Flood Management Report

Poesten Kill Watershed and Flood Mitigation Assessment

July 27, 2019

Rensselaer County, New York

Prepared for:

New England Interstate Water Pollution Control Commission
& Hudson River Estuary Program (NYSDEC)
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Prepared by:

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FORWARD

Tropical Storm Irene caused significant flood damage in 2011 across the 96-square mile Poesten Kill watershed. The Rensselaer Plateau Alliance (RPA) saw an opportunity and secured funding in 2018 from Hudson River Estuary Program (HREP) and New England Interstate Water Pollution Control Commission (NEIWPCC) to develop a plan with a goal to reduce the flood damage in future storms. RPA hired The Chazen Companies with subcontracted services of Interfluve P.C. to assist with the analysis. The team conducted public meetings and developed a watershed working committee to consider and advance specific stormwater opportunities.

The working committee, consisting of local residents and representatives of the towns and city governments, helped the engineers and scientists of Chazen and Interfluve understand the history and local impacts of Irene and other storms. The committee also contributed ideas for flood mitigation strategies. In fact, an innovative strategy came out of this process: The idea to build naturally-based or lightly engineered outlet controls at certain wetlands in the watershed that meet certain conditions. While this system does not interfere with streams flowing from wetlands during normal circumstances, in the event of a 25 year or bigger flood, they would slow the flow from the wetlands down just enough to reduce the peak flooding in the watershed below. Modeling shows that this strategy could reduce downstream flooding by more than half a foot during future floods, meaning the difference between overtopping flood walls in the City of Troy and staying within the walls; reducing damage to agricultural lands and structures; and allowing continued use of existing bridges and culverts. The wetland outlet controls also “work with nature” rather than requiring big earthmoving projects and are astonishingly cost-effective to construct.

None of the many other flood mitigation plans that we have reviewed present such a bold strategy to reduce peak flows on a watershed scale, so we are very pleased to present this strategy to accomplish this goal. This strategy, of course, is just one of many strategies developed by the plan since we do also address some specific needs in particular locations. A cost benefit analysis shows which strategies and/or designs might result in the biggest bang for the buck. We would prefer to focus on recommended projects of highest priority that also provide the most benefit for the cost.

The Rensselaer Plateau Alliance plans to continue to work actively with the committee to look for opportunities to implement strategies outlined in this plan. We are hopeful that this plan will help support funding for projects that will reduce future flooding and restore important stream habitats. If you would like comment or be involved, please contact Rensselaer Plateau Alliance at info@rensselaerplateau.org, or call (518) 712-9211.

The Rensselaer Plateau Alliance is grateful to the committee members who volunteered their time to help with this project and to the experts at Chazen and Interfluve without whom this work would not have been possible. We thank the Hudson River Estuary Program, NYS Department of Environmental Conservation, and New England Interstate Water Pollution Control Commission for funding this project. We also thank the staff of the Hudson River

Estuary Program who have attended our meetings, provided feedback and thoughts, and conceived of grants seeking innovative green stormwater designs.

Jim Bonesteel
Executive Director
Rensselaer Plateau Alliance

EXECUTIVE SUMMARY

Tropical Storm Irene caused significant flood damage in 2011 across the 96 square mile Poesten Kill watershed. The Rensselaer Plateau Alliance (RPA) observed the damage and secured funding in 2018 from HREP and NEIWPCC to advance a watershed scale analysis of flood hazards and stormwater management opportunities. To assist this analysis, RPA retained The Chazen Companies with subcontracted services of Interfluve P.C. to assist with this analysis, conducted public meetings, and developed a watershed working committee to consider and advance specific stormwater opportunities.

Several strategic opportunities were inherent in a project of this magnitude, including the opportunity to broadly seek flood management projects, even where the benefits of a stormwater management option in one location benefits flood damage hazard elsewhere. Another opportunity included the mutually-agreeable objective of RPA and HREP/NEIWPCC to explore naturally-based stormwater management options as well as traditional engineered designs. Finally, the unique geography of the Poesten Kill watershed, with the lightly settled Rensselaer Plateau in the watershed, provided unique peak flood control opportunities to detain stormwater in headwater locations.

More than 25 projects were developed. Some have been evaluated only conceptually, others have benefitted from hydraulic modelling, preliminary regulatory review, and preliminary design. The proposed projects fall in the following categories:

Traditional Engineered Designs

- Implement pre-storm drawdown policies for the Dunham Reservoir to create stormwater detention capacity ahead of predicted major storms.
- Upgrade culvert dimensions in select locations.
- Increased bridge spans for two Town roads in Brunswick.
- Monitor a failing stream bank near McChesney Avenue Extension to determine if more significant mitigation is required.
- Construct berms around several low-lying homes in Poestenkill or relocate the structures.
- Remove berm by the soccer fields in Brunswick.

Nature-Based Resiliency and Flood Management Strategies

- Stabilize the river-cut bank at McChesney Avenue Extension, likely with high bank revegetation and by benching of the inside of the bend to create more flood volume dispersal under high-energy conditions.
- Restore natural creek habitat along target sections of the Poesten Kill and Quacken Kill to stabilize bed and shorelines otherwise subject to mobilization during extreme weather. This work would also improve ecological value, including restoring trout habitat.
- Construct outlet controls on select wetlands in remote locations, augmenting existing stormwater detention capacity. Hydraulic modeling, review of this design with Regulators, preliminary engineering design, and identification of a pilot project site,

indicate a unique watershed opportunity to lower peak flows from 100, 200 and 500 year storms. This would achieve the following:

- lowered peak flows passing through the City of Troy.
- Alleviate the need to implement culvert upsizing projects.
- Alleviate the need to remove a berm and expand bridge spans in Brunswick.
- Reduce the need for protection and/or relocation of structures in Poestenkill.
- Lower peak flows eroding the bank approaching McChesney Avenue Extension.
- Protect the bed and banks along the upper Poesten Kill and Quacken Kill so eventual natural stream restoration processes can occur.

All projects have been subject to Cost-Benefit-Analysis. Wetland Outlet Controls provide the greatest benefit. Many cost less than $50,000 to implement while some cost between $80,000 and $150,000. A few discrete culvert and bridge projects cost more. Collectively, all the stormwater management practices identified by this assessment cost far less than repeating the net costs attributed to Tropical Storm Irene.

In addition to the projects listed above, the watershed municipalities are encouraged to support various land use planning strategies which help detain, soak in, and spread out floodwaters, including:

- Land Preservation to protect existing floodplains, wetlands, open and green spaces in a vegetated manner that provide floodwater storage Landscape replanting or restoration may be warranted in cases where land is eroded or fragmented, or streams are incised. Land acquisition or easements which prevent or limit future development may be considered.
- Enhanced land use guidance or regulations such as:
    - Municipal designation of Critical Environmental Areas (CEA) ensuring enhanced review for projects proposed in areas providing floodwater control benefits.
    - Municipal adoption of No Adverse Impact (NAI) floodplain management strategies, and participation in MS4 and National Flood Insurance Program NFIP community rating system programs, as applicable.
    - Municipal review and amendment of municipal zoning and flood damage prevention ordinances to strengthen flood resilience management
    - Implementation of Transfer of Development Right (TDR) or Conservation subdivision ordinance to discourage landscape fragmentation.

Preliminary implementation, permitting guidance, and funding discussion are also provided in the assessment report.

1.0 INTRODUCTION

1.1 Project Background

Tropical Storm Irene caused what all parties concede was millions of dollars of flood damage in 2011 across the 96 square mile Poesten Kill watershed. Streambed damage has yet to be mitigated, occurring along the upper Poesten Kill creek principally in the Town of Poestenkill and also along the Quacken Kill tributary creek in the Towns of Grafton and Brunswick. Various culverts and several bridges were washed out and stormwater flowing off the Rensselaer Plateau spread across valley farms and sports fields in Brunswick, before speeding through confined channels of the lower Poesten Kill and storm walls in the City of Troy to reach the Hudson River. Witnesses suggest structures near the Mt. Ida dam in Troy appeared near collapse during peak flow periods and that peak flood levels barely remained below flood walls in the City of Troy.

Following the storm, emergency stream clearing efforts, primarily in Poestenkill and Brunswick, included channeling and debris removal resulting in both intentional and incidental berms which have subsequently confined creek beds and damaged trout habitat. Culverts and bridges damaged during the storm were generally rebuilt in kind.

As used throughout this report, the Poesten Kill (two words) refers to the creek, and Poestenkill (one word) references the Town or either of its hamlets.

To better manage the landscape and prepare for future flood events, and to help mitigate stream damage lingering since 2011, the Rensselaer Plateau Alliance (RPA) applied for funds from the New England Interstate Water Pollution Control Commission (NEIWPCC) and the New York State Department of Environmental Conservation's Hudson River Estuary Program (HREP). Funding was provided in 2018 and RPA retained the Chazen Companies and Inter-Fluve to work with watershed communities and identify technically viable and locally-supported restoration and resiliency projects improving the watershed's overall preparedness for future flooding events.

RPA hopes conclusions of this study will be beneficial both to the Poesten Kill watershed and perhaps also to other watersheds seeking experience and concepts to review. The project calendar and budget period for this project began in 2018 and ended on July 27, 2019.

1.2 Project Scope and Objectives

The governing objective of this study has been to provide communities in the Poesten Kill watershed with direction for improving their resilience to flooding and protecting their natural resources. Accordingly, this project has identified and describes a range of opportunities to mitigate flood hazards and improve community resilience using a blend of naturally-based flood management approaches and traditional flood management engineering strategies.

<u>Public Involvement</u>: Significant effort was made to enlist the public in development of these flood management recommendations. Team involvement included a kick-off meeting with municipal

and organizational principals, two well-publicized public meetings where preliminary maps and discussion identified locations of historic and current flooding, and conceptual mitigation projects were discussed, and feedback was solicited, and two meetings of watershed team assembled by the Rensselaer Plateau leadership in order to build constituent enthusiasm to implement project recommendations.

Development and Evaluation of Recommended Management Practices: Meetings, targeted field visits, and discussions with local leaders helped define a list of flood hazard areas and opportunity locations for mitigation projects. Chazen developed a HEC-RAS watershed model into which HydroCAD model runs from discrete potential project sites have helped assess likely peak flow reduction benefits during normal and extreme weather events. The project team held a pre-application discussion with NYSDEC and USACOE personnel to vet a conceptual wetland detention program identified as a potentially significant tactical unit for peak flood management in the Poesten Kill watershed. Cost Benefit assessments were completed, comparing mitigation project budget estimates with associated potential damage estimates.

Briefly, the project scope has included the following Tasks:

- Task 1. Develop a Quality Assurance Project Plan (QAPP).
- Task 2. Complete field reconnaissance, assemble critical geographic mapping, and gather local input.
- Task 3 - Supplement Task 2 data with geomorphic review and hydraulic model development, concentrating on locations significantly affected by Tropical Storm Irene.
- Task 4 - Flood hazard mitigation strategies & cost-benefit analysis, including NYSDEC and ACOE meetings, model analysis, and preliminary design analysis of a novel wetland detention outlet control concept. Narrative and visual renderings were provided for select option to help watershed residents envision these approaches.
- Task 5 – Public involvement, including development of a program committee, two public meetings, numerous site visits, and mailings and press notices inviting meeting attendance.
- Task 6 – Preparation of this report.

2.0 WATERSHED MAPPING, MODELING, AND FLOODING HISTORY

2.1 Topography and Land Use

The Poesten Kill watershed covers 96 square miles in northern Rensselaer County. The watershed includes primarily the Towns of Brunswick, Poestenkill, Grafton, portions of the City of Troy, and margins of other Towns including the Towns of Berlin and Sand Lake **(Figure 1A).**

Elevations also vary sharply across the watershed, with lowlands between sea level and 800 feet above mean sea level (amsl) in the western sections, then rising steeply to the Rensselaer Plateau in the east **(Figure 8)**.

- The main stem of the Poesten Kill extends from Troy to the south section of the Town of Brunswick where the Quacken Kill tributary enters the Poesten Kill. For much of this reach, the creek flows between steeply rising banks with limited flood plain margins. The Sweet Milk Creek adds flow to this lower stream reach.

- Above Garfield Road in Brunswick, the upper Poesten Kill rises steadily through the Town of Poestenkill, flowing within narrowing flood plain areas and gaining elevation steadily through the hamlets of Poestenkill and East Poestenkill. The highest elevation reaches often flow directly on bedrock, passing through series of wetlands, eventually reaching headwaters at Dyken Pond. Tributary flows entering the upper Poesten Kill include Newfoundland Creek near Garfield Road, Bonesteel Creek near Columbia Hill Road, and a tributary sometimes referenced as Potter Creek which approximately follows Fifty-Six Road, among others.

- The Quacken Kill first rises gradually as it winds through wide valley areas in central and northern portions of Brunswick. It then turns east to ascend steeply toward headwaters in the Town of Grafton, gaining flow from numerous tributaries. Notable headwater water bodies include Dunham Reservoir and the Grafton Lakes **(Figures 1A and 1B)**.

The geography of the Poesten Kill includes both lightly-settled woodlands in headwater areas, hamlet and suburban density and some agriculture in portions of Grafton, Brunswick, and Poestenkill, and heavily-settled urban density tightly-constrained around walled creek margins in the City of Troy, near the Hudson River. Development density is greater at the base of the Rensselaer Plateau escarpment than in the uplands and is greatest in and near the City of Troy **(Figure 3)**.

<u>Key points: The following Topographic and Land Use factors influence watershed-scale flood management planning</u>:

- Headwater areas on the Rensselaer Plateau include significant expanses of low-gradient wetlands and lightly-settled woodlands.
- Broad floodplains exist in Brunswick, along with more limited floodplains in Poestenkill **(Figure 2A)**. Stormwater flowing off the plateau spreads on these floodplains and deposits sediments. Some structures, bridges, and roads occupy mapped flood zones.
- Between Brunswick and the eastern limits of the City of Troy, the Poesten Kill flows through confined banks. Floodplains are limited and few structures are threatened by flooding.
- Flood prone areas exist in the City of Troy near the Hudson River. In this final half mile of the Poesten Kill there is little available space for floodwater management controls or detention. Structures are built within feet of walled stream banks and flood peaks threaten structures and roads.

2.2 Flooding History

2.2.1 Tropical Storm Irene

Tropical Storm Irene passed over the Poesten Kill watershed in 2011. The watershed has no USGS flow gage, but flow in the nearby Hoosick Creek approached the 0.5% (200 year storm) statistic. Watershed modelling analysis described below in this report also agrees that Tropical Storm Irene likely represented a 0.5% storm. Currently-mapped flood zones are shown on **Figure 2A** and locations referenced below are noted on **Figures 1A** and/or **1B**.

By no means an exhaustive listing, interviews conducted by Chazen and RPA with municipal officials and many watershed residents described the following areas of flooding and damage during and following Tropical Storm Irene. Photo credits to June Butler, Linda VonDerHeide, Interfluve, and The Chazen Companies.

Quacken Kill (from headwaters down to confluence with the Poesten Kill):

- Route 2 suffered extensive damage. One lane of Route 2 was washed out between Bulson Road and the Brunswick BBQ and Brew property (see image at right), and a water line was torn off a bridge where the Quacken Kill passed under Route 2 near Laughing Earth Farm. Route 2 was fully washed out where an unnamed tributary passes through a culvert near Stuffle Street. The concrete box culvert survived as the road bank washed out around it. The road was later reconstructed around the existing culvert supplemented by reinforced upstream wingwalls. A small bridge on Roark Road, immediately below this Route 2 culvert was not washed out although stormwater may have briefly overtopped the bridge.

- The impoundment behind an unused dam on the Quacken Kill, below Palitsch Road, filled with bedload sediments transported during the storm. Route 2 was reportedly not flooded in this vicinity.

- Floodwater flowing off the Rensselaer Plateau spread across established floodplains in Brunswick between Cropseyville and Garfield Avenue. Most areas with reported flooding reportedly matched existing floodplain area mapping (**Figure 2A**) but floodwater energy was high so scoured stream bed and banks, deposited sediment from upland areas in backwater areas, and damaged two Town bridges.

    - Significant sediment bedload was deposited by the creek where water velocity slowed, with significant accumulations at the soccer fields by the intersection of Routes 2 and 351. After the storm, heavy equipment was used to clear this sediment and construct a berm between the creek and soccer fields to direct future storm sediment deposition away from the fields.

    - Bridges in Brunswick on White Church Road and on Dearstyne Road were washed out. They have since been replaced with similar structures.

    - Owners of Wagner Farms near Garland Road reported significant sediment and debris deposition on the floodplain sections of their agricultural lands as well as stream channel migration. Nearby flooding also reportedly occurred (and occurs regularly) along Creek Road upstream of Eagle Mills.

<u>Upper Poesten Kill</u> (from headwaters down to confluence with the Quacken Kill)

- A mix of severe flooding, variable sediment scours and deposition, and stream relocation occurred along approximately ten miles of the upper Poesten Kill, between Dodge City Road on Plank Road and the hamlets of East Poestenkill and Poestenkill. Portions of this reach were subsequently excavated using heavy equipment following Tropical Storm Irene, resulting in side-cast berms and unsecured bed sediments d evoid of stabilizing rock or wood vanes and still today lacking riffle and pool structuring.

- A culvert bridge was washed out on Plank Road, at the northern-most crossing of the upper Poesten Kill. This was subsequently replaced with an in-kind structure. No other bridges or culverts were washed out or overtopped along the upper Poesten Kill, including all creek crossings in the hamlets of Poestenkill and East Poestenkill.

- Flooding and road damage occurred along Blue Factory Hill Road in both Poestenkill and Grafton, with repairs needed in the section between North and Clickner Roads. Bonesteel Creek took out part of a lane for a short distance, visible today where there is new riprap on the roadside.

- Along a tributary aligned with Fifty-Six Road, road culverts were washed out under North Road just below the Campfire Girl's Dam along with the northern-most crossing of this creek under Fifty Six Road. These have been replaced with in-kind structures.

- Six homes on Empire Drive nearest to the Poesten Kill experienced flooding at grade. Floodwaters also approached other structures and deposited considerable debris in the vicinity of Franklin Avenue and the Poestenkill firehouse.

<u>Lower Poesten Kill</u>

Limited damage was reported along the Poesten Kill below its confluence with the Quacken Kill. **Figure 2B** indicates that 100- and 500-year flood zones are closely constrained to the creek. Some concerns and observations were, however, offered.

- Concern was expressed about the integrity of the Mt. Ida Dam, as peak flood levels passed this location.

- In the City of Troy, the peak flood level neared the top of stream walls but did not exceed them. Had the peak flow been higher, structure and road flooding would have occurred in the vicinity of Canal Avenue and Ida Street.

2.2.2 Other Floodwater Concerns

Town of Brunswick officials have reported difficulty managing floodwater along an approximately 500 foot section of South Road, where hillside runoff floods the road and fails to reach a former receiving wetland area.

A river bend on the lower Poesten Kill has also meandered near McChesney Avenue Extension, appearing to threaten the road and nearby structures. The location currently exhibits as a high, unsecured bank.

<u>Key points: the Flooding History reviewed above provides the following influence on watershed-scale flood management planning</u>:

- Considerable flood damage occurred high in the watershed during Tropical Storm Irene, washing out culvert-style road crossings on the Rensselaer Plateau and two bridges below the escarpment, in Brunswick.
- Sediment deposition on floodplains in Brunswick was significant, filling also the impoundment behind an unused dam along Route 2.
- Stream morphology damage and sediment relocation were significant along several miles of the upper Poesten Kill, in and above the hamlet of Poestenkill.
- Any increase in peak flows above that experienced during Tropical Storm Irene will result in flooding of structures and roads in the City of Troy.

2.3 Geology, Groundwater, and Wetlands

Bedrock geology of the Poesten Kill watershed includes varying classes of sedimentary rock. The high-elevation Rensselaer Plateau is supported by graywacke, describing a gritty shale or impure sandstone, which is resistant to mass wasting and erosion. Softer shales, including the Nassau formation and limited exposures of the Normanskill shale near the City of Troy, underlie the lower elevation portions of the watershed.

None of these bedrock formations have inherent groundwater porosity, so groundwater movement and associated springs and water wells are dependent on subsurface water migration through fractures resulting from the region's tectonic history, compression and decompression during formation, and flexing under regional glacier advances.

The most recent glaciation of the watershed ended less than 20,000 years ago. Advancing ice scoured the bedrock topography and left sediment coatings as ice stalled and then melted from the landscape. Glacial till covers most of the watershed, consisting of mixed and compressed silty clay along with randomly-interspersed pebbles to boulder-sized clasts. Primarily below the escarpment, water flowing away from the melting ice also deposited coarsely-sorted sediments near ice margins (mapped as kame deposit), broad sand and gravel outwash deposits across broad floodplain, and fine silts and clays in temporary glacial lakes. These various surficial geologic formations are depicted approximately on **Figure 4**.

Glacial till and silty lake clay deposits typically have low groundwater permeability which limit groundwater recharge, and promote high stormwater runoff rates during rain events. Soils at grade derived from such deposits are dominant across the Rensselaer Plateau, all higher elevation areas in Brunswick, and in the City of Troy.

Both kame deposits and outwash sand and gravel deposits typically offer higher groundwater permeability due to their open porosity. Groundwater recharge rates during rainfalls can be high through such deposits, curtailing peak stormwater runoff rates by infiltrating stormwater below grade, where it can migrate slowly toward streams and lakes over weeks to months. This cycling of precipitation through sediments and bedrock geology stabilizes creek flow during dry periods, supports drilled wells and riparian wetlands. Areas with such higher-permeability sediments in the Poesten Kill watershed exist primarily along the lower Quacken Kill flowing through Brunswick and portions of the upper Poesten Kill including near the hamlets of Poestenkill and East Poestenkill.

Soils are assigned to one of four Hydrologic Soil Groups, A through D. HSG A soils are most porous while HSG D soils are clay-rich and impermeable. **Figure 5** shows the distribution of Hydrologic Soil Groups on the Poesten Kill watershed. A preponderance of low-permeability HSG C and C/D soils is evident, broadly restricting infiltration and facilitating runoff during storm events.

Wetlands form where the groundwater's upper surface, or watertable, is coincident with grade. Wetlands can also form where geologic formations have such poor porosity that surface water ponds, or is perched, above the watertable for long enough periods each year to permanently modify vegetation and the structure of soils. Substantial acreages of wetlands are found in the Poesten Kill watershed. More than 2,000 acres of NYSDEC wetlands (wetlands over 12.4 acres) are found on the Rensselaer Plateau alone, with another 1,700 acres of NYSDEC wetlands found below the escarpment (**Figure 2B**). Smaller National Wetland Inventory (NWI) wetlands add additional wetland acreage (**Figure 2C**).

Wetlands on the Rensselaer Plateau generally have clear boundaries, constrained by distinct bedrock elevation changes. These wetlands are formed in depressions mined into the greywacke formation by glacier movement over the Rensselaer Plateau. They are interconnected by streams winding through narrow bedrock channels which pass across the bedrock topography. **Figure 9** provides a visual example of such wetlands on the Rensselaer Plateau.

Wetlands below the escarpment generally have boundaries which grade more gently onto adjoining lands. In western sections of Poestenkill and in Brunswick, they lie in area with gently rising topographic margins on glacial outwash plains which filled wide expanses of nearly-level topography.

<u>Key points: the following Geologic, Groundwater, and Wetland conditions influence watershed-scale flood management planning</u>:

- Low permeability bedrock and soils are dominant in this watershed, generally promoting high rates of runoff during precipitation events. Only limited areas with kame and outwash sand and gravel deposits exhibit porosity promoting groundwater infiltration and moderating runoff rates into streams.
- Wetlands on the Rensselaer Plateau have defined boundaries, and runoff leaves these wetlands through narrow streams notched into bedrock.
- Wetlands below the plateau have more gently-sloping margins and discharge to streams which can migrate across expansive floodplains.

2.4 Hydrology and Climate

The Rensselaer Plateau is a dominant geologic presence which influences hydrology of the Poesten Kill watershed. Precipitation totals are reportedly higher on the plateau than below, converging stormwater velocity accelerates as it flows off the escarpment, and expansive land areas at the base of the escarpment become locations for floodwater spreading.

Oher factors influencing watershed hydrology include the generally low permeability of soils and geologic features, resulting in elevated runoff volumes and only limited areas with high infiltration rates. The shale below the escarpment and the greywacke on the plateau are sufficiently monolithic to have allowed formation of evenly distributed and dendritic stream networks across the watershed.

The confined bed and banks of the Poesten Kill between western Brunswick and the Hudson limits floodwater spreading or slowing in these reaches.

Climate models suggest the region including the Poesten Kill watershed may receive more annual precipitation in the future, and that some of this may be delivered by higher-volume individual events. Accordingly, modelling and management options assessed here include review of the 200-year (0.5%) and 500-year (0.2%) flood events.

Climate models also suggest regional warming, which may influence hydrology by exacerbating evapotranspiration, soil moisture drying, or landscape drying which may promote wildfires which are often followed by mobilization of soils no longer secured by vegetation. These factors may all result in longer drought flow conditions in the creek and tributaries but are unlikely to significantly influence the peak volumes of occasional 0.5% or 0.2% floods, so will not be considered further in this assessment.

<u>Key Hydrology and Climate Points:</u> Topography of the Rensselaer Plateau raises rainfall rates in the headwaters, accelerates stream flow off the plateau, and floods foothill areas. Climate modeling suggests higher-volume storm events may become more frequent in the future.

2.5 Open Space

Open space can be evaluated both on the basis of land use, and on the basis of conserved status. Considered as land use, **Figure 3** indicates that significant portions of the eastern watershed consist of lightly-settled woodlands and rural settlements. Additional open space including agricultural land is also present across central portions of the watershed including much of Brunswick and the western sections of Poestenkill. Urban and densely developed land is dominant near the Hudson River and the City of Troy.

Considerable land In the Poesten Kill watershed is conserved in various ways (**Figure 7**). On the Rensselaer Plateau overall, some 10,600 acres are currently owned by conservation organizations including the Rensselaer Plateau Alliance and the Conservation Fund, much of which is likely to be transferred to the New York State Department of Environmental Conservation in the future to be managed as State Forest and State Forest and Wildlife Management Areas. Portions of this acreage lie in the Poesten Kill watershed.

Additional conserved land in the Poesten Kill watershed includes:

- The Grafton Lakes State Park.
- The Dyken Pond Environmental Education Center with lands owned by Rensselaer County.
- The Poestenkill Community Forest owned by the Rensselaer Plateau Alliance.
- The Barberville Falls Preserve owned by the Nature Conservancy.
- The Geiser Preserve owned by the Rensselaer Land Trust.

<u>Key points: Open Space relationships influence watershed-scale flood management options</u>:

- Low-density land uses are found primarily in the upper watershed.
- A wide range of open space land easements and ownership arrangements exist, offering opportunities to work with potentially sympathetic land owners to pilot test and/or implement flood management strategies with consenting land owners.

3.0 GEOMORPHOLOGY ASSESSMENT

In conjunction with Chazen, Interfluve advanced most geomorphological analysis included in this assessment. Their summary document is provided in **Appendix 1**. The following paragraphs transcribed from the Interfluve assessment describe the essential geomorphology of the Poesten Kill watershed. Table and figure references have been removed.

> "The landscape of the Poesten Kill watershed is dominated by a prominent topographic step defined by the western boundary of the Rensselaer Plateau. This topographic control accounts for many of the patterns of flood and sediment transport dynamics observed in the watershed. The upper reaches of the Poesten Kill and Quacken Kill that originate on the plateau and flow west down the escarpment, are characterized by steep and confined channels with small floodplains.
>
> Slopes along the mainstem channels are on the order of 100 ft/mile or 0.02, with higher slopes occurring locally and along tributaries. The combination of high slope and confinement is capable of generating flood flows with sufficient velocity and depth to erode and transport the abundant sediment present in the surficial deposits forming the hillslopes adjacent to the channels as well as other debris (e.g., large wood). This is reflected in anecdotal descriptions of the damages experienced during Tropical Storm Irene which included blocking of culverts and catastrophic failure of associated road infrastructure such as the damage to Route 2 near the intersection with Stuffle Street in Grafton (Quacken Kill), Plank Road in Poestenkill (Poesten Kill), and Fifty Six Road in Poestenkill (Potter Creek).
>
> These steep upland reaches transition abruptly onto the broad plain at the base of the plateau, and channel slopes reduce dramatically. When flows reach this break in slope, they slow and expand onto the floodplain, resulting in a rapid reduction in sediment transport capacity and abrupt deposition of sediment. During Tropical Storm Irene, deposition of substantial volumes of sediment along the Quacken Kill in the village of Brunswick and the Poesten Kill in the village of Poestenkill damaged soccer fields and residential property and filled the channels, reducing conveyance capacity and forcing more flow overbank.
>
> Throughout the watershed, there is evidence that a combination of dredging, berming, and straightening has been a typical management response to these flood and sediment impacts. This approach has resulted in entrenched and over-wide channels that are disconnected from adjacent floodplains, which may serve to reduce the flood risk to properties in the immediate vicinity of the activity but is likely to exacerbate flood peaks in downstream reaches."

