Silver Brook Watershed Management Plan



July 15, 2009

NJ090193, #71088.0004

Prepared for:
The Great Swamp Watershed Association
568 Tempe Wick Road
Harding Township, NJ 07960

Prepared by:
AKRF, Inc.
100 Centre Blvd., Suite 102H/J
Marlton, NJ 08053

ACKNOWLEDGEMENTS

The Great Swamp Watershed Association (GSWA) would like to thank The Stony Brook Millstone Watershed Association for providing the funding needed to complete the Silver Brook Watershed Management Plan. In addition, GSWA would like to thank the volunteers of the GSWA Stream Team for their time and effort conducting stream surveys that were critical to the development of this Plan.

TABLE OF CONTENTS

I. INTRODUCTION

The Silver Brook Watershed is located within Morris and Harding Townships in Morris County, NJ. Silver Brook, sometimes referred to as Catfish Creek, is a tributary to Great Brook, which is one of the five subwatersheds that drain to the Great Swamp National Wildlife Refuge (Figure 1). The Great Swamp Watershed Association, a non-profit organization that conducts monitoring, outreach and advocacy work within the Great Swamp Watershed, is developing a restoration plan for the Silver Brook Watershed. The Silver Brook Watershed Management Plan summarizes existing knowledge of conditions within the watershed, defines an overarching management strategy, outlines management priorities, and identifies specific restoration projects to improve in-stream flows, water quality and channel habitat. These proposed enhancements will benefit Silver Brook as well as Great Brook and the Great Swamp.

Silver Brook is a priority watershed for implementing a comprehensive restoration plan for several reasons:

- Because Silver Brook is located within the headwaters of the drainage area of the Great Swamp National Wildlife Refuge, conditions within Silver Brook have an important impact on the quality of the environment within this regionally-significant protected area.
- Silver Brook is located within the Highlands Planning Area, which imparts an additional regulatory impetus for land conservation and water resource protection and restoration.
- The Silver Brook Watershed is located in close proximity to the headquarters of The Great Swamp Watershed Association and contains the Great Swamp Watershed Association Conservation Management Area. Its locale makes Silver Brook Watershed an ideal focus for GSWA's long term watershed stewardship, education, and restoration implementation activities.
- Silver Brook is a manageably-sized watershed where a focused restoration program can result in meaningful improvements to resource quality over relatively short time periods.
- Most stream impairment within the watershed can be addressed with cost-effective retrofits, riparian enhancement and selective in-stream restoration.

This combination of factors creates an environment where a concerted watershed restoration effort has a great prospect for implementation and successful outcomes. Measurable success within the Silver Brook Watershed will provide justification and a template for addressing similar issues in other Great Brook and Great Swamp watersheds.

The Silver Brook Watershed Management Plan supports several larger scale planning initiatives including the Highlands Regional Master Plan and the Great Swamp Watershed Management Plan.

Highlands Regional Master Plan

The Silver Brook Watershed is part of the Upper Passaic River Basin and is located in northwestern New Jersey within the Highlands Planning Area. This region provides about half of New Jersey with drinking water and is valued as an important scenic and environmental resource (Highlands 2008). Compliance with strict standards for water and natural resource protection are required by law within the Highlands Protection Area. Within the Highlands Planning Area, observance of these principals is encouraged but not required. The Highlands Regional Master Plan (RMP) provides an historic, geographic, and human values context for natural resource management and land use planning within the Protection and Planning Areas. It establishes goals, policies, and objectives that articulate specific aims, and it defines programs that provide a framework for execution of the plan (Highlands 2008). Goals included in the RMP that are relevant to the Silver Brook Watershed Management Plan include (Highlands 2008):

- Forest enhancement and protection;
- Inclusion of natural resource protection into the plans and regulations of individual municipalities;
- Stream protection, restoration, and enhancement;
- Riparian area protection, restoration, and enhancement;
- Open space preservation and stewardship;
- Steep slope protection; and
- Habitat protection and enhancement.

Great Swamp Watershed Management Plan

The Silver Brook Watershed Management Plan directly supports the management goals set forth by the Great Swamp Watershed Management Plan for the improvement of the Great Swamp. The Great Swamp Watershed Management Plan was developed by the Ten Towns Great Swamp Management Committee (Ten Towns Committee) in 1997 and approved by the New Jersey Department of Environmental Protection in August 2006. The Great Swamp Watershed Management Plan advises that existing conditions within the watershed be assessed and that strategies to meet the goals of the plan be implemented (TTC 1997). The goals of the Great Swamp Watershed Management Plan include (TTC 1997):

- The maintenance of the present ecological condition of the Great Swamp as a wildlife refuge;
- The decrease of existing stormwater peak flows and volumes;
- The improvement of water quality within the Great Swamp and its tributaries;
- The improvement of the macroinvertebrate population and diversity within streams;
- The restoration of geomorphic stability to unstable streams;
- The maintenance or reduction of the present flooding within the Great Swamp; and

- The maintenance of properly functioning treatment plants and septic systems.

Prior Studies

The Silver Brook Watershed Management Plan incorporates studies and data collection efforts pertinent to the watershed, using these sources to provide information on existing conditions and issues that have been identified as priorities in the past. Previous and ongoing efforts to characterize the Silver Brook Watershed include a 1997 study (Najarian 1997) that investigated pollutant loads from various sources and concluded that non-point source pollution contributed more than 80% of phosphorus loading to the Great Swamp. Subsequently, the Ten Towns Committee conducted a non-point source pollution survey identifying sites contributing to pollution within the Great Brook watershed (F. X. Browne 2001). This report identified areas of excessive erosion, denuded riparian zones, and stormwater outfalls throughout the watershed. A later effort initiated by the Ten Towns Committee inventoried existing detention basins and stormwater outfalls (F. X. Browne 2003). In 2002, the Ten Town Committee developed water quality standards for the Great Swamp Watershed (F. X. Browne 2002a) and produced a report on the water quality at that time (F. X. Browne 2002b). A more recent water quality report for the Great Swamp Watershed was completed in 2007 (Princeton Hydro 2007). Volunteers coordinated by the Great Swamp Watershed Association and known as the Stream Team conduct stream habitat and land use surveys throughout Great Brook and monitor water quality at two locations within the Silver Brook Watershed (Figure 1). The Great Swamp Watershed Association manages the Great Swamp Watershed Association Conservation Management Area, a 51 acre property in Harding Township that lies within the Silver Brook Watershed. This management area is the site of past and ongoing ecological restoration activities such as invasive plant removal and stream bank re-vegetation using tree plug planting.

II. PROJECT GOALS

The Silver Brook Watershed Management Plan development process aims to:

- Compile and summarize the existing condition of Silver Brook and its tributaries using existing assessment data and supplemental field data collection;
- Articulate broad management goals for the Silver Brook Watershed; and
- Identify specific project opportunities for sediment reduction, water quality enhancement, and in-stream habitat improvement.

The study will serve as the basis for implementation of future watershed restoration efforts within the Silver Brook Watershed and will provide a model for management of other Great Brook subwatersheds. Inventories of existing sources of non-point source pollution, areas of excessive bank erosion and denuded riparian buffers, and some existing stormwater detention and outfall locations have been identified in past efforts. The current effort builds on this work by providing additional insight into the geomorphic stability of Silver Brook and focuses on identifying specific, actionable, and cost-effective project opportunities that would be most effective at improving in-stream flow, water quality, and channel habitat. In addition, it identifies and prioritizes areas with stormwater retrofit potential. Implementation of identified projects will reduce peak flows and sediment loading, improve channel habitat and geomorphic stability, and eventually improve water quality and reduce nutrient loads downstream within the Great Swamp.

III. ASSESSMENT METHODS

AKRF conducted both desktop and field assessments to characterize conditions within Silver Brook Watershed and to identify opportunities for restoration. AKRF conducted a GIS-based desktop evaluation of the channel network to delineate the watershed boundary, identify high priority stream reaches and access points, and to locate probable existing stormwater facilities. Relevant GIS layers included topography, roads, streams, water bodies, wetlands, contours, and aerial photographs. Aerial photographs taken in 2008 were obtained from the New Jersey Office of Information Technology, Office of Geographic Information Systems (Trenton, NJ). NJ-IMAP provided aerial photographs for comparison from 1930, 1995/97 and 2002. During this process AKRF also collected and reviewed existing studies, as well as water quality and flow data provided by the Great Swamp Watershed Association.

Field assessments were conducted on February 5, April 15, and May 26, 2009. These assessments included mapping geomorphic features and near-stream infrastructure; evaluating the channel network with regards to channel bed and bank stability, riparian buffer intactness, and in-stream habitat quality; and photo documentation of the channel network.

In addition to channel and watershed investigations, a stormwater management facility inventory was compiled from aerial photographs, existing studies (F. X. Browne 2003) and field surveys. The size of the drainage area treated by the facility, the type of facility (categorized as detention, retention, or swale/filter strip), the condition of inlet and outlet structures, the type of vegetation on the basin floor, the basin configuration, and the condition of the receiving channel were observed and considered when prioritizing stormwater retrofit opportunities (Table 1). Treated drainage areas were estimated by measurement in GIS, but should not be used for detailed project design. Existing engineering reports and/or a detailed field survey would be required for confirmation.

IV. WATERSHED DESCRIPTION

A. Geographic Context

The Silver Brook Watershed is approximately 2,644 acres (4.1 square miles) and lies within northwestern New Jersey. Silver Brook is within the upper Passaic River drainage and is a 1st-to-3rd order tributary to Great Brook, entering Great Brook approximately 3 miles upstream of the Great Swamp National Wildlife Refuge Boundary.

The Silver Brook Watershed is situated in the Highlands Physiographic Province, near the border with the Piedmont Physiographic Province (Dalton 2003). The Highlands Province is characterized by steep and rounded ridges with valleys that are deep and narrow, while the Piedmont Province has rolling plains and a fertile landscape (Dalton 2003). The Silver Brook Watershed's physical characteristics are more similar to those found in the neighboring Piedmont Province.

Physiography within the Highlands Region is strongly influenced by glacial activity. The most recent geologic event impacting the Highlands Region was the Wisconsin glaciation. The terminus of the glacier reached the area which is now the Great Swamp National Wildlife Refuge around 18,000 years ago before it began to recede, forming a glacial lake that eventually became the Upper Passaic River. Lands covered by the advancing and retreating glacier were scraped by the movement of the ice mass. The land area that is now the Silver Brook Watershed was north of the glacial lake and beneath the glacier; however, being near the glacial terminus, it likely experienced less disturbance than more northern areas, leaving the watershed with soils supportive of hardwood forests and agriculture.

Silver Brook has varied geomorphic forms that include both steep, confined tributaries and slow, meandering channels that wind through the unconfined valley floor. Stream reaches flowing from valley ridges are relatively high-gradient and straight. The cobble-to-small boulder dominated bed materials within these high gradient channels are arranged in step-pool formations. Downstream reaches include both channelized and meandering stretches and flow through alluvial valleys with silt, sand and gravel substrates. Reaches in the middle portion of the watershed are transitional forms characterized by moderate channel slopes, gravel-to-cobble substrates and riffle/pool and plane-bed forms (see Section V.B for details).

B. Surrounding Land Use

Past and present land use within a watershed influences stream condition and stability. Stream channels in the Mid-Atlantic region, including those of the Silver Brook Watershed, have responded somewhat predictably to a pattern of land use over the last two centuries (Wolman 1967). In the early 1800s, land in the Piedmont region was predominantly hardwood forests, and stream channels were stable. Deforestation and land clearing associated with a period of crop-intensive agriculture resulted in large quantities of sediment delivered to the streams. This increase in sediment loading led to channel and valley aggradation. Following this agricultural phase, many lands were turned over to grazing or allowed to regenerate second growth forests which resulted in a reduction of sediment delivery to streams. During this phase, around the mid 1900s, fine sediments that had accumulated in stream channels were scoured away, and many streams reached a point of quasi-equilibrium. Beginning in the 1960s, construction related to new development and roads cleared large areas of land, and again large quantities of sediment were eroded from the landscape and delivered to streams, leading to the aggradation of fine materials within stream channels. The resulting urbanization produced a built-out landscape with large quantities of impervious cover and few sources of landscape-derived sediment. In response to increases in storm flows and low rates of sediment input, stream channels draining urban areas began to widen and downcut. This phase of stream response to urbanization continues within many watersheds today.

Within the Silver Brook Watershed, the condition of the stream network indicates that the watershed likely followed a pattern of land use similar to others in the region. Aerial photographs, circa 1930, show land use in the watershed at that time to be primarily agricultural. An agricultural period of deforestation, channel straightening, and ditching occurred, most likely, in the 1800s or early 1900s. Fertile alluvial (stream-derived) soils were under active cultivation in the lower reaches of the Silver Brook Watershed for many years. Aerial images show that streams within or adjacent to farm fields had minimal buffers and many were ditched or straightened. Some forested areas were intact in the 1930s aerial photographs, primarily in the vicinity of the present-day Great Swamp Watershed Association Conservation Management Area. Like other streams in the region, modifications related to agriculture that occurred in the Silver Brook Watershed probably led to the delivery of large amounts of landscape-derived sediments to the stream. More recent aerial photographs show forest regrowth within some agricultural areas since the early 1900s. This return to a more forested state may have led to widespread scour of accumulated fine sediments and downcutting within the channel as the input of sediments from the landscape was reduced.

The construction of a major roadway, Interstate 287 (I-287) and housing developments initiated another phase of significant disturbance to Silver Brook. US-202 (US-202), Sand Spring Road and James Road are apparent on the 1930 aerial photograph, but I-287 and numerous residential streets and buildings were not yet constructed. Dates inscribed on I-287 culverts suggest that it was constructed in the 1960s. The interstate bisects the watershed and major stream alterations were required to construct the road and to maintain connection between the northern and southern portions of the watershed. Four large concrete culverts (Photograph 1) allow sections of Silver Brook to flow beneath the interstate and Harter Road (south of I-287).

Urbanization has continued through the last few decades, including construction of commercial parks and additional residential developments and apartment complexes, and has increased the amount of impervious cover in the watershed. Areas of accumulated fine sediments observed within the lower reaches of the network are likely the result of construction-related erosion and migrating headcuts within the channel network. There are numerous examples of channel response to urbanization within Silver Brook that follow the patterns observed within other streams of the region (see Section V for details). Construction of new developments, particularly in areas of the watershed that are currently fielded or forest, continues today.

Current land use within the Silver Brook Watershed consists primarily of urban residential uses, but includes areas of rural residential, commercial, recreational (e.g., golf course, park, etc.) and forested use. Residential neighborhoods vary in age. The oldest developments occur in the corridor between I-287 and US-202 and west of Harter

Road. Developments that were likely built in the last 20 years are located east of Harter Road and north of US-202. The Mt. Kemble Corporate Center, a large corporate park located in the north central portion of the watershed, also appears to have been built in multiple phases with more recent areas occurring on the eastern side of the complex. The majority of properties occupied by residential developments are connected to the municipal sewer system, but the more rural southern portion of the watershed is not. Stormwater management facilities (e.g., detention basins, retention basins, etc.) throughout the watershed are primarily designed for flood protection, but water quality treatment of stormwater runoff is largely unaddressed.

V. CHANNEL DESCRIPTION

A. Channel Network Description

A map showing the Silver Brook channel network is provided in Figure 2. The channel network has been divided into reaches for referencing purposes. Channel reaches on the mainstem of Silver Brook are given MS designations, while tributary channels are given TR designations. Reaches were delineated primarily on the basis of tributary junctions or stream crossings (e.g., bridges, dams, etc.). Areas within the channel network where channelization, instability, headcuts, and denuded riparian zones occur are shown in Figure 3 and described in further detail within this section.

The Silver Brook channel network includes a mainstem channel (MS-1 through MS-5), which originates at the ridge crest along Bailey Hollow Road and flows roughly southeast for approximately 2.5 miles, crossing beneath I-287 and James Street, to its confluence with Great Brook. It is joined by five major tributaries, three that enter from the north and two that enter from the south. Tributary 1 (TR1), also known as Bayne Brook, originates near Bayne Park and the intersection of Glen Alpin Road and Blue Mill Road and flows northeast to meet the Silver Brook mainstem near its confluence with Great Brook. Tributary 2 (TR2) originates near Spring Brook Country Club and the intersection of Harter Road and Alvord Road and flows south through residential neighborhoods and forest remnants to meet Silver Brook near the James Street crossing. A tributary (TR2-1a) enters TR2-1 just upstream of the Tiger Lily Lane crossing and drains the areas immediately north and south of I-287 and east Harter Road. Originating near Sand Spring Road, Tributary 3 (TR3) flows from the south through forests to meet the mainstem within the Great Swamp Watershed Association Conservation Management Area property. Tributary 4 (TR4) originates near the intersection of Shadow Brook Lane and US-202 and flows along the north side of I-287 to meet the mainstem from the west. A fifth tributary (TR5) originates north of US-202 near Forest Drive. This tributary is directed underground after entering a riprap-lined swale just north of US-202. At this point it appears to joins a large underground conveyance system. This underground conveyance system probably originates near Forest Drive where a system of underground concrete pipes convey stormwater from adjacent developments (visible as tan semi-circle northeast of TR5-3), presumably to a series of treatment swales, basins and ponds adjacent to the Mt. Kemble Corporate Center. Two reaches (TR5-1 and TR5-2) emerge as open channels at the southern end of the corporate center. TR5-1 joins the Silver Brook mainstem just north of the I-287 crossing. Flow from TR5-2 appears to be infiltrated before reaching the Silver Brook mainstem, most likely in the vegetated median of I-287.

B. Channel Forms

The geomorphology of a stream channel describes both its physical form and the processes that have and continue to influence this form. Channel form includes three-dimensions of analysis: lateral pattern (e.g., meander pattern, etc.), longitudinal form (e.g., channel slope, etc.), and dimension (i.e., the channel's cross-sectional characteristics). Numerous classification schemes have been developed to systematically describe channel form. The classification system described by Montgomery and Buffington (1997) is used to guide descriptions in this management plan (Figure 4).

As described earlier, the Silver Brook channel network is situated within a valley that is partially confined with steep, mostly forested hillslopes in the upper reaches and that is unconfined with little-to-no surrounding hillslope within its lower reaches. Accordingly, the Silver Brook channel network displays varied geomorphic forms that range from steep, confined channels to meandering reaches flowing through the unconfined valley floor.

The upper reaches of the Silver Brook channel network are high-gradient or moderate-gradient channels. Stream reaches running through high-gradient, confined valleys (MS5 and TR5-3) have relatively straight channels that assume step-pool bedforms (Photograph 2). These segments cut through colluvial (loose, slope-derived) material, have cobble-dominated substrate, few meanders and steep banks. Upstream reaches running through moderate-gradient and largely unconfined valley segments (TR4-1, TR4-2, and TR1-3) are meandering channels with step-pool or plane-bed bedforms dominated by a combination of gravel- and sand-sized materials (Photograph 3). These reaches are typically shallow with few pools, low banks and a large accessible floodplain. Although erosion of outer bends and deposition of sediment on point bars is natural, excessive bank and bed erosion in these reaches is likely the result of an altered flow regime due largely to the introduction of unmanaged stormwater. TR1-3, TR4-2, and the upper portions of TR4-1 have characteristics expected of largely undisturbed systems; however downstream sections of TR4-1 display regions of inner bank erosion, incision, and deposition of fine materials.

Mid-network reaches flow through unconfined, moderate-gradient valleys and typically assume a meandering form (MS4, TR1-2, TR2-2, TR2-1a, TR3-2, and TR5-1). Bedforms are predominantly riffle/pool or plane-bed and are dominated by cobble and gravel substrates (Photograph 4). Although these reaches are not naturally confined and have wide accessible floodplains, most flow through areas that impose artificial restrictions. Private homes, roads, bridges, and maintained fields constrain the lateral movement of the channels in reaches MS4, TR1-2 and TR2-2. Reaches TR3-2, TR2-1a and TR5-1 flow through forested terrain and are accordingly less laterally confined.

Despite constrictions, MS4, TR1-2, TR2-2, and TR3-2 display geometry that would be generally consistent with naturally-formed channels in similar valley types.

Mid-network reaches tend to be the most impacted by stormwater flows, particularly those reaches located down gradient of the Mt. Kemble Corporate Center. For instance, Reach TR5-1 displays a channelized lateral form, high banks and disconnection from the floodplain suggestive of incised streams severely impacted by unmanaged urban runoff. TR5-2 is a gully that originates at a headcut and has severely eroded and undercut banks and a channelized lateral form. Upslope of the headcut overland flow forms small channels through the forest. Reach TR2-1a alternates between actively down-cutting and aggrading sections. Numerous incised channels and ditches originate from I-287 or properties along James Street and have a similar pattern of alternating incising and aggrading sections. Currently the confluence of TR2-1a with TR2-1 appears to be aggrading as evidenced by the formation of mid-channel point bars. Lower-network reaches (MS1, MS2, MS3, TR1-1, TR2-1, and TR3-1) are dominated by low-gradient channels with wide, unconfined, alluvial floodplains (Photograph 5). Most of these reaches are surrounded by forested wetlands. The channel bedform consist primarily of plane-bed or dune-ripple forms. Bed material is noticeably smaller in size, ranging from gravel-to-silt sized particles, with sand and silt being the dominant substrates. Sections of MS1 flow through meadow and emergent wetlands. In most reaches (TR2-1, TR3-1, MS3, and the upstream portion of MS2) the channels are straight and appear somewhat incised (Photograph 6). Straightening of these reaches was apparent in the 1930 aerial photograph and was likely related to the adjacent agricultural land use. Channel straightening often leads to channel incision because the increase in channel slope associated with channel straightening increases available hydraulic energy. In subsequent years, increasing rates of sediment production from migrating headcuts and increasing storm flows due to urban development may have led to recent bed aggradation within lower-network reaches. Channel adjustments are discussed in more detail in Section V.D.

Ditches are common throughout the watershed. Many are probably associated with attempts to drain swamps for agricultural practices or for mosquito control. Others are associated with roads or may have been constructed to convey stormwater runoff away from a building or property. The condition of ditches range from actively downcutting to actively aggrading and depends on when the ditch was constructed and land use within the area it drains.

C. Channel Banks

Channel bank characteristics vary throughout the Silver Brook Watershed. Channel banks are often near vertical, and range from low (i.e. < 2 ft.) to high (i.e. > 6 ft) depending on the degree of incision within the reach. Within intact mid-network reaches and downstream reaches, banks are typically more gently sloped and sometimes covered with wetland and riparian vegetation. Although bank height ranges from less than 1 foot to more than 6 feet, heights of 1 to 2 feet is most common. Bank erosion within the Silver Brook network is common, but only occasionally severe. In most locations, bank erosion appears to be relatively minor with low rates of bank retreat and is usually on outer bends and associated with natural meander extension processes. The most severe bank erosion occurs along TR4-1, TR5-1, TR5-2, MS2 and MS3. Within TR5-1, vertical faces of up to 5 feet are common and erosion is continuous on both the left and right banks. TR5-2 is a gullied to a depth sometimes greater than 3 feet with exposed banks and tree roots on both sides of the channel. Erosion within TR4-1 is also prevalent with the most severe erosion occurring where the reach meanders in close proximity to the I-287 sound barrier wall (Photograph 7). Within this reach, mass wasting occurs at several locations and the observed instability is probably due to channel confinement by I-287 to the south and stormwater inputs from residential areas. Within the mainstem reaches (MS2 and MS3), bank heights are often more than 3 feet. In reaches with excessive bank erosion, channels are typically incised well below the root horizon. Rip-rap and other bank revetments are uncommon within the watershed.

D. Channel Instability and Adjustment

Numerous researchers have demonstrated predictable channel responses to urbanization (e.g. Schuum *et al.*, 1984, Simon and Hupp, 1986, Simon, 1989, etc.). These sequences, termed Channel Evolution Models (CEMs) have been successfully used to conceptualize these responses. CEMs predict that channels first undergo a rapid phase of bed lowering in response to increases discharge and reductions in sediment load (Figure 5). As bank heights increase, channel downcutting eventually stimulates increased rates of bank retreat, leading to a pronounced channel widening phase. Ultimately, channel downcutting and widening sufficiently reduce shear stress and stream power to levels that encourage the formation of new depositional features (e.g., point bars, etc.) within the over-widened channel. Increased rates of bedload transport from stream incision processes occurring in upstream reaches increases sediment supply to downstream reaches.

An indication of channel instability is the presence of headcuts. Headcuts, also known as ‘knick points’, are locations of rapid grade change within a channel bed. They occur when a stream has excess hydraulic energy in relation to its sediment load. This ‘sediment starved’ state leads to lowering of the channel bed as the headcut migrates upstream. Increased rates of sediment production from stream banks typically follow bed lowering. These eroded sediments are subsequently deposited at some downstream point where hydraulic energy is sufficiently diminished. Headcuts migrate upstream and can cause excessive erosion in reaches that were previously stable.

Channel features within Silver Brook represent a range of channel evolution stages and include reaches that appear both geomorphically stable and unstable. Most areas of rapid channel evolution occur within the mid-network reaches. Areas of apparent instability appear to be associated with major disturbance such as roads and concentrated stormwater discharges. Unstable mid-network reaches (TR2-1, TR4-1, TR5-1, and TR5-2) may be responding to more recent urbanization including the construction I-287 and increases in impervious surface area associated with residential and commercial developments. These reaches appear to be within the early stages of channel evolution with either rapid bed elevation changes or lateral migration and widening through bank erosion occurring actively during high flows. In these areas, rapid downcutting is occurring or has occurred and the channels are incised, resulting in the highest bank heights within the watershed. Three headcuts were identified within the watershed (along TR2-1a, TR4-1, and TR5-2). These unstable reaches have the potential to destabilize adjacent reaches within the channel network (e.g., TR4-1, etc.) or to contribute volumes of sediment that cause downstream reaches to aggrade (TR2-1a). The high percentage of fine sediments within the lower reaches (e.g., MS2 and MS3, etc.) may be derived in part from these eroding channels; however, field assessment data suggests that the incision processes are somewhat isolated by constraints such as road crossings.

Other mid-network residential reaches (MS-4, TR1-2, TR2-2 and TR3-2) appear to be relatively stable with occasional areas of minor bank erosion and channel widening. One location that should be monitored, however, is a large outlet structure delivering stormwater to TR2-2. There is some evidence of downcutting where the outflow from the structure meets the stream, and the development of a headcut that would migrate upstream through currently stable reaches is possible.

Upper network reaches appear geomorphically stable for the most part. Rates of sediment production are low in these areas. Upper-network reaches including MS-5, TR1-3, TR4-2, and TR5-3 appear to be relatively stable with bank erosion, incision and aggradation absent or rare.

In channelized lower-network reaches, which were probably straightened nearly 100 years ago, there is evidence of past progression through stages of channel evolution and presently seem to be in a quasi-stable but degraded state. The steep and often bare banks and perched nature of tributary channels (dropping 1-2 feet to the mainstem) suggest a history of downcutting (Photograph 8) and that tributaries are still adjusting to historical downcutting within the Silver Brook mainstem. Many sections of the lower channelized reaches are homogeneous in width and depth and laden with fine sediments. There is evidence that some sections of the mainstem reaches (MS1-MS3) are aggrading (rising of the stream bed due to fine sediment deposition) or have done so in the past. In some sections, the presence of meanders, riffle/pool sequences and point bars within the incised channel indicate a relative balance between erosion and deposition without rapid migration of the channel vertically or laterally. Sections of the TR2-1 streambed do appear to be actively aggrading (Photograph 9) probably due to continued bank erosion within the reach and transported sediment from the unstable upstream reach TR2-1.

E. Sediment Dynamics

Channel stability is directly tied to the relationship between stream energy and sediment. When a channel is in balance, the influx and export of sediment to a given reach is in approximate balance; although the channel may migrate laterally, its form remains consistent. Instability occurs when this state of quasi-equilibrium is altered due to natural- or human-induced disturbance. For example, an increase in stream energy as a result of unmanaged stormwater runoff often leads to in-stream erosion and the export of sediment from a reach.

In the Silver Brook Watershed, predominantly stable channel forms suggest that sediment production and transport is likely fairly low in most locations. The significant exception to this conclusion is the presence of headcutting and areas of excessive bank erosion within some mid-network reaches. The presence of aggradational channel forms (e.g., midchannel bars, fine unconsolidated sediment) in areas downstream of bank erosion suggests that increased rates of sediment production from incising streams may be significantly impairing downstream areas (Photograph 10). Aggradation within TR2-1 is likely due to actively-eroding sections immediately upstream, while the sand and silt substrate of the lower mainstem reaches (MS1-MS3) are possibly derived from both the adjacent banks and from erosion within upstream reaches. Within downstream portions of the channel network, frequent flooding onto the adjacent floodplain likely results in the transport and deposition of sediment from within the active channel onto the floodplain surface.

F. Riparian Zone Characteristics

The majority of the Silver Brook channel network is buffered by second growth riparian forests. The riparian forest provides some, although not all, of the functions associated with a mature forest. Temperature moderation, for instance, is provided at similar levels as would be expected under pristine forests. However, sediment and nutrient removal, rates of large woody debris (LWD) recruitment, organic matter loading, and degree of root reinforcement may all be compromised by the underdeveloped shrub and understory tree communities. Deer browse on the understory probably contributes to the inadequate shrub cover in the riparian forest. The Great Swamp Watershed Association is attempting to reduce deer browse within the Conservation Management Area by installing barrier fencing around large areas of the riparian forest.

Mid-network and downstream reaches (e.g., MS4, TR2-2, TR1-1 and TR1-2, etc.) are sometimes bordered by poor riparian buffers. In the Bayne Brook reaches, one side of the stream channel is typically denuded with open fields or turf grass dominating cover. Other reaches flow through residential areas that provide some canopy cover, but consist largely of denuded or grassy banks and little-to-no understory other than the invasive multiflora rose (*Rosa multiflora*). Often houses are within close proximity to the stream.

G. In-Stream Habitats

High quality in-stream habitat for primary producers, invertebrates, and fish is present within many channel forms. In general, streams that are heterogeneous, or patchy, will provide a greater diversity of habitats capable of supporting a more diverse assemblage of organisms than streams that are uniform. Patchiness is important at multiple scales. Watershed-scale heterogeneity in the Silver Brook channel network is represented by the presence of stream habitats ranging from channels flowing through emergent wetlands to the step-pool sequences of the upper-network reaches. An example of small scale patchiness is the surface of individual cobbles lying within a stream channel, each providing a discrete area of habitat. Natural structures within a channel, such as pieces of wood, provide additional habitat diversity, greater surface area for organisms to inhabit, and an important food sources for bacteria and fungi.

Stream disturbance can result in impaired aquatic habitat. For example, excessive amounts of fine sediments delivered to a stream channel can fill the interstitial spaces between bed materials that are used by organisms. Larger bed material becomes embedded, which makes the stream bed more uniform and reduces available surface area and habitat diversity. In addition, exchange between water flowing in the channel and through the substrate (i.e. hyporheic flow) can be reduced or eliminated. Channelization of a stream reduces its length, thereby increasing the slope of the channel and the velocity of the water. The straightening process typically removes natural habitat heterogeneity including variations in flow that occur within riffle/pool and ripple-dune sequences that are often associated with a meandering channel. In addition, it reduces the frequency with which the stream spreads onto its floodplain, a process that provides important exchanges between the stream and the surrounding riparian zone.

Although the type and diversity of in-stream habitats found within Silver Brook are similar to the spectrum of habitats that would be expected in relatively undisturbed watersheds of similar valley configuration, a number of reaches are degraded by either instability or straightening. Stable channels within upper and mid-network reaches offer organisms a variety of substrates and water velocities and may support a diverse assemblage of macroinvertebrates. However, variation in channel depth is lacking, and pools, when present, have sub-optimal depths. In downstream reaches, changes in velocity within ripple-dune sequences and meanders offer some habitat diversity, but substrates are fairly uniform and are often covered with fine grain material. Occasionally woody debris, undercut banks and overhanging vegetation contribute to the structural complexity of the stream. Also, sections of MS1 that flow through emergent wetlands and meadows add habitat variety to the watershed. In unstable reaches, channels are typically either scoured or filled with sediment, in either case lacking heterogeneity, stable substrate, and cover. It is likely that these unstable reaches, such as TR2-1, are unable to support a healthy population of invertebrates.

In all channels, we observed a relative paucity of LWD and debris piles. This may occur for several reasons. First, the lack of small-to-mid-sized trees in the riparian canopy may reduce the incidence of tree-fall. Second, altered urban hydrology may create hydraulic conditions that limit the formation of large and stable LWD piles. Finally, clearing of tree-fall from within channels, especially within residential areas, is a common practice. Increasing the abundance of LWD within the channel network is a key management action, especially within lower reaches where the addition of stable substrate may be particularly important to increasing macroinvertebrate population density and community diversity and may also increase the availability of fine particulate organic matter and seston for filter-collector benthic organisms. This is especially important in shaded stream sections where primary production is limited by low light conditions.

H. Water Quality

Volunteer stream monitoring occurs four times per year within the Silver Brook Watershed. One site is located at the end of Tiger Lily Lane on the Great Swamp Watershed Association Conservation Management Area (CMA) property; the other is located at Wexford Lane along Bayne Brook. The entire Silver Brook Watershed is classified by NJDEP as FW2 with designated uses including: maintenance, migration and propagation of natural biota, primary and secondary contact recreation, industrial and agricultural water supply, public potable water supply after filtration and any other reasonable uses. Sites monitored for temperature, pH, DO, turbidity, conductivity, TDS, and sodium and chloride content, have produced results within the New Jersey Surface Water Quality Standards for these streams except in the categories of turbidity and pH. Measurements of pH taken at the CMA in Silver Brook were lower than the 6.5-8.5 range designated as the New Jersey water quality standard for FW2 waters on 3 out of 4 survey dates in 2008. In addition, turbidity was just over the chronic level on one of the dates, but may have been due more to weather related conditions on that particular day than an intrinsic problem. No elevated levels of nitrogen and phosphorus bearing nutrients or total suspended solids (TSS) were recorded at either Silver Brook site in 2008 (Curran 2009).

Water quality within Great Brook has also been monitored. A 2002 report (F. X. Browne 2002b) found that Great Brook did not meet water quality standards for base flows and/or storm flows set for the Great Swamp Watershed (F. X. Browne 2002a) in the following areas: Total Phosphorus, Dissolved Reactive Phosphorus, Total Kjeldahl Nitrogen, and Total Suspended Solids. A more recent water quality report for the Great Swamp Watershed was completed in 2007 (Princeton Hydro 2007) and reported the Great Brook continued to fall short of water quality standards under both baseflow and storm conditions. Sections of Great Brook downstream of the Silver Brook confluence were identified on New Jersey's 2006 Integrated List of Waters as not attaining New Jersey Water Quality Standards for the Aquatic Life (general) category. However, the cause of this non-attainment status was listed as unknown and remediation of the segment was listed as a low priority in the Draft New Jersey's 2008 303(d) List of Impaired Waters with Priority Ranking. Other categories (e.g., primary contact recreation, agricultural water supply, etc.) indicated that a lack of data prevented the completion of the assessment.

VI. STORMWATER MANAGEMENT

Unmanaged stormwater can contribute to non-point source pollution and result in increased frequency of channel forming flows, increased peak flows, channel bank and bed erosion due to increased flow velocities, and reduced baseflows. Non-point source pollution has been identified as a leading threat to the Great Swamp National Wildlife

Refuge (TTC 1997 and F. X. Browne 2001). Land areas with a high percentage of impervious cover (i.e., rooftops and pavement) are the primary contributors of unmanaged stormwater. In many residential landscapes, stormwater facilities are either absent or are only designed to provide detention of large storms. Recent regulatory changes have resulted in design changes that provide enhanced groundwater recharge, water quality treatment, and channel protection.

The degree of stormwater management within Silver Brook Watershed varies substantially, as developed areas were constructed under differing sets of stormwater regulations. Within older developments, stormwater is conveyed from impervious surfaces directly to on-stream outfalls with no detention or treatment (Photograph 11). In more recently developed areas (e.g., areas developed in the 1980s and 1990s), flood control detention is provided (Photograph 12). Infiltration-based or extended detention stormwater management systems such as bioretention areas, and constructed wetlands were less common, as most development preceded the adoption of stormwater regulations that require these practices. Existing stormwater management facilities that were identified during desktop and field reconnaissance efforts (Figure 6) were categorized into one of three categories and are listed in Table 1. Basins categorized as 'retention' appeared to be permanent-ponded structures. Basins categorized as 'detention' were typically designed to convey small storm events quickly through the structure and to detain larger flood events. Most of these basins drain through orifices that lie at the basin floor, allowing little time for infiltration of stormwater. Detention basin floors range from mowed grass with concrete flow paths to common reed-dominated wetlands. Even those basins containing some wetland plants, design for infiltration or extended detention of small storm events was not apparent. The other category included mostly stormwater conveyance structures such as grass, rip-rap or vegetated swales and large graded areas of pervious surface (typically grass) leading to inlet structures.

VII. DESIGN CONSTRAINTS

Design constraints, including historical and cultural resources, sensitive environmental resources such as wetlands, vernal pool habitat, and riparian forests, land ownership, and site access issues, are critical considerations in developing a feasible restoration plan. Within the Silver Brook Watershed, the primary design constraints are coordination with private landowners and the presence of regulated wetlands and vernal pool habitat. Retrofitting and constructing stormwater treatment facilities such as retention basins or infiltration facilities require additional investigation of site constraints. For instance, the infiltration capacity of the soils within an existing basin or a proposed site dictate what type of facility or retrofit action would be most appropriate. For example, well drained soils favor infiltration techniques, while constructed wetlands are a more suitable option for soils that retain water for long periods.

