow rates than LShw wetlands.
4) Lotic stream (LS) wetlands had higher base flow concentrations of SO_4, likely due to underlying geologic materials and chemical interactions with saturated dissolved oxygen concentrations.
5) LS had the highest median concentrations of NO_3, TDN (total dissolved N), Na, Cl, and SC (specific conductance) compared to TE wetlands. This is likely because LS wetlands receive pollutants from anthropogenic sources, influenced by the landscape position and stream flow path. LS and LShw positions allow for surface waterborne pollutants to be potentially retained or transformed.
6) DOC and SO_4 concentrations increased with storm flow discharges for both TE and LS wetland types. Both indicators are typical of saturated wetlands. TE wetlands generally had high [DOC].
7) Lotic headwater stream (LShw) wetlands exhibited an attenuation of outflow discharges from storm events. Both inflow and outflow discharges were

measured. This finding accounts for the flood mitigation functionality of headwater wetlands.

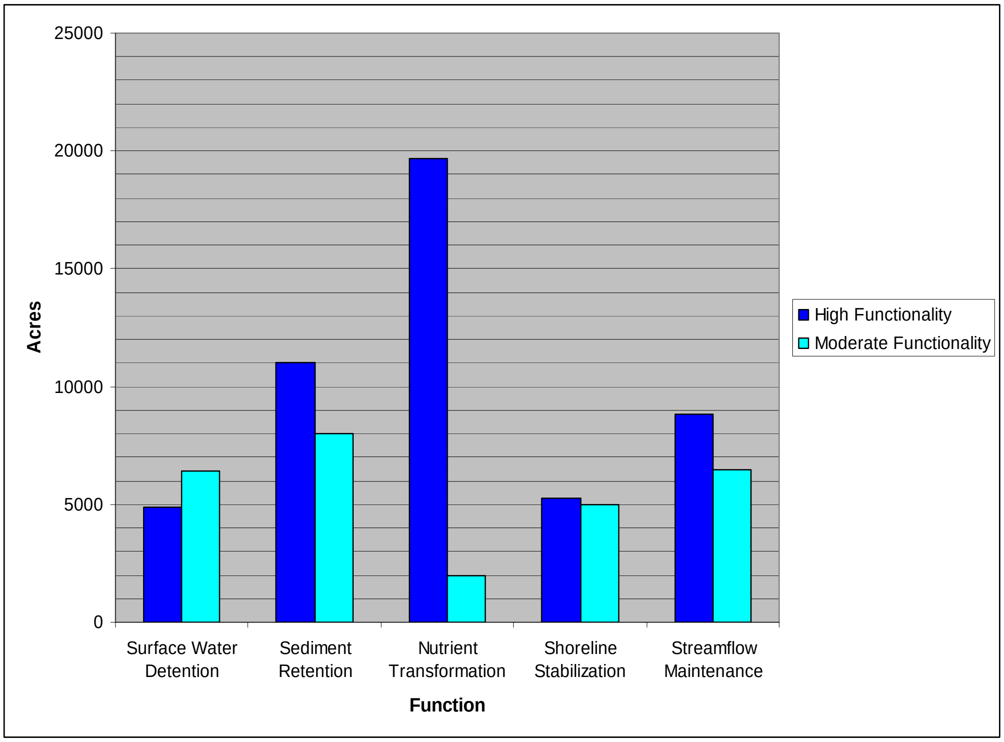

Figure 38: *Predicted Functionality for Wetlands within the Upper Delaware Basin, by Acreage.* Based on the results from the Watershed-Based Preliminary Assessment of Wetland Functions (W-PAWF).

Table 12: Comparison of Predicted Functionality for Wetlands within the Upper Delaware Basin and Total NWI Wetland Coverage within the Basin
(Based on the results from the Watershed-Based Preliminary Assessment of Wetland Functions (W-PAWF))

Ecological Function	**High** (Acres)	**% of Total NWI Wetlands** (High Values)	**Moderate** (Acres)	**% of Total NWI Wetlands** (Moderate Values)
Surface Water Detention	4,868.5	22%	6,434.1	30%
Sediment Retention	11,017.1	51%	7,986.9	37%
Nutrient Transformation	19,683.2	91%	1,974.4	9%
Shoreline Stabilization	5,245.2	24%	5,013.6	23%
Streamflow Maintenance	8,844.1	41%	6,477.6	30%

Note: The Upper Delaware Basin has a total of 21,659.1 acres of NWI wetlands.

3.3.2 Streamside Health Model: Upper Delaware Basin Assessment

Applying the streamside health model developed by Meixler (2003), the predicted conditions of all NHD 1:24 K flowline headwater streamside conditions were assessed for the Upper Delaware Basin (**Figure 39**). Headwater stream functionality was linked to the predicted status of streamside health of all headwater streams in the Upper Delaware Basin. Riparian buffers in "excellent or good" conditions are predicted to be high functioning streams (Meixler, 2003). Moderately-functioning streams have buffers rated as "fair." Finally, the least functioning streams have buffers categorized as "poor or very poor." The streamside health assessment was applied to an urban catchment area, including Deposit, NY (**Figure 40**). Streamside areas with developed land and cultivated crop land uses were predicted to have the greatest negative impacts on streamside conditions (Meixler, 2003). "Very poor" conditions are located mainly in or near the urban area of Deposit, NY (**Figure 40**).

Other headwater streamside corridor buffers located in urban areas throughout the Upper Delaware Basin also displayed similar "very poor" conditions. This may be caused by increased intensity of human land-cover disturbance in urban areas. The majority of the stream corridors within the watershed are considered to be in either excellent or good conditions. The overall summary for the streamside health assessment for the watershed are: 76% excellent, 0% good, 15% fair, 9% poor, and 0% very poor conditions (**Figure 39**). Approximately 24% of the headwater streamside corridors have conditions which could be improved to either good or excellent health conditions.

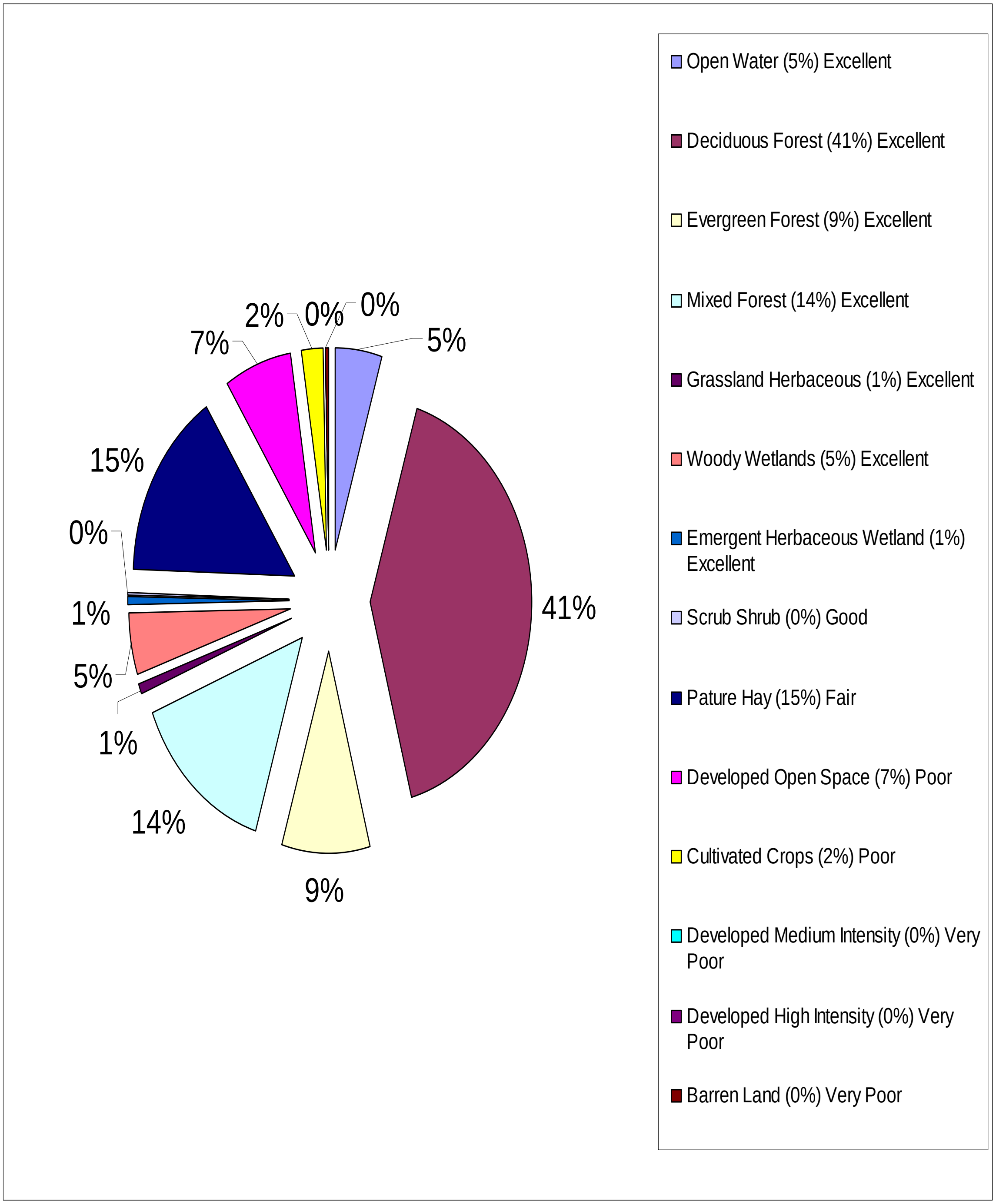

Figure 39: *Streamside Health Assessment Model Results: Upper Delaware Basin, NY/PA.* Note: Total headwater streamside area within the Upper Delaware Basin was 39,838.85 acres.

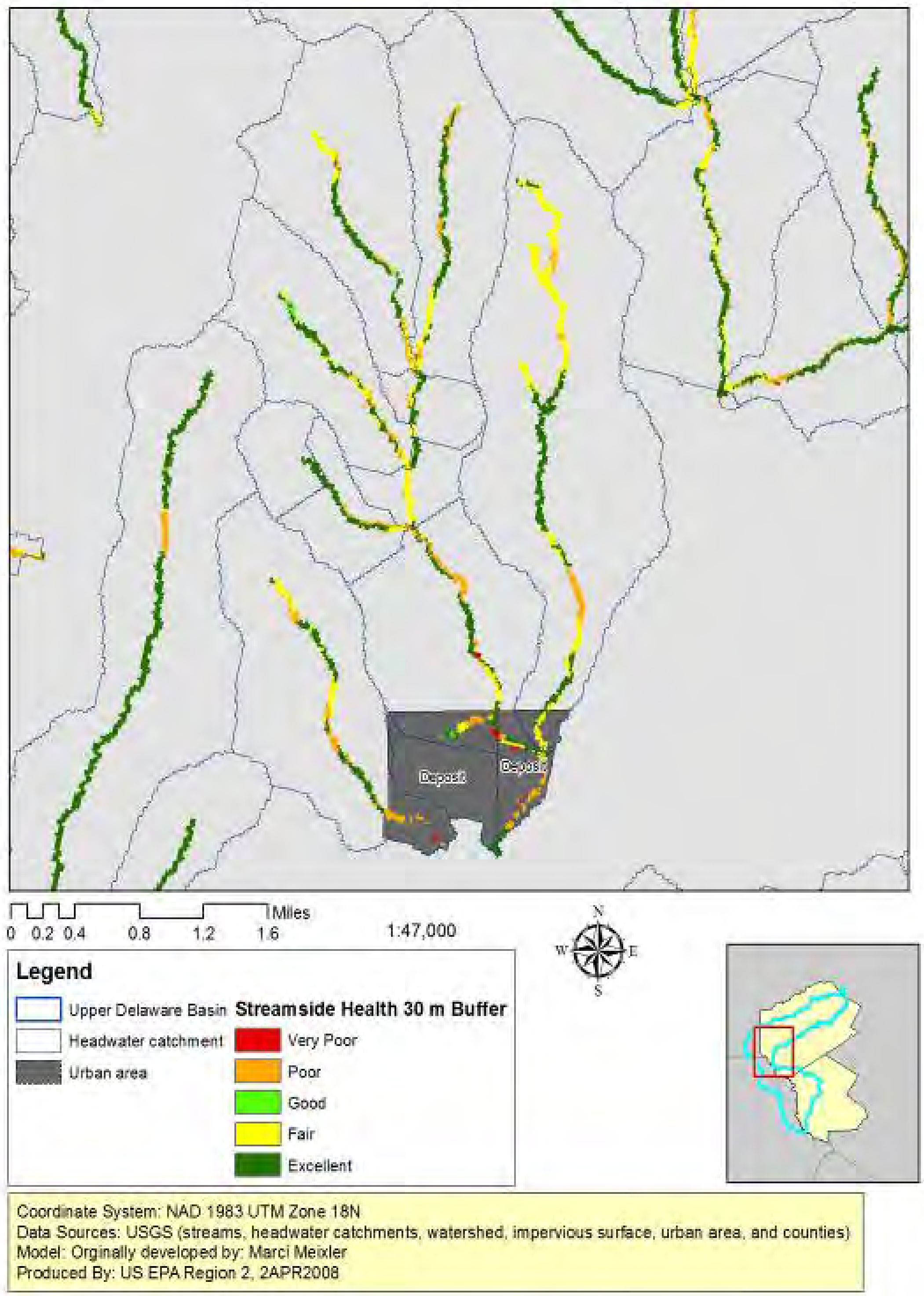

Figure 40: *Map of Streamside Health Assessment Model: Upper Delaware Basin, Deposit, Delaware County, NY*: zoomed in view of streamside assessment results for headwater catchments containing portions of Deposit, NY.

3.4 FLOOD STORAGE ASSESSMENT

3.4.1 Wetland Stormwater Monitoring

A NYCDEP study of reference wetlands within the watershed of the New York City municipal water supply system indicated that lotic headwater stream and terrene wetlands attenuate downstream storm water discharges (NYCDEP, 2005). Cirmo, 2006 conducted an intensive assessment of storm hydrology and water quality of terrene and lotic headwater stream wetlands within the Upper Delaware Basin. The reference wetland sites included two wetlands within the Cannonsville Reservoir: the Cannonsville Locust Spring, a terrene wetland (CLS) and the Cannonsville Sherruck Brook (CSB), a lotic headwater stream wetland (Cirmo, 2006). Reference wetlands outside of the Upper Delaware Basin, but within the New York City municipal water supply system included the Ashokan Mink Hollow (AMH), a lotic headwater stream wetland in the Ashokan drainage basin; and the Schoharie Fanny Brook (SFB), a terrene wetland in the Schoharie drainage basin (Cirmo, 2006).

3.4.2 Wetland Water Storage Capacity

The surface water detention functionality of: 1) the entire Upper Delaware Basin, 2) a typical rural headwater catchment for 1-year and 100 year, 24-hour storm events, 3) a typical urban headwater catchment for 1-year and 100-year storm events, and 4) storm event hydrographs for both the rural and urban (Stamford-Hobart) headwater catchments were calculated from NYCDEP reference wetlands data and results from the W-PAWF analysis.

Prior climatic conditions of the two different storm events likely affected the stormwater monitoring data from the NYCDEP reference wetlands. Dry conditions before a rain event would leave more open pore space in soils, partially empty or dry wetlands, and extra capacity for plant tissues to absorb additional surface water. Conversely, prior wet conditions leading up to a storm event would leave less capacity for soils, wetlands, and other plants to store additional surface water. In the *Appendix* variations in rates of precipitation between September and October from 1971 – 2000 are displayed (**Figures A.4 – A.5**).

Stormwater reference wetlands monitoring data were summarized (**Tables 14 – 15**). Both reference wetlands have LLWW (landscape position, landform, water flow path, and waterbody) characteristics of high-performance surface water detention. The storage capacity of each of the reference wetlands was estimated (**Table 15**). The storage constant was calculated to assess the stormwater detention capacity of all high or moderate performing NWI wetlands within the watershed (**Table 15**). The stormwater detention capacity of NWI wetlands within the watershed was estimated (**Table 16**). A storage capacity constant was derived from each storm event and the associated reference wetland monitoring data. The surface area of all NWI wetlands within the watershed rated as having high or moderate surface water detention values from the W-PAWF assessment was multiplied by the "storage capacity constants" calculated from each reference wetland and its associated storm event. Base-maps show predicted high and moderate values of all NWI wetlands performing surface water detention mainly in the portions of the watershed located within Delaware and Sullivan counties (**Figures 40 – 41**).

Table 13: Part One: Characteristics of Selected NYCDEP Reference Wetlands and Associated Storm Events (Cirmo, 2006)

Storm Event ID/ Reference Wetland	**Basin**	**LLWW Wetland Type**	**Surface Area** (m^2)	**Time Period**
F05/AMH	Ashokan	Lotic stream, middle gradient, basin, through-flow, headwater, beaver-induced	33,040.4	10/7-10/ 2005

Table 13 (cont.)

Storm Event ID/ Reference Wetland	**Basin**	**LLWW Wetland Type**	**Surface Area** (m^2)	**Time Period**
D04/CSB	Cannonsville	Lotic stream, intermittent gradient, basin, through-flow, headwater	22,495.9	9/28-30/ 2004

Note: **Figures 20 – 21** in the methods section provide illustrations of the AMH and CSB reference wetlands. The LLWW Codes are: LS2BATHh-wbv for F05/AMH and LS4BATHhw for D04/CSB.

Table 14: Part Two: Characteristics of Selected NYCDEP Reference Wetlands and Associated Storm Events (Cirmo, 2006)

Storm Event ID/ Reference Wetland	**Prior Climatic Conditions**	**Total Precipitation** (cm)/ (in)	**Surface Water Detention Value**
F05/AMH	Dry	17.37 cm	High
		6.84 in	
D04/CSB	Wet	1.4 cm	High
		.55 in	

Table 15: Part Three: Characteristics of Selected NYCDEP Reference Wetlands and Associated Storm Events Characteristics (Cirmo, 2006)

Storm Event ID/ Reference Wetland	**Time Period**	**Total Precipitation** (cm)	**Storm Event Interval** (Delaware County)	**Water In** (m^3)	**Water Out** (m^3)	**Water Stored** (m^3)	**Storage Constant** (m^3/m^2)
F05/AMH	10/7-10/2005	17.37	~ 100 year	53,000	10,107	42,893	1.3
D04/CSB	9/28-30/2004	1.4	Less than 1 year	8,836	5,656	3,180	.14

Reference wetlands data, from different areas within the New York City municipal water supply system at different points in time were analyzed (**Tables 13 – 16**). For other storm events these NYCDEP reference wetlands did not have a net positive amount of stormwater stored, releasing more stormwater than they actually detained (Cirmo, 2006). The AMH wetland had a positive net storage for 2 out of 5 monitored storm events, while the CSB reference wetland had a positive net storage for 1 out 3 monitored storm events (Cirmo, 2006). The highlighted reference wetlands and their associated storm events (**Tables 13 – 15**) illustrate the potential for wetlands in the New York City municipal water supply system to detain surface water from storm events.

Table 16: Predicted Stormwater Detention for Upper Delaware Basin NWI Wetlands Based on Selected NYCDEP Reference Wetlands' Stormwater Data (Cirmo, 2006)

Storm Event ID/ Reference Wetland	**Prior Climatic Conditions**	**Time Period**	**Total Precipitation** (cm) / (in)	***All High*** **Detention NWI wetlands** (m^3) / (acre foot)	***All Moderate*** **Detention NWI Wetlands** (m^3) and (acre foot)
F05/AMH	Dry	10/7-10/2005	17.37 cm	25,612,881.36	33,849,060.26
			6.84 in	20,764.7 acre ft	27,441.88 acre ft
D04/CSB	Wet	9/28-30/2004	1.4 cm	2,758,310.30	3,645,283.41
			.55 in	2,236.2 acre ft	2,955.28 acre ft

During the F05 storm event the AMH reference wetland was able to detain more water than the CSB reference wetland during the D04 storm event; most likely there were drier prior climatic conditions for F05/AMH than for D04/CSB. The two reference wetlands may also have had different depths which could have caused differences in the storage constants calculated and applied to the NWI wetlands within the Upper Delaware Basin. If the reference wetlands had identical depths more uniformity could have been applied with predicted surface water detention calculations for NWI wetlands in the Upper Delaware Basin.

Figure 41: *NWI Functional Assessment: Surface Water Detention: Upper Delaware Basin, Delaware County, NY.*

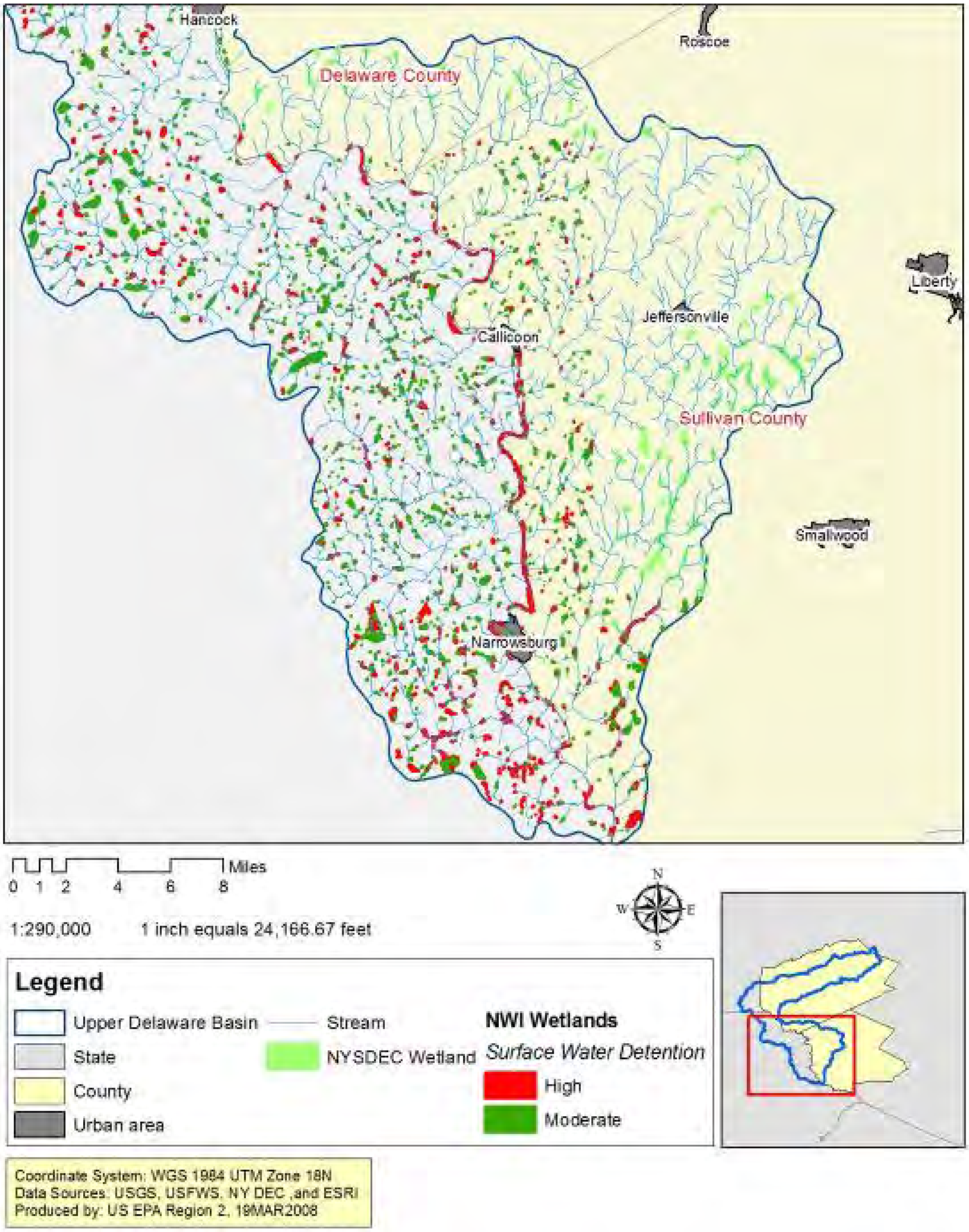

Figure 42: *NWI Functional Assessment: Surface Water Detention: Upper Delaware Basin, Sullivan County, NY.*

The majority of NWI wetlands predicted to have either high or moderate surface water detention values are located adjacent or within headwater streams (**Figures 41 – 42**). Very few wetlands located away from headwater streams have predicted high or moderate surface water detention functional values. The wetland functional assessment was not applied to NYSDEC freshwater wetlands, because the GIS datasets have different attributes associated with the wetlands compared to NWI wetlands. It could be assumed that NYSDEC headwater wetlands are highly likely to also have high to moderate predicted surface water detention functional values.

Additional stormwater data were derived from the TR-55 and TR-20 assessments of the rural and urban catchments data. These models were used to calculate existing surface water storage capacity and storage deficit of NWI wetlands within the selected catchments. The catchment specific calculations were based on storage capacity constants for the F05/AMH and D04/CSB storm events and respective reference wetlands from the Cirmo, 2006 study. The storage constants (m^3/m^2) from the respective reference wetlands and associated storm events were multiplied by the surface area (m^2) of all NWI wetlands from the W-PAWF assessment predicted to have high or moderate surface water detention functionality. The existing storage capacity of all high or moderately performing NWI wetlands within the Upper Delaware Basin was estimated (**Figure 42**). Under prior dry conditions the watershed has a much greater capacity to detain surface water runoff. Prior wet conditions limit the ability of the watershed to accommodate stormwater runoff (**Figure 43**).

The TR-20 model was applied to the 100-year, 24-hour antecedent dry conditions and the 1-year, 24-hour antecedent wet conditions within typical rural and urban headwater catchments within the watershed. The TR-55 and TR-20 models do not account for wetland land-cover and the associated storm water detention capacities of wetlands within the watershed. The existing storage capacity of all NWI wetlands with predicted high or moderate surface water detention functionality within each catchment was calculated by multiplying the storage constant (m^3/m^2) from the reference wetlands and associated storm events (F05/AMH and D04/CSB) by the surface area (m^2) of NWI wetlands (high to moderate surface water detention functionality) within the catchment. The existing storage of NWI wetlands within the catchment was subtracted from the total stormwater runoff calculated from the TR-20 analyses. The total storage needed for each catchment was calculated by adding the existing storage and storage deficit values.

Estimations were made for existing storage capacity, storage deficit, and total storage capacity needed for the rural headwater catchment (**Figures 43 – 45**). The same surface water detention analyses were applied to a typical urban catchment (**Figures 47 – 49**). The predicted existing surface water detention capabilities provided by NWI wetlands within both the urban and rural headwater catchments do not manage all surface water from either a 1-year, 24-hour storm event with antecedent wet conditions or a 100-year, 24-hour storm event with antecedent dry conditions. Since the reference wetlands and associated storm events used for calculating "wetland storage estimates" only highlight positive net storage of stormwater from the Cirmo, 2006 study, the predicted storage estimates may be over estimated.

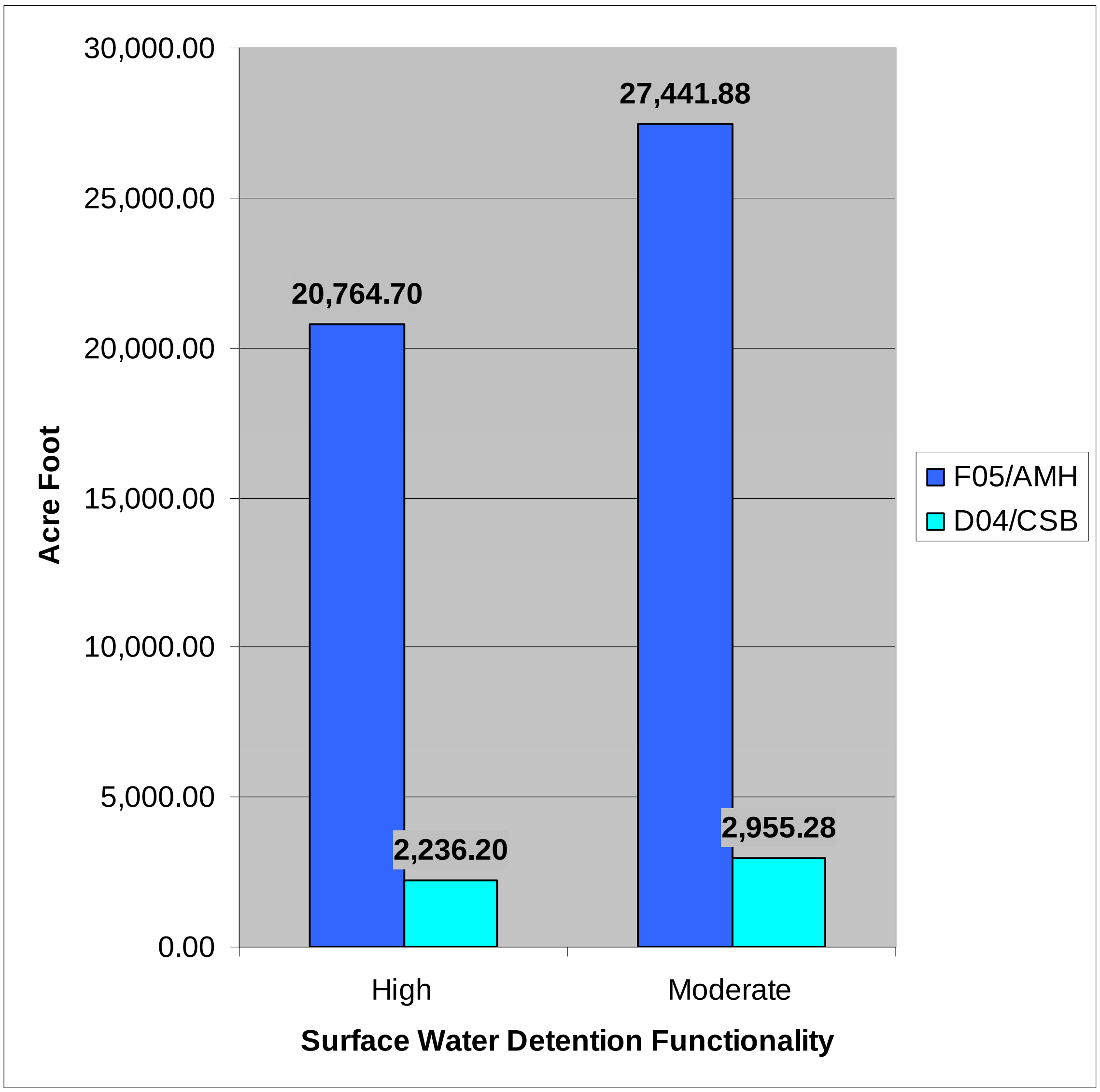

Figure 43: *Surface Water Detention (Storage Capacity) of NWI Wetlands: Upper Delaware Basin.*

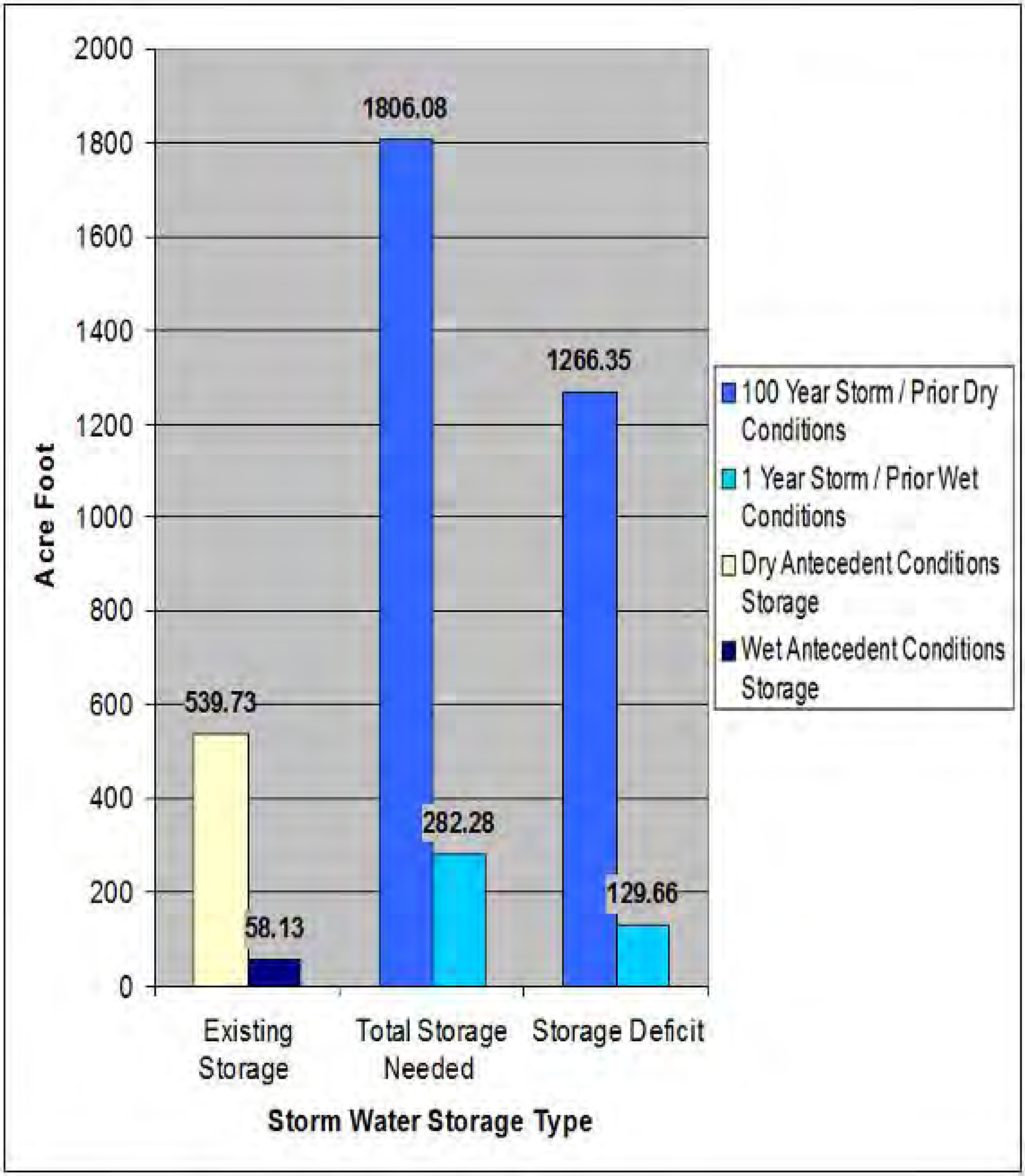

Figure 44: *Wetland Surface Water Storage (1-Year and 100-Year, 24-Hour Storm Events): Rural Headwater Catchment.* Note: the different storm events are based on the results from the Cirmo, 2006 study.