Based on these field observation, Interfluve recommended the following general flood management strategies for the Poesten Kill watershed:

- "Measures in the headwaters area of the plateau should focus on increasing flood storage and detention;
- Measures along the steep channels of the escarpment should be aimed at increasing resilience of road infrastructure, slowing flows, and reducing erosion; and
- Measures in the lowlands at the base of the escarpment should focus on floodplain and channel restoration, including relocation of vulnerable development types and restrictions on future development."

4.0 COMMUNITY ENGAGEMENT

The Rensselaer Plateau Alliance (RPA) and Chazen initiated this project by conducting community and municipal outreach to establish a working team familiar with the full watershed. Meetings were held with the Supervisors of Grafton and Poestenkill, the deputy Supervisor of Brunswick, and City leaders, organizational representatives, and individuals. Inter-Fluve and Chazen visited select locations with some of these individuals to inspect locations of concern. RPA and Chazen are grateful for the contributions of all these participants.

A series of meetings was held over the project work period. Public meetings were advertised by RPA using press releases, social-media and email notices by various local organizations, and direct post-card mailings to property owners owning land abutting potential project sites. RPA assembled an action committee of individuals showing particular project interest. This committee met twice during the project period. The meeting attendance sheets are provided in **Appendix 4**, and summarized here:

June 28, 2018. Kick-off meeting held at Chazen office in Troy, New York. 14 in attendance. Project concerns, purpose, interests, and first assigned tasks with schedules were reviewed.

December 12, 2018. First Public meeting held at Poestenkill Firehouse. 33 in attendance. Preliminary watershed observations were presented with conceptual flood management ideas. Comments received including skepticism that anything would come of this project, some anger and blame expressed over condition of the Poesten Kill today following Tropical Storm Irene, and a lively discussion ensued considering the various flood water management options offered for consideration.

April 24, 2019. Committee meeting held at Chazen offices in Troy. 12 in attendance. Detailed discussion reviewed wetland outlet control opportunities and concerns, along with review of other potential projects. Conversation turned also to future implementation opportunities and grant funds.

May 23, 2019. Second Public meeting was held at Poestenkill Firehouse, in Poestenkill. 18 signed in, with at least 7 additional present from NYSDEC, RPA and Chazen, for an estimated total attendance exceeding 25. Draft final project locations and findings were presented. Public comment was lively and generally positive. A privately-owned, small wetland was offered by an attendee for consideration as a pilot outlet control evaluation site.

July 18, 2019. Final organizational meeting is scheduled for Chazen offices in Troy. Nine were in attendance. Discussion and feedback on draft report. Review of implementation opportunities and funding sources.

Meeting attendance levels and numbers of meetings exceeded targets established for this project, providing a measure of community support for the blend of flood management strategies identified, vetted, and prioritized through this watershed scale planning project.

5.0 FLOOD MANAGEMENT & MITIGATION STRATEGIES

5.1 Overview Analysis of Options and Opportunities

A mix of standard and unique factors have influenced selection and development of flood management strategies for the Poesten Kill watershed. These include the following:

- There is little room for increased peak flows in the City of Troy during future flood events. During Tropical Storm Irene, floodwaters now recognized to be consistent with a 0.5% flood (see **Section 6**) nearly inundated urban structures built within feet of the walled creek. As a result, upstream flood management measures that increase peak flows are discouraged.

- There is little opportunity to expand floodwater detention in the lower third of the watershed between Troy and southern Brunswick due to confined channel morphology.

- Flood plains and wetlands along the lower Quacken Kill, middle Poesten Kill, Newfoundland Creek, and Sweet Milk Creek are surrounded by built structures with gentle breaks-of-slope rising to structures or roads. Strategies to enhance stormwater detention in these areas must be sensitive to built environments.

- Extensive open space exists on the Rensselaer Plateau. Floodwater detention detained on the plateau could reduce peak flows throughout the watershed.

- Many wetlands on the Rensselaer Plateau are remote and have no nearby development, discharge through narrow outlets incised into bedrock, and exhibit discrete margins bounded by rising, bedrock slopes.

- Much of the watershed has low permeability soils and bedrock which limit infiltration of stormwater. Therefore, detention rather than infiltration strategies are most likely to be successful on a watershed scale. Where infiltration does occur the built environment already encroaches on wetlands, and the watertable is near grade so unsaturated aquifer storage is limited.

Most floodwater management strategies fall into three categories. *Detention strategies* hold back stormwater and curtail peak flows. These require space for temporary floodwater impoundment. Examples of traditional detention strategies include reconnected floodplains and built detention basins with outlet controls. *Managed flow strategies* guide flow past assets like bridges or structures, but those also tend to increase downstream peak flows. Examples include upsized culverts and bridges, and floodplain benching. Finally, *land use planning strategies* help ensure that natural landscapes are preserved and development doesn't encroach on wetlands or floodplains.

The vulnerability of Troy to increased peak flows has led the RPA study team to prioritize floodwater detention strategies throughout the watershed. There is also limited floodplain availability and/or community tolerance for floodwater detention in Brunswick or western Poestenkill so the team considered detention opportunities higher in the watershed. A series of traditional and non-traditional conventional and "green" design concepts emerged. These are summarized below. Select projects were subsequently tested via hydraulic modeling described and summarized in **Section 6.0**.

5.2 Peak Flow Reduction Strategies

5.1.1 Dam Management

There are many dams in the Poesten Kill watershed. Most are run-of-river dams which begin and end storms full of water, thus offering negligible detention value during a storm. Those few which are not run-of-river dams are often encircled by residences with owners intolerant of significant variability in water levels, so levels of most such dams are not actively managed to benefit downstream flood peaks.

Four dams are known to have functioning water level controls which could be used to manage water levels to assist with flood mitigation. These are Dyken Pond (NYS ID 244-1420), Dunham Reservoir (NY ID 243-1430), and three lakes at the Grafton Lakes State Park (NYS IDs 243-1442, 243-1444, and 243-1447). All could be drawn down prior to pending storms to create available detention volume. Doing so would require attentive management, and a willingness to accept a lowered lake condition for some time if a predicted storm failed to materialize.

The three lakes at Grafton State Park flow from one into the next, and then downstream into the Dunham Reservoir. Typically, confident tracking of the pending arrival of significant storms is restricted to a maximum of three days' notice. Depending on release velocities, simultaneous three-day discharges from these four lakes may yield poorly distributed detention volumes and only certain unwatering of Long Pond, which offers a public bathing beach. Among these reservoirs, therefore, Chazen recommends only aggressive unwatering of Dunham Reservoir prior to a predicted storm, as the furthest downstream and largest reservoir of the four under consideration.

Dyken Pond also has infrastructure allowing reservoir water level control. Anecdotally, Chazen understands that some pre-storm drawdown measures were taken in 2011 in advance of Tropical storm Irene to create some detention capacity behind this dam. Residents living around the lake are nonetheless reportedly sensitive to the lowering and raising of lake levels. As outlined in Section 5.1.2, an alternate downstream stormwater management strategy installed in the same watershed as Dyken Pond may offer comparable floodwater mitigation benefits with fewer management and property impacts.

Thus, of the five dams currently known to be amendable to active water level control, only Dunham Reservoir was further examined under this study:

Dunham Reservoir is managed by the NYS Parks Department, which has recently upgraded two 24-inch low-level outlet pipes in the 91-acre Dunham Reservoir. The watershed area flowing to Dunham reservoir is 9.5 square miles (6,080 acres). According to the 2014 Emergency Action Plan (EAP), by Civil Dynamics the Dunham Reservoir Dam has two 24-inch diameter low-level outlets as well as a 12-inch diameter low level outlet (LLO). Calculations prepared by Civil Dynamics Engineering,P.C., dated March 3, 2014 indicate that a single 24-inch diameter LLO is sufficient to lower 90% (52.3 cfs) of the reservoir storage volume below the normal pool in 14 days. The additional draw down of the 12-inch LLO would add another 62.5 ac-ft in 72 hours.

Based on the values above, Chazen calculated the approximate drawdown achievable by these LLOs in 72 hours to be 690 ac-ft, or 6.9 feet below the spillway elevation of 1,324-ft. Chazen developed a model using HEC HMS v. 4.3, to evaluate the resulting peak discharge, assuming a three day draw down via these LLOs during normal weather conditions, with concurrent upstream inflows. Modeling completed under this project is described in Section 6. The model developed for Dunham Reservoir assumes the outlet controls remain open during the modelled storm event so overflow eventually reaches the reservoir spillway late during a significant storm. The rate of overflow is governed by the current spillway width of approximately 100 feet. Under these assumptions, the following controlled and uncontrolled peak discharge rates appear feasible for 100-, 200- and 500-year storm events if pre-storm drawn is implemented (**Table 1**).

Table 1: Dunham Reservoir Peak Discharge Summary

Flood Event	Dunham Reservoir Watershed Peak Uncontrolled Entering the Reservoir (cfs)	Current Dunham Reservoir Peak Discharge (cfs)	Dunham Reservoir Peak Discharge -after 3 day draw down (cfs)
100-year	153.8	67.3	23.0
200-year	210.2	101.1	27.4
500-year	269.8	139.1	31.5

The large reservoir evidently already provides meaningful storm peak moderation as entering peak floodwater spreads across the lake and abutting reservoir land (cf. columns 2 and 3), reducing peak discharges to between 40 and 50 percent of the inflowing peak. Pre-storm drawdown significantly increases this benefit, (cf. columns 2 and 4), suggesting that implementing this pre-storm flood management option can provide valuable flood damage protection to the Quacken Kill as it flows down along Route 2 and as it slows and spreads in Brunswick before mixing into the Poesten Kill.

Chazen evaluated the benefit of implementing this single measure on peak flows in the City of Troy. The model run suggests the 100, 200 and 500 year flood levels in The City of Troy could be reduced as follows:

Table 2: Dunham Reservoir Management, Benefit in City of Troy

Flood Event	Modeled Peak flow passing through City of Troy (cfs)	Modeled Streamflow in City of Troy with pre-storm drawdown at Dunham Reservoir (cfs)	Flow benefit, as percentage of uncontrolled peak	Flow Benefit, as lowered peak (feet)
100-year	6371.3	5877.2	92.2%	0.25
200-year	8416.1	8157.5	96.9%	0.10
500-year	10616.1	10497.3	98.9%	0.03

In principal, implementing pre-storm drawdown actions would seem to be a zero-cost project. However, the proposal likely warrants analysis and review through the NYS Parks Department, confirmation of LLO assumptions and inclusion in this facility's Operations and Maintenance Plan for pre-storm dam drawdowns and a decision matrix and personnel assignment. For this review and plan development, an implementation budget of $20,000 is estimated and assigned.

5.1.2 Wetland Stormwater Detention

A conceptual design to passively increase temporary floodwater storage on remote upland wetlands was suggested by an RPA board member and has been evaluated extensively by Chazen. Numerous wetlands, primarily on the Rensselaer Plateau, appear well-suited to augmented detention of floodwater during significant storms. More than 2,000 acres of NYSDEC wetlands are found in depressions mined by glaciers into the plateau's high-elevation bedrock topography, interconnected by narrow streams passing through remote and forested landscapes. As examples of such geography, portions of NSYDEC wetlands T-16 and T-20 are shown on **Figure 9**. An additional 1,700 acres of NYSDEC wetlands lie below the escarpment, also potentially suitable for augmented floodwater storage but generally situated in more traditional settings that include gradually-graded margins with surrounding structures and managed land amidst wider stream corridors (**Figure 2B**).

Concepts were explored to construct restricted outlets on select wetlands. Approaches were modeled and appeared capable of reducing downstream peak flood levels by increasing existing temporary storage capacity already present on wetlands. This concept therefore appeared to represent a unique opportunity to work with nature to manage watershed-scale flooding.

Chazen and Interfluve then considered various potential outlet control designs, and concluded that simple versions of "wing walls" or levees built outside the Ordinary High Water Mark (OHWM) could be effective. The approach avoids impinging on any normal functioning of the stream or wetland by keeping the design outside of and above the stream bed and banks, enhancing stormwater detention value on wetlands only during extreme weather. Detained water volumes passively drain from the wetlands following storms.

Outlet controls constructed at such individual wetlands would offer greatest peak flood relief first to culverts or structures immediately downstream of the controls. But as importantly, the cumulative benefit of networked wetland outlet controls constructed across the watershed would curtail overall peak flood flows as far downstream as the City of Troy. Modeling of outlet control devices explored in Section 6 of this report confirms that peak flows below individual wetlands equipped with outlet controls appear able to reduce 100-, 200-, and 500-year peak floods to between 50% and 90% of current uncontrolled flows, and how networks of control devices could reduce peak flood levels passing through Troy.

Chazen and RPA next met with regional permitting personnel at Region 4 headquarters, on February 1, 2019 to discuss this potential project approach. The meeting was coordinated by Ms. Kate Kornak, the Region 4 Deputy Permit Administrator. Summary notes from that meeting prepared by Chazen are found in **Appendix 5**. Follow-up emailed communication from Trevor Brady, in the Region 4 Stream Permits program, confirm various concerns detailed in the February meeting notes, and are also found in **Appendix 5**. RPA and Chazen were attentive of the preliminary feedback given to this design concept by Region 4 and are hopeful and optimistic that outlet control devices can receive permits, perhaps via a project initiated by a closely-monitored pilot project that identifies performance conditions and lessons-learned suitable for subsequent applications. The February meeting confirmed that each outlet control device would require a local benefit justification in addition to a net watershed benefit analysis, so considerable effort was expended in this report to focus modeling on both the individual and net cumulative peak flow benefits of wetland outlet controls.

Appendix 2 provides preliminary design options for several different wetland outlet control designs. All involve simple and low profile barriers to flow on banks below a wetland. Options include simple berms, reinforced berms, or concrete block barriers. The design footprints are small but result in significant temporary detention on the upstream existing wetlands until they drain naturally within a few days. The preliminary outlet control dimensions are shown on **Table 3.** These were selected in consideration of 2-foot contour LIDAR topographic mapping, preferring structures generally approximately three feet high and matching existing stream bank widths. Structures taller than three feet were only recommended where peak flow reduction was nominal and wetland margins exhibited sufficient vertical control to allow taller detention structures

Chazen and RPA identified 14 wetlands in the Poesten Kill watershed potentially suitable for construction of wetland outlet controls. All but one on the Rensselaer Plateau. The locations are shown collectively on **Figure 10** with associated sub-watersheds shown collectively on **Figure 11**. Individual maps and associated sub-watershed are provided in **Appendix 3**. **Table 3** summarizes the model run results for these proposed detention sites. In general, flow controls on smaller wetlands below large watersheds show less benefit, while outlet controls on large watersheds below smaller watersheds yield greater benefits. Wetland T-16 passes through three elevation stages so has been recommended for three outlet control locations.

Table 3. Peak Flow Projects - Peak Discharge Reduction Benefits

Detention Project, NYSDEC Wetland ID or Location Name	Drainage Area (sq mi)	Storage Area (ac.)	Outlet Control Approx. Dimensions		Peak Discharge Existing and Controlled Values Units for all values are cubic feet per second (cfs) except Flow Benefit which is expressed as a precentage of current flow											
			Opening Width (ft)	Height (ft)	100-yr, current	100-yr controlled	Peak Flow Reduction	Flow Benefit	200-yr, current	200-yr, controlled	Peak Flow Reduction	Flow Benefit	500-yr, current	500-yr, controlled	Peak Flow Reduction	Flow Benefit
AP-6	1.06	57.5	10	3	122.3	56.7	65.6	46%	164.3	82.7	81.6	50%	206.3	109.7	96.6	53%
AP-14*	8.33	45	25	3	718.6	317.9	400.7	44%	947.1	740.1	207	78%	1183.1	1089.3	93.8	92%
AP-29	5.24	54.9	15	4	171.9	132.6	39.3	77%	229.8	169.9	59.9	74%	289.7	214.2	75.5	74%
G-31*	5.25	36.3	15	5	191.8	142.4	49.4	74%	261.2	189.5	71.7	73%	333	243.4	89.6	73%
G-32	2.65	32.2	12	4.5	169	110.2	58.8	65%	228.2	144.4	83.8	63%	289.7	183.3	106.4	63%
G-35	1.93	19	15	5.5	190	183.7	6.3	97%	249.3	242.7	6.6	97%	310.9	303.2	7.7	98%
T-8	0.55	55.3	10	2	46.5	11.7	34.8	25%	62.3	18.1	44.2	29%	78.9	25.5	53.4	32%
T-11	1.31	30.5	10	3	154.5	134.3	20.2	87%	202.2	176.2	26	87%	251	240.6	10.4	96%
T-12*	1.55	27.8	10	4	134.8	93.3	41.5	69%	179.2	127.3	51.9	71%	227.1	211.6	15.5	93%
T-16A	2.73	170.3	20	3	206.3	156.1	50.2	76%	277.3	198.3	79	72%	351.9	248.3	103.6	71%
T-16B			20	3	156.1	79.9	76.2	39%	198.3	118.2	80.1	43%	248.3	152.2	96.1	43%
T-16C			15	3	79.9	35.6	44.3	17%	118.2	64.7	53.5	23%	152.2	95.2	57	27%
T-20*	4.53	67.6	25	3	191.9	164.8	27.1	86%	261	211.5	49.5	81%	332.4	261.2	71.2	79%
T-24*	9.2	61.1	12	4	296.8	151.7	145.1	51%	404.7	202.4	202.3	50%	516.5	260.9	255.6	51%
T-27	2.67	58.7	15	5	400.8	353.1	47.7	88%	513.2	443.3	69.9	86%	623	618.1	4.9	99%
Kersch	0.066	8.2	5	2	21	11.2	9.8	53%	29.3	16.3	13	56%	35.1	10.7	24.4	30%

*These wetlands are directly downstream of other potential project wetlands, so flow benefit improves when upstream projects are also implemented.

Outlet control dimensions for wetlands based on existing stream widths and avaialable wetland freeboard estimated from LIDAR topographic mapping.

Approximate construction costs and annual maintenance costs are included in **Appendix 2** for the designs conceived by Chazen, varying eventually around $40,000 per location for permitting, design and construction, with approximately $1,300 additional for annual maintenance. Design and construction of the first pilot installations will cost more as all parties (design, permitting, construction) each gain familiarity with the strategy. Naturally-appearing alternatives were prepared by Interfluve (**Appendix 1** Concepts 2 and 3) and estimated by Interfluve to cost approximately $200,000 to construct. Interfluve Concepts 2 and 3 are reproduced in **Appendix 2** for ease of review.

The individual benefit of wetland detention structure offers critical peak flow benefit to immediately-downstream features. Discussion of a few examples helps provide familiarization with these concepts.

- Installing an outlet control constraint immediately below wetland T-12 would reduce the 1% storm event upstream of the North Road culverts to 69% of the uncontrolled flow, thereby lessening stress on the Camp Fire Girls dam and an immediately adjacent road and culvert.
- Installing three outlet controls in series at wetland T-16, situated downstream of Dyken Pond, reduces peak flow of approaching the previously washed-out culvert on Plank Road to just 17% of the uncontrolled flow for a 1% storm, and 54% of the 0.2% storm. This benefit Likely "right sizes" the existing culvert on Plank Road and the next downstream culvert on Dutch Church Road. The passive flood control management benefit of these proposed three outlet control devices appears to alleviate the need to recommend pre-storm drawdown activities at Dyken Pond.
- Installing an outlet control on the 19-acre Wetland G-35 was evaluated for potential benefit to the downstream culvert passing under Route 2 near Stuffle Road, and the associated Route 2 road damage that occurred during Tropical Storm Irene. The wetland size is small and without conducting a detailed site visit, the peak flood moderation benefit of an outlet control at G-35 appears limited, so further evaluation of the rebuilt condition of the Route 2 culvert and this potential wetland control project is needed to resolve this potential opportunity and benefit.
- The peak flow reduction benefit of wetland T-24 appears modest when assessed as a solitary wetland control feature, since only 61 wetland acres are modeled to detain flow from a 9.2 square mile contributing watershed. The analysis and benefit however is likely to improve if analyzed cumulatively with installation also of upstream outlet control devices on wetlands T-27 and T-16 so is retained as a recommended outlet control location project.
- An RPA board member owns the property containing what is referred to as the Kersch wetland on Table 3. The drainage area and the wetland itself are smaller than the other potential project wetlands. This offers the opportunity to implement a pilot project on a non-NYSDEC wetland with fewer permitting steps and modest construction dimensions. Communication with NYSDEC may still be warranted to establish observation and monitoring programs informing subsequent NYSDEC review of permit applications for other sites with NYSDEC wetlands.

Outlet control devices would appear to be ideal green design options where wetlands and surrounding land can accept temporary detention of several feet of water storage. The control

device footprints themselves are small, consisting of little more than low-elevation wingwalls to the sides of the stream bed, and the costs of construction are less than the costs of features needing protection (e.g. road culverts, downstream structure foundations, roads). Wetlands are already areas subject to periodic inundation. Finally, the peak flow control benefits benefit both local assets and cumulatively protect entire down-watershed locations.

Table 4 presents the modelled benefits in the City of Troy resulting from implementation of all 14 outlet control considered by this study. Modelling methodology is discussed further in **Section 6**. The results suggest that a 1% peak storm flow would be reduced to 85.3% of the current volume passing through the City of Troy, lowering the water levels flowing past the flood walls along Canal Avenue by 0.47 feet, and that the 0.5% and 0.2% storms would see declines with 0.34 feet, and 0.25 feet, respectively.

Table 4: Wetland Control Device Benefits, City of Troy (RS 1171.695)

Flood Event	Existing Peak flow passing through City of Troy (cfs)	Modeled Streamflow in City of Troy with outlet controls at 14 wetland sites (cfs)	Flow benefit, as percentage of uncontrolled peak	Flow Benefit, as lowered peak (feet)
100-year	6371.3	5439.7	85.3%	0.47
200-year	8416.1	7560.6	89.8%	0.34
500-year	10616.1	9873.4	94.2%	0.25

The cumulative benefit of the passive wetland outlet control devices under consideration appears significant to RPA and to Chazen, at very favorable incremental cost points, making wetland outlet controls a preferred, naturally-based floodwater management strategy with benefits both in proximity to every controlled wetland and valuable net downstream flood control benefits.

Table 5 below**,** presents the modelled benefit resulting from implementing both the 14 wetland outlet controls and actively managing Dunham Reservoir prior and during predicted significant storms (i.e. 3-day drawdown).

Table 5: Wetland Control Device and Dunham Reservoir Management Benefits, City of Troy (RS 1171.695)

Flood Event	Existing Peak flow passing through City of Troy (cfs)	Modeled Streamflow in City of Troy with pre-storm drawdown at Dunham Reservoir and 14 wetland control sites(cfs)	Flow benefit, as percentage of uncontrolled peak	Flow Benefit, as lowered peak (feet)
100-year	6371.3	5132.8	80.6%	0.65
200-year	8416.1	7127.3	84.7%	0.54
500-year	10616.1	9324.1	87.8%	0.44

5.2.3 Dam Removal

Several dams were considered for removal during this flood management assessment study. Those examined more carefully were on the Quacken Kill along Route 2 dam (State ID 225-1432) and the Camp Fire Girls dam (ID 244-1361) near North Road and Fifty Six Road. Chazen also briefly reviewed conditions at the Mt. Ida dam (ID 226-1391) but recognized that significant study by others is currently focusing on this location so we defer to those studies.

The Route 2 dam is recognized as the Quacken Kill Dam in the NYS dam registry. It is a "run of river" dam built into a stretch of creek with significant gradient and a confined stream valley. Its likely benefit in the past was its 25 foot vertical drop rather than its storage volume. The impoundment is now largely filled with sediments, reportedly accumulated during Tropical Storm Irene. Local officials indicate no flooding of the road of any structures occurred during Tropical Storm Irene at this location. While removing this dam would improve fish passage, it does not appear to offer much flood management benefit. Removal of the dam would of course also remove hazard of an uncontrolled, catastrophic dam failure. The reported impoundment size is only approximately 1 acre, so even if the sediment were removed and a low-level outlet were actively managed to increase available detention capacity prior to predicted storms, it could provide only nominal peak flow attenuation value. No further analysis of this option was advanced in this study.

The Camp Fire Girls dam near North Road offers slightly more potential detention capacity than the Route 2 dam if it were to be converted to a managed dam actively un-watered prior to predicted storms. Otherwise, however, like the Quacken Kill Reservoir dam, this three-acre impoundment functions as a shallow "run of river" dam providing little current flood control benefit during extreme weather. Its removal would again improve fish passage, and as noted above removal of any dam removes the hazard of an uncontrolled, catastrophic dam failure. No further analysis of this option was advanced in this study.

5.3 Stream Resilience During Flooding

Bed and bank stability can significantly influence stream vulnerability to sediment movement and geomorphological undermining and damage during significant flood events. Extensive channel migration and debris flow occurred during Tropical Storm Irene. Post-storm clearing and straightening in places resulted in side-cast debris and sediment berms and little remaining woody debris, riffle and pool structure, or anchoring features in the streams. Eight years after Tropical Storm Irene, some stream reaches continue to function without anchoring features, rock or log vanes, vegetated banks, or naturalized top-of-bank transitions. Trout fishing has reportedly suffered.

5.3.1 Creek Restoration

Chazen and Interfluve visited select locations of concern to review storm-damaged reaches noted to be particularly vulnerable to ongoing sediment mobilization during even modest storms. Extensive sections of the upper Poesten Kill, between Empire Drive and Plank Road do not exhibit an intact and stable streambed. Interfluve provides a discussion of these factors (**Appendix 1**, page 27, 30-32). Sections of the Quacken Kill along Route 2 also exhibit storm-related residual damage.

Interfluve has recommended a conceptual restoration model for damaged stream segments (**Appendix 1**, Concept 4 drawing) and a restoration budget recommendation of approximately $150,000 per 500 linear feet of stream restoration.

Stream restoration not only incrementally slows peak flows and significantly anchors sediment and banks, but also restores ecological vitality which is an identified community concern. Trout habitat historically recognized in the upper Poesten Kill remains significantly damaged.

5.3.2 High Bank Stabilization

An outer bend in the lower Poesten Kill has caused slope instability approaching McChesney Avenue Extension and an existing structure. Rates of encroachment are unknown and the of grade on the interior of the bend is modest and unconstrained and thus may provide some relief for floodwater movement and energy during extreme weather events. Geomorphology in this location is considered by Interfluve (**Appendix 1**).

A recommendation for this location involves first damage monitoring, followed by mitigation if warranted.

1. Establish a monitoring program to determine the rate of bank migration. This could involve comparative reviews of aerial photography every few years, collected by drone or otherwise, or may include survey pins and annual monitoring to assess the rate of bank failure migration relative to assets including the road, any utilities, and structure(s). An approximate annual budget of $5,000 is recommended. Reducing peak flows past this location will slow rates of erosion.

2. Implement a mitigation program if required. Likely project components could include some degree of anchoring of the toe of the outer bend and high bank revegetation, accompanied by redirection of stream energy using rock or log vanes and some benching of the inner bend to create more space for flood volume dispersal under high-energy conditions. No formal budget is recommended here but allocating between $750,000 and $1.5 million may be appropriate for a project requiring reformatting of the stream flow channel to redirect flow energy.

5.4 Conveyance Through Culverts and Bridges

5.4.1 Culverts

Undersized culverts can lead to roadway failure or to nuisance or significant flooding. In such locations culvert upsizing is the frequent recommendation. However where temporary detention occurs behind culverts without imposing threats to structures, some mitigation is offered to downstream peak flood levels. Any culvert installed in a manner which limits aquatic passability should be reinstalled "at grade" (**Figure 6**), however given the sensitivity of the City of Troy to flood management strategies which might increase downstream peak flows, and the history of bridge failures along the Quacken Kill in Brunswick, upsizing of culverts should be considered separately and carefully.

Several locations with culverts of concern, or locations appearing to need culverts, were considered in the Poesten Kill watershed.

- A culvert under Route 2 near Stuffle Road in Grafton failed during Tropical Storm Irene when a Quacken Kill tributary washed out the road. Its NAACC Aquatic Passability Score is 0.41 for Survey ID site 47737. It is unknown whether the culvert became blocked or the stormwater volume exceeded the culvert capacity. The culvert is not perched and was itself not washed out, so after the storm the road was reportedly reconstructed without upsizing the culvert. It does appear that new wing walls were added to the upstream side to better protect the road during future overtopping. Chazen examined the opportunity to "right size" this culvert by recommending a wetland outlet control structure on wetland G-35 upstream from this culvert. Our preliminary analysis suggests more detailed analysis of this wetland control project is warranted and as well as confirmation of any improved engineering design at the culvert.

  Wetland G-35 could be visited to examine and settle Chazen's outlet control model assumptions on the ground, the reliability of the new culvert wingwalls could be examined to the 200- and 500-year flood conveyance scenarios, and if warranted the culvert should be considered for an opening upgrade. Estimated fees for the evaluations of wetland G-35 and the engineering assumptions used to reconstruction the bridge may require a budget of $25,000. Installing the wetland control device, if found to add value, should be budgeted for $40,000. If no other avenue is viable, re-building the road with a more significant culvert is estimated to cost in the range of $500,000. Further discussion of this location is advanced by Interfluve, (**Appendix 1**, pages 11-14)

- A section of South Road in Brunswick extends across a hillside, intercepting hillside flow which reportedly both overtops the road, mines the ditch on the uphill side, and diverts water past a natural swale at the bottom of the hill which formerly received this flow. Interfluve examined this location **(Appendix 1**, pages 17-19 and Interfluve's Appendix B Recommendations) and recommended a series of frequently-spaced culverts crossing the road to convey water to the natural swale. A small berm is also recommended to prevent

overflow from the swale area. Interfluve's estimated the cost for these collective improvements is approximately $150,000.

- Culverts on North Road immediately below the Campfire Girl's Dam, and further north on Fifty Six Road, each in Poestenkill, were overtopped and washed out during Tropical Storm Irene. In both locations, it is not known if the culverts became blocked with debris or if flow volumes simply exceeded the culvert capacity. On North Road the greater likelihood is that the flow volume exceeded the culvert capacity since the dam impoundment likely captures any debris. The NAACC Aquatic Passability Score for this culvert is 0.09. Further north on Fifty Six Road, paired culvert at the northernmost creek/road crossing have NAACC scores of 0.11 and 0.65 (Survey IDs 47653 and 13048, respectively). The estimated cost to upsize all these culverts, including engineering design, downstream impact modelling, and construction likely each exceeds $250,000 per crossing. These culverts are also reviewed by Interfluve **(Appendix 1**, pages 24-26). Interfluve noted and Chazen agrees that efforts to upsize culverts at the North Road culvert may be complicated by the presence of the adjacent dam spillway and thus adding potential project design and construction costs.

  Wetlands T-11 and T-12 lie upstream of these culvert crossings suggests that outlet control devices could reduce flow from each wetland by approximately 30% during the 100-year flood, with a yet greater combined benefit if both wetlands implement outlet controls. The effect of these controls would help "right size" both culverts so neither may require redesign and re-construction.

5.4.2 Bridges

Two bridges over the Quacken Kill were reportedly washed out during Tropical Storm Irene, both in Brunswick, one on White Church Road and the other on Dearstyne Road. Each was reportedly reconstructed after Irene with approximately the same dimensions. Constructing more substantial bridges with wider spans in either location would likely cost in the range of $1,000,000.

Examination of the benefits of upstream peak volume detention also offers an opportunity to reduce future stress on these bridges by limiting future peak flows using strategies reviewed in Section 5.1.1, effectively rendering these bridges right-sized to pass mitigated future peak flow flows. As noted in Section 5.1.1, active management of Dunham Reservoir prior to future predicted storms can reduce the peak flow of Quacken Kill by better than 80% at the top of the escarpment, evening out flow expected in Brunswick. Closer examination of the benefits of active Dunham Reservoir management is recommended to determine whether the bridges must be scheduled for eventual upsizing or can be maintained as is.

5.5 Protection or Relocation of At-Risk Structures

Residences, properties, and both public and commercial structures along the upper Poesten Kill were threatened by Tropical Storm Irene:

Soccer fields in Cropseyville were flooded and left covered with debris. Portions of the Wagner Farms at the confluence of the Quacken Kill with the Poesten Kill were similarly both flooded, scoured in places, and also left covered with debris. Examination of **Figure 2A** clarifies where routine flooding and extreme weather may be expected along the lower Quacken Kill between Cropseyville and the Wagner Farms, primarily in the Town of Brunswick. The greatest opportunity to manage and protect assets during future flooding in these areas may be to implement active pre-storm drawdown management of Dunham Reservoir and to install outlet controls on wetlands G-31, G-32, G-35. The cost of implementing these projects in Grafton would appear less than reconstructing either Brunswick bridge or responding to other flood-related damage at either soccer complex or agricultural lands extending to Wagner Farms. The berm established along the soccer fields still allows inundation of the soccer fields since back-flooding remains feasible but will direct sediment elsewhere. Anecdotally the berm also now directs a share of recent floodwaters onto areas previously not subject to flood. These may all need additional or revised management if peak flow management approaches at the Dunham Reservoir and Grafton wetlands are not implemented.

Along the upper Poesten Kill, in Poestenkill, multiple homes were flooded on Empire Drive west of the Poestenkill hamlet center, and homes along Franklin Street were threatened by flooding. Homes and yards were threatened along the upper Poesten Kill as far upstream as Plank Road near Dutch Church Road. Construction of protective berms around the lower elevation homes on Empire Drive are estimated to cost at least $30,000 per structure and buyouts would cost far more. The dollar value to correct the creek damage is harder to estimate but Interfluve has recommended $150,000 per 500 feet, equivalent to approximately $1.5 million per mile. With such costs, it is possible that only select reaches of this stream will be selected for reconstruction, leaving the balance to eventually return toward a natural stream morphology if not disrupted by subsequent significant flooding.

Protecting the whole upper stream from future flooding, and protecting existing residences along Empire Drive and Franklin Street may be best achieved by installing wetland outlet controls on wetlands AP-14, AP-6 and T-8 (Bonesteel creek), wetlands along Fifty-Six Road (T-11 and T-12), and the network of wetlands near and north of the intersection of Plank and Dutch Church Roads (T-24, T-27, T-16, T-20). If these are implemented and peak flows are confirmed to be mitigated, natural restoration of the upper Poesten Kill creek may continue to evolve over time, assisted perhaps by targeted watercourse restoration investments including rock and log vanes that accelerate re-established ecological and sediment stabilization in priority reaches.

5.6 Future Flood Planning and Response Protocols

The current condition of the upper Poesten Kill is reportedly due in part to response activities taken immediately after Tropical Storm Irene, including use of heavy machinery to straighten the creek and remove all accumulated debris. Some stream restoration activities are necessary following storms, but guidance has improved to both manage creeks during normal weather conditions and to respond after such events. Several resources are provided in **Appendix 6**, including a pre-storm stream management white paper prepared by practitioners and scientists in Dutchess County, NY, and various documents developed by the New York State Department of Environmental Conservation and the Delaware County Soil & Water Conservation District office. These should be reviewed, and considered when evaluating any stream management or storm response activities.

5.7 Land Use Planning and Protection Strategies

In addition to the specific projects and flood response strategies recommended above, watershed municipalities are encouraged to support various land use planning strategies which help detain, soak in, and spread out floodwaters. Many programs collectively contribute to this objective.

Stream resilience and flood peak attenuation across the Poesten Kill watershed already benefit from the substantial acreage of wooded open space, primarily on the Rensselaer Plateau. Generally-silty soils (hydrogeologic soil group C) across much of the watershed do not favor high infiltration rates but preservation of woody vegetation and mature ground cover slows stormwater flow toward watercourses, and avoiding development on flood plains preserves natural locations for floodwater spreading and temporary detention during severe weather.

Substantial open space protection is already advanced by the Rensselaer Plateau Alliance and other organizations. Expanding conservation land holdings or easements protective of existing floodplains, wetlands, and otherwise open and green spaces which provide flood storage from development will preserve existing stormwater resilience capacity in the watershed. Where necessary, landscape restoration practices could be conducted including riparian buffer plantings and re-grading/revegetation of erosional areas. Priority lands for conservation might include those within 500-year floodplains and parcels enclosing large NYSDEC wetlands suitable for wetland outlet controls.

Municipalities should be encouraged to consider opportunities to further preserve existing landscape resilience, considering some or all of the following land use programming options:

- Designate Critical Environmental Areas (CEAs), focusing on land prone to flooding and thus threatening human health or hydraulic catchment areas also offering significant ecological value, ensuring detailed assessments when land development is proposed.
- Adopt No Adverse Impact (NAI) floodplain management policies to complement SEQRA requirements, ensuring that actions of one property owner do not adversely increase flood peaks or increased erosion and sedimentation on other properties.

Adopt Transfer of Development Right (TDR) or conservation development ordinances, promoting infilling within existing or desired community centers, and clustering new developments, to limit watershed landscape fragmentation.

- Ensure that MS4 permit conditions are adhered to within applicable parts of the watershed.
- Participate in the National Flood Insurance Program (NFIP) Community Rating System (CRS), encouraging communities to exceed minimum requirements managing development in floodplains. Benefits may include discounted flood insurance premiums, although administrative costs can reportedly be burdensome. Intermunicipal cost-sharing options could be explored. Adopting the NFIP law locally ensures review of cumulative damages and prohibits construction of critical facilities within priority flood plain areas.
- Adopt local laws minimizing disturbances of steep slopes. These become more vulnerable to sediment mobilization once disturbed, leading to stream and downstream sedimentation.
- Ensure that stormwater detention practices are optimized on new or redeveloped project sites. Planning board project reviews and zoning updates should recognize the benefits of low impact design, on-site stormwater detention, and on-site infiltration practices where practical.
- Review and amend municipal zoning and flood damage prevention ordinances to strengthen flood management, perhaps including incorporation of strategies summarized in **Appendix 6**.

These and additional practices summarized in watershed management assessments recently completed for the Saw Kill watershed in northern Dutchess County and the lower Moodna Creek in western Orange County, provide valuable tools for preservation of existing landscapes currently providing natural flood protection in the Poesten Kill watershed. Costs to implement these programs vary.

6.0 HYDROLOGIC AND HYDRAULIC ANALYSES

6.1 Hydrological Analysis

For comparison purposes, the estimation of the streamflow values for return periods (*Tr*) 100-, 200-, and 500-yr for the area of study (AOS) of the Poesten Kill watershed was performed via (a) rainfall-runoff model HEC-HMS (Version 4.3, U.S. Corps Army of Engineers, Washington D.C.) and (b) USGS *StreamStats* application (https://streamstats.usgs.gov/ss/). These procedures are described in the next subsections.

6.1.1 Design Rainfall Estimation

Before running the rainfall-runoff model, it was necessary to estimate the design rainfall for the return periods to be evaluated, namely 100-, 200-, 500-yr. For that, the AOS maximum daily (24-h) rainfall was retrieved from the Extreme Precipitation in New York and New England Web Tool (http://precip.eas.cornell.edu/). The rainfall depths at 1-h time intervals (rainfall distribution) were derived from the 100-, 200-, and 500-yr Intensity-Duration-Frequency (IDF) curves of the location near Dyken Pond (approximate geographical coordinates 42.714° N and 73.427° W) to account for the orographic effect on rainfall. This reference location was selected as being representative of the AOC, sensitive to the watershed relief.

The total maximum 24-h rainfall depths for 100-, 200-, and 500-yr were 6.48 in, 7.68 in, and 9.60 in, respectively. The corresponding hyetographs of the 24-h rainfall depths were developed using the alternating block method (Chow et al., 1988). **Tables 6, 7**, and **8** show the 1-h increment rainfall depths. Images 1, 2, and 3 depict the design rainfall hyetographs.

Table 6. 24-h Rainfall Distribution (*Tr* = 100-yr)

Time (h)	Intensity (in/h)	P (in)	P Increment (in)	Hyetograph Ordinates
1	2.45	2.45	2.45	0.04
2	1.50	3.00	0.55	0.08
3	1.16	3.48	0.48	0.08
4	0.94	3.76	0.28	0.11
5	0.81	4.05	0.29	0.12
6	0.72	4.32	0.27	0.13
7	0.64	4.48	0.16	0.15
8	0.57	4.56	0.08	0.16
9	0.52	4.68	0.12	0.27
10	0.48	4.80	0.12	0.29
11	0.45	4.95	0.15	0.48
12	0.42	5.04	0.09	2.45
13	0.40	5.20	0.16	0.55
14	0.38	5.32	0.12	0.30

Time (h)	Intensity (in/h)	P (in)	P Increment (in)	Hyetograph Ordinates
15	0.36	5.40	0.08	0.28
16	0.35	5.60	0.20	0.20
17	0.33	5.61	0.01	0.16
18	0.32	5.76	0.15	0.15
19	0.31	5.89	0.13	0.12
20	0.30	6.00	0.11	0.12
21	0.3	6.30	0.30	0.09
22	0.29	6.38	0.08	0.08
23	0.28	6.44	0.06	0.06
24	0.27	**6.48**	0.04	0.01

Table 7. 24-h Rainfall Distribution (*Tr* = 200-yr)

Time (h)	Intensity (in/h)	P (in)	P Increment (in)	Hyetograph Ordinates
1	2.91	2.91	2.91	0.1
2	1.77	3.54	0.63	0.11
3	1.37	4.11	0.57	0.11
4	1.11	4.44	0.33	0.13
5	0.95	4.75	0.31	0.14
6	0.85	5.10	0.35	0.15
7	0.75	5.25	0.15	0.17
8	0.67	5.36	0.11	0.19
9	0.61	5.49	0.13	0.23
10	0.56	5.60	0.11	0.33
11	0.52	5.72	0.12	0.57
12	0.49	5.88	0.16	2.91
13	0.46	5.98	0.10	0.63
14	0.44	6.16	0.18	0.35
15	0.42	6.30	0.14	0.31
16	0.40	6.40	0.10	0.21
17	0.39	6.63	0.23	0.18
18	0.38	6.84	0.21	0.16
19	0.37	7.03	0.19	0.15
20	0.36	7.20	0.17	0.13
21	0.35	7.35	0.15	0.12
22	0.34	7.48	0.13	0.11
23	0.33	7.59	0.11	0.10
24	0.32	**7.68**	0.09	0.09

Table 8. 24-h Rainfall Distribution (*Tr* = 500-yr)

Time (h)	Intensity (in/h)	P (in)	P Increment (in)	Hyetograph Ordinates
1	3.67	3.67	2.91	0.12
2	2.20	4.40	0.73	0.13
3	1.71	5.13	0.73	0.14
4	1.38	5.52	0.39	0.15
5	1.18	5.90	0.38	0.19
6	1.05	6.30	0.40	0.20
7	0.92	6.44	0.14	0.23
8	0.82	6.56	0.12	0.25
9	0.74	6.66	0.10	0.32
10	0.68	6.80	0.14	0.39
11	0.63	6.93	0.13	0.73
12	0.59	7.08	0.15	2.91
13	0.56	7.28	0.20	0.73
14	0.53	7.42	0.14	0.40
15	0.51	7.65	0.23	0.38
16	0.49	7.84	0.19	0.27
17	0.48	8.16	0.32	0.23
18	0.46	8.28	0.12	0.21
19	0.45	8.55	0.27	0.19
20	0.44	8.80	0.25	0.17
21	0.43	9.03	0.23	0.14
22	0.42	9.24	0.21	0.14
23	0.41	9.43	0.19	0.13
24	0.40	**9.60**	0.17	0.10

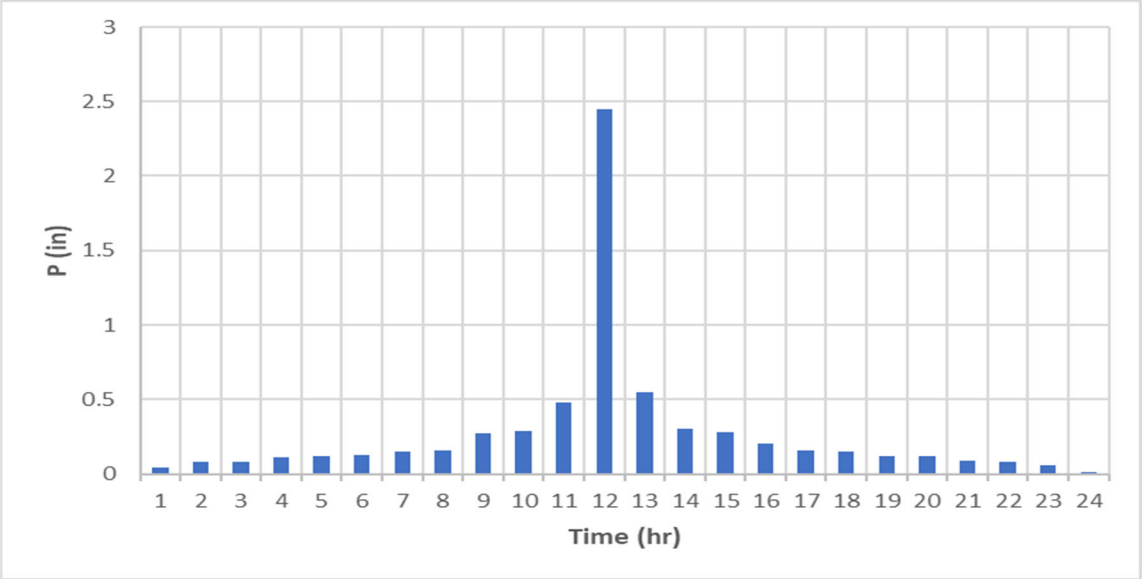

Image 1. 100-yr Design Hyetograph

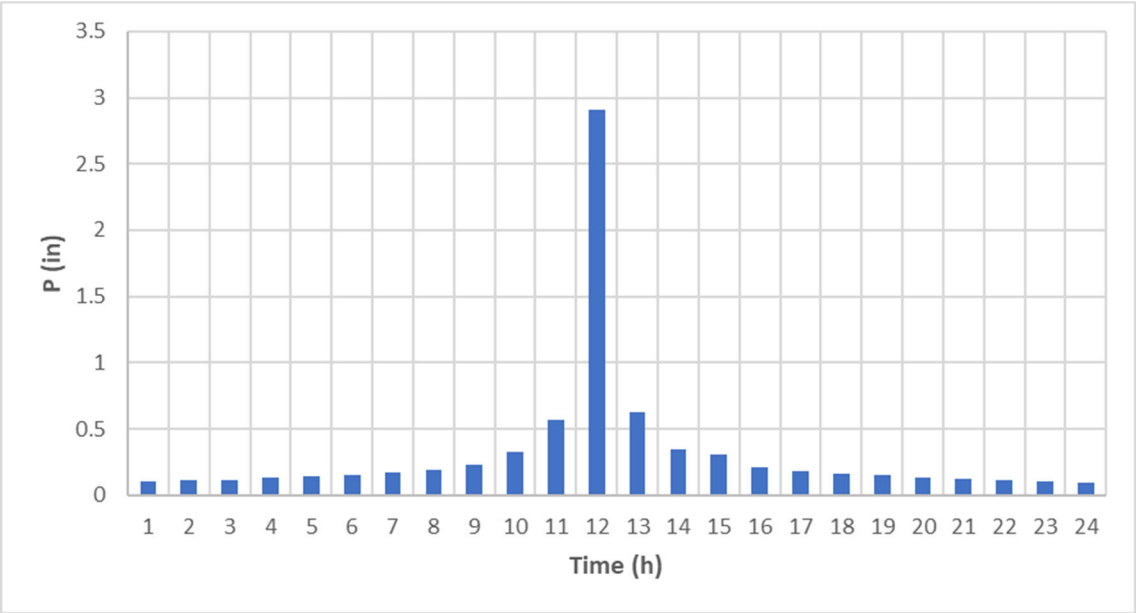

Image 2. 200-yr Design Hyetograph

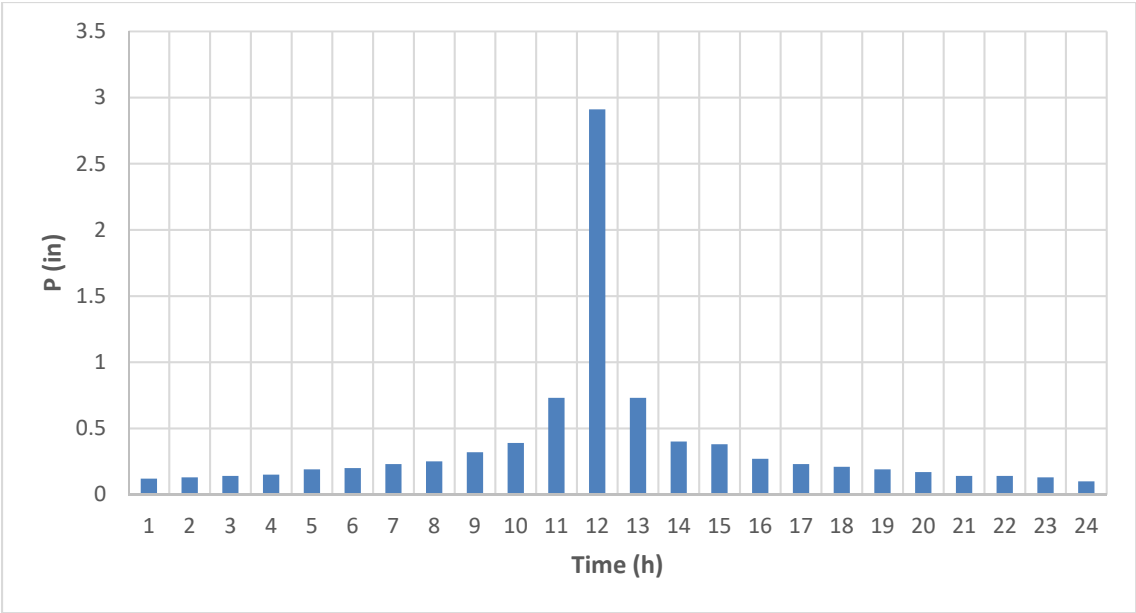

Image 3. 500-yr Design Hyetograph

A frequency analysis of the multiannual maximum daily rainfall time series was then performed. The objective was to determine the return period associated with Tropical Storm Irene, occurring in August of 2011 (blue cell in **Table 7**). Then, the Irene rainfall value could be used to estimate ––via rainfall-runoff modeling (HEC-HMS)–– the streamflow generated for calibration purposes. The rainfall value used as input for the HEC-HMS model for Tropical Storm Irene was obtained from rain gage Cropseyville (Site ID 77-0002; Elevation: 1,480 ft; geographical coordinates 42.7328° N; 73.5057° W), which was most appropriately sited to the AOS. The data used were the maximum 24-h multiannual time series, retrieved from NOAA Atlas 14 website (https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=ne) (**Table 9**).

According to the performed frequency analysis, the daily rainfall depth observed during Irene (7.36 inches, dated August 28, 2011 in **Table 7**) has a return period of nearly 200 years. Thus, the streamflow value obtained from existing conditions HEC-HMS model for Tropical Storm Irene can be compared to the 200-yr streamflow value from *USGS StreamStats* (regression equations) at the location referenced in the previous paragraph (also see Section 6.1.3). These two streamflow values will be similar after the calibration.

Table 9. Multiannual Maximum Daily Rainfall Time Series at Cropseyville Rain Gage

Year	**9/1/1950**	**7/18/1951**	**6/1/1952**	**4/27/1953**	**8/31/1954**	**8/11/1955**	**9/24/1956**	**6/26/1957**
P-24h (in)	3.55	1.91	2.27	2.30	3.03	2.55	1.93	2.47
Year	**7/26/1958**	**11/7/1959**	**7/30/1960**	**4/1/1962**	**9/29/1963**	**3/10/1964**	**9/1/1965**	**9/22/1966**
P-24h (in)	1.74	2.02	2.30	1.84	1.18	1.57	1.46	2.04
Year	**7/21/1967**	**4/25/1968**	**7/29/1969**	**6/18/1970**	**8/28/1971**	**10/7/1972**	**12/21/1973**	**11/21/1974**
P-24h (in)	2.16	2.31	2.25	1.85	3.64	3.07	2.34	2.01
Year	**6/29/1975**	**8/10/1976**	**10/17/1977**	**1/9/1978**	**9/3/1979**	**8/6/1980**	**2/2/1981**	**7/18/1982**
P-24h (in)	3.52	3.94	2.46	1.66	2.23	2.43	2.60	2.53

Year	11/25/1983	7/7/1984	8/8/1985	7/27/1986	10/4/1987	8/29/1988	7/5/1989	8/7/1990
P-24h (in)	2.65	2.60	2.18	2.50	4.75	2.02	1.71	2.71
Year	10/6/1991	9/23/1992	4/23/1993	3/4/1994	7/26/1995	7/13/1996	4/18/1997	3/16/1998
P-24h (in)	2.14	2.01	2.05	1.70	3.75	2.98	2.00	1.98
Year	9/16/1999	6/6/2000	3/5/2001	6/5/2002	11/19/2003	9/17/2004	10/8/2005	1/18/2006
P-24h (in)	5.80	3.50	1.70	2.62	1.86	2.25	3.68	1.74
Year	4/15/2007	10/25/2008	10/31/2009	9/30/2010	8/28/2011	9/18/2012	7/22/2013	
P-24h (in)	2.29	2.87	3.34	3.90	**7.34**	2.32	3.88	

6.1.2 Design Streamflow Estimation via HEC-HMS Modeling & Wetland Outlet Control Designs

Two hydrologic models were developed using HEC-HMS. The existing conditions model was created for the entire Poesten Kill watershed. Stream flows resulting from this model were compared with stream flow values estimated via *USGS StreamStats* for the 100-, 200-, and 500-year return periods to calibrate the model.

Once the stream flows resulting from the existing conditions model were close to those estimated via *USGS StreamStats*, a post-condition model was created for the watershed. The post-condition model incorporated a storage area at each proposed wetland outlet control location to estimate the peak flow attenuation benefits at each location. The resulting peak flows were then entered into the HEC-RAS model to evaluate the total potential benefit in Troy.

Table 3 summarizes the streamflow values for the pre- and post-condition scenarios at each proposed wetland outlet control location. This table also provides the preliminary outlet control design specifications for each wetland outlet. The peak flow reduction benefits vary based on the size of the wetland, available inundation depth variability, and the size of the upstream watershed. The Table summarizes only the individual project benefit but cumulative benefits accrue where stream flow through wetland sequences, and would need to be analyzed cumulatively. See **Figure 11** for the locations of each proposed wetland detention project within the Poesten Kill watershed, with their associated sub-watersheds.

6.1.3 Streamflow Estimates via USGS StreamStats

USGS StreamStats is a web-based application that permits the calculation of, among other variables, the streamflow values for different return periods at a given location by means of regression equations developed by Lumia et al. (2006). **Table 10** summarizes the 100-, 200-, and 500-yr streamflow values at geographical coordinates 42.72066° N; -73.69818° W (**Image 4**).

Table 10. StreamStats Streamflow Values

Streamflow, Q (cfs)		
100-yr	**200-yr**	**500-yr**
7280	8660	10700

Source: USGS StreamStats

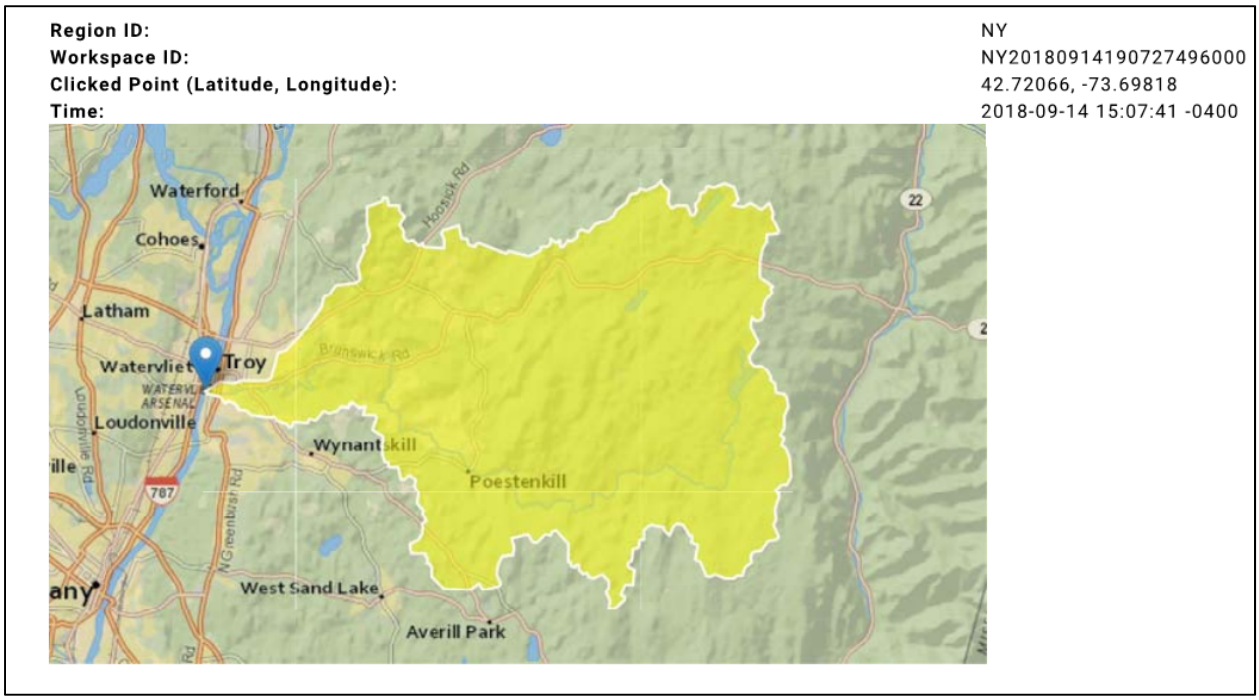

Image 4. Watershed at Calibration Location

The calibrated existing conditions HEC HMS model resulted in a streamflow of 8515.8 cfs for the 200-yr storm event, which is close to the streamflow value given by StreamStats (8660 cfs).

6.2 Hydraulic Analysis

Two steady-flow one-dimensional (1D) hydraulic models were created for the Poesten Kill including all major tributaries; one for the existing conditions and another one for the proposed condition (proposed storage areas). The models were created using HEC-RAS (Version 5.0.3, U.S. Corps Army of Engineers, Washington D.C.). Also, HEC-geoRAS extension was used to process geospatial data in ArcGIS before importing into the HEC-RAS model. Stream geometry data was incorporated into the model based on the Digital Elevation Model (DEM) and contour map derived from LiDAR (Light Detection and Ranging) data downloaded from New York State Orthos Online.

6.2.1. HEC-RAS Model for Existing Conditions

This model was used to further calibrate the HEC-HMS results for the existing conditions. For that, the 200-yr streamflow value obtained from HEC-HMS (existing conditions for Tropical Storm Irene) at each of the model components (main streams and tributaries) were input into HEC-RAS to confirm that the water level observed/reported by local officials during Irene Storm as *just below the channel maximum elevation without overflowing* at a 674-ft reach located between geographical coordinates 42°43’12.57” N; 73°41”38.01” W (channel reach located between First

Street and Fourth Street and Canal Ave Ida Street in the city of Troy, NY). The water level obtained at the referenced location was indeed below the maximum elevation (**Image 5**). To achieve this calibration, and analyze the volume of water contained in the creek when filled just below the stone wall margins, Chazen measured the dimensions of the channel at the bridges in the City of Troy.

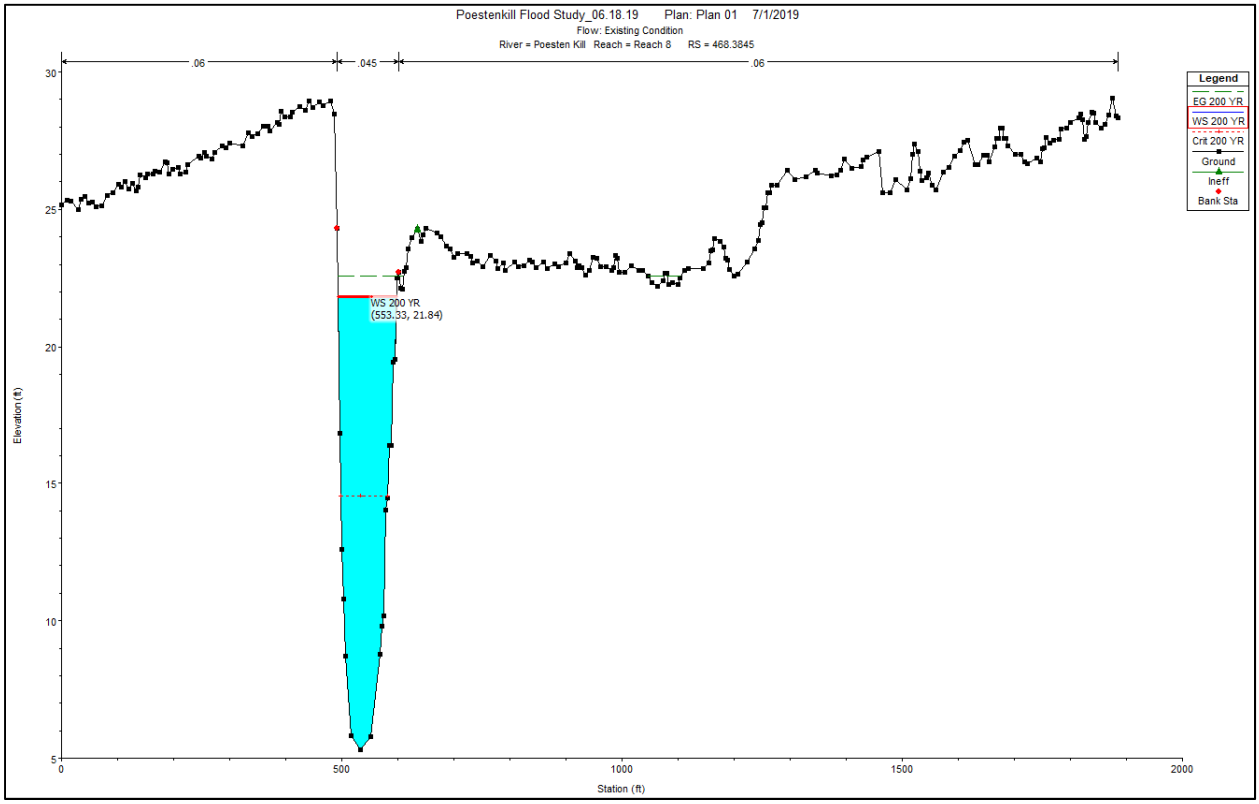

Image 5. HEC-RAS Calibration Water Level Results (Cross Section 486.3845)

6.2.2. HEC-RAS Model for Proposed Conditions

After this calibration, the second model could be advanced to analyze the impact the streamflow attenuation caused by the proposed wetland detention and Dunham reservoir detention project has on the water surface level at different locations at return periods 100-, 200-, and 500-years. The streamflow values input into HEC-RAS were those obtained from HEC-HMS Proposed Condition Model. **Table 5** found in Section 5.1.2 above, summarizes the water level difference at Cross Section 468.3845 (approximate geographical coordinates 42°43’12.01” N; 73°41’33.34” W). The complete set of results can be found in **Appendix 7**.

6.3 Cost Benefit Analysis

Cost benefit analysis (BCA) contrasts investment value of stormwater management projects against desired benefits.

Numerous projects with estimated implementation budgets were developed in Section 5.0. BY way of review, these include costs in various ranges:

- $15,000 to $20,000 range: to advance a pilot wetland control project on a small wetland, establish a pre-storm drawdown program at Dunham Reservoir, and establish monitoring for an eroding slope on McChesney Avenue Extension.
- $40,000 on average: for multiple wetland outlet control structures on numerous NYSDEC wetlands, and a $50,000 options analysis at the Route 2/Stuffle Road culvert.
- $100,000 to remove a berm constructed along soccer fields in Brunswick which direct sediment off the fields, and which may be directing flooding and sedimentation onto other nearby properties.
- $150,000 to install a series of new culverts on a section of South Road in Brunswick, to limit sedimentation and erosion and restore overland flow to a wetland area.
- Replace culverts on North Road and Fifty-Six Road in Poestenkill, estimated each at $250,000 to $300,000.
- Replace two culvert bridges near the Route 2/Stuffle Street intersection, estimated collectively at $500,000.
- Increase bridge spans at Dearstyne and White Church Roads in Brunswick, expected to cost between $750,00 and $1,000,000.
- Restore stream reaches damaged in 2011 during and following Tropical Storm Irene. Estimated cost is $150,000 for 500 feet. Up to 10 miles of stream appear damaged. Perhaps 3,000 linear feet could be prioritized for restoration in the coming years.
- $1,500,000 to mitigate stream bank erosion near McChesney Avenue Extension using benching and stream energy redirection.

These project costs, with estimated budget benefits if implemented, are summarized on **Table 11**. The dollar-cost benefits of implementing these projects are approximate but are estimated below and also shown on **Table 11**. Some may eliminate the need for more significant flood management responses. For example:

- Managing Dunham Reservoir with pre-storm controlled drawdowns may relieve risk of future washout for two bridges in Brunswick (each otherwise needing replacement @ $1,000,000) and the eventual relocation of sports complexes near Cropseyville if they are repeatedly flooded and must relocated (estimated at $1,000,00 to relocate).
- Establishing controls on wetlands G-31 and G-32 reinforcing the benefits described above since these wetlands flow into Dunham Reservoir, and also protects culverts and immediately-downstream properties adjacent to each wetland, adding $250,000 in benefits to each wetland project, yielding collective potential cost saving benefits of $3,250,000 for these outlet controls.
- Establishing an outlet control on wetland G-35, or conducting a more detailed confirmatory wetland and culvert study in this location may relieve or confirm the available relief needed to alleviate spending $500,000 to replace the culverts at the Stuffle/Route 2 intersection in Grafton.
- Establishing an outlet control at wetland AP-29 protects culverts and airport property, for which an avoided damage cost budget of $500,000 is estimated.

- Installing wetland outlet controls on AP-6 and T-8 reduces future property damage and culvert damage along Blue Factory Hill Road, for which an avoided damage cost budget of $150,000 is estimated based on a conservative estimate of damage occurring during Tropical Storm Irene.
- Installing a wetland outlet control on AP-14 reduces peak flow damage for properties in the hamlet of Poestenkill, including the need for additional creek restoration. A combined avoided damage cost budget of $2,500,000 is assigned for property protection and stream bed restoration including foundation protection for six homes on Empire Drive.
- Outlet controls on wetlands T-11 and T-12 are expected to reduce peak flows through culverts on Fifty Six and North Roads, saving the need to spend $500,000 to upgrade both culverts.
- Installing outlet controls on wetlands T-16, T-20, T-24, and T-27 protect individual nearest culverts, individual nearby properties, and extensive reaches of the Poesten Kill, collectively assigned approximate avoided damage cost benefits of $1,000,000 for damage. The actual avoided damage costs are likely higher, when considering flooding hazard experienced by numerous homes along Plank Road and the extensive damage to the upper Poesten Kill Creek still remaining after Tropical Storm Irene.
- Monitoring streambank erosion near McChesney Street Extension may demonstrate that mitigation estimated to cost $1,500,000 is unnecessary.
- Removing a berm along the Grafton soccer fields may lead to recurring cost associated with clear sediment off the fields following storms. A budget of $200,000 over 20 years is assigned for clearing sediment. This may be off-set by reduced flood damage cost anecdotally now imposed on other properties following berm construction.

The final column of **Table 11** provides an approximate Benefit-Cost Ratio (BCR), providing a numerical expression of the cost effectiveness of a project. Projects are considered cost effective where the BCR is 1.0 or greater. These are guidance factors only since the cost of present versus future money is not considered, and all costs are approximate only. Notwithstanding, for example,

- Where managing Dunham Reservoir for $20,000 may relieve the future need to spend $3,000,000 for two new bridges and relocated sports facilities, the BCR is 150. This project appears to be extremely cost effective.
- Installing individual wetland outlet structure, for approximately $40,000 apiece once the first few pilot projects are designed and settled, are expected to alleviate the need to upsize various culverts and bridges, or aggressively protect various properties, variably valued at $300,000 or above, with resulting BCR values are 12.5 to over 80. On the basis of the BCR scores, these projects also each appear very cost effective.
- Where project upgrades are simply paid for now, to prevent future failure and reconstruction costs following a storm, the approximate ratio between current and future costs might suggest BCR values of approximately 1. This overlooks the cost of present versus future money but also the un-dimensioned costs associated with catastrophic failures during storm events.

- Streambed restoration including rock and timber vanes also exhibits a similar BCR value of 1.0 since sediment stabilization costs replace future post-storm stabilization costs, although significant ecological benefits of stream restoration offer additional advantage.
- The BCR for removing the berm at the soccer field appears as a negative value since removing the soccer berm may result in field maintenance costs or even facility relocation which exceeds the cost of removing the berm.

Projects with the highest BCR values are wetland outlet controls structures and management of Dunham Reservoir and so are recommended for priority attention.

Table 11 - Benefit Cost Ratios - Poesten Kill Watershed Management Projects

			Proposed Project		Protective Benefit if Project is Constructed		BCR
			Project	Cost	Description	Benefit*	
Poesten Kill Creek	Quacken Kill	Upper Quacken Kill	Manage Dunham Reservoir with pre-storm drawdowns	$20,000	Downstream peak flood control protects Route 2, socccer fields, and two bridges in Brunswick. Cost benefit is the estimated saved cost to replace 2 bridges and relocate soccer fields.	$3,000,000	**150**
			Outlet Control, Wetland G-31	$40,000	Reduces flow into Dunham Reservoir, protects 2 local culverts, a few homes, + the benefits above	$3,250,000	**81.25**
			Outlet Control, Wetland G-32	$40,000	Reduces flow into Dunham Reservoir, protects 1 local culvert, a few homes, + the benefits above	$3,250,000	**81.25**
		Quacken Kill on Escarpment	Outlet Control, Wetland G-35	$40,000	May alleviate need to replace Route 2 culvert. Cost benefit is estimated saved cost for replacement	$500,000	**12.5**
			Detailed study of Route 2/Suffle Road culvert and G-35 for resilience	$50,000	May demonstrate that Route 2 culvert is stable, with or without needing G-35 outlet control	$500,000	**10**
			Replace Route 2 culvert at Stuffle, Grafton	$500,000	Installing a larger culvert would prevent a future unexpected faillure. This work may be unnecesary based on detailed study and/or G-35 outlet control.	$500,000	**1**
			Install series of culverts on South Road, Brunswick	$150,000	Limits flooding on South Road and restores overland flow to a wetland area	$150,000	**1**
		Lower Quacken Kill	Remove Soccer field berms, Brunswick	$100,000	Allows natural stream flow but exposes soccer field to debris damage. "Benefit" is cost of debris removal.	-$200,000	**-2**
			Increase span on Dearstyne Rd Bridge, Brunswick	$1,000,000	Benefit is bridge integrity during future storms	$1,000,000	**1**
			Increase span on White Church Road, Brunswick	$1,000,000	Benefit is bridge integrity during future storms	$1,000,000	**1**
	Upper Poesten Kill	Newfoundland Creek	Outlet Control, Wetland AP-29	$40,000	Protects road culverts and reduces flooding near Rensselaer County Airport and Route 355. Cost benefit is estimated damage fee if culverts and/or airport are damaged by a future storm.	$500,000	**12.5**
		Streambed Restoration for prioritized 3,000 linear feet, Poestenkill		$900,000	Stabilizes sediment and restore ecological value in priority reaches	$900,000	**1**
		Outlet Control, Kersch Property		$15,000	Pilot test of small Wetland Outlet Control Structure, NWI wetland, so no NYSDEC permits neeeded	$15,000	**1**
		Protect select structures in Poestenkill with berms or buyouts		$500,000	Facilitates flood zone and protects structures and occupants	$500,000	**1**
		Bonesteel Creek	Outlet Control, Wetland AP-6	$40,000	Protects property and culverts along Blue Factory Hill Road, and improves benefit of AP-14 control	$150,000	**3.75**
			Outlet Control, Wetland T-8	$40,000	Protects property and culverts along Blue Factory Hill Road, and arrests peak flow entering AP-14	$150,000	**3.75**
			Outlet Control, Wetland AP-14	$40,000	Arrests Peak flow entering the Poesten Kill just above Poestenkill, limiting stream and property damage. Benefit greater with AP-6 and T-8 controls	$2,500,000	**62.5**
		Potter Creek	Outlet Control, Wetland T-11	$40,000	Reduces peak storm flows on 56 Road and North Road culverts	$500,000	**12.5**
			Outlet Control, Wetland T-12	$40,000	Reduces peak storm flows on 45 Road culvert	$500,000	**12.5**
			Upsize North Road Culverts, Poestenkill	$300,000	Avoid future culvert failure, work likely unnecessary if T-11 and T-12 flood peaks are managed.	$300,000	**1**
			Upsize Fifty Six Road Culvert, Poestenkill	$300,000	Avoid future culvert failure, , work likely unnecessary if T-11 and T-12 flood peaks are managed.	$300,000	**1**
		Poesten Kill Eastern headwaters	Outlet Controls, Wetland T-16 (warrants 3 control installs)	$100,000	Reduce flow leaving Dyken Pond protecting both Plank Road and Dutch Church Road culverts, and properties and Poesten Kill along Plank Road	$1,000,000	**10**
			Outlet Controls, Wetland T-20	$40,000	Reduce flow leaving Dyken Pond protecting both Plank Road and Dutch Church Road culverts, and properties and Poesten Kill along Plank Road. Works best with T-16.	$1,000,000	**25**
			Outlet Control, Wetland T-24	$40,000	Reduce flow flooding properties along Plank Road, works best with T-16, 20, and 27	$1,000,000	**25**
			Outlet Control, Wetland T-27	$40,000	Reduce flooded properties along Plank Road approaching Poestenkill, works best with T-24	$1,000,000	**25**
	Monitor McChesney Ext. Slope Erosion			$10,000	Annual monitoring fee, which may suggest mitigation is not needed	$1,500,000	**150**
	Mitigate McChesney Ext. Slope Erosion			$1,500,000	benching and stream redirection to stabilize slope	$1,500,000	**1**

A project is considered cost-effective when the BCR is 1.0 or greater

* Most benefit estimates reflect alleviated future storm damage costs

7.0 CONCLUSIONS & SUMMARY RECOMMENDATIONS

7.1 Suggested Implementation Plan

The strategies developed and described in this report were developed collaboratively by RPA with technical input from Chazen and Interfluve, feedback from numerous local community leaders and members, and representatives from various local organizations.

Chazen's suggested implementation plan includes review of this report by the active stream flooding committee assembled by RPA, stabilization of a working committee to advance inquiry and implementation of selected plans. This may warrant intermunicipal agreements or at least confirmation of assigned participants.

It would be beneficial to advance at least one wetland outlet control pilot project in the very near future. One candidate site may be the Kersch wetland site, suggested because it has a potentially-willing landowner, and is not a NYSDEC wetland so permitting requirements will be simpler than for the larger wetland sites described in this report. The Kersch site could be used to collect detailed data describing peak flow reduction benefits and for other "lessons learned" during permitting, design, construction, and maintenance. Depending on site conditions and the owner's preferences for the outlet control, this location could be sized more aggressively to detain stormwater also during more frequent storms, thus increasing the likelihood that storm events and "lessons learned" will accrue more quickly than if the site is designed to control runoff from only the largest storms.

Concurrently, active engagement is recommended with select property owners where outlet control devices have been envisioned by this process, to explore precise site suitability and owner interest. This process is likely to lead to development of a refined list of candidate project sites. Conversations with owners may lead to interest in the use of conservation easement to compensate land owners for use of their wetlands, as warranted. Implementing wetland controls on land currently being transitioned to ownership by the State of New York provides other opportunities for land use agreements.

Active engagement with NYS Office of Parks and Recreation is also recommended to advance active pre-storm management of Dunham Reservoir. OPRHP has indicated they might consider removal of the concrete spillway wall on the dike portion of the Dunham reservoir, effectively lowering the normal operational water level in the reservoir by about five feet and presumably widening the spillway overall in ways that might address dam stability and reduce the risk of a sunny day failure. It has the potential to slightly increase total reservoir storage capacity during a major storm depending on how much of the remaining dam abutments will remain to constrict release volumes during major storms, but would not provide the full benefit of pre-storm drawdown actions described and modelled in this report.

Finally, funding sources outlined below plus additional funding sources will need to be identified and vetted for project suitability. This will allow implementation over time of the various projects and strategies suggested by this study.

7.2 Funding Sources

Numerous funding sources are available to implement flood management strategies.

- Some strategies suggested by this review are sufficiently cost-effective and low-budget they may be implemented and funded locally by private or public sources.

- Projects offering flood damage abatements benefits to Brunswick, including to bridges, farms, and McChesney Avenue, could potentially be cost effective investments for Grafton or citizen groups in Grafton.

- Similarly, the significant flood abatement opportunities this study has identified for the City of Troy may justify City investments in numerous floodwater detention projects in Poestenkill, Berlin, and Grafton.

- Intermunicipal agreements or cooperatively-funded programs may be devised for such investments, comparable to reginal MS4 stormwater agreements.

- Components of this plan could be incorporated into the Rensselaer County Multi-Jurisdictional Natural Hazard Mitigation Planning process.

- Insurance companies or other flood-sensitive organizations may fund pilot or permanent wetland outlet control programs, as methods to reduce future damage claims.

- The NYS Office of Parks and Recreation could be encouraged to finance preparation of pre-storm drawdown protocols at the Dunham Reservoir concurrent with any modification designs planned for the current spillway.

The following New York State grant funding programs may also support projects:

1. Individual grant opportunities via the Hudson River Estuary Program.

HREP opportunities are posted from time-to-time which may be suitable for pilot projects or green design project funding. Opportunities will need evaluation on a case by case basis.

2. Consolidated Funding Application (CFA) Resources

Online resource portal opens in May with application deadline July. Individual program specific application requirements must be considered. Grant award announcements typically December.

DEC Climate Smart Communities Grant Program: The program funds climate change adaptation and mitigation projects and includes support for projects that are part of a strategy to become a Certified Climate Smart Community. While not required, it is strongly recommended associated Towns become official members of the Climate Smart Communities network.

Eligible Applicants: Any county, city, town, borough, or village of the State of New York is eligible to apply. Registered or Certified Climate Smart Communities receive additional points in the competitive scoring system.

Adopt the Climate Smart Communities Pledge: Formally adopting the Climate Smart Communities Pledge as a municipal resolution initiates a community's commitment to climate action. Use the model resolution as a template (linked here).

Purpose: Relevant to the Poesten Kill project, the program funds climate adaptation projects for flood risk reduction and nature-based solutions such as wetland protections to address physical climate risk due to sea level rise, and/or storm surges and/or flooding. Efforts should be based on available data predicting the likelihood of future extreme weather events, including hazard risk analysis data.

Amount: $10,000 minimum up to $2,000,000, 50% required match.
Land acquisition or the value of a conservation easement may be used as match.

Climate Change Mitigation Easement: To satisfy the terms of the grant contract, grant recipients for implementation projects that involve construction, physical improvements, restoration, rehabilitation, or other site work will be required to obtain a climate change mitigation easement (like a conservation easement) if the property is not owned by the grant recipient.

Application: Consolidated Funding Application (CFA), Annual Round submission May-July.

Environmental Facilities Corporation Green Innovation Grant Program (EFC-GIGP): Program supports projects across New York State that utilize unique stormwater infrastructure design and create cutting-edge green technologies.

Eligible

Applicants: Municipalities, Two or more municipalities with a shared water quality infrastructure project, State Agencies, Interstate Agencies, Private Entities, Soil and Water Conservation Districts.

Purpose: To maximize opportunities that leverage the multiple benefits of green infrastructure, spur innovation in the field of stormwater management, build capacity to construct and maintain green infrastructure, and/or facilitate the transfer of new technologies and practices to other areas across the state.

Amount: up to 90% of eligible project expenses, 10% match.

Application: Consolidated Funding Application (CFA), Annual Round submission May-July.

New York State Department of Environmental Conservation Water Quality Improvement Program (DEC WQIP): WQIP is a competitive, reimbursement grant program that funds projects directly addressing documented water quality impairments which may be categorized as wastewater treatment improvement projects, non-agricultural nonpoint source abatement and control, land acquisition for source water protection, aquatic habitat restoration, municipal separate storm sewer system upgrades and salt storage.

Eligible Applicants: Municipalities, Soil and Water conservation districts, Not-for-profit corporations.

Purpose: *Aquatic Habitat Restoration* is focused on work that improves aquatic habitat connectivity at road/stream crossings or dams, with the primary intent to restore the natural movement of organisms. Projects should remove barriers to aquatic connectivity and must focus on culverts, bridges or dams that are causing these obstructions.

Amount: up to 75% project costs, maximum $250,000.

Application: Consolidated Funding Application (CFA), Annual Round submission May-July.

Funding programs accepting applications year-round:

State and Municipal Facilities Program (SAM/DASNY): Capital grant programs sourced from State elected officials that support community and economic development.

Eligible Applicants: Varies, primarily municipal awards.

Purpose: Discretionary program, typically funds community and economic development.

Amount: Varies from $5,000 – multi-million grant awards.

Application: Dialogue with State representatives

Finally, and in addition, Federal Pre-Disaster Mitigation Grant funding might be explored. The PDM Program is designed to help States and local communities implement pre-disaster natural hazard mitigation programs that reduce overall risk to populations and structures from future hazard events, concurrently also reducing future need for future Federal disaster funding. This program offers plan and project grants for which mitigation planning is a key process to break the cycle of disaster damage, reconstruction, and repeated damage. PDM grants are funded annually by Congressional appropriations and are awarded on a nationally competitive basis. FEMA requires state and local governments to develop and adopt hazard mitigation plans as a condition for receiving non-emergency disaster assistance, which could include funding for PDM mitigation projects such as those developed here for the Poesten Kill watershed. Completion of this flood assessment report may substantively contribute to meeting the FEMA pre-condition for developing a hazard mitigation plan.

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Figures

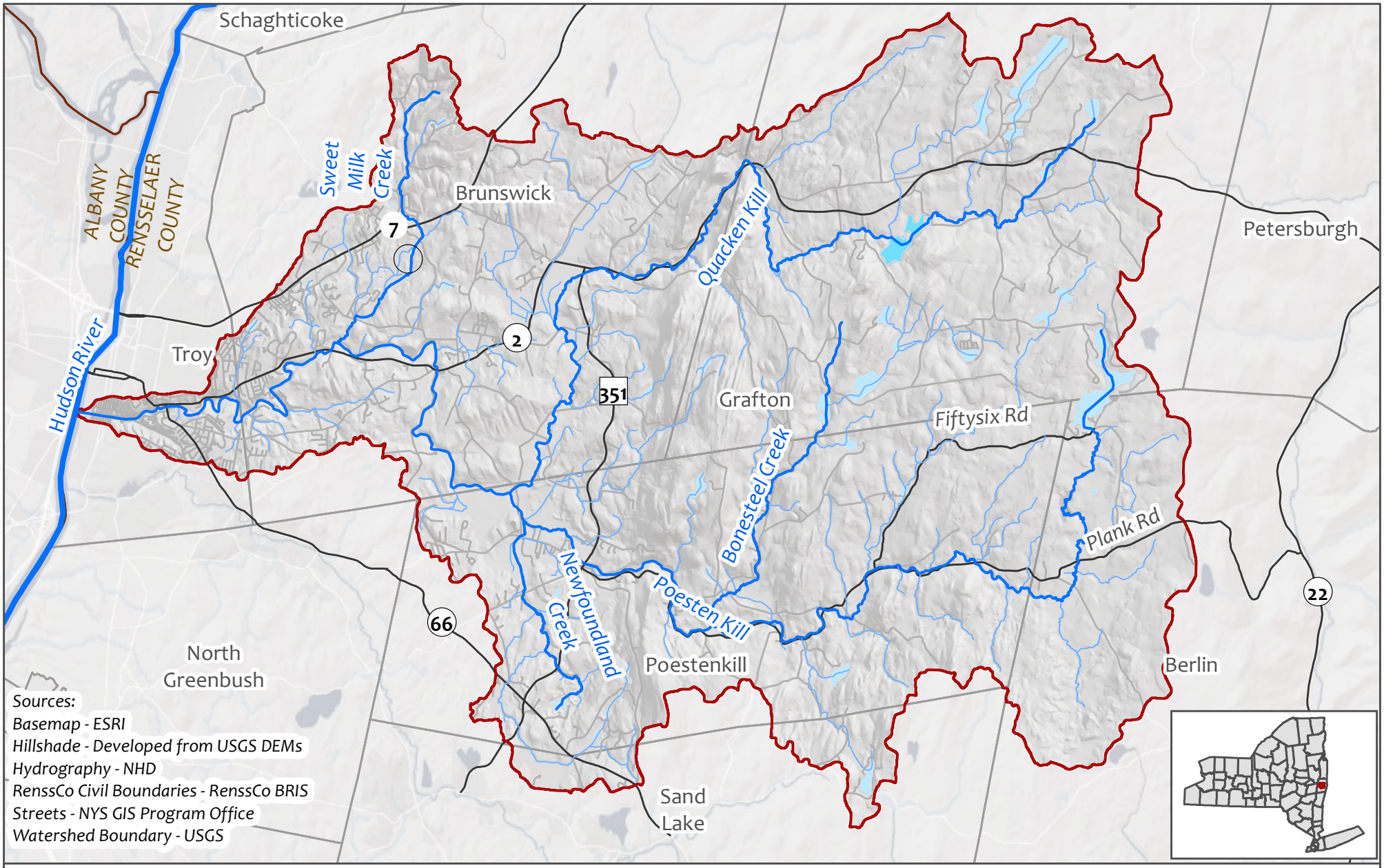


Figure 1a. Watershed Overview

N

0 1 2 4 Miles

Poesten Kill Watershed
Waterbodies
Streams/Rivers
Streets
Town Boundaries

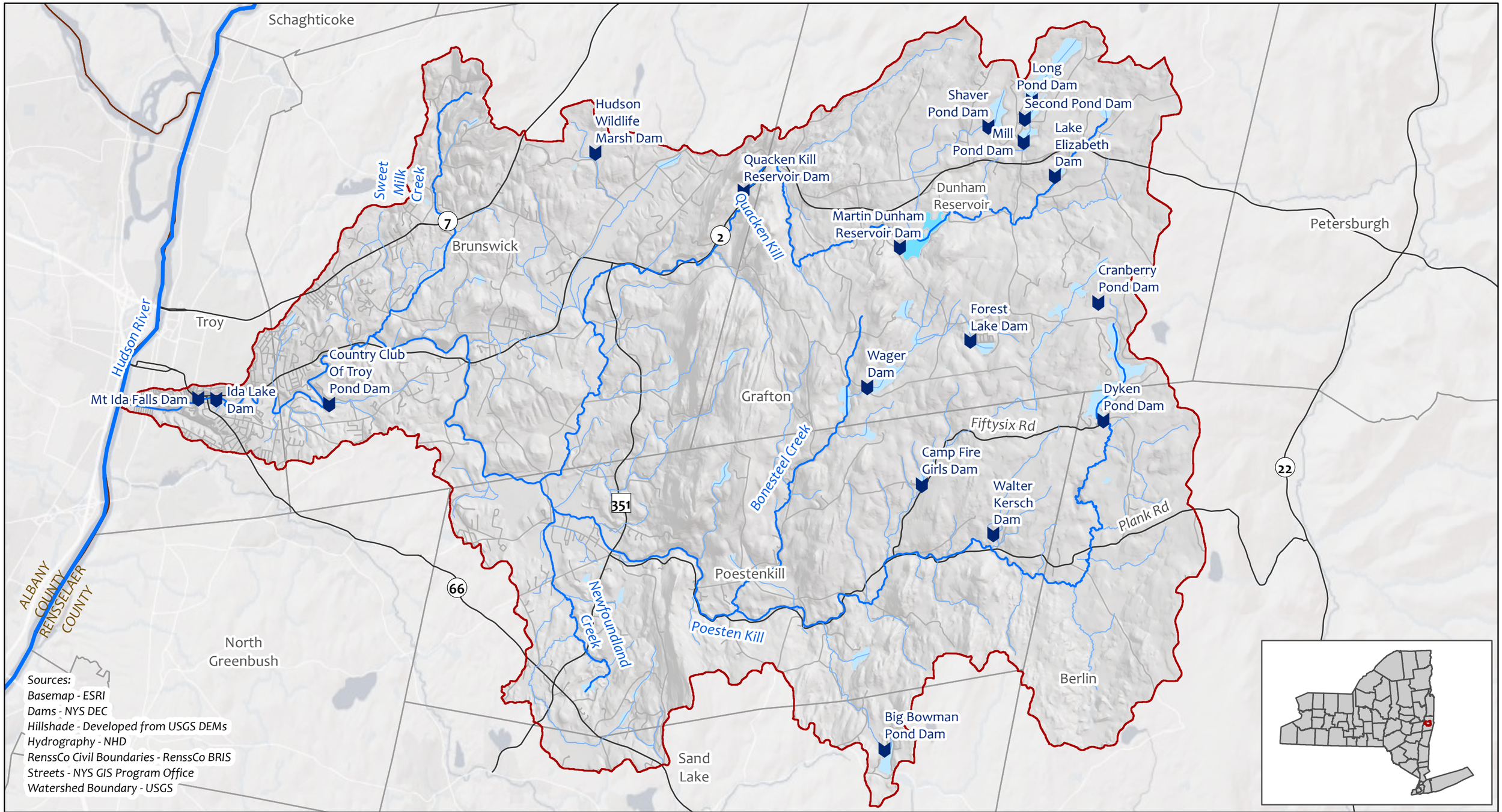


Figure 1b. Detailed Watershed Overview

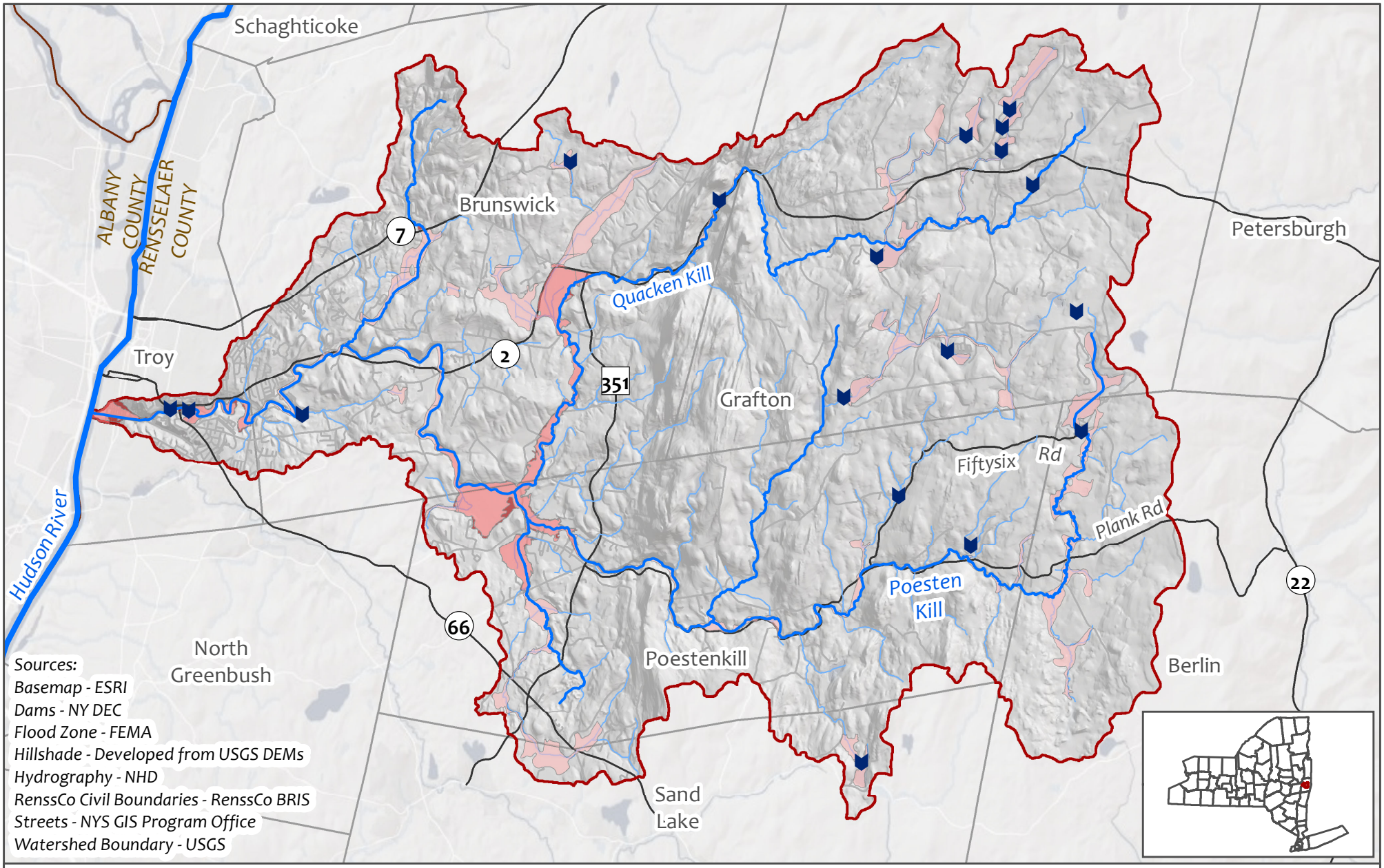


Figure 2a. Flood Hazard Zones Mapped by FEMA

N

0 1 2 4 Miles

FEMA Flood Zone

- 100-yr Flood Zone *BFE not determined*
- 100-yr Flood Zone *BFE determined*
- 500-yr Flood Zone
- Dams
- Poesten Kill Watershed
- Streams/Rivers
- Streets
- Town Boundaries

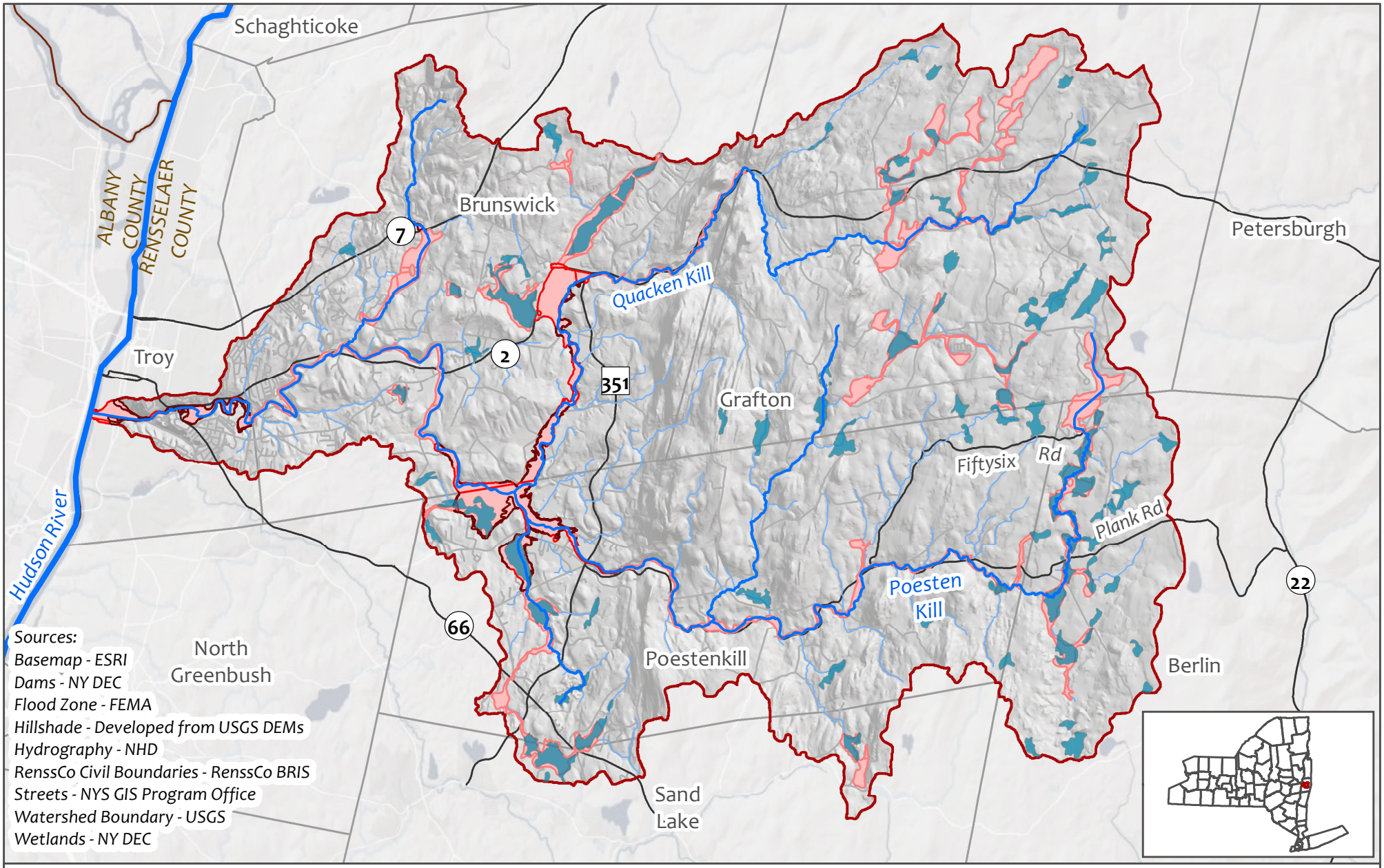


Figure 2b. NY DEC Wetlands

N

0 1 2 4 Miles

FEMA Flood Zone

- 100-yr Flood Zone *BFE not determined*
- 100-yr Flood Zone *BFE determined*
- 500-yr Flood Zone
- DEC Wetlands
- Poesten Kill Watershed
- Streams/Rivers
- Streets
- Town Boundaries

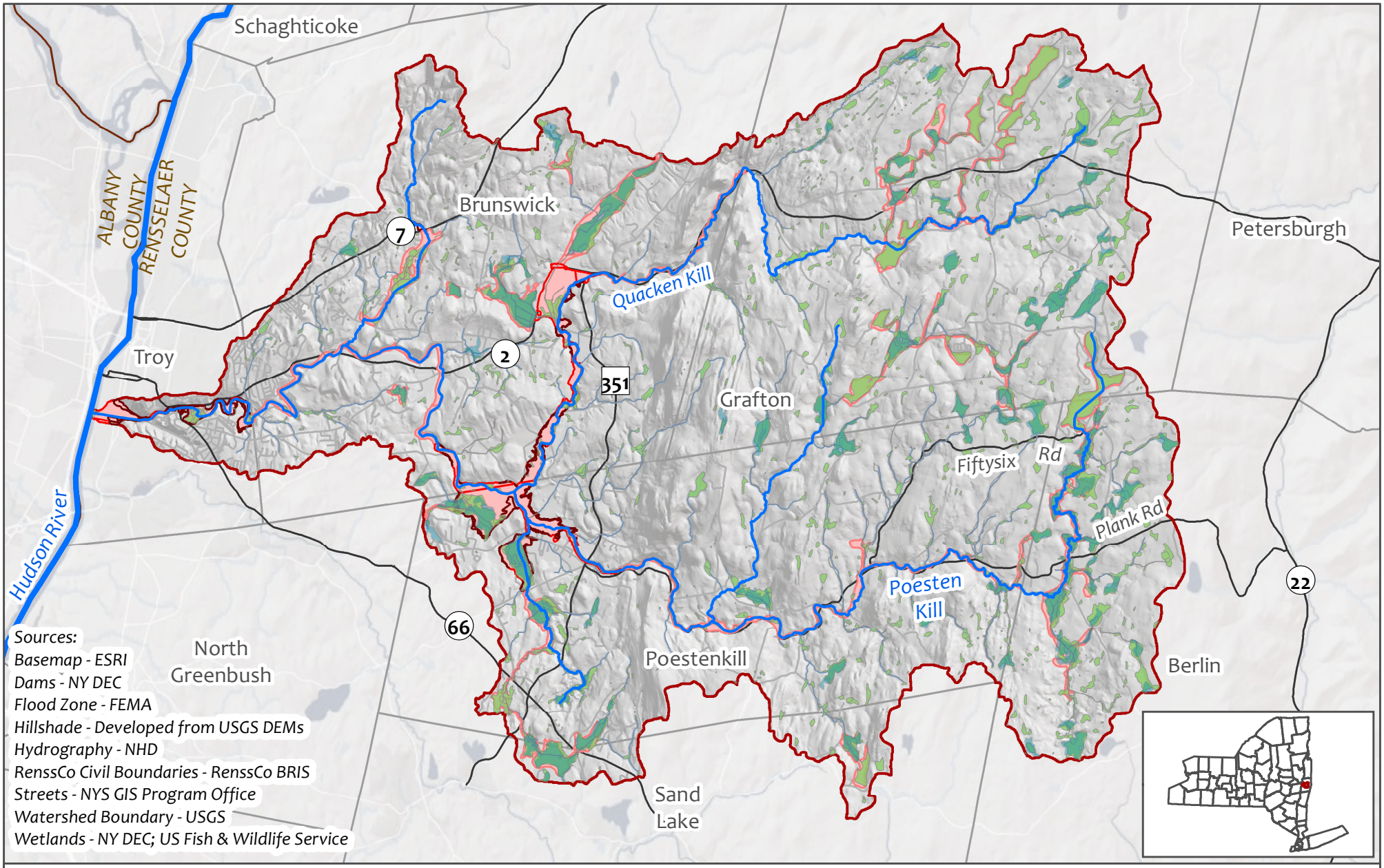


Figure 2b. NWI and NY DEC Wetlands

N

0 1 2 4 Miles

FEMA Flood Zone

- 100-yr Flood Zone *BFE not determined*
- 100-yr Flood Zone *BFE determined*
- 500-yr Flood Zone
- NWI Wetlands
- DEC Wetlands
- Poesten Kill Watershed
- Streams/Rivers
- Streets
- Town Boundaries

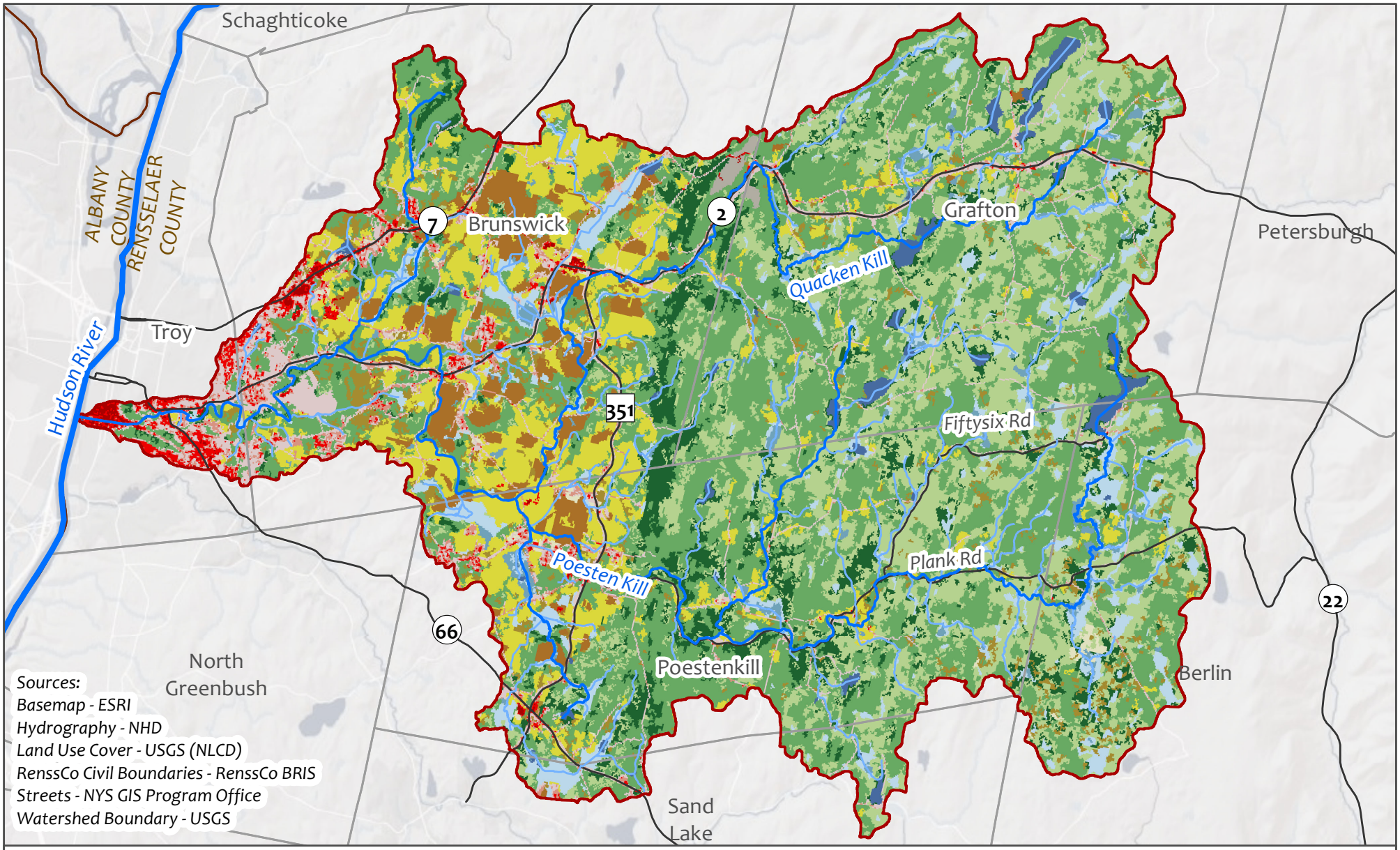


Figure 3. Land Use Cover

N

0 1 2 4 Miles

Open Water	Barren Land (Rock/Sand/Clay)	Grassland/Herbaceous
Developed, Open Space	Deciduous Forest	Pasture/Hay
Developed, Low Intensity	Evergreen Forest	Cultivated Crops
Developed, Medium Intensity	Mixed Forest	Woody Wetlands
Developed, High Intensity	Shrub/Scrub	Emergent Herbaceous Wetlands

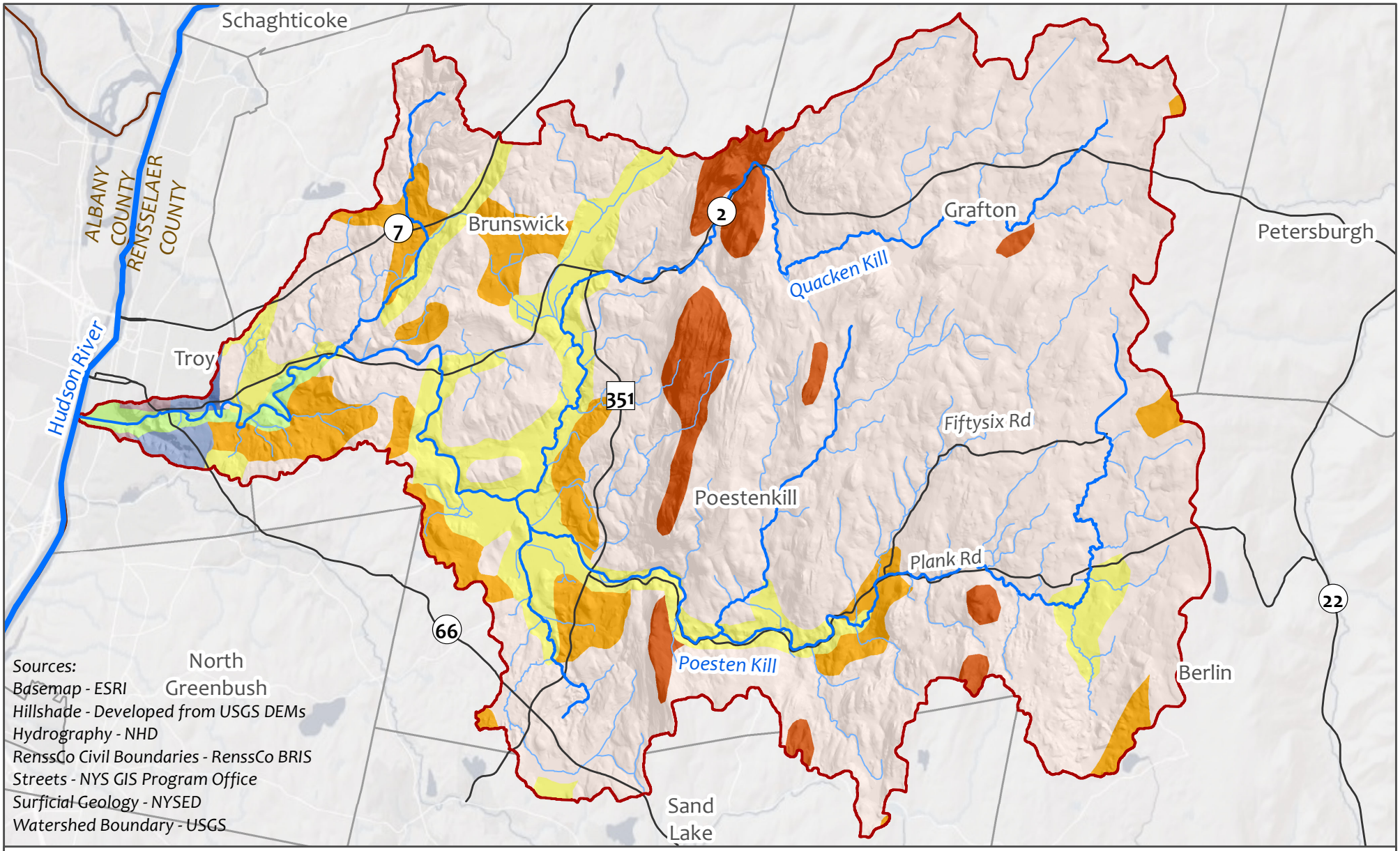


Figure 4. Surficial Geology

N

0 1 2 4 Miles

Material

- Alluvium
- Bedrock
- Kame deposits
- Lacustrine beach
- Lacustrine delta
- Lacustrine silt and clay
- Outwash sand and gravel
- Till
- Poesten Kill Watershed
- Streams/Rivers
- Streets
- Town Boundaries

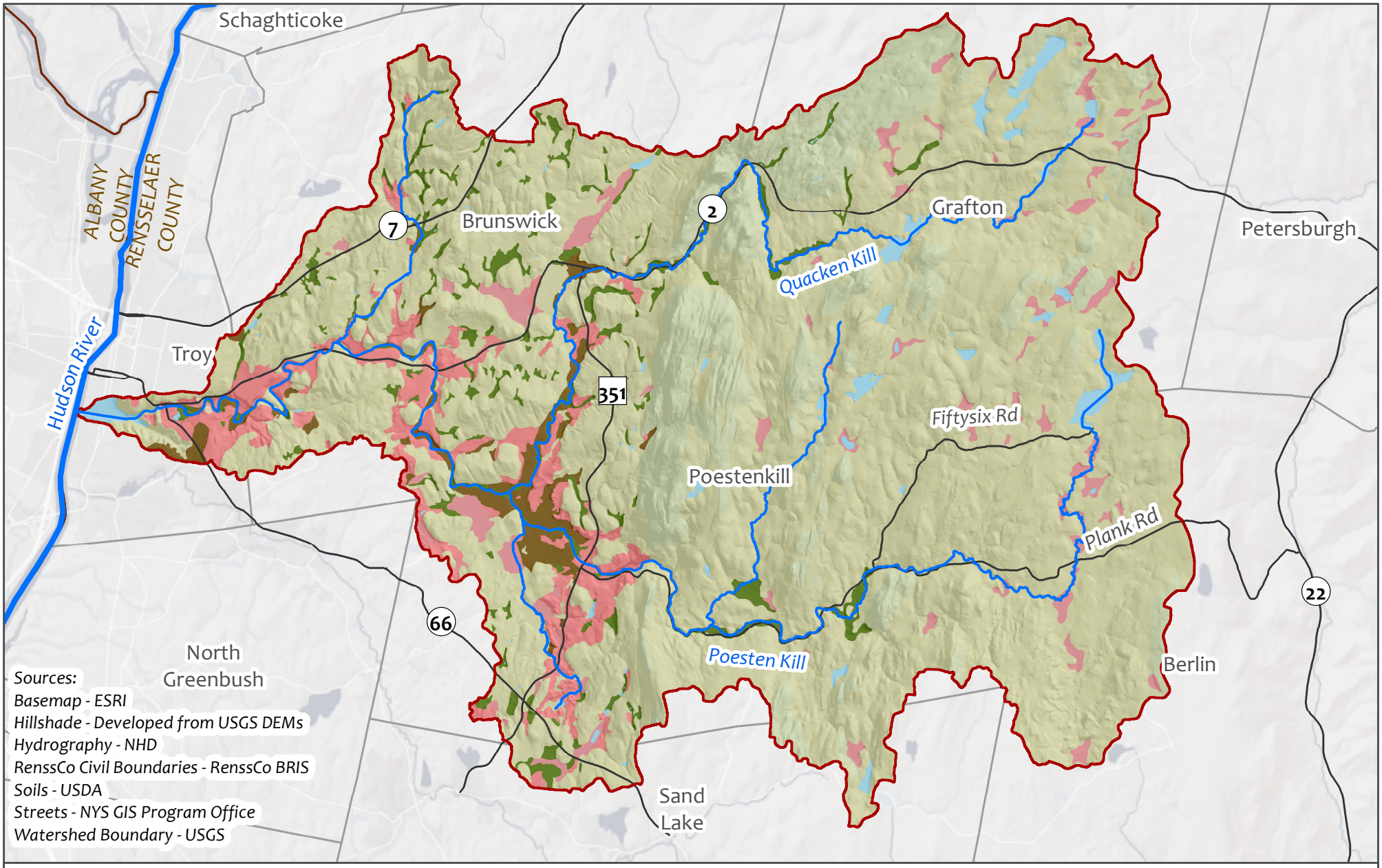


Figure 5. Hydrologic Soil Groups

N

0 1 2 4 Miles

Hydrologic Soil Group

- A and A/D
- B
- C and C/D
- D
- Waterbodies/Unclassified
- Poesten Kill Watershed
- Streams/Rivers
- Streets
- Town Boundaries

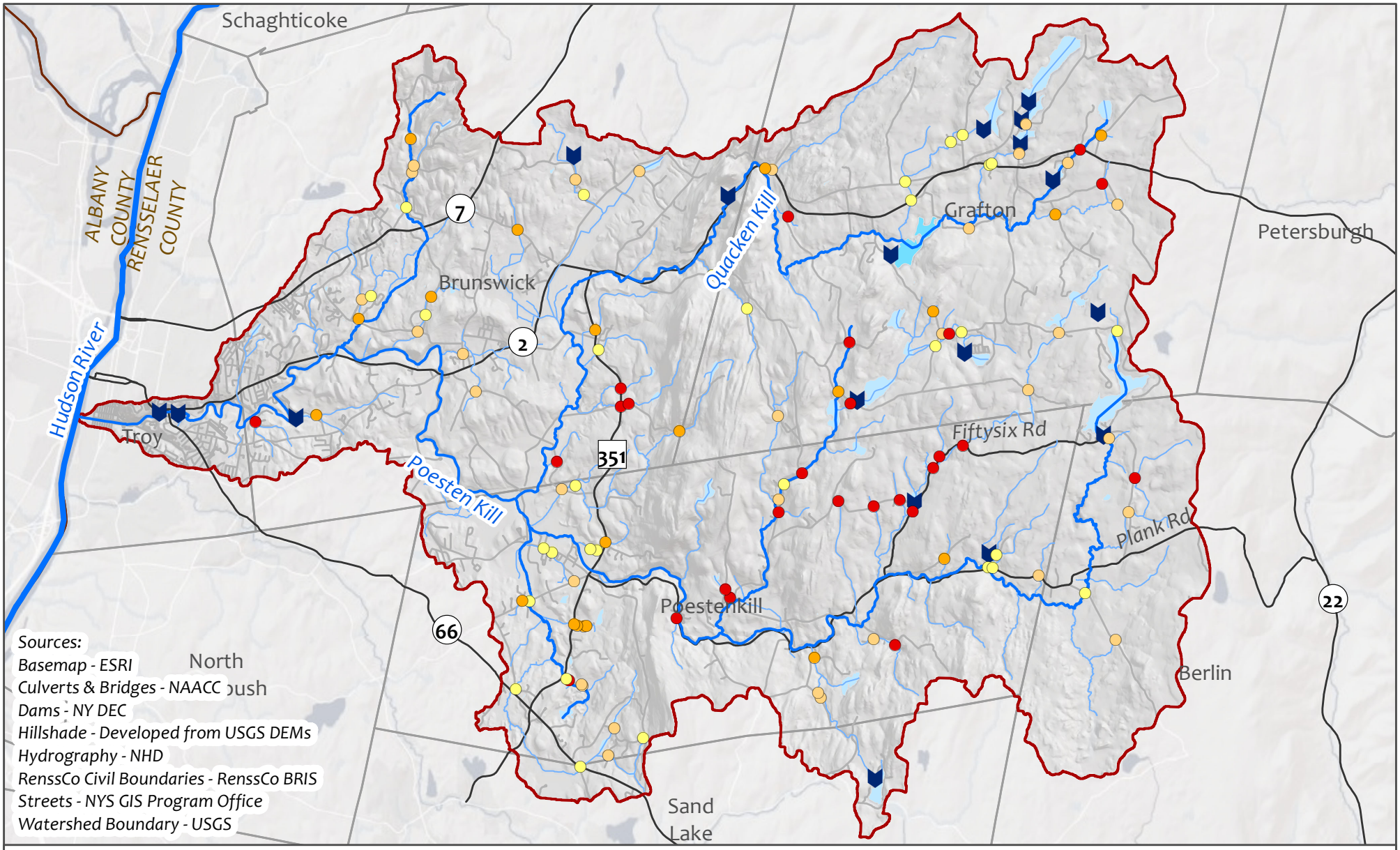


Figure 6a. Culverts and Bridges: Aquatic Organism Passability

N

0 1 2 4 Miles

Culvert and Bridge Passability

- Minor barrier
- Moderate barrier
- Significant barrier
- Severe barrier

- Dams
- Poesten Kill Watershed
- Streams/Rivers

- Waterbodies
- Streets
- Town Boundaries

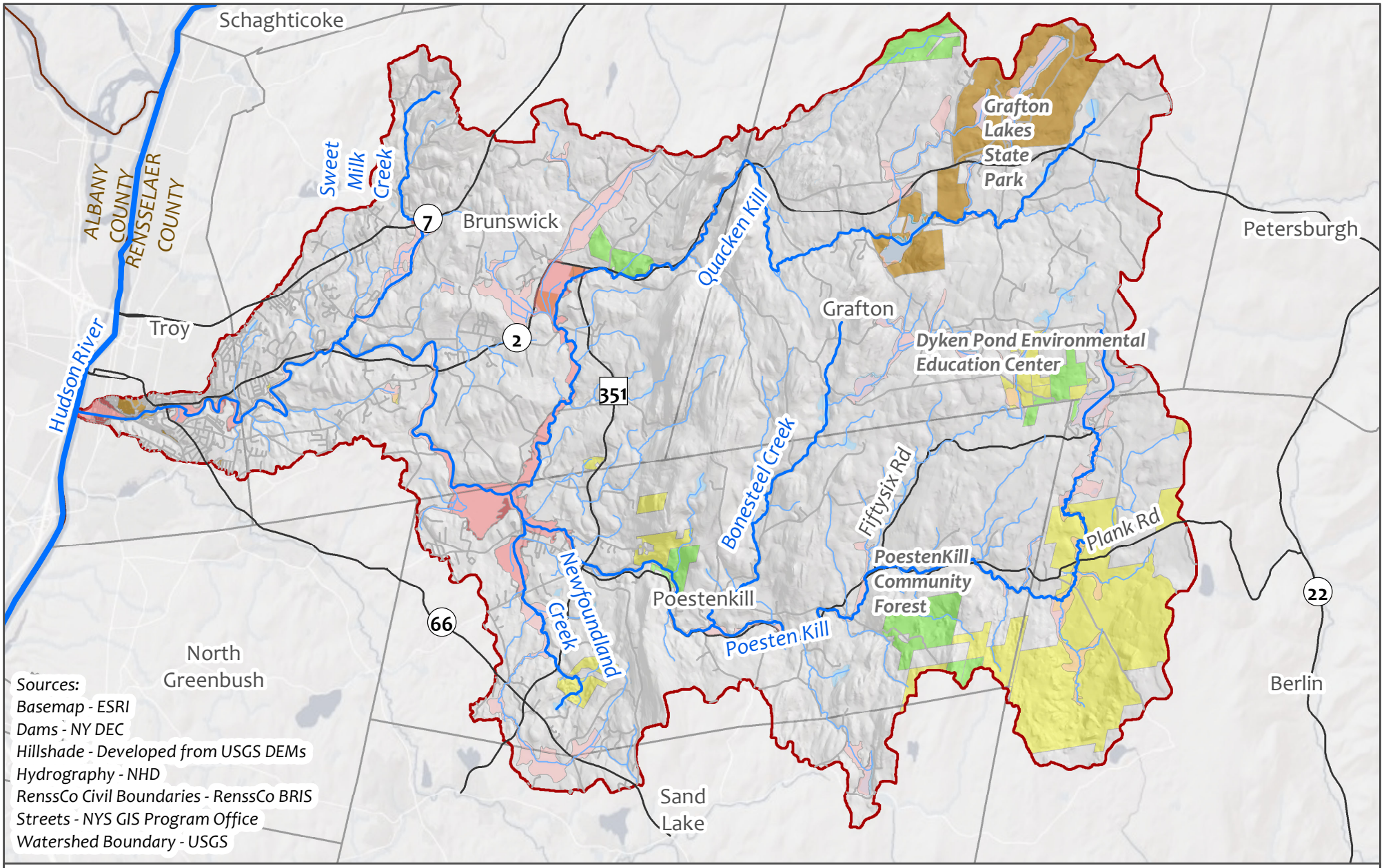


Figure 7. Conserved Lands

N

0 1 2 4 Miles

Conserved Lands by Ownership

Nonprofit Owned	*1,383 acres*
Government Owned	*2,585 acres*
Privately Owned	*4,049 acres*

FEMA Flood Zone

- A
- AE
- X500

- Poesten Kill Watershed
- Waterbodies
- Town Boundaries
- Streams/Rivers
- Streets

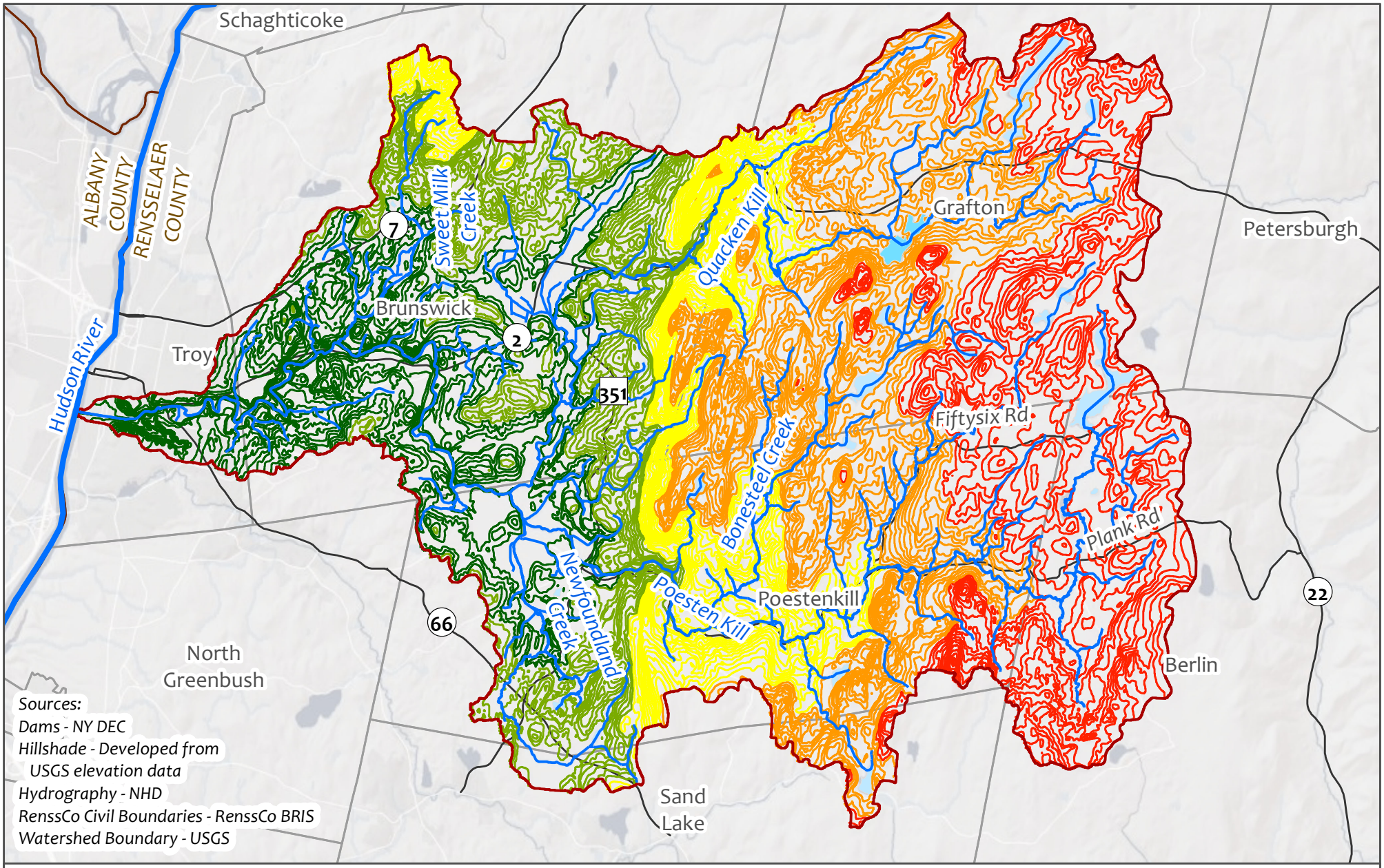


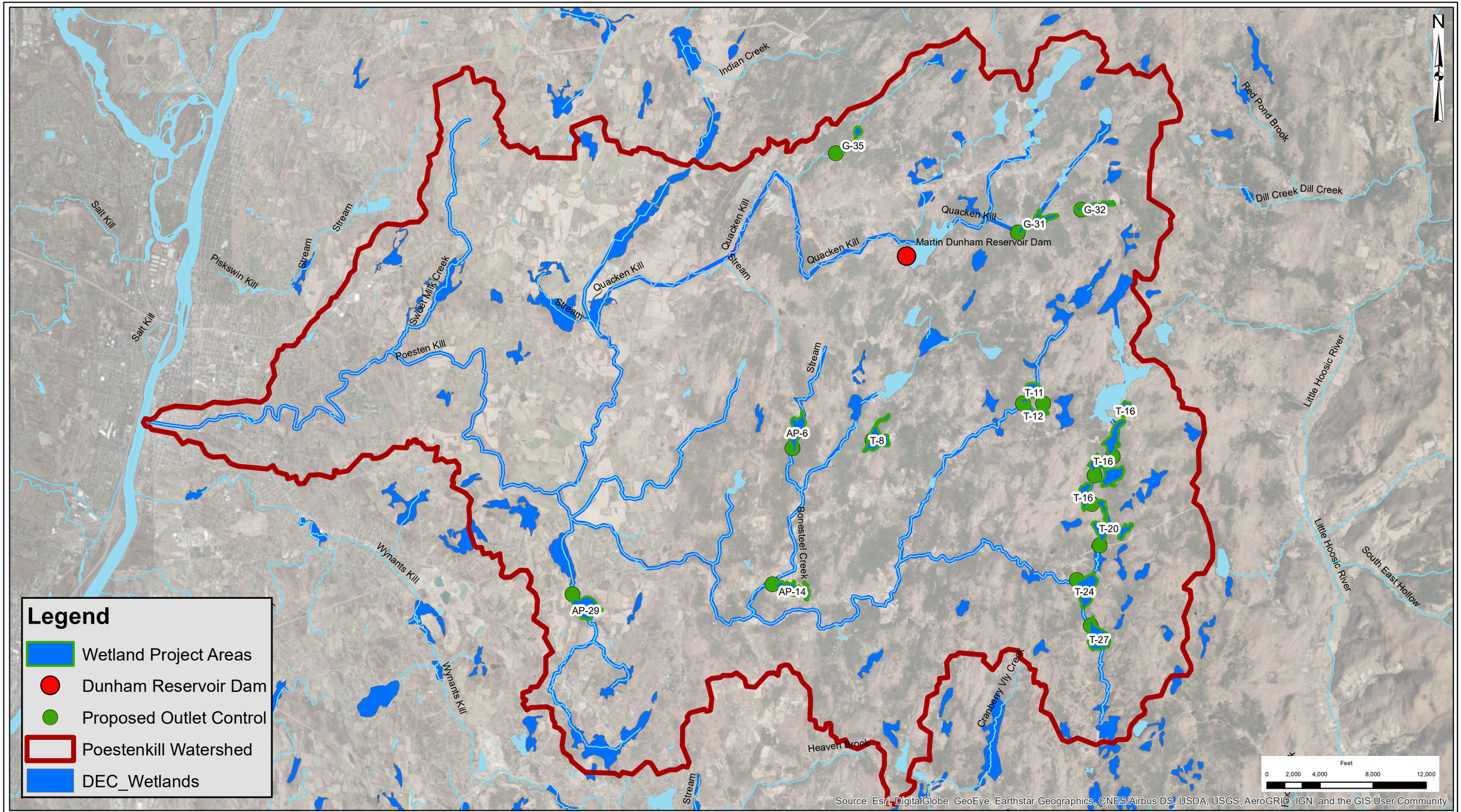
Figure 8. Elevation

N

0 1 2 4 Miles

Contour (feet)		
0 - 540	811 - 1170	Poesten Kill Watershed
541 - 810	1171 - 1500	Streams/Rivers
	1501 - 1890	Waterbodies
		Town Boundaries

Figure 9. Unscaled screen shot of sections of lobes of NYSDEC Wetlands T-16 and T-20 upstream of Plank Road in the Town of Poestenkill, on the Rensselaer Plateau. The image shows the wetlands, their narrow stream outlets, and the general lack of abutting structures. Stream flow is from north to south (top to bottom of page) and passes through a culvert on Plank Road. Augmented stormwater detention on these and similar wetlands could be implemented via outlet control structures that further restrict the velocity of flow leaving these wetlands.



Engineers/Surveyors
Planners
Environmental Scientists
Landscape Architects

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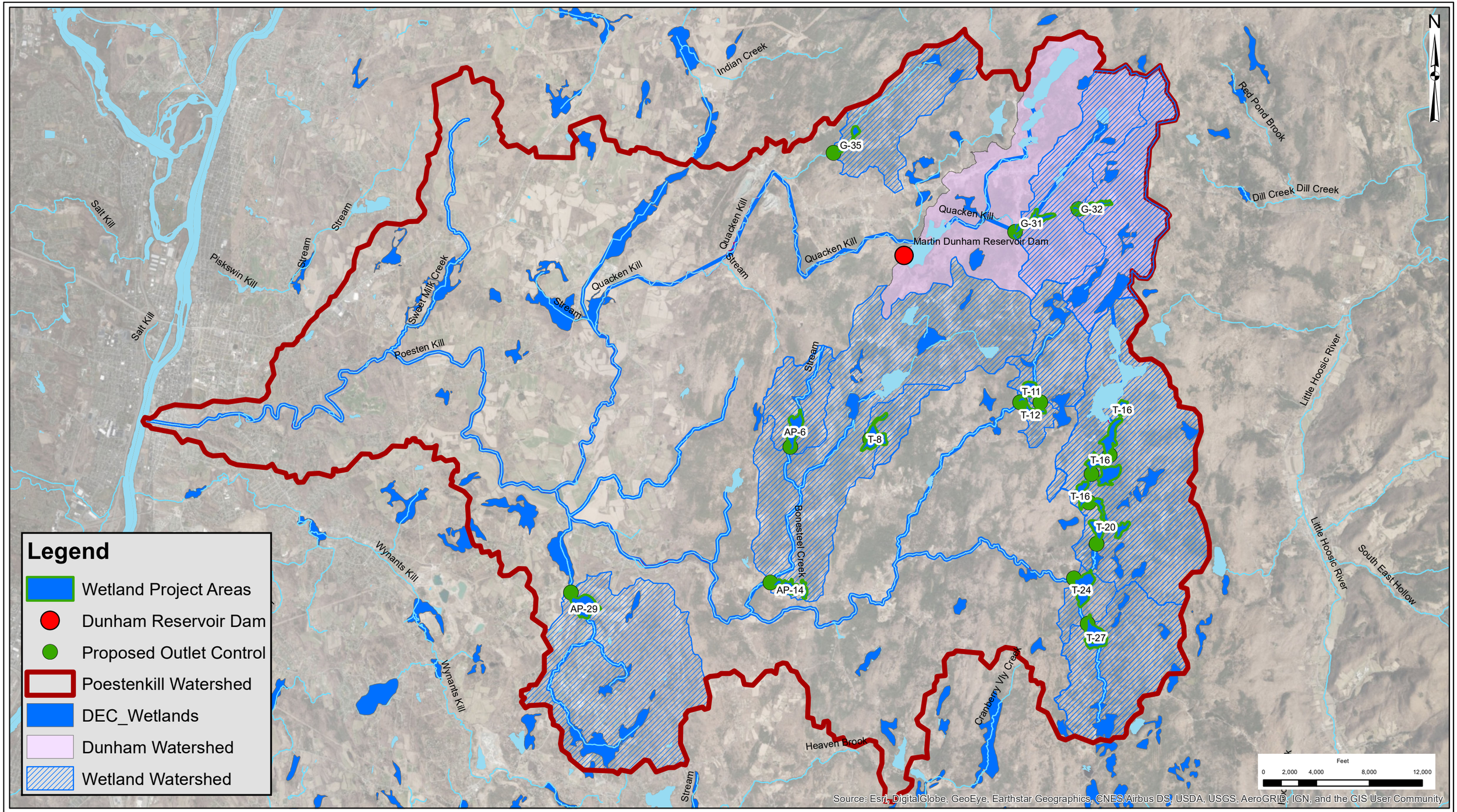
Poesten Kill Watershed and Flood Mitigation

Proposed Project Area Location Map

Rensselaer County, New York

Drawn:	JLB
Date:	07/01/2019
Scale:	1:80,000
Project:	41822.00
Figure:	10



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Poesten Kill Watershed and Flood Mitigation

Proposed Project Area Watershed Location Map

Rensselaer County, New York

Drawn:	JLB
Date:	07/01/2019
Scale:	1:80,000
Project:	41822.00
Figure:	11

APPENDICES

Appendix 1: Geomorphology Assessment

TECHNICAL MEMORANDUM

To: Russell Urban-Mean, The Chazen Companies

From: Candice Constantine and Keith Kantack, Inter-Fluve Engineering, PLLC

Date: May 10, 2019

Re: Task 4: Poesten Kill Watershed and Flood Mitigation Assessment: Geomorphic Assessment and Review of Potential Flood Management Options

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Executive Summary

Inter-Fluve Engineering was contracted by The Chazen Companies (Chazen) to assist in completing a flood mitigation assessment and developing a strategy for increasing flood resilience in the Poesten Kill watershed in Rensselaer County, New York. Inter-Fluve's role in the project focuses on characterizing the relevant geomorphic processes occurring the basin and identifying flood mitigation alternatives related to channel and floodplain geomorphology and function. Our approach was to build on existing knowledge and work by reviewing existing data and consulting with stakeholders followed by a targeted reconnaissance-level field assessment. Fieldwork was focused on areas with known flooding issues and histories of flood damages as well as opportunity areas where project implementation may provide flood mitigation benefits.

The Poesten Kill and its main tributary, the Quacken Kill, originate in the uplands of the Rensselaer Plateau and flow generally west towards the Hudson River, which the Poesten Kill empties into at Troy, New York. As the streams descend the western escarpment of the plateau, they transition from steep, confined channels to gently sloping channels with broader floodplains. This transition induces deposition, which has had a persistent flood impact in the communities located along the base of the escarpment. This natural predilection for deposition of sediments along the base of the escarpment is exacerbated by a legacy of artificial channel modification including dredging, straightening, and clearance for agriculture. Another persistent challenge is recurring erosive damage to road infrastructure along the steep reaches of the escarpment.

Based on our findings, we recommend a watershed-wide approach to flood risk management that is tailored to the unique landscape attributes of the Poesten Kill watershed;

- Measures in the headwaters area of the plateau should focus on increasing flood storage and detention;
- Measures along the steep channels of the escarpment should be aimed at increasing resilience of road infrastructure, slowing flows, and reducing erosion; and

- Measures in the lowlands at the base of the escarpment should focus on floodplain and channel restoration, including relocation of vulnerable development types and restrictions on future development.

We provide site-specific examples of this strategy for a select number of locations included in the targeted field assessment along with broader, watershed-wide recommendations.

Introduction

BACKGROUND

The Poesten Kill watershed, an approximately 96 square-mile area, is located in Rensselaer County of the Hudson Valley region, New York (Figure 1a, Appendix A). The region experiences high intensity precipitation events (i.e., more than two inches in 24 hours) that produce damaging floods. This project is a joint effort by a number of stakeholders, including local town governments, the Rensselaer Plateau Alliance (RPA), Trout Unlimited, the New England Interstate Water Pollution Control Commission (NEIWPCC), and the New York State Department of Environmental Conservation's Hudson River Estuary Program (HREP), to explore opportunities to improve flood resiliency in the Poesten Kill watershed. Inter-Fluve's role is to characterize the relevant geomorphic processes occurring in the watershed and identify flood mitigation and community resilience alternatives related to channel and floodplain geomorphology and function. This technical memo summarizes our review of existing data, geomorphic field assessment, and recommendations.

ASSESSMENT SCOPE

The scope of our assessment includes:

- Review of existing data, including publicly available aerial imagery, GIS data, anecdotal information, and existing reports to develop an understanding of geologic context, watershed history, and basin-scale watershed processes;
- Completion of a field assessment to collect data in targeted areas and investigate reach-scale processes; and
- Identification of measures to improve flood resilience through the restoration of geomorphic form and function.

Figures and field data referenced or generated for this study are included in the following appendices:

- Appendix A – Existing Data - Figures produced for the project by RPA;
- Appendix B – Recommendations - Concept plans for select recommendations; and
- Appendix C – Field Data Collection Sheets.

Existing Data Review and Basin-Scale Analysis

GEOLOGICAL SETTING

The Poesten Kill watershed is underlain by the Rensselaer greywacke on the Rensselaer Plateau, and by the black shale and limestone of the Nassau formation in its lower reaches[1]. Both units are Cambrian in age. The current landscape was shaped by tectonic activity during the Taconic Orogeny (440 million years ago) and by repeated glaciations in the Pleistocene, the most recent concluding less than 20,000 years ago. The watershed is dominated by the plateau and its western boundary which forms a steep escarpment, dividing the watershed in half (Figure 1).

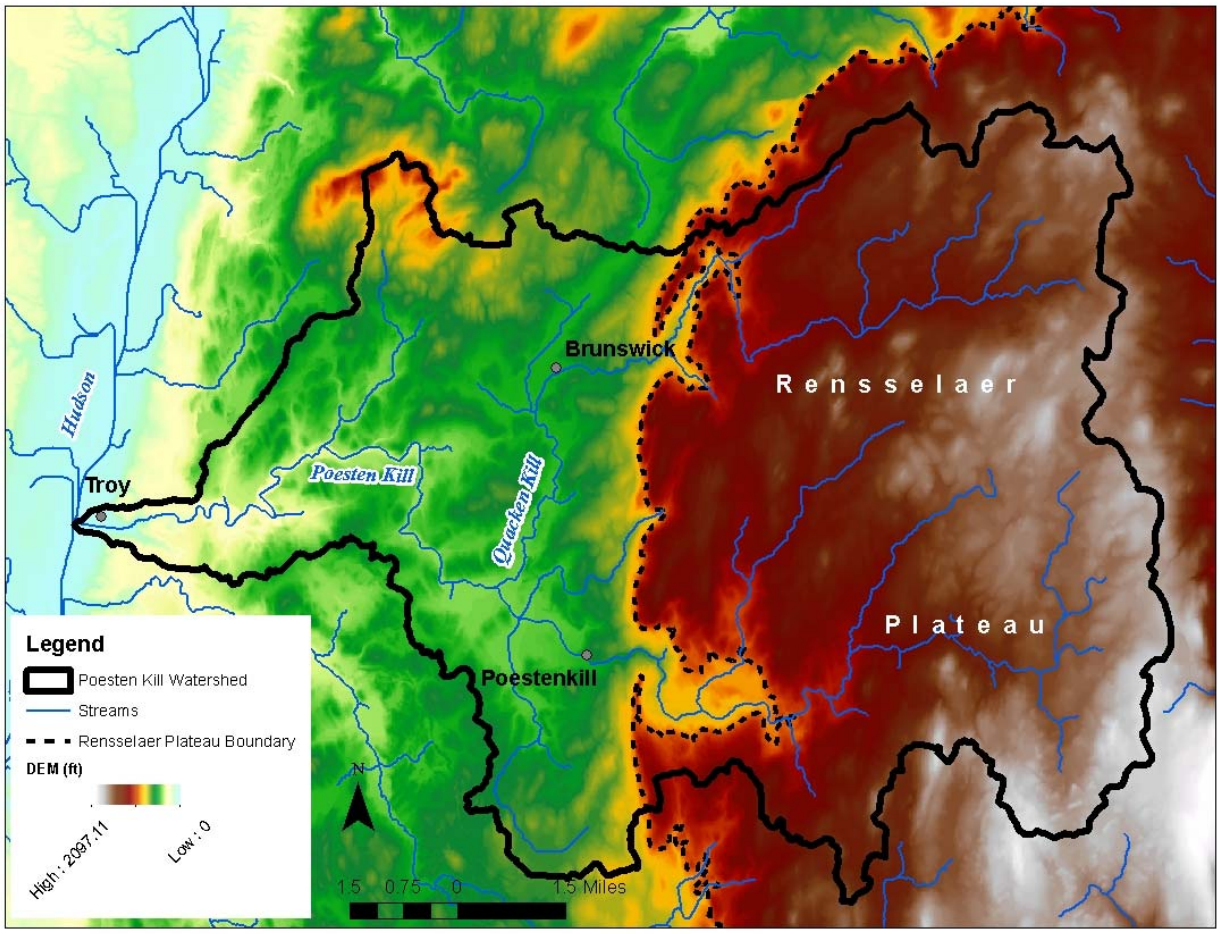

Figure 1. Map of Poesten Kill watershed with digital elevation model (DEM) and shaded relief map. The watershed is outlined in black. The Rensselaer Plateau is the elevated land (colored red/white) delineated by a dashed black line. DEM from USGS/CUGIR.

[1] Source: New York State Education Department (NYSED). http://www.nysm.nysed.gov/research-collections/geology/gis

The Poesten Kill and its primary tributary, the Quacken Kill, occupy narrow valleys formed in bedrock and surficial deposits of material associated with Pleistocene glacial activity including till, kame deposits, and outwash sands and gravels. Alluvial deposits (sand to gravel) are mapped along the downstream, low-gradient reaches of the mainstem Poesten Kill along with terraces of lacustrine deposits near the mouth of the creek (Figure 4, Appendix A). Descriptions of the primary surficial geology units found in the watershed are provided below[2].

> *Recent alluvium* – Oxidized fine sand to gravel. Permeable. Generally confined to floodplains within valleys. In larger valleys, may be overlain by silt. Subject to flooding. Thickness 1 to 10 meters.
> *Till* – Variable texture (boulders to silt), usually poorly sorted sand-rich diamicton. Deposition beneath glacier ice. Permeability varies with compaction. Variable thickness (1 to 50 meters).
> *Kame deposits* – Coarse to fine gravel and/or sand, includes kames, eskers, kame terraces, kame deltas, ice contact, or ice cored deposition. Lateral variability in sorting, texture and permeability. May be firmly cemented with calcareous cement. Variable thickness (10 to 30 meters).
> *Outwash sand and gravel* – Coarse to fine gravel with sand. Proglacial fluvial deposition. Well-rounded and stratified, generally finer texture away from ice border. Permeable. Variable thickness (2 to 20 meters).

LAND USE / LAND COVER

Primary land cover types in the majority rural watershed[3] are forest (64%), which dominates the uplands on the plateau, and agriculture (14%) found in the lowlands (Figure 3, Appendix A). Numerous wetlands are mapped along watercourses and in low-lying areas (Figure 2b, Appendix A), with wetland cover totaling approximately 7% of the watershed and open water, primarily reservoirs, another 2%. Four percent of the watershed is currently classed as low to high intensity development with an additional 5% shown as developed open space. The remaining 4% of land cover comprises barren land, grassland, and shrub/scrub.

Where allowed to grow, riparian buffers of forest and wooded wetland help to stabilize banks, provide a source of large wood to the system, help protect watercourses from the impacts of adjacent land uses, and provide shade and cover for aquatic species. In the Poesten Kill watershed, intact riparian buffers are most common along headwater tributaries on the plateau. On the plateau, the narrow valleys along the mainstem Quacken Kill and Poesten Kill have been developed for residential use and transportation infrastructure, and thus riparian buffers have been compromised to make room for homes and roads. In lowland areas to the west of the plateau, both development

[2] http://www.nysm.nysed.gov/research-collections/geology/gis. Accessed September 12, 2018.
[3] As provided in the U.S. Geological Survey's National Land Cover Database (2011). https://www.mrlc.gov/nlcd2011.php

and agricultural practices have encroached into riparian buffers along many reaches of the mainstem channels and their tributaries. A brief review of historical photographs dating back to the 1950s indicates that riparian cover has improved somewhat since then when the lowlands were nearly entirely farmed right up to the tops of the channel banks[4].

FLOOD AND CHANNEL DYNAMICS

The landscape of the Poesten Kill watershed is dominated by a prominent topographic step defined by the western boundary of the Rensselaer Plateau (Figure 2). This topographic control accounts for many of the patterns of flood and sediment transport dynamics observed in the watershed. The upper reaches of the Poesten Kill and Quacken Kill that originate on the plateau and flow west down the escarpment, are characterized by steep and confined channels with small floodplains. Slopes along the mainstem channels are on the order of 100 ft/mile or 0.02 (Table 1), with higher slopes occurring locally and along tributaries. The combination of high slope and confinement is capable of generating flood flows with sufficient velocity and depth to erode and transport the abundant sediment present in the surficial deposits forming the hillslopes adjacent to the channels as well as other debris (e.g., large wood). This is reflected in anecdotal descriptions of the damages experienced during Tropical Storm Irene which included loss of riparian trees, blocking of culverts, and catastrophic failure of associated road infrastructure such as the damage to Route 2 near the intersection with Stuffle Street in Grafton (Quacken Kill), Plank Road in Poestenkill (Poesten Kill), and Fifty Six Road in Poestenkill (Potter Creek).

Table 1. Channel slopes along the Poesten Kill and Quacken Kill

Reach	Slope	ft/mile
Quacken Kill Upper: Dunham Reservoir to Brunswick	0.021	111
Quacken Kill Lower: Brunswick to confluence with Poesten Kill	0.0036	19
Poesten Kill Upper: Dyken Pond to Poestenkill Village at Quacken Kill confluence	0.018	96
Poesten Kill Lower: Downstream of Poestenkill Village	0.0097	51

These steep upland reaches transition abruptly onto the broad plain at the base of the plateau, and channel slopes reduce dramatically (Figure 2 and Table 1). When flows reach this break in slope, they slow and expand onto the floodplain, resulting in a rapid reduction in sediment transport capacity and abrupt deposition of sediment. During Tropical Storm Irene, deposition of substantial volumes of sediment along the Quacken Kill in the Towns of Brunswick and the Poesten Kill in the Town of Poestenkill damaged soccer fields and residential property and filled the channels, reducing conveyance capacity and forcing more flow overbank.

[4] Historical aerial imagery via NETRonline www.historicaerials.com/viewer . Accessed October 13, 2018.

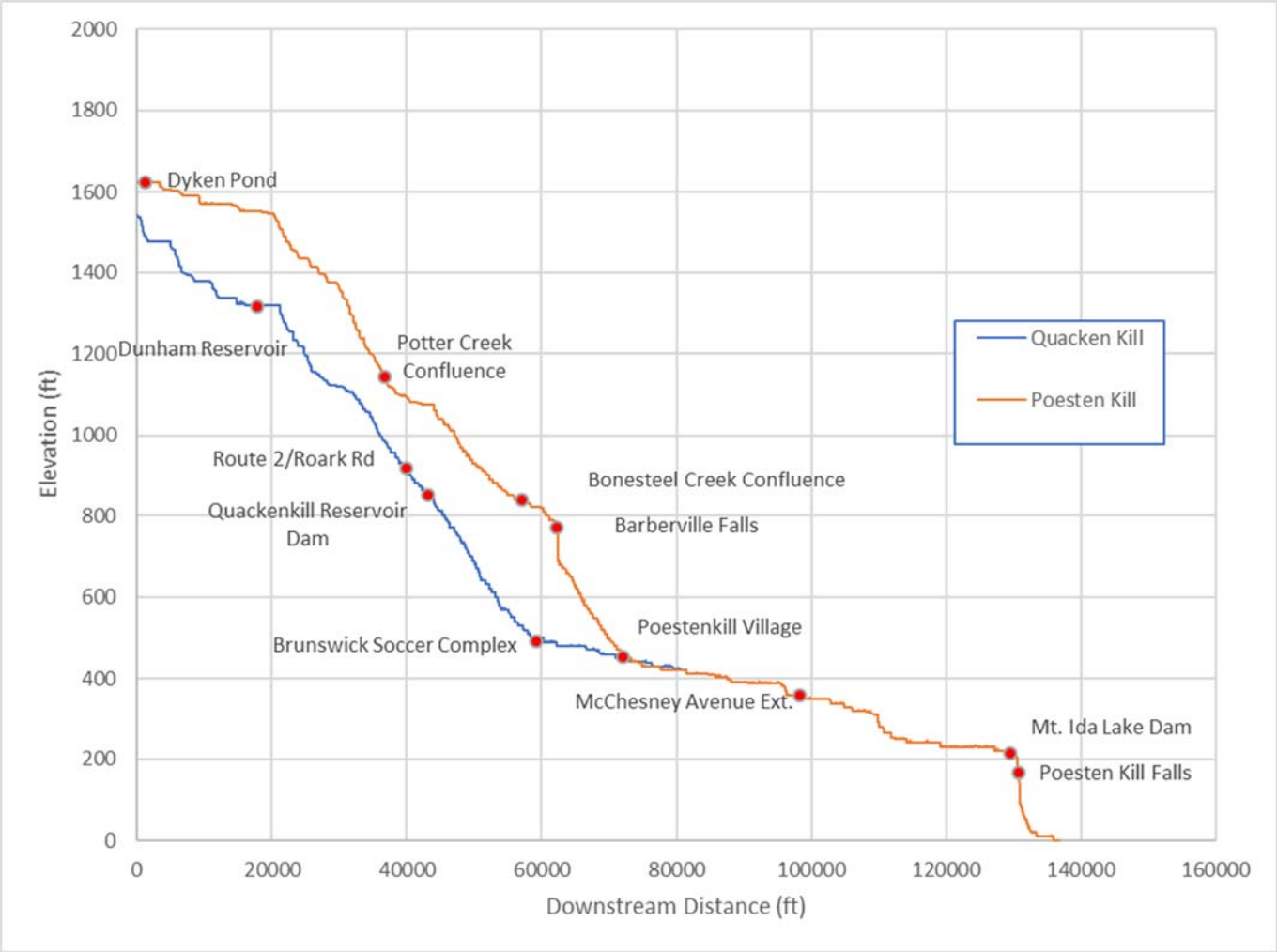

Figure 2. Longitudinal profiles of the Poesten Kill and Quacken Kill, from the headwaters to the confluence with the Hudson River. Points of interest referenced in the report are shown along the profile as red dots. Elevation data derived from 10-meter DEM (CUGIR).

Throughout the watershed, there is evidence that a combination of dredging, berming, and straightening has been a typical management response to these flood and sediment impacts. This approach has resulted in entrenched and over-wide channels that are disconnected from adjacent floodplains, which may serve to reduce the flood risk to properties in the immediate vicinity of the activity but is likely to exacerbate flood peaks in downstream reaches.

The Poesten Kill flows into the Hudson River at Troy. The confluence is downstream of the federal dam and thus within the limits of the Hudson River Estuary.

Studies of climate change impacts in the northeastern U.S. have documented and continue to anticipate a shift toward more extreme precipitation events and higher peak flood flows. For example, Horton et al. (2014) found that the amount of precipitation falling in the heaviest storm events increased by over 70% between 1958 and 2010. Thus, under current climate change

projections, flooding and flood-related impacts in the watershed are likely to intensify. Adaptation is necessary to avoid increasingly significant impacts.

ECOLOGY

According to RPA, the plateau is the fifth largest forested area in New York. Forest types include Appalachian oak-pine, deciduous wetland, evergreen northern hardwood, evergreen plantation, oak, successional hardwood, and sugar maple mesic forests[5]. The watershed provides habitat to fisher, bear, bobcat, moose, porcupine, hermit thrush, and black-throated blue warbler among many other animals as well as rare plants. A complete list of vegetative and animal species can be found on the RPA's website[6].

The New York Audubon Society has recognized the relatively unfragmented forested tract of the Rensselaer Plateau extending from Grafton Lakes State Park in the Poesten Kill watershed in the north to Cherry Plain State Park and the Capital District Wildlife Management Area in the south as an Important Bird Area[5]. The forest is home to an abundance and diversity of birds, including many at-risk species.

Poesten Kill watershed has historically been home to a healthy fish population. Presently there are brook trout (*Salvelinus fontinalis)* in both the Quacken Kill and Poesten Kill. The mainstem of the Poesten Kill is also home to brown trout (*Salmo trutta*). However, according to Trout Unlimited[7], many pools, which are critical habitat for trout, have been destroyed by recent dredging in the river. In addition to brown and brook trout, the watershed is also home to lower trophic level aquatic organisms such as dace, minnows, crayfish, and macroinvertebrates.

As a tributary to the Hudson River Estuary, the Poesten Kill watershed falls within the scope of the recently published Hudson River Comprehensive Restoration Plan (Parters Restoring the Hudson, 2018). The existing conditions assessment included in the plan is limited to the estuary and 200 meters upstream of the first barrier on each tributary; however, the plan outlines several restoration goals and actions that are applicable to tributary watersheds such as removing barriers to aquatic organism passage, improving resilience of native plant and animal communities, reducing excess sediment delivery to the estuary, and improving stormwater management. Other goals and actions such as watershed education are transferrable.

[5]Audubon Important Bird Areas, Rensselaer Forest Tract. https://www.audubon.org/important-bird-areas/rensselaer-forest-tract?site=ny&nid=5341&site=ny&nid=5341
[6] Rensselaer Plateau Alliance, Wildlife. https://www.rensselaerplateau.org/wildlife
[7] Bob Davis, Trout Unlimited, personal communication on October 4, 2018.

Geomorphic Field Assessment

Two Inter-Fluve geomorphologists conducted field surveys on August 20 and 21, 2018, accompanied for a day by a hydrogeologist from Chazen and several local representatives. One geomorphologist returned on April 17, 2019 to get a closer look at some sites during leaf-out conditions. Our intention was to inspect a number of sites (Figure 3) that exemplify the range of challenges and opportunities that exist within the watershed rather than cover the entire 96 square miles, which includes over 90 miles of perennial streams.

Observations made and data collected in the field are summarized below and include photos and the field data collection sheets within Appendix C. Flows during the field assessment were well above the median daily discharge due to a high flow event two days earlier generated by a 2-inch precipitation event. Using the nearby USGS streamflow gage on the Hoosic River (gage number 01334500) as a reference (Figure 4), flows during the survey were roughly one quarter of the peak flow event two days prior, which was roughly one tenth of the flow experienced during Tropical Storm Irene in 2011.

Sites are listed below in order from upstream to downstream, first along the Quacken Kill and then along the Poesten Kill. References to right and left bank are from the standard perspective of looking downstream.

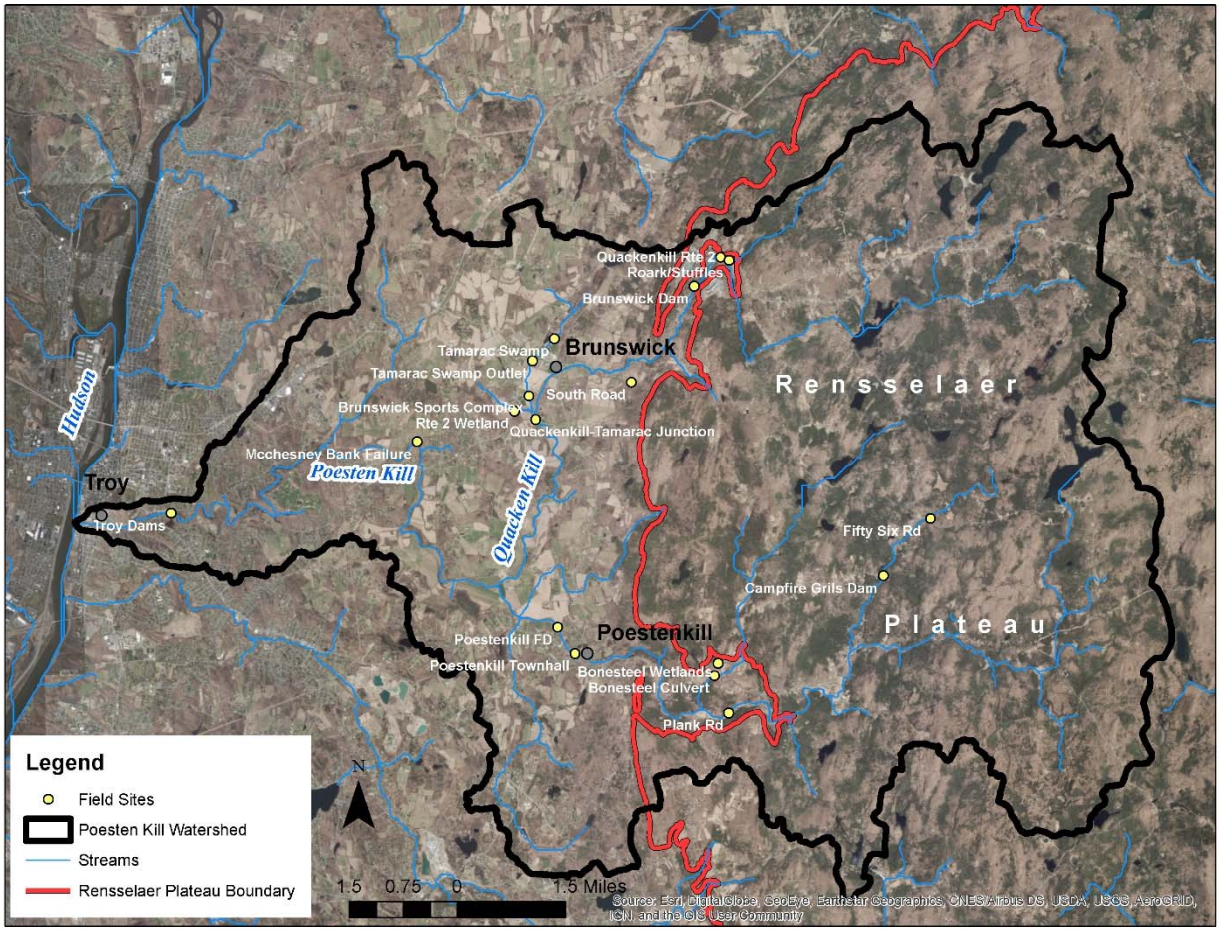

Figure 3. Map of Poesten Kill watershed with field sites labeled. The Rensselaer Plateau escarpment is delineated by a red line.

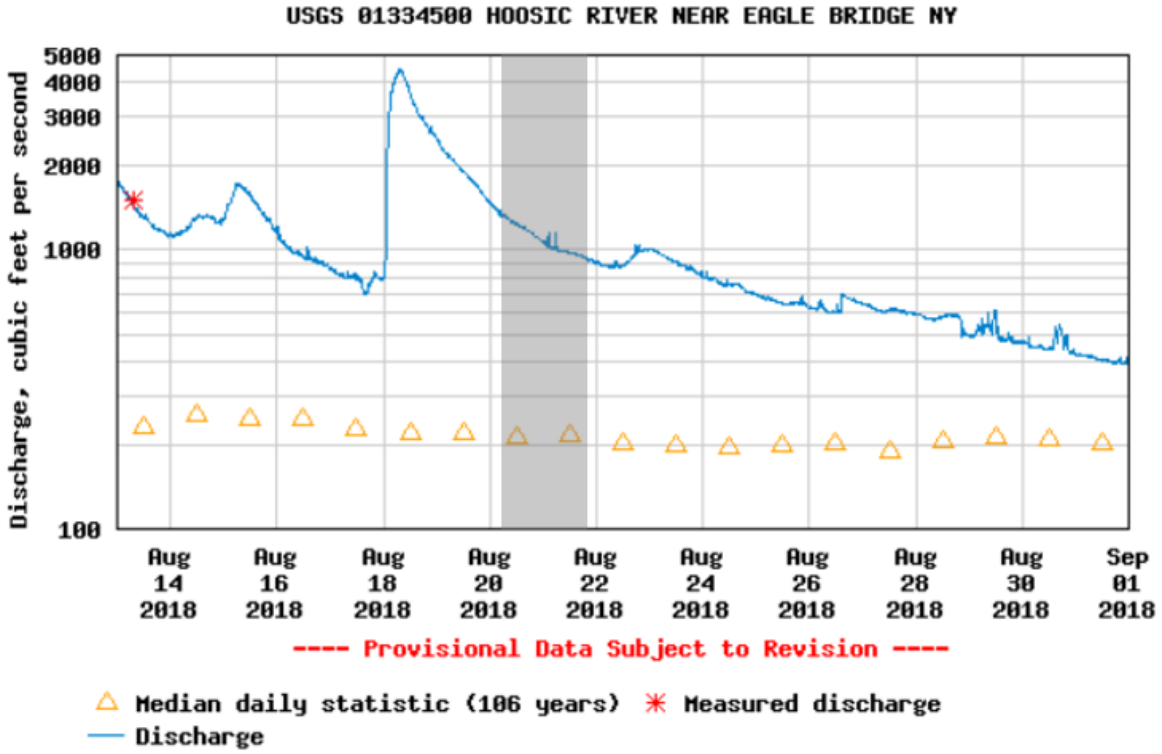

Figure 4. Hydrograph of the Hoosic River in Rensselaer County, a representative gage near the Poestenkill watershed. An approximately 2-inch rain storm produced the high flow event on August 18, 2018. The field survey occurred on August 20 and 21 (shaded in grey) while flows remained well above the median daily discharge. Plot generated at the USGS Surface-Water Daily Data for the Nation website https://waterdata.usgs.gov/nwis/dv?.

ROUTE 2 AT INTERSECTION WITH STUFFLE STREET AND ROARK ROAD CROSSING

A tributary of the Quacken Kill crosses under New York State Route 2 near the intersection with Stuffle Street in Grafton. The drainage area at this point is 2.3 square miles. This site is located on the steep escarpment of the Rensselaer Plateau. The tributary is steep and confined as it approaches Route 2 where it flows into a 4.5-foot wide, 4-foot high concrete box culvert (Figure 5). The stream approaches the culvert at an angle, resulting in a situation that is hydraulically inefficient with the potential for scour by impinging flow against the right bank. A residence on Stuffle Street is located within 10 to 20 feet of the top of the right bank. The culvert, wingwalls, channel banks, and Route 2 road embankment show signs of relatively recent repairs. Anecdotal information and a subsequent conversation with the Town of Brunswick[8] confirm that high flows during Tropical Storm Irene overtopped the culvert and washed out Route 2 at this location, interrupting access and causing substantial damage to the highway. It appears that the original culvert was repaired when the highway was rebuilt but was not replaced with a larger structure with a more hydraulically favorable orientation. Woody debris was observed on the road embankment slope above the headwall, indicating that more recent high flow events than Irene have caused water to back up behind the culvert.

Approximately 300 feet downstream, the tributary crosses under Roark Road through a similarly sized box culvert. Both the Route 2 and Roark Road culverts have concrete bottoms, are perched at their downstream ends, and have been classified as moderate (Route 2) and severe (Roark Road) barriers to aquatic organism passage[9]. Along this section, bankfull width is on the order of 30 feet, and the channel exhibits step-pool morphology dominated by boulders and cobbles with smaller material such as gravel deposited in pools. The channel appears stable through this section, showing no signs of either aggradation nor incision or bank erosion. Between Route 2 and Roark Road, the stream flows through a 4.5-foot wide, 5-foot high box culvert associated with a road crossing that is no longer in use (Figure 6). A substantial build-up of debris was present along the upstream face of the embankment on the date of our inspection. The valley bottom topography in the area suggests that when the culvert is blocked, flow overtops the stream and runs onto Roark Road, possibly affecting access and residences on Roark Road. Approximately 100 feet downstream of Roark Road, the stream empties into the Quacken Kill (Figure 7) and flows under Route 2. The Route 2 bridge has an approximately 40-foot span.

At the time of the survey, the inspected box culverts were roughly one-quarter full, and high-water marks indicated that they were nearly full during the storm that occurred just prior to our field investigation. Given that flows during the survey were only one quarter of the recent summer high-flow event, it suggests that the culverts are overwhelmed during normal high flow events such as

[8] Bill Bradley, Town of Brunswick, personal communication on August 28, 2018.
[9] North Atlantic Aquatic Connectivity Collaborative
https://www.streamcontinuity.org/cdb2/naacc_search_crossing.cfm

the annual flood as well as during extreme precipitation events. This area is outside the extent of existing FEMA flood mapping.

Figure 5. Tributary culvert entrance beneath Route 2 near intersection with Stuffle Street in Grafton. Note concrete repairs to wingwalls and headwall and rip rap repair to right bank. White arrow indicates debris most likely deposited during a recent high flow event when flow backed up behind the culvert.

Figure 6. Looking upstream at relic culvert from a disused road crossing of the Quacken Kill tributary between Route 2 and Roark Road

Figure 7. Quacken Kill immediately upstream of the Route 2 bridge at Paltisch Road and downstream of the Stuffle Street tributary confluence

QUACKEN KILL RESERVOIR DAM

The Quacken Kill Reservoir Dam (Figure 8), owned by the City of Troy, is located along Route 2 on the Quacken Kill approximately 0.75 mile downstream of the Roark Road site. The drainage area at this point is 18 square miles. According to the New York State Inventory of Dams[10], the run-of-the-river dam is 200 feet wide and 25 feet high with a 60-foot-wide concrete spillway and was built in 1905 for public water supply. The impoundment extends approximately 750 feet upstream during low flow and is 150 feet across at its widest point. A steep valley wall rises up from the reservoir on river right. Route 2 runs through the valley above the reservoir on river left. During a high flow event, the reservoir likely provides a trivial amount of flow retention due to its run of the river design. There does not appear to have been any flooding of Route 2 related to the presence of the dam during Tropical Storm Irene. However, large volumes of coarse sediment were delivered to the impoundment, reducing storage capacity of the reservoir.

The water supply facilities of the dam are no longer in use, and we understand that the City has split the parcel and is currently in negotiations to sell both parcels to neighboring quarries. NYS DEC Division of Water, Bureau of Flood Protection and Dam Safety was unable to locate the latest dam inspection report when contacted for this study.

ROUTE 2 DOWNSTREAM OF QUACKEN KILL RESERVOIR DAM

The channel downstream of the dam is generally steep with a boulder bed and step-pool morphology. The channel is constrained to the narrow valley and runs adjacent to Route 2, crossing under the road at a few locations. Where valley width allows, the channel is flanked by low forested floodplain areas that show signs of recent inundation.

This portion of the channel is the source area for the coarse sediment that ends up deposited in the lowland reaches through Brunswick (see Tamarac Road Area below). While we noted bank erosion in some areas, there does not appear to be an issue with widespread vertical or lateral instability. Material is likely derived from the gradual reworking of glacial surficial deposits along the entire length of the channel and tributaries and delivered downstream during flood events.

At two locations, the road surface dips down and sits nearly level with the top of bank (Figure 9). These locations appear to have been dredged and may be particularly vulnerable to flooding and damage. Where residential properties along Route 2 abut the stream, debris including construction materials and trash was found in the channel and along the banks.

[10] http://gis.ny.gov/gisdata/inventories/details.cfm?DSID=1130

Figure 8. Quacken Kill Reservoir Dam

Figure 9. Looking upstream along the Quacken Kill as it runs along Route 2

SOUTH ROAD

Rensselaer County[11] raised the issue of repeated washout and repairs of an incised drainage ditch running along South Road in Brunswick (Figure 10). This site is located near the bottom of the escarpment, just upstream of Brunswick Soccer Complex. The road and ditch, which have been cut into a steep hillside, intercept overland flow paths, small intermittent hillside drainages, and shallow subsurface stormflow (i.e. shallow groundwater moving through soil) that would have otherwise discharged to a low-lying wetland area at the bottom of the hillside as shown in Figure 11. The wetland is not currently shown in mapping by USFWS or NYS DEC. The wetland would naturally drain to the south, and its current outflow is via a 1-foot-diameter culvert under a low spot on South Road. During the survey, there was evidence that the recent rain storm had washed gravel and cobbles out of the ditch and across the road at the bottom of the hill. The material cleaned off the road and out of the ditch at the base of the slope has been piled up along the sides of the ditch to

[11] Linda von der Heide, Rensselaer County Planning, email correspondence on July 16, 2018.

form berms. Another berm has been constructed near the outlet of the wetland to prevent water backing up behind the culvert from overtopping the road.

Figure 10. Incised ditch along South Road, Brunswick

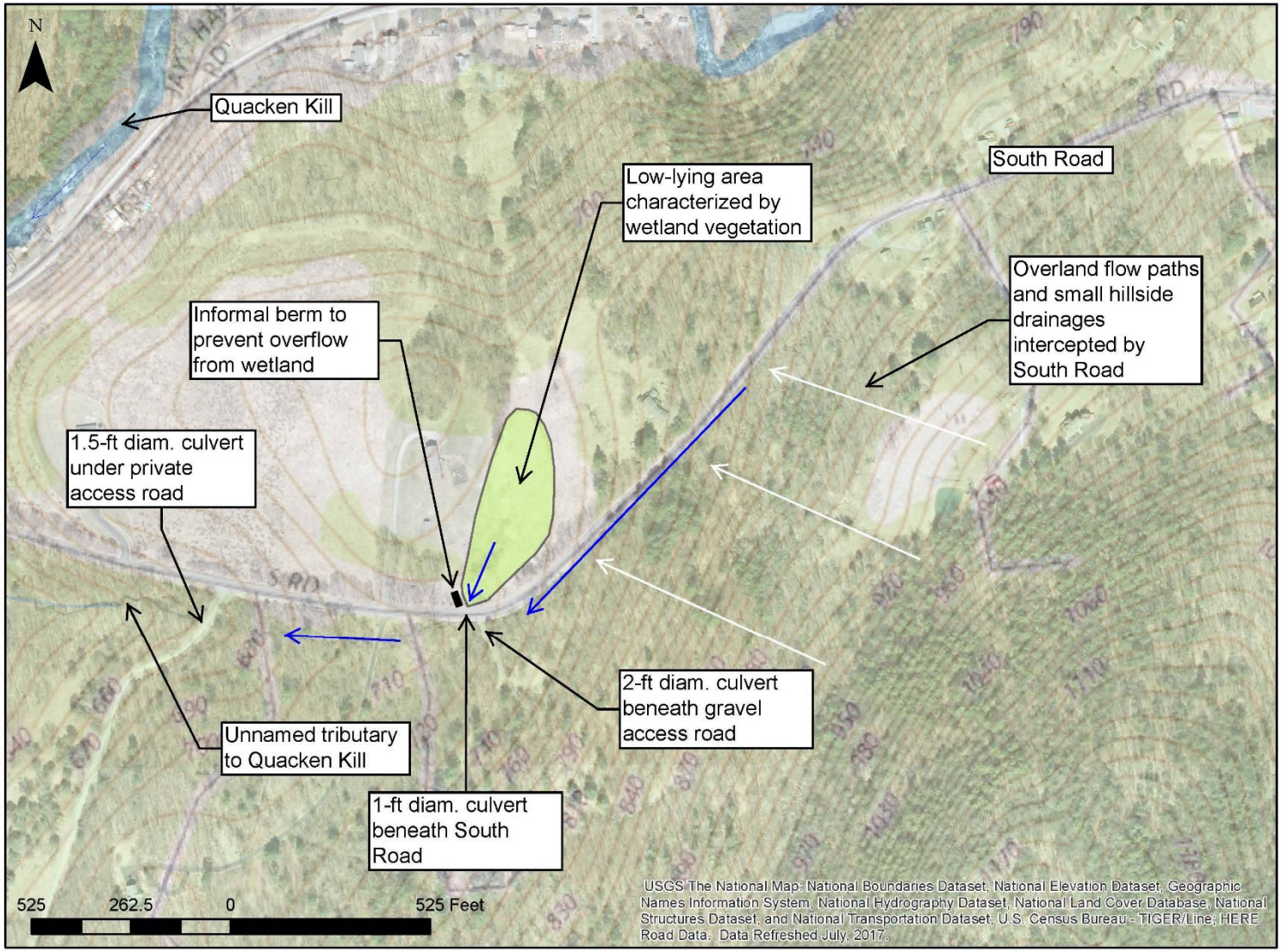

Figure 11. South Road, Brunswick, showing interception of overland flow paths and intermittent hillside channels by South Road, channelized flow along the road ditch (blue arrows) and into an unnamed tributary to the Quacken Kill. Approximate extent of low-lying area of wetland vegetation shown in green. Data sources: 2017 Rensselaer County high-resolution digital orthoimagery (NYS Office of Information Technology Services, GIS Program Office, 2017) and USGS topo map (source data listed on map).

TAMARAC ROAD AREA

The Brunswick Soccer Complex is located at the toe of the escarpment coming off the Rensselaer Plateau and immediately downstream of the New York State Route 351 bridge (Figure 12). The drainage area at the soccer complex is 21 square miles. During Tropical Storm Irene, large volumes of coarse sediment were deposited in the channel and on the floodplain at the complex. The floodplain was cleared and the channel dredged and the material placed at the top of the right bank to form a berm between the channel and the soccer complex. The top of the berm sits an estimated 2 to 4 feet above floodplain level.

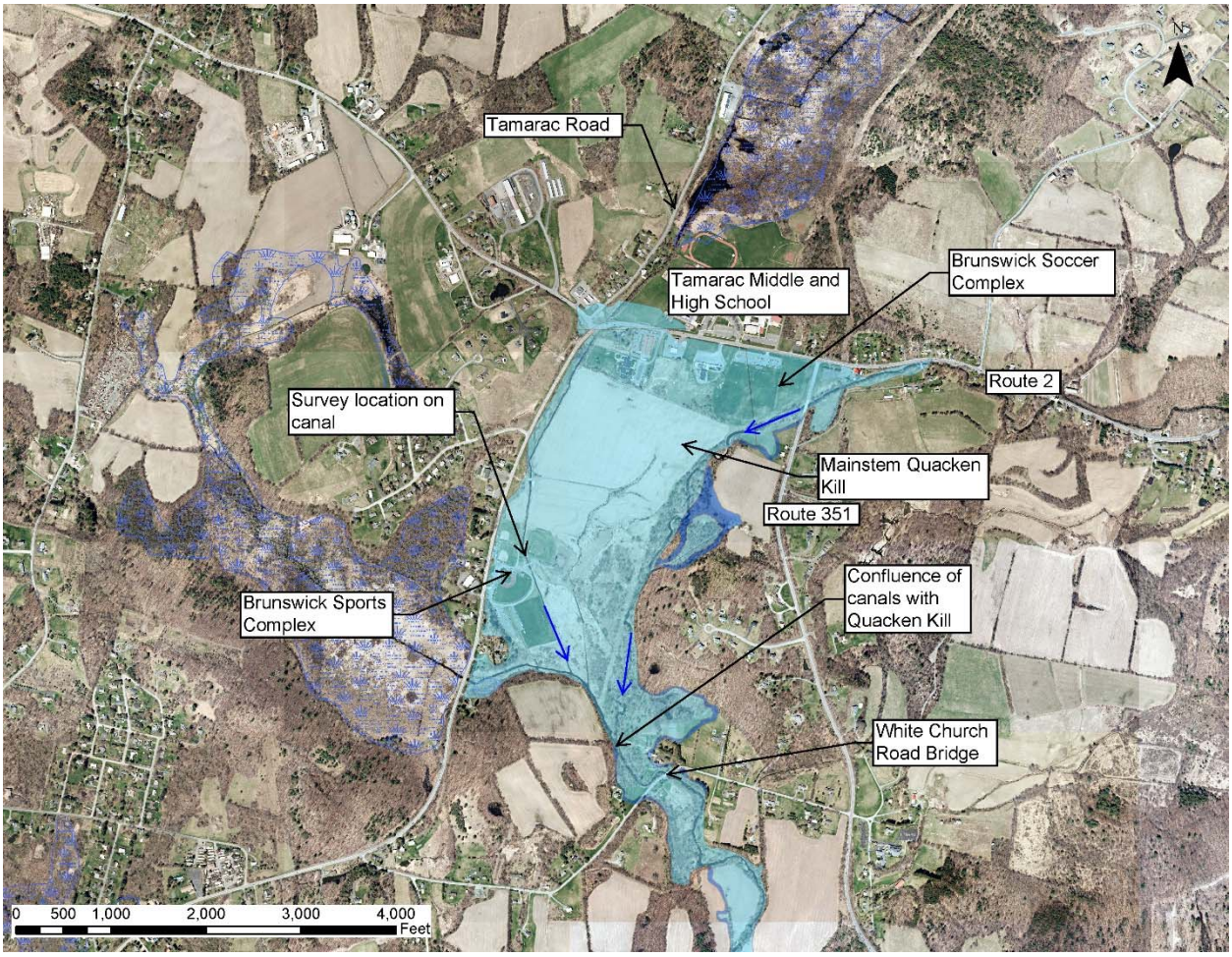

Figure 12. Tamarac Road area in Brunswick showing mainstem Quacken Kill, wetlands and drainage canals. Blue arrows indicate flow direction. Freshwater wetlands mapped by the New York Department of Environmental Conservation (NYS DEC wetlands) and FEMA 1% annual chance (light blue) and 0.5% annual chance (dark blue) flood extents are shown. Basemap imagery is 2017 Rensselaer County high-resolution digital orthoimagery (NYS Office of Information Technology Services, GIS Program Office, 2017).

A tributary of the Quacken Kill flows through a wetland draining a low-lying area at the toe of the escarpment between the Tamarac Middle and High School and Tamarac Road in Brunswick (Figure 12). The drainage area at this point is 3.6 square miles. At the outlet of this wetland, the flow enters an earthen canal that conveys the water along a farm field and through the Brunswick Sports Complex. In total, the canal runs nearly a mile to the confluence with the Quacken Kill. The canal is trapezoidal and measures approximately 22 feet wide and has been dredged to a depth of approximately 5 to 6 feet below the surrounding floodplain surface (Figure 13). The bed is muddy and weedy with no bedforms present. Flow on the day of the survey was approximately 1.7 feet deep and sluggish despite observations of moderate flow and flow velocities in other channels on the day of the survey.

Figure 13. At the Brunswick Sports Complex on Route 2, looking upstream at the tributary draining wetlands along Tamarac Road

Additional canals were dug to drain other wetland areas in the same vicinity (Figure 12). Further investigation of the downstream canal and its confluence with the Quacken Kill (see White Church Road section) indicates that sediment deposition and flow depths along the Quacken Kill control base level and drainage of the canals and wetlands. At the time of the survey, moderate flow in the Quacken Kill caused a backwater effect in the canals such that discharge from the canals was relatively low. This suggests that during flood events, water is held in the wetlands and along the canals until flow levels in the Quacken Kill have dropped, allowing these low-lying areas to drain. This is consistent with FEMA mapping which shows the entire floodplain between the canal and the Quacken Kill within the limits of flooding during a 100-year event.

We surveyed an approximately 1,000-foot-long reach of the Quacken Kill upstream of the White Church Road Bridge to the confluence with the drainage canals. The drainage area at this point is 26.6 square miles Along this reach, the channel has a bankfull width of approximately 50 feet and a bankfull depth of approximately 4 feet. The channel appears stable, showing no signs of persistent aggradation or erosion. The bed is composed predominantly of gravel and cobbles, with a median grain size of approximately 1.5 inches. Deep pools are found on the outsides of channel bends and associated with occasional large wood elements, but the channel otherwise has a consistent depth from bank to bank, with no pronounced thalweg. The channel sits in a broad valley with forested floodplain along both banks. More detailed observations are included in the data sheets in Appendix C.

A large mid-channel bar has formed at the confluence where the drainage canal empties into the Quacken Kill (Figure 14). The cross section at this location is locally relatively wide, which causes flood flows from the Quacken Kill to slow and deposit bed material, building the bar. Evidence of recent flattening of the vegetation growing on the bar indicates that although flow in the Quacken Kill was still moderate at the time of the survey, it had receded since the peak of the runoff following the 2-inch precipitation event. As discussed in the previous section, moderate flow in the Quacken Kill appeared to be causing a backwater effect in the upstream drainage canals (Figure 14B). Surface flow velocity in the Quacken Kill was estimated in the field to be approximately 4 ft/s; surface flow velocity along the drainage canal was negligible.

Figure 14. (A) Looking downstream across the mid-channel bar at the confluence of the drainage canal on right and mainstem Quacken Kill on left. (B) Drainage canal where it enters Quacken Kill showing backwater effect as a result of moderate flow level in the Quacken Kill.

FIFTY SIX ROAD AND THE CAMPFIRE GIRLS DAM

Near the intersection of Fifty Six and North Roads, Potter Creek, a tributary of the Poesten Kill flows over the privately owned Campfire Girls Dam. The drainage area at this point is 3.8 square miles. This site is located on the escarpment of the plateau. According to the New York State Inventory of Dams, the concrete gravity and earthen run of the river structure was built in 1926 and is 65 feet wide and nine feet high with a 40-foot-wide concrete spillway. The area of the impoundment is approximately 5.5 acres. At the base of the spillway, Potter Creek passes under North Road through two large, round corrugated metal culverts, both perched on the downstream end (Figure 15A). During Tropical Storm Irene, high flows over the dam washed out North Road, leaving the original culvert and part of the concrete headwall. The Town of Poestenkill installed a second culvert when they repaired the road following the flood. The actual benefit in terms of flow conveyance is likely limited because of the close proximity to the spillway where substantial turbulence and complex hydraulics make flow entrance into the culverts highly inefficient. The twin culverts would also be prone to blockage by debris transported over the dam in a flood.

Improvements were also made to the earthen embankment portion of the dam on river left following Tropical Storm Irene. The embankment on river right exhibits bare soil, extensive tree growth, and animal burrowing, suggesting that it may remain vulnerable to damage during future extreme events (Figure 15B).

Approximately one mile upstream of the Campfire Girls Dam, Potter Creek flows under Fifty Six Road through twin 36-inch PVC culverts (Figure 16). The creek overtopped the road at this location during Tropical Storm Irene and destroyed a section of the road. The current configuration of the twin culverts plus an additional overflow culvert on the right bank was reconstructed by the Town of Poestenkill as a like-for-like replacement of what was in place prior to Irene. High-water marks from the recent precipitation event indicated that the culverts had been flowing more than half full.

Figure 15. (A) Campfire Girls Dam taken from North Road. The culverts carrying flow from the base of the spillway under the road are visible in the foreground. (B) View of a portion of the earthen embankment on river right.

Figure 16. Outlets of twin 36-inch culverts on Potter Creek at Fifty Six Road, approximately one mile upstream of Campfire Girls Dam

PLANK ROAD

Plank Road runs through the narrow Poesten Kill valley along the face of the Rensselaer Plateau escarpment east from the hamlet of Poestenkill upstream past Barberville Falls to the headwaters of the watershed. Residences are located along the road where the valley is locally wide enough for limited property development; these areas correspond with local reductions in channel gradient. Multiple bridge crossings and the close proximity of the road and homes to the stream channel mean that Plank Road, similar to Route 2 along the Quacken Kill, is particularly vulnerable to the effects of extreme flood events. During Tropical Storm Irene, abundant coarse sediment sized from gravel to boulders was deposited in the channel, Plank Road was washed out, and private residences were damaged. The stream was subsequently dredged and material piled onto the top of the left bank to form a berm (Figure 17).

Figure 17. Looking upstream at the Poesten Kill as it flows along Plank Road upstream of Barberville Falls and the Blue Factory Road bridge. Bed material dredged from the channel has been piled up at the top of the bank on river left (right side of photo).

BONESTEEL CREEK WETLANDS

Bonesteel Creek is a primary tributary of the Poesten Kill upstream of its confluence with the Quacken Kill. This site is also located on the escarpment. Upstream of Columbia Hill Road near the intersection with Blue Factory Road, Bonesteel Creek flows through an approximately 55-acre mapped wetland situated in a small valley underlain by outwash sands and gravels. The drainage area at this point is 8.3 square miles. A tributary enters the wetland from the north. Aerial photographs show drainage ditches dug through the wetland (Figure 18). A portion of the wetland is currently protected under a conservation easement through the Wetlands Reserve Program of the U.S. Natural Resources Conservation Service (NRCS).

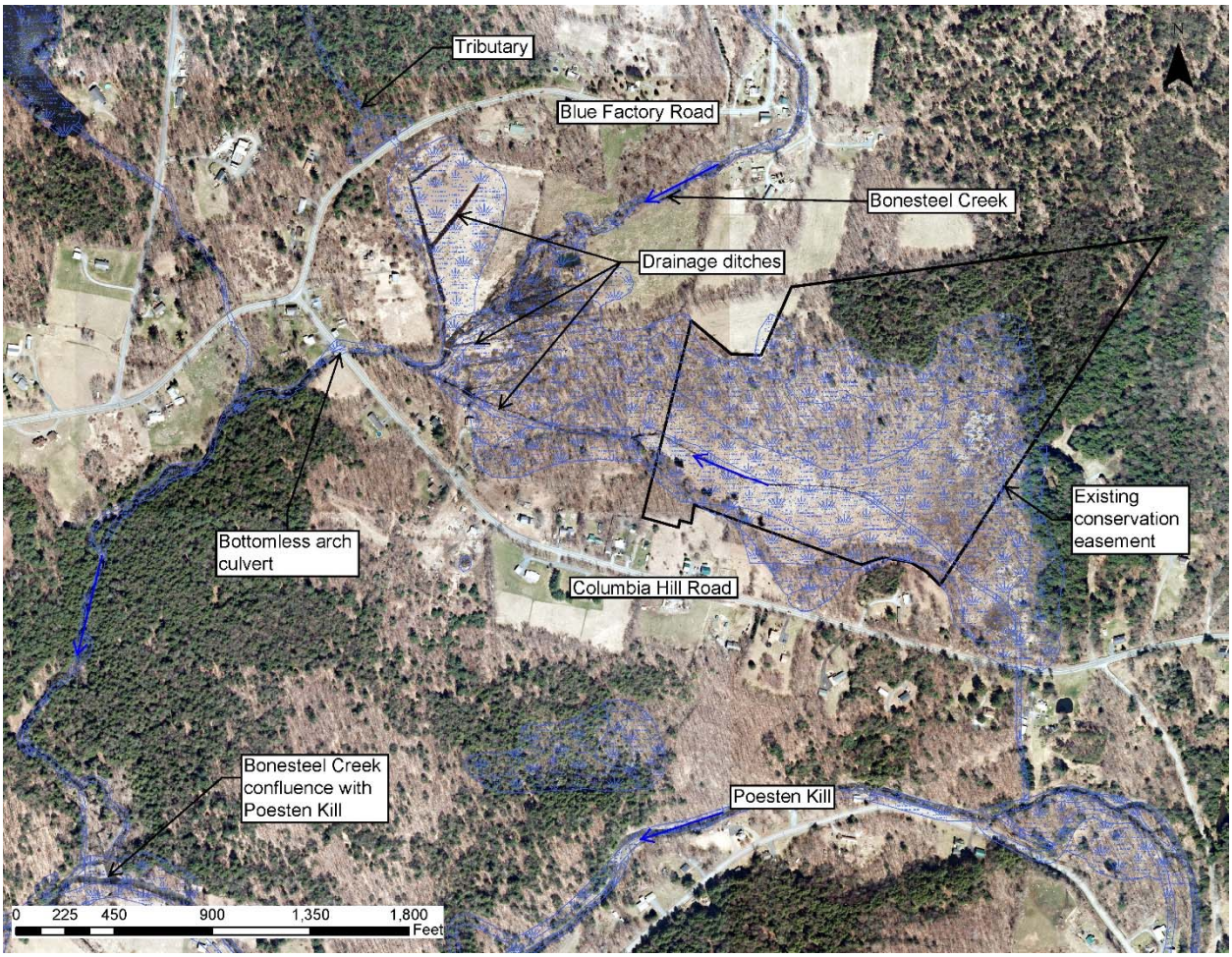

Figure 18. Wetlands (light blue shading) along Bonesteel Creek upstream of Columbia Hill Road showing drainage ditches. Black polygon is an existing conservation easement held by NRCS. Data sources: 2017 Rensselaer County high-resolution digital orthoimagery (NYS Office of Information Technology Services, GIS Program Office, 2017), National Wetlands Inventory (U.S. Fish and Wildlife Service), NYS DEC wetlands, and National Conservation Easement Database.

Channel flow resumes at the outlet of the wetland (Figure 19), approximately 350 feet upstream of the Columbia Hill Road culvert. The channel here is approximately 20 feet wide with a floodplain corresponding to bankfull conditions that narrows toward the culvert. The channel bed is composed of cobbles and gravel, and an existing riffle appears to provide the grade control for outflow from the wetland. Floodplain vegetation includes a combination of mature trees and herbaceous species, and evidence of recent activity suggests that the understory is actively managed and cleared. Hence, roughness elements such as large wood and boulders are scarce both in the channel and on the floodplain, with the wetland draining relatively unimpeded. Rensselaer County replaced the culvert under Columbia Hill Road with a large bottomless arch following washout of the road during Tropical Storm Irene.

Figure 19. Downstream end of Bonesteel Creek wetland located upstream of Columbia Hill Road

POESTENKILL VILLAGE

Just downstream of Poestenkill village, an approximately 700-foot-wide floodplain is situated between the Poestenkill Fire Company and the mainstem of the Poesten Kill (Figure 20), approximately 0.5 mile upstream of the Quacken Kill confluence. The drainage area at this point is 38 square miles. The reach extending from here approximately one mile upstream to the White Church Road (Route 351) bridge is located at the stream's abrupt transition from higher to lower gradient (Figure 2), in an area prone to deposition. Large volumes of coarse sediment were deposited in this reach during Tropical Storm Irene, and some low-lying properties were flooded. Following the flood, and historically during other large magnitude events, the channel was dredged and straightened along much of its length with the dredged material used to construct a berm at the top of the left bank (Figure 21). Review of historical photographs suggests that dredging and straightening has been part of the management strategy along this reach since at least the 1950s[12].

Gradient declines through this reach from approximately 0.01 ft/ft at the Route 351 bridge and flattening out at approximately 0.005 ft/ft at the fire station. In the channel near the station, bankfull width and depth were measured to be approximately 50 feet and 3.6 feet, respectively. The channel is oversized, and bankfull depth was estimated based on the elevation of a top of small floodplain bench on river right and indicators such as the top elevation of persistent granular erosion and bottom elevation of perennial vegetation growth. The top of the berm on river left sits approximately 2 to 3 feet higher than estimated bankfull and 1 to 2 feet above floodplain level (Figure 21). The bed is composed of mostly gravel and cobbles, with a median grain size of approximately 2 inches. The combination of lower gradient and oversized dimensions has made this stretch of the channel particularly prone to deposition. Dredging has also resulted in low complexity in flow and habitat; some alternating bars are present, but the reach is generally devoid of other features such as deep pools, overhanging banks, and large wood that would serve as habitat for fish and other aquatic species.

[12] Historical aerial imagery via NETRonline www.historicaerials.com/viewer . Accessed October 13, 2018.

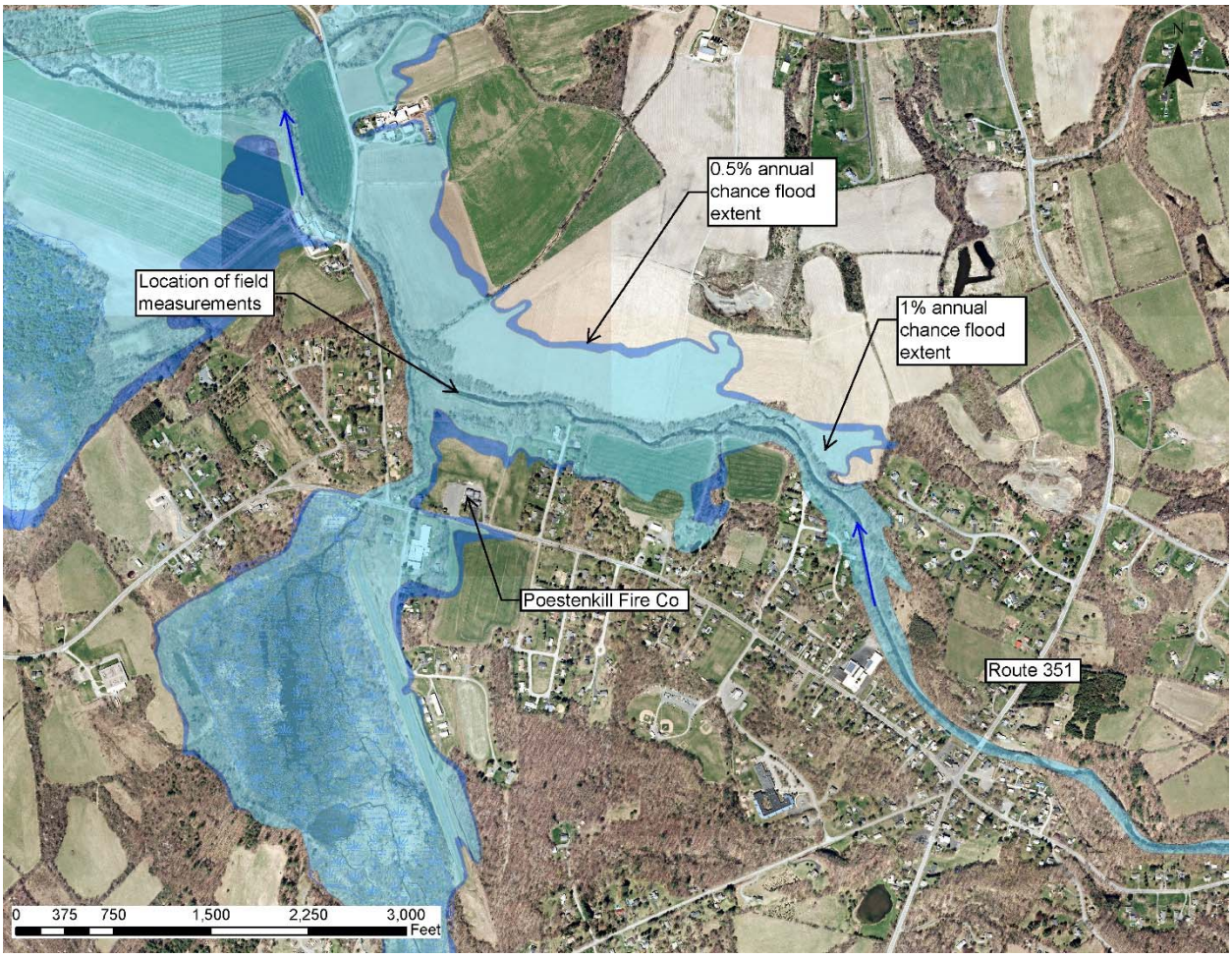

Figure 20. Mapped flood extents along the Poesten Kill at the Poestenkill Fire station. Data sources: 2017 Rensselaer County high-resolution digital orthoimagery (NYS Office of Information Technology Services, GIS Program Office, 2017) and FEMA flood extents.

Figure 21. Looking upstream along the Poesten Kill channel at the Poestenkill Fire Station. Dredging and construction of a berm from dredged gravel has disconnected the channel from its floodplain on river left (right side of photo). A lower floodplain bench is visible on river right (left side of photo) adjacent to farm fields.

MCCHESNEY AVE EXTENSION BLUFF EROSION

We observed the eroding bluff forming the right bank of the Poesten Kill at McChesney Ave Extension, and County-owned road, in Brunswick. The drainage area at this point is 84.2 square miles. Analysis of aerial imagery shows that the eroding face has been present since at least 1952[13]. In that time, the bluff has been steadily retreating. The failing portion of the bluff is an approximately 100 feet tall and 400 feet long section of the bank along an outside bend in the river. The eroding material is mapped as till, and the face of the slope is unvegetated and poorly consolidated, with rills and gullies dissecting the surface (Figure 22). During precipitation events, the bluff is likely a notable source of sediment, via erosion at the toe by elevated flow in the Poesten Kill and mobilization of sediment down the face of the slope by surface runoff. Numerous deposits of coarse sediment observable in the channel downstream of the bend were likely derived from this

[13] Historical aerial imagery via NETRonline www.historicaerials.com/viewer . Accessed October 13, 2018.

source. In addition to water quality issues created by high sediment loading, continued bank retreat poses a threat to McChesney Ave Extension and a residence at the top of the scarp. Currently the top of the eroding face is 20 to 30 feet from the road.

The Town of Brunswick has been visually monitoring bank retreat over a number of years and has confirmed that retreat continues to occur at a steady rate[14]. The County extended the guard rail along the road at the top of the bluff in summer 2018 to improve road user safety. No other improvements are planned at the site and no formal monitoring program is in place.

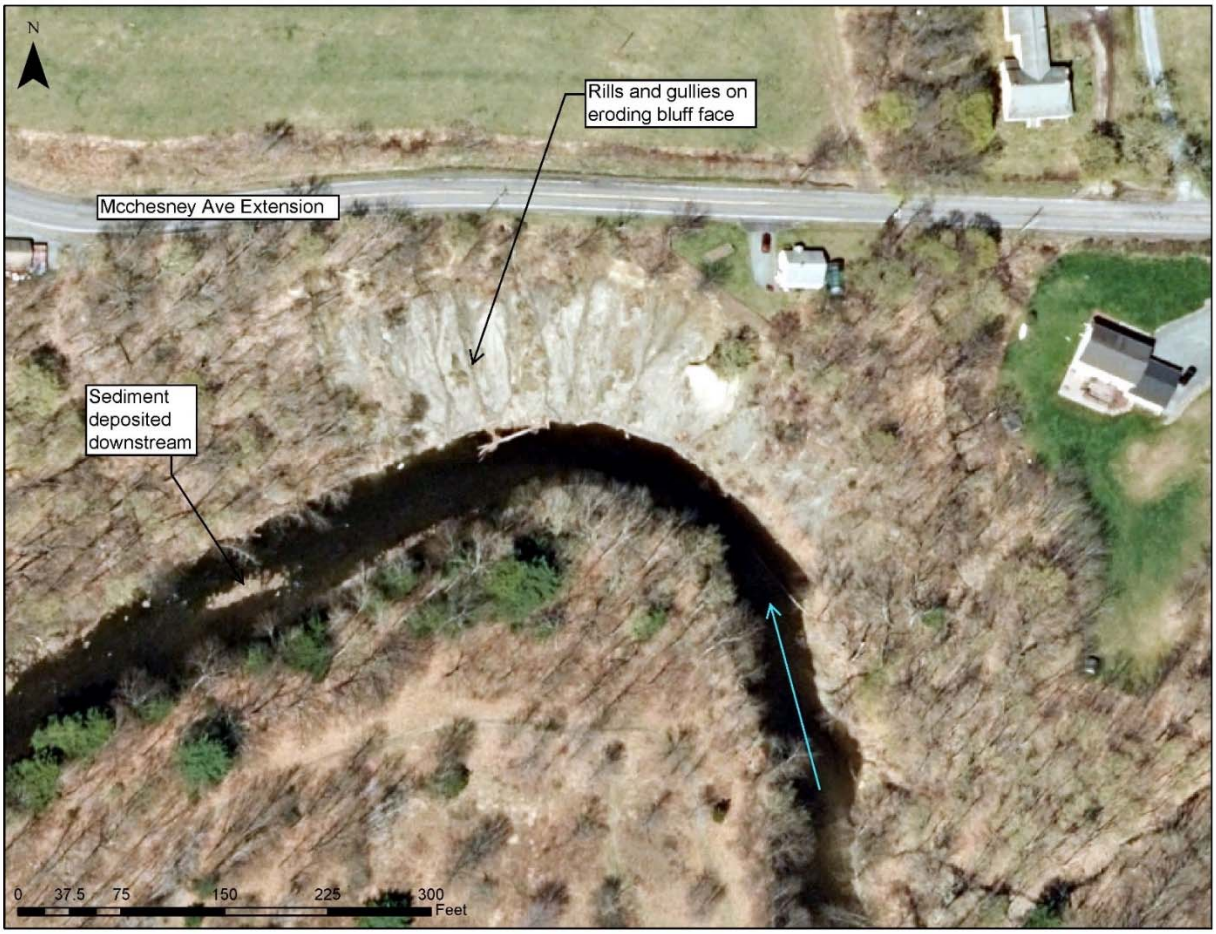

Figure 22. Eroding bluff at Mcchesney Ave Extension in Brunswick. Blue arrow indicates flow direction in the Poesten Kill. Data source: 2017 Rensselaer County high-resolution digital orthoimagery (NYS Office of Information Technology Services, GIS Program Office, 2017).

[14] Bill Bradley, Town of Brunswick, personal communication on November 9, 2018.

IDA LAKE DAM

Ida Lake Dam is located on the Poesten Kill within the City of Troy. It is one of two dams owned by the City; the second being Mt Ida Falls Dam located approximately 1,100 feet downstream at the head of the Poesten Kill Gorge. Originally constructed in 1912, the 135-foot-long, 12-foot-high timber spillway structure was reconstructed in 2000-01 after it breached in 1998 (CDM Smith, 2012). The dam sustained damage during Tropical Storm Irene, and a recent inspection revealