Alternative Futures for Headwater Stream and Wetland Landscapes in the Upper Delaware Basin, New York, USA

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Project Abstract:

From September 2004 to June 2006, flood events of national significance occurred within the Upper Delaware Basin of New York. The lower portion of the watershed is approximately 120 miles northwest of New York City. In particular, Sullivan and Delaware counties 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 drinking watershed overlaps the Upper Delaware Basin, providing drinking water to millions of people. Degradation of stream resources may also limit recreational uses such as fishing and other recreational activities.

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 flood storage and water quality maintenance, and to both preserve and enhance these functions. Headwater streams and wetlands are especially important as providers of these services.

In order to understand complexities of the watershed, a landscape analysis of flood storage capacity and water quality maintenance contributions of wetlands and streams was completed. Analyses included: 1) watershed-based preliminary assessment of wetland functions (W-PAWF), 2) wetland storage capacity derived from stormwater monitoring of New York Department of Environmental Protection reference wetlands, 3) identification of aggregated headwater stream networks, and 4) stream corridor condition assessment, using a Cornell Streamside Health Model.

The wetland assessment prioritized National Wetland Inventory wetlands having high or moderate performance values for: surface water detention, nutrient transformation, and nutrient and particulate retention. Most NWI wetlands had moderate or high values. Stormwater monitoring of reference wetlands derived estimates of stormwater storage capacity of all digitally available NWI wetlands for both a one year (prior dry conditions) and one hundred year (prior wet conditions) storm event. Results show that there is a deficit of flood storage capacity from existing wetland and stream resources. 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 81.21% (1,745.38 stream miles) of the total stream network as headwater reaches. Streamside condition results prioritized degradation potential using adjacent land-uses ranging in human induced disturbance. 76% of headwater stream reaches are predicted to be in excellent or good conditions. The remaining 24% of stream corridors are predicted to be in fair to poor conditions.

In addition to baseline ecological and hydrologic conditions, alternative future scenarios were created based on selected ecosystem services of headwater streams and wetlands. The SLEUTH (slope, landcover, exclusion, urbanization, transportation, and hillshade) urban growth model, calibrated for the Upper Delaware Basin was used to project future scenarios for 2030. Using predicted flood attenuation and water quality functions, general scenarios tested: 1) existing urban development trends and protection of wetlands and streams and 2) different levels of wetland and stream buffer protection. The baseline scenario looked at the protection of all existing NWI wetlands with high or moderate performance of these functions and New York State Department of Environmental Conservation freshwater regulatory wetlands. Under existing development trends, Sullivan County will experience increased levels of impervious surface coverage that is likely to negatively impact stream and wetland resources.

Ecological, hydrologic, and urban growth analyses provided necessary information for selecting appropriate conservation designs for 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. I conclude the baseline analyses of ecological and hydrologic functions from this study informed appropriate selection of conservation design-based BMPs for possible flood and water quality management strategies for an urbanizing Upper Delaware Basin. This project is applicable to watersheds across the world having to find solutions for managing more frequent intense floods and increases in urban development.

Introduction:

History of Flooding and 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, 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 property, human life, stream-bank erosion, sediment accumulation, and degraded water quality and aquatic habitat (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 of the historic population centers of Delaware and Sullivan counties are at risk to frequent floods, because they are located in valleys, along side streams, and reservoirs (Delaware County, 2006). Such impacts have not occurred in the region since the flood of 1955 (Delaware River Basin Flood Mitigation Task Force, 2007).

Additionally, 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 occur frequently within Delaware County, as there are many 100 year and 500 year floodplains within the county (Delaware County, 2006).

Some of the possible reasons behind the flooding events include: increases in the percent of impervious surfaces and amount of urban development, channelization of tributaries or drainage ditches, reservoir management, loss of riparian vegetation and other natural infiltration areas, and the installation or retrofitting or conventional stormwater pipes discharging into the Delaware River (Delaware River Basin Flood Mitigation Task Force, 2007). One example of a future development in Sullivan County involves the construction of a Native American casino (New York State, 2007). With this facility would come hard surfacing from additional parking lots and future adjacent buildings. Other areas in Sullivan County are experiencing increased development pressures with people investing in second homes (Sullivan County, 2007). Vegetation lost due to development causes the floodplain to lose its ability to infiltrate flood waters and stabilize soil resources; causing increased soil erosion and flash flood events.

The primary reason for the flood events was unusually large amounts of rain and snowmelt during and prior to the floods. Over a seven-day time span during the June 2006 flood, certain areas in the northern and western parts of the basin received over 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, which is a part of the Upper Delaware Basin, where precipitation during March was above normal (Suro et al., 2006). During the 2005 and 2006 flood events the stream reaches and soils were probably completely saturated with little capacity to store additional water. The public is concerned that human induced modifications of the basin, such as land development, reservoir management, and other floodplain encroachment will cause past flood events to occur on an annual basis (Delaware River Basin Flood Mitigation, 2007).

Community stakeholders affected by the flood events have resorted to various emergency solutions to restore damaged properties or stream reaches. According to the New York State Department of Conservation (NYSDEC) the most common solutions for fixing local streams include stream bank stabilization with rip rap or sediment removal from small streambed reaches

(Issacs, 2007). These stream projects are permissible under a permit issued by the NYSDEC, but many projects are conducted illegally without permits. 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, 1998). 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, 1998). Hardening of the streambank prevents natural lateral stream migration within the floodplain and forces high-energy laden waters downstream (Bernhardt and Palmer, 2007). Resultant downcutting 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 their water filtration and evapotranspiration functions of stream waters (Bernhardt and Palmer, 2007).

Characteristics of the Watershed:

Location:

The Upper Delaware Basin is an eight digit hydrologic unit code (HUC-8), cataloging unit, or a watershed. Which means it 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. It is located northwest of New York City and is within driving distance. Stamford, located at the top of the watershed is about 160 miles from New York City. Close to the bottom of the watershed is Narrowsburg, located about 120 miles from New York City.

Part of the New York City drinking water supply system is located in and adjacent to the Upper Delaware Basin. Various reservoir basins make up the New York City watershed within the Catskill Mountains region. Protecting drinking water quality within the New York City watershed is of utmost importance to stakeholders in New York City and the New York City Department of Environmental Protection. The Cannonsville Reservoir is the only reservoir located within the Upper Delaware Basin. Other reservoirs are located within basins adjacent to the Upper Delaware Basin.

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. There are three Omerik Level III ecoregions located within the Upper Delaware Basin, including the Northern Appalachian Plateau and Uplands, the Northeastern Highlands, and the North Central Appalachians. 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 along 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. 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. 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, depicts a minimum elevation of 747.15 feet and a maximum of 3,089.07 feet. The total topographic relief is 2,341.92 feet.

The existing topography of the watershed was formed by recent glaciations. The parent material of most soils originates from glacial till deposits in the uplands. The layer of till is commonly thin and stony, with a depth of 40 inches. Underneath the permeable glacial till usually resides a slow 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. Less often found are "fluvaquents," which are frequently flooded along narrow stream channels (Delaware County Soil and Water Conservation District, 2004).

Land use and cover:

In the upland region deciduous forest is the dominant vegetative coverage within the West Branch basin (Cannonsville basin, northern part of the Upper Delaware 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 cover along streams, tributaries, and hillsides include mainly 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 coverage only makes up a small fraction of the West Branch basin at about 0.1% (Delaware County Soil and Water Conservation District, 2004). The most dominant and pervasive land uses within the West Branch basin include dairy farming and forestry (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 dominant land-cover types of the Upper Delaware Basin include: deciduous forest, mixed forest, and pasture/hay.

Existing Wetland Resources:

The Upper Delaware Basin has a variety of wetland resources, ranging in size, vegetation, and hydrologic conditions. **Table 1** and **Table 2** provided details about the spatial extent of digitally available National Wetlands Inventory data for the Upper Delaware Basin. A portion of the watershed currently does not have digital NWI data. The New York State Department of Environmental Conservation (DEC) does have digitally mapped wetlands for areas missing digital NWI data. Most analyses completed in this study relied mainly on digital NWI data for matters of consistency. Field identification of non-digitally available NWI wetlands was conducted in the fall of 2007.

Table 1: Upper Delaware Basin NWI Wetland Surface Area Summary

Total NWI Wetland Acres	21,659.1
Total NWI Wetland M^2	87,651,262.04

Table 2: Upper Delaware Basin Wetland Types (NWI data, current as of 1997)

Wetland Type	**Total (acres)**	**Percent of Total Wetlands**
Freshwater Emergent Wetland	3,019.30	13.94
Freshwater Forested/Shrub Wetland	5,669.99	26.18
Freshwater Pond	2,808.55	12.97
Lake	8,273.22	38.19
Other	13.20	0.06
Riverine	1,876.25	8.66
Total Wetlands	21,660.5040	100.00

Note: this chart only accounts of currently available NWI digital data. A portion of the Upper Delaware Basin currently does not have digital NWI data.

Wetland Gains and Losses:

The Upper Delaware Basin is located within the Appalachian Highlands Ecoregion, which was one of the study areas for the Huffman & Associates 1999 report. Historically (circa 1780s) wetlands made up 5-12% of total land-cover of the Upper Delaware Basin (Dahl, 1990). According to the 2001 USGS National Land Cover Dataset wetlands make up only 1.21% of total land-cover of the basin. Wetlands located within the Appalachian Highlands Ecozone in 1999 represented 3.6% of the surface area, but the statewide average was 7.2%. The percentage of wetlands greater than 12.4 acres is also smaller in the Appalachian Highlands Ecozone/Ecoregion. 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, 1999). Under the New York state Freshwater Wetlands Act, wetlands smaller than 12.4 acres are not protected (New York State Department of Environmental Conservation, 2008). This leaves a good proportion of the wetlands within the Appalachian Highlands Ecozone unprotected from land-use change.

The most recent and focused trends analysis (1980s to 2003) of the Delaware watershed (includes the Cannonsville Reservoir Basin and basins within the New York City watershed but outside of the Upper Delaware Basin) there is a reported gain of 3.99% of wetland coverage (Tiner et al., 2005). Although there have been gains in total wetland coverage, the actual ecological quality and performance of constructed wetlands may be of lesser value than natural wetlands.

Defining Headwater Streams:

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, 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, 2003 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). Within the sub-basin the aggregated lengths of headwater stream reaches includes about 73% of the total stream network's length.

Importance of Headwater Streams and Wetlands:

Wetland functions:

Northeastern wetlands provide important ecological/hydrologic functions within the Upper Delaware Basin, which affect water quality and flood management. The mass majority of wetlands have hydrologic connections to stream networks or other wetlands via groundwater pathways. Both wetlands and headwater streams share common ecological and hydrologic functions. Some of the areas are missing digital GIS data, but hard copy data does exist.

Some of the most relevant wetland functions included: nutrient transformation; stream flow maintenance; surface water detention; sediment and particulate retention; inland shoreline stabilization; and diverse wildlife habitats. **Table 3** describes most of these functions in greater detail.

Table 3: Wetland Functions
(Tiner, 2003)

Wetland Function	Description
Nutrient transformation	• Retain sediments and adsorbed nurtrients. Periodically flooded and seasonally saturated wetlands perform this function. • Nitrogen fixation via micro-bacterial reduction ($N0_3$ to N_2 gas). • Phosphorus removal via plant uptake.
Stream flow Maintenance	• Source of groundwater that may sustain streamflow. • Headwater wetlands provide streamflow. • Floodplain wetlands detain water as bank storage and later release it as streamflow.
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.
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 likely will capture sediments.
Inland shoreline stabilization	• Vegetated wetlands stabilize soil or substrate and reduce erosion.

Headwater stream functions:

Headwater streams provide many important ecological and hydrologic functions within a given watershed. About 53%, 2,900,000 km (1,801,976.46 miles), of total stream length in the United States, excluding Alaska is comprised of headwater streams. Ephemeral and intermittent streams comprise 50 %, 1,460,000 km (907,201.94 miles), of total headwater stream length in the U.S., not including Alaska. In New York ephemeral and intermittent streams make up 11%, 11,900 km (7,394.32 miles), of total stream length (Nadeau and Rains, 2007). It is important to assess the total spatial scale of the headwater stream network of the Upper Delaware Basin to predict total contributions of ecological and hydrologic functions.