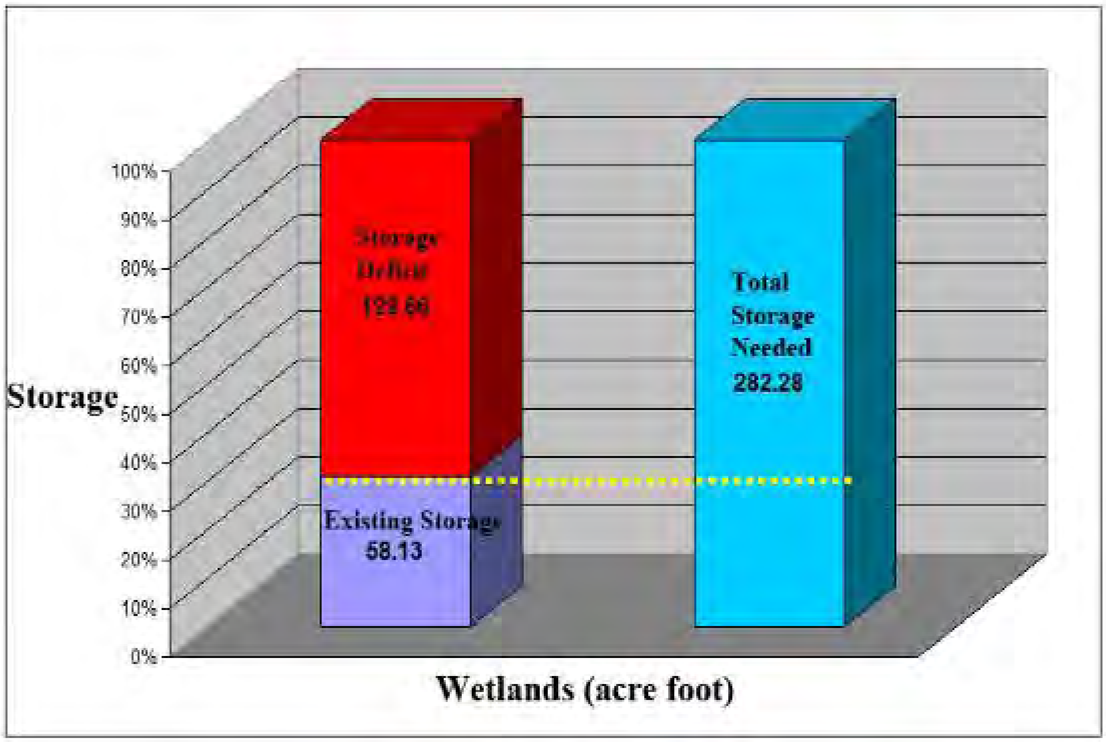

Figure 45: *1-Year, 24-Hour Storm Event Wetland Surface Water Storage: Rural Headwater Catchment.*

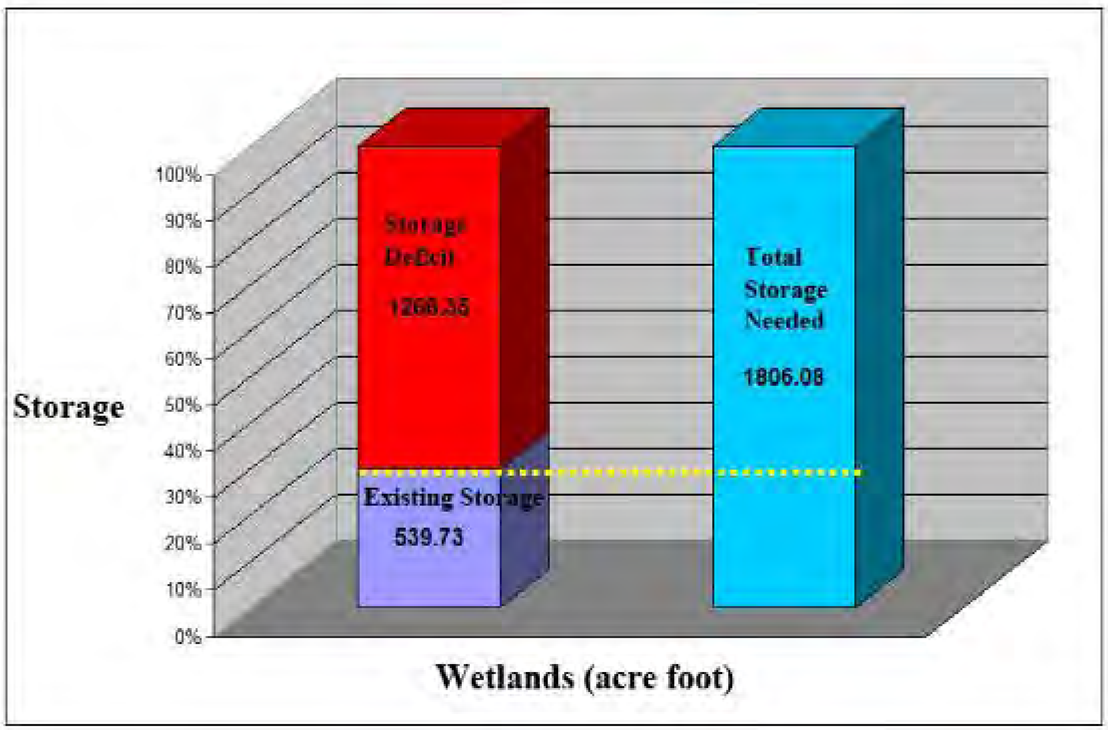

Figure 46: *100-Year, 24-Hour Storm Event Wetland Surface Water Storage: Rural Headwater Catchment.*

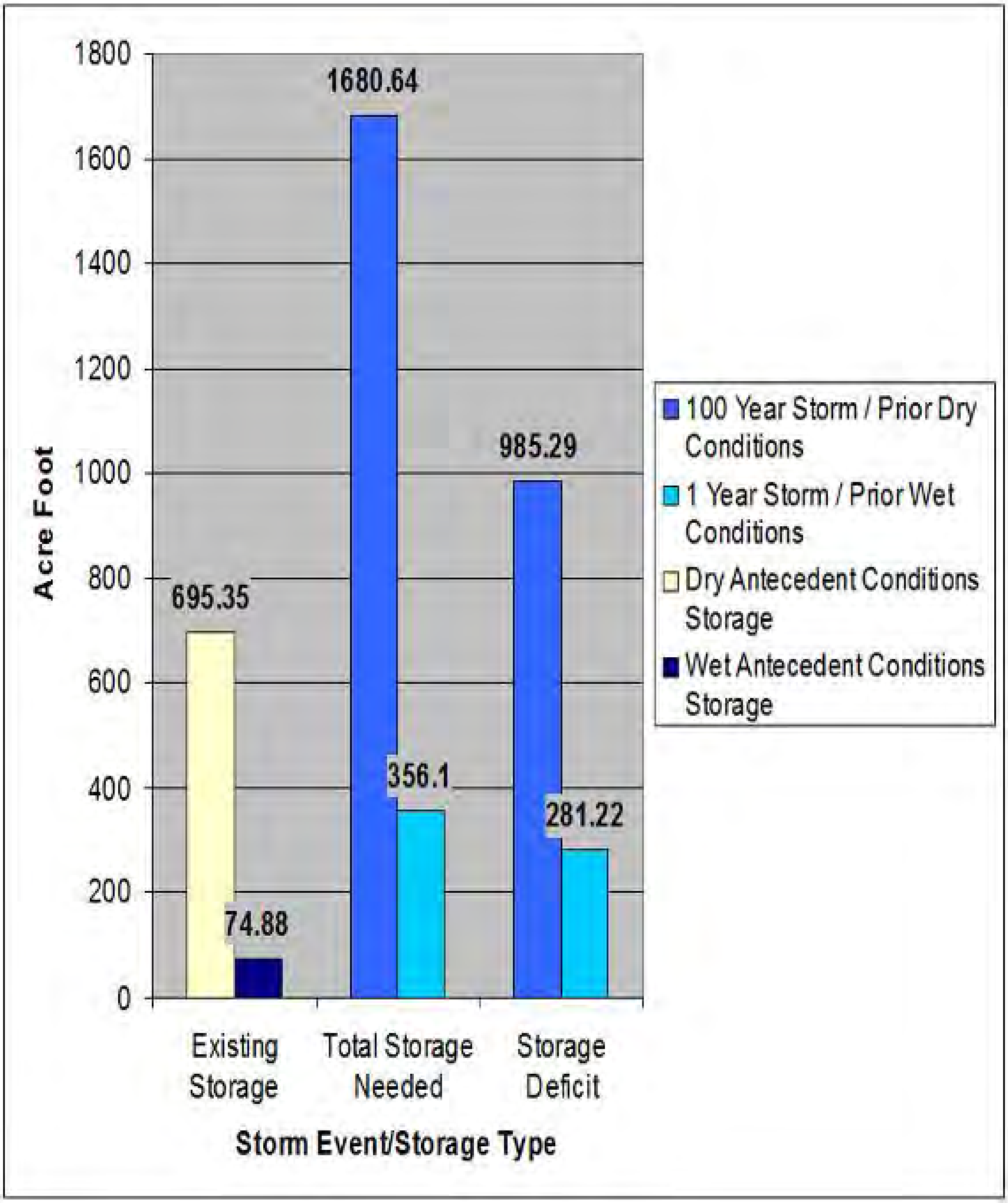

Figure 47: *Wetland Surface Water Storage (1-Year and 100-Year, 24-Hour Storm Events): Urban Headwater Catchment.* Note: the different storm events are based on the results from the Cirmo, 2006 study.

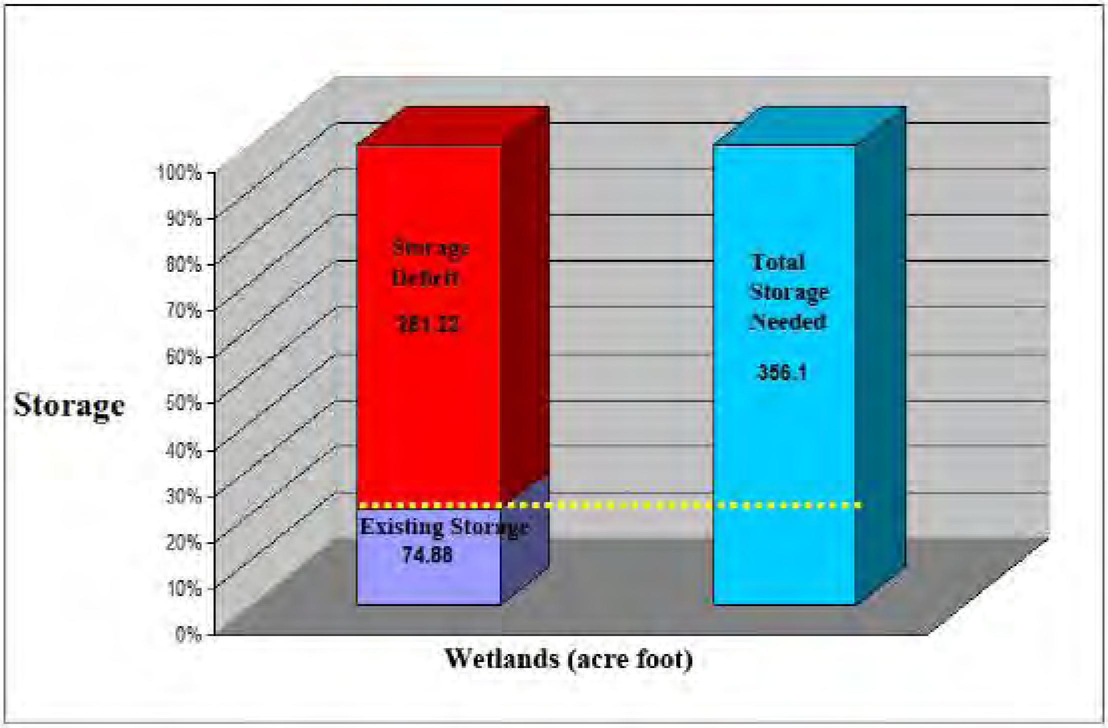

Figure 48: *1-Year, 24-Hour Storm Event Wetland Surface Water Storage: Urban Headwater Catchment.*

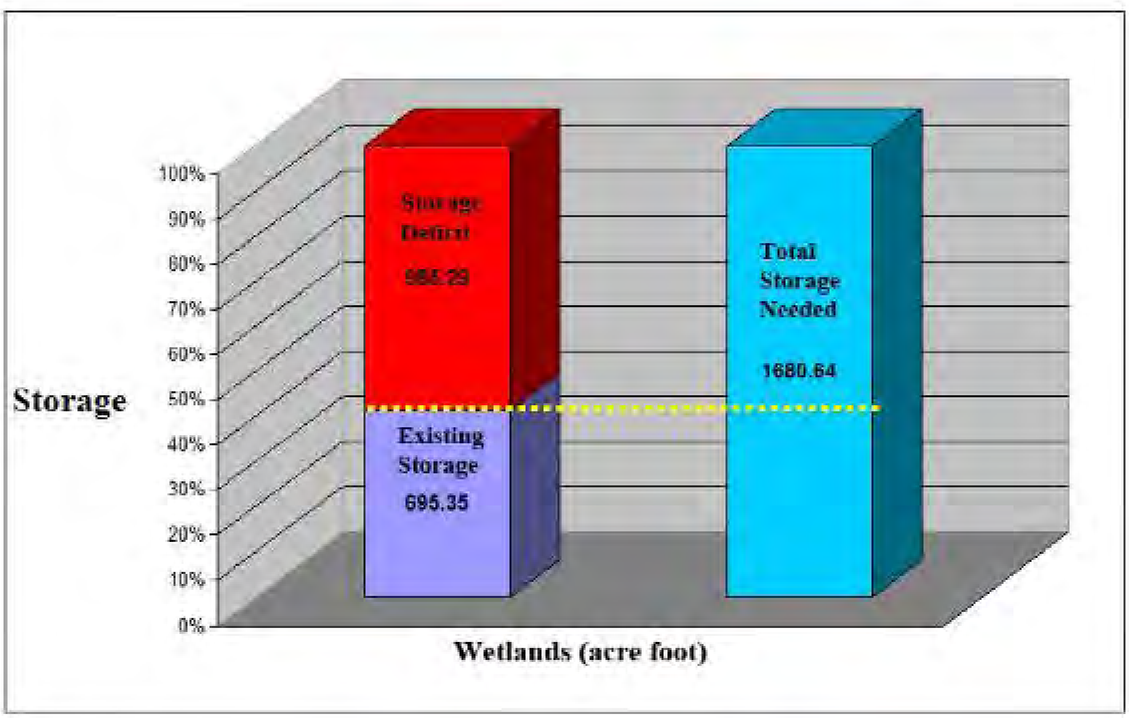

Figure 49: *100-Year, 24-Hour Storm Event Wetland Surface Water Storage: Urban Headwater Catchment.*

The rural headwater catchment is closer to managing existing stormwater detention needs for a 1-year, 24-hour prior wet conditions storm event. With the 100-year, 24-hour prior dry conditions event, there is a slightly greater need for surface water detention capabilities in the rural headwater catchment.

The urban catchment is closer to managing existing stormwater detention needs for a 100-year, 24-hour prior dry conditions storm event. With the 1-year, 24-hour prior wet conditions event the urban headwater catchment needs a greater amount of surface water detention capabilities. Under prior dry conditions both the urban and rural headwater catchments may be able to more adequately manage a 1-year, 24-hour storm event because of the greater availability of storage from wetlands. But currently under prior wet conditions both headwater catchment types need more surface water detention storage capabilities even for a 1-year, 24-hour storm event.

Currently for overbank flooding from streams the NYSDEC recommends managing for the 10-year storm 24-hour peak discharge (New York State DEC, 2003). It would be beneficial to have 10-year, 24-hour storm event data for the NYCDEP stormwater reference wetlands to more accurately predict stormwater management detention needs. Under existing conditions, wetland resources within the rural and urban headwater catchments would likely be unable to manage all surface water runoff from a 10-year, 24-hour storm event with antecedent wet or dry conditions.

3.5 URBAN AND LAND-COVER CHANGE TREND ANALYSES

3.5.1 Wetland Loss and Gains

It is important to understand how land use change has been affecting the abilities of wetlands to perform important ecological functions, such as water quality protection, flood attenuation, and other related functions. Baseline data and trend analyses of historical wetland losses and gains depict how land use change may contribute to losses or gains of associated ecological services. Various analyses were conducted of status and trends studies of wetland resources applicable to the Upper Delaware Basin at the national, state, and watershed scale. All of these studies depict wetland land-cover change occurring within the Upper Delaware Basin. Three different studies were analyzed for information relevant to wetland land-cover change applicable to the watershed.

The three studies include the following temporal periods and spatial scales: 1780’s to 1980’s national study (Dahl, 1990); mid-1980’s to mid-1990’s state-wide ecozones (Huffman and Associates, Inc., 1999); and 1980’s to 2003 watershed specific (Tiner et al., 2005). Collectively these studies provide information relevant to historical and modern day wetland land-cover change. Results from the watershed specific study, Delaware Watershed within the New York City municipal water supply system (*see* **Figure 10**), provides the most accurate portrayal of wetland land-cover change within the Upper Delaware Basin.

Since the beginning of colonial times the Upper Delaware has experienced an overall loss of wetland coverage Dahl (1990). A US Fish and Wildlife Service (USFWS) study conducted by Dahl (1990) estimated percentages of wetland loss for New York from circa 1780’s to circa 1980’s; estimates were calculated for historical wetland coverage in the Upper Delaware from circa 1780’s and circa 1980’s. The historical wetland estimates for the 1780’s were mainly based from: 1) narratives of the landscape, 2) partially on historical colonial or state records, and 3) land use records focusing on land-cover change and historical wetland coverage. These records are not as accurate as using remote sensing or field surveys, but they give a rough estimate of wetland coverage for colonial times. Estimates were calculated for historical wetland coverage in the Upper Delaware Basin from circa 1780’s and circa 1980’s.

A more accurate representation of existing wetland coverage was estimated from the National Land Cover Data (NLCD) 2001 dataset using ArcGIS software; with 1% of the watershed classified as wetlands (USGS, 2003). This is at the low end of the estimated surface coverage of wetlands circa 1980’s from the Dahl, 1990 study. From circa 1780’s to 2001 it is estimated that 4% to 11% of the total land-cover classified as wetlands within the Upper Delaware was converted to other land-cover types. The minimum predicted wetland loss from total wetland land-cover circa 1780’s to 2001 is approximately 76%. Since the Dahl 1990 report is based on a national study the results may not accurately portray wetland loss at the scale of the Upper Delaware Basin. The NLCD 2001 dataset is also limited, because it is based on land-cover types classified into

30 meter by 30 meter grid-based cells. Small wetlands may not be represented in the NLCD 2001 dataset. The USFWS NWI data provides the highest resolution of present wetland land-cover, but currently not all of the Upper Delaware Basin is represented by digital NWI data. The historic (Dahl, 1990) wetland data and more current wetland land-cover data for the Upper Delaware Basin were analyzed together (**Table 17**).

Table 17: Estimated Historic Wetland Coverage and Wetland Loss in the Upper Delaware Basin
(Dahl, 1990 and USGS, 2003)

Time Period	**Wetland Acres**	**Percent Land-Cover: Wetlands**	**Estimated Watershed Land-cover Change of Wetlands from Circa 1780s** (Acres / Percent)	**Estimated Wetlands Loss From Circa 1780s** (Percent)
Circa 1780's	38,142.1 to 91,541.0	5 – 12%	0 0%	0%
Circa 1980's	7,628.4 to 38,142.1	1 – 5%	30,513.7 to 53,398.9 4 – 7 %	80 – 58%
2001	9,230.4	1%	28,911.7 to 82,310.7 4 – 11%	76 – 90%

A more specific and relatively modern study, mid 1980's – mid 1990's, of wetland land- cover change was based on ecozones found in New York (Huffman and Associates, Inc., 1999). The Upper Delaware Basin is located within the Appalachian Highlands Ecozone, which was one of the study areas for the report done by Huffman and Associates, Inc., 1999. Wetlands located within the Appalachian Highlands Ecozone in 1999 represented 3.6% of the surface area, with the statewide average at 7.2%. The percentage of wetlands greater than 12.4 acres is also smaller in the Appalachian Highlands Ecozone. In 1999, the statewide average of wetlands greater than 12.4 acres was 80.3%, but only 67.1% in the Appalachian Highlands Ecozone (Huffman and Associates, Inc., 1999). This means that New York protects fewer wetlands in the Appalachian Highlands Ecozone, than in other parts of the state. Under the New York

State Freshwater Wetlands Act, wetlands smaller than 12.4 acres are not protected by the state (New York State DEC, 2008).

Wetland coverage increased in the Upper Delaware Basin from the mid 1980's to the mid 1990's (Huffman and Associates, Inc., 1999) (**Table 18**). The results were based on wetland mapping using aerial photography of a stratified random sample of USGS quads covering all of the ecological zones of New York (**Table 18**). The results give the relative trends of wetland coverage within the different ecozones of New York (Huffman and Associates, Inc., 1999). The Huffman and Associates, Inc., 1999 study may be more useful or accurate than the Dahl, 1990 study, because of the methods used and the scale of the study being smaller. A more recent study, Tiner et al., 2005 (**Table 19**), of reservoir basins within the Delaware Watershed provide more watershed-specific data on wetland land-cover change than the Dahl, 1990 and Huffman and Associates, Inc., 1999 reports. The Huffman and Associates, Inc., 1999 and Tiner et al., 2005 reports differ significantly for land cover-type changes for most wetland types. This is likely caused by the difference in scales between ecozones and watersheds.

The most recent US Fish and Wildlife Service wetlands status and trends report for 1998-2004 shows evidence of slight gains in freshwater wetlands and ponds in the Upper Delaware Basin region (Dahl, 2006). A portion of these gains are attributed to new ponds, where about 10 new ponds are estimated within the Upper Delaware Basin (Dahl, 2006). Compared to portions of upstate New York, the watershed appears to have experienced smaller gains in both freshwater ponds and wetlands (Dahl, 2006). The increase in wetland acreage in the watershed is likely due to abandonment and reversion of agricultural lands. The estimated gains from the Dahl, 2006 study are based on national maps with coarse resolution and may not accurately portray the resolution of watershed-based wetland land-cover change.

The Tiner et al., 2005 results give more descriptive details about wetland land-cover gains and losses (**Table 19**). The Delaware Watershed boundaries from the Tiner et al., 2005 study overlap with the Cannonsville Reservoir Basin, located within the Upper Delaware Basin. The other New York City reservoir basins illustrated in **Figure 10** (located in the methods section), are adjacent to the Upper Delaware Basin and are also located within the Appalachian Highlands Ecozone.

Table 18: Mid-1980s to Mid-1990s Wetlands Status and Trend Analysis of New York State: Appalachian Highlands Ecozone
(Huffman and Associates, Inc., 1999)

Land-cover or Wetland Type	**Mid-1980's Acreage**	**Mid-1990's Acreage**	**Change in Acreage / Percent**	**Net Change** (Acres)
Forested	226,436	260,513	+16,077	+2,421
			+7%	
Shrub/scrub	103,007	97,887	-5,120	
			-5%	
Emergent	66,838	51,531	-15,307	
			-23%	
Open Water	28,982	35,754	+6,771	
			+23%	

There was a net increase in wetland types within the Appalachian Highlands Ecozone (**Table 18**) (Huffman and Associates, Inc., 1999). Even though there was a net gain of 2,421 acres of wetlands, that does not account for the ecological quality of the wetlands gained. For example, constructed wetlands or less mature wetland areas have lower estimated ecological performance functions than mature natural wetlands.

Table 19:
Delaware Watershed Wetland: Wetland Coverage Differences from 2003 and 1980's Surveys (Tiner et al., 2005)

Wetland Type	**2003** (Acres)	**1980's** (Acres)	**Net Change** (Acres)	**Percent Change**
Emergent	2,005.2	1,806.9	+198.3	+11%
Forested	955.1	923.9	+31.2	+3%
Scrub-Shrub	921	890.7	+30.3	+3%
Total Palustrine	5,816.5	5,091.7	+724.8	+14%
Riverine	141.7	146.8	-5.1	-3%
Lacustrine	576.1	1,044.9	-468.8	-45%
All Wetlands	**6,534.3**	**6,283.4**	**+250.9**	**+4%**

The Delaware Watershed includes the Cannonsville Reservoir, Neversink Reservoir, Pepacton Reservoir, and Rondout Reservoir basins. In the Tiner et al., 2005 study, the 1980's aerial photography used of the Cannonsville Reservoir Basin was taken at a time of unusually low water conditions. In the 1980's wetland survey of the Cannonsville

Reservoir Basin, 2,000 acres of exposed bottoms were included in the total lacustrine wetland acreage (**Table 19**). The 2,000 acres of exposed bottoms, classified as lacustrine wetlands were subtracted from the 1980's survey of the Cannonsville Reservoir to more accurately depict normal conditions (**Table 19**). The "Total Palustrine" wetlands category includes certain wetland types not included in **Table 19**.

3.5.2 Sullivan County Building Permit Activity

In addition to changes in wetland land-cover, changes in urban land-cover affect performance levels of wetland and headwater stream resources. One indicator of urban land-cover change is the status and trends of annual building permits allocated in a given county. Annual rates of additional residential units have increased in Sullivan County since 1990 (Sullivan County, 2007). Understanding the amount of additional residential building permits gives insight to possible impacts on valued ecological services from wetlands and headwater streams. Delaware County was not analyzed, because it has limits on building activities due to a large portion of the county lying within the New York City municipal water supply system watershed.

Some areas in Sullivan County are experiencing increased development pressures with people investing in second homes (Sullivan County, 2007). An analysis was conducted of residential building permits documented in Sullivan County from 1990 to 2006 (**Figure 50**). Residential building permit activity has been occurring at an increasing rate, especially since 2000. From 2000 to 2006, the annual number of building permits ranged from 316 (2000) to 848 (2005) (see *Appendix*, **Table A.4**). From 1990 to 2006 there was an increase of approximately 1,186% in total residential building permits (based on total summation of annual building permits) in Sullivan County. Building activities are commonly associated with increases in impervious surface cover. Greater stormwater runoff may be associated with increases in impervious surface cover resulting from residential building activities.

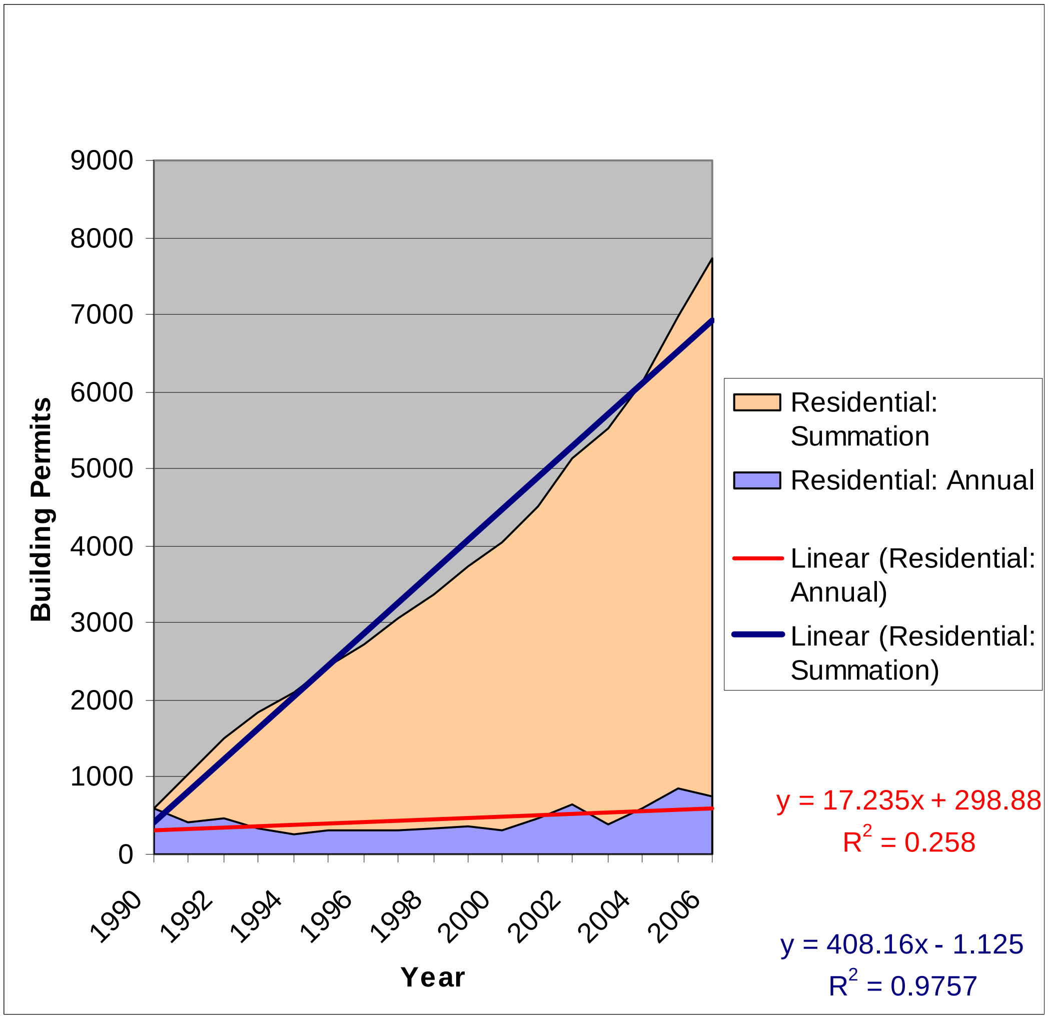

Figure 50: *Sullivan County, NY: Residential Building Permit Activity (1990-2006)* Sullivan County, 2007.

A positive linear trend line is observed for residential building permit activity from the 1990 – 2006 (**Figure 50**). Approximately 17 additional residential permits are accounted per year. The summation of annual residential permits shows an increase in permits, especially since 2000. The residential summation has a strong positive linear trend, while the annual residential trend line does not have a strong relation (Sullivan County, 2007).

In 2006 there were 34,586 residential parcels in Sullivan County, with a mean surface area of 255,089 square feet per parcel (Kiyan, 2008). In 2008 there were an additional 717 residential parcels from 2006, indicating that there has been increased growth in residential parcels within the county (Kiyan, 2008). Some portion of the surface area of any given residential parcel is impervious surface, including buildings, roads, and sidewalks. Stormwater management efforts within Sullivan County need to address increases in stormwater runoff associated with annual increases in residential parcels. The residential summation represents the overall increase in residential building permits and associated impervious surface cover for the entire time frame (**Figure 50**).

3.5.3 SLEUTH Urban Growth Model Analysis: Upper Delaware Basin

The SLEUTH urban growth model provided an analysis of projected future urban development up to the year 2030 based on existing development trends for counties within the Upper Delaware Basin. Jantz, 2008 ran analyses of projected urban development within the various counties based on existing development trends. The existing development scenario showed areas with strong attraction, neutrality, and strong resistance to development. All of the counties within the watershed show a mixture of attraction, neutrality, and resistance to development. The New York City municipal water supply system watershed is one of the largest areas within the Upper Delaware Basin which restricts development.

The close proximity to New York City makes certain areas within the Upper Delaware Basin more attractive for future development (**Figures 51 – 52**). From these resistance and attraction layers the SLEUTH model projected future development under existing development trends for all of the counties. The model was calibrated at the municipal and county level, with high predictive capabilities.

The percent increase of urban development expected to occur within Delaware, Sullivan, Pike, and Wayne counties was estimated from 2000 – 2030 (**Figure 53**). A closer analysis of expected increases in urban development for each county was conducted (**Figure 55**).

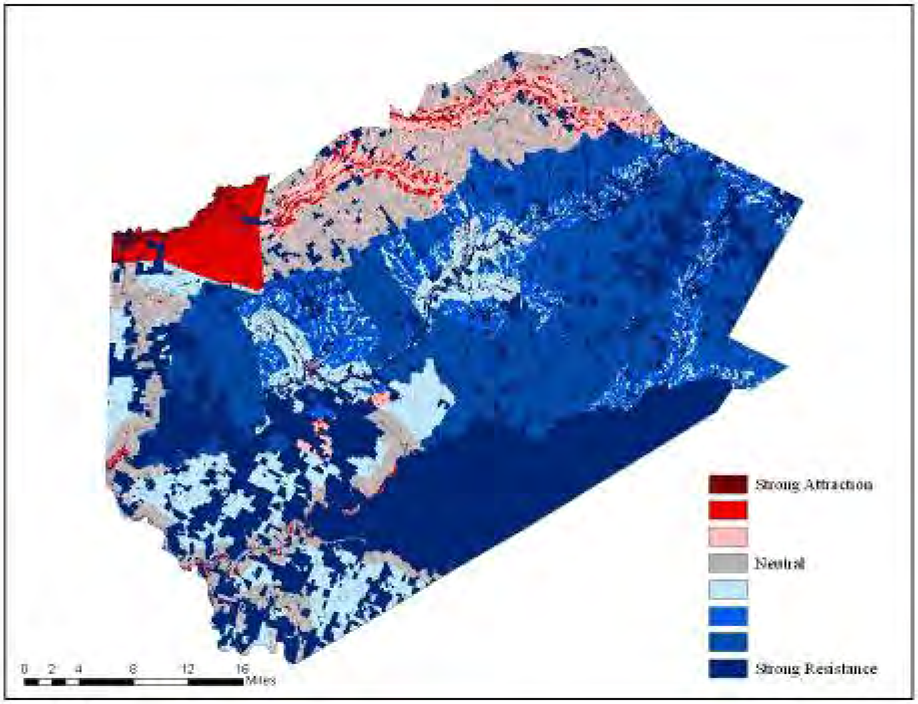

Figure 51: *SLEUTH Model: Delaware County, NY Exclusions and Attractions* (Jantz, 2008).

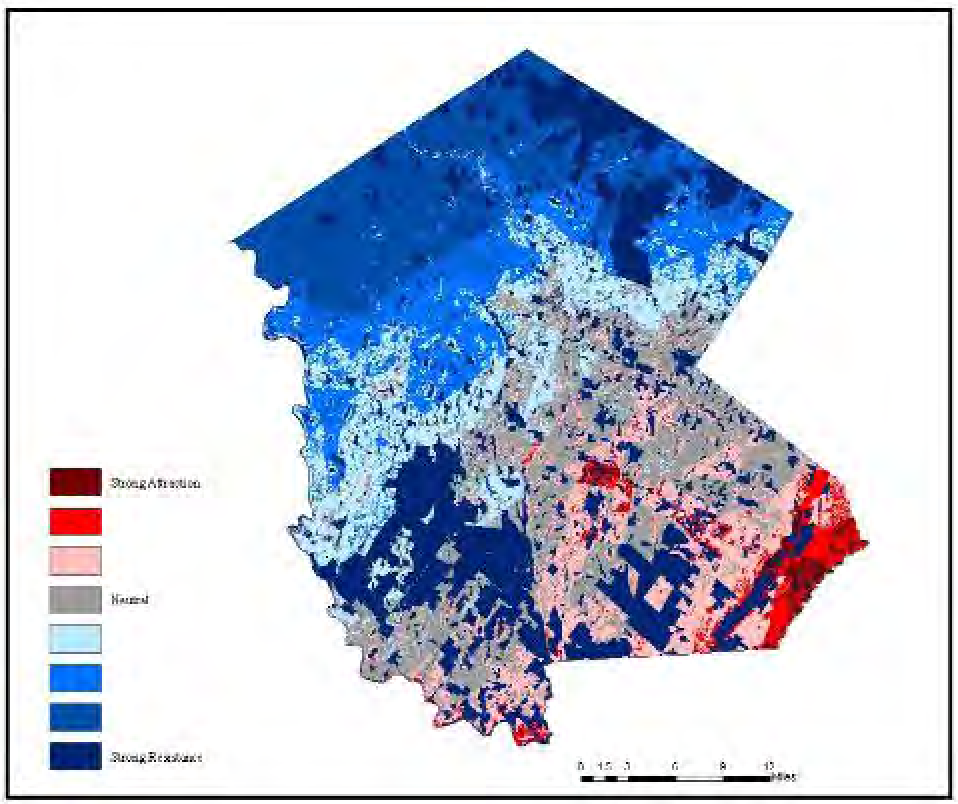

Figure 52: *SLEUTH Model: Sullivan County, NY Exclusions and Attractions* (Jantz, 2008).

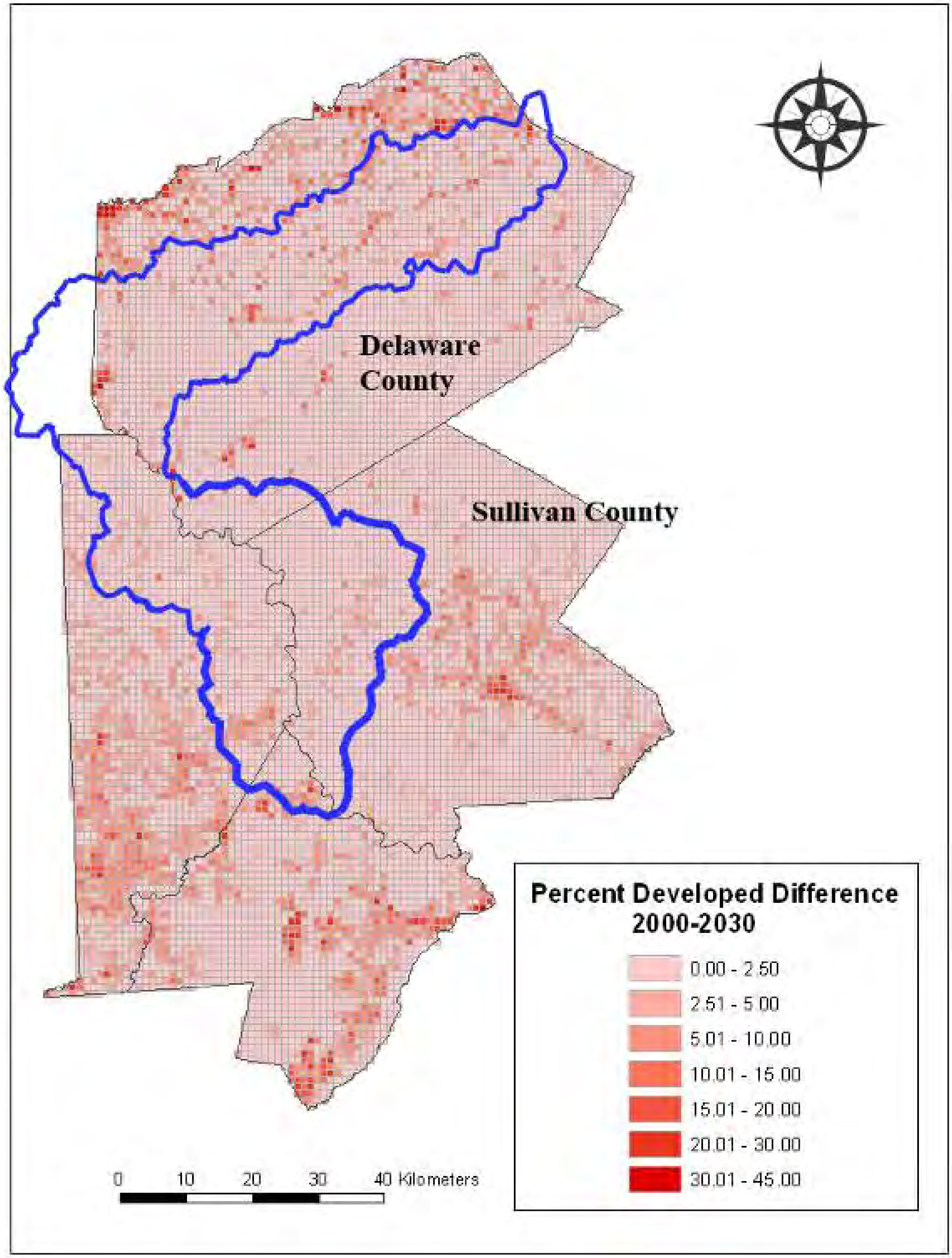

Figure 53: *Existing Development Conditions: SLEUTH Model Upper Delaware Basin Projected Percent Change of Developed Land from 2000 – 2030* (Jantz, 2008).

Within the Upper Delaware Basin, Delaware County has the greatest range in developed land categories, ranging from 0 – 2.5 % to 30 – 45 % (**Figure 53**). In Sullivan County it appears that the greatest developed land category is 10 – 15%. Generally existing future development is predicted to occur in concentrated areas of each county. The portions of Delaware and Sullivan counties within or adjacent to the New York City municipal water supply system watershed have less development pressures than other parts of the Upper Delaware Basin, because of existing environmental protection strategies (Jantz, 2008). Areas within Delaware County north of and outside of the Upper Delaware Basin are generally predicted to have greater amounts of developed land than county land within the basin.

Urban land development is expected to increase for both Delaware and Sullivan counties from 1984 to 2030 under existing urban development trends (**Figure 54**). Sullivan County is expected to experience the greatest increase in urban land development, while Delaware County is expected to have the least (Jantz, 2008). By 2030, Sullivan County is expected to have about 7.5% total impervious surface cover (Jantz, 2008). Delaware County is predicted have approximately 2.8% impervious surface cover by 2030 (Jantz, 2008). Most areas of Sullivan County located within the Upper Delaware Basin appear to have less urban development predicted compared to areas of Delaware County within the basin. Increases in impervious surface cover were further analyzed (**Table 20**). The amount of urban development in Sullivan County is predicted to double from 2005 to 2030. Impervious surface estimates in do not include existing roads, which may exclude a significant portion of impervious surface cover (**Table 20**). Based on the average width of county roads within Sullivan County (23 feet), existing roads in Sullivan County could account for 7,204.2 acres of impervious surface cover (1.1% of land-cover within the county). Predicted land development adjacent to the Upper Delaware Basin within Delaware and Sullivan counties will likely contribute to increases in stormwater runoff within the basin.

Understanding how predicted urban development under existing conditions may impact wetlands and headwater streams is an important aspect of this study. Under the existing development trend scenario (baseline), all wetlands were considered a protected data layer (strong resistance) for the SLEUTH model analysis. While freshwater wetlands are protected under law from development by the NYSDEC, the US Army Corps of Engineers, and the US EPA there are still existing and past cases of wetlands being developed for urban land uses.

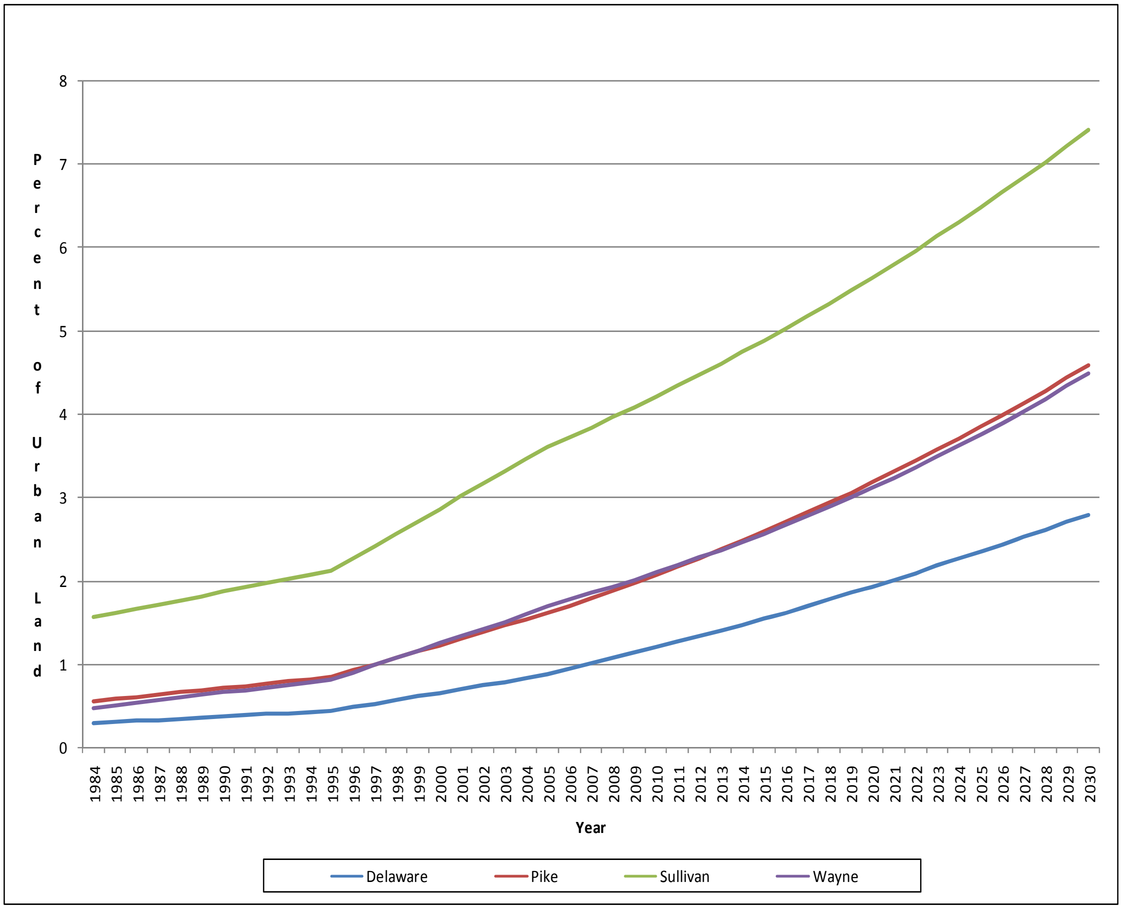

Figure 54: *SLEUTH Model: Percent Urban Land by County, 1984 – 2030* (Jantz, 2008).

Using the SLEUTH model existing conditions data, a spatial analysis of urban land and wetland land-cover change in Sullivan County for 2030 was conducted (**Figure 55**). These results give an overly optimistic view of wetland land-cover change for Sullivan County. The existing model scenario predicts that all wetlands are protected from land-cover change. Wetland loss and mitigation data from US Army Corps of Engineers (USACE) Philadelphia District and New York District offices were compiled from 1992 to 2006 to better understand actual wetland loss and mitigation within the basin (**Table 21**). USACE records of wetland loss and mitigation prior to 1992 have been cited as being inaccurate and/or incomplete because of changes in management of data records (USACE, 2008). The Philadelphia District office includes Wayne and Pike counties of PA and the New York District office includes Sullivan and Delaware counties.

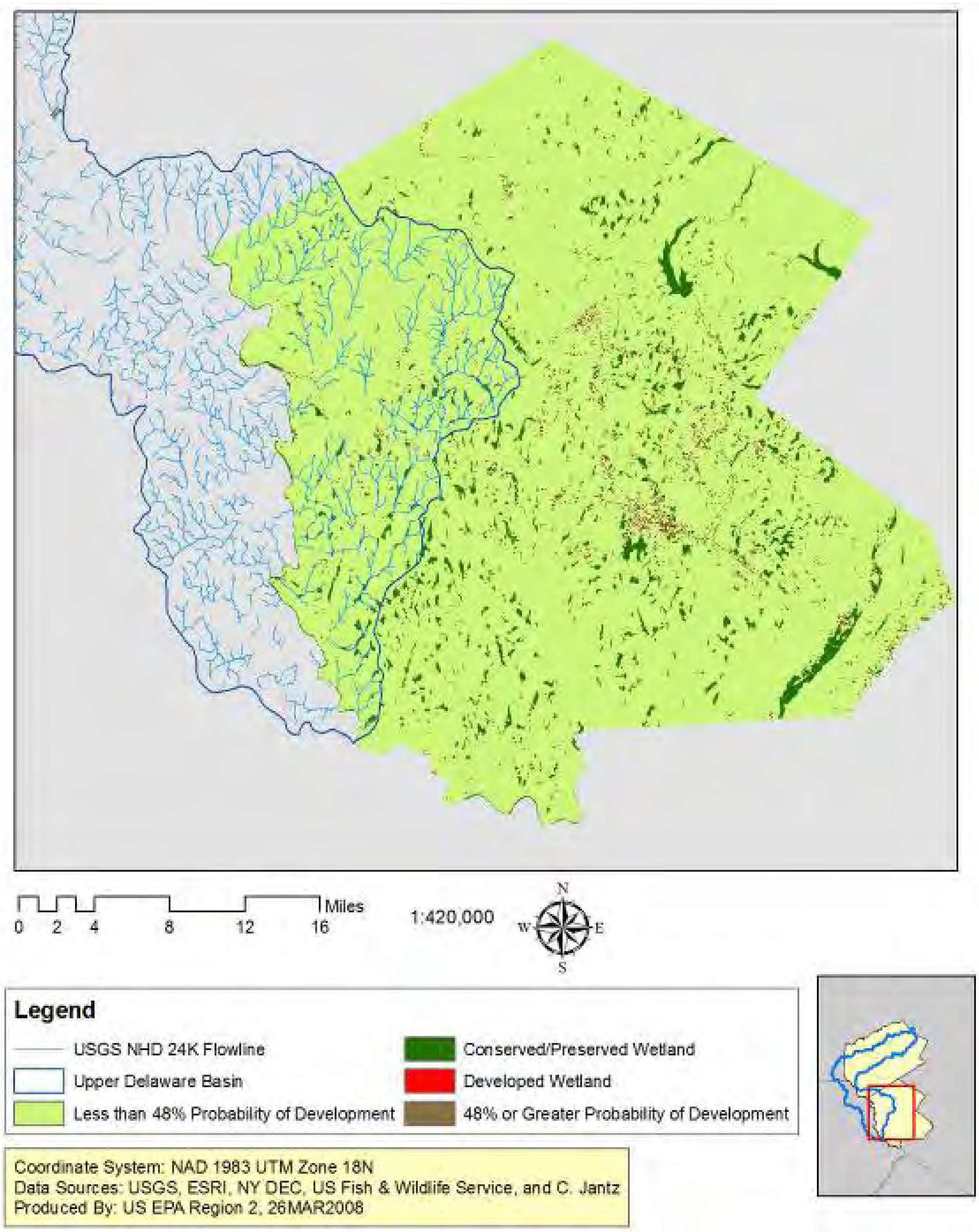

Figure 55: *SLEUTH Model Existing Urban Development and Wetlands Cover Trends for 2030: Sullivan County, NY.*

Only 2.6 acres (approximately .01%) of the total 31,404.79 acres of wetlands within the county is expected to be developed by 2030 (**Figure 55**). Based on historical wetland loss from US Army Corps of Engineers 404 permits, from 2005 - 2030 Sullivan County is predicted to have 46 wetland acres filled (**Table 21**). Since Sullivan County is expected to have the greatest amount of urban development of all counties within the basin, it is likely that a greater number of wetland acres could be lost compared to other counties within the basin.

The percent of wetlands likely to be developed is relatively low, but the amount of land with a 48% or greater probability of being developed is high within the county (**Figure 55**). The impacts from this increase in urban development will have stormwater impacts (increased surface water runoff) on existing wetlands within Sullivan County and the Upper Delaware Basin. Habitat fragmentation from development occurring between wetlands likely will impede the delivery of ecological functions/services from wetlands.

Table 20:
SLEUTH Model: Existing Urban Development Projections for Sullivan County 2005 to 2030

Year	**% Impervious Land in County**	**Impervious Land** (Acres)	**Change of Impervious Land from 2005** (Acres / %)
2005	3.6 %	22,917.1	0
2030	7.5 %	47,743.9	24,826.8
			108%

Note: Sullivan County has a total land area of 636,585.1 acres.

Table 21: US Army Corps of Engineers 404 Wetland Permit Losses and Mitigation and Predicted Wetland Losses and Mitigation for Delaware, Sullivan, Wayne and Pike Counties, NY/PA.
(USACE Philadelphia District, 2008 and USACE New York District, 2008)

County	**Wetland Loss (Filled) 1992 - 2006** (acres)	**Wetland Mitigation 1992-2006** (acres)	**Annual Average Wetland Loss (Filled)** (acres/yr)	**Annual Average Wetland Mitigation** (acres/yr)	**Predicted Wetland Loss (Filled) 2005 – 2030** (acres)	**Predicted Wetland Mitigation 2005 – 2030** (acres)
Wayne (PA)	41.76	1.09	2.78	.07	69.5	1.75
Pike (PA)	5.61	.5	.4	.03	10	.75
Delaware (NY)	11.36	2.9	.76	.19	19	4.75
Sullivan (NY)	27.56	27.68	1.84	1.85	46	46.25

Note: Predicted wetland loss and mitigation is based on the annual averages for wetland losses and gains.

Landscape modifications resulting in wetland losses are not equivalent to wetland mitigations (**Table 21**). For example, wetland mitigation may include wetland creation, restoration, preservation, or enhancement. Wetland mitigation projects are often partially successful, if successful at all; which may mean mitigated wetlands do not meet required acreage or replaced functionality of wetlands lost (Matthews and Endress, 2008). Also, mitigation may not take place on site or may not actually occur (Brown and Veneman, 2001). Filled wetlands occur on site and impact intact functioning wetlands. Even though Sullivan County is predicted to have 0.25 acres more wetlands mitigated than wetlands filled, these cannot be compared directly (**Table 21**).

Overall Sullivan County is expected to have a substantial increase in impervious surface as a result of future urban development. The SLEUTH model analyses for future urban development under existing conditions only gives the predicted amount of impervious surface expected. The model does not show how buildings, subdivisions, or roads will be built within any of the counties. Where impervious surface is located within a given headwater catchment or the watershed affects water quality and flood management efforts. If impervious surfaces are concentrated in certain areas within a given headwater catchment, then there may be variable effects on stormwater runoff, infiltration, and evapotranspiration rates caused by future urban development patterns (**Figure 56**).

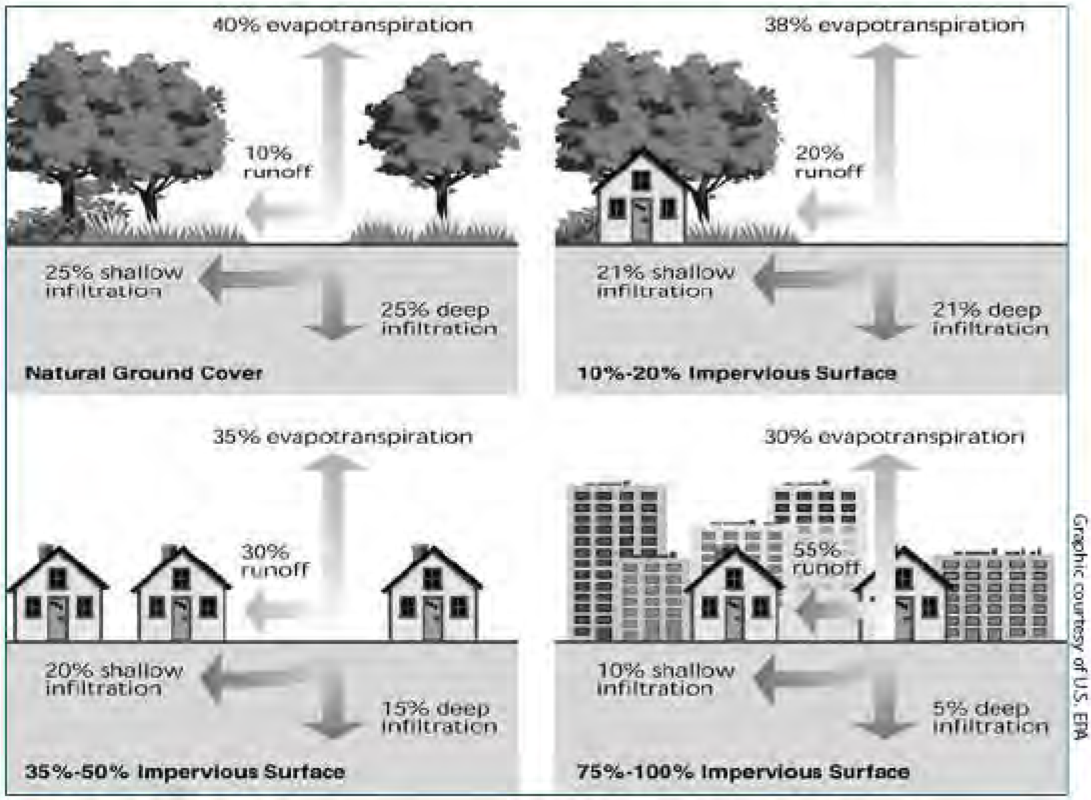

Figure 56: *Urban Development and Associated Stormwater Runoff Rates* (Richards, 2006).

The SLEUTH model predicts Sullivan County to have approximately 7.5% impervious surface cover by 2030 under existing conditions; but certain areas within the county are expected to have greater overall concentrations of impervious surface coverage than others. Areas with higher concentrations of impervious surface cover will experience increased volumes of stormwater runoff. The SLEUTH model future scenario under existing development trends shows development occurring in both concentrated and sprawl-like patterns. If the majority of development is concentrated in confined areas, then there will be a decrease in overall stormwater runoff volume and associated impacts on water quality (**Figure 57**). Different scenarios of urban development patterns for a hypothetical 10,000 acre catchment with 10,000 houses were analyzed (**Figure 57**).

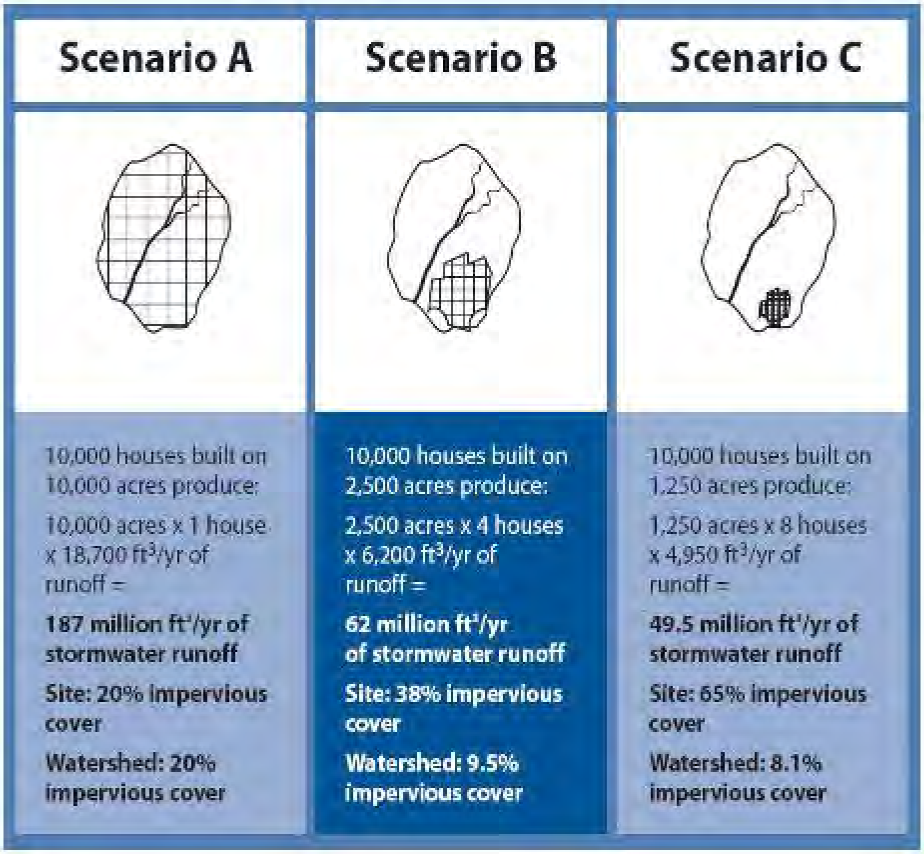

Figure 57: *Alternative Residential Land Use Scenarios of 10,000 Houses Located Within a 10,000 Acre Watershed* (Richards, 2006).

The various development scenarios display differences in overall stormwater runoff volumes within the watershed. The more concentrated houses are within a watershed, the less overall stormwater runoff produced within the watershed. Concentrating impervious surfaces within a portion of the watershed leaves more room within the watershed to detain or infiltrate stormwater runoff (Richards, 2006).

The Center for Watershed Protection uses the sub-watershed scale for protecting sensitive streams, which is between 320 and 19,200 acres. Within the Upper Delaware Basin the average NHDPlus headwater catchment is 662.72 acres. The average NHDPlus headwater catchment containing a portion of an urban area is 2,116.39 acres. Thus the scenarios in **Figure 57** may be applied to catchments with existing or predicted future urban areas within the Upper Delaware Basin.

If the pattern of future urban development is concentrated within certain areas of any given headwater catchment, there will be less stormwater runoff than with uncontrolled urban sprawl or development. Future urban development expected within the Upper Delaware Basin may be planned to decrease stormwater runoff, alleviating negative impacts on stream and wetland resources. The SLEUTH model may produce alternative future scenarios, which are designed to protect, conserve, preserve, and enhance existing wetland and headwater streams resources. SLEUTH Model input conditions which could create alternative future scenarios that would facilitate continued protection and enhanced functionality of headwater stream and wetland resources were proposed (**Table 22**).

Table 22: Alternative Future Scenario Input Conditions for the SLEUTH Model: Protection and Enhancement of Ecological Functions of Headwater Streams and Wetlands

Model Input Condition
100 foot buffer around all headwater streams and wetlands.
Limit future development to existing urban areas.
Allow the majority of development to have only clustered or compact development patterns.
Set an impervious surface threshold of 10% for each individual headwater catchment within the watershed.
Aggregate headwater catchments into small groups which include one urban area, but still set a 10% impervious surface threshold.

3.6 GIS DATABASE

To assess conditions of wetland and headwater stream resources all relevant and available GIS data were collected and stored in a geospatial database. Data source types included: wetlands and headwater streams, watershed and catchments, digital elevation models, public infrastructure, government boundaries, aerial photography, land-cover, soils, and predicted future urban growth. After the data were acquired the metadata were recorded using the EPA Metadata Editor. Current metadata associated with all datasets allows for quick recognition of various important attributes. All metadata records may be viewed using ESRI's ArcCatalog program.

These different GIS datasets facilitated spatial and tabular analyses that were performed for this project. The *Appendix* provides an abbreviated metadata list of all major GIS datasets used (**Table A.5**). Descriptions and potential uses of the GIS datasets are given below (**Table 23**). Potential future users of the datasets may replicate or use additional spatial or tabular analyses. Note that all of the datasets are available to the public for no cost.

Table 23: GIS Metadata Summary: GIS Data Descriptions and Potential Uses

GIS Data Layer	**Description and Potential Uses**
Counties	The main counties of interest within the Upper Delaware Basin were Sullivan and Delaware counties, because they overlay the majority of the basin within EPA Region 2. Other counties within the Upper Delaware Basin include: Schoharie and Broome of New York; and Wayne and Pike of Pennsylvania. Counties are traditional land management and policy boundaries.
Impervious surfaces (urban areas and roads)	The amount of impervious surface and its location has direct effects on how stormwater flows into water conduits, such as streams or wetlands. Questions addressed by impervious surface cover analysis may include: 1) how does increased impervious surface cover affect streams, wetlands, riparian areas, and other pervious water conduits; 2) is there a balance between the amount of impervious surface created and the ability of the landscape to store, detain, and filter stormwater; and 3) what are the effects on ground-water flow and associated hydrological connections? Locating impervious surfaces and understanding their proximity to wetlands and headwater streams may give evidence for hydrological disturbances.
Public streets	Provide spatial reference of streets in relation to streams, wetlands, and other public infrastructure. May be used to figure out how roads contribute to storm and flood water discharges into streams and wetlands. May assist planning and design of existing and future roads for flood and stormwater management.

Table 23 (cont.)

GIS Data Layer	Description and Potential Uses
Aerial photographs (past 20 years, 1986 – 2006)	Illustrate how land use changes have occurred throughout the watershed. Trends in land-cover change may be associated with or compared with the recent increase in frequency and intensity of flood events. Historical aerial photographs were used to create raster-based grids of both impervious surface and tree canopy cover for the Upper Delaware Basin (Jantz, 2008). Aerial photos of existing conditions were used as base-maps for various spatial analyses, including the SLEUTH model.
Land-cover	Assist with understanding landscape classifications of both urban and rural areas. May help figure out how these land-cover types may be affecting stormwater and water quality protection functions of wetlands and headwater streams in the watershed.
10 and 30 meter digital elevation models (DEMs)	Understanding how water moves through the watershed is best determined by contour lines. Hydrological analysis tools, such as the ArcGIS Spatial Analyst, TauDem, Archydro, and Basins 4.0 can use DEM data to illustrate how and where water moves throughout various parts of the watershed.
Watershed and catchments	Provides boundary of the Upper Delaware Basin (USGS 8 digit Hydrologic Unit (HUC)) and its headwater catchments (NHDPlus first order stream drainage area delineation) located within Delaware and Sullivan counties. Delineate and predict where water moves throughout the landscape (starting and end points).

Table 23 (cont.)

GIS Data Layer	Description and Potential Uses
Hydrography	Includes spatial locations of catchments, streams, and waterbody types. May be used to define the catchment drainage area of headwater stream reaches. Once catchments have been identified, the amount of surface water running off from the catchments may be determined. NHDPlus flowlines and headwater catchments were used as the baseline data for the headwater stream network aggregation. NHD high resolution and NYCDEP stream flowlines were overlain with the NHDPlus base-map data. Overall this data assisted with understanding how adjacent land-cover types affect these waterbodies. Also it helped with portraying hydrological connections between streams and wetlands.
Headwater streams	These have been defined as the aggregation of all first and second order streams (Freeman et al., 2007). These are critical areas since they influence how water enters the watershed and subsequent downstream catchments. It is important to understand the geographic extent of the headwaters and the adjacent land-cover types that affect the ecological health of these water-bodies. Wetlands that appear to be isolated from navigable streams or other tributaries may actually have a hydrological (surface or ground water) connection to headwater streams.

Table 23 (cont.)

GIS Data Layer	Description and Potential Uses
Wetlands (NWI Enhanced (Hydrogeomorphic-Classifications) and NYSDEC)	Facilitated the location and identification of surface area, probable flood water storage capacity, and other water quality and flood management related functions of NWI wetlands. Helped with understanding how much of the watershed is currently classified as wetlands.
SLEUTH urban growth model	Provided historical and existing datasets of impervious surface cover within the Upper Delaware Basin. Sullivan County released a copy of its SLEUTH model dataset to be used for this project. The SLEUTH data also provide projected trends of impervious surface coverage to 2030 under existing development scenarios. Alternative future scenarios may be created to understand possible effects on natural resources, such as wetlands and headwater streams.
Hydric soils	Locating these soil types helped interpret where water is usually stored and possible locations of wetlands. Predicting the locations of historic wetlands or proposed wetland restorations or creations should be based off of hydric soil locations.
Stormwater infrastructure	Gives the spatial location and types of stormwater infrastructure within the watershed. This may help identify areas needing more stormwater infrastructure capacity upstream to accommodate flood events. Locating man-made stormwater infrastructure, wetlands, and headwater streams may help interpret how stormwater is collectively managed in the watershed. Natural landscape features, such as wetlands and riparian corridors, that manage stormwater may be enhanced, protected, or created to complement more conventional engineered stormwater structures.

Table 23 (cont.)

GIS Data Layer	Description and Potential Uses
Ecoregions (Omernik's)	Delineates a regional ecosystem based on the integrity and quality of such characteristics as: physiography, geology, soils, hydrology, vegetation, wildlife, and land use. Provides another way of defining ecosystems beyond the watershed concept.

3.7 SELECTION OF BEST MANAGEMENT PRACTICES (BMPS) FROM EXISTING DESIGN PRECEDENTS

Various options exist for selecting stormwater BMPs that meet flood management and water quality protection needs in both urban and rural contexts. All of the BMPs selected for this section are based on the results from previous analyses of baseline urban trends and ecological functions/services provided within the watershed. The hydrologic assessments of the watershed indicate there is a "deficit" in stormwater detention. BMPs are needed to increase the capability of the watershed to detain flood waters and protect water quality.

The 10-year, 24-hour storm event peak discharge rate is the recommended focus for managing overbank flooding (New York State DEC, 2003). BMPs should be designed to manage the 10-year, 24-hour peak discharge, and also need to act as conduits for stormwater under more frequent storm events, such as a 2-year, 24-hour storm event (New York State DEC, 2003). Stormwater should be conveyed under non-erosive and safe conditions to, from, and through stormwater BMPs under 2-year, 24-hour peak discharge storm events (New York State DEC, 2003). With the focus of managing for 10-year and 2-year, 24-hour storm events, BMPs may be selected for necessary flood attenuation and/or stormwater conveyance needs.

Treatment of stormwater runoff by both structural and nonstructural BMPs provide protection of existing hydrology and associated functions of natural wetlands and headwater streams (EPA, 1996). Management of stormwater runoff done without physical alteration of the landscape is considered a "nonstructural BMP." Physical alteration of stormwater runoff characteristics, such as flow, velocity, and duration are considered "structural BMPs (EPA, 1996)."

BMP design precedents have been borrowed with permission from the New York State Stormwater Management Design Manual; stream restoration projects conducted by the Greene County Soil and Water Conservation District and the NYCDEP; the National Engineering Handbook: Part 654 Stream Restoration Design by the NRCS; and technical stormwater management reports from the Center for Watershed Protection.

There are two general headwater catchment types, urban and rural, which form the broad basis for selecting stormwater BMPs. Generally urban catchments have a greater amount of impervious surface cover compared to rural catchments, which requires certain BMPs for maintaining flood attenuation and water quality needs. Urban catchments may already have man-made stormwater infrastructure that may need to be retrofitted to meet existing stormwater storage needs. Both urban and rural headwater catchments may use stormwater BMPs as part of smart urban growth planning strategies. Within the headwater catchment management framework, stormwater BMPs are broken down into different development contexts: residential sub-division, building or site design, public infrastructure (roads and parking lots), stream and wetland resources, and open space. From this framework a stakeholder may choose appropriate stormwater BMPs for a given headwater catchment and specific site context.

The following tables provide lists and accompanying descriptions of selected BMPs. BMP strategies are outlined for urbanizing and rural areas (**Table 24**). Most headwater streams within the watershed require certain types of BMPs because they support sensitive properties, such as good water quality, high biodiversity, trout habitat, and are in low development density areas (New York State DEC, 2003). BMPs most appropriate for areas near sensitive headwater streams were prioritized (**Table 25**). After a BMP strategy is chosen for a specific headwater catchment context, more specific stormwater management practice designs may be selected. The various capabilities of different stormwater management designs to accommodate water quality, channel, and flood protection were analyzed (**Table 26**). Accompanying **Tables 24 – 26** are illustrations of some of the stormwater BMPs. Stormwater BMPs that only provide water quality protection functions are located in the *Appendix*; although these BMPs may be combined with other BMPs to detain stormwater (**Table A.6**). Transition areas in between urban and rural contexts may use combinations of the recommended stormwater BMP strategies (**Table 24**).

Table 24: BMP Strategies for Urbanizing and Rural Areas
(Nisenson, 2005)

BMP Strategies	**Urbanizing Area**	**Rural Area**
Building and building site design	Detention of rooftop rain water, disconnect downspouts, native flora landscaping, minimize soil compaction, minimum set back from streams and wetlands, bio-infiltration cells, and green roofs.	Minimize soil compaction, green roofs, and minimum set backs from streams and wetlands.
Low impact development (LID)	Retrofit parking lots for stormwater management, tree canopy coverage, bio-swales, narrower streets, smaller parking lots, compact or cluster developments.	Large scale LID, including conservation easements, riparian forest buffers, and constructed stormwater wetlands.
Structural BMPs	Cisterns or rain barrels, bio-infiltration (rain garden, bio-swale, and pervious pavement), and constructed stormwater wetlands.	Livestock fences near streams or riparian corridors, and stormwater treatment trains leading into existing natural wetlands.
Design strategies and policies	Urban infill or redevelopment, impervious surface restrictions (catchment-based), open space, conservation design, and rural planning, and stream and wetland restoration and buffering.	Watershed and headwater catchment based impervious surface limitations.
Watershed or headwater catchment based	Regional or watershed-based stormwater management planning and regional open space and park planning.	Regional and watershed-based planning, acquisition of land for stormwater detention, and impervious surface limits.

Table 25: Watershed Selection of Stormwater Management Practices for Sensitive Streams (New York State DEC, 2003)

Stormwater Management Practice	Design Considerations for Sensitive Streams
Wetlands	• Need channel protection. • Restricted use in streams and trout waters.
Ponds	• Channel protection a priority. • Minimize permanent pool area and encourage shade habitat for trout.
Infiltration	• Use for groundwater recharge. • Provides channel protection when combined with a detention facility.
Filtering Systems	• Provides channel protection when combined with a detention facility.
Open Channels	

Different stormwater BMPs may be used in combination to meet various management needs (**Table 25**). Site design of BMPs within or near sensitive streams needs to be done carefully as to not disturb stream functions (New York State DEC, 2003).

Table 26: Wetland and Pond Stormwater Management Practices and Designs: Performance Capabilities for Water Quality, Channel, and Flood Protection (New York State DEC, 2003)

Stormwater Management Practice	Designs	Water Quality Protection			Channel Protection	Flood Control
		Bacteria	*Metal*	*Nitrogen*		
Wetland	Pocket wetland, pond/ wetland, shallow wetland, and extended detention wetland	Good	Fair	Good	Good	Good[1]

Table 26 (cont.)

Stormwater Management Practice	Designs	Water Quality Protection			Channel Protection	Flood Control
		Bacteria	*Metal*	*Nitrogen*		
Pond	Pocket pond, wet pond, wet extended detention pond, micropool ED, and multiple pond	Good	Good	Good	Good	Good

"Good" water quality protection functionality includes pollutant removal rates of: > 70% bacteria, > 60% metals, and > 30% total nitrogen (**Table 26**). "Fair" water quality protection includes pollutant removal rates of: 35-70% bacteria, 30-60% metals, and 15-30% total nitrogen (**Table 26**). A pocket wetland design needs to accommodate extra detention to be a good flood control option. [1] Stormwater management practices (SMPs) primarily rated as "good" for water quality protection are located in the *Appendix* (**Table A.6**).

A graphical overview of the main stormwater BMP categories mentioned in the previous tables is provided in the following sections: 1) stream and wetland infrastructure (**Figures 58 – 68**); 2) urban infiltration systems (**Figures 69 – 72**); and 3) residential scale development and site design (**Figures 73 – 77**). Some of the specific stormwater BMPs illustrated in the following sections have not been mentioned before, but are very similar in function to previously recommended BMPs.

3.7.1 Stream and Wetland Protection, Preservation, Enhancement, Restoration, and Creation

Figure 58: *Wooded Stormwater Wetland* (Cappiella et al., 2008).

The wooded stormwater wetland BMP is used to slow down stormwater runoff that would normally enter a nearby stream (**Figure 58**). Deep pools allow for sediments and attached pollutants to settle out of the water. Shallow vegetated meander flow paths provide additional water detention and filtration. By the time the stormwater has reached the last deep pool it has been cleansed and has slowly passed through the wetland system. Control structures at the entrance and exit points of this BMP control the quantity of stormwater managed by the system.

There are three recommendations for site selection of this BMP: 1) be located within the upper portion of the floodplain; 2) be adjacent to the riparian buffer; and 3) have a 100 foot buffer between this BMP and the stream which water is being discharged into. Wooded wetlands are found throughout the Upper Delaware Basin (**Figure 59**).

Figure 59: *Upper Delaware Basin Wooded Wetland.*

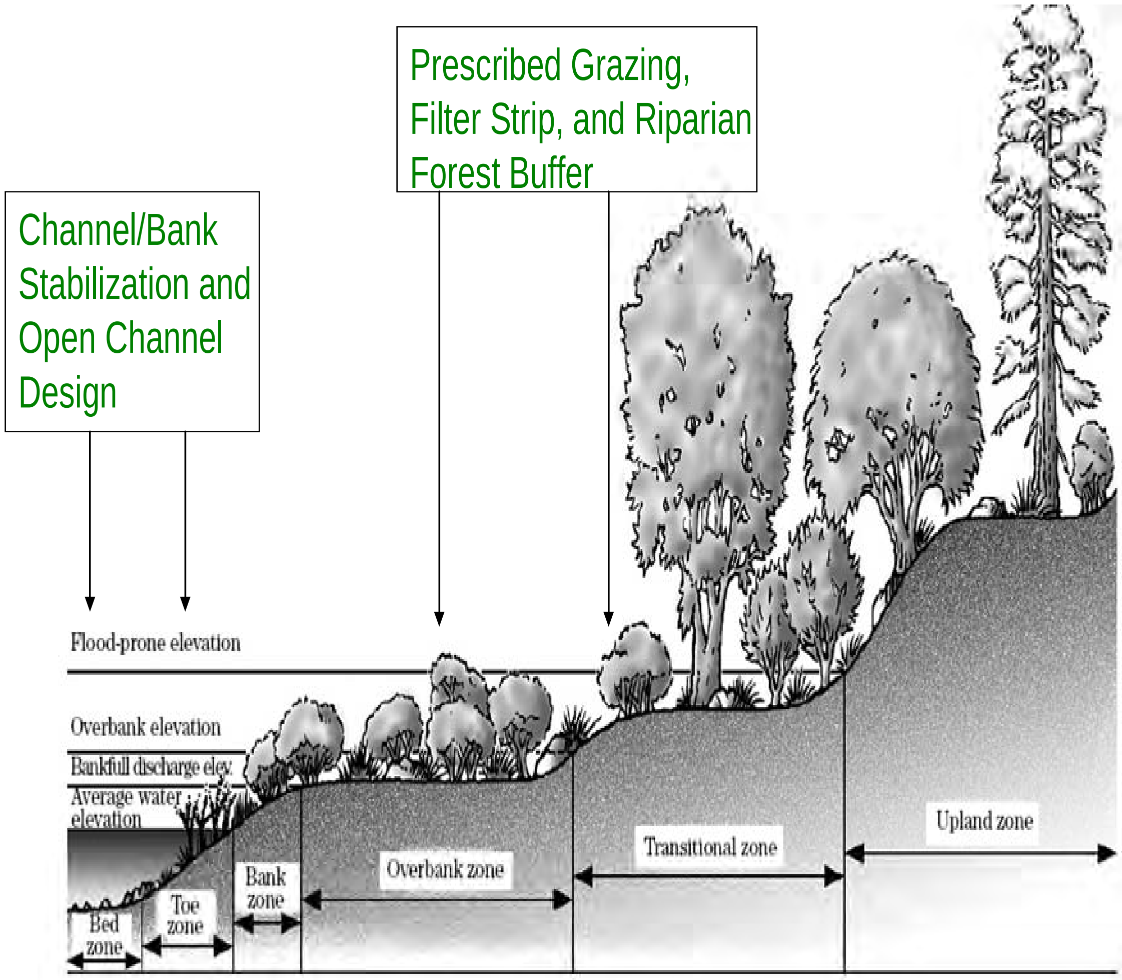

Figure 60: *Stream Landscape Restoration* (NRCS, 2007).

Restoration of headwater streams should take a landscape perspective because there are different BMPs suitable for different parts of a stream landscape (**Figure 60**). Currently the Upper Delaware Basin and the New York City municipal water supply system watershed stream restoration efforts focus on channel/bank stabilization and open channel design. Other management options in the floodplain or transitional zone focus on intact vegetated riparian buffers, filter strips, and prescribed grazing (NRCS, 2007).

Various governmental agencies, such as the Delaware County SWCD, the NYCDEP, and the Greene County SWCD have been using the open channel design approach for restoring sections of various streams within the New York City municipal water supply system watershed. One variation of this design approach is called "Rosgen Geomorphic Channel Design." The Rosgen approach is used for restoring or rehabilitating disturbed streams by restoring physical dimensions and stream meander patterns by mimicking undisturbed reference streams within the watershed or similar watersheds (NRCS, 2007). Disturbed streams are classified by their fluvial geomorphology characteristics (valley and stream type); bankfull flow morphological relations; and compared to abiotic and biotic characteristics of reference streams located in similar morphological zones or areas (NRCS, 2007).

Disturbed streams within the Upper Delaware Basin exhibit similar morphological traits, such as channel incision, disconnection from their former floodplains, and altered meander patterns. The open channel design and Rosgen design approaches attempt to restore streams altered by these disturbances. Some of the common objectives using the Rosgen approach include: 1) flood level reduction, 2) improved water quality, 3) improved wetlands, and 4) reduction of sediment load, land loss, and associated nutrients (NRCS, 2007).

Within the New York City municipal water supply system watershed the Greene County SWCD and the NYCDEP have completed a Rosgen-based stream restoration of a third order stream. The project was called Big Hollow, which involved a stream section that exhibited bank failure and disconnection from the floodplain. The stream section was assessed prior to restoration (**Figure 61**). Various stream restoration techniques were implemented to stabilize the stream bank, connect the stream to its floodplain, and control the flow of water through the stream channel (**Figure 62**).

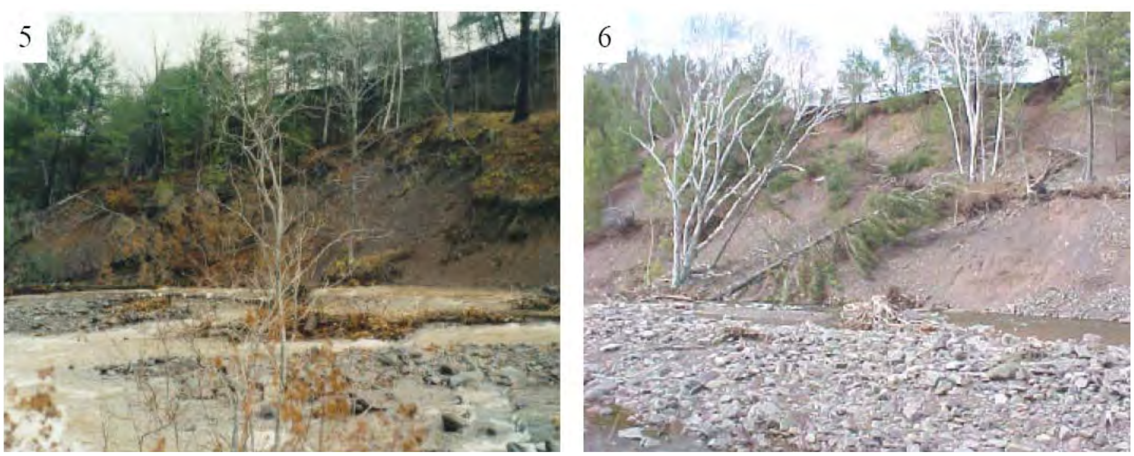

Figure 61: *Stream Restoration of Third Order Stream, Preconstruction (1998 – 2000): Big Hollow, Greene County* (Greene County SWCD, 2006).

Figure 62: *Stream Restoration of Third Order Stream, Construction/Restoration (2001 – 2002): Big Hollow, Greene County* (Greene County SWCD, 2006).

The stream was reconnected to its floodplain (Photo 19). The cross vanes were used to stabilize the stream banks (Photo 19). Photo 20 shows a zoomed in image of a cross vane, which is a control structure for directing stream flow to the center of the channel. Photo 21 also shows the stream connected to its floodplain, but the bank has also been regraded and stabilized. The stream was restored to a natural-like meander pattern and reconnected to the floodplain (Photo 22) (Greene County SWCD, 2006).

Throughout the New York City municipal water supply system watershed, the Greene and Delaware County Soil and Water Conservation Districts and NYCDEP practice many of the stream restoration techniques employed with the Big Hollow Project. A closer examination of these restoration techniques and others are given below (**Figures 63 – 68**).

Figure 63: *Recreating Stream Meander Geometry* (New York City DEP, 2008b).

Stream meanders or bends slow down stream velocity and decrease the slope gradient, which reduces erosion of stream banks (**Figure 63**). At meander bends, pools form and riffles and glides are formed between the pools. Restoring the stream geometry includes mimicking the horizontal pool – riffle/glide patterns. In addition to restoring meander geometry, the vertical profile (bankfull channel width and bankfull channel depth) is also restored to reference conditions (New York City DEP, 2008c).

Figure 64: *Cross Vane Rock Structure, Greene County, NY.*

Cross vane rock structures direct the flow of a stream to the center of the channel (**Figure 64**). It also acts as a grade control, allowing the water to change in vertical height over a shorter than normal distance. The *Appendix* provides typical construction drawings of a cross vane structure designed by the Greene County SWCD (**Figure A.6**).

Another kind of stream restoration technique involves wetland restoration along stream banks. The Greene County SWCD has created wetlands in combination with stream restorations for the purpose of surface water detention. Another way to incorporate wetland creation as a BMP is with highway or road projects which stabilize adjacent stream banks. The Greene County SWCD has worked with the New York State Department of Transportation to implement combinations of bioengineering approaches with more traditional rock-based rip-rap methods.

One example of this approach is the use of a “pocket wetland (**Figure 65**).” Pocket wetlands are generally small in size and may be used in areas with little room between road infrastructure and streams. The pocket wetland is a small constructed riverine wetland which provides infiltration of surface water (**Figure 65**). This wetland restoration was combined with traditional rock-based rip-rap along a road corridor.

Figure 65: *Pocket Wetland, Greene County, NY.*

Stream restoration techniques may involve other "bioengineering" approaches, such as stabilizing stream banks with vegetative mats. NYCDEP and the SWCD of Delaware and Greene counties have used vegetation to armor and stabilize eroding stream banks. Examples include using dormant willow cuttings in making live fascines and stakes to be planted along stream banks (**Figure 66**) (New York City DEP, 2008c). With this BMP the vegetation within the fascines provides shoreline stabilization from in-stream waters and overland surface water runoff (**Figure 66**).

Figure 66: *Vegetative Bank Armoring, New York City Drinking Water Watershed* (New York City DEP, 2008b).

Vegetative buffers may also be applied at “zero order” streams or swales leading to headwater streams (**Figure 67**). Various trees, shrubs, and herbaceous plants may be planted along a swale; stormwater runoff is slowed down as it flows through the vegetative swale and sediments and pollutants are trapped by the vegetation.

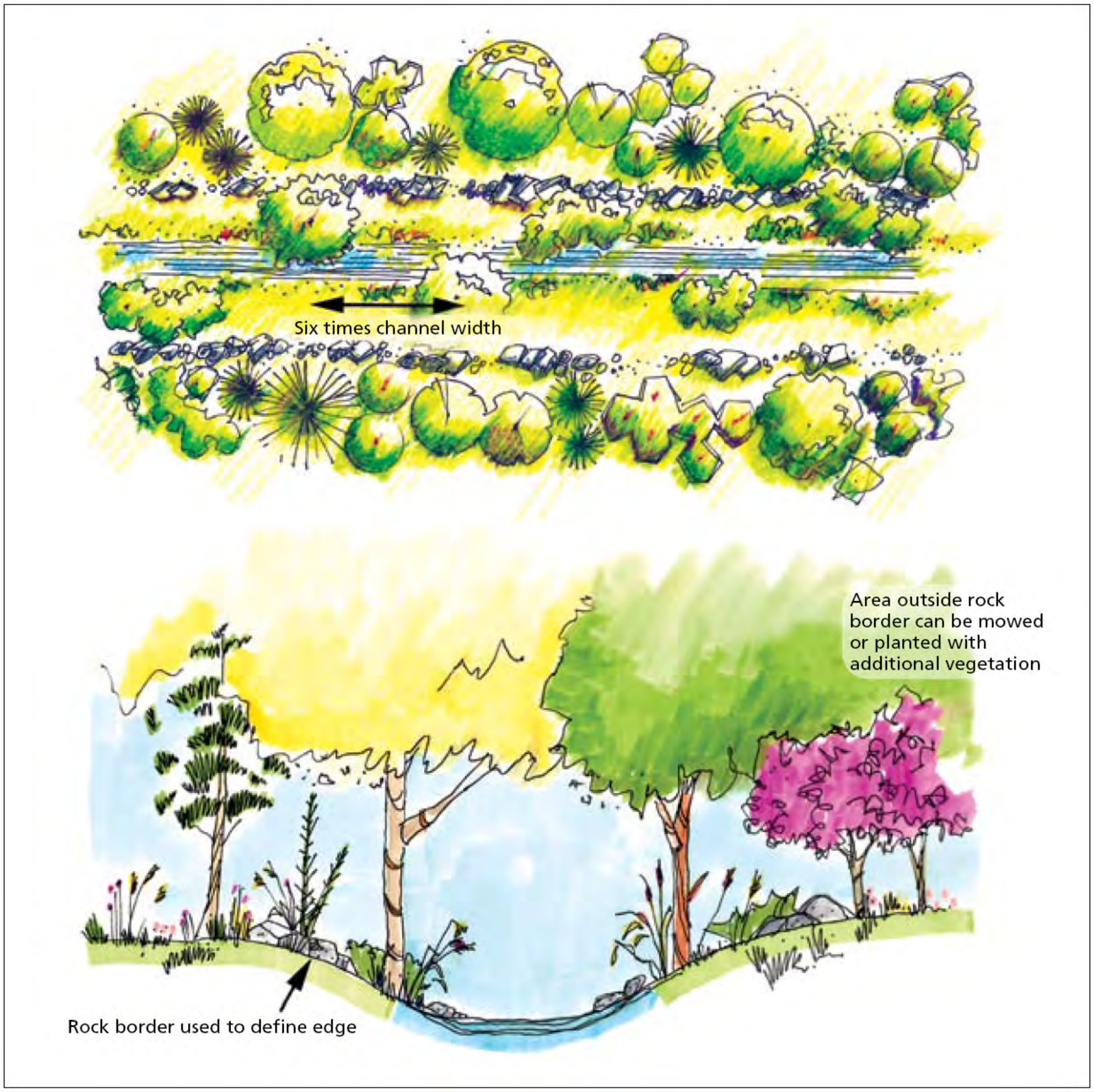

Figure 67: *Vegetative Swale* (Cappiella et al., 2006).

Another more structural method of stream restoration involves accommodating stream and road infrastructure needs. Many culverts within the Upper Delaware Basin do not adequately accommodate stream flows, especially under high flow conditions. These culverts need to be increased in size to allow certain large storm flows to pass through them (**Figure 68**). Also culverts need to be designed so they do not degrade the stream passage that they intersect. The bottom of culverts should be connected to the bottom of the stream channel so that stream incision or down-cutting of the channel does not occur. A culvert in Greene County (**Figure 68**) was constructed to accommodate larger volumes of stormwater than the old culvert. The culvert was also designed so that its bottom connected with the bottom of the stream channel, allowing for smooth stormwater conveyance and aquatic life passage.

Figure 68: *Resized Culvert, Greene County, NY.*

3.7.2 Urban Stormwater Infiltration Systems

In urbanized landscapes site characteristics such as concentrated impervious surfaces warrant the use of specific stormwater BMPs. Ordinary urban infrastructure, such as sidewalks, streets, highways, and parking lots have options for limiting their stormwater runoff impacts. Most of these BMPs involve ways of creating infiltration areas within the urban infrastructure. By allowing stormwater to be treated on site in urban areas, less stormwater runoff will flow into nearby headwater streams and wetlands. Various options for urban stormwater infiltration systems were analyzed (**Figures 69 – 72**).

Figure 69: *Typical Urban Planter.*

Vegetation planted in urban planters, located between sidewalks and roads absorb precipitation and surface water (**Figure 69**). The planters may be designed to have "curb-cuts" to allow stormwater runoff to infiltrate the vegetative islands. In addition to their stormwater management function, urban planters may also provide canopy cover for shade and aesthetic beauty to streetscapes.

Figure 70: *Parking Lot Pocket Wetland.*

Small pocket wetlands may be incorporated into parking lot designs to intercept stormwater runoff from both the parking lot and the surrounding landscape (**Figure 70**). Infiltration pipes or curb-cuts may be used in the parking lot design to allow surface water to enter the wetland. The wetland also provides aesthetic beauty not normally found in parking lot settings.

Figure 71: *Small Parking Lot Stormwater Retrofits* (Schueler et al., 2007).

Three different types of retrofits are illustrated: a) permeable pavers, b) dry vegetated swale, and c) a perimeter sand filter (**Figure 71**). On site stormwater infiltration increases when any of these BMPs are designed into an existing parking lot. The pavers are located in parking stales, where less car traffic (wear and tear) occurs. The dry swale is a simple feature that allows stormwater runoff from the parking lot to infiltrate into the ground. The swale also slows the velocity at which stormwater flows to nearby streams or other water bodies. The last BMP, the perimeter sand filter acts as a storm drain that detains surface water and lets it percolate through the sand medium. Water is adsorbed by the sand medium, which collects pollutants attached to water molecules. When water leaves the filter, the pollutants are left attached to the sand medium (Schueler et al., 2007).

Figure 72: *Highway Right of Way Vegetative Swale* (Schueler et al., 2007).

Highway right-of-ways usually have drainage ditches located within them. Many of roads within the Upper Delaware Basin have drainage ditches lined with rocks or other compacted impervious surfaces which expedite stormwater flow to streams. A conventional roadside ditch may be designed as a "vegetative swale," allowing stormwater runoff from roads to infiltrate into adjacent right of ways (**Figure 72**). Vegetation within the swale soaks up water, slows the velocity of flow, and traps associated sediment particles. Many roads within the Upper Delaware Basin are located close to streams, so any vegetative buffer between roads and streams may attenuate peak stormwater runoff and protect water quality.

3.7.3 Residential Scale BMPs

Stormwater BMPs may be applied at the site scale or at the residential subdivision scale. Sullivan County is expected to have continual increases in residential development, and the layout of such landscape features will have impacts on stormwater runoff. To conserve, preserve, and protect existing ecological services provided by headwater streams and wetlands new residential developments may choose appropriate stormwater BMPs. The main priorities of new residential developments in the watershed should be: 1) manage all additional stormwater runoff caused by construction activities, so that post-development runoff is equal or less than pre-construction runoff rates; 2) to preserve the physical integrity of headwater stream riparian buffers and associated floodplains; and 3) provide appropriate buffers and stormwater treatment trains adjacent to all wetland resources. Within these design guidelines developers may plan new subdivisions that accommodate urban growth needs and integrate existing ecological services of the landscape.

Most conventional residential subdivisions create more impervious surface cover than is necessary to accommodate human needs. Housing units and their associated parcels may be reduced in size allowing less land to be developed. This form of development is called clustered or compact development (**Figure 73**). It allows the same number of residential units built in a conventional development to be built on less land. The amount of impervious surface cover may be reduced by having less compacted soils within housing parcels and reduced length of roads and sidewalks (Center for Watershed Protection, 1995). Surface water runoff may be reduced by the decrease in impervious surface cover within the compact development scenario.

A given subdivision may be designed to have larger common open space areas within a compact development. Multiple uses may be derived from the common open spaces, such as stormwater detention and treatment, passive recreation, and wildlife habitat. Stream and wetland buffers may be incorporated into common open space areas, providing both protection of sensitive ecological areas and other residential community needs (**Figure 73**).

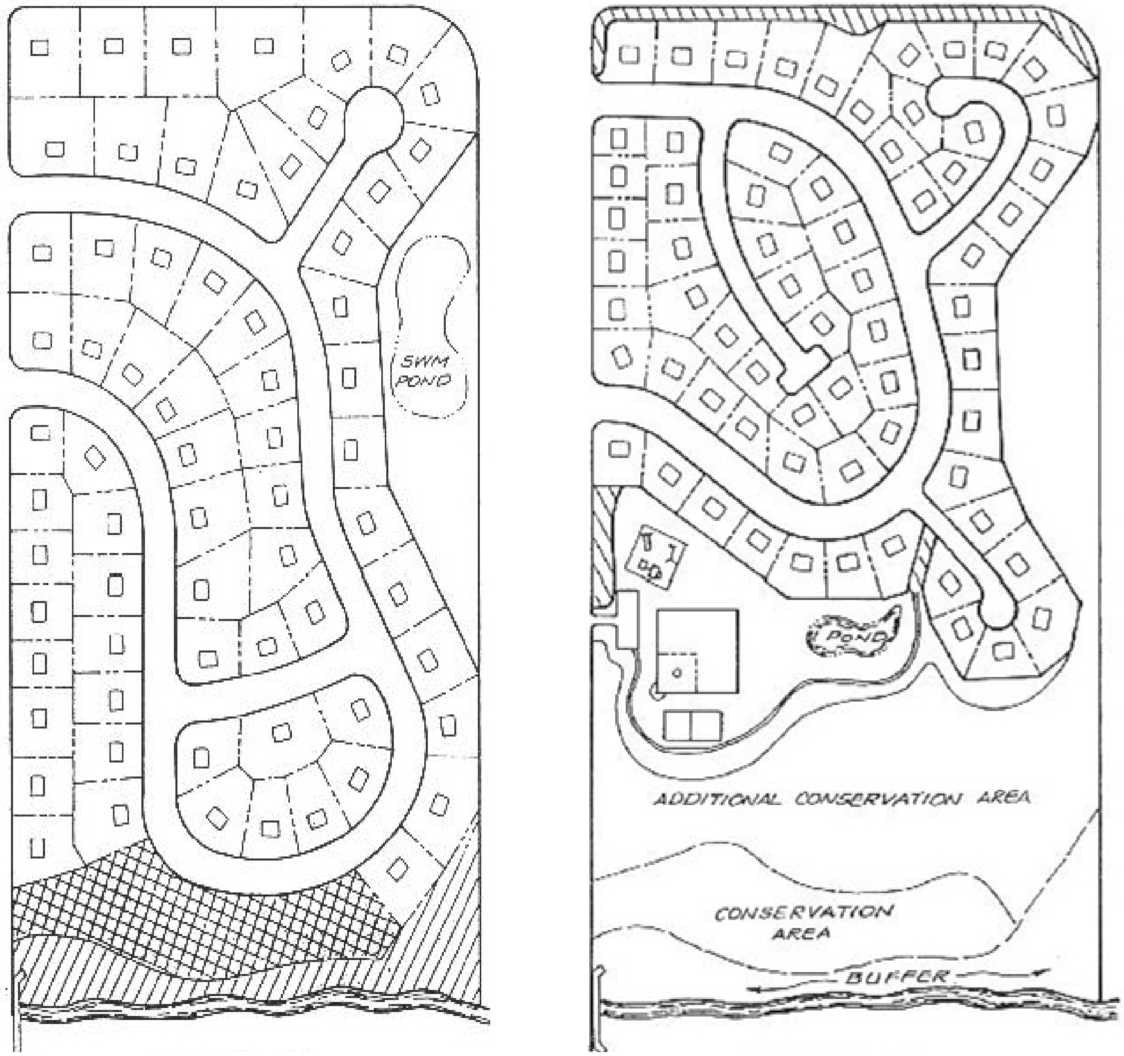

Figure 73: *Cluster/Compact Development* (Center for Watershed Protection, 1995).

Both development pattern templates provide protective measures for streams and wetlands with buffer areas and stormwater ponds. The design on the left has housing units with normal or non-compact units, but has reserved areas, such as wetlands and the floodplain off limits to development. The template on the right is a compact development with more stormwater BMPs incorporated into the overall plan. The compact design has more common open space areas which have multiple uses, from stormwater management, passive recreation, and wildlife habitat. Street length has also been reduced, decreasing impervious surface cover and the amount of time it takes to travel through the road network.

Within any given residential subdivision various stormwater BMPs may be implemented, from common open spaces to more site design based BMPs. Each housing parcel may incorporate BMPs into its landscape and building with rain gardens, a vegetative (green) roof, native landscaping, and porous pavement to name a few (**Figures 74 – 77**).

Figure 74: *Common Open Space Stormwater Detention Pond.*

Centralized stormwater detention ponds may be designed into areas designated as common open space (**Figure 74**). If designed properly a detention pond may have multiple functions, including stormwater detention and filtering, passive recreation, and wildlife habitat.

Figure 75: *Residential/Commercial Rain Garden Design* (Melin, 2008).

Each residential unit may manage its own stormwater runoff with the incorporation of a rain garden, which in essence is an ephemeral pond or wetland (**Figure 75**). They may be sized appropriately to manage all surface water from the residential parcel. Usually native plants accustomed to the site's climate are planted throughout the garden. Stormwater is detained within the garden usually only for a short time period, such as a day or two after a storm event. The rain garden also has multiple benefits, including stormwater management, aesthetic beauty, and wildlife habitat.


Figure 76: *Native Landscaping.*

Residential front and back yards may incorporate native plants for multiple purposes, such as increased stormwater infiltration and filtering; enhanced aesthetic beauty; wildlife habitat; and decreased maintenance needs (**Figure 76**). Use of native plants in a residential parcel allows for multiple ecological, hydrological, and aesthetic functions to passively occur all at once. Native plants have ecological adaptations which make them well suited to the climatic and physiographic characteristics of the region.

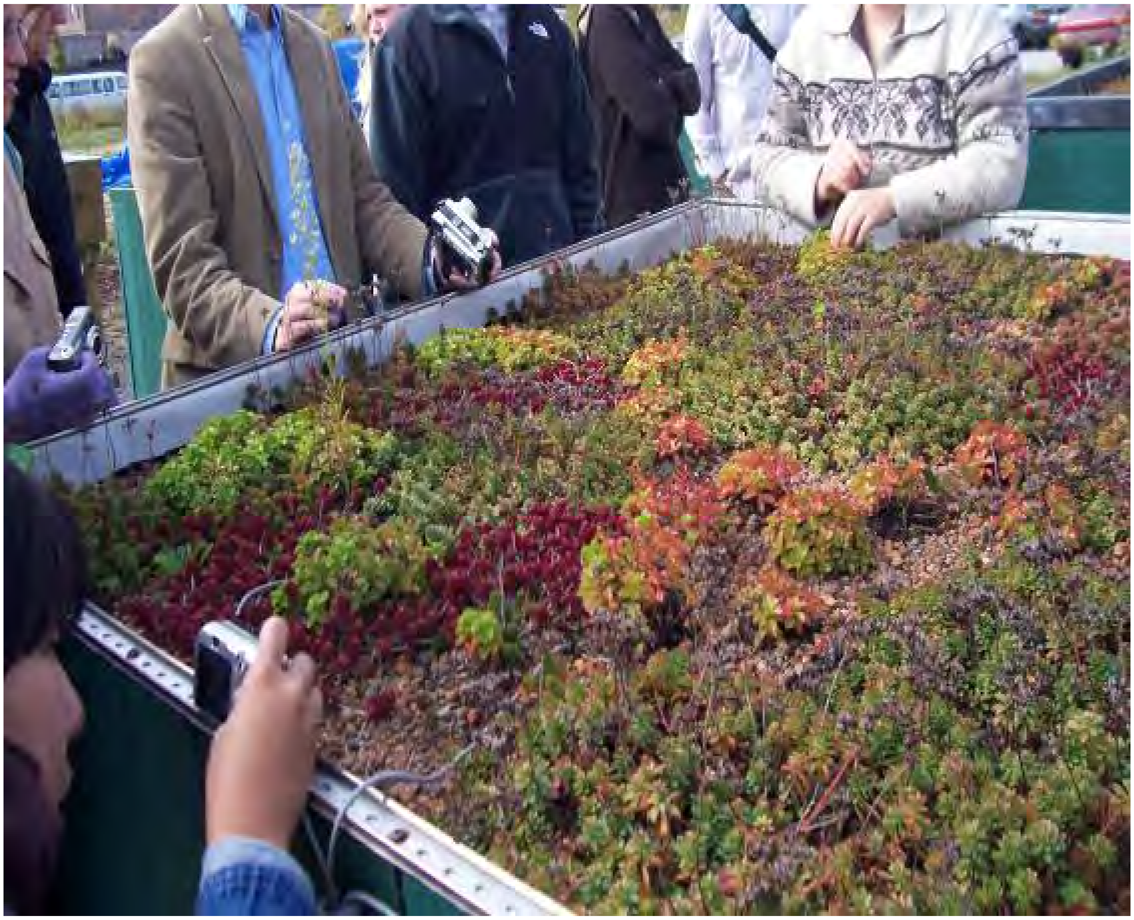

Figure 77: *Green Vegetative Roof.*

Residential and commercial buildings may manage stormwater runoff with vegetation growing on their roofs. Green roofs may be absorb and filter various amounts of stormwater runoff, based on the density and type of vegetation planted (**Figure 77**). The structural stability of any given roof limits the density of plants for green roof designs. Typically plants adapted to the climate, either native or non-native are used in green roof designs. Multiple benefits are derived from green roofs, including on site stormwater management, cooler temperatures of the building, aesthetic beauty, and wildlife habitat.

3.7.4 Costs and Funding of Stormwater BMPs

Once appropriate BMPs are selected for stormwater management needs, the economic costs of constructing BMPs should be evaluated. Constructing stormwater BMP retrofits within existing urban development areas has additional site constraints compared to undeveloped land (Schueler et al., 2007). In urban areas, existing infrastructure, such as roads, buildings, and existing stormwater infrastructure create constraints for constructing new stormwater retrofits. Retrofitting existing stormwater infrastructure with BMPs should enhance and protect ecological services of the watershed, especially from wetlands, streams, and forests (Schueler et al., 2007). Stormwater BMP retrofits should also have reasonable maintenance costs after construction (Schueler et al., 2007).

The median 2006 construction costs of various stormwater BMP retrofits were collected (**Table 27**). These stormwater BMP retrofits are not for existing wetlands or streams, but are for developed areas or other areas within a watershed. Most communities that invest in implementing stormwater BMP retrofits at the headwater catchment scale spread the costs over 5 – 10 years (Schueler et al., 2007). Other costs, such as maintenance of stormwater BMP retrofits also need to be considered. For addressing flood control, channel protection, and water quality protection needs and objectives, pond and wetland stormwater retrofits may be the most economically feasible solutions based on construction costs. BMPs may also cost less when they are constructed off of existing development sites (Schueler et al., 2007). Most headwater catchments in the Upper Delaware Basin have minimal existing urban development, which could allow opportunities for low cost BMPs in non-developed areas. Stormwater BMPs could be constructed most cost effectively in undeveloped areas upstream of existing urban developments within the watershed.

Table 27: Median 2006 Construction Costs of Stormwater BMP Retrofits (Schueler et al., 2007)

BMP Retrofit	**Cost (Dollars) / Ft^3 of Treated Stormwater**
Pond	$3
Rain Garden	$4

Table 27 (cont.)

BMP Retrofit	Cost (Dollars) / Ft^3 of Treated Stormwater
New Storage	$5
Large Bioretention Cell	$11
Infiltration	$15
Structural Sand Filter	$20
Impervious Cover Conversion	$20
Stormwater Planter	$27
Small Bioretention Cell	$30
Permeable Pavers	$120
Extensive Green Roof	$225

The NYCDEP currently funds a stormwater retrofit program which addresses existing stormwater runoff sources in the New York City municipal water supply reservoir basins (New York City DEP, 2008a). The BMPs funded by the NYCDEP are meant to solve existing erosion and/or pollution problems associated with stormwater runoff (New York City DEP, 2008a). In 1997 New York City funded $7.625 million dollars for the Stormwater Retrofit Program, which is administered by the Catskill Watershed Corporation (New York City DEP, 2008a). In 2003 the Stormwater Retrofit Program was extended through 2012 when the NYCDEP allocated $7.55 million dollars and contracted with the Catskill Watershed Corporation (CWC). The CWC funds three types of stormwater programs: 1) future stormwater program for new construction, 2) stormwater retrofit program to correct existing conditions, and 3) community stormwater infrastructure planning and assessment program (Catskill Watershed Corporation, 2005).

The CWC's Future Stormwater Program monetarily assists property owners who need to implement stormwater pollution prevention plans to mitigate disturbance of natural drainage areas (Catskill Watershed Corporation, 2005). The program covers eligible costs exceeding what a property owner would have to pay to meet federal and state stormwater standards (Catskill Watershed Corporation, 2005). For small businesses (less than 100 employees) the CWC covers 50 % of eligible costs and the remaining 50% may be funded by the NYCDEP (Catskill Watershed Corporation, 2005). For large businesses, institutions, and municipalities the CWC covers 100% of eligible costs. Individual homeowners and low-income housing providers may have 100% of the costs associated with implementing stormwater pollution prevention plans funded by applying for a separate program with the NYCDEP (Catskill Watershed Corporation, 2005).

The CWC's Stormwater Retrofit Grant Program provides funds to resolve water quality problems caused by erosion or substandard stormwater management existing before or on Jan. 21, 1997 (Catskill Watershed Corporation, 2005). The program is open to individual property owners, businesses, organizations, and municipalities for funding design, construction, implementation, and maintenance of stormwater BMPs (Catskill Watershed Corporation, 2005). The CWC covers 85% of eligible costs and applicants must pay the remaining 15% of the costs (Catskill Watershed Corporation, 2005).

The CWC's Community Stormwater Planning and Assessment Grant Program encourages villages, towns, and counties to conduct comprehensive assessments of their existing stormwater infrastructure (Catskill Watershed Corporation, 2005). The assessments should identify and evaluate existing stormwater infrastructure and identify and prioritize potential sites for BMP installations (Catskill Watershed Corporation, 2005). Creating a GIS database, mapping, and evaluating existing stormwater infrastructure is an example of a type of project the CWC's Community Stormwater Planning and Assessment Grant Program would cover (Catskill Watershed Corporation, 2005).

The NYCDEP also has a Stream Management Program which funds stream restoration and stream management plans to resolve stream bank and bed erosion, degraded water quality, flood hazard risks, and degraded fisheries habitat (New York City DEP, 2008d). New York City has committed approximately $31 million dollars for stream management within the New York City municipal water supply reservoir basins (New York City DEP, 2008d). An additional $5 million dollars for stream management has been secured by the NYCDEP with partnering federal and state agencies and non-governmental groups (New York City DEP, 2008d). The NYCDEP involves local organizations (Soil and Water Conservation Districts), communities, and landowners with developing stream management plans and restoration and protection projects in priority watershed sub-basins (New York City DEP, 2008d).

3.8 ECONOMIC VALUATION OF ECOLOGICAL FUNCTIONS

One way to examine the economic values of the ecological functions is to analyze the costs associated with the recent extreme flood events. Wetlands and headwater streams that provide flood attenuation during an extreme storm event may produce a net reduction in economic costs and damages. In addition the water quality protection function, filtering or cleansing of water, also provides a "net reduction of economic damages (Heimlich et al., 1998)." An adequate amount of functioning wetland and headwater stream resources may act as flood protection tools, utilities, or insurance for both public and private welfare. If ecological functions of these natural resources are below a certain threshold, such as equal to or greater than 11% impervious surface coverage of a headwater catchment, than human and environmental welfare may be at greater economic risk (Zielinski, 2002 and Farber et al., 2002).

Economic costs accrued from recent flood damages within the Upper Delaware Basin provide a picture of potentially avoidable costs via increased ecological functionality from wetland and headwater stream resources. Both Sullivan and Delaware counties experienced economic costs due to damages and losses caused by recent flood events within the Upper Delaware Basin. From the September 2004 (Hurricane Ivan) storm event, preliminary reports cited by a local newspaper (Times Herald Record) estimated flood damages in Sullivan County to have been $10 million (Brooks, 2005). These reports may or may have not taken into account all of the undocumented economic damages and losses caused by the flood.

A summary was created for the monetary costs caused by the floods recorded from the National Flood Insurance Program (NFIP) for Delaware and Sullivan counties (**Table 28**). Flood damage costs of public infrastructure, such as damaged roads were also analyzed (**Table 29**). Data for Delaware County was not available for public infrastructure, but Pike County, PA is also located in the Upper Delaware Basin.

The total federal monetary aid cost was approximately $52.1 million dollars (**Table 28**, **Table 29**). Note that both the NFIP and public infrastructure monetary aid analyses do not account for all of the costs associated with damages and losses caused (loss of life, water quality damages, and uninsured damages) by the storm events. The predicted monetary value of surface water detained by NWI wetlands from the W-PAWF may be related to the costs of constructing new stormwater storage retrofits capable of detaining the volume of stormwater detained by existing wetlands. Predicted construction costs of surface water detention provided by existing NWI wetlands for the rural and urban catchment (*see* section 3.4.2) were estimated (**Table 30**). For the 1-year, 24-hour prior wet conditions storm event the costs of surface water detention provided by NWI wetlands in the rural and urban catchment are below the total costs of **Tables 28 – 29** combined. For the 100-year, 24- hour, prior dry conditions storm event the predicted construction costs of surface water detention provided by NWI wetlands within the urban and rural catchments greatly exceed the combined federal aid costs.

Table 28: Upper Delaware Basin, National Flood Insurance Program (NFIP) Claims in Delaware and Sullivan Counties NY (2004-2006)
(Delaware River Basin Commission, 2007c)

Date/Event	County	Total ($) Claims
Sept. 2004 Hurricane Ivan	Delaware	1,094,442
	Sullivan	1,298,775
April 2005	Delaware	891,654
	Sullivan	1,435,457
June 2006	Delaware	10,835,288
	Sullivan	7,544,181
Total Cost	**$ 23,099,797.00**	

Table 29: Upper Delaware Basin, Federal Money for Repairing Public Infrastructure: Pike and Sullivan Counties NY (2004-2007)
(Bosch, 2008)

Date	County	Total ($) Federal Aid
2004	Pike	354,000
	Sullivan	13,100,000
2005	Pike	328,000
	Sullivan	5,200,000
2006	Pike	111,000
	Sullivan	9,700,000
2007	Pike	None
	Sullivan	220,000
Total Cost	**$29,013,000.00**	

Table 30: Construction Costs of Existing NWI Wetlands: Urban and Rural Headwater Catchment

Catchment Type	**Storm Event**	**Existing Surface Water Detention** (Cubic feet)	**Cost of New Stormwater Storage Retrofits** (Dollars)
Urban	1-year, 24-hour, prior wet conditions	3,261,772.84	$16,308,864
	100-year, 24-hour, prior dry conditions	30,289,446.44	$151,447,232
Rural	1-year, 24-hour, prior wet conditions	2,532,142.84	$12,660,714
	100-year, 24-hour, prior dry conditions	23,510,639.14	$117,553,196

Note: the storm events are based on the storm events associated with the NYCDEP reference wetlands stormwater monitoring data used for this study. Based on values from **Table 27** and **Figures 44** and **47**.

With increased wetland surface coverage and more intact and unmodified headwater stream channels and riparian corridors it is likely that a significant portion of economic costs associated with flood damages and losses could be reduced. Any cost reductions from flood damages and losses (loss of property, loss of life, and damaged public infrastructure) will benefit property owners, municipalities, and insurance providers. Monetary aid given for flood repairs could be allocated to address the need for additional stormwater BMPs within the watershed, focusing on flood management and water quality protection functions of headwater streams and wetlands.

Currently substantial monetary aid given for flood repairs and maintenance projects focuses on repairing sites to their previous conditions. The actual flood repair and maintenance methods used may not implement stormwater BMPs that address long term flood management and water quality protection needs of the watershed. Stormwater BMPs selected in this study should be evaluated and considered for monetary aid for flood repair and maintenance projects. Site assessment methods, stormwater BMP designs, and associated costs need to be readily accessible to landowners and local governmental agencies considering flood repair and maintenance projects within the watershed. The stormwater programs funded by the NYCDEP could be supplemented by federal or state flood management funds. Currently the NYCDEP stormwater programs may not have enough money to address flood management and water quality protection needs associated with the recent past intense storm events.

3.9 INTEGRATION AND APPLICATION OF ASSESSMENTS, ALTERNATIVE FUTURES, AND BMPS

Various combinations of using the assessments, alternative futures, and BMPs highlighted in this study may be used for proposing flood management and water quality protection solutions for the watershed. This section outlines the general assessment, planning, and design phases and associated resources which may be employed for protecting wetland and headwater stream resources. A general outline of integrating the assessment, planning, and design phases for headwater catchments was created (**Table 31**). More specific planning strategies for this study focused on flood management and water quality protection are outlined for wetlands, streams, and smart growth urban development (**Tables 32 – 34**).

Table 31: Integrative Assessment, Planning, and Design Process
(Schueler et al., 2007)

Phase	**Process**
Management Goals and Objectives	Set stormwater management goals and objectives that meet client and stakeholder needs. Figure out who is in charge of setting county or municipal stormwater management plans.
Computer-Based Assessments	Assemble and utilize readily available GIS-based resources. Create base-maps of the project area and associated watershed resources. Assess the need for additional functionality from existing stormwater management infrastructure.
Field-Based Assessments	Use base-maps and other information gained from the computer-based assessments to indentify the feasibility of stormwater management site design options.
BMP Selection and Evaluation	Develop and evaluate BMP conceptual designs which address management needs; may be easily adapted to site constraints; and are economically feasible.

Table 32: Wetland Assessment, Planning, and Design

Phase	Process	Resources
Computer-Based Assessments	Watershed-based preliminary assessment of wetland functions (W-PAWF): predicting functionality of wetlands.	NWI wetlands, topography, soils, aerial photography, stream networks, and watershed boundary
	TR-55 and TR-20 stormwater runoff models: assessing stormwater runoff for desired storm event types.	Total NWI wetlands surface area, land-cover types, soils, stream network, drainage area, and county precipitation rates
	Surface water storage capacity of wetlands: applying empirical stormwater records to all NWI wetlands within a drainage area.	Stormwater monitoring data from reference wetlands and TR-55 and TR-20 model results
	Impervious surface model: assessing predicted vulnerability of wetland resources to predicted hydrologic modifications	Impervious surface cover and headwater catchment boundaries
	SLEUTH urban growth model: assessing how future urban development will impact existing wetland resources.	Existing and futures predicted impervious surface cover layers and NWI and NYSDEC wetlands data
Field Assessments	Wetland delineations and detailed site analyses.	GIS base-maps from computer-based assessments
BMP Selection and Evaluation	Based on probability of addressing assessment results, management goals and objectives, and being cost-effective.	Wetland and pond BMP design templates

Table 33: Stream Assessment, Planning, and Design

Phase	Process	Resources
Computer-Based Assessments	Headwater stream network delineation: compile all available GIS-based stream network data.	NYCDEP, NHDPlus, and NHD high resolution stream datasets and watershed boundary
	Assessment of existing streamside conditions: use of streamside health model methodology.	National Land Cover Data, headwater stream network, and catchment boundaries
	Impervious surface model: assessing predicted vulnerability of stream resources to predicted hydrologic characteristics.	Impervious surface cover and headwater catchment boundaries
	SLEUTH urban growth model: assessing how future urban development will impact existing stream corridors.	Existing and futures predicted impervious surface cover layers and headwater stream network

Table 33 (cont.)

Phase	Process	Resources
Field Assessments	Stream corridor assessments	GIS base-maps from computer-based assessments
BMP Selection and Evaluation	Based on probability of addressing assessment results, management goals and objectives, and being cost-effective.	Vegetative swales and buffers, natural channel design, and pond design templates

Table 34: Smart Growth Urban Development Assessment, Planning, and Design

Phase	Process	Resources
Computer-Based Assessments	Impervious surface model: assessing predicted vulnerability of wetland resources to predicted hydrologic modifications	Impervious surface cover and headwater catchment boundaries
	SLEUTH urban growth model: assessing how future urban development spatial patterns may occur.	Existing and future predicted impervious surface cover data layers
	TR-55 and TR-20 models: assessing stormwater runoff for desired storm event types under existing and proposed land-cover scenarios.	Total NWI wetlands surface area, land-cover types, soils, stream network, drainage area, and county precipitation rates
Field Assessments	Site analysis of probable development areas.	GIS base-maps from computer-based assessments
BMP Selection and Evaluation	Based on probability of addressing assessment results, management goals and objectives, and being cost-effective.	Cluster/compact development patterns, rain gardens, bioretention basins, native landscaping BMP design templates

The various strategies for integrating the assessment, planning, and design phases for headwater catchments show similarities and differences for managing wetlands, headwater streams, and urban development. To highlight how some of these strategies may actually be implemented, different computer-based assessments and possible BMPs for the Stamford-Hobart headwater catchment were explored in a case study.

CHAPTER 4
HEADWATER CATCHMENT CASE STUDY

4.1 WETLAND AND STREAM ASSESSMENTS, PLANNING, AND DESIGN: STAMFORD- HOBART HEADWATER CATCHMENT

This section illustrates the use of the assessment methodologies in the development of a management plan for the Stamford-Hobart headwater catchment. The steps followed in this case study mirror the ones used for the Upper Delaware Basin study. After reviewing this case study the reader should understand how to apply the assessments, planning, and design components to other headwater catchments within the watershed.

4.2 EXISTING WETLAND RESOURCES

The Stamford-Hobart headwater catchment has a variety of NWI wetland types (**Table 35**). The total NWI wetland acreage for the catchment is 222.1 acres or 3% of the total land area of the catchment (**Figure 78**).

Table 35: Upper Delaware Basin Wetland Types (NWI, 1997)

Wetland Type	**Total (acres)**	**Percent of Total Wetlands**
Freshwater Emergent Wetland	96.6	43%
Freshwater Forested/Shrub Wetland	72.9	33%
Freshwater Pond	52.2	24%
Riverine	.3	0%
Total Wetlands	222.1	100%

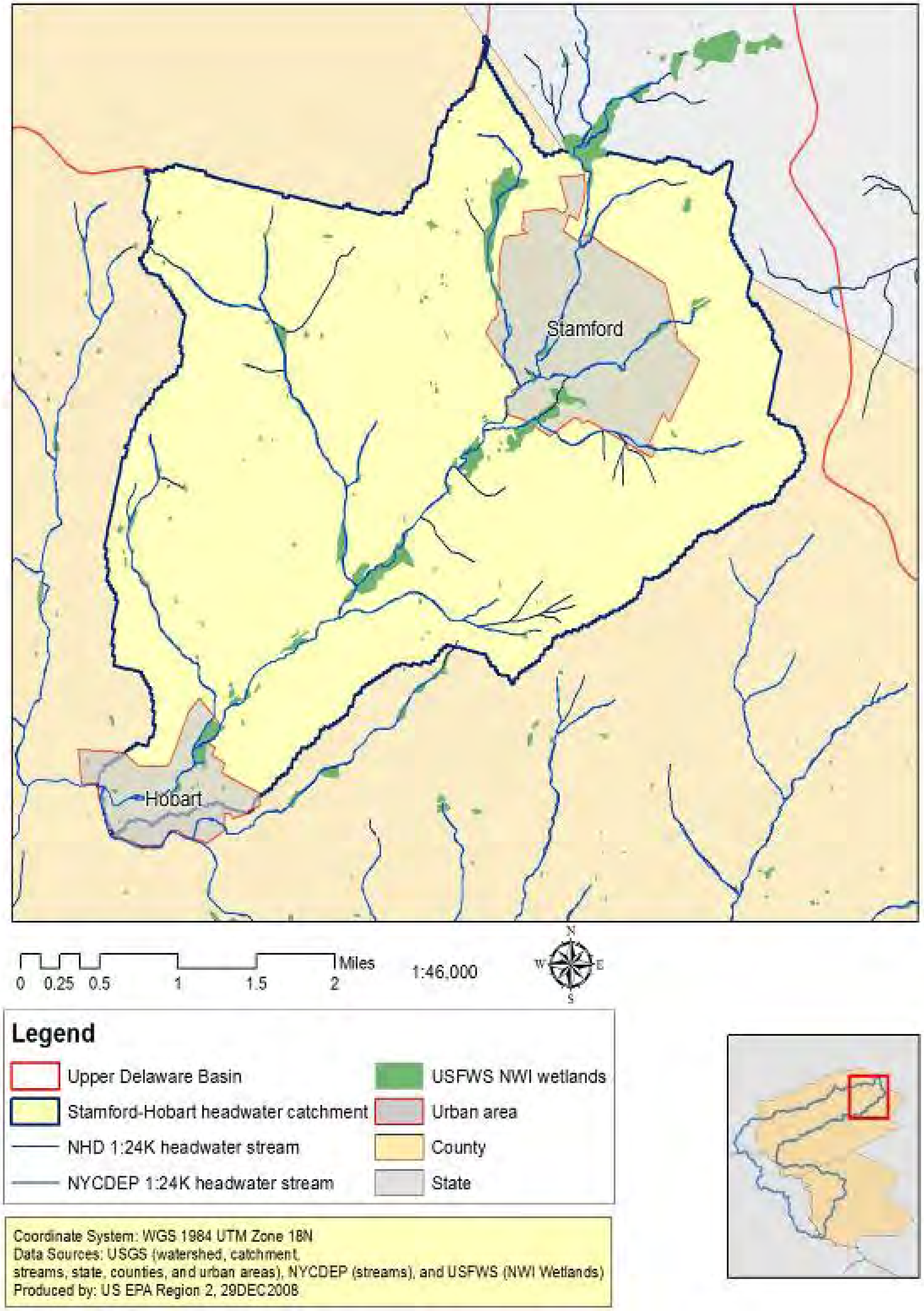

Figure 78: *Stamford-Hobart Headwater Catchment NWI Wetlands.*

4.3 HEADWATER STREAM DELINEATION

To delineate the headwater streams within the Stamford-Hobart headwater catchment three GIS datasets were used: NHDPlus 1:100 K, NHD high resolution 1:24 K, and the NYCDEP 1:24 K stream datasets. At the 1:100 K resolution the catchment only has one first order stream, estimated to be 5.4 miles (**Figure 79**, **Table 36**). When the resolution is increased to 1:24 K the headwater stream network linear distance increases 346% or to 24.1 miles (**Figure 80**, **Table 37**). The NHDPlus dataset distinguishes headwater streams by first and second order streams, but the NHD high resolution dataset does not. All NHD high resolution stream reaches within the NHDPlus headwater catchments are assumed to be headwater streams.

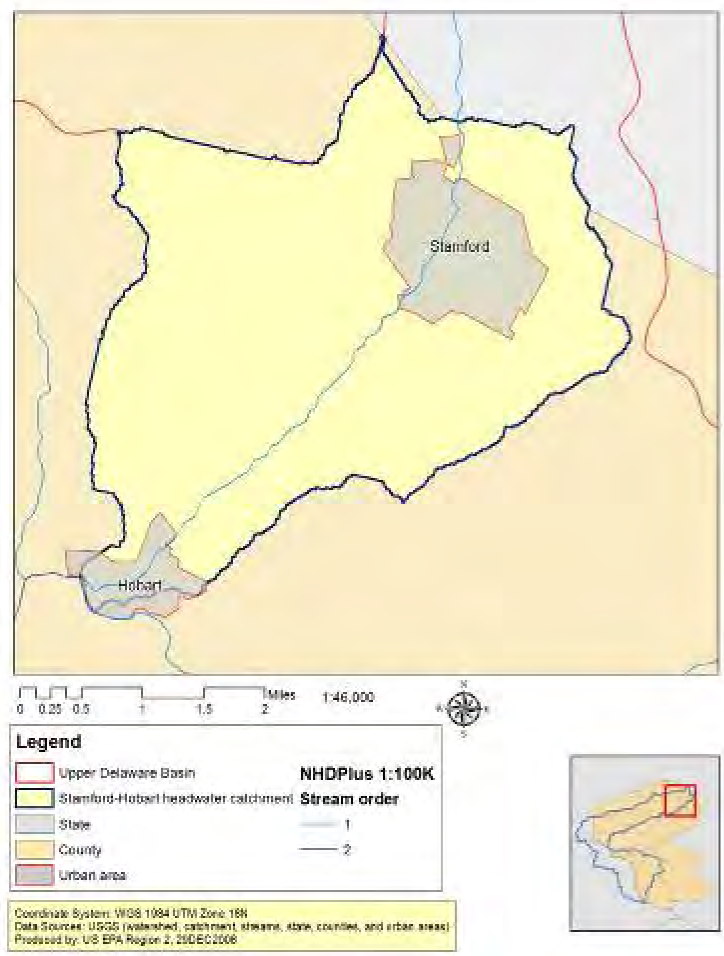

Figure 79: *Stamford-Hobart Headwater Catchment 1:100 K Headwater Stream Network, Delaware County, NY.*

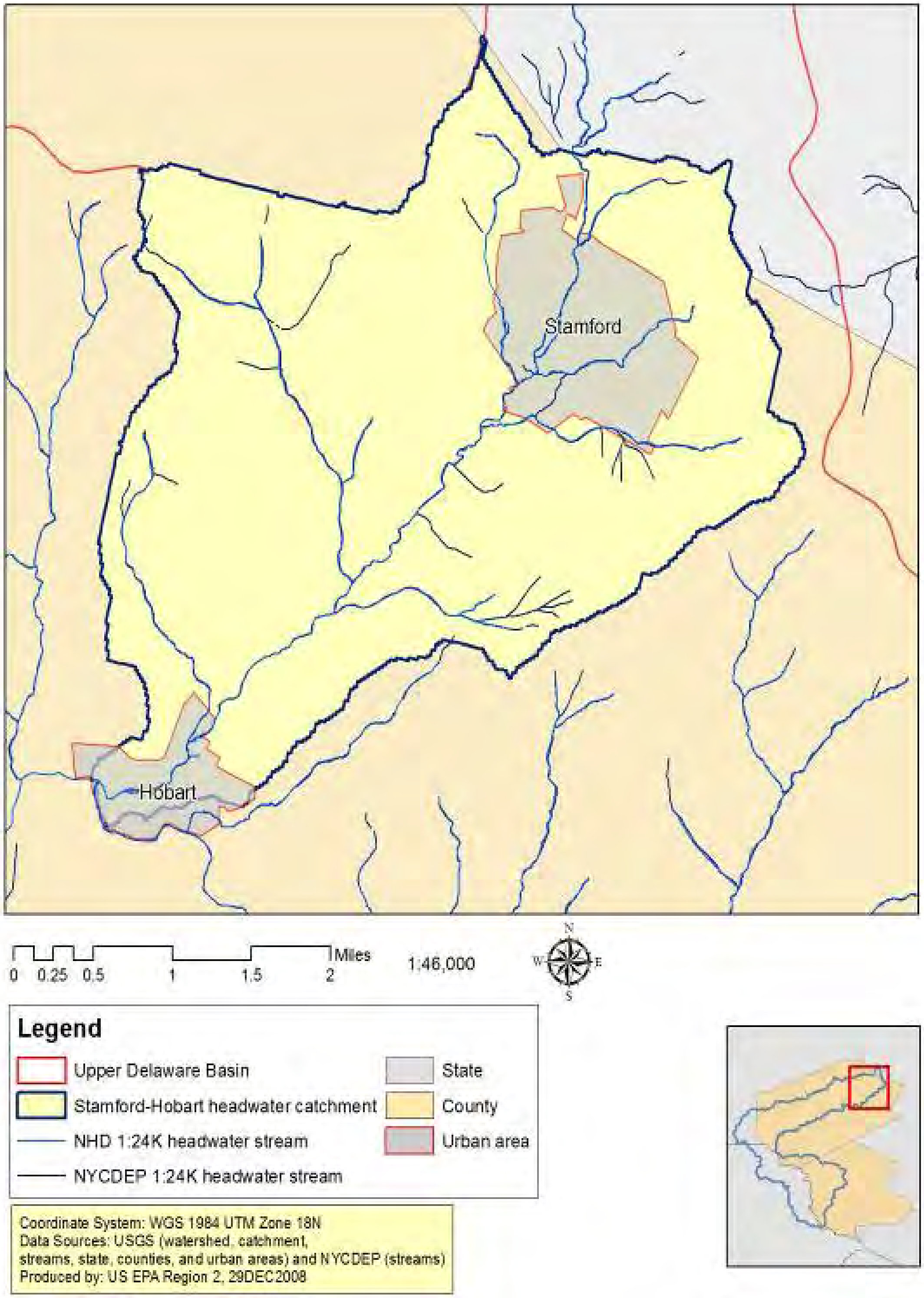

Figure 80: *Stamford-Hobart Headwater Catchment 1:24 K Headwater Stream Network, Delaware County, NY.*

Table 36: Stream Length Statistics: Stamford-Hobart Headwater Catchment (NHDPlus medium resolution (1:100K) flowlines)

Water Boundary	**Stream Category**	**Total Length of Stream System** (miles)	**Percent of Total Stream System** (miles)
Stamford-Hobart headwater catchment	First order streams	5.4	100%
	Second order streams	0	0
	Summation of first and second order streams	5.4	100%

Table 37: Stream Length Statistics: Stamford-Hobart Headwater Catchment (1:24K flowlines)

Water Boundary	**Stream Category**	**Total Length of Stream System** (miles)	**Percent of Total Stream System** (miles)
Stamford-Hobart headwater catchment	NHD 1:24 K headwater stream	20.4	85%
	NYCDEP headwater stream (additional miles to NHD 1:24K network)	3.7	15%
	Summation of NHD and NYCDEP streams	24.1	100%

Note: NHD high resolution data does not distinguish first and second order streams.

Comparisons between the headwater stream networks from the 1:100 K and 1:24 K datasets reveal that higher resolution data greatly increases total stream network length, from 5.4 miles to 24.1 miles. It is evident that many headwater stream reaches intersect the urban boundaries of Stamford and Hobart (**Figure 80**).

4.4 HYDROLOGIC ANALYSES

4.4.1 USGS Stream Gauge Data

The annual peak stream flow measurements (maximum daily average) of the USGS stream gauge USGS 01421610 West Branch Delaware River at Hobart, NY (drainage area of 15.5 mi^2 (Brooks, 2005)) from 2000 until 2007 were identified (**Figure 81**). In 2004 the peak flow of greatest recorded magnitude (738 ft^3/sec) occurred and was associated with remnants of Hurricane Ivan.

Since this stream gauge only has seven years of recorded peak stream flow events, recurrence intervals of the flow events cannot be accurately determined. Continued recording of peak stream flow events at this stream gauge will allow for accurate recurrence intervals to be calculated in the future.

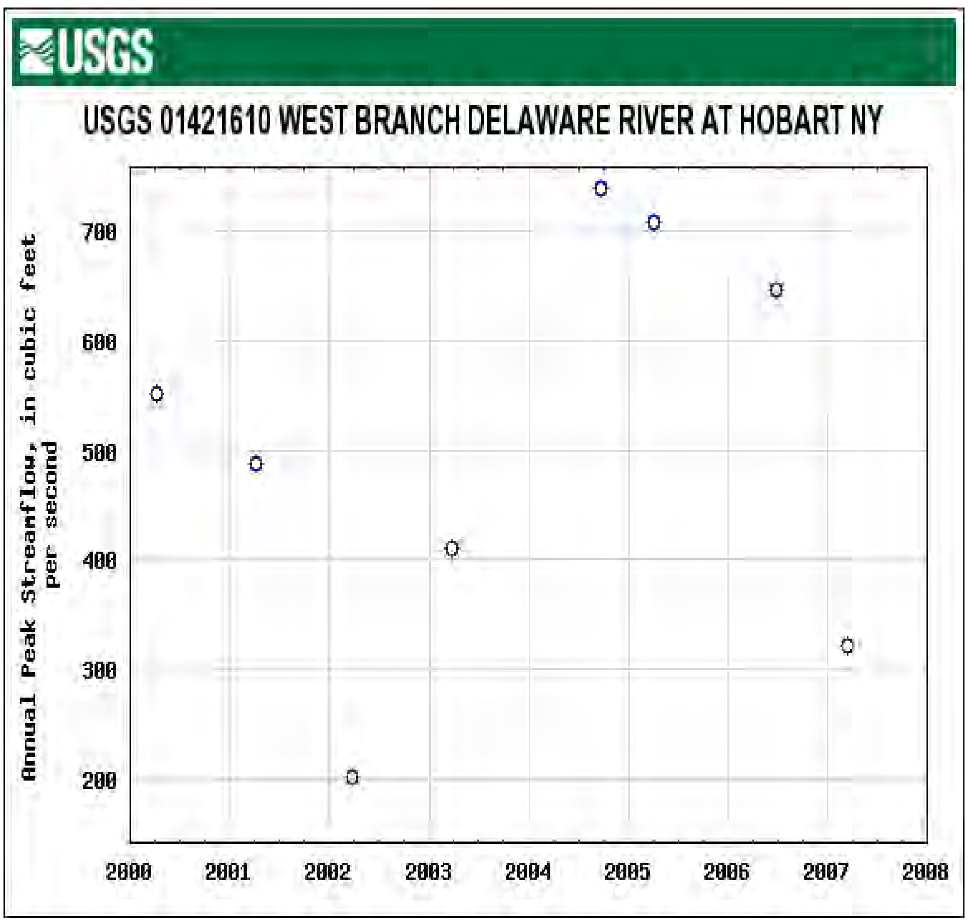

Figure 81: *USGS 01421610 West Branch Delaware River at Hobart, NY*: peak annual stream flow at Hobart, NY (USGS, 2008).