NJDEP requires permits to complete projects that disturb wetlands (Fresh Water Wetlands Permit) or stream channels (Open Water Fill and/or Flood Hazard Area [FHA] Permits). The permitting effort necessary for implementation of a proposed project is an important cost consideration. Approval of permits is not certain and mitigation is often required. For any in-channel work, a project applicant must obtain a FHA Permit and sometimes an Open Water Fill Permit, as well. The NJDEP also requires a Freshwater Wetland Permit if jurisdictional wetlands are disturbed (e.g., grading, fill, earth disturbance, etc.). Much of the riparian corridor, especially in downstream mainstem reaches (MS1-MS3), contains wetland indicator plants such as skunk cabbage (*Symplocarpus foetidus*), and many of the stormwater basins contain common reed (*Phragmites australis*) and/or broadleaf cattail (*Typhia latifolia*). Freshwater wetland delineations and an official Letter of Interpretation (LOI) from the NJDEP are required to determine jurisdictional boundaries. In addition, potential vernal habitat areas were identified in the vicinity of TR2-1a and any disturbance in this area would likely require a survey for vernal habitat. Disturbance within the 300 foot Highlands Open Waters buffer described within the Highlands Regional Master Plan may require a waiver from the Highlands Council if the area is not considered disturbed.

The majority of the land within the Silver Brook Watershed is privately owned. Therefore, most projects will require upfront cooperation with landowners. Identification of and coordination with property owners associated with each proposed project is a critical first step in project planning.

VIII. RESTORATION RECOMMENDATIONS

Improved management of the Silver Brook Watershed can be achieved through a multifaceted approach that includes restoration activities, land use planning, regulatory enforcement, and outreach and education. The focus of this report is to identify restoration opportunities within the stream corridor and the surrounding landscape. However, these restoration activities should be complemented by the implementation of other management strategies that are critical to sustained improvement of in-stream flows, water quality and stream habitat. For instance, the adoption of land use, stream protection, septic and stormwater ordinances that protect watershed resources would provide a consistent regulatory framework to guide future development activities in Morris and Harding Townships. These ordinances should be consistent with recommendations provided in both the Great Swamp Watershed Management Plan and the Highlands Regional Master Plan. The Ten Towns Committee has developed model ordinances for stormwater management, soil erosion and sediment control, steep slopes, stream buffers, tree preservation and removal, and wetlands protection. In addition, the New Jersey Highlands Council provides a vision for protection and smart development that could be adopted by the Townships in future revisions of their comprehensive plans and natural resources protection and land development ordinances.

Although, historical channelization and agricultural era sedimentation are still impairing present-day stream channels within the Silver Brook Watershed, unmanaged or mismanaged stormwater has substantially destabilized several stream channel segments in the watershed in recent decades and is a key management concern. Improvements to riparian buffers, active restoration of severely impaired stream segments, and in-stream habitat improvement work will complement improved stormwater practices to achieve improved in-stream resources and downstream reductions in pollutant loading. Accordingly, we outline a restoration plan for the Silver Brook Watershed that combines hydrologic regime modification, as achieved through the implementation of improved stormwater management for both commercial and residential areas, with selective riparian and in-channel restoration. Improved stormwater management and stream restoration is expected to improve habitat and water quality within the Silver Brook, to improve water quality in the larger Great Brook watershed, and to reduce sediment loads to the Great Swamp. Implementation of the proposed work will help to achieve the broader management goals outlined in the Ten Towns Great Swamp Watershed Management Plan.

A. Stormwater Management

Hydrologic regime modification can play an important role in accelerating recovery in urban stream channels, while also augmenting base flow, creating wetland/upland habitat, and providing water quality treatment. We anticipate that implementation of stormwater management improvements will be the most efficient means of stabilizing incising and aggrading stream channel segments and improving water and habitat quality. We propose a strategy for stormwater management that focuses first on achieving stormwater management within large drainage areas with a high percentage of impervious cover and second on reconfiguring existing flood control basins to provide water quality treatment and channel protection functions where such retrofits are easily implemented. Retrofitting basins to increase retention time of small storm events and improve treatment with features such as pocket wetlands or extended detention would be beneficial. Numerous stormwater facilities, including detention and retention basin have been constructed within the watershed (Figure 6 and Table 1), and many of these identified basins provide retrofit opportunities.

We identify three areas of developed land, each with one or more existing basins, where improved stormwater management facilities would be of greatest benefit to Silver Brook (Figure 7). In all cases, stream reaches receiving stormwater runoff from these areas show signs of instability. The first area is comprised of the residential neighborhoods north of I-287 and west of Sand Spring Road. Three main flood control basins treat runoff from this area and could be retrofitted (Project 1). The Mt. Kemble Corporate Center and housing developments along Rolling Hill Drive located on a hilltop north of US-202 drain through three main basins located along the southern and eastern margins of the commercial park. We recommend retrofitting two of these basins (Project 2). Properties along James Street to the south of I-287 and east of Harter Road drain to TR2-1a. In addition, areas north of I-287, most likely including athletic fields and some of the residential development along Hilltop Circle, drain through a culvert under I-287 to join TR2-1a. Much of this runoff is currently untreated and receiving stream reaches are severely impaired. The project proposes the retrofitting of the existing basin behind the Allied Surgical Group building and the creation of an additional treatment facility just south of I-287 (Project 3).

In addition to these priority areas, another opportunity for stormwater management improvement is retrofitting the basin located at the intersection of Tiger Lily Lane and Harter Road (Project 9).

B. In-stream Rehabilitation

Although in-stream restoration can be costly and is itself a disturbance to the stream channel, it is sometimes an appropriate course of action, particularly when coupled with upstream stormwater management. In reaches identified as unstable during this analysis, existing conditions do not generally warrant large-scale channel realignment or restoration. However, a modest program of limited in-stream intervention is recommended to stabilize headcuts, reduce stream bank and bed erosion at severe sites, and improve in-stream habitats. Straightened and channelized reaches, particularly those within and adjacent to the Conservation Management Area (MS2 and MS3), would require larger scale channel realignment and are considered a more long-term goal.

As short term priorities, we specifically recommended four in-stream rehabilitation projects that intend to improve geomorphic stability, reduce streambank erosion and enhance in-stream and riparian habitat. The instability of TR5-1, TR4-1 and TR5-2 discussed in section V.D of this report will be addressed through headcut stabilization and bank grading along selected areas and are discussed in Projects 4, 5 and 6, respectively. In-stream habitat will be enhanced within reaches MS2 and MS3 through the addition of structural elements to the channel (Project 7). Specifically, the strategic placement of coarse-grained point bars and large woody debris will increase habitat heterogeneity and promote meander formation within the incised channel.

In the future, strategies for channel realignment along MS2 and MS3 should be considered. Given the long period of time (nearly a century or more) that these reaches have been straightened and channelized, they are relatively stable at present and are not an immediate concern. However, the establishment of more natural, meandering channel forms would increase the variety and quality of in-stream habitats. Obtaining regulatory approval for extensive channel relocation/riparian/floodplain construction activities around these mainstem reaches may be problematic given the likely disturbance of jurisdictional wetlands and the possible presence of endangered species such as swamp pink (*Helonias bullata*). Non-traditional methods that require fewer disturbances to the channel and adjacent land areas during installation, such as inducing meanders with the strategic placement of large woody debris, may be the most feasible approach to increasing habitat diversity in downstream reaches. This method requires a large undeveloped floodplain where flooding would occur and the river would be given the space to cut a new channel alignment though existing floodplain.

C. Landscape Management

Numerous management actions can be implemented throughout the watershed that will improve the in-stream habitat and water quality of Silver Brook and downstream waters. A combination of short-term restoration activities, such as the establishment or enhancement of forested riparian buffers (Project 8), and long-term planning, such as advocating for stream-friendly ordinances and the acquisition (or otherwise ensuring the preservation) of the remaining forested lands within the watershed, is needed. Despite improved stormwater management techniques required for new construction, continued development of low density housing south of the mainstem of Silver Brook has the potential to adversely impact stream resources. Preserving these areas as open space and forest would be the most effective strategy for preventing further impacts to water quality and habitat within Silver Brook. The adoption of policies that encourage enhancement of existing stormwater management structures to treat water quality storms, in addition to those associated with new developments, could be encouraged.

In addition, outreach to local homeowners, businesses, and public officials can be an effective strategy for increasing the adoption of stream-friendly practices, especially within developed areas of the watershed. Much of the land in the Silver Brook Watershed is privately owned and outreach provides an opportunity to present information to landowners (private or commercial) whose cooperation is critical for restoration projects. Another form of outreach involves engaging the public in restoration efforts. Homeowners can assist in stream restoration by planting riparian buffers, removing structures and stockpiles from the stream edge, managing stormwater on their property and ensuring that septic systems are adequate. Corporate challenge events, where groups of employees volunteer for restoration activities, can bring local businesses into the field as well.

Within the Silver Brook Watershed, efforts to coordinate a comprehensive outreach program are underway. The Great Swamp Watershed Association has devised an outreach program that will provide education and information on non-point source pollution reduction and best management practices to three target audiences: homeowners, local businesses, and recreation providers (e.g. parks, etc.). Once established, the “Streamside Series” will promote environmental stewardship through Streamside Living, Streamside Working, and Streamside Playing programs. This effort should enhance the participation of watershed residents in the implementation of restoration projects. For example, we identify priority areas for riparian buffer enhancement (Project 8), but also recommend that planting within other areas with denuded buffers, specifically those running through residential neighborhoods (MS4 and TR2-2), be incorporated into volunteer and resident out-reach programs such as this.

IX. PROJECT COST

Order-of-magnitude costs associated with implementation of the restoration plan are provided. These materials and installation costs are estimated based on the scope described for each specific project, but refined costs are not possible until a detailed engineering design has been developed. Costs for individual projects are presented with the proposed project descriptions and include cost for engineering design, but not for permitting efforts. A 25% contingency is also added to the cost to account for unforeseen constraints and obstacles. Additional costs will be required for long-term maintenance and monitoring of project sites.

X. PROJECT MAINTENANCE AND MONITORING

A comprehensive maintenance and monitoring plan is essential for understanding project performance, to maintain long-term project performance, and for assessing the degree to which restoration efforts achieve stated goals. The maintenance and monitoring plan should establish project performance criteria and link performance criteria to stated restoration goals. We anticipate that routine project monitoring and maintenance will be conducted by Great Swamp Watershed Association.

Stream Restoration Sites

Monitoring activities at stream restoration sites should include photo-documentation and visual inspections following major storm events and on a quarterly basis. Monumented cross-sections should be established within project sites and should be resurveyed annually to assess physical channel changes. Formal vegetation surveys may be added to provide additional information concerning vegetation community development. Specific monitoring requirements may be established by NJDEP in connection with project permit authorizations.

Stormwater facilities

Monitoring at the stormwater facilities should include identifying and removing invasive species, inspection of structures (e.g., inlet and outlet structures, etc.) for signs of deterioration, inspection of berms for signs of structural problems, trash removal, and sediment removal in designated forebay areas. Specific monitoring requirements may be established by NJDEP in connection with project permit authorizations.

Watershed Wide

In addition to routine maintenance and monitoring at project sites, a watershed-wide monitoring program should be considered to assess the overall performance of the restoration effort with respect to project goals (e.g. sediment load reduction, base flow improvement, water quality enhancement, habitat improvements, etc.). Given the integrated watershed restoration approach outlined in this document, Silver Brook may provide an excellent opportunity to conduct a focused monitoring program to assess the effects of a combined hydrologic regime modification and in-channel restoration on in-stream recovery.

Macroinvertebrate

Changes to macroinvertebrate communities may provide an integrative measure of improvements to water and habitat quality. However, because macroinvertebrate communities may be highly reflective of local habitat conditions and may exhibit significant inter-annual variability, sufficient spatial and temporal sample density is essential. Also, because macroinvertebrate recolonization in urban watersheds may be limited by biogeographic factors (e.g. local extirpation, etc.), macroinvertebrate community metrics may suggest less suitable water and habitat quality that in fact exist.

A lack of macroinvertebrate response may indicate biogeographic barriers to recolonization and may suggest the need for active reintroduction.

Macroinvertebrate sampling can also be used as a metric for assessing changes in water quality. When used for this purpose, assessments should follow the NJDEP Water Monitoring and Standards and use methods of collection and analysis employed by the state's Ambient Biomonitoring Network (Poretti *et al.* 2007). These assessment standards use genus level identification.

Water Quality

Monitoring of ambient water chemistry during base flow (dry-weather) conditions (which is most representative of conditions experienced by aquatic organisms) can be used to assess the impact of restoration measures on the water quality within Silver Brook and its tributaries. We recommend collecting water quality samples downstream of the proposed projects to assess the impact of projects on water quality. In particular, continued monitoring within the mainstem on CSA property remains valuable because it would include both pre and post project data. Samples should be analyzed for a battery of analytes including total suspended solids, nitrogen and phosphorus species, BOD5, fecal coliform, and selected metals.

Water quality and flow monitoring during wet-weather is essential for assessing the impact of stream restoration and stormwater projects on downstream pollutant loading. Of particular interest is the effect of these measures on reductions to fine sediment loading, a key project goal. To assess the influence of the restoration program on sediment loading, we would recommend the establishment of a water quality and flow monitoring station within MS1 in addition to the existing monitoring sites within MS3 and TR1-1.

Geomorphic Monitoring

Channels within the Silver Brook channel network will continue to respond both to hydrologic and sediment load changes due to historical urbanization and the additional changes to sediment loading and hydrology that are likely to occur as a result of the proposed restoration measures. Visual monitoring after significant storm events should be conducted to detect large changes in channel morphology. Repeated bank pin measurements and cross-section surveys are useful for detecting changes in rates of lateral and vertical adjustment to corroborate and refine projected channel evolution sequences.

XI. REFERENCES

Curran, K. 2009. Great Swamp Watershed Association 2008 Nutrient and TDS Monitoring Data. Provided by Kelley Curran.

Dalton, R. 2003. Physiographic Provinces of New Jersey. New Jersey Geological Survey (NJGS) Information Circular. NJGS, Trenton, NJ.

F. X. Browne. 2001. Nonpoint Source Inventory of the Great Brook Watershed Technical Report and Appendices. Prepared for the Ten Towns Great Swamp Watershed Management Committee. Cedar Knolls, NJ.

F. X. Browne. 2002a. Great Swamp Watershed Water Quality Standards. Prepared by F.X. Browne, Inc. for the Ten Towns Great Swamp Watershed Management Committee. Cedar Knolls, NJ.

F. X. Browne. 2002b. Great Swamp Watershed Water Quality Monitoring Report. Prepared by F.X. Browne, Inc. for the Ten Towns Great Swamp Watershed Management Committee. Cedar Knolls, NJ.

F. X. Browne. 2003. 2002 Detention Basin Retrofit and Stormwater Outfall Inventory. Prepared by F.X. Brown, Inc. for the Ten Towns Great Swamp Watershed Management Committee. Cedar Knolls, NJ.

Kondolf, M.G. and Hervé Piégay, eds. 2003. Tools in Fluvial Geomorphology. John Wiley & Sons Ltd. England. Figure 11.11: p. 308.

Montgomery, D. R. and J. M. Buffington. 1997. Channel-reach morphology in mountain drainage basins. Geological Society of America Bulletin 109:596-611.

Najarian, Associates and Maser, Sosinski & Associates. 1997. A Status and Assessment Study of Stormwater Discharges within the Great Swamp Watershed. Prepared for the NJ DEP.

New Jersey Highlands Water Protection and Planning Council (Highlands). 2008. Highlands Regional Master Plan. State of New Jersey Highlands Water Protection and Planning Council. Chester, NJ.

Poretti, V., D. Bryson, and T. Miller. 2007. Standard operating procedures: Ambient biological monitoring using benthic macroinvertebrates, field, lab and assessment methods. New Jersey Department of Environmental Protection, Bureau of Freshwater and Biological Monitoring. Water Monitoring and Standards Document No. BMNJ2.

Princeton Hydro, LLC. 2007. Great Swamp Watershed Water Quality Monitoring Report. Prepared by Princeton Hydro, LLC. For the Ten Towns Great Swamp Watershed Management Committee. Cedar Knolls, NJ.

Saldi-Caromile, K., K. Bates, P. Skidmore, J. Barenti, D. Pineo. 2004. Stream Habitat Restoration Guidelines: Final Draft. Co-published by the Washington Departments of Fish and Wildlife and Ecology and the U.S. Fish and Wildlife Service. Olympia, Washington. Fluvial Geomorphology Appendix, Figure 3: p. 9.

Schuum, S.A., Harvey, M.D., and C.C. Watson. 1984. Incised Channels: Morphology, Dynamics, and Control. Water Resources Publications, Littleton, CO.

Simon, A and C.R. Hupp. 1986. Channel evolution in modified Tennessee channels. In Proceedings of the 4" Federal Interagency Sedimentation Conference. Las Vegas. hiV, USGPO, Washington DC, 8.22 - 8.29.A model of channel response in disturbed alluvial channels. Earth Surface Processes and Landforms. 13, 1 1 - 26.

Simon, A. 1989. A model of channel response in disturbed alluvial channels. Earth Surface Processes and Landforms, 14: 11-26.

Ten Towns Great Swamp Watershed Committee (TTC). 1997. Great Swamp Watershed Management Plan (GSWMP). Ten Towns Great Swamp Watershed Committee. Cedar Knolls, NJ.

Wolman, M.G. 1967. A cycle of sedimentation and erosion in urban river channels. Geografiska Annaler. Series A, Physical Geography, Vol. 48, No. 2/4, Landscape Processes: Essays in Geomorphology, pp. 385-395.

Appendix A
Priority Restoration Projects

Project 1: Harding Green Drive Stormwater Management

Reach: TR4-1

Estimated Costs: $425,000

This site is located between I-287 and US-202 and west of Sand Spring Road. Urban residential neighborhoods cover the majority of the space and TR4-1 runs within a wooded section between the residential areas and the I-287 sound barrier wall. Stormwater is conveyed from street intakes to one of three main flood control basins located along the southern margin of the residential area. Basin 1 is a dry detention basin with paths directly from basin inlets to the outlet structure providing no treatment of the water quality or channel forming precipitation events. Basin 2 is a ponded retention basin with a culvert draining directly to TR4-1. Basin 3 is a detention basin with the basin floor dominated by common reed and the outflow draining directly to TR4-1. The objectives of the proposed project are to increase the retention time for water quality and channel forming events within these existing basins. With these improvements, downstream reach TR4-1 will experience lower peak volumes and erosional velocities, arresting the further degradation of this reach. It is anticipated that these improvements will cascade downstream and result in a reduction of excessive sediment load to downstream section of TR4-1 and mainstem reaches.

The proposed project will involve retrofitting the three existing basins. Modifications include lengthening the flow path, naturalizing the basin floor using native vegetation, and adding a water quality orifice to provide extended detention of small storms to Basin 1 and 3. In addition, the proposed project will involve day-lighting the stormwater outflow pipe from Basin 3 and installing a constructed wetland at this location. Basin 2 appeared to have a large amount of suspended sediment which presumably flows to the receiving channel. To improve settling of suspended solids, the proposed project will retrofit Basin 2 by installing a sediment forebay at the basin inlets, replacing the existing outflow structure with one that retains both small and large storm events, and installing a constructed wetland at the outflow. The proposed project will reduce peak flows and hydraulic energy within the receiving channel, lessening channel erosion and improving water quality.

Determining ownership of the parcels of land where the basins lie and coordinating with the property owner will be a critical first step. Because construction will take place largely within existing stormwater facilities, construction access will be relatively convenient from existing roadways, and construction staging could be located within the parking lots adjacent to Basins 1 and 2. Planning and permitting efforts will be routine for Basins 1 and 2. Basin 3 will need to be accessed over private property and will take additional coordination with that landowner. In addition, the presence of common reed and possibly other wetland indicator plants may necessitate a New Jersey Department of Protection (NJDEP) Freshwater Wetlands Permit for construction activities.

View of Basin 2.

Project 2: Mt. Kemble Corporate Center Stormwater Management

Reach: TR5-1 and TR5-2

Estimated Construction Costs: $1,340,000

This site is located north of I-287 between the upper reaches of the mainstem Silver Brook and TR2. The area is covered mostly by impervious parking lot and commercial buildings. Stormwater drainage within the area is managed with both underground conveyance and surface conveyance, including a grassed swale (Basin 12) and large detention basin (Basin 14) on the east margin of the area, and ultimately drains to either Basin 5 or 16. On a normal working day, the parking lot appeared unused in several sections. The objectives of this proposed project are to reduce impervious areas and enhance the capacity for water quality treatment within existing basins. Improved stormwater management will lower peak volumes and erosional velocities within downstream reaches TR5-1 and TR5-2 and arrest the further degradation of these reaches. We anticipate that these improvements will cascade downstream and result in a reduction of excessive sediment load to downstream mainstem reaches.

The proposed project consists of converting underutilized sections of the parking lot, particularly those in the vicinity of Basin 5 to native meadow (Project 2a). This will increase the area of pervious cover at the site, providing increased infiltration area for stormwater. The project also includes retrofitting Basins 5 (Project 2a) and 14 (Project 2b) to provide extended detention of water quality and channel-forming flows. The retrofits will involve lengthening the flow path within the basin, naturalizing the basin floor using native vegetation, and adding a water quality orifice to provide extended detention of small storms. Sediment forebays will be installed at the basin inlets.

The commercial complex is privately owned and coordination with the property owner will be essential. These proposed treatments are contingent upon the cooperation of the property owner and verification of the percentage and locations of underused parking spaces. The site is easily accessible from the parking lot of the commercial complex. Construction will take place largely within existing stormwater facilities and construction staging could be located within the existing parking lot. Both basins are un-mowed and vegetated with common reed present. Permitting will likely require a NJDEP Freshwater Wetlands Permit.

View of outlet structure from Basin 5.

Project 3: Allied Surgical Group Building Stormwater Management

Reach: TR2-1a

Estimated Construction Costs: $469,000

The project site is located between I-287 and James Street and east of Harter Road. Runoff from properties that lie along James Street and from properties north of I-287 flows through drainage ditches and unstable channel sections to reach TR2-1. Basin 19, located behind the Allied Surgical Group Building, and Basin 20, located within the center of the adjacent apartment complex, were the only identified facilities in place to treat either flood events or small storm events. The Church of Jesus Christ of Latter-day Saints and the extensive parking lot adjacent to it appear to direct runoff from impervious areas through curb cuts into drainage ditches along the edges of the parking lot—apparently entering the stream untreated. The forested area behind these buildings has numerous intermittent ditches and incised channels. A headcut has developed in the small channel that receives flow from Basin 19. The objectives of this proposed project are to reduce impervious areas and increase the capacity to treat runoff from both large and small storm events before it enters the stream network. Improved stormwater management will lower peak volumes and erosional velocities within downstream reaches TR2-1a and TR2-1 and arrest the further degradation of these reaches. These improvements are expected to cascade downstream and result in a reduction of excessive sediment load to downstream mainstem reaches.

The proposed project consists of retrofitting the outflow of Basin 19, stabilizing the headcut located within the small channel downstream of Basin 19, reducing impervious cover on the site, and creating an additional stormwater treatment facility. This additional facility will consist of a constructed wetland located at the site of the headcut and outflow from Basin 19. The construction of a wetland in this location will stabilize the headcut, preventing further erosion and deposition of sediments with the downstream channels, dissipating concentrated stormwater runoff and providing water quality treatment. The parking lot behind the Church of Jesus Christ of Latter-day Saints includes an additional parking area that appears to be in a deteriorating state, with cracks and vegetation common. The proposed project will replace this parking lot with a constructed wetland that receives runoff from properties along James Street as well as flow from north of I-287. The basin will include a sediment forebay, native vegetation and an outlet structure appropriate to treat both flood and water quality rain events. The areas around the basin will be restored to a native riparian forest.

View of headcut at outflow of Basin 19.

View of looking upstream at TR2-1a.

Cooperation of property owners will be crucial to the success of this proposed project. The land is most likely privately owned, but collaboration with the Department of Transportation may increase the likelihood of success. These proposed treatments are contingent upon the cooperation of the property owners and verification of the percentage and locations of underused parking spaces. The site is easily accessible from parking lots of commercial buildings along James Street. The floor of Basin 19 contains common reed and work that modifies this basin will likely require a NJDEP Freshwater Wetland Permit. It is also possible that jurisdictional wetlands exist in the surrounding forested area, and further investigations will be necessary to determine if a wetland permit will be required for construction activities. In-stream work will require a Flood Hazard Area Permit from the NJDEP. In addition, the proposed project site has been identified as potentially containing vernal habitat. A survey will need to be completed to determine limitations imposed by the presence of and proximity to these resources. Although proposed activities in this area of the watershed may have regulatory complications, the lack of treatment for stormwater runoff from these areas and the poor habitat and unstable conditions within downstream stream reaches make action a priority.

Project 4: Stream Restoration—TR5-1

Reach: MS3

Estimated Construction Costs: $771,000

The site is located within a tributary to Reach MS3. The stream originates from Basin 5 within the commercial complex and drains through a wooded area. The channel is currently unstable and is incised well below the root horizon. Channel banks are nearly vertical and are up to 5 feet high. The stream channel assumes pool/riffle bed morphology, but deposition from bank erosion is evident with numerous point bars. Due to these conditions, stream habitat is poor.

The proposed project consists of restoring floodplain access and improve in-stream habitat. Retrofit of Basin 5 (Project 2) will improve management of stormwater flows entering the channel. The installation of a constructed wetland at the head of the channel will also reduce peak flows and improve water quality. Floodplain areas will be lowered by three-to-four feet and replanted with native trees and shrubs. Root wads and placed woody debris piles will be installed to enhance in-stream habitat. Woody debris piles will be anchored to the stream bed and bank using Duckbill-type earth anchoring systems.

Access to the site will most likely be from the parking lot of the commercial complex. Skunk cabbage, a wetland indicator species, grows within the floodplain terrace along portions of the reach. It is possible that the reach flows through jurisdictional wetlands and further investigations will be necessary to determine which permits will be needed for construction activities. In-stream work requires a Flood Hazard Area Permit from the NJDEP and possibly a NJDEP Freshwater Wetlands Permit as well.

View downstream in TR5-1.

Project 5: Stream Restoration—TR4-1

Reach: TR4-1

Estimated Construction Costs: $202,000

The site is located within TR4-1, which is tributary to the Silver Brook mainstem at the head of MS3. Much of this reach flows through a forested area, but is largely confined by I-287 to the south. The reach is also impacted by stormwater discharges from three flood control basins draining the urban residential area adjacent and to the north (see Project 1) and a stormwater outfall from I-287 entering the reach from the south. Upstream of the outfall, the stream is intact. Downstream of the outfall, the stream progresses through a section with excessive erosion to a headcut in the vicinity of Basin 3 (see Figure 3). The section of the reach downstream of the headcut to the Sand Spring Road crossing has characteristics of a depositional channel, reflecting the sediment load contributed by the eroding upstream section. Channel instability within this reach is likely due to exaggerated peak flows from under-managed stormwater. Improved management of stormwater (see Project 1) will reduce peak flows and channel energy and erosion. The headcut should be stabilized with an in-channel step pool to prevent the further upstream procession and to protect upstream sections which currently have no or only minor instability issues.

View upstream at headcut within TR4-1.

The site could be accessed through the stream channel from the location of either the Basin 2 or 3 retrofits (see Project 1). Forested wetlands may comprise the riparian floodplain and require a NJDEP Freshwater Wetlands Permit for access and construction activities. In-stream work requires a Flood Hazard Area Permit from the NJDEP. Permission and coordination with private landowners to access the site will likely be required.

Project 6: Stream Restoration—TR5-2

Reach: TR5-2

Estimated Construction Costs: $548,000

The site is located just south of the Mt. Kemble Corporate Center and the large existing retention basin (Basin 16). A gully has developed where overland flow from the corporate center is concentrated within the forest. The gully originates at a headcut which will continue to progress up-gradient toward Basin 16. Reducing the energy of peak flows originating from the existing retention basin and arresting the processes of stream lengthening by the up-stream migration of the headcut will protect the existing basin.

The proposed project will involve the construction of a constructed wetland at the headcut to dissipate concentrated flows from the existing detention basin and to stabilize the headcut. Floodplain areas will be lowered by one to two feet and replanted with native trees and shrubs, mitigating effects of recent incision and promoting connection of the channel with its floodplain.

Access to the site will be from the parking areas at the commercial park and some clearing of forested areas will be necessary to access the site. The project site did not appear to have wetland plants or hydrology and obtaining a NJDEP Freshwater Wetland Permit is not anticipated. However, in-stream work requires a Flood Hazard Area Permit from the NJDEP.

View upstream at headcut within TR5-2.

Project 7: In-stream Habitat Enhancement

Reaches: MS2 and MS3

Estimated Construction Costs: $120,000

Mainstem reaches that flow through the Great Swamp Watershed Association Conservation Management Area (MS2 and MS3) have been straightened and channelized leaving largely homogeneous habitat with little structure or cover. Within many sections of these reaches, the stream flows over a fairly uniform bed at low and relatively constant velocities. Bed aggradations occur in areas where the stream lacks the energy to export fine sediments. Large woody debris (LWD), which often provides a structural component within such low gradient streams, is rarely present within the stream channel.

The proposed project will enhance in-stream habitat within MS2 and MS3 through the addition of structural elements to the channel. Coarse-grained materials will be placed within sections of downcut and straightened channel to create incipient point bars. These point bars will introduce variations in stream velocity and will promote the formation of meanders within the incised channel. Intermixed with point bars, LWD, in the form of root wads, debris jams, or individual logs, will also be placed within the existing channel. LWD will not only provide stable colonization surfaces for aquatic macroinvertebrates and cover for fish, but will also induce localized scour, creating pool habitat. Point bars and LWD will be strategically placed to maximize meander and pool formation.

The property is owned by the Great Swamp Watershed Association (GSWA) and would therefore not require additional approval from or cooperation with other landowners. Furthermore, the network of volunteers committed to GSWA projects would reduce costs for project implementation. To avoid any unnecessary disturbance to the riparian zone and surrounding forested wetlands, the proposed project is mainly confined to the stream channel. Even so, a NJDEP Freshwater Wetland Permit and NJDEP Flood Hazard Area Permit will be required for temporary disturbance during installation activities and for in-stream work. Access to the stream channel will require a temporary construction entrance that extends from the terminus of Tiger Lily Lane to the stream channel.

View looking downstream within MS3.

Project 8: Riparian Buffer Restoration

Reaches: MS2, tributary to MS3, TR1-1, and TR1-2

Estimated Construction Costs: $352,000

Site a	**$29,400**
Site b	**$88,200**
Site c	**$81,000**
Site d	**$66,000**
Site e	**$87,300**

The riparian forest is denuded or absent in a number of locations throughout the watershed (Figure 7). Priority areas for restoration include those along stream sections bordered by open fields (Project 8a, 8c, and 8e), golf courses (Project 8b), or parks (Project 8d). In these identified areas, little or no vegetation other than grass/lawn exist along one or both sides of the stream. Areas should be planted with native tree, grass, and shrub species, ideally to a width of 100 feet on either side of the stream.

Two zones of riparian buffer enhancement are important—outer bank stabilization and riparian forest restoration. Intensive planting along the eroding outer banks of meanders will promote the development of a dense root structure and improve bank stability. An alternating series of slit trenches with live whips and shrubs should extend approximately 20 feet from the top of the stream bank. Slit trenches ensure that the root depth of the proposed plantings is sufficient to reach the water table and are often constructed with a mini-excavator. The goal of riparian planting within the zone beyond this near bank area is to increase the width of the riparian zone, thus restoring functions lost to forest clearing. Using individual tree protection or fencing of a larger area will protect plantings from deer browse and improve the likelihood of survival.

Replanting riparian buffers are anticipated to have the following benefits:

- Increasing the rate of pollutant and nutrient removal from the soil, thus reducing the amounts that reach the stream;
- Stabilizing the stream banks;
- Reducing daytime temperatures;
- Providing habitat within the forest and stream; and
- Providing food for stream organisms.

Riparian planting is not expected to require permits except where planned within jurisdictional wetlands. Riparian planting can be accomplished with aid from volunteers which can substantially reduce costs. In addition to riparian buffer planting, allowing fields to return to a forested state will enhance uptake of nutrients and pollutants and reduce overland flow from storm events. Given their proximity to the stream and the potential for wetland habitat to be present, the fields east and west of James Street just south of where the road crosses Silver Brook are ideal candidates.

View looking downstream at TR1-2 within Bayne Park (Site 7d).

Project 9: St. Mark Lutheran Church Stormwater Management

Reach: MS2

Estimated Construction Costs: $25,000

The site is located at the intersection of Old Harter Road and Tiger Lily Lane and drains stormwater from St. Mark Lutheran Church The existing dry detention basin is a shallow turf grass basin with three inflows and an outlet structure that drains to the adjacent forested area. Flows through the basin travel directly from inlets to the outlet and the existing design does not provide water quality treatment or management of channel-forming flows.

View of Basin 24.

The proposed project will increase the retention capacity of the basin by increasing the depth and modifying the outlet structure. The retrofit will involve reconfiguring the lower outlet structure orifice at an elevation higher than the current outlet to increase ponding depth for the water quality storm. The upper outlet structure orifice will be redesigned, as needed, to provide effective management larger storm events. The flow path of stormwater within the basin will be increased, and the removal of particulates will be enhanced with the installation of sediment forebays at each inlet structure. Replanting the basin floor with native species will increase evapotranspiration and provide pollutant uptake and slower flows.

The basin may be located on private property and confirmation of ownership and coordination with the land owner will be essential. Access to the basin is readily available from Tiger Lily Lane and the church parking lot and provides an adequate construction staging area. Because construction will take place largely within the existing basin and this area does not include either regulated waters or wetlands, permitting efforts are expected to be minimal.

Appendix B

Table

Table 1
Stormwater Treatment Facility Inventory

ID	Type	Estimated Drainage Area Treated (SF)	Vegetation on Basin Floor	Retrofit Priority
Basin 1	Detention	343,000	Mowed Grass	High
Basin 2	Retention	1,492,000	Water	High
Basin 3	Detention	783,000	Wetland	High
Basin 4	Retention	656,000	Water	Low
Basin 5	Detention	1,857,000	Wetland	High
Basin 6	Other	67,000	Mowed Grass	Low
Basin 7	Other	56,000	Mowed Grass	Low
Basin 8	Detention	709,000	Riprap	Low
Basin 9	Other	138,000	Mowed Grass	Low
Basin 10	Other	60,000	Mowed Grass	Low
Basin 11	Retention	357,000	Water	Low
Basin 12	Other	3,068,000	Wetland	Low
Basin 13	Other	10,000	Riprap	Low
Basin 14	Detention	1,951,000	Wetland	High
Basin 15	Other	78,000	Mowed Grass	Low
Basin 16	Retention	5,145,000	Water	Low
Basin 17	Detention	1,680,000	Wetland	Low
Basin 18	Detention	751,000	Wetland	Low
Basin 19	Detention	152,000	Wetland	High
Basin 20	Detention	114,000	Mowed Grass	Low
Basin 21	Detention	396,000	Wetland	Low
Basin 22	Retention	526,000	Water	Low
Basin 23	Retention	2,196,000	Water	Low
Basin 24	Detention	87,000	Mowed Grass	High
Basin 25	Detention	281,000	Wetland	Low
Basin 26	Retention	271,000	Wetland	Low
Basin 27	Detention	588,000	Unknown	Low
Basin 28	Detention	972,000	Unknown	Low
Basin 29	Retention	2,051,000	Water	Low
Basin 30	Other	153,000	Riprap	Low
Basin 31	Retention	540,000	Water	Low
Basin 32	Retention	3,389,000	Water	Low
Basin 33	Detention	240,000	Wetland	Low

Notes:

See Figure 6 for basin locations.

Other refers to areas of pervious surface draining to inlets that have little to no retentive capacity. Retention basins typically have permanent pools. Detention basins are typically vegetated with mowed grass or wetland plants.

Drainage areas were estimated in GIS.

Vegetation on basin floor indicates that present at time of observance.

Prioritization was based on treated drainage area, retrofit feasibility and the condition of receiving stream reaches.

Appendix C
Figures

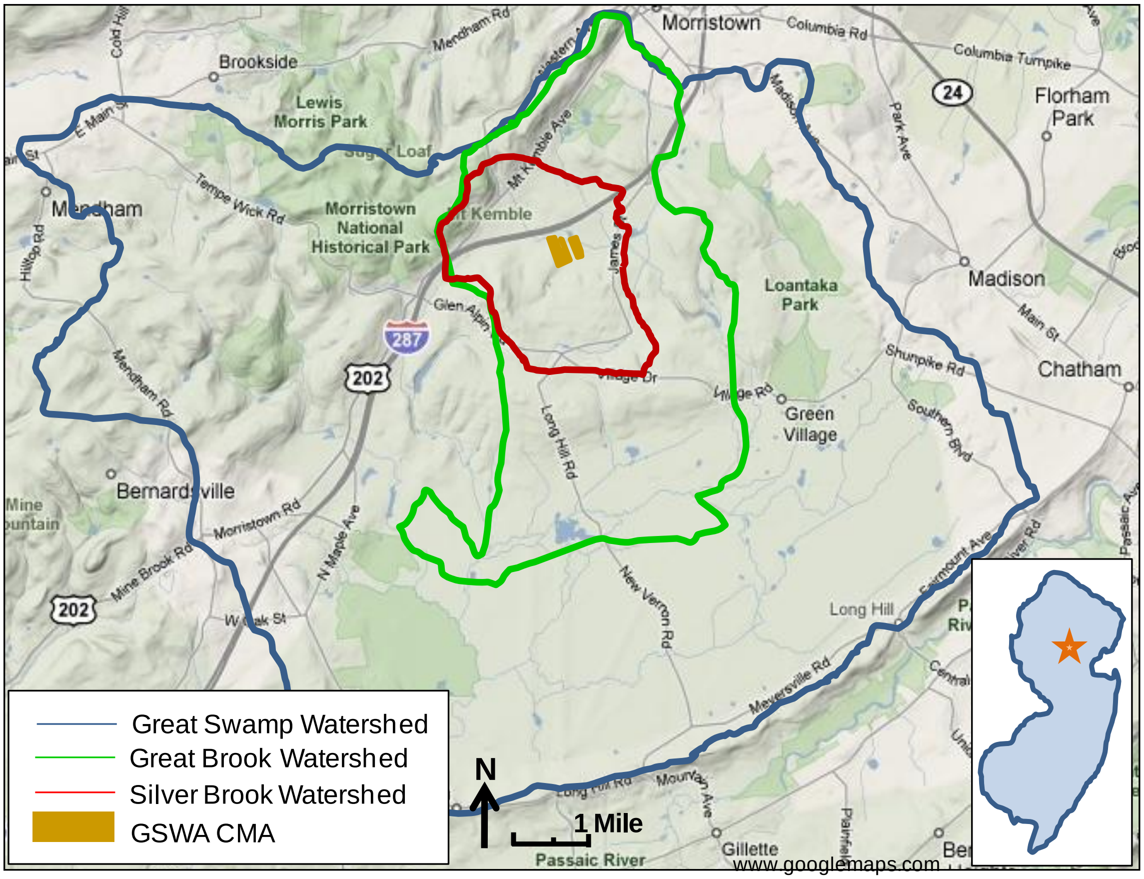
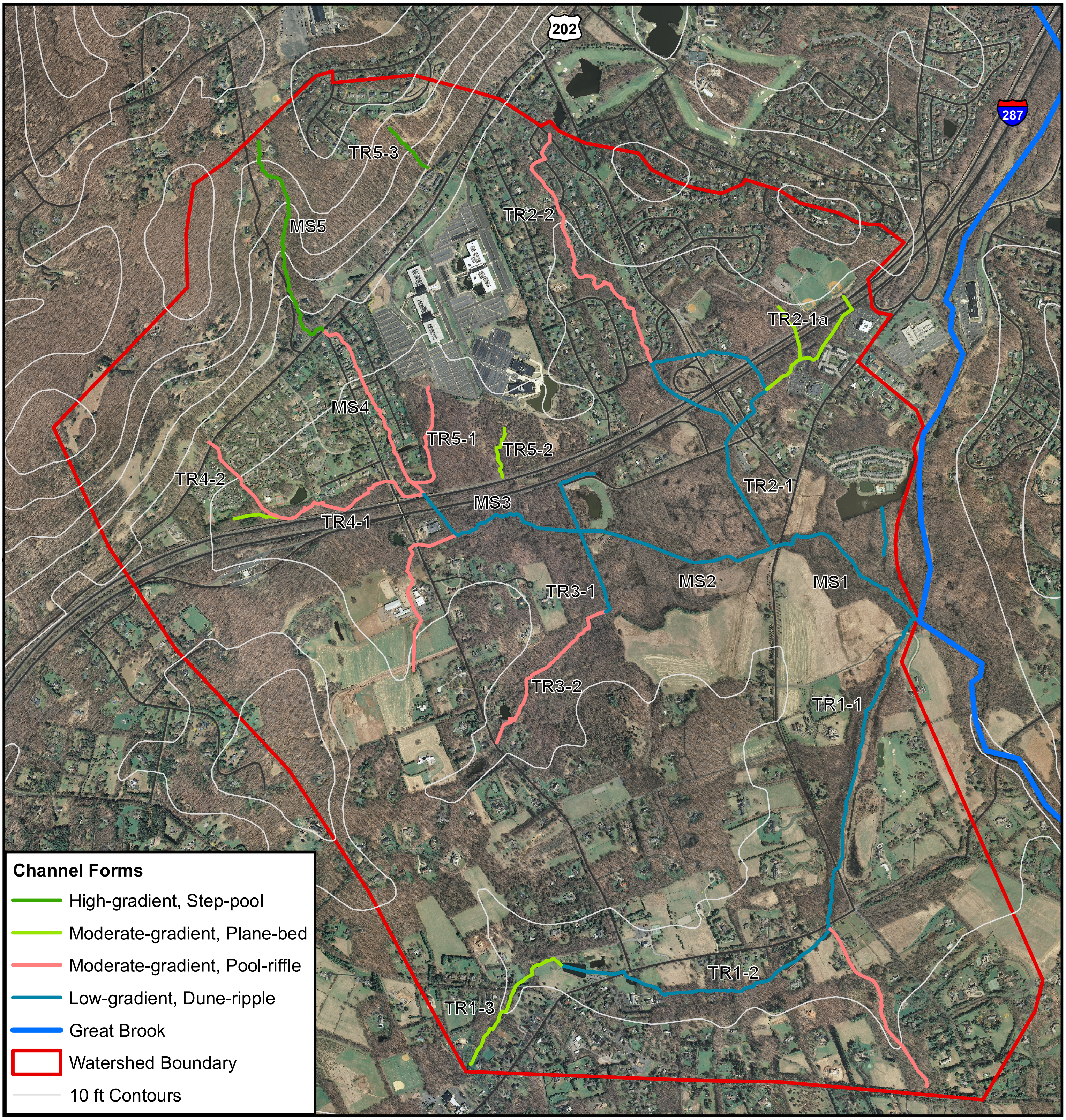


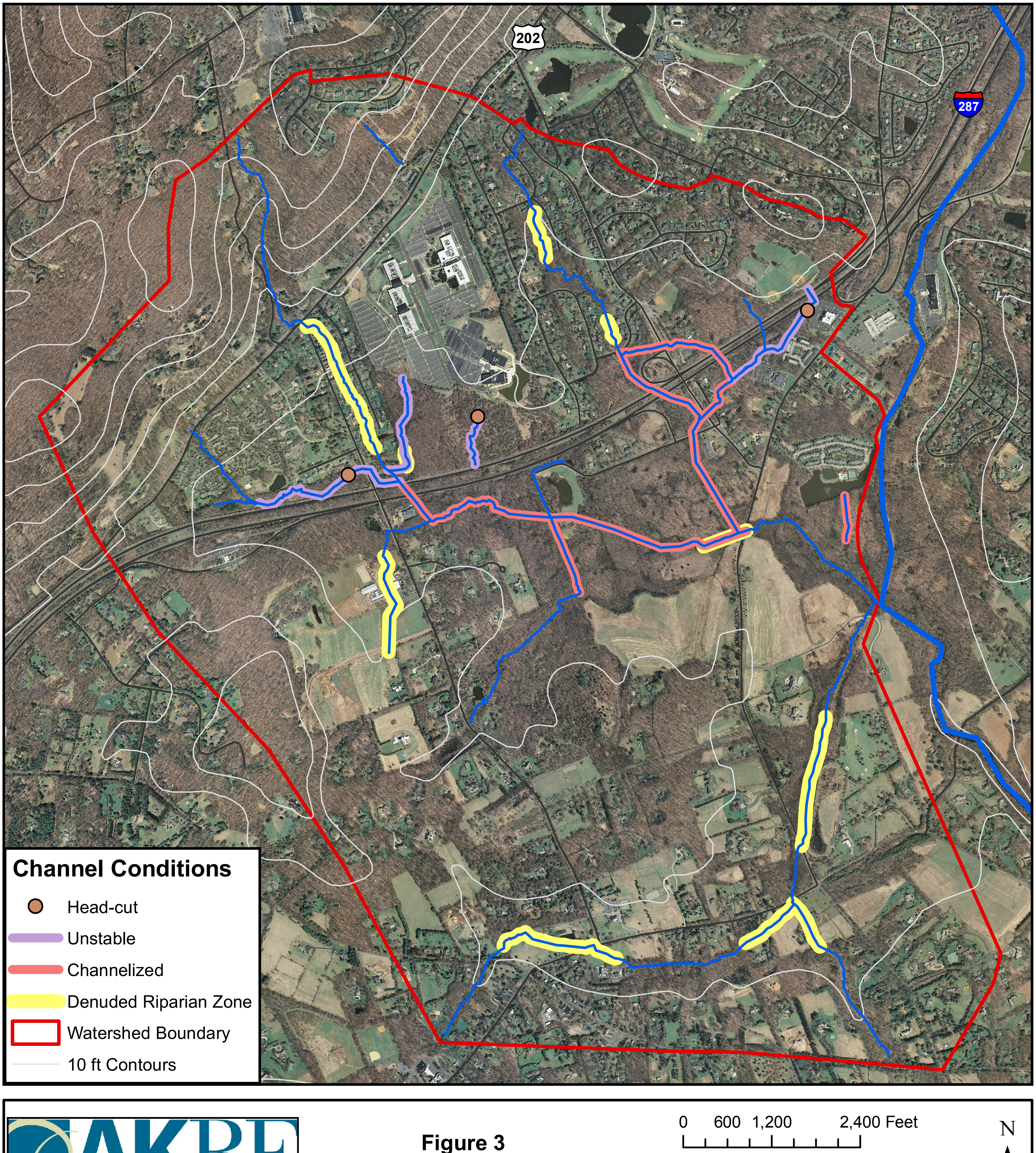
Figure 1. Location of the Silver Brook Watershed and the Great Swamp Watershed Association Conservation Management Area (GSWA CMA) within the Great Brook and Great Swamp Watersheds.



AKRF

Figure 2
Silver Brook Stream Reaches

Aerial: NJ Office of Information Technology
Office of Geographic Information Systems
Trenton, NJ 2008



AKRF

Figure 3
Silver Brook
Channel Corridor Conditions

Aerial: NJ Office of Information Technology
Office of Geographic Information Systems
Trenton, NJ 2008

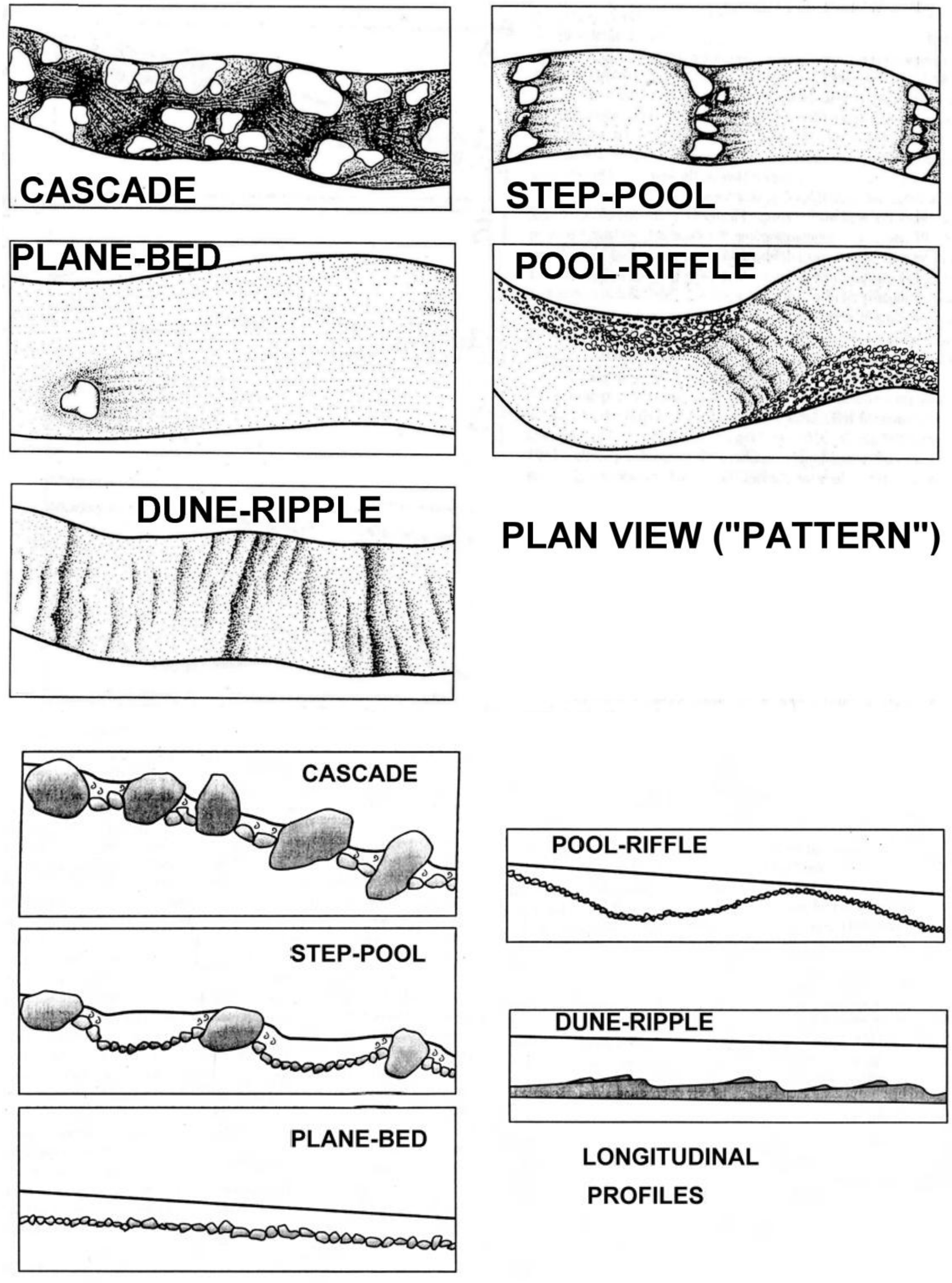


Figure 4: Stream channel forms as classified by Montgomery and Buffington (Saldi-Caromile *et al.* 2004).

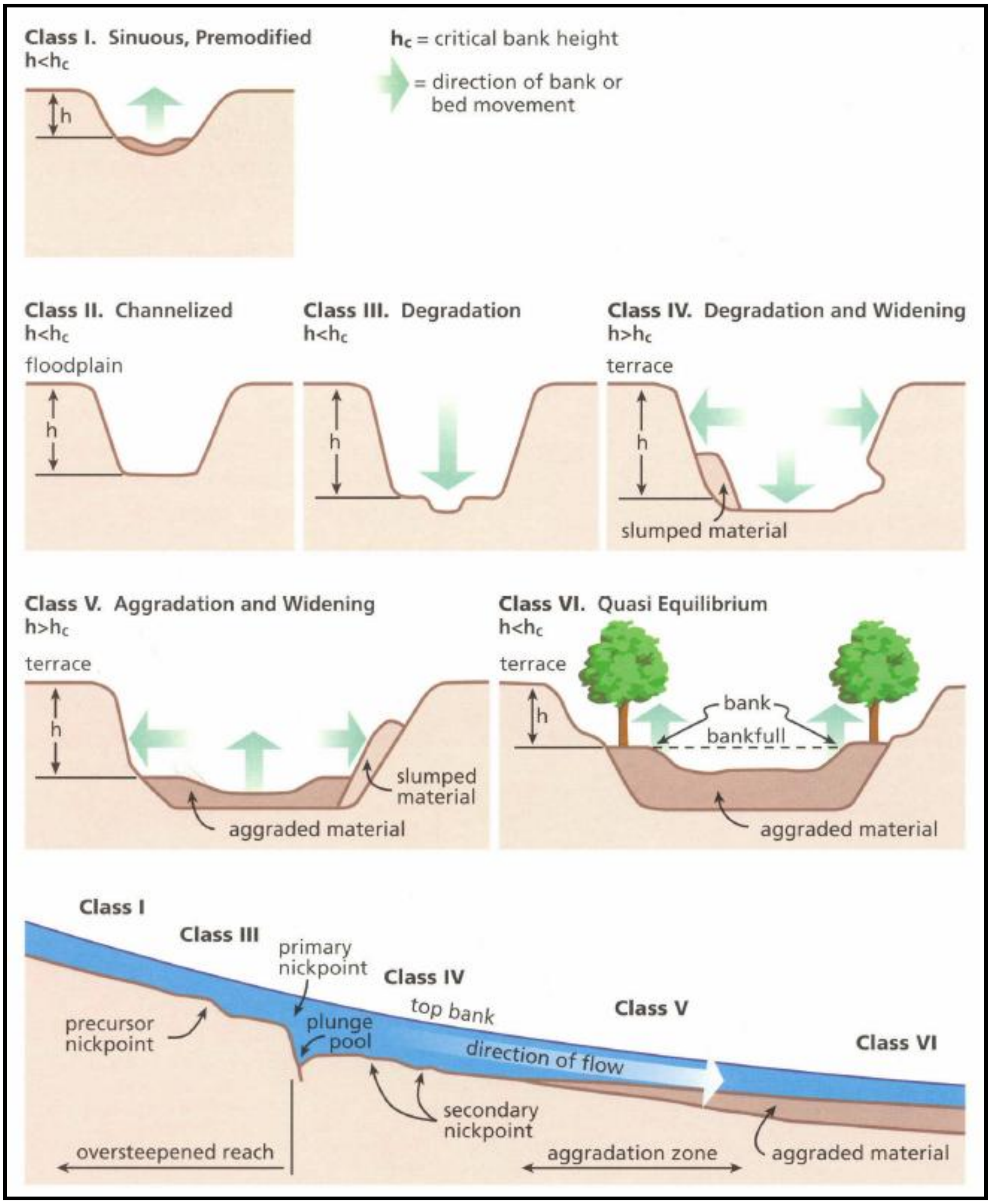


Figure 5. Six-stage model of channel evolution adapted from Simon, 1989 (Kondolf and Piégay, 2003)

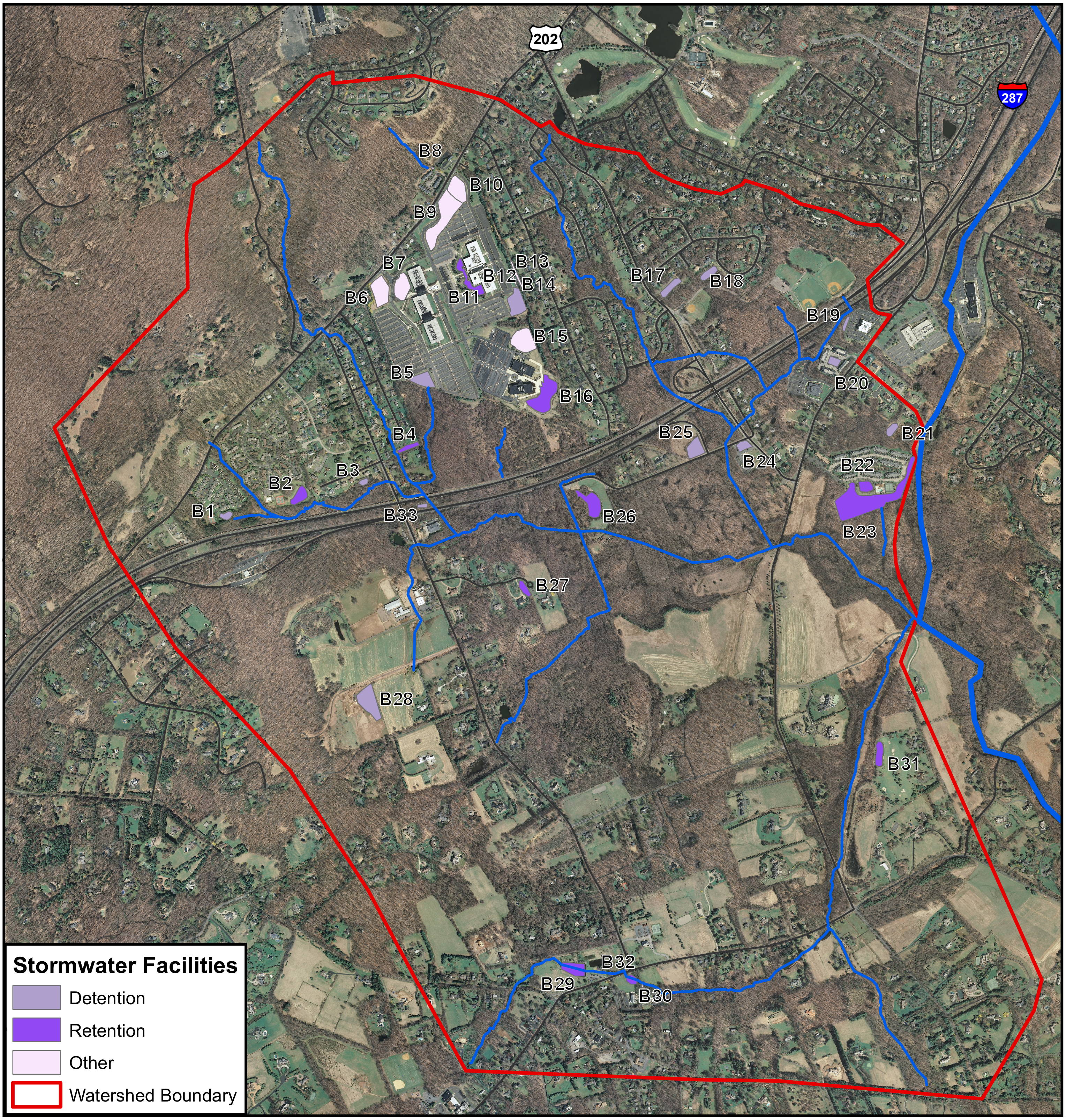
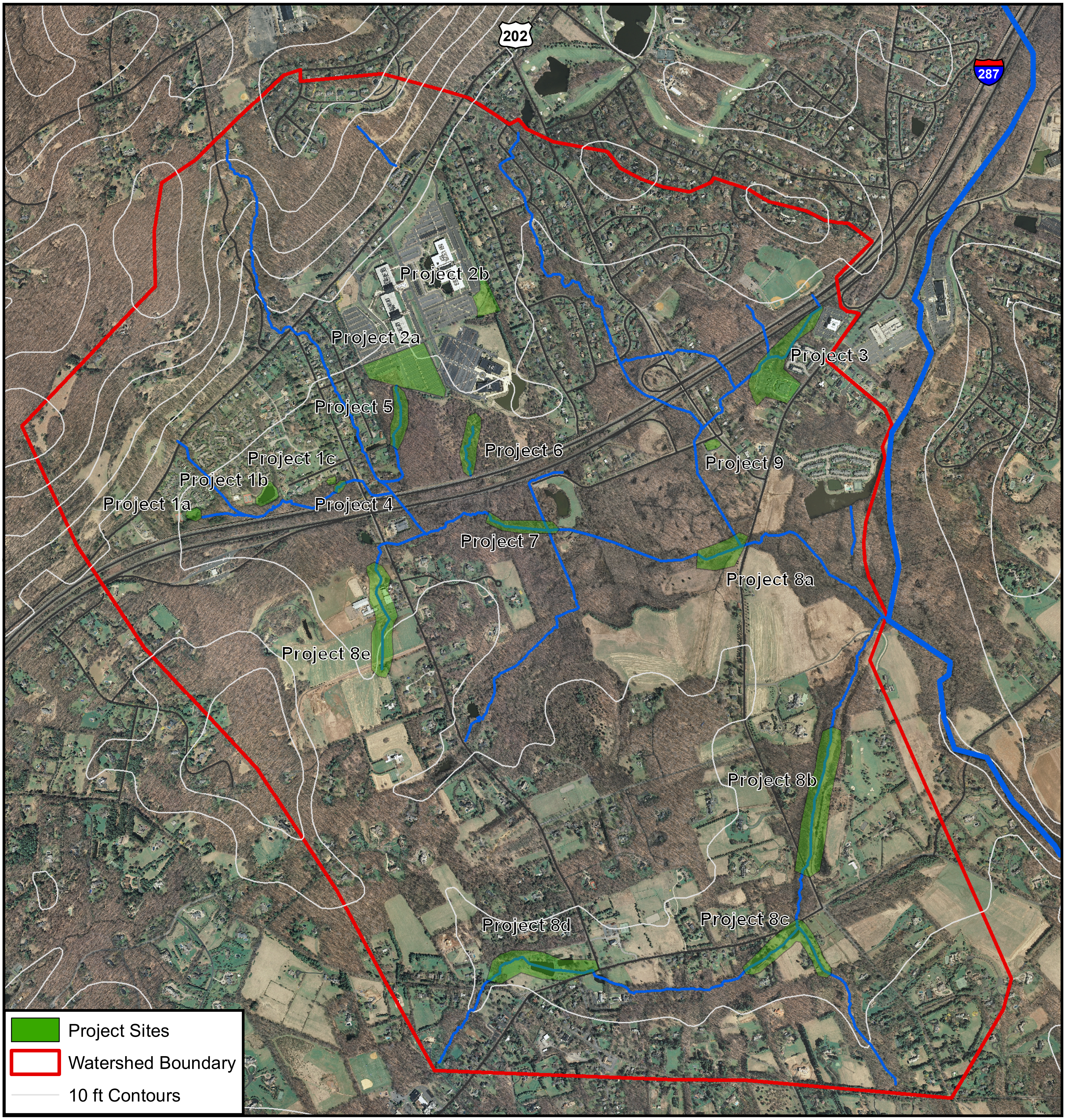


Figure 6
Silver Brook Watershed
Stormwater Treatment Facilities

0 625 1,250 2,500 Feet

Aerial: NJ Office of Information Technology
Office of Geographic Information Systems
Trenton, NJ 2008

N



AKRF

Figure 7
Silver Brook Watershed
Project Sites

0 625 1,250 2,500 Feet

Aerial: NJ Office of Information Technology
Office of Geographic Information Systems
Trenton, NJ 2008

N

Appendix D
Photographs

Photograph 1: View looking downstream at I-287 crossing over MS3. The culvert is typical of I-287 stream crossings.

Photograph 2: View looking downstream at TR5-3.

Photograph 3: View looking downstream at TR4-1.

Photograph 4: View looking downstream at TR2-2.

Photograph 5: View looking downstream at MS3.

Photograph 6: View looking upstream at MS3.

Photograph 7: View looking upstream at TR4-1 showing erosion along an outer bend exposing structural support of the I-287 sound barrier wall.

Photograph 8: View of a perched floodplain terrace and small channel dropping 2-3 feet to enter TR2-1.

Photograph 9: View upstream of aggrading section of TR2-1. TR2-1a enters from the right side of the photograph.

Photograph 10: View upstream of aggrading section of TR2-1a.

Photograph 11: View of Basin 21.

Photograph 12: View of an outfall delivering stormwater runoff from I-287 directly to TR4-1.