Some of the main ecologic and hydrologic functions that headwater streams provide within a given watershed included: mitigating flood frequency and intensity; storage and recharge groundwater resources; trap sediments and pollution; maintenance of water quality and quantity; recycling of nutrients; and diverse habitats for flora and fauna (Meyer et al., 2003). **Table 4** provides more in depth descriptions of these functions.

Table 4: Headwater Stream Functions:
(Meyer et al., 2003)

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.
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. • Reduce nutrients flowing to downstream reaches. • Riparian vegetation reduces sediment loads to streams.
Maintenance: water quality and quantity	• Moderate high flow (flood) and maintain low flow (dry/drought) volumes. Baseflow regulates groundwater flow to stream channel during dry periods.
Nutrient recycling	• Aquatic organisms consume 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. • Microorganisms transform organic matter into food for other aquatic organisms.
Nutrient recycling	• Headwater streams act as sources of dissolved organic carbon (from in-channel (autochthonous) and out of channel (allochthonous) sources).
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 species, including: algae, bacteria, fungi, aquatic and terrestrial plants, invertebrates, fish, amphibians, birds, and mammals.

Alterations of Headwater Streams and Associated Impacts:

Urban development which occurs within landscapes containing headwater streams, wetlands, and riparian areas alters localized and downstream hydrologic and ecologic functions. The most probable headwater stream modifications that have occurred in Delaware and Sullivan counties are: piped discharge, hard surfacing, streambed disturbance, streambank armoring, and channelization (Issacs, 2007). 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 usually impervious surfaces that direct water at greater velocities and shorter temporal scales to nearby streams. Streambank armoring is used to stabilize banks and prevent soil erosion. Stream channelization 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, 2007). Unfortunately this action only causes more sediment to return to the streambed over time. 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 and there is not a collective watershed management approach for avoiding or mitigating negative effects of flooding events (Issacs, 2007). Successful long term stormwater management (improved water quality and reduced peak storm flows) 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 general all of these modifications have negative effects on the stream corridor system. Most of them increase 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 recently become an important issue with the Supreme Court rulings related to the Clean Water Act (CWA). 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, Carabell v. Army Corps of Engineers*, and *S.D. Warren Co. v. ME Board of Environmental Protection*. These recent court rulings highlight the need to determine CWA jurisdiction 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).

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 reactionary fix and rebuild solutions with flood events within the Upper Delaware Basin. In order for this to occur various studies, plans, and funds will be necessary to allow people to understand how best to live in floodplain areas. Floods will always occur and people need to learn to live harmoniously with annual flood events (Delaware River Mitigation Task Force, 2007. Any future successful floodplain management should address the ecological and hydrologic functions of headwater stream reaches and wetlands. An understanding of baseline conditions of ecological services or functions provided by wetlands and headwater streams will provide important information for existing and future stormwater management and urban planning needs.

Existing stream, county, and municipal plans in the Upper Delaware Basin do not focus on the ecological services provided by wetlands and headwater streams. This study provides analyses which focus on ecologic and hydrologic functions of baseline conditions of wetlands and headwater streams. Any deficits of ecological services, focusing on water quality protection and flood attenuation, are addressed with alternative future scenarios and appropriate BMPs for protecting, preserving, enhancing, and restoring ecological functions.

Main Research and Design/Planning Questions:

This study asks many questions relating to how ecological services provided by wetland and headwater streams resources contribute to flood and water quality management in regards to sustaining human well being. A basic understanding of existing baseline ecological services, focusing on water quality protection and flood attenuation functions was assessed at the watershed scale. Based on the baseline ecological functions, do existing conditions provide sufficient levels of service for water quality protection and flood attenuation needs? Assessing baseline conditions of the ecological functions at the watershed scale required using GIS resources. Various GIS-based assessment tools were evaluated and utilized for the purpose of understanding baseline ecological functions of wetland and headwater stream resources.

Once there was an understanding of the baseline ecological services, the focus of analyses looked at existing urban development and land use trends. How do these existing trends affect the delivery of baseline ecological services? Do existing land-use change trends conflict with flood and water quality protection management needs? If there was a conflict of interest between existing development trends and delivery of sufficient ecological services, what alternative future scenarios could be proposed? Alternative futures explored both existing development trends and conservation and protection of wetland and stream resources. Proposing alternative futures for the watershed allows stakeholders to understand that development needs and delivery of sufficient of ecological services can occur together or separately.

Once broad-based alternative futures are proposed for the counties within the watershed, what best management practices (BMPs) can be used as design templates for supporting development needs and appropriate levels of ecological services? What BMPs are appropriate for urban and rural catchments? What different scales of development can incorporate BMPs to create the desired alternative future?

After all of these assessment tools and results have been compiled how can they compliment existing stream and county management plans? Can the results from this study give stakeholders within the watershed a better understanding of how to manage ecological services that protect water quality and mitigate flood events? For watersheds experiencing similar issues as the Upper Delaware Basin, how can assessment tools used in this study be applied again?

Methods:

Headwater Stream Delineation:

In order to create a headwater stream network using GIS resources, three different data sources were compiled. These included NHDPlus (1:100K resolution), National Hydrography Dataset high resolution (1:24K), and New York City Department of Environmental Protection (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. In order 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. Statistical 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 watershed. Data was extrapolated from the NYCDEP headwater streams to the entire Upper Delaware Basin to give an idea of what the overall increase in potential headwater stream length would be.

Comparisons were made between the different headwater stream resolution datasets; also the overall contribution of headwater streams to all streams within the watershed was analyzed.

Hydrologic Analyses:

USGS Stream Gage Monitoring

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 gages were located within the watershed using a GIS data set. Only a small portion of the stream gage locations had long term monitoring. Two stream gages with long term monitoring data and locations towards the bottom of the watershed were selected for analysis. It was assumed that stream gages further down in the watershed would display the overall trends of changes in annual peak discharge rates.

USGS stream gage “01434000” Delaware River at Port Jervis, NY is located towards the end of the Upper Delaware River Basin in northwestern Orange County. The monitoring period for the Port Jervis stream gage was from 1904 to 2006 (102 year). The southern most USGS stream gage within the Upper Delaware Basin is USGS stream gage “01428500 Delaware River above Lackawaxen River near Barryville, NY.” This second stream gage had monitoring data available from 1964 to 2006 (42 years).

Climate Change Assessments

An analysis of previous climate change studies of New York and the Catskill Mountains region, focusing on precipitation and flooding was conducted. Additional analysis involved looking at long term mean annual stream discharge rates within the watershed.

An additional climate change assessment focused on changes in predicted extreme precipitation for a 24 hour accumulation period and recurrence intervals of 2, 10, and 100 year from 1993 to 2003. Isohyetal maps depicting the different extreme storm events were collected from the Northeast Regional Climate Center's website. Changing trends in the frequency and intensity of extreme precipitation events were analyzed for stormwater management needs.

Impervious Surface Model

Once the larger scale hydrologic trends were completed an "impervious surface model" created by the Center for Watershed Protection was applied to selected headwater catchments. The impervious surface model assumes that 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 manmade impervious surfaces, such as roads, parking lots, and buildings are closely located 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 subwatershed scale (.5 – 30 square miles) the appropriate use of the model for stream management. The NHDPlus catchtments within the watershed are the same size as the subwatersheds mentioned by Zielinski, 2002. **Table 5** provides detailed classifications of predicted impacts and concerns related to certain levels of impervious surface coverage in a given subwatershed.

Table 5: Impervious Surface Model of Headwater Streams:
Quality Assessment Classifications
(Adopted from Center for Watershed Protection, 1995)

Headwater Stream Classification	**Sensitive Stream: 0-10% Impervious Surface**	**Degrading Stream: 11-25% Impervious Surface**
Stability of Channel	Stable	Unstable
Water Quality	Good-Excellent	Fair-Good
In-stream Biodiversity	Good-Excellent	Fair-Good
Resource Concern(s)	Maintaining channel stability and Protecting biodiversity	Restoring or maintaining Stream quality
Water Quality Concern(s)	Controlling sedimentation and maintaining proper water temperature	Controlling metal and nutrient loading

In order to prioritize catchments for use with the impervious surface model, an analysis of all existing land cover types was conducted. The National Land Cover Data set 2001, the most current national land cover data set, 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, NHDPlus catchments, urban areas, and public roads the "impervious surface threshold" 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.

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. In order 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 was 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 is between twenty acres (.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'Conner, 2008, Fennessey, 2001, and TR-55 Workgroup, 2002). The two catchments used for this study fall within the applicable spatial range for small wooded watersheds. Also, model analyses were compared to actual USGS recorded peak flow discharges for drainage areas of similar size and storm event return interval.

Functional Assessments:

Watershed-based preliminary assessment of wetland functions

A functional assessment of all NWI wetlands within the Upper Delaware Basin was conducted using the U.S. Fish & Wildlife Service's "Watershed-based Preliminary Assessment of Wetland Functions (W-PAWF) (Tiner, 2003). The U.S. Fish and Wildlife Service adopted the hydrogeomorphic assessment method developed by Dr. Mark Brinson to assess functions of NWI wetlands (Tiner, 2003). From this assessment predicted ecological functions have been determined, including surface water detention, sediment retention, nutrient transformation, shoreline stabilization, and streamflow maintenance. These ecologic 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 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 classified. 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 New York State Department of Environmental Conservation (DEC) has digitally mapped wetlands for this portion of the Upper Delaware. DEC freshwater wetlands are only mapped if they are 12.4 acres or larger. Within the area of the Upper Delaware Basin lacking digital NWI data, 108 DEC wetlands exist. A total of 2,384.09 acres are accounted for with these DEC wetlands. The W-PAWF assessment was not applied to the DEC wetlands because they did not include the NWI Cowardian classifications. Also the DEC wetlands represent a small portion of all wetlands mapped within the Upper Delaware Basin.

Cornell Streamside Health Assessment

Stream functions are affected by adjacent land-cover and land-uses. In order to assess the probable functionality of headwater stream reaches a "streamside health model analysis was completed for all headwater streams within the Upper Delaware Basin. In order to understand the overall ecological health of streamside habitats of the watershed, a GIS-based model created by Marxi Meixler, 2003 was implemented. 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 highly human modified land-cover types are predicted to have the lowest rating for streamside health.

The model uses various GIS data sets 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 USGS National Land Cover Dataset (NLCD) 2001 (land-cover). 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 26.90547493 m^2. Once the streamside buffer is in a grid format, the grid is 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. **Table 6** outlines the streamside health model classification of streamside conditions as they relate to the NLCD 2001 land-cover types.

Table 6: 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
Poor	Developed Open Space
	Cultivated Crops
Very Poor	Developed Medium Intensity
	Developed High Intensity
	Barren Land

Flood Storage Assessment:

Wetland Stormwater Monitoring and Storage Capacity

Stormwater monitoring data from two NYC DEP reference wetlands was 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. The NYC DEP stormwater monitoring data recorded surface water inputs and outputs of high performing wetlands in different places within the New York City drinking water watershed. Results of reference wetlands detaining stormwater from different storm events were used to predict storage capacity of all NWI wetlands with predicted moderate to high performance functionality.

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; 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. Understanding the existing stormwater detention deficits allowed for recommendations for additional storage capacity for the aforementioned 1 and 100 year storm events.

Urban Trend and Land-cover Change Analyses:

Wetland Loss and Gains

It is important to understand how land-use change has been affecting the abilities of wetlands to perform important ecologic 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 status and trends analyses of wetland resources applicable to the Upper Delaware Basin have been conducted 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 ecoregions (Huffman and Associates, 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-use change. Results from the watershed specific, Delaware Watershed within the New York City drinking watershed, provides the most accurate portrayal of wetland land-use change within the Upper Delaware Basin.

Building Permit Activity Trends, Sullivan County, NY

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. Greater annual rates of additional residential units have been occurring in Sullivan County for since 1990 (Sullivan County, 2007). Understanding the amount of and trend of additional residential building permits gives insight to possible implications on valued ecological services from previous land-cover types. 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 drinking water watershed.

SLEUTH Urban Growth Model

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). In order 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 hillshade (Woods Hole Research Center, 2008).

Using historical impervious surface maps (representing urban development) from 1986 to 2006, SLEUTH is 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 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. Existing and alternative future development scenarios were compared to plan out delivery of critical ecological services.

GIS Database:

Most of the assessments and analyses carried out in 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 conducted. All of the datasets were collected for free 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.

Once the GIS data was 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. A summary of EPA's metadata standards is provided in **Table 7**.

Table 7: 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.
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	Currentness of metadata information and the party responsible for it.

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 hydrologic functions of wetlands; conditional assessment of headwater stream corridors: climate change; stormwater monitoring; urban and wetland land cover change; and 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 recommended BMPs acts as a toolbox to use for stormwater management. BMPs currently used within the New York City drinking watershed and New York state formed the basis of BMP design precedents and recommendations. Sources of BMP designs came from Greene County Soil and Water Conservation District, the New York State DEC, 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 greater 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 mainly based on the amount of existing and expected urban development (impervious surface cover). Rural catchments with headwater stream corridors in fair to very poor conditions were also prioritized for implementation of BMPs.

The scale of recommended BMPs ranged from residential developments, roadways, sidewalks, parking lots, individual housing units, 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.

Economic Valuation of Ecological Functions

The ecological functions provided by wetlands and headwater streams may be attributed to various economic values. Providing an economic valuation of the ecological functions allows society to understand approximate costs associated with wetlands and headwater streams. Within the context of this study, flood attenuation and water quality protection are the primary functions of interest.

Some of the negative economic losses caused by flood events are avoidable with proper stormwater management and planning. The existing landscape and environmental conditions of the Upper Delaware Basin cause there to be a need for increases in delivery of 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 ecologic 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 be potentially avoided with future investments in improving and enhancing ecological services of wetlands and headwater stream resources.

Integrating Assessments, Alternative Futures, and BMPs into Existing Stream and County Management Plans

In order for this project to have the greatest impact on watershed management of the Upper Delaware Basin, methods and results utilized need to be disseminated to county, municipal, and other local stakeholders. Existing county and stream management plans within the Upper Delaware Basin have opportunities to incorporate methods, tools, and results from this project into existing stormwater and water resources management goals and objectives.

Three existing county and stream management plans were analyzed, Delaware County Action Plan, Sullivan County: Sullivan 2020 Toolbox, and the West Branch of the Delaware River Stream Corridor Management Plan, for the potential to fill in management gaps of wetland and headwater stream resources. Management goals and objectives from these plans were aligned with the outcomes from this watershed management study.

Results:

The results section mostly includes sections of the project that dealt directly with GIS applications. Some results based indirectly on GIS applications are also included in this section. Further results are available for the other sections upon request from the primary author.

Headwater Stream Delineation:

Headwater streams provide many important ecological and hydrologic functions within a given watershed. About 53%, 2,900,000 km (1,801,976.46 miles), of total stream length in the United States, excluding Alaska is comprised of headwater streams. Ephemeral and intermittent streams comprise 50 %, 1,460,000 km (907,201.94 miles), of total headwater stream length in the U.S., not including Alaska. In New York ephemeral and intermittent streams make up 11%, 11,900 km (7,394.32 miles), of total stream length (Nadeau and Rains, 2007)

In the Upper Delaware Basin, **Table 8** shows the stream length statistics for streams in: the whole basin (1:100K resolution), headwater catchment basins (first and second order streams). The percentage of total headwater catchment basin stream length is compared to the total Upper Delaware Basin stream length in “Calculations from **Table 8**.” From these calculations it appears that 77.62% of the total stream 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. In the Upper Delaware Basin NHDPlus headwater catchment basins there is a total of 963.55 stream miles. These same catchment basins at the 1:24K scale contain 1,243.72 stream miles. **Table 9** outlines the stream length statistics for the 1:24K headwater streams in the watershed. There is a difference of 280.17 stream miles between the 1:100K and 1:24K NHD data-sets. **Figure 1** highlights the difference in stream miles between the medium and high resolution stream data.

Table 8: 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)**
Upper Delaware Basin	All stream segments	1,241.37
Headwater catchment basins	First order streams	740.19
	Second order streams	223.36
	Summation of first and second order streams	963.55

Note: headwater stream segments based on USGS NHDPlus 1:100K flow-line data.

Table 9: Stream Length Statistics: Upper Delaware Basin Headwater Streams and Basins (1:24K flowlines)

Water Boundary	**Stream Category**	**Total Length of Stream System (miles)**
Upper Delaware Basin	All stream segments	2,149.33
Headwater basins	NHD 1:24 K	1,695.39
	New York City Department of Environmental Protection (NYCDEP) (limited basins)	667.21 (49.99 additional miles)
	Summation of NHD and NYCDEP streams	1,745.38

Note: NYCDEP streams dataset only includes portions of the New York City watershed within the Upper Delaware Basin. NYCDEP streams only cover 39.09% of the surface area of all headwater basins. If NYCDEP 1:24 K data covered the entire Upper Delaware Basin the total headwater stream length would equal

Calculations from Table 8:

- Total Headwater (first and second order streams) Stream Length / Total Upper Delaware Basin Stream Length =
  963.55 / 1,241.37 = **77.62 %**
- Total First Order Stream Length / Total Upper Delaware Basin Stream Length = 740.19 / 1,241.37 = **59.63%**

Calculations from Table 8 and 9:

- *Percentage of 1:24 K Stream Network Classified as Headwaters*: (1,745.38/2,149.33)*100 = **81.21%**
- *Additional Stream Miles From 1:24 K data:* Total Headwater Stream Length (1:24 K) - Total Headwater Stream Length (1:100 K) = 1,745.38 - 963.55 = **781.83 miles**
- *Percent increase of Headwater Stream Length from 1:24 K data:* [(Total Headwater Stream Length (1:24 K) - Total Headwater Stream Length (1:100 K)]/ (Total Headwater Stream Length (1:100 K))]*100 = [(1,745.38-963.55)/(963.55)]*100 = **81.14%**
- *Increase of Stream Length from NYCDEP Streams (within NYCDEP headwater basins):* NYDEP 1:24K Headwater Stream Length – NHD 1:24K Total Headwater Stream Length = 667.21 – 617.22 = **49.99 miles**
- *Percent Increase of Stream Length from NYCDEP Streams:* [100- ((NHD 1:24 K within NYCDEP basins / NYCDEP 1:24 K)*100)] = [100- ((617.22 / 667.21) *100)] = **7.49 %**
- *Predicted headwater stream length from extrapolating NYCDEP 1:24 K stream data to all headwater stream basins within the Upper Delaware Basin:*
  (% Increase of Stream Length * NHD 1:24 K Total Headwater Stream Length) + NHD 1:24 K Total Headwater Stream Length = (.0749*1,695.39) + 1,695.39 = **1,822.37 miles (126.98 extra stream miles)**

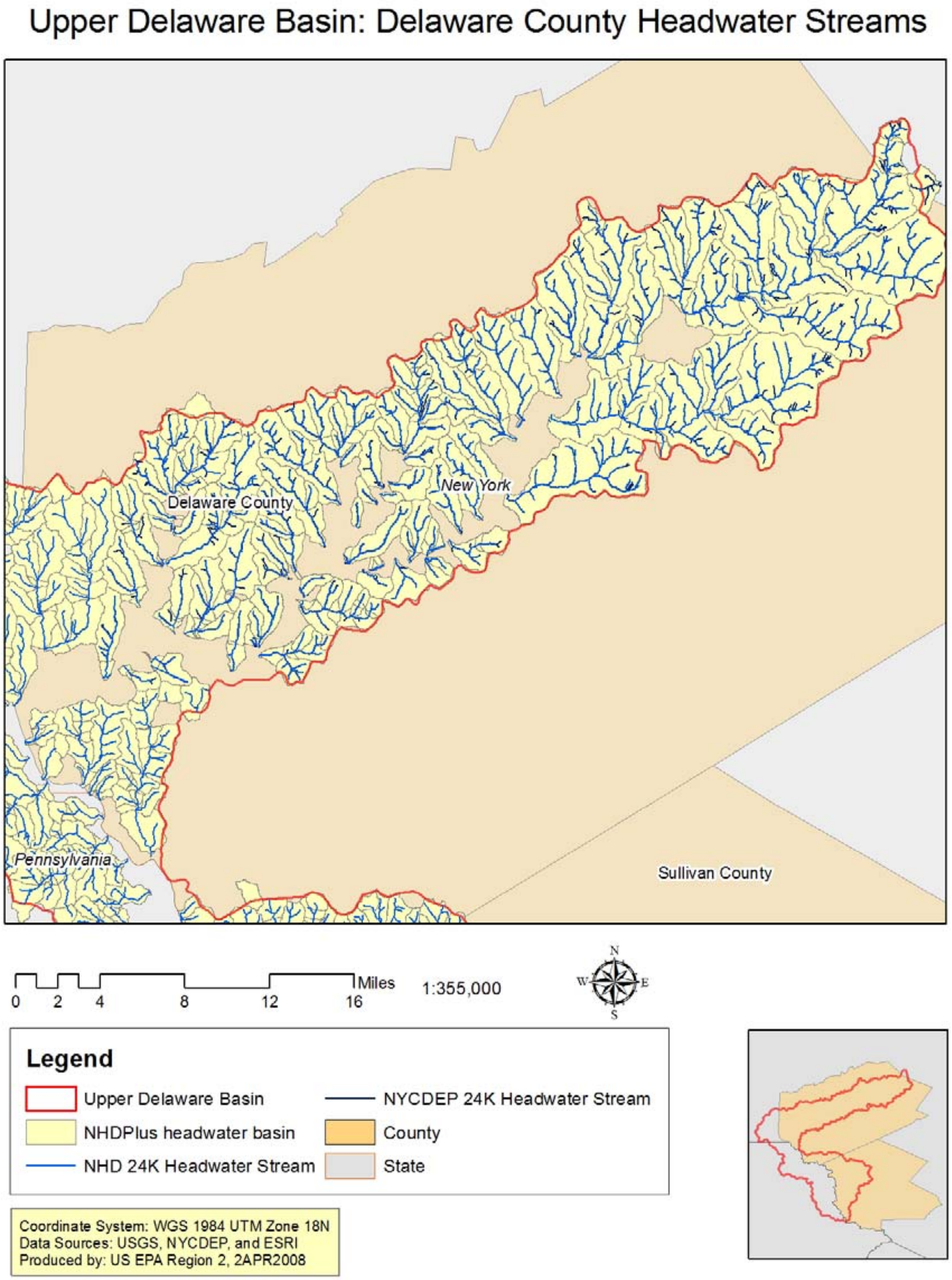


Figure 1: *Upper Delaware Basin: Headwater Streams of Delaware County*. Includes 1:24K streams.

Hydrologic Analyses:

USGS Stream Gage Monitoring

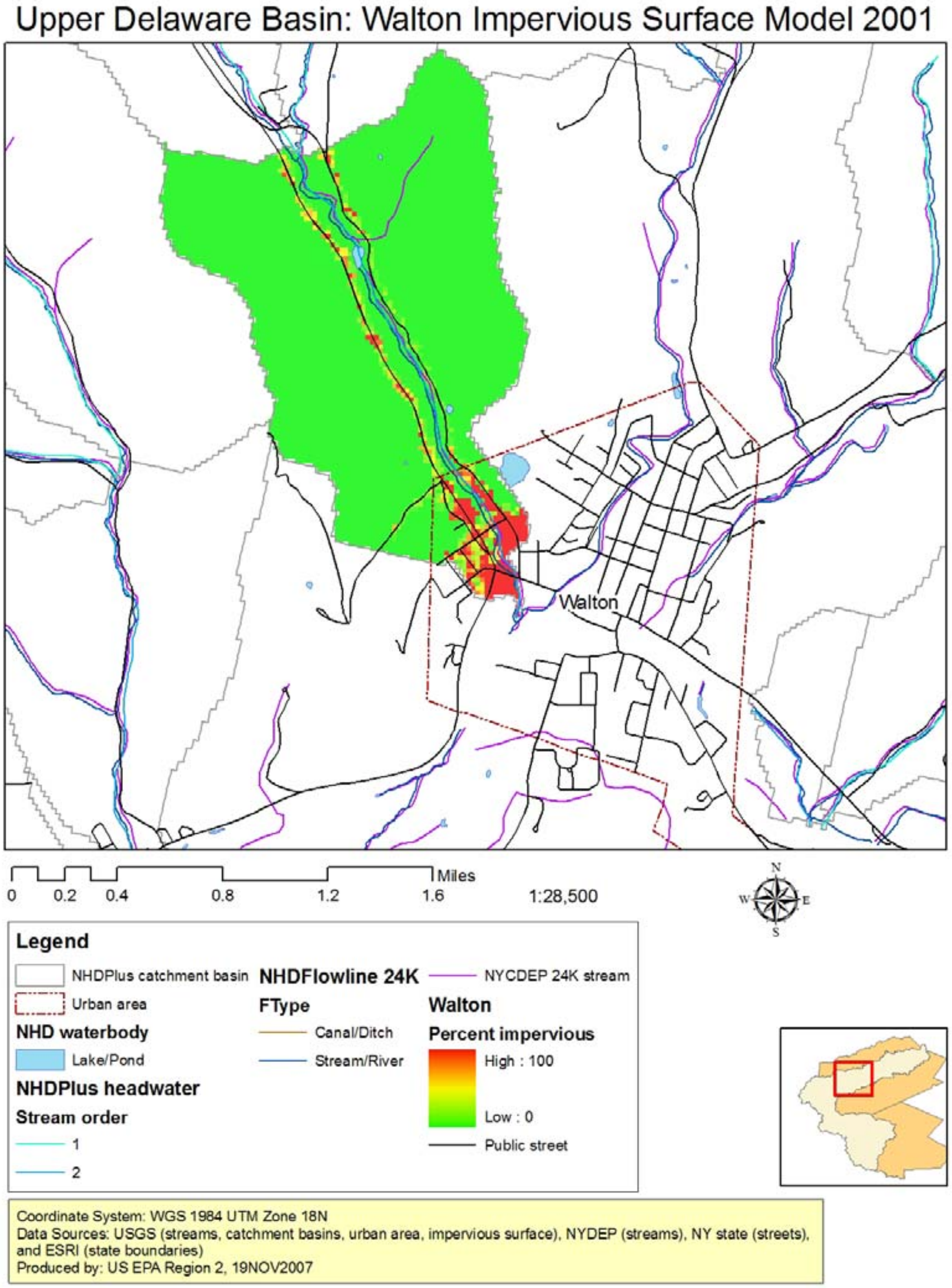
In 1955 and from 2004 to 2006 there were recorded increases in annual peak stream flow compared to other recorded years. Port Jervis is located towards the end of the Upper Delaware River Basin in northwestern Orange County. The southern most USGS stream gage within the Upper Delaware Basin is USGS stream gage “01428500 Delaware River above Lackawaxen River near Barryville, NY.”

Impervious Surface Model:

Land Cover Analysis and Prioritizing Urban Catchments

In order to prioritize urban and rural catchments an analysis of all existing land cover types within the watershed was conducted. The National Land Cover Data set 2001 was used for this analysis. This assessment made it clear that urban areas are currently not a large portion of land cover types within the watershed. Forest cover is the most dominant land-cover type within the Upper Delaware Basin. Agriculture is the most noticeable land cover type based primarily on human activity.

The Walton catchment is at 11.1% impervious surface coverage, making it likely to be negatively impacted. The Walton catchment likely needs to increase the amount of pervious surfaces to improve headwater stream water quality, habitat, and fluvial geomorphic stability. **Figure 2** illustrates the Walton “impervious surface” model for the year 2001.



Coordinate System: WGS 1984 UTM Zone 18N
Data Sources: USGS (streams, catchment basins, urban area, impervious surface), NYDEP (streams), NY state (streets), and ESRI (state boundaries)
Produced by: US EPA Region 2, 19NOV2007

Figure 2: Walton Impervious Surface Model 2001: the percent "red" in the Walton color-ramp indicates percent impervious cover (based on USGS 2001 National Land-cover Data-set). *"Percent Impervious Surface"* of Walton NHDPlus headwater catchment basin (raster grid-mask): 11.1%. "*Acres of 100% Impervious Surface"* within Walton headwater catchment basin: 28 acres. Total Acres within Walton headwater catchment basin: 1,047.88 acres (1.64 sq. miles). Note: NHD catchment basin area (vector) = 1.65 sq. miles, a difference of .01 sq. miles = .6 %. The Walton catchment is predicted to have impacted streams, including: altered stream geometry, channel erosion and widening, physical habitat degradation, and less stream biodiversity (Zielinski, 2002).

TR-55 and TR-20 Analyses (stormwater runoff)

The two tables below provide peak flow discharge rates for storm events applicable to the Upper Delaware Basin/Catskills region. Two USGS flood reports for the Neversink River Basin (2006) and the Upper Delaware River Basin (2005) are represented in **Table 14**. Results from **Table 14** are compared to baseline conditions from TR-55 analyses (**Table 15**), modeled for urban and rural NHDPlus headwater catchments in the Upper Delaware Basin of relatively similar drainage areas and locations within the New York City drinking water watershed. The surface area classified as "wetlands" is relatively similar for both the urban and rural NHDPlus catchments. Forest and agricultural-uses are the dominant land cover types in the rural catchment. Various watersheds within the Catskills area have stormwater runoff records for different stream segments.

The urbanized headwater catchment demonstrates higher peak flow rates than the rural catchment in **Table 15**. The rural catchment does not have a centralized urban area or municipality such as the urban catchment. This is likely due to the higher amount of impervious surface cover in the urbanized portions of the Stamford-Hobart catchment. There was sharp contrast between the storm peaks in the urban and rural catchments.

Data from the East Branch Neversink River, NE of Denning, NY stream gage location demonstrates the greatest similarity in comparison to the TR-55 results. It is worth noting that there is a 24 year recording period and known recurrence interval (20 years) for this stream gage at the East Branch Neversink River location.

Results from **Table 15** were used as baseline stormwater runoff data. The baseline data was later used to create scenarios where increases in forested wetland and riparian corridor land cover is applied to typical headwater basins in the Upper Delaware Basin. It is predicted that increased forested wetland and riparian corridor coverage will decrease the predicted peak flow discharges from TR-55 and TR-20 analyses.

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-use 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 14: Recent USGS Flood Report Summary Data for the Catskills Region

Location	**Date of recording**	**Context**	**Drainage Area (sq. miles)**	**Peak Flow previous maximum (CFS)**	**Peak Flow (CFS)**	**Recurrence Interval**
East Branch Neversink River, NE of Denning, NY	1991-2005	Rural	8.93	3,070 *(9/16/99)*	2,920 *(4/2/05)*	20 years
Town BR SE of Hobart, NY	1998-2004	Urban-Rural	14.30	4,400 *(7/4/99)*	1,840 *(9/18/04)*	N/A

(Brooks, 2005)

Table 15: TR-55 Model Results: Existing Conditions for Typical (Urban and Rural) Headwater Catchments of the Upper Delaware Basin

NHDPlus Headwater Basin	**Context**	**Drainage Area (sq. miles)**	**1 Year Peak Flow Event (CFS)**	**10 Year Peak Flow Event (CFS)**	**25 Year Peak Flow Event (CFS)**
Stamford-Hobart	Urban	11.75	737.61	2,813.31	3,435.09
Rural basin W of Hobart	Rural	7.73	294.53	1,264.11	1,553.36

Functional Assessments:

Watershed-based preliminary assessment of wetland functions

Of all of the NWI wetlands within the Upper Delaware Basin 70.74% of them were deemed to perform at least one of the ecological functions of interests. Many of the NWI wetlands were assessed to have more than one predicted ecologic function. 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 classified. 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. The results from the Upper Delaware Basin W-PAWF are highlighted in: **Table 16 and Table 17**. A portion of the southeastern side of the basin does not currently have digital NWI data.

The New York State Department of Environmental Conservation (DEC) has digitally mapped wetlands for this portion of the Upper Delaware. DEC freshwater wetlands are only mapped if they are 12.4 acres or larger. Within the area of the Upper Delaware Basin lacking digital NWI data, 108 DEC wetlands exist. A total of 2,384.09 acres are accounted for with these DEC wetlands. The W-PAWF assessment was not applied to the DEC wetlands because they did not include the NWI Cowardian classifications. Also the DEC wetlands represent a small portion of all wetlands mapped within the Upper Delaware Basin.

In addition to the W-PAWF completed for the Upper Delaware Basin, an earlier project conducted by the NYCDEP in 2006, titled Project 4.2 - Wetland Water Quality Functional Assessment, classified and monitored reference wetlands with the W-PAWF assessment methodology for wetlands located within the NYC Watershed. A portion of the Upper Delaware Basin, the West Branch Delaware River Basin, is located within the NYC Watershed. Wetlands from the NYCDEP study provide monitored results of actual ecological functions of reference wetlands. Reference wetlands included both terrene and lotic stream wetlands. These results may be referenced to the functions predicted from the W-PAWF conducted for the 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 baseflow concentration 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 and the landscape position and stream flow path. LS and LShw positions allow for surface water borne 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) 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.

Table 16: Upper Delaware Basin Watershed-based Preliminary Assessment of Wetland Functions (W-PAWF) Results

Ecologic Function	High (acres)	Moderate (acres)
Surface Water Detention	4,868.53	6,434.06
Sediment Retention	11,017.13	7,986.86
Nutrient Transformation	19,683.18	1,974.38
Shoreline Stabilization	5,245.19	5,013.55
Streamflow Maintenance	8,844.08	6,477.64

Table 17: Upper Delaware Basin NWI Wetland Land Surface Summary

Total NWI Wetland Acres	21,659.1
Total NWI Wetland M^2	87,651,262.04

Cornell Streamside Health Assessment

The predicted status of streamside health of all headwater streams in the Upper Delaware Basin is linked to headwater stream functionality. Riparian buffers in “excellent or good” conditions are predicted to be high functioning streams. Moderately functioning streams have buffers rated as “fair.” Finally, the least functioning streams have buffers categorized as “poor or very poor.” **Table 18** outlines the streamside health assessment results for all headwater stream corridors within the Upper Delaware Basin. A detailed illustration of the streamside health assessment for an urban catchment area is provided in **Figure 3**. The majority of the stream corridors were assessed to be in either excellent or good conditions. The following is the overall results of the assessment: 76% excellent, .24% good, 15% fair, 9% poor, and .32% very poor. Approximately 24% of the headwater stream corridors have conditions which could be improved to either good or excellent health conditions.

Table 18: Upper Delaware Basin Streamside Health Model Analysis

Class	**Streamside (30 m buffer)**	**Acres**
Open Water (5%)	Excellent	1900.31
Deciduous Forest (41%)	Excellent	16389.70
Evergreen Forest (9%)	Excellent	3509.80
Mixed Forest (14%)	Excellent	5685.00
Grassland Herbaceous (1%)	Excellent	266.92
Woody Wetlands (5%)	Excellent	1991.94
Emergent Herbaceous Wetland (1%)	Excellent	227.08
Scrub Shrub (.24%)	Good	95.61
Pasture Hay (15%)	Fair	6155.10
Developed Open Space (7%)	Poor	2649.28
Cultivated Crops (2%)	Poor	844.58
Developed Medium Intensity (.1%)	Very Poor	35.85
Developed High Intensity (.02%)	Very Poor	7.97
Barren Land (.2%)	Very Poor	79.68
	Total	39838.85

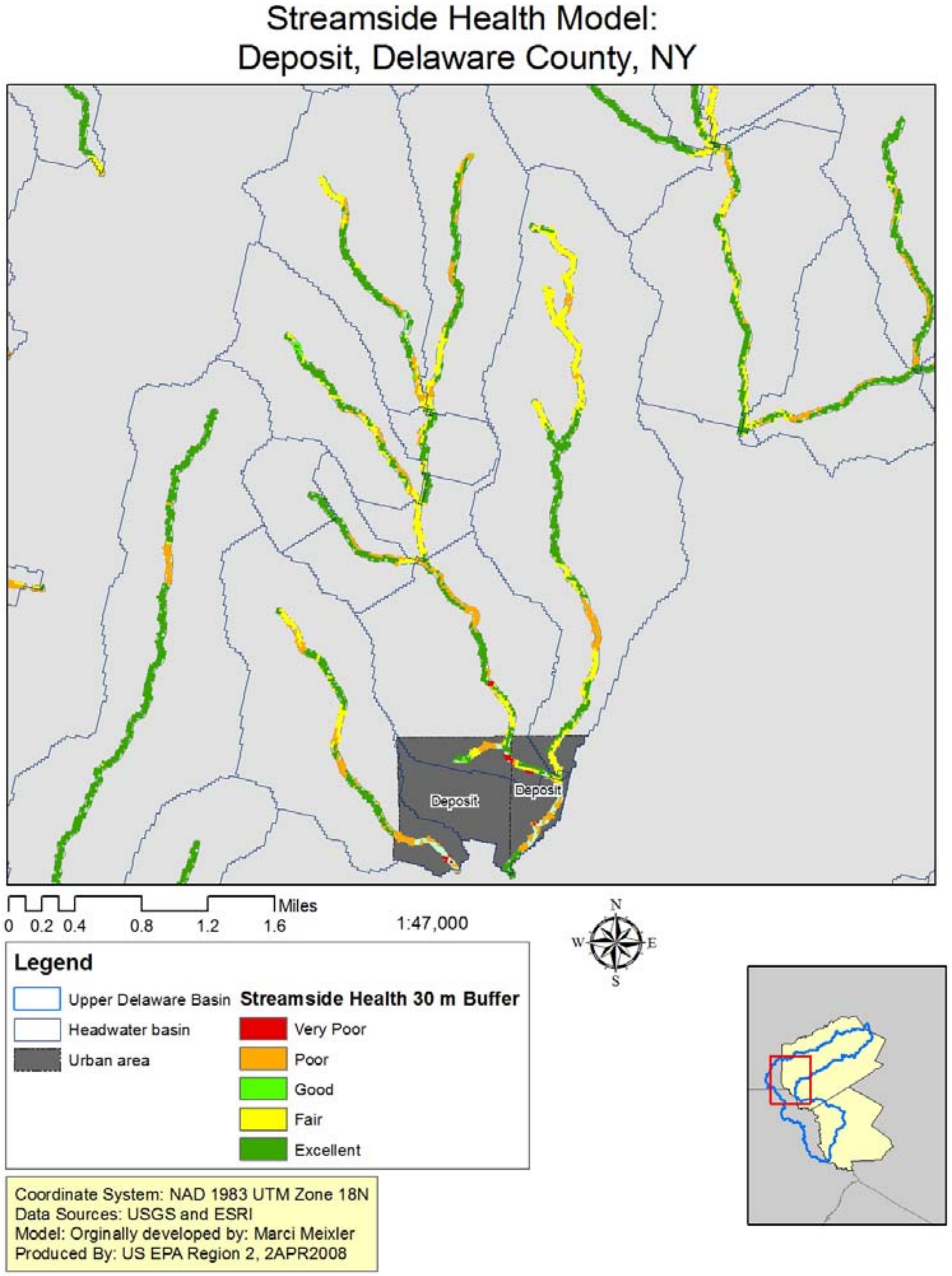


Figure 3: *Upper Delaware Basin Streamside Health Model of Deposit, Delaware County, NY*: depicts a zoomed in view of streamside assessment results for headwater catchments containing portions Deposit, NY. Note that "very poor" conditions are located mainly in or near the urban area of Deposit, NY. Other headwater stream buffers in urban areas also display similar "very poor" conditions. This may be caused by increased intensity of human land-cover disturbance in urban areas.

Flood Storage Assessment:

Wetland Stormwater Monitoring

A New York Department of Environmental Protection (NYCDEP) study of reference wetlands within the New York City Watershed indicates that lotic headwater stream and terrene wetlands attenuate downstream storm water discharges (NYC DEP, 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. Reference wetland sites were located on NYCDEP or New York State Department of Environmental Conservation (NYSDEC) property. The sites included two wetlands within the Cannonsville Reservoir: the Cannonsville Locust Spring, a terrene wetland (CLS) and the Cannonsville Sherruck Brook, a lotic headwater stream (CSB) (Cirmo, 2006). These lotic reference wetlands attenuated some of the additional stream flow from the storms.

Wetland Water Storage Capacity

The tables and maps below describe the surface water detention functionality of: 1) the entire Upper Delaware Basin, 2) a typical rural headwater catchment for 1 year and 100 year 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.

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.

The actual stormwater reference wetlands monitoring data is summarized in **Tables 19.** Both reference wetlands have HGM or 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 calculated to assess the stormwater detention capacity of all high or moderate performing NWI wetlands within the watershed in **Table 20.** 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 was multiplied by the “two storage capacity constants.” **Figure 4** displays all high and moderate values of NWI wetlands performing surface water detention mainly in the portion of the watershed located within Delaware County.

Table 19: NYC DEP Reference Wetland and Stormwater Event Characteristics:

Event ID/ Reference Wetland	*Basin*	*LLWW Wetland Type*	*Surface Area (m^2)*	*Time Period*	*Prior Climatic Conditions*	*Total Precipitation (cm)*	*Surface Water Detention Value*
F05/AMH	Ashokan	LS2BATHhwbv	33,040.4	10/7-10/2005	Dry	17.37	High
D04/CSB	Cannonsville	LS4BATHhwbv	22,495.87	9/28-30/2004	Wet	1.4	High

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

Note: These highlighted reference wetlands depict different locations within the New York City drinking water watershed at different points in time. Other NYCDEP reference wetlands monitoring different storm events did not have a positive amount of water stored. These highlighted reference wetlands illustrate the potential for wetlands in the New York City drinking water watershed to detain surface water from storm events.

Table 20: NYC DEP Reference Wetlands' Stormwater Detention Functions Applied to All Upper Delaware Basin NWI Wetlands:

Event ID/ Reference Wetland	**Prior Climatic Conditions**	**Time Period**	**Total Precipitation (cm)**	***All High* Detention NWI wetlands (m^3)**	***All Moderate* Detention NWI Wetlands (m^3)**
F05/AMH	Dry	10/7-10/2005	17.37	**25,612,881.36**	33,849,060.26
D04/CSB	Wet	9/28-30/2004	1.4	**2,758,310.30**	3,645,283.41

Event ID/ Reference Wetland	**Prior Climate Conditions**	**Time Period**	**Total Precipitation (cm)**	***All High* Detention NWI Wetlands (acre foot)**	***All Moderate* Detention NWI Wetlands (acre foot)**
F05/AMH	Dry	10/7-10/2005	17.37	**20,764.7**	27,441.88
D04/CSB	Wet	9/28-30/2004	1.4	**2,236.2**	2,955.28

The F05/AMH event and reference wetland was able to store more water than D04/CSB, most likely because of there were drier prior conditions for F05/AMH.

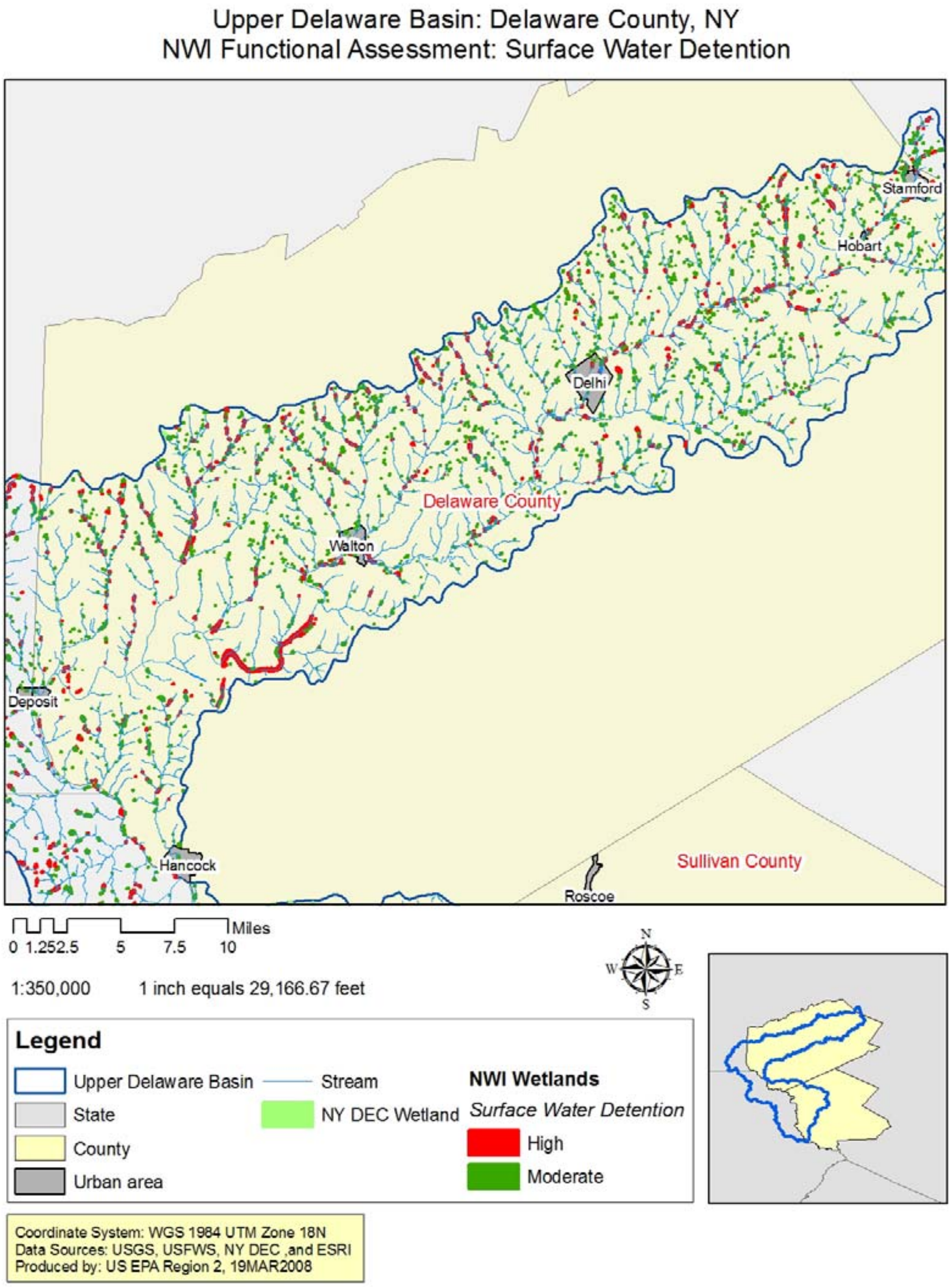


Figure 4: the majority of NWI wetlands performing either high or moderate surface water detention are located adjacent or within headwater streams. Very few wetlands located away from headwater streams have high or moderate performing surface water detention functionality.

The TR-55 and TR-20 assessments of the rural and urban catchments provided data to calculate out the existing storage capacity and storage deficit of wetlands. The catchment specific calculations were based on the storage capacity constants for the F05/AMH and D04/CSB storm events and respective reference wetlands. **Figure 5** displays the existing storage capacity of all high or moderately performing NWI wetlands within the watershed.

The existing storage capacity, storage deficit, and total storage capacity needed for the urban catchment is illustrated in **Figure 6**. The same surface water detention analyses were applied to the rural catchment. The TR-55 model was used again for the rural and urban catchments, but based existing needs for additional stormwater storage capacities. The 1 year prior wet conditions scenario was used, because it was the closet in representing actual flood and water quality management recommendations. **Table 21** outlines the results from the proposed TR-55 model analyses for additional stormwater storage capacity within the typical urban and rural catchments.

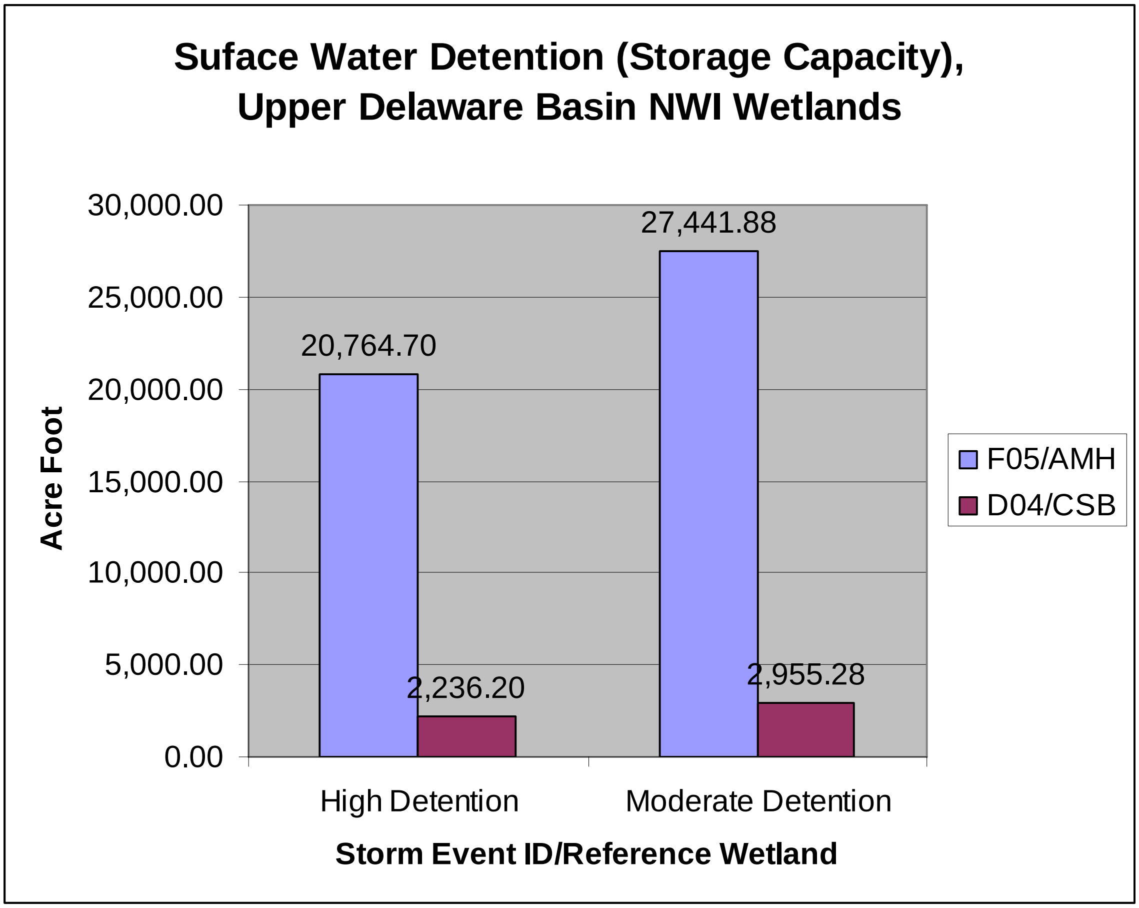


Figure 5: Under the prior dry conditions the watershed has a much greater capacity to detain surface water runoff. Prior wet conditions limit the ability of the watershed to accommodate stormwater runoff.

The rural catchment is much closer to managing its existing stormwater detention needs for a 1 year prior dry conditions storm event. With the 100 year prior dry conditions event the rural catchment has a greater need for surface detention capabilities. Although this 100 year storm event is towards the extreme limit of storm events which have recently occurred within the watershed. For managing overbank flooding from streams, the New York State DEC recommends managing for the 10 year 24 hour peak discharge rate. It would be helpful to have 10 year storm event data from the stormwater reference wetlands to more adequately predict manageable stormwater detention needs.

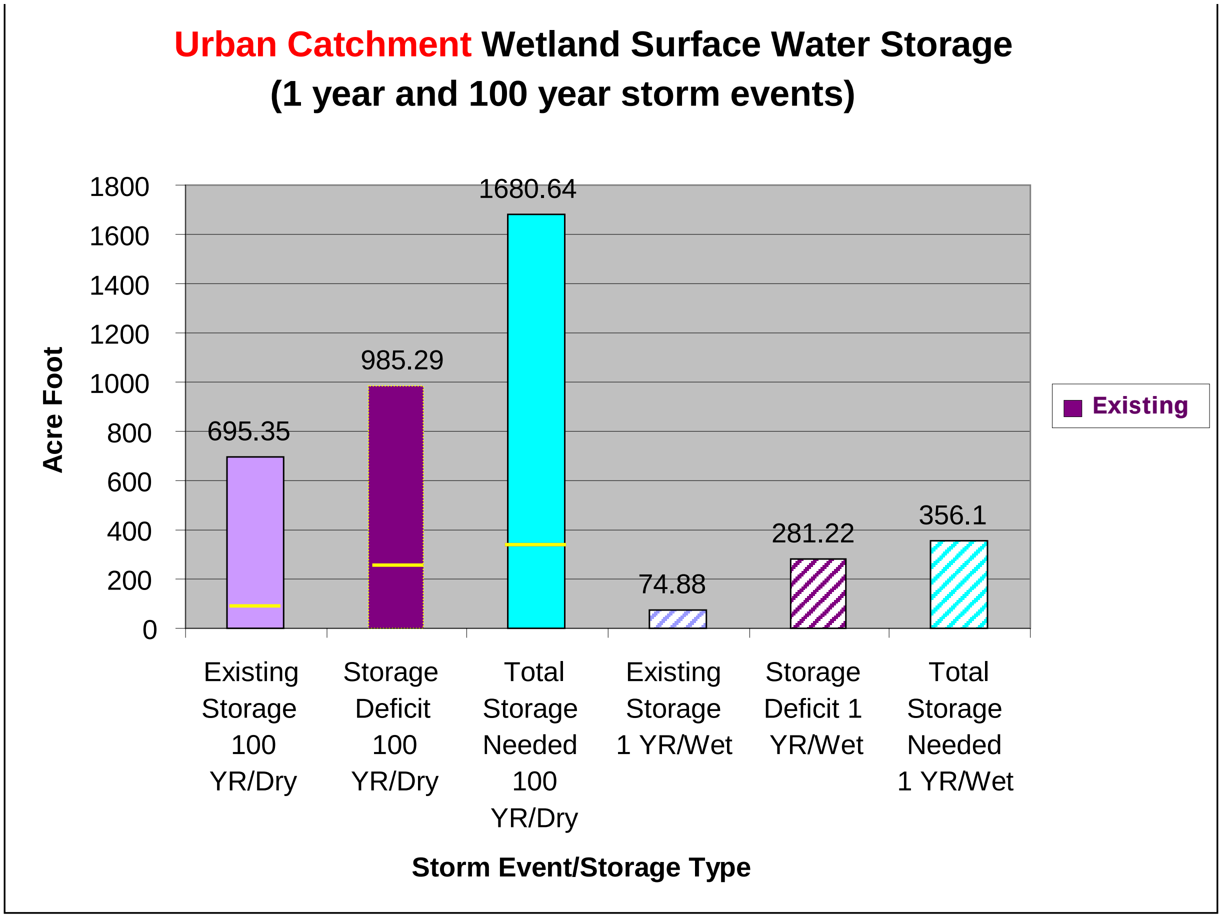


Figure 6: The urban catchment is much closer to managing its existing stormwater detention needs for a 1 year prior dry conditions storm event. With the 100 year prior dry conditions event the urban catchment has a greater need for surface detention capabilities.

Table 21: TR-55 Model Results: Proposed (enhanced, restored, or constructed wetlands and riparian buffers) Conditions for Typical (Urban and Rural) Headwater Catchments of the Upper Delaware Basin.

NHDPlus Headwater Basin	**Context**	**Drainage Area (sq. miles)**	**1 Year Peak Flow Event (CFS)**	**10 Year Peak Flow Event (CFS)**	**25 Year Peak Flow Event (CFS)**
Stamford-Hobart	Urban	11.75	674.95	2,682.56	3,293.39
Rural basin W of Hobart	Rural	7.73	268.03	1,195.21	1,484.62

Note: all peak flow rates have been reduced when compared to the results from **Table 15**, mainly from the conversion of land-cover types to wooded land-cover. Results from this table are based on additional forested wetlands needed for a 1 year storm event with prior wet conditions in September. The 1 year storm event is similar to 2 year storm event for managing stormwater conveyance under safe and non-erosive conditions. The 10 year, 24 hour storm event is the focus of management efforts to control overbank flooding (New York State DEC, 2003).

SLEUTH Model Analysis

The SLEUTH urban growth model provided a statistical data of projected future development up to the year 2030 based on existing development trends for counties within the Upper Delaware Basin. Jantz, 2007 ran analyses of where development was most likely to occur within the various counties based on existing development trends. This baseline development scenario data shows areas with strong attraction, neutral, 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 drinking water 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 attractable for future development. 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 levels of predictive capabilities.

The existing development scenario (baseline) has wetlands as a protected data layer (strong resistance) input for the model. While freshwater wetlands are protected under law from development by the New York State DEC, 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. The SLEUTH model existing development conditions were analyzed further for Sullivan County in **Table 24**. These results give an overly optimistic view of wetland land-use change for Sullivan County. Statistical results of increases in impervious surface cover are provided in **Table 25**.

Table 24: SLEUTH Model Existing Urban Development Trends 2030:
Sullivan County, NY: Wetlands

Total Wetlands (acres)	*Developed Wetlands (acres)*	*Conserved Wetlands (acres)*
31,404.79	38.62 (.12%)	31,366.17 (99.88%)

While the percent of wetlands likely to be developed is relatively low, the amount of land with a 48% or greater of being developed is great. The impacts from this increase in urban development will have stormwater impacts on existing and future wetlands within Sullivan County and the Upper Delaware Basin. Habitat fragmentation from development occurring in between wetlands likely will impede the delivery of ecologic functions/services by wetlands.

Table 25:
SLEUTH Model: Existing Urban Development Projections for Sullivan County 2005 to 2030

Probability of Urban Development Occurring (% greater than or equal to)	2005 Existing Amount of Urban Development (Acres)	Increase in Urban Development from 2005 (Acres)	Percent Increase in Urban Development from 2005
4%	632,289.71	621,882.63	5,975.57%
24%	20,662.23	10,255.15	98.54%
48%	15,768.49	5,361.41	51.52%
76%	11,917.44	1,510.36	14.51%
100%	10,443.61	36.53	.35%

2005 Impervious Surface:
(.04*632,289.71) + (.24*20,662.23) + (.48*15,768.49) + (.76*11,917.44) + (1*10,443.61) =
25,291.59 + 4,958.94+ 7,568.88+ 9,057.25 + 10,443.61= **57,320.27 Acres**

Additional Impervious Surface Under Existing Conditions for 2030:
(.04*621,882.63) + (.24*10,255.15) + (.48*5,361.41) + (.76*1,510.36) + (1*36.53) =
24,875.31 + 2,461.24+ 2,573.48 + 1,147.87+36.53= **31,094.43 Acres**

Increase in Impervious Surface by 2030:
(31,094.43/57,320.27)*100= **54.25%**

Total Acres in Sullivan County: 636,585.11 Acres
Existing % Impervious Surface (2005) = (57,320.27/636,585.11)*100= **9%**
(31,094.43/636,585.11)*100= **4.88%**
% Additional Future Impervious Surface (2030) = (31,094.43/636,585.11)*100= **4.88%**
Total % Impervious Surface 2030 = 9% + 4.88 % = **13.88%**
Difference in Impervious Surface (2030 – 2005) = (57,320.27 – 31,094.43) **= 26,225.84 Acres**
Percent Increase in Impervious Surface (2005 – 2030) = (31,094.43/57,320.27)*100 = **54.25%**

Overall Sullivan County is expected to have a substantial increase in impervious surface cover as a result of future urban development. The SLEUTH model analyses for future urban development for under existing conditions only gives the predicted amount of impervious surface expected. It does not show hope buildings, subdivisions, or roads will be built within any of the counties. How impervious surface is located within a given catchment or the watershed will affect water quality and flood management efforts. If impervious surfaces are concentrated in certain areas within a given catchment, then there may be an overall decrease in negative effects from future development.

Various concentrations of impervious surface cover affect the amount of stormwater runoff that comes off a given site. Overall Sullivan County is expected under existing development trends to have 13.88% impervious surface cover; 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 greater 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 one area, than overall stormwater runoff volume will be less.

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 density development. Any amount of future urban development expected within the Upper Delaware Basin may be planned out so that there is less stormwater runoff affecting stream and wetland resources. The SLEUTH model may be given alternative future scenarios, which are designed to protect, conserve, preserve, and enhance existing wetland and headwater streams resources. Following is a list of conditions which could create alternative future scenarios which would facilitate continued and enhanced functionality of headwater streams and wetlands.

Alternative Future Scenario Conditions:
Ecological Functions of Headwater Streams and Wetlands

- 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 all headwater catchments.
- Aggregate headwater catchments to include at least one urban area, but still set a 10% impervious surface threshold.

GIS Database

In order to assess conditions of wetland and headwater stream resources all relevant and available GIS data was collected and stored in a geospatial database. Data sources included: wetlands and headwater streams, watershed and catchments, digital elevation, public infrastructure, government boundaries, aerial photography, land-cover, soils, and predicted future urban growth. After the data was acquired the metadata was 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.

All together these different datasets facilitated the spatial analyses performed for this project. Descriptions and potential uses of the GIS datasets are given below. 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 14: GIS Metadata Summary
GIS Data Descriptions and Potential Uses:

- **Counties:** Sullivan and Delaware counties were the focus of all counties within the Upper Delaware Basin, 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)***:** it's very important to have an idea of how much impervious surface there is and its proximity to stream reaches and wetlands. The amount of impervious surface and its location has direct effects on how stormwater flows into water conduits, such as streams or wetlands. As impervious surface coverage has increased over time how have streams, wetlands, riparian areas, and other pervious surfaces been affected? Is there a balance between the amount of impervious surface created and the ability of the landscape to store, retain, and filter stormwater? 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 of hydrological disturbances.
- **Public Streets:** figure out how roads contribute to storm and flood water discharges into streams and wetlands. Understand whether or not certain roads are located in the correct places for managing flood and storm water.
- **Aerial photographs** *(past 20 years, 1986-2006)***:** illustrate how land-use changes have occurred throughout the watershed. Trends in land-use 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 and Brown de Colstoun, 2007). Aerial photos of existing conditions were used as base maps for various spatial analyses.
- **Land cover:** understand landscape classifications of both urban and rural areas. Figure out how these land-use types may be affecting the stormwater and water quality protection functions of wetlands and headwater streams in the watershed.
- **10 m and 30 m 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:** define the 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 where water moves throughout the landscape (starting and end points).
- **Hydrography:** locate and identify various stream and waterbody types. Define the catchment drainage area of headwater stream reaches. Figure out the amount

of water running off from the headwater catchments. NHDPlus flowlines and headwater catchments were used as the base data for the headwater stream network aggregation. NHD high resolution and NYC DEP stream flowlines were overlain with the NHDPlus base map data. Overall this data assisted with understanding how adjacent land-uses affect these waterbodies. Also it helped with portraying hydrological connection between streams and wetlands.

- **Headwater streams:** these will be 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-uses that affect the ecologic health of these waterbodies. 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.
- **Wetlands** *(NWI Enhanced (Hydrogeomorphic-classifications) and NYS-DEC)***:** locate and identify the surface area, probable flood water storage capacity, and other water quality and flood management related functions. Understand how much of the watershed is currently classified as wetlands.
- **SLEUTH Urban Growth Model:** provides historical and existing datasets of impervious surface cover for the Upper Delaware Basin. Sullivan County released a copy of its dataset our use with this project. The SLEUTH data also provides 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 will help interpret where water is usually stored and probable vegetative types. Predicting the locations of historic wetlands or proposed restoration should be based off of hydric soil locations.
- **Stormwater infrastructure:** where and what kind of stormwater infrastructure feeds water into the Upper Delaware Basin system? This may help identify areas needing more stormwater infrastructure capacity upstream to accomodate flood events. Locating man-made stormwater infrastructure, wetlands, and headwater streams may help interpret how they collectively manage stormwater 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 stormwater engineered structures.
- **Ecoregions** *(Omernik's)***:** delineate 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.

Selection of Best Management Practices (BMPs) From Existing Design Precedents

Various options exist for selecting 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 ability 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, but they also need to be able to act as conduits for stormwater under more frequent storm events, such as a 2 year 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 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 New York City Department of Environmental Protection; and the National Engineering Handbook: Part 654 Stream Restoration Design by the NRCS.

There are two 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. Both urban and rural headwater catchments may use stormwater BMPs as part of smart growth planning strategies. Within the catchment 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 BMPs. **Table 26** provides BMP strategies for urbanizing and rural areas. 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). **Table 27** outlines BMPs most appropriate for areas near sensitive headwater streams. After a BMP strategy is chosen for a specific headwater catchment context, more specific stormwater management practice designs may be selected.

Table 26: 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

Note: This table may be used to prioritize BMP strategies for urban and rural NHDPlus headwater catchments. Areas in between urban and rural areas may use a combination of strategies recommended for the two types of areas.

Table 27: 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	

Note: This table provides an outline of design considerations for the different stormwater management practices. Different stormwater BMPs may be used in combination to meet various management needs. 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).

Conclusion:

This study answered many questions related to assessing ecological services provided by existing wetland and headwater stream resources within the changing landscape of the Upper Delaware Basin. Many factors play a role in the recent increase frequency of intense storm events, including: climate change; increases in impervious surface coverage; and a deficit of baseline ecological functions to meet human needs. Many baseline analyses, alternative futures, stormwater BMPs, and resource management integration recommendations were given to address water quality protection and flood management concerns.

Overall this study thoroughly answered all of the research questions initially proposed. It is evident from GIS mapping of headwater streams, that the majority of the stream network (81.21%) within the Upper Delaware Basin is classified as headwaters. The water quality of headwater streams greatly affects the overall water quality of the watershed. Wetlands are often associated with headwater streams within the landscape, so the exchange of water between the two resources greatly affects watershed water quality.

The headwater stream network within the Upper Delaware Basin may have a greater spatial extent than what existing USGS 1:24 K NHD data depicts. LIDAR (light detection and ranging) technology is able to provide even higher resolution topographic mapping, producing digital elevation models which may provide the probable 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 unveil unmapped wetlands. Other future GIS applications could also map out historical wetland locations from aerial photography. Most areas of the United States only have broad estimates of historical wetland coverage. This limits the ability to estimate historical levels of ecological services provided by wetlands within any watershed.

Although, with existing mapping resources of headwater streams and wetlands baseline analyses still gave adequate representations of probable ecological functions. Water quality protection and flood attenuation is provided through at ecological services at both high and moderate levels. There exists a deficit in stormwater detention capabilities given human management needs. The existing ability of wetlands to detain flood waters in typical and rural headwater catchments is limited regardless of prior climatic conditions and storm intensity and return frequency interval.

Trends in climate change show increases in precipitation and storm intensity and frequencies, meaning more management measures will be necessary in the future to avoid flood damages and other associated losses. Landscape change from urban development is also increasing and is expected to do so through the year 2030. With these expected changes in climate and urban land uses within the watershed, ecological services need to be preserved, protected, enhanced, and restored.

Alternative future scenarios at the watershed, county, and municipal levels may provide broad plans for concentrating future development in existing urban areas. In order to properly manage future intense flood events and protect water quality, headwater catchments need to be seen as the management scale to implement "impervious surface cover" limits. Rural and urban headwater catchments have different flood management and water quality protection needs. Appropriate stormwater BMPs should be selected based on baseline ecological, hydrologic, and impervious surface model, and urban growth model results. BMPs may be applied at different spatial scales, allowing for roadways, parking lots, residential subdivisions, and individual housing parcels to implement appropriate technologies.

The results and recommendations from this study are meant to be used by stakeholders within the Upper Delaware Basin. Existing stream and county management plans already express interests in protecting water quality, managing stormwater, and maintaining ecosystem functions. This report 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. Other urbanizing watersheds experiencing similar issues faced in the Upper Delaware Basin may also use and apply these assessment tools and recommendations.

Bibliography:

Alexander, R.B., E.W. Boyer, R.A. Smith, G.E. Schwarz, and R.B Moore. 2007. The Role of Headwater Streams in Downstream Water Quality. *Journal of the American Water Resources Association* 43(1): 41-59. http://www.blackwellsynergy.com/toc/jawr/43/1

Bernhardt, E.S. and M.A. Palmer. 2007. Restoring streams in an urbanizing world. Freshwater Biology 52, 738-751.

Bosch, A. "Working to head off the next big flood: Five hard-hit communities search for lifesaving solutions." *Times Herald-Record* 30 March 2008. Accessed: 18 Mar. 2008. <http://www.recordonline.com >

Brinson, M. M. 1993. A Hydrogeomorphic Classification for Wetlands. U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS. USA. Technical Report WRP-DE-4.

Brooks, L.T. 2005. Flood of September 18-19, 2004 in the Upper Delaware River Basin, New York. U.S. Geological Survey Open-File Report 2005-1166, 123 p.

Burns, D.A., J. Klaus, and M.R. McHale. 2007. Recent climate trends and implications for water resources in the Catskill Mountain region, New York, USA. *Journal of Hydrology* 336 (1-2): 155-170.

Cappiella, K. and L. Fraley-McNeal. 2007. The Importance of Protecting Vulnerable Streams and Wetlands at the Local Level: Wetlands and Watersheds Article #6. Center for Watershed Protection, Ellicott City, MD. Accessed: 13 Aug. 2007. <http://www.cwp.org/pubs_download.htm>

Center for Watershed Protection. 1995. Site Planning for Urban Stream Protection. Ellicott City, MD. Accessed: 13 Aug. 2007. <http://www.cwp.org/pubs_download.htm>

Cirmo, C.P., J.P. Smith, N. Hendricks, D. Lyons, and J. Green. 2006. Catskills/Delaware West-of-Hudson Wetland Monitoring Intensive Site Study Final Report. State University of New York College. Cortland, NY.

Conservation Design Forum, Illinois Dept. of Natural Resources, Kane County, The Conservation Foundation, and the US EPA. 2003. Blackberry Creek Watershed Alternative Futures Analysis Project. Accessed: 3/20/07. http://www.nipc.org/environment/sustainable/conservationdesign/blackberrycreek/BCAF%20Full%20Report.pdf

Dahl, T.E. 2006. Status and Trends of Wetlands in the Conterminous United States 1998 to 2004. U. S. Department of the Interior; Fish and Wildlife Service, Washington D.C.

Dahl, T.E. 1990. Wetlands losses in the United States 1780's to 1980's. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. Jamestown, ND: Northern Prairie Wildlife Research Center Online. Accessed: 10/7/07. <http://www.npwrc.usgs.gov/resource/wetlands/wetloss/index.htm > (Version 16JUL97).

Delaware County Planning Department. 2006. Delaware County Multi-Jurisdictional Hazard Mitigation Plan. Delhi, NY. Accessed: 13 May 2008. < https://delawarecountyplanning.com/html/hazard-mitigation.html >

Delaware County Soil and Water Conservation District. 2004. West Branch of the Delaware River Stream Corridor Management Plan (Draft). Walton, NY. Accessed: 20 June 2007. <http://www.co.delaware.ny.us/depts/h2o/publications.htm>

Delaware River Basin Commission. 2007. Comparative Analysis of the National Flood Insurance Program (NFIP) Claims in the Delaware River Basin for September 2004, April 2005 & June 2006 Flood Events. Trenton, NJ. Accessed: 17 March 2008. <http://www.state.nj.us/drbc/drbc.htm >

Delaware River Basin Flood Mitigation Task Force. 2007. Delaware River Basin Interstate Flood Mitigation Task Force Action Agenda. Delaware River Basin Commission, Trenton, NJ. Accessed: 7 Aug. 2007. <http://www.state.nj.us/drbc/Flood_Website/taskforce/Action-agenda_0707/index.htm>

Farber, S.C., R. Costanza, and M.A. Wilson. 2002. Economic and ecological concepts for valuing ecosystem services. *Ecological Economics*. 41(3): 375-392.

Federal Geographic Data Committee. 2000. Content Standard for Digital Geospatial Metadata Workbook Version 2.0. Washington, D.C. Accessed: 15 Mar. 2008. <http://www.fgdc.gov>

Fennessey, L.A.J., A.C. Miller, and J.M. Hamlett. 2001. Accuracy and Precision of the NRCS Models for Small Watersheds. *Journal of the American Water Resources Association* 37(4): 899-912.

Federal Interagency Stream Restoration Working Group (10/1998). Stream Corridor Restoration: Principles, Processes, and Practices. By the Federal Interagency Stream Restoration Working Group (FISRWG)(15 Federal agencies of the US gov't). GPO Item No. 0120-A; SuDocs No. A 57.6/2:EN 3/PT.653. ISBN-0-934213-59-3.

Freeman, M. C., Pringle, C. M., and C. R. Jackson. 2007. Hydrologic Connectivity and the Contribution of Stream Headwaters to Ecological Integrity at Regional Scales. *Journal of the American Water Resources Association* 43(1): 5-14. http://www.blackwellsynergy.com/toc/jawr/43/1

Greene County Soil and Water Conservation District. 2003. Batavia Kill Stream Management Plan. Cairo, NY. Accessed: 27 Aug. 2007. <http://www.gcswcd.com/stream/bataviakill/smp/>

Greene County Soil and Water Conservation District. 2006. Big Hollow Restoration Project, Batavia Kill. Implementation and Monitoring Report. New York City Department of Environmental Protection. Kingston, NY.

Greene County Soil and Water Conservation District. 2007. Rock Cross Vane (SR-03). Construction Detail. Cairo, NY.

Heimlich, R.E., K.D. Wiebe, R. Claassen, D. Gadsby, and R.M. House. 1998. Wetlands and Agriculture: Private Interests and Public Benefits. Resource Economics Division, Economic Research Service, U.S. Department of Agriculture. Agricultural Economic Report No. 765.

Riexinger, P., J. Broadway, and T. Huffman. 1999. Wetlands Status and Trend Analysis of New York State Mid-1980's to Mid- 1990's. New York State Department of Environmental Conservation. Albany, NY.

Jantz, C.A. 2007. "Modeling land cover change in the Upper Delaware River Basin, River Valley GIS Meeting, Tuesday, December 11, 2007." Shippensburg University. Shippensburg, PA.

Jantz, C.A., and S.J. Goetz. 2007. Can smart growth save the Chesapeake Bay? *Journal of Green Building* 2(3):41-51. Accessed: 30 Mar. 2008.
< http://www.whrc.org/resources/published_literature/index.htm >

Lumia, R., D.A. Freehafer, and M.J. Smith. 2006. Magnitude and Frequency of Floods in New York: U.S. Geological Survey Scientific Investigations Report 2006–5112.
United States Geological Survey (USGS). Reston, VA.

Machung, L. 2006. Safe Drinking Water Act – Grant 4 Final Report: Project 4.2 – Wetland Water Quality Functional Assessment. New York City Department of Environmental Protection. Flushing, NY.

Meixler, M. 2003. Streamside health and vulnerability mapping. Department of Natural Resources, Cornell University. Ithaca, NY. Accessed: 18 Jan. 2008.
<http://www.dnr.cornell.edu/hydroecology/mm/gismodel.htm >

Meyer, J. L., L.A. Kaplan, D. Newbold, D.L. Strayer, C.J. Woltemade, J.B. Zedler, R. Beilfuss, Q. Carpenter, R. Semlitsch, M.C. Watzin, and P. H. Zedler. 2007. Where Rivers are Born: The Scientific Imperative for Defending Small Streams and Wetlands. American Rivers and the Sierra Club. Washington, DC. Accessed: 28 Aug. 2007. < http://www.sierraclub.org/healthycommunities/rivers/ >

Miller, S.J., and D. Davis. Optimizing Catskill Mountain Regional Bankful Discharge and Hydraulic Geometry Relationships. American Water Resources Association 2003 International Congress. Kingston, NY. Accessed: 28 Jan. 2008.
<www.nyc.gov/html/dep/html/watershed_protection/pdf/smp.pdf >

Mitsch, W.J. and J.G. Gosselink. *Wetlands.* 2nd ed. New York: Van Nostrand Reinhold, 1993.

Nadeau, T., and M. C. Rains. 2007. Hydrological Connectivity Between Headwater Streams and Downstream Waters: How Science Can Inform Policy. *Journal of the American Water Resources Association* 43(1): 118-133. http://www.blackwell-synergy.com/toc/jawr/43/1

National Oceanic and Atmospheric Administration. 2008. “Remote Sensing for Coastal Management, LIDAR”. Charleston, SC. Accessed: 27 May 2008. <http://www.csc.noaa.gov/crs/rs_apps/sensors/lidar.htm>

New York City Department of Environmental Protection. 2006. West of Hudson Wetlands Monitoring Program. Kingston, NY.

New York City Department of Environmental Protection. 2008. Catskill Streams: Library and Image Gallery. Kingston, NY. Accessed: 27 May 2008. <http:///www.catskillstreams.org/index.html>

New York City Department of Environmental Protection. 2008. Catskill Streams: Stewardship: Instream. Kingston, NY. Accessed: 27 May 2008. <http:///www.catskillstreams.org/stewardship_instream.html>

New York State, Department of Environmental Conservation. 2003. New York State Stormwater Management Design Manual. Albany, NY. Accessed: 18 Jun. 2007. <http://www.dec.ny.gov/>

New York State, Department of Environmental Conservation. 2008. “Freshwater Wetlands Program: What are Freshwater Wetlands?” Albany, NY. Accessed: 5 May 2008. <http://www.dec.ny.gov/lands/4937.html>

New York State, Office of the Governor. 2007.“State Authorizes Catskill Casino: Spitzer and Mohawk Chiefs Issue Joint for Final Federal Approval.” Albany, NY. Accessed: 9 Aug. 2007. <http://www.ny.gov/governor/press/0219071.html>

Nisenson, L. 2005. Using Smart Growth Techniques as Stormwater Best Management Practices. United States Environmental Protection Agency, Washington, D.C. Accessed: 20 May 2008. <http://www.epa.gov/smartgrowth/publications.htm>

Northeast Regional Climate Center. 2008. New York State Precipitation Extremes: Isohyetal Maps: New York State 24 Hour 100 Year Storm Event Precipitation (2003 and 1993). Map. Ithaca, NY. Accessed: 28 Mar. 2008. < http://www.nrcc.cornell.edu/pptext/isomaps.html>

Pacific Northwest Ecosystem Research Consortium. Willamette River Basin Planning Atlas: Trajectories of Environmental and Ecological Change. 2nd Ed. Ed. David Hulse, Stan Gregory, and Joan Baker. Corvallis, OR.: Oregon State University Press, 2002. Accessed: 20, Oct. 2007. <http://www.fsl.orst.edu/pnwerc/wrb/Atlas_web_compressed/PDFtoc.html>

Richards, Lynn. 2006. Protecting Water Resources with Higher Density Development. United States Environmental Protection Agency, Washington, D.C. Accessed: 20 May 2008. <http://www.epa.gov/smartgrowth/publications.htm>

Schueler, T., D. Hirschman, M. Novotney, and J. Zielinski. 2007. Urban Subwatershed Restoration Manual No. 3: Urban Stormwater Retrofit Practices. Version 1.0. Ellicott City, MD. Accessed: 26 Nov. 2007. <www.cwp.org>

Schumacher, B. 2003. "Fact Sheet: The Importance and Benefits of Primary Headwater Streams." State of Ohio Environmental Protection Agency. Columbus, OH. Accessed: 29 Aug. 2007. < http://www.epa.state.oh.us/dsw/wqs/headwaters/ >

Schumacher, B. 2003. "Fact Sheet: Ohio EPA's Primary Headwater Stream Project: Key Findings." State of Ohio Environmental Protection Agency. Columbus, OH. Accessed: 29 Aug. 2007. < http://www.epa.state.oh.us/dsw/wqs/headwaters/ >

Sullivan County, Department of Planning and Community Development. 2007. "Sullivan County Building Permit Activities: 1990-2006." Monticello, NY.

Sullivan County, Department of Planning and Community Development. 2005. Sullivan County 2020 Toolbox. Monticello, NY. Accessed: 27 May 2008.
< http://co.sullivan.ny.us/orgmain.asp?orgID=401&storyID=163&sId= >

Suro, T.P. and G.D. Firda. 2006. Flood of April 2–3, 2005, Neversink River Basin, New York: Department of Interior. U.S. Geological Survey. Open-File Report 2006–1319, 98 p.

The Conservation Fund. 2004. Green Infrastructure – Linking Lands for Nature and People: Case Study Series. Maryland's Green Infrastructure Assessment and GreenPrint Program. Arlington, VA. Accessed: 24 June 2007. < www.conservationfund.org >

Tiner, R.W. 2005. Assessing Cumulative Loss of Wetland Functions in the Nanticoke River Watershed Using Enhanced National Wetlands Inventory Data. *Wetlands* **25**:405-419.

Tiner, R.W., J. Q. Swords, and H.C. Bergquist. 2005. Wetlands of the Delaware and Catskill Watersheds of the New York City Water Supply System: 2003 Status. U.S. Fish and Wildlife Service, National Wetlands Inventory, Ecological Services, Region 5, Hadley, MA. Prepared for the New York City Department of Environmental Protection, Valhalla, NY. 34 pp. plus appendices.

Tiner, R.W. 2003. Correlating Enhanced National Wetlands Inventory Data with Wetland Functions for Watershed Assessments: A Rationale for Northeastern U.S. Wetlands. U.S. Fish and Wildlife Service, National Wetlands Inventory Program, Region 5, Hadley, MA. 26 pp.

United States Department of Agriculture - Natural Resources Conservation Service. 2007. Stream Restoration Design, Part 654, National Engineering Handbook. Washington, D.C. Accessed: 14 Nov. 2007. < http://policy.nrcs.usda.gov/media/pdf/H_210_654_4.pdf >

United States Department of Interior. U.S. Geological Survey. 2008. “Water Resources of the United States: Hydrologic Unit Maps”, Reston, VA. Accessed: 14 May 2008. <http://water.usgs.gov/GIS/huc.html>

United States Department of Interior. U.S. Geological Survey. 2007. “Peak Surface Flow: Port Jervis”, NY. Albany, NY. Accessed: 20 Aug. 2007. <http://waterdata.usgs.gov/ny/nwis/current/?type=flow>

United States Environmental Protection Agency. Office of Water. 1996. Protecting Natural Wetlands: A Guide to Stormwater Best Management Practices. Washington, D.C.

United States Environmental Protection Agency. Office of Environmental Information. 2007. EPA Metadata Editor Version 2.1 Installation Instructions and Detailed Usage Guide. Washington, D.C.

United States Environmental Protection Agency. Office of Information Collection and Office of Environmental Information. 2007. Geospatial Metadata Technical Specification Version 1.0. Washington, D.C. Accessed: 20 May 2008. <http://geodata.epa.gov>

WinTR-55 Workgroup. 2002. WinTR-55 User Manual. Natural Resources Conservation Service, Washington, D.C.

Westergard, B.E., C. I. Mulvihill, A.G. Ernst, and B.P. Baldigo. 2005. Regionalized Equations for Bankfull-Discharge and Channel Characteristics of Streams in New York State - Hydrologic Region 5 in New York: U.S. Geological Survey Scientific Investigations Report 2004-5247, 16 p. Accessed: 11 Nov. 2007. <http://ny.usgs.gov/>

Western Regional Climate Center. 2008. 72-month Standardized Precipitation Index through the end of February 2008. Map. Reno, NV. Accessed: 28 Mar. 2008. < http://www.wrcc.dri.edu/spi/spi.html>

Woods Hole Research Center. 2008. “Overview of the SLEUTH Model.” Falmouth, MA. Accessed: 16 May 2008. <http://www.whrc.org/midatlantic/modeling_change/SLEUTH/sleuth_overview.htm>

Zielinski, J. 2002. Watershed Vulnerability Analysis. Center for Watershed Protection, Ellicott City, MD. Accessed: 1 July 2007. <http://www.cwp.org/pubs_download.htm>