4.4.2 Impervious Surface Model: Land Cover Analysis

The National Land Cover Data (NLCD) 2001 was used for the impervious surface model analysis (**Table 38**, **Figure 82**). Forest cover is the most dominant land-cover type within the catchment, followed closely by agriculture. This assessment made it clear that urban development is currently not a large portion of land-cover types within the catchment (only 11%). The majority of the developed areas are classified as “developed open space,” which has less impervious surface than low, medium, and high intensity developments.

Table 38: National Land Cover 2001 Statistics: Stamford-Hobart Headwater Catchment

Land-Cover Type	**Acres**	**% of Total Catchment Area**
Open Water	17.4	0
Developed, Open Space	575.4	8
Developed, Low Intensity	115.2	2
Developed, Medium Intensity	44.0	1
Developed, High Intensity	8.3	0
Deciduous Forest	3,285.1	43
Evergreen Forest	200.2	3
Mixed Forest	285.1	4
Scrub/Shrub	15.9	0
Pasture/Hay	2,122.8	28
Cultivated Crops	647.5	8
Woody Wetlands	219.9	3
Emergent Herbaceous Wetlands	12.9	0
Grassland/Herbaceous	31.1	0

Note: because of significant digits some of the land-cover types are labeled as having zero percent cover within the catchment.

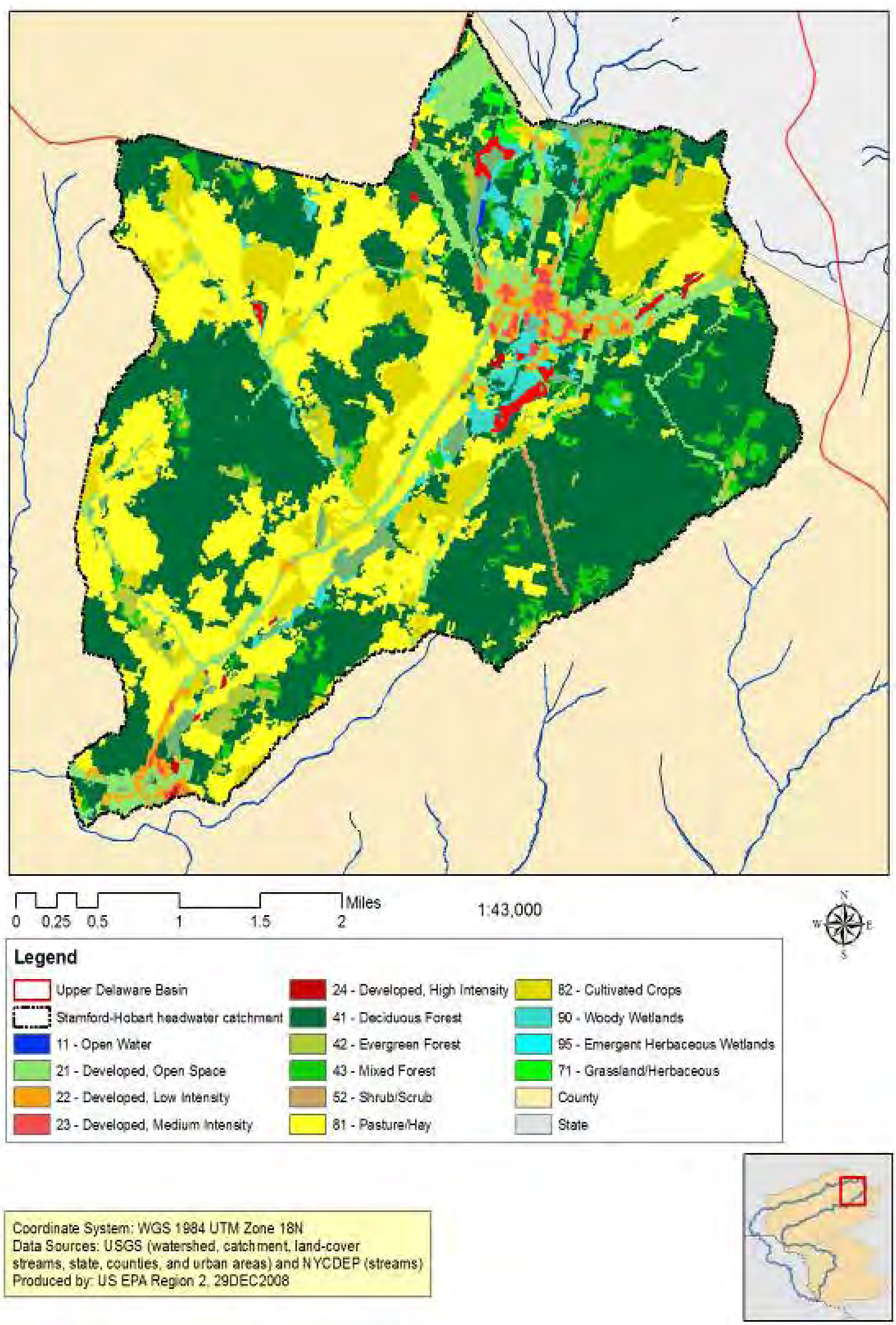

Figure 82: *National Land Cover Data 2001: Stamford-Hobart Headwater Catchment.*

The "impervious surface model (Zielinski, 2002)" was applied to the Stamford-Hobart headwater catchment. The impervious surface area of the catchment is 1% (**Figure 31**), which is well below the 11% impervious threshold, demarcating good to fair water quality characteristics and stable stream channel geometry (Zielinski, 2002). The total area with 100% impervious surface within the Stamford-Hobart headwater catchment was 101.7 acres. Total acres within the Stamford-Hobart headwater catchment was 7,563.8 acres (11.8 sq. miles). Stream quality of the Stamford-Hobart headwater catchment is predicted to be good. This includes good water quality, excellent habitat quality, diverse insect and fish communities, and stable stream channels (Zielinski, 2002).

As the Stamford-Hobart catchment approaches the 11% impervious threshold, it should be properly managed for future increases in impervious surface cover. Stormwater BMPs should be evaluated and instituted to maintain and protect stream resources in this headwater catchment.

4.4.3 TR-55 and TR-20 Analyses (Stormwater Runoff)

The urban catchment used for the TR-55 analyses from the results section was the Stamford-Hobart headwater catchment (**Table 39**, **Figure 83**). The New York State Stormwater Design Manual recommends detaining overbank flood waters for 10-year, 24-hour storm events (New York State DEC, 2003). For the Stamford-Hobart headwater catchment the predicted peak flow event for a 10-year, 24-hour storm is 2,813.31 ft^3/sec.

Table 39: TR-55 Model Results: Existing Conditions for Stamford-Hobart Headwater Catchment

NHDPlus Headwater Basin	**Context**	**Drainage Area** (mi^2)	**1-Year Peak Flow Event** (CFS) *(CFS/mi^2)	**10-Year Peak Flow Event** (CFS) *(CFS/mi^2)	**25-Year Peak Flow Event** (CFS) *(CFS/mi^2)
Stamford-Hobart	Urban	11.75	737.61 *62.78	2,813.31 *239.43	3,435.09 *292.35

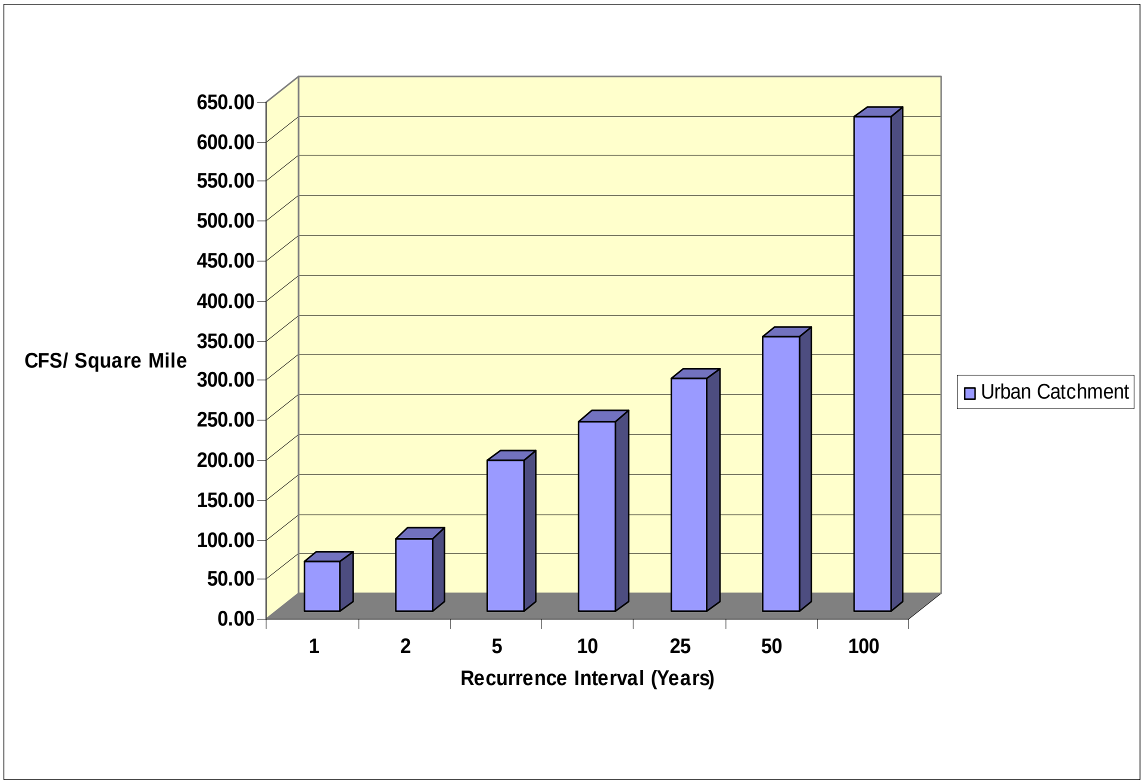

Figure 83: *TR-55 Model 24-Hour Peak Discharge Rates per Square Mile: Stamford-Hobart Headwater Catchment.* Note: the catchment size is 11.8 sq. miles.

4.5 FUNCTIONAL ASSESSMENTS

4.5.1 Watershed-Based Preliminary Assessment of Wetland Functions

The W-PAWF from the Upper Delaware Basin was re-assessed for the Stamford-Hobart headwater catchment. Of all of the NWI wetlands within the Stamford-Hobart headwater catchment, 100% of them were predicted to perform at least one of the ecological functions of interest. Many of the assessed NWI wetlands were found to perform more than one predicted function of interest (**Figure 84**, **Table 40**). The two most common wetland functions found among the wetland acres were sediment retention and nutrient transformation. GIS-based maps of the surface water detention and sediment retention functions were created from the W-PAWF (**Figures 85 – 86**).

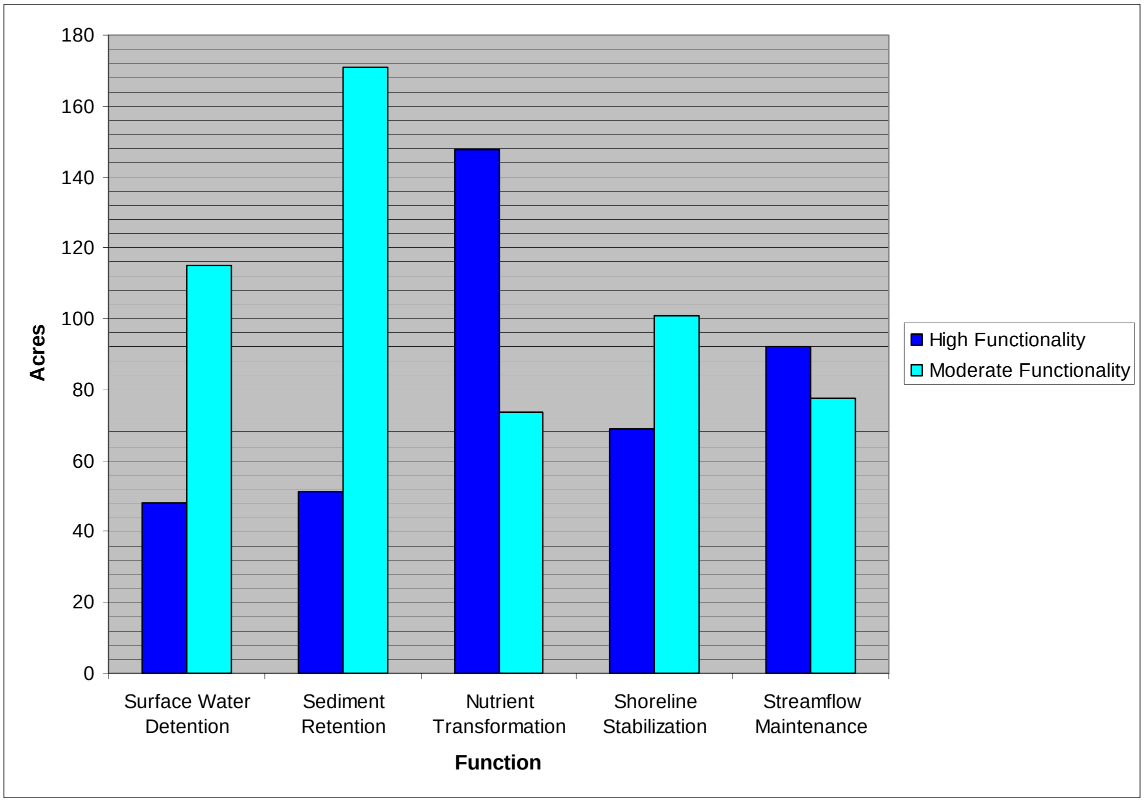

Figure 84: *Predicted Functionality for Wetlands within the Stamford-Hobart Headwater Catchment, by Acreage.* Based on the results from the Watershed-Based Preliminary Assessment of Wetland Functions (W-PAWF).

Table 40: Comparison of Predicted Functionality for Wetlands within the Stamford-Hobart Headwater Catchment
(Based on the results from the Watershed-Based Preliminary Assessment of Wetland Functions (W-PAWF).)

Ecologic Function	**High** (Acres)	**% of Total NWI Wetlands** (High Values)	**Moderate** (Acres)	**% of Total NWI Wetlands** (Moderate Values)
Surface Water Detention	47.9	22%	115.2	52%
Sediment Retention	51.0	23%	170.8	77%
Nutrient Transformation	147.7	67%	73.8	33%
Shoreline Stabilization	69.0	31%	100.9	45%
Streamflow Maintenance	92.3	42%	77.6	35%

Note: The Stamford-Hobart headwater catchment has a total of 222.1 acres of NWI wetlands.

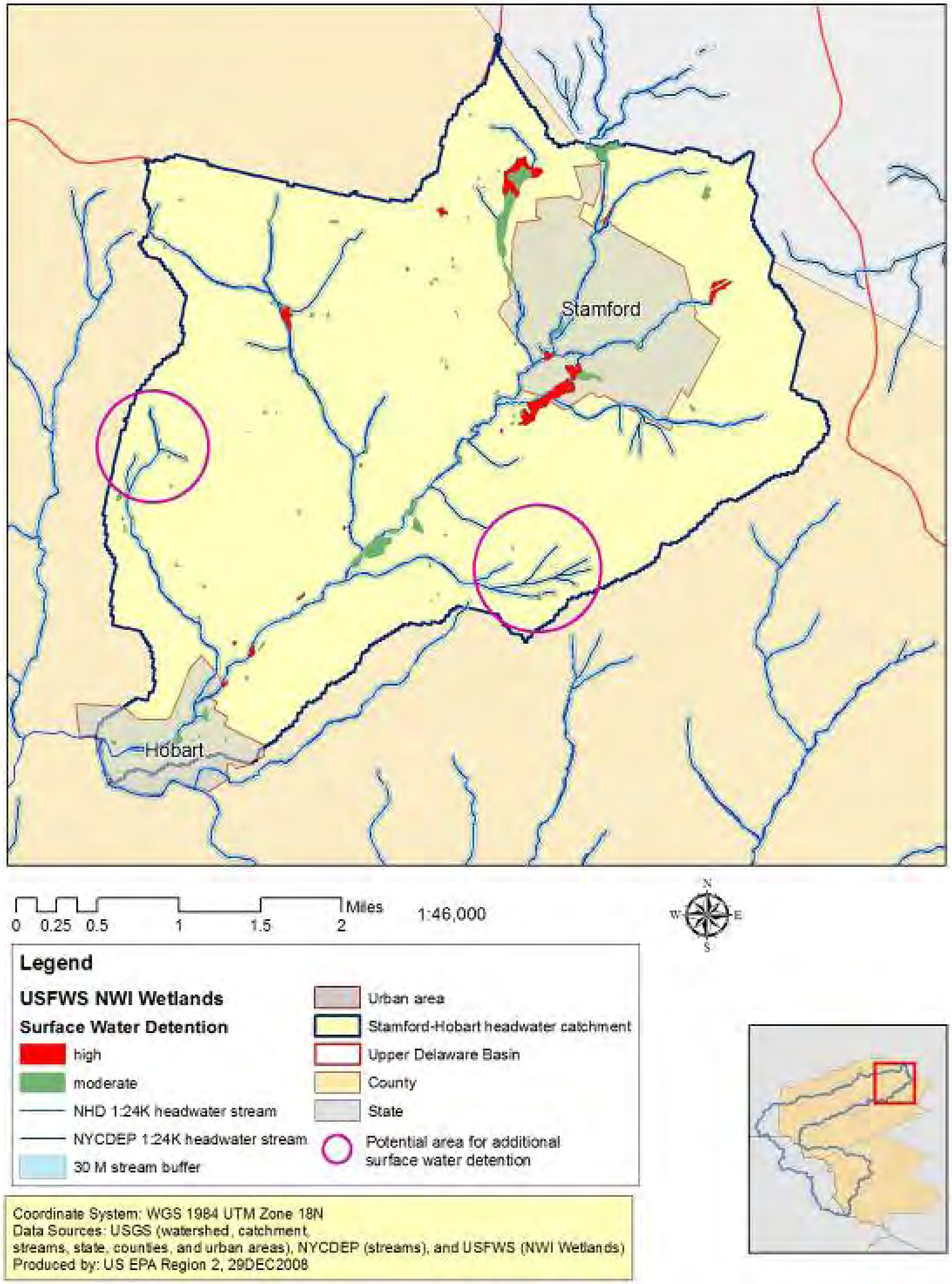

Figure 85: *Stamford-Hobart Headwater Catchment: Predicted Surface Water Detention Functionality of NWI Wetlands, Delaware County, NY.*

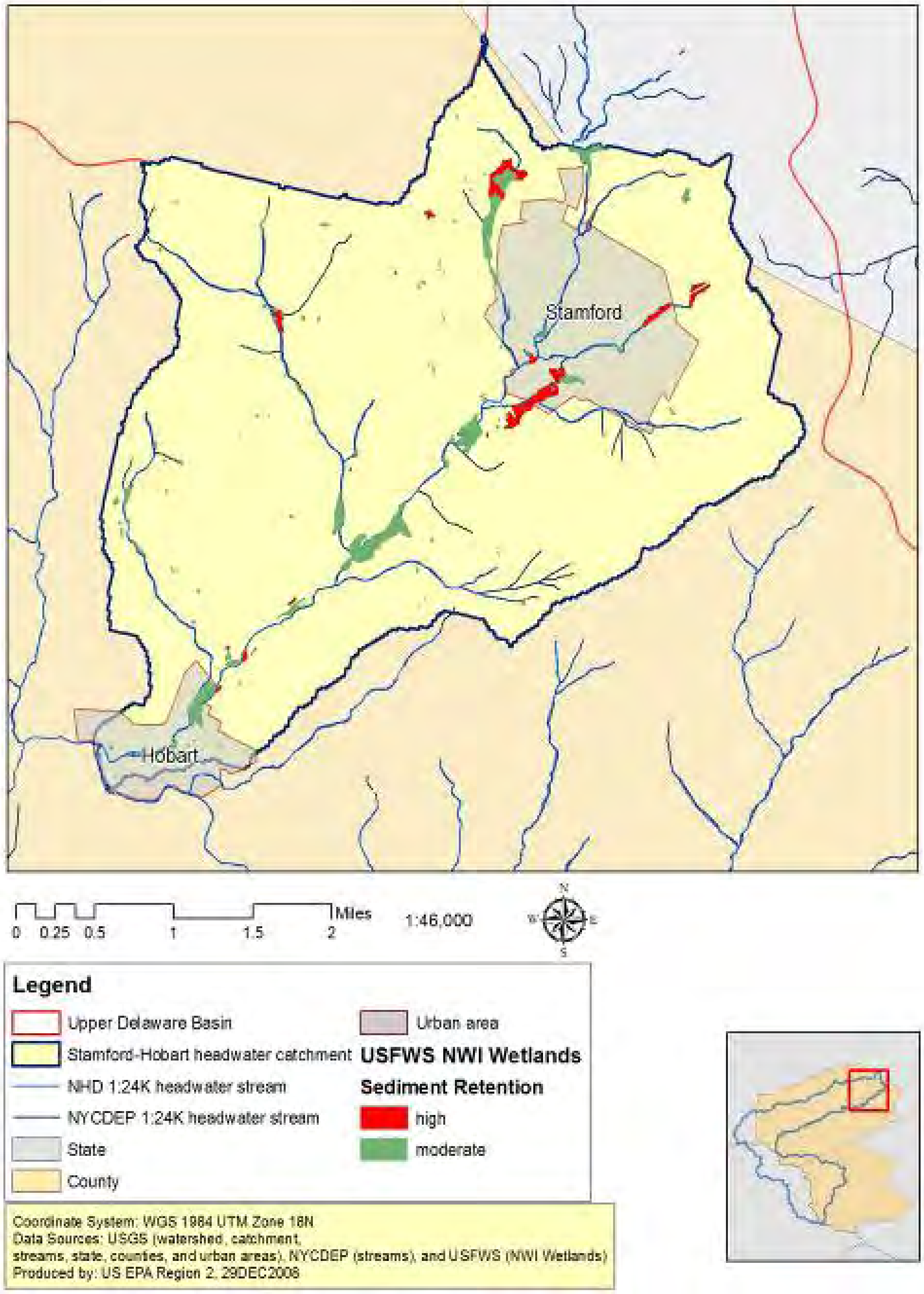

Figure 86: *Stamford-Hobart Headwater Catchment: Predicted Sediment Retention Functionality of NWI Wetlands, Delaware County, NY.*

4.5.2 Streamside Health Model: Stamford-Hobart Headwater Catchment

The catchment is composed of 20.4 miles of NHD 1:24 K headwater stream miles. The overall conditions of the streamside corridors based on the Streamside Health Model are: 62.7% excellent, 21.1% fair, 11.9% poor, and 4.2% very poor (**Figure 87**).

Approximately 45.4% of the 30 m riparian corridors within the catchment could be prioritized for field assessment and possible mitigation.

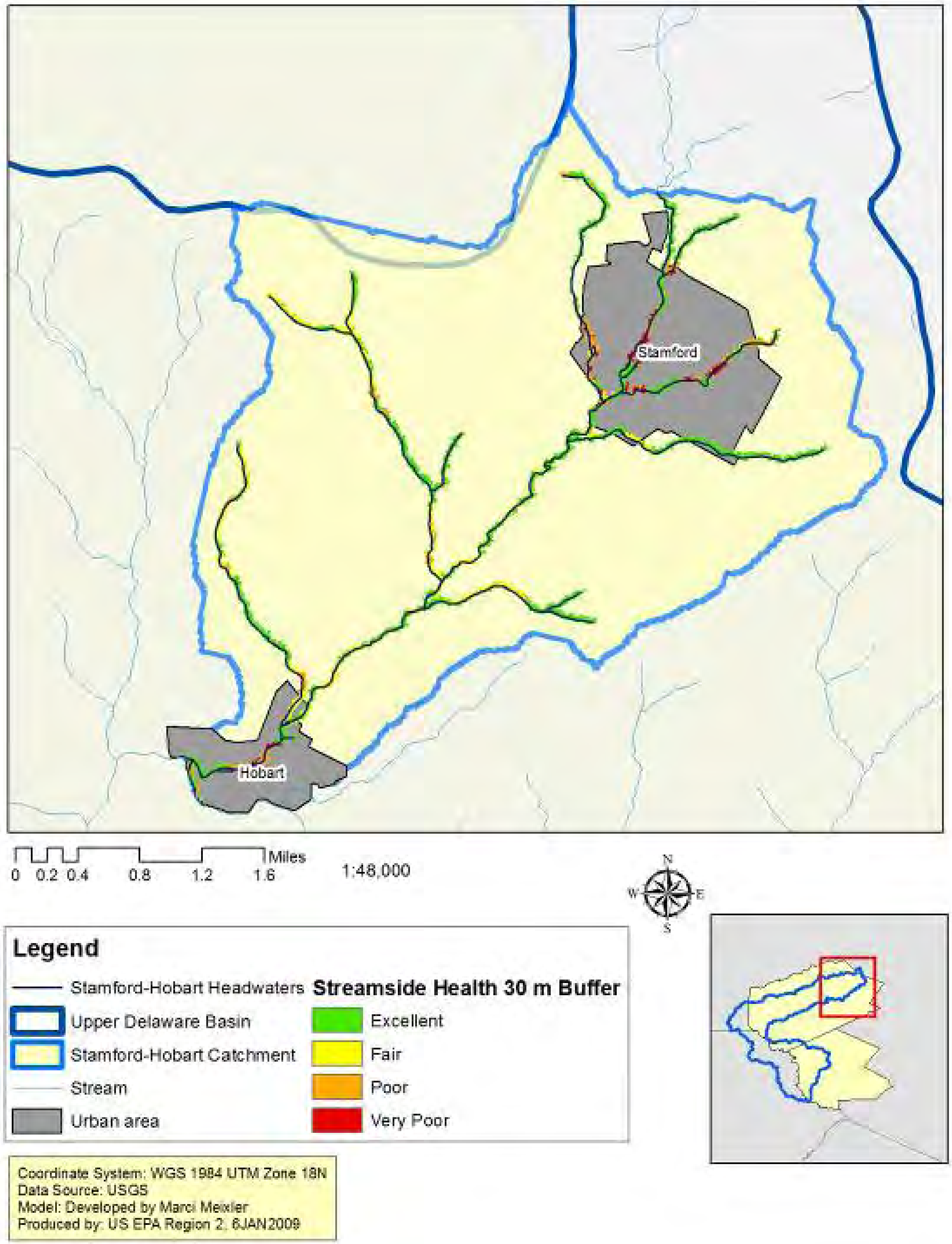

Figure 87: *Streamside Health Assessment Model: Upper Delaware Basin, Stamford-Hobart Headwater Catchment, Delaware County, NY*
Note: the model was only applied to NHD 1:24K flowlines.

4.6 FLOOD STORAGE ASSESSMENT

4.6.1 Wetland Water Storage Capacity

The surface water detention functionalities of the Stamford-Hobart headwater catchment for 1-year and 100-year, 24-hour storm events were calculated from NYCDEP reference wetlands and results from the W-PAWF analysis from the "results section". Additional stormwater data were derived from the TR-55 and TR-20 assessments of the Stamford-Hobart headwater catchment. These models were used to calculate existing storage capacity and storage deficit of NWI wetlands within the catchment. The catchment specific calculations, described in the "results section" were based on the storage capacity constants for specific storm events and associated reference wetlands, including: F05 storm event (autumn after dry period)/Ashokan Mink Hollow wetland (AMH) and D04 storm event (autumn)/Cannonsville Sherruck Brook wetland (CSB) from the Cirmo, 2006 study.

For other storm events the AMH and CSB reference wetlands did not have a net positive amount of stormwater stored, releasing more stormwater than they actually detained (Cirmo, 2006). The AMH wetland had a positive net storage for 2 out of 5 monitored storm events, while the CSB reference wetland had a positive net storage for 1 out 3 monitored storm events (Cirmo, 2006). The highlighted reference wetlands and associated storm events (AMH/F05 and CSB/D04) illustrate the potential for wetlands in the New York City municipal water supply system to detain surface water from storm events. The storage constants calculated for wetland surface water storage capacity are only based on positive net storage data from the Cirmo, 2006 study.

The existing storage capacity, storage deficit, and total storage capacity needed for the Stamford-Hobart headwater catchment was calculated (**Figures 88 – 90**). The predicted existing surface water detention capacity provided by NWI wetlands for the Stamford-Hobart headwater catchment does not manage all surface water from either a 1-year, 24- hour storm event with antecedent wet conditions or a 100-year, 24-hour storm event with antecedent dry conditions. Although under antecedent dry conditions, the existing storage of wetlands could accommodate a 1-year, 24-hour storm event. Under antecedent wet conditions, there is less existing stormwater storage capacity from wetlands. Since the reference wetlands and associated storm events used for calculating "wetland storage estimates" only highlight positive net storage of stormwater from the Cirmo, 2006 study, the predicted storage estimates may be over estimated.

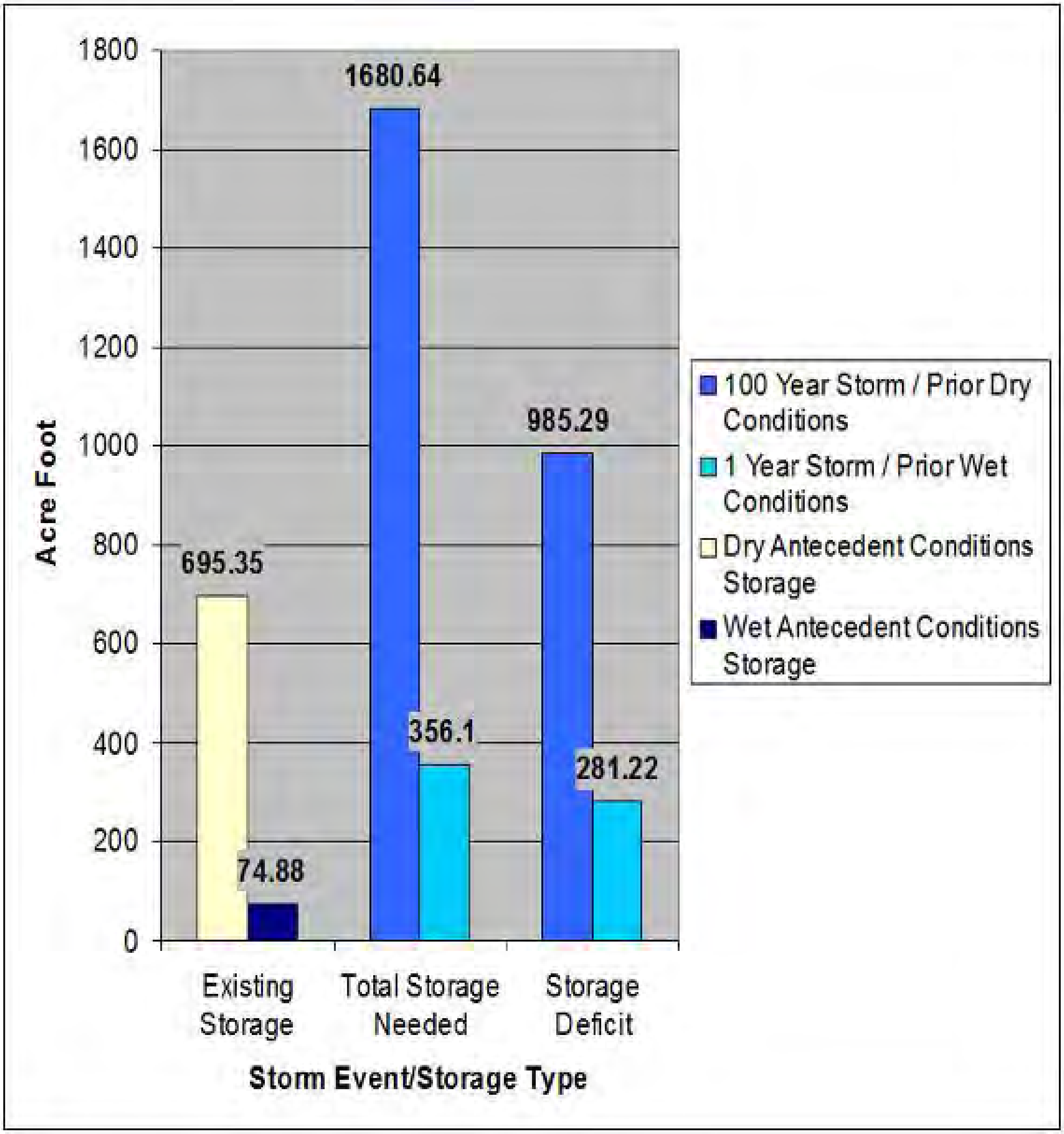

Figure 88: *Wetland Surface Water Storage (1-Year and 100-Year, 24-Hour Storm Events):Stamford-Hobart Headwater Catchment.* The different storm events are based on the results from the Cirmo, 2006 study.

The Stamford-Hobart headwater catchment is closer to managing existing stormwater detention needs for a 100-year, 24-hour prior dry conditions storm event. With the 1-year, 24-hour prior wet conditions event the catchment's storage deficit is 79% of the total storage needed. The storage deficit of the 100-year, 24-hour prior dry conditions storm event only represented 59% of the total stormwater storage needed.

Currently for overbank flooding from streams, the NYSDEC recommends managing for the 10-year storm, 24-hour peak discharge (New York State DEC, 2003). It would be helpful to have 10-year, 24-hour storm event data for the NYCDEP stormwater reference wetlands under prior wet and dry conditions to more accurately predict stormwater management detention needs. Such data would provide information necessary to compute storage constants for wetlands under 10-year, 24-hour storm events.

Under existing conditions, wetland resources within the Stamford-Hobart headwater catchment would likely be unable to manage all surface water runoff from a 10-year, 24-hour storm event with antecedent wet conditions. The peak flow rates for 1, 10, and 100-year, 24 hour storm events were modeled for the Stamford-Hobart catchment using the TR-55 model (**Table 41**). The 10-year, 24-hour peak flow event is 2,075.7 CFS greater than the 1-year, 24-hour peak flow event. Under prior dry conditions existing wetland resources are more likely to accommodate surface water storage needs from a 10-year, 24-hour peak flow event versus a 100-year, 24 hour peak flow event. The 100-year, 24-hour peak flow event is 4,493.97 CFS greater than the 10-year, 24-hour peak flow event.

Table 41: TR-55 Model Results: Existing Conditions for Stamford-Hobart Headwater Catchment of the Upper Delaware Basin

NHDPlus Headwater Basin	**Context**	**Drainage Area** (mi^2)	**1-Year Peak Flow Event** (CFS) *(CFS/mi^2)	**10-Year Peak Flow Event** (CFS) *(CFS/mi^2)	**100-Year Peak Flow Event** (CFS) *(CFS/mi^2)
Stamford-Hobart	Urban	11.75	737.61 *62.78	2,813.31 *239.43	7,307.28 *621.9

4.7 SLEUTH URBAN GROWTH MODEL ANALYSIS

Under existing development conditions the SLEUTH model predicts Delaware County will have approximately 2.8% of its land area classified as urban development (Jantz, 2008). The Stamford-Hobart headwater catchment boundary was laid over the SLUETH 2030 existing conditions scenario map (**Figure 91**). The urban boundary of Stamford has areas predicted to have up to 20 – 30 % increases in urban development from 2000 – 2030. Similarly, the model predicts up to 10 – 15 % increases in urban development in Hobart. Future stormwater management within the catchment should address the predicted increases in impervious surface resulting from urban development. Using the SLEUTH GIS data, Delaware County could assess the total increase in impervious surface area for the Stamford-Hobart headwater catchment.

Areas within Delaware County, north of and outside of the Upper Delaware Basin are generally predicted to have greater amounts of developed land than land within the basin and county. Predicted land development adjacent to the Upper Delaware Basin within Delaware County will likely contribute to increases in stormwater runoff within the basin and the Stamford-Hobart headwater catchment.

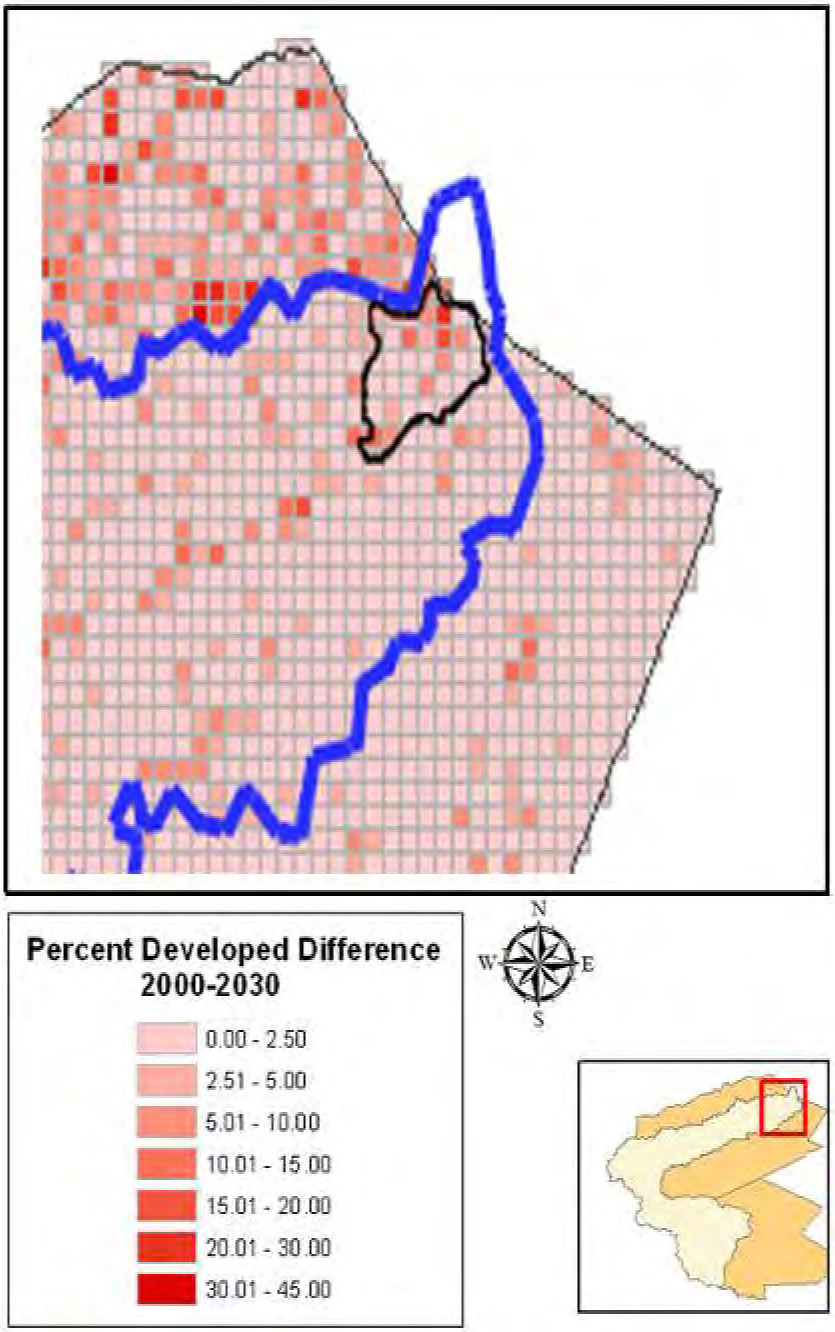

Figure 91: *Existing Development Conditions: SLEUTH Model Stamford-Hobart Projected Percent Change of Developed Land from 2000 – 2030* (Jantz, 2008).

4.8 GIS DATABASE

The GIS resources used for this case study came from the GIS database created for the Upper Delaware Basin study. Once a GIS database has been created for any watershed, it may be applied to smaller drainage areas such as headwater catchments. GIS-based layers created for the Stamford-Hobart headwater catchment were all derived from the existing GIS database for the Upper Delaware Basin. The *Appendix* provides an abbreviated metadata list of all major GIS datasets used (**Table A.5**) in this case study. Descriptions and potential uses of the GIS datasets are given in section 3.6 (**Table 23**) of the results chapter. The main GIS datasets used in this case study included the following: impervious surface cover (urban areas and roads), land-cover, urban area boundaries, HUC-8 watershed, NHDPlus headwater catchments, hydrography (stream reaches or flowlines), freshwater wetlands (NWI and NYSDEC), and digital elevation models (10 m and 30 m).

Base-maps of the Stamford-Hobart headwater catchment were created with the following GIS-based layers: wetlands, streams, land-cover, urban area boundaries, watershed, and catchment boundaries. Hydrological and ecological assessments for the Stamford-Hobart headwater catchment were completed using appropriate GIS base-maps. For each GIS-based assessment a unique set of GIS layers were used (**Table 42**). Potential future users of the GIS datasets may replicate or attempt additional spatial or tabular analyses. Note that all of the datasets are available to the public at no cost.

Table 42: Stamford-Hobart Headwater Catchment: GIS Data Used for Hydrological and Ecological Assessments

Assessment	**GIS Layers Used**	**Outcome of Assessment**
Impervious Surface Model	NLCD Impervious Surface and NHDPlus Catchment	Predict stream and water quality degradation.
Wateshed-Based Preliminary Assessment of Wetland Functions (W-PAWF)	NWI Wetlands, Digital Elevation Models (10 m and 30 m) , NHD and NYCDEP 1:24 Flowlines, and NHDPlus catchment	Predict water quality and flood protection functions of NWI wetlands.

Table 42 (cont.)

Assessment	GIS Layers Used	Outcome of Assessment
Streamside Health Model	NHD 1:24 K Flowlines, NLCD Land-Cover 2001, and NHDPlus catchment	Predict the ecologic health of streamside areas of NHD 1:24 K flowlines.
Flood Storage Assessment	NWI and NYDEC Wetlands; and NHDPlus catchment	Predict flood storage capacity from existing wetland resources under reference conditions.
SLEUTH Urban Growth Model	2000-2030 Percent Change in Impervious Surface, NHDPlus catchment, and HUC-8 watershed	Predict future increases in impervious surface cover within the headwater catchment.

4.9 SELECTION OF BEST MANAGEMENT PRACTICES (BMPS) FROM EXISTING DESIGN PRECEDENTS

Catchment-based BMP strategies require different approaches for urbanizing and rural areas. Urban areas, such as Stamford and Hobart should focus on regional stormwater management planning and regional open space and park planning. In rural areas of the catchment, regional planning should focus on acquisition of land for stormwater detention and impervious surface limits (below 11% impervious cover) (Nisenon, 2005).

Actual design strategies and policies for BMPs within the catchment are also different for urban and rural areas. For the urban areas of Stamford and Hobart, design strategies should focus on urban infill or redevelopment, impervious surface restrictions (below 11% impervious cover), open space, conservation design, and rural planning, and stream and wetland restoration and buffering (Nisenon, 2005). In rural areas of the catchment, design strategies should focus on headwater catchment based impervious surface limits (below 11% impervious cover) (Nisenon, 2005).

Specific structural and low impact development (LID) BMPs are recommended below based on the stream, wetland, and flood storage assessment results for the Stamford-Hobart catchment. Placement of these BMPs should be evaluated based on the rural or urban context of the catchment.

1.) Based on results from the W-PAWF and streamside health model, there are areas within the catchment that could be enhanced for additional surface water detention and water quality protection (**Figures 85 – 87**). There is a predicted range for a surface water detention deficit for the catchment. The range of the surface water storage deficit includes the following: 281.22 acre foot for a 1-year, 24-hour storm under antecedent wet conditions; and 985.29 acre foot for a 100-year, 24-hour storm with prior dry conditions. Pond or wetland stormwater BMPs could be implemented in areas with low amounts of existing surface water detention from NWI wetlands (**Figure 85**).

Constructed ponds and wetlands should be sited outside of 30 m (100 foot) headwater stream buffers to protect stream integrity. Based on the surface water storage deficit from existing NWI wetlands, additional ponds and wetlands could be constructed to detain excess stormwater runoff. New stormwater storage retrofits could be located upstream of the urban areas of Stamford and Hobart. The majority of existing land-cover types in this catchment is not urban, allowing for multiple opportunities for off-site stormwater storage locations. New ponds and wetlands properly sited within this catchment may provide good water quality protection, channel protection, and flood control (**Table 43**) (New York State DEC, 2003). Examples of a wooded stormwater wetland design and an actual wooded wetland in the Upper Delaware Basin may be found in the results chapter, section 3.7 (**Figures 58 – 59**).

Table 43: Wetland and Pond Stormwater Management Practices and Designs: Performance Capabilities for Water Quality, Channel, and Flood Protection
(New York State DEC, 2003)

Stormwater Management Practice	**Designs**	**Water Quality Protection**			**Channel Protection**	**Flood Control**
		Bacteria	*Metal*	*Nitrogen*		
Wetland	Pocket wetland, pond/ wetland, shallow wetland, and extended detention wetland	Good	Fair	Good	Good	Good[1]
Pond	Pocket pond, wet pond, wet extended detention pond, micropool ED, and multiple pond	Good	Good	Good	Good	Good

2.) The stream corridor assessment indicated that 45.4% of the stream corridors could be further assessed for possible mitigation. The outer edges of the 100 foot stream corridor buffers with predicted fair, poor, and very poor conditions should be assessed for locations of constructed ponds or wetlands. Streamside corridors upstream of urban areas having fair to very poor conditions should be prioritized for mitigation (**Figure 92**). Possible BMPs for impaired stream corridors could include: vegetative bank stabilization, open channel design, riparian forest buffer, vegetative swale, and re-sized culverts; examples of these BMPs may be found in the results chapter, section 3.7 (**Figures 60** and **62 – 68**). To address water quality, stream channel, and flood protection, pond and wetland BMP designs should be evaluated. Pond and wetland BMP designs are rated as providing substantial amounts of water quality, stream channel, and flood protection functions (New York State DEC, 2003) (**Table 43**).

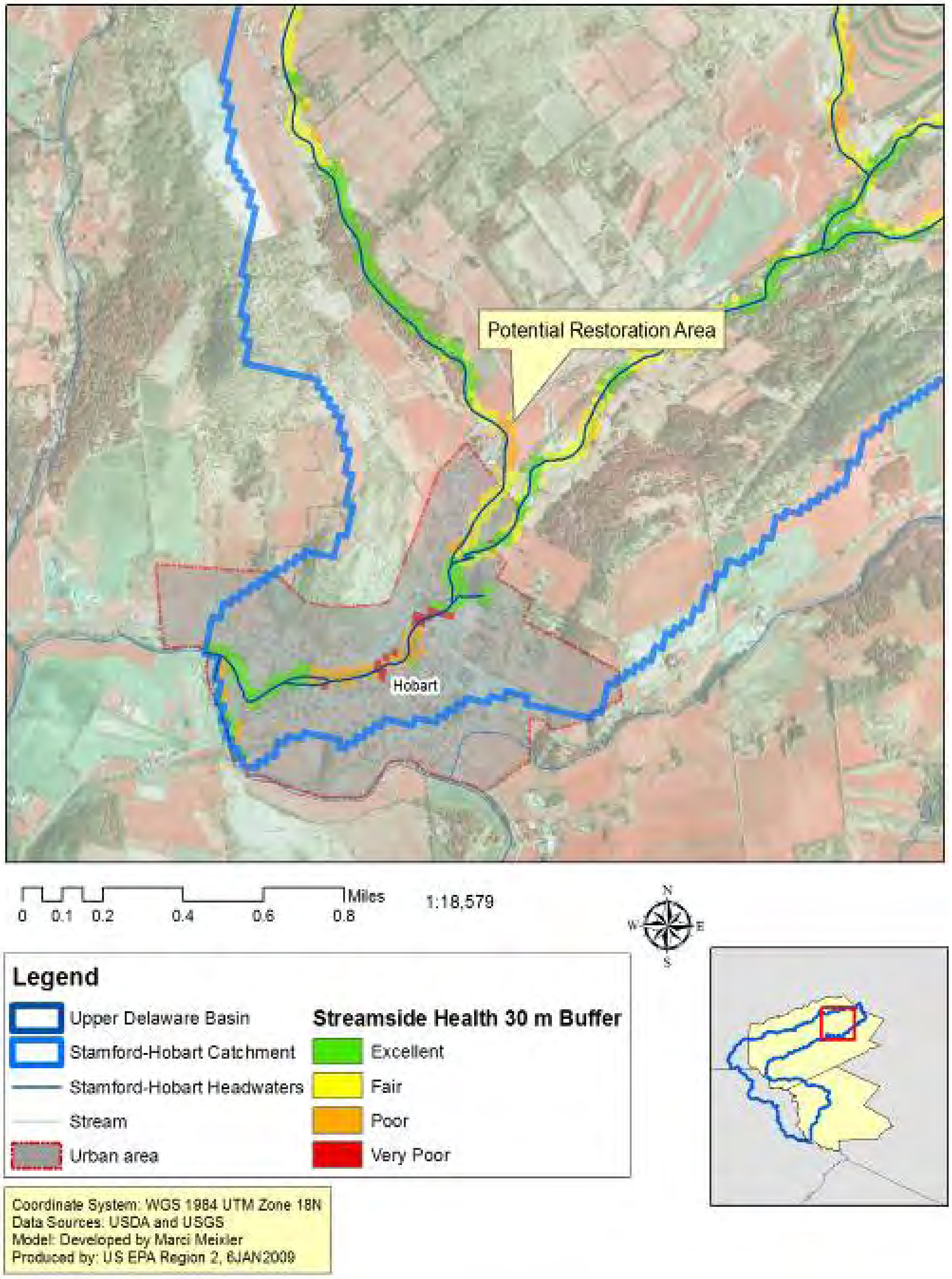

Figure 92: *Potential Stream Restoration or Stormwater BMP Area: Stamford-Hobart Headwater Catchment.*

3.) The actual amount of stormwater needed to be managed may be determined from the TR-55, TR-20, and flood storage assessment results (**Table 39**, **Figure 83**). The proposed BMPs should be designed to manage a 10-year, 24-hour peak discharge for overbank flooding and stormwater conveyance needs (New York State DEC, 2003).

Based on the TR-55 results, the 10-year, 24-hour peak flow event is 2,813.31 CFS for the entire catchment. The surface water detention deficit data of NWI wetlands within the catchment could also be used to determine the quantity of stormwater to manage. The range of the surface water storage deficit includes the following: 281.22 acre foot (12,249 ,943.38 ft^3) for a 1-year, 24-hour storm under antecedent wet conditions; and 985.29 acre foot (42,919,233.02 ft^3) for a 100-year, 24-hour storm with prior dry conditions. Stormwater monitoring of reference wetlands within the Stamford-Hobart catchment would improve the accuracy of the surface water storage assessment results.

4.) The SLEUTH model predicted that there would be an increase in urban development in certain areas of the catchment. Areas expected to have the greatest amount of development should be prioritized for stormwater BMP. Existing urban areas may be retrofitted with LID BMPs to increase stormwater infiltration, evapotranspiration, and detention. LID BMP strategies should also be selected and evaluated to address future urban development. Some of the possible LID-based BMPs include placing sand-filters, bioswales, or pocket wetlands in commercial and industrial parking lots; increasing tree canopy cover (tree planters) along road-ways and along stream corridors (riparian buffers); existing and future urban areas should incorporate native landscaping (rain gardens), green roofs, and open space stormwater detention ponds; and future residential developments should have compact or cluster design patterns and narrow street widths. Design examples of these LID BMPs are located in the results chapter, section 3.7 (**Figures 67** and **69 – 77**). It is likely that a combination of LID and pond/wetland based stormwater BMPs could address existing and future stormwater management needs within the Stamford-Hobart headwater catchment.

5.) Based on the median 2006 construction costs of stormwater BMPs, the following BMP retrofit practices may be the most cost effective: ponds, new storage, large bioretention cells, infiltration, structural sand filters, impervious cover conversion, and stormwater planters (Schueler et al., 2007).

4.9.1 Funding of Stormwater BMPs

The stormwater BMPs selected for the Stamford-Hobart headwater catchment may be funded by the NYCDEP's and Catskill Watershed Corporation's (CWC) stormwater retrofit programs and stream management program. The CWC's Future Stormwater Program could fund BMPs for new development sites. For areas needing stormwater retrofits, the CWC's Stormwater Retrofit Grant Program could provide funds for improving water quality impairments and upgrading substandard stormwater management infrastructure. For community stormwater planning needs, which may require GIS-based analyses, the CWC's Community Stormwater Planning and Assessment Grant Program could be of assistance. The municipalities of Stamford and Hobart could both apply for the Community Stormwater Planning and Assessment Grant Program to conduct more involved GIS-based assessments of existing structural and non-structural stormwater management infrastructure.

For headwater stream corridors, the NYCDEP Stream Management Program could be used to fund field assessments of stream corridors predicted to be in fair, poor, and very poor conditions. After field assessments have been completed, the NYCDEP Stream Management Program could fund the evaluation, design, construction, and maintenance of stream restoration BMPs for stream corridors needing mitigation. Further funding for stormwater BMPs could come from federal and state flood management monetary aid sources.

4.10 ECONOMIC VALUATION OF ECOLOGICAL FUNCTIONS

Wetlands and headwater streams that provide flood attenuation during an extreme storm event may produce a net reduction in economic costs and damages. An adequate amount of functioning wetland and headwater stream resources may act as flood protection tools, utilities, or insurance for both public and private welfare. To analyze the costs associated with the recent extreme flood events, the federal monetary aid for flood damages and losses has been compared to predicted surface water detention provided by NWI wetlands within the Stamford-Hobart headwater catchment.

The total federal monetary aid cost was $52,112,797 (**Tables 28 – 29**). Note that both the NFIP and public infrastructure monetary aid analyses do not account for all of the costs associated with damages and losses (uninsured damages and loss of life) caused by the storm events. Economic costs accrued from recent flood damages within the Upper Delaware Basin provide a picture of potentially preventable costs via increased or enhanced ecological functionality from wetland and headwater stream resources.

The monetary value of surface water detained by NWI wetlands from the W-PAWF may be estimated by determining the costs of constructing new stormwater storage retrofits that provide equal storage volume (**Table 43**). For the 1-year, 24-hour prior wet conditions storm event, the estimated monetary value of surface water detention provided by NWI wetlands in the catchment is $35,803,933 less than the total known federal monetary aid costs for the Upper Delaware Basin (**Table 43**). However, for the 100-year, 24-hour prior dry conditions storm event the predicted monetary value of surface water detention provided by NWI wetlands within the catchment is $99,334,435 greater than the combined federal aid monetary costs (**Table 43**). The total monetary value of surface water detention provided by NWI wetlands is more evident under dry antecedent conditions.

Table 43: Estimated Monetary Values of Surface Water Detention Provided By Existing NWI Wetlands: Stamford-Hobart Headwater Catchment

Storm Event	**Existing Surface Water Detention** (Cubic feet)	**Cost of New Stormwater Storage Retrofits** (Dollars)	**Cost Differential New Stormwater Storage Retrofits VS. Total Federal Monetary Aid** (Dollars)
1-year, 24-hour, prior wet conditions	3,261,773	$16,308,864	$35,803,933 Less than Fed. Aid
100-year, 24-hour, prior dry conditions	30,289,446	$151,447,232	$99,334,435 Greater than Fed. Aid

Note: the storm events are based on the storm events associated with the NYCDEP reference wetlands stormwater monitoring data used for this study. Based on values from **Table 27** and **Figure 47**. Total known monetary aid was $52,112,797.

Currently, substantial monetary aid given for flood repairs and maintenance projects focuses on repairing sites to their previous conditions. The actual flood repair and maintenance methods used may not implement stormwater BMPs that address long term flood management and water quality protection needs within the watershed. Stormwater BMPs recommended in this case study should be evaluated and considered for monetary aid for short, intermediate, and long term flood repair, maintenance, and management projects. Proactive institution of the recommended BMPs may mitigate future flood damages and water quality degradation within the Stamford-Hobart catchment. The existing stormwater programs funded by the NYCDEP could be supplemented by federal or state flood management funds.

The construction cost of addressing the existing storage deficit of NWI wetlands within the catchment for the 1-year, 24-hour prior wet conditions event was evaluated (**Table 44**). The cost of detaining the storage deficit was based on cubic feet of surface water detained. Only the construction cost of new stormwater storage retrofits are represented, other life cycle costs include long maintenance (**Table 44**). The total predicted construction cost of the stormwater retrofits is $9,137,252 greater than the total federal monetary aid already allocated for flood damages and losses for the Upper Delaware Basin. Any investments in stormwater retrofits would need to be viewed as long term public infrastructure projects.

The construction costs of addressing the storage deficit could be paid over an extended time period (30 – 50 years) with interest added to the total cost. Financial summaries of a 30-year and 50-year loan with 6.5% interest were calculated for the cost of new storage retrofits for the catchment (**Table 45**). On an annual basis the cost per year is lower with both loans, $56,604,345.5 less for the 30-year loan and $57,106,725.7 less for the 50-year loan.

Table 44: Stamford-Hobart Catchment: Construction Cost of New Stormwater Storage Retrofits for Managing a 1-Year 24-Hour Storm, Prior Wet Conditions Storm Event

Existing Surface Water Detention Needed (Cubic feet)	**Cost of New Storage Retrofits** (Dollars)
12,250,009.86	$61,250,049

Note: based on values from **Table 27** and **Figure 47**. Total known monetary aid was $52,112,797.

Table 45: Summary of Financing New Stormwater Storage Retrofits with 30 and 50 Year Loans with 6.5% Interest Rate

Loan Type (6.5% Interest)	**Annual Principal and Interest**	**Total Interest**	**Total Cost**
30 Year	4,645,703.5	139,371,105.5	200,621,154.5
50 Year	4,143,323.3	207,166,163.2	268,416,212.2

Note: calculations are based on an amortization schedule for a 1,000,000.00 loan extrapolated to the total cost of the stormwater storage retrofit cost (ARSIDIAN LLC, 2009). The monetary value of the construction costs (without financing) of the stormwater retrofits would be $61,250,049.

Field assessments of streams and wetlands prioritized by the computer-based assessments could provide important site analysis information to further the design and planning process of the recommended BMPs. Overall, this example highlighted how some of the assessments and BMPs included in this study could be integrated for proposing water quality and flood management solutions at the headwater catchment scale. A brief summary of the BMPs recommended in this case study was compiled to illustrate the options for providing water quality and flood protection in the Stamford-Hobart catchment (**Table 46**).

Table 46: Summary of BMPS Recommended for the Stamford-Hobart Catchment

BMP	Function	
	Water Quality Protection	***Flood Protection***
Pond	**X**	**X**
Wetland	**X**	**X**
Vegetative Swale/Bioswale	**X**	*
Vegetative Stream Bank Stabilization	**X**	**X**
Open Channel Design	**X**	**X**
Riparian Forest Buffer	**X**	**X**
Re-sized Cluvert		**X**
Sand Filter	**X**	*
Native Landscaping (rain garden)	**X**	*
Green Roof	**X**	*
Compact Cluster Development	**X**	*
Narrow Streets	**X**	*

Note: X = yes for a BMP performing a given function. A BMP with a * indicates that the BMP provides minimal performance for that particular function (Center for Watershed Protection, 1995 & 2007, New York State DEC, 2003, and NRCS, 2007).

CHAPTER 5
SUMMARY & CONCLUSIONS

The recent peak flood events of 2004 to 2006 may be associated with the general changes in climate conditions of the Catskill Mountain region, which includes greater precipitation, surface water runoff, potential evapotranspiration, warmer air temperatures, and earlier peak snowmelt from 1952 – 2005 (Burns et al., 2007). Within the Upper Delaware Basin, from 1993 - 2003 the predicted 100-year, 24-hour storm events have increased in magnitude and have less variance in peak flow rates (Northeast Regional Climate Center, 2008). Existing climate data may necessitate further management measures in the future to avoid flood damages and other associated losses. Many factors may be involved in the recent increase in frequency of intense storm events (90-year plus recurrence intervals) and associated impacts, including: hurricanes, snowmelt, and stalled frontal systems; climatic trends; impervious surface coverage; and a deficit of baseline ecological functions from wetlands and headwater streams to meet human needs.

Historically, the Upper Delaware Basin region has experienced a loss of wetlands; from circa 1780's to 2001 it is estimated between 4% to 11% of the total land-cover classified as wetlands within the watershed was converted to other land-cover types. The most recent study of wetland land-cover change in the basin documented losses of 3% of riverine and 45% of lacustrine wetlands (Tiner et al, 2003). These wetlands are responsible for attenuating overbank flooding from headwater streams. Loss of these types of wetlands may cause associated functional losses of surface water detention, shoreline stabilization, sediment retention, stream flow maintenance, and nutrient transformation services within the watershed. Recent intense flood events which occurred in the watershed may have been exacerbated by the loss of historical wetlands and their associated ecological and hydrological functions.

Evaluative procedures to determine existing baseline ecological and hydrological conditions of the Upper Delaware Basin were developed. In addition, alternative future scenarios, stormwater BMPs, and economic valuations of ecological functions were evaluated to address water quality protection and flood management concerns within the watershed.

Headwater Stream Network Delineation:

Information regarding existing levels of baseline ecological and hydrological conditions was assessed using multiple GIS-based resources. GIS resources utilized for mapping headwater streams revealed that the majority of the total stream network, 81% at 1:24 K scale, within the Upper Delaware Basin was classified as headwaters. There were 781.8 additional headwater stream miles identified from medium to high resolution (1:100K to 1:24K) headwater stream datasets. Comparisons between the headwater stream networks from the 1:100 K and 1:24 K datasets reveal that higher resolution data greatly increases total stream network length. The state of New York only regulates stream reaches mapped at the 1:100 K resolution, leaving a great number of stream miles unprotected. The water quality of headwater streams greatly affects the overall water quality of the watershed. If New York City wants to increase protection of its drinking water supply, then it needs to work with New York State to regulate all headwater stream reaches, using the highest resolution data available.

Future mapping of headwater streams could employ LIDAR (light detection and ranging) technology. LIDAR is able to provide even higher resolution topographic mapping, producing digital elevation models which may provide the locations of headwater stream reaches (National Oceanic and Atmospheric Administration (NOAA), 2008). Such topographic data could reveal evidence of a larger spatial extent of headwater streams in the watershed. Such mapping has been conducted by FEMA on a limited basis within the East Branch of the Delaware River for floodplain mapping. LIDAR also has the ability to locate depressions within the landscape, which could possibly reveal unmapped wetlands and their connections to headwater streams. Additionally, LIDAR data could provide useful insights of the potential stormwater detention capacity of the landscape (depressions and floodplain areas).

Hydrologic Analyses:

USGS stream gauge records within and right outside the basin indicated that there have been 3 storm events from 2004 to 2006 with 90-year or greater recurrence intervals. Remnants of hurricanes, snowmelt, and a stalled frontal system partially caused these rare and intense storm events. More hydrologic records for headwater stream gauges are needed to understand the recurrence interval of such flood events within the headwater drainage areas.

The impervious surface model was applied to various headwater catchments with urban developments (Walton, Stamford, and Hobart NY). Results from the model showed urban development within headwater catchments may contribute significant amounts of impervious surface cover compared to total surface area within the catchment. Headwater catchments approaching 11% impervious surface cover were prioritized as being vulnerable to water quality degradation and unstable stream channels.

Stormwater modeling using the TR-55 and TR-20 models was utilized for typical urban and rural headwater catchments to predict differences in stormwater runoff rates. The urban catchment had 1% more impervious surface than the rural catchment, but also had a larger drainage area. Most of the headwater catchments representative of dominant urban, agricultural, and rural land-covers lacked USGS stream gauge records with known recurrence intervals for comparison with predictions from the stormwater model results. More USGS stream gauge monitoring stations could be located within headwater catchments dominated mainly by urban, agricultural, and/or rural land-cover types.

Based on CFS/square mile, for a 10-year, 24-hour storm event, the urban catchment was predicted to have approximately 1.5 times more stormwater runoff than the rural catchment. Managing stormwater runoff in headwater catchments experiencing flooding problems should focus management efforts on the 10-year, 24-hour storm event (New York State DEC, 2003).

Functional Assessments:

Water quality and flood protection functions of wetlands were predicted by conducting a watershed-based preliminary assessment of wetland functions (W-PAWF) (Tiner et al., 2002) for the basin. Out of all of the NWI wetlands within the basin assessed, 70.74% were predicted to perform at least one function of interest at a high or moderate level. Many of the NWI wetlands were predicted to perform multiple functions of interest to the study.

Better estimates using the W-PAWF of NWI wetlands could be obtained with greater availability of digital NWI data for the watershed. Digital NYSDEC wetlands could be classified with the 1979 NWI Cowardian classification system, allowing the wetlands to be included in future W-PAWFs.

Results from the streamside health model (Meixler, 2003) revealed 76% of 1:24 K NHD headwater stream corridors were predicted to be in excellent condition. The remaining 24% of headwater stream corridors were predicted to be in fair to very poor conditions. Stream corridors assessed to be in fair to very poor conditions should be evaluated in the field to determine if stream mitigation practices are necessary to improve streamside health conditions. If the streamside health model was applied to the NYCDEP 1:24 K stream network it would further knowledge about predicted streamside corridor conditions within the watershed. The model could also incorporate the slope and soil types of the stream corridors to assess stream bank stability and surface water runoff and infiltration rates. An impervious surface threshold value could be developed specifically for the Upper Delaware Basin by monitoring streamside health conditions in urbanizing headwater catchments.

Flood Storage Assessment:

Existing flood storage capabilities of NWI wetlands within the basin were evaluated from both a 1-year, prior wet conditions and a 100-year, prior dry conditions storm, 24-hour events based on NYCDEP monitored stormwater wetlands and the W-PAWF analysis. Under the dry prior climatic conditions the wetlands were able to accommodate greater quantities of stormwater runoff. Closer analyses of existing flood storage, flood storage deficit, and total flood storage needed from existing wetlands were conducted for typical rural and urban headwater catchments using the same NYCDEP stormwater wetlands data. Both the rural and urban catchments had predicted flood storage deficits, based on existing flood detention capacity of NWI wetlands for the 1-year, prior wet conditions 24-hour storm and 100-year, prior dry conditions 24-hour storm.

NYCDEP stormwater wetlands data were very useful in predicting stormwater storage capacity at the headwater catchment scale. The flood storage assessment from this study was limited by the types of storm events and number of wetlands available from the NYCDEP wetland stormwater monitoring data. There were only two reference wetlands and two different storm events used as references for the flood storage assessment. A general range was determined for existing stormwater detained, stormwater storage deficits, and total storage needed for typical urban and rural headwater catchments.

A greater number of reference wetlands are needed to understand how wetlands manage stormwater during storm events of varying magnitudes and frequencies under changing climatic conditions. Stormwater monitoring records of wetlands with high surface water detention capacities should be monitored throughout the watershed, especially in urban headwater catchments. Greater variety of wetland stormwater monitoring records could allow for more accurate predictions of actual stormwater detention deficits within the watershed. Monitoring data should focus on the 10-year, 24-hour storm event peak discharge rate for managing overbank flooding from streams (New York State DEC, 2003).

Urban Land-Cover Change Analysis:

Land-cover change in Sullivan County was assessed from annual increases in residential building permits, which was associated with increases in impervious surface cover. Total residential building permit activity increased from about 600 total permits in 1990 to 7,718 permits in 2006 (based on total summation of annual building permits); an increase of approximately 1,186% in total residential building permits in Sullivan County. Greater stormwater runoff may be associated with increases in impervious surface cover resulting from increased residential building activities.

The SLEUTH urban growth model predicted that under existing development conditions Sullivan County would have a 108% increase in impervious surface cover by 2030. Sullivan and Delaware counties are expected to have approximately 7.5% and 2.8% total impervious surface cover respectively in 2030 (Jantz, 2008). Since urban development within the watershed often occurs in narrow valleys, with shallow soils, and near streams, increases in stormwater runoff are likely to occur as a result of predicted increases in impervious surface cover.

The SLEUTH model data predicted that existing wetlands will be impacted or filled (2.6 acres) as a result of predicted future urban development. The US Army Corps of Engineers historical 404 wetland permit data for Sullivan County indicates that under existing development conditions 46 acres of wetlands would be predicted to be lost or filled by 2030. Future wetland losses predicted by the SLEUTH model existing development scenario are very conservative. Losses of future wetland resources would result in diminished water quality and flood protection within Sullivan County.

Areas expected to lose wetland resources in the future should prioritize wetland protection efforts to reduce possible future flood damages and loses. Communities vulnerable to future wetland losses caused by urban development could find funding sources for wetland protection measures. Such funding sources could come from the NYCDEP and Catskill Watershed Corporation stormwater management programs.

Further investigation of alternative future scenarios at the watershed, county, and municipal levels may provide broad plans for concentrating future development in existing urban areas. The model could run alternative scenarios that protect, enhance, preserve, and restore water quality and flood protection services performed by wetland and headwater stream resources. Alternative future SLEUTH model scenarios could set a 10% impervious surface threshold for urbanizing headwater catchments. Development scenarios informed by conservation-based alternative futures from the SLEUTH model may facilitate more detailed urban design plans and management efforts.

GIS Database:

The GIS-based assessments used for this study helped create a useful GIS database for future applications. This database may be used for future stormwater and flood management projects for the Upper Delaware Basin. The descriptions and potential uses of the GIS data within this database may assist other GIS users in creating similar databases for other watersheds or headwater catchments.

Selection of BMPs:

Appropriate stormwater BMPs were selected based on results from the assessments of baseline ecological and hydrological functions of wetland and headwater stream resources, hydrologic records, impervious surface assessments, and urban growth model results of this study. Existing stormwater BMP design precedents were selected for wetland and stream restorations, urban infiltration systems, and residential subdivision and site design templates. The selected stormwater BMPs may be applied at different spatial scales, allowing for roadways, parking lots, residential subdivisions, and individual housing parcels to be planned and designed with appropriate stormwater management technologies. Proposing actual site designs of the selected BMPs may require field assessments within the watershed. When stormwater BMPs are implemented within the watershed, their performance should be monitored to assess their effectiveness at meeting water quality and flood protection goals and objectives. Proactive flood management and water quality protection efforts should attempt to employ the various BMPs selected in this study, while planning at the headwater catchment scale.

Economic Valuation of Ecological Functions:

Wetlands and headwater streams that provide flood attenuation during an extreme storm event may produce a net reduction in economic costs from damages. The water quality protection functions of wetlands and headwater streams, filtering or cleansing of water also provide a "net reduction of economic damages (Heimlich et al., 1998)." The federally funded monetary aid, approximately $52.1 million dollars from 2004 – 2007, to address recent flood damages within the Upper Delaware Basin provide an approximation of potentially avoidable costs via increased flood protection from wetland and headwater stream resources. Water quality damages from flood events were not addressed in the federal monetary aid records analyzed.

A portion of the wetlands within the Stamford-Hobart headwater catchment were predicted to detain surface water, providing approximately $16.3 million and $151.4 million dollars of free stormwater management services for two separate storm events. Currently, substantial monetary aid focuses on flood repairs and maintenance projects that repair sites to their previous conditions. Little is invested in proactive "repair" practices that eliminate further flooding and water quality degradation, such as stormwater BMP retrofits; and wetland and headwater stream enhancement and protection.

A significant portion of economic costs associated with flood damages and losses could be reduced by increased wetland coverage and more intact and unmodified headwater stream channels and riparian corridors within the watershed. Proactive monetary investments in protecting, preserving, and enhancing existing ecological services provided by headwater streams and wetlands may significantly reduce monetary costs, property damage, and loss of human life associated with flood events in the watershed. Stormwater BMPs selected in this study should be evaluated and considered for monetary aid for flood repair and maintenance projects.

Case Study:

The Stamford-Hobart headwater catchment case study provides an example of how to conduct all of the assessments, planning, and design components of this study with a headwater catchment. The case study demonstrates that the computer-based assessments should be complemented with field assessments to complete the planning and design process. Assessing and managing wetland and headwater stream resources for water quality and flood protection may be more easily done at the smaller headwater catchment scale compared to an entire watershed.

The results and recommendations from this study are meant to be used by stakeholders, such as local landowners, planners, soil and water conservation districts, and municipal governments within the Upper Delaware Basin. Existing stream and county management plans already highlight interests in protecting water quality, managing stormwater, and maintaining ecosystem functions. This study and the accompanying GIS tools and data may be useful for future watershed management issues related to flood management, water quality protection, and implementing smart urban growth development practices. Other urbanizing watersheds experiencing similar issues faced in the Upper Delaware Basin may also use and apply these assessment tools and recommendations for water quality and flood protection.

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APPENDIX A

Table A.1: Stream Modifications and Their Probable Effects

(Data compiled from the Federal Interagency Stream Restoration Working Group, 1998)

Stream Modification	***Probable Direct Effects***
Channelization	**1.** Nonpoint pollution **2.** Increased peak flood energy and peak flood elevation **3.** Decreased interflow and subsurface flow **4.** Decreased groundwater inflow to stream **5.** Increased flow velocity **6.** Channel widening, side-cutting, and down-cutting **7.** Increased stream gradient and reduced energy dissipation **8.** Reduced flow duration **9.** Reduced stream meander **10.** Increased sediment and contaminant loads in stream **11.** Decreased capacity of stream to store or filter energy and materials **12.** Loss of riparian vegetation **13.** Increased streambank erosion and channel scour **14.** *Loss of adjacent wetland functions: water storage, sediment capture, recharge, and habitat* **15.** Reduction of stream flora assimilation of nutrients and pesticides
Vegetative Clearing	**1.** Nonpoint pollution **2.** Increased levels of fine sediment and contaminants **3.** Increased flood energy and peak elevation **4.** Decrease infiltration of surface runoff and interflow and subsurface flow **5.** Reduced groundwater recharge and inflow to stream **6.** Increased flow velocities, Increased stream migration **7.** Channel widening, side-cutting, and down-cutting **8.** Reduced flow duration **9.** Decreased capacity of floodplain, upland, and stream to store or filter energy and materials **10.** Loss of riparian vegetation **11.** Increased streambank erosion and channel scour **12.** Reduction of stream flora assimilation of nutrients and pesticides
Streambank Armoring	**1.** Increased flood energy and peak elevation **2.** Decrease infiltration of surface runoff and interflow and subsurface flow **3.** Reduced groundwater recharge and inflow to stream **4.** Increased flow velocities **5.** Channel widening, side-cutting, and down-cutting **6.** Increased stream gradient and reduced energy dissipation **7.** Reduced flow duration, Reduced stream meander **8.** Increased sediment and contaminant loads in stream **9.** Decreased capacity of stream to store or filter energy and materials **10.** Loss of riparian vegetation **11.** Reduction of stream flora assimilation of nutrients and pesticides

Table A.1 (cont.)

Stream Modification	***Probable Direct Effects***
Streambed Disturbance	**1.** Nonpoint pollution **2.** Increased levels of fine sediment and contaminants **3.** Increased flood energy and flow velocities **4.** Increased stream migration **5.** Channel widening, side-cutting, and down-cutting **6.** Increased stream gradient and reduced energy dissipation **7.** Reduced flow duration **8.** Reduced stream meander **9.** Increased sediment and contaminant loads in stream **10.** Decreased capacity of stream to store or filter energy and materials **11.** Increased streambank erosion and channel scour **12.** Loss of riparian vegetation **13.** *Loss of adjacent wetland functions: water storage, sediment capture, recharge, and habitat* **14.** Reduction of stream assimilation of nutrients and pesticides
Hard Surfacing	**1.** Nonpoint pollution **2.** Increased levels of fine sediment and contaminants **3.** Increased flood energy and peak elevation **4.** Decrease infiltration of surface runoff and interflow and subsurface flow **5.** Reduced groundwater recharge and inflow to stream **6.** Increased flow velocities **7.** Reduced stream meander **8.** Increased stream migration **9.** Channel widening, side-cutting, and down-cutting **10.** Reduced flow duration **11.** Increased sediment and contaminant loads in stream **12.** Decreased capacity of floodplain, upland, and stream to store or filter energy and materials **13.** *Loss of wetland functions: water storage, sediment capture, recharge, and habitat* **14.** Reduction of stream assimilation of nutrients and pesticides
Woody Debris Removal	**1.** Nonpoint pollution **2.** Increased levels of fine sediment and contaminants **3.** Increased flood energy **4.** Reduced groundwater recharge **5.** Increased flow velocities **6.** Increased stream migration **7.** Channel widening, side-cutting, and down-cutting **8.** Increased stream gradient and reduced energy dissipation **9.** Reduced flow duration **10.** Decreased capacity of floodplain, upland, and stream to store or filter energy and materials **11.** Increased sediment and contaminant loads in stream **12.** Increased streambank erosion and channel scour **13.** Loss of riparian vegetation **14.** Reduction of stream assimilation of nutrients and pesticides

Table A.1 (cont.)

Stream Modification	***Probable Direct Effects***
Levees	**1.** Increased levels of fine sediment and contaminants **2.** Increased flood energy and peak elevation **3.** Reduced groundwater recharge and inflow to stream **4.** Increased flow velocities **5.** Channel widening, side-cutting, and down-cutting **6.** Increased stream gradient and reduced energy dissipation **7.** Reduced flow duration **8.** Decreased capacity of floodplain, upland, and stream to store or filter energy and materials **9.** Increased streambank erosion and channel scour **10.** Loss of riparian vegetation, **11.** Loss of adjacent wetland functions: water storage, sediment capture, recharge, and habitat **12.** Reduction of stream flora assimilation of nutrients and pesticides
Piped Discharge	**1.** Point source pollution **2.** Increased levels of fine sediment and contaminants, **3.** Increased flood energy, **4.** Decrease infiltration of surface runoff and interflow and subsurface flow, **5.** Reduced groundwater recharge, **6.** Increased flow velocities, **7.** Increased stream migration, **8.** Channel widening and down-cutting, **9.** Increased stream gradient and reduced energy dissipation, **10.** Reduced flow duration, **11.** Decreased capacity of floodplain, upland, and stream to store or filter energy and materials, **12.** Increased sediment and contaminant loads in stream, **13.** Increased streambank erosion and channel scour, and **14.** Reduction of stream flora assimilation of nutrients and pesticides.

Table A.2: **National Land Cover Data 2001: Upper Delaware Basin**

Land cover type:	**Acres:**
Open water:	11,029.6
Developed, open space:	27,943.9
Developed, low density:	2,379.6
Developed, medium density:	514.6
Developed, high density:	174.8
Barren land:	2,848.8

Table A.2 (cont.)

Land cover type:	Acres:
Deciduous forest:	443,721.6
Evergreen forest:	38,043.0
Mixed forest:	84,228.6
Scrub shrub:	3,627.0
Grassland/herbaceous:	4,495.8
Pasture/hay:	116,500.0
Cultivated crops:	18,030.3
Woody wetlands:	8,339.8
Emergent herbaceous wetland:	953.4
Total Acres:	**762,830.8**

Table A.3: Regression Equations for Estimating Peak Discharge of Rural Unregulated Streams of the Upper Delaware Basin
(Lumia et al., 2006)

Storm Event	***Region 3***	***Region 4***
2 year	$Q=90.8(A)^{.853}$	$Q=61.3(A)^{.812}$
10 year	$Q=185(A)^{.848}$	$Q=124(A)^{.775}$
25 year	$Q=249(A)^{.843}$	$Q=161(A)^{.761}$

Note: Q = discharge (ft^3/second) and A = area (mi^2)

Table A.4: Sullivan County Residential Permitting Activity: 1990-2006
(Sullivan County, 2007)

Year	**Total Residential Permits**	**Summation: Annual Residential Permits**
1990	600	600
1991	425	1,025
1992	472	1,497
1993	341	1,838
1994	271	2,109
1995	321	2,430
1996	301	2,731

Table A.4 (cont.)

Year	Total Residential Permits	Summation: Annual Residential Permits
1997	318	3,049
1998	326	3,375
1999	353	3,728
2000	316	4,044
2001	462	4,506
2002	637	5,143
2003	390	5,533
2004	595	6,128
2005	848	6,976
2006	742	7,718

Table A.5: GIS Metadata Summary

Data Layer	Author	Publication Date	Data Type	Access Location	Date Accessed
Counties	USGS	2001	Vector	http://www.nationalatlas.gov/atlasftp.html	Jul. 2007
Urban Areas	USGS	2001	Vector	http://www.nationalatlas.gov/atlasftp.html	Aug. 2007
New York State Public Streets	New York State	2007	Vector	http://www.nysgis.state.ny.us	Aug. 2007
National Agriculture Imagery Program Mosaic	USDA	2002	Raster	http://datagateway.nrcs.usda.gov	Jul. 2007
National Land Cover Data 2001	USGS	2003	Raster	www.mrlc.gov	Aug. 2007
National Elevation Dataset (10 m and 30 m)	USDA-NRCS And USGS	2007	Raster	http://gisdata.usgs.net/ned/	Aug. 2007
Hydrologic Unit (watershed boundary)	USGS	2005	Vector	http://www.nationalatlas.gov/mld/hucs00m.html	Aug. 2007
National Hydrography Dataset Plus (NHDPlus)	US EPA and USGS	2005	Vector	http://www.horizon-systems.com/nhdplus/data.php	Aug. 2007

Table A.5 (cont.)

Data Layer	Author	Publication Date	Data Type	Access Location	Date Accessed
National Hydrography Dataset NHD High Resolution	USGS	2006	Vector	http://nhd.usgs.gov/data.html	Aug. 2007
NWI-Enhanced Wetlands	US Fish and Wildlife Service, Northeast Region	2005 (FWS) and 2008 (EPA)	Vector	http://www.fws.gov/nwi/ or http://www.fws.gov/filedownloads/ftp_gis/R5	Aug. 2007
New York State Regulatory Freshwater Wetlands	New York State Dept. of Environm-ental Conservat-ion	2001	Vector	http://cugir.mannlib.cornell.edu	Aug. 2007
SLEUTH Dataset	Claire Jantz, Shippensb-urg University and Sullivan County Planning and Environm-ental Managem-ent Departme-nt, NY	2007	Raster	http://co.sullivan.ny.us	Dec. 2007
Soil Survey Geographic Database	USDA-NRCS	2005-2007	Vector	http://SoilDataMart.nrcs.usda.gov/	Aug. 2007
Omernik's Level III Ecoregions of the Continental United States	US EPA	2005	Vector	http://nationalatlas.gov/atlasftp.html	May 2008

Table 6-a: Stormwater Management Practices and Designs:
Primarily for Water Quality Protection (New York State DEC, 2003)

Stormwater Management Practice (SMP)	SMP Designs	Water Quality Protection		
		Bacteria	*Metal*	*Nitrogen*
Filter	Surface sand filter (SF) [1], underground SF, organic SF, and perimeter SF, bioretention[1]	Good	Good	Good
Infiltration	Dry well, infiltration trench, and shallow I-basin	Good	Good	Fair
Open Channel	Dry and wet swale	Fair	Good	Poor

Note: "good" water quality protection functionality includes pollutant removal rates of: > 70% bacteria, > 60% metals, and > 30% total nitrogen. "Fair" water quality protection includes pollutant removal rates of: 35-70% bacteria, 30-60% metals, and 15-30% total nitrogen. The design of a surface sand filter or a bioretention filter needs to accommodate extra detention to be a good flood control option. [1]

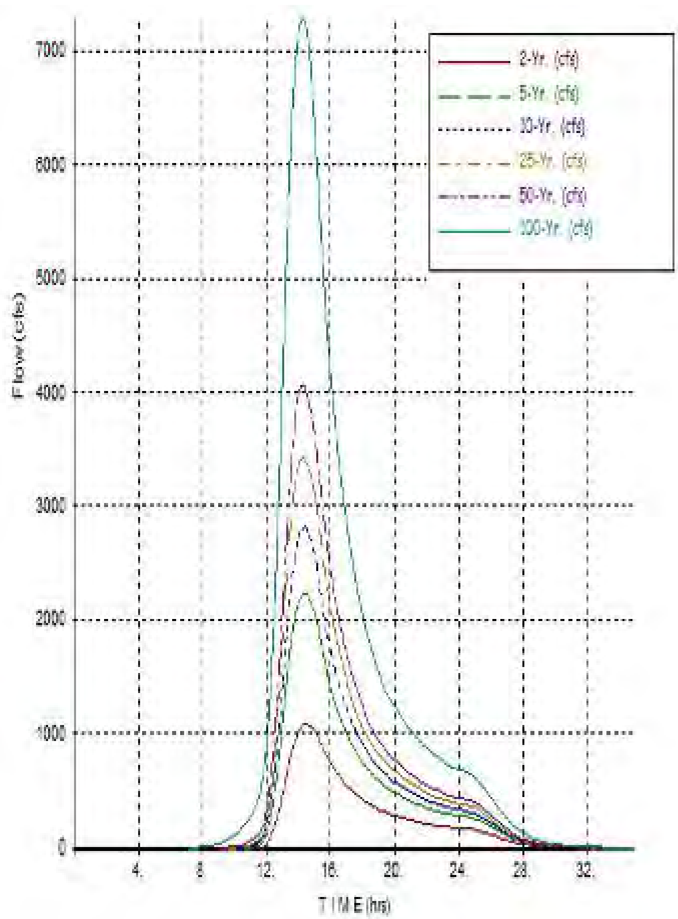

Figure A.1: *TR-55 Hydrograph: Urban Catchment (Stamford and Hobart, NY).*

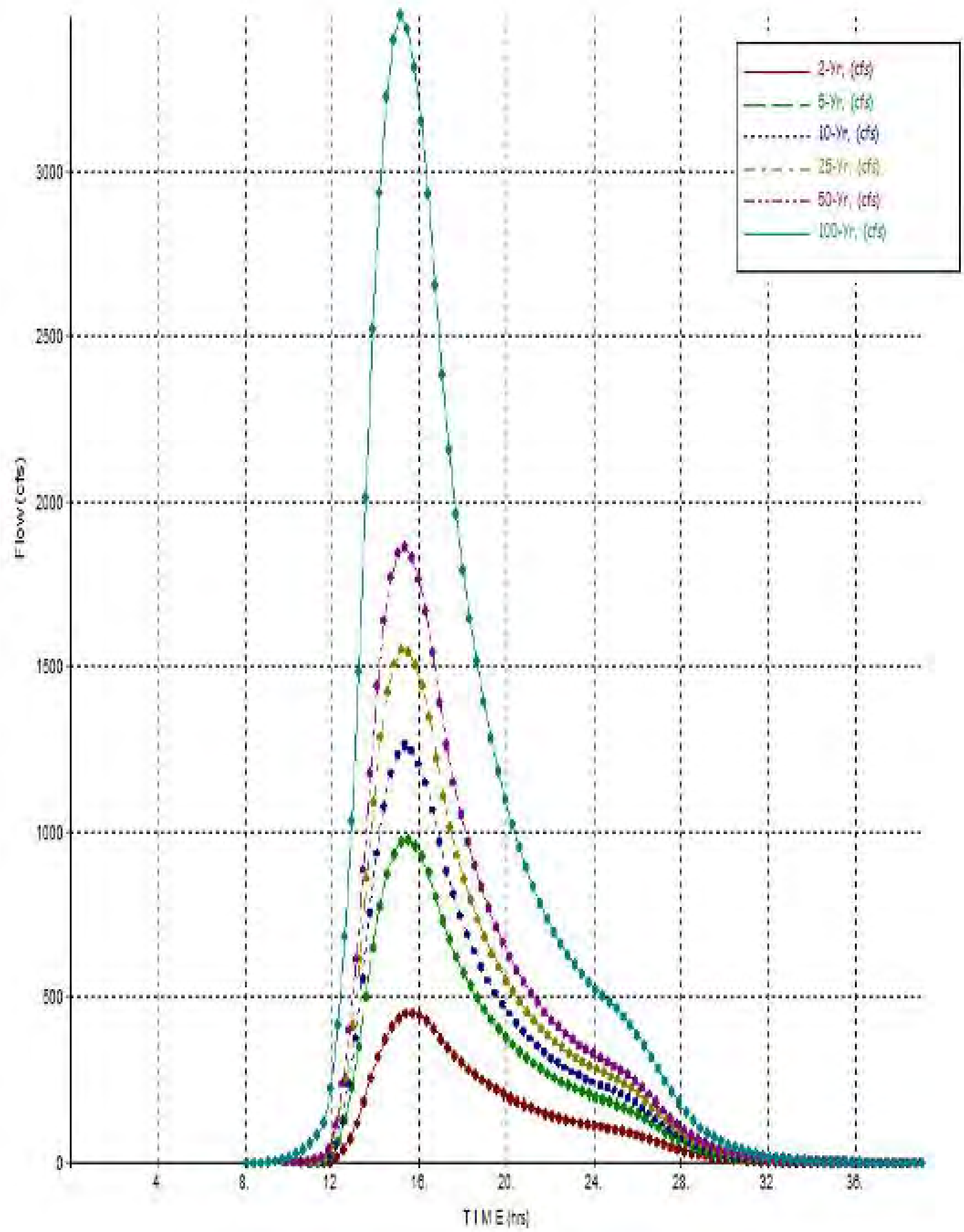

Figure A.2: *TR-55 Hydrograph: Rural Catchment (Delaware County, NY).*

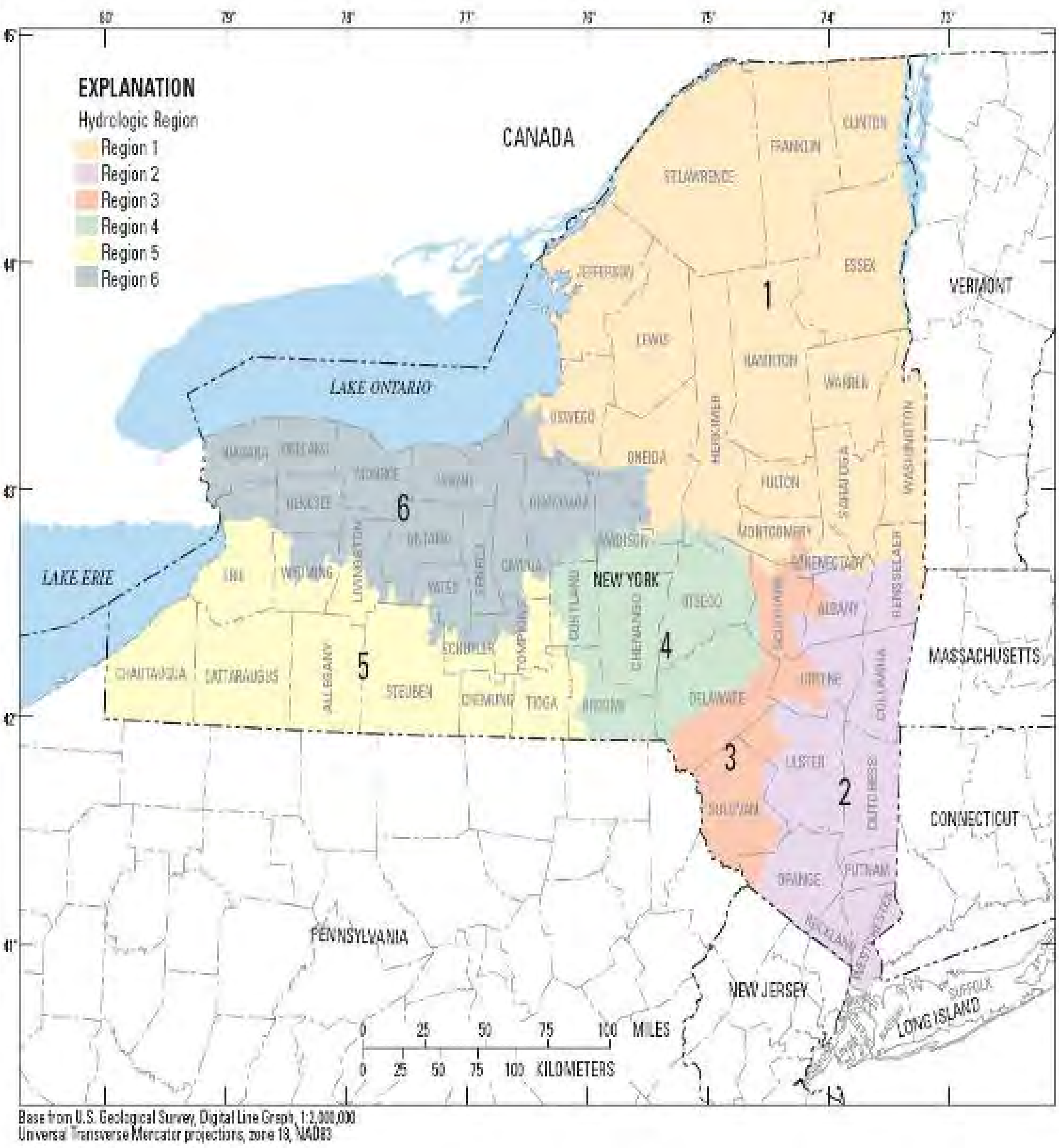

Figure A.3: *Hydrologic Regions for Estimating Peak Discharge of Rural Drainage Areas* (Lumia et al., 2006).

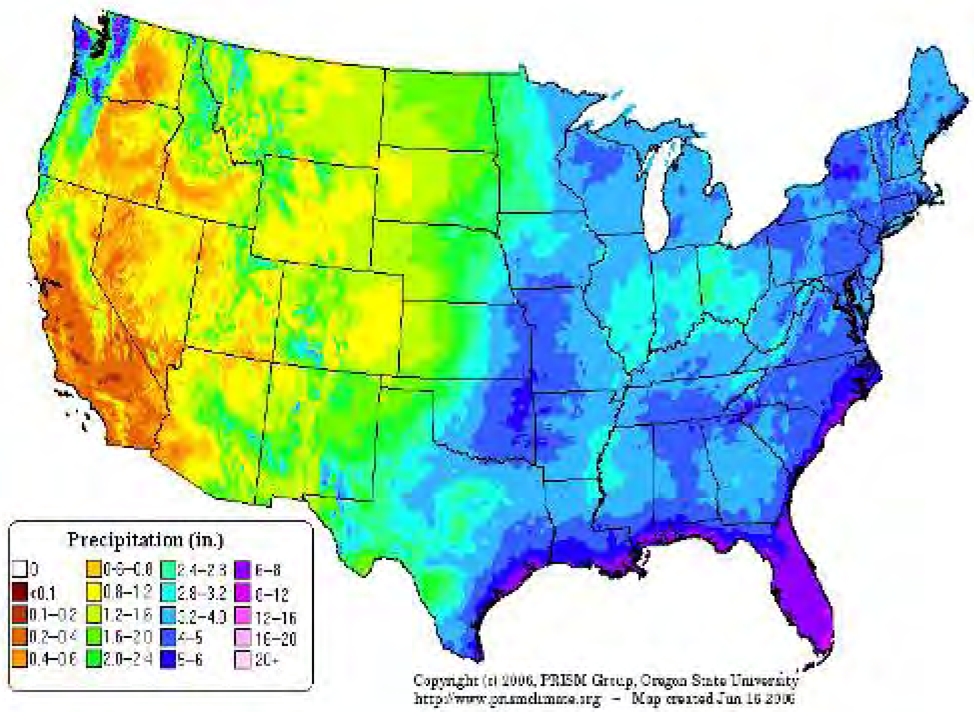

Figure A.4: *Precipitation Records for September 1971 – 2000* (PRISM Group, 2006) Compared to the month of October, September was a wetter time period.

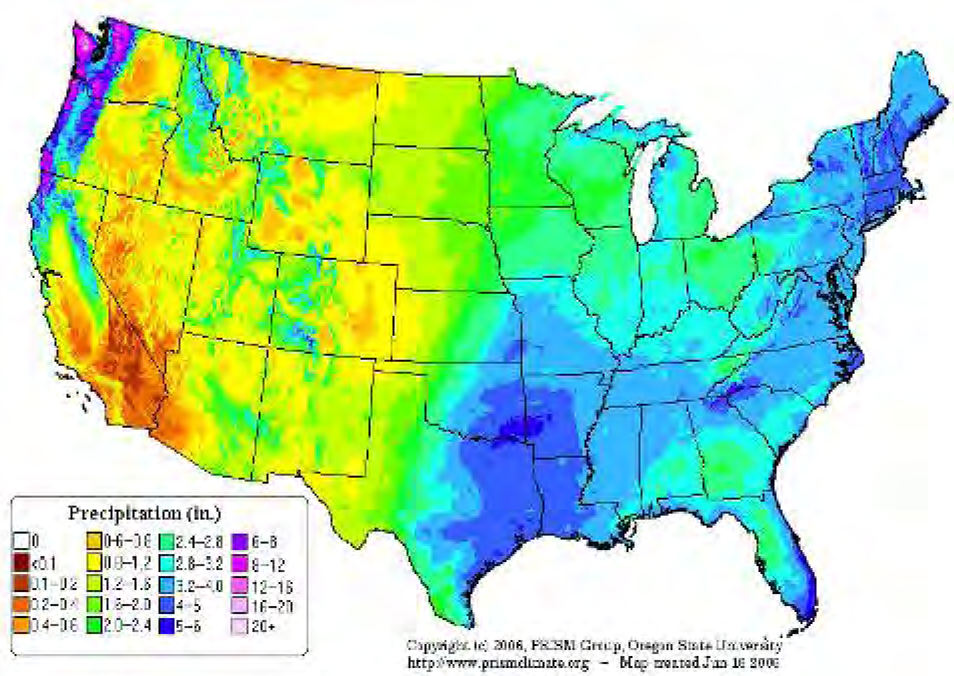

Figure A.5: *Precipitation Records for October 1971 – 2000* (PRISM Group, 2006) October is characterized as a drier month than September.

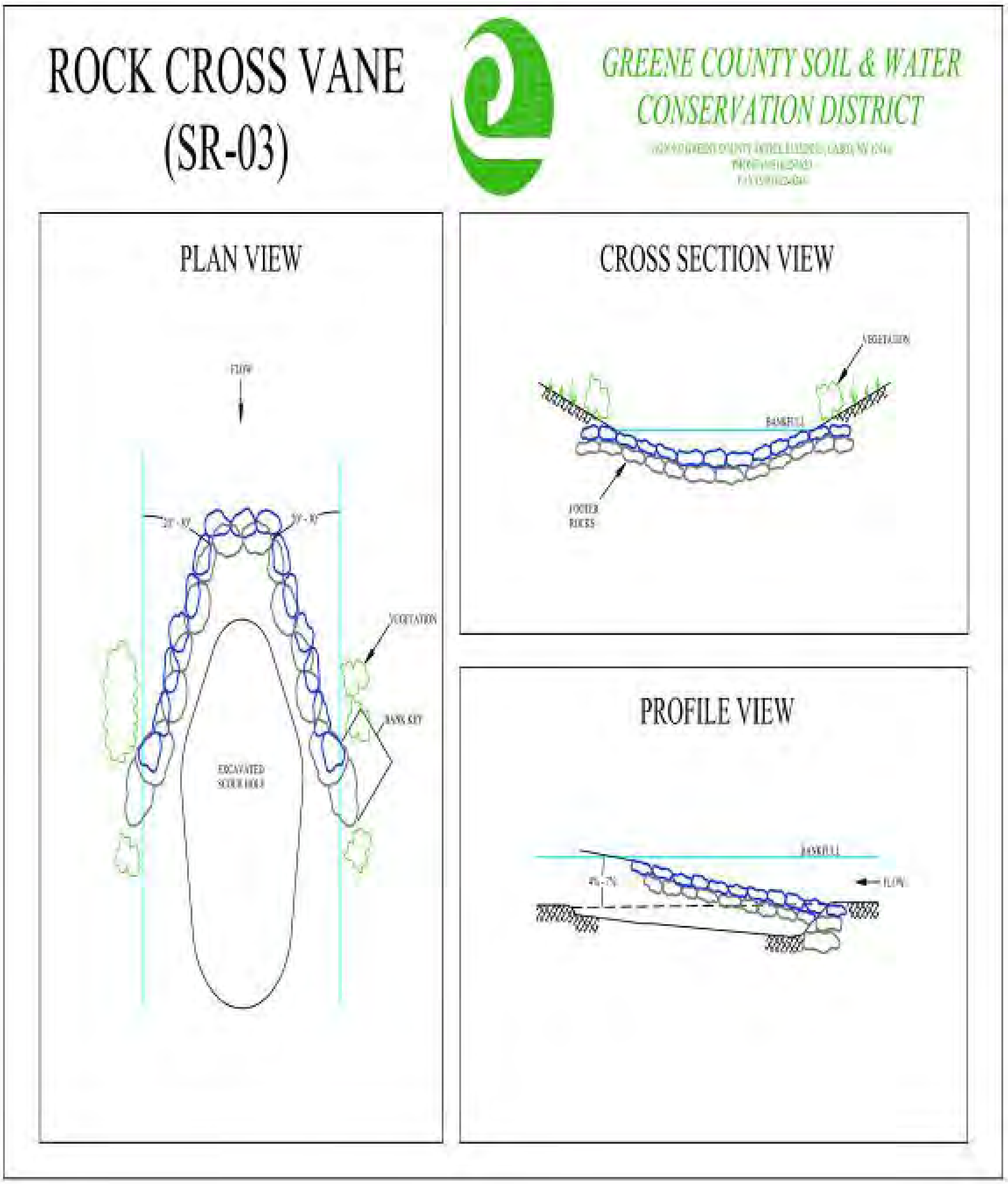

Figure A.6: Typical Rock Cross Vane Structure Construction Drawing (Greene County SWCD, 2007).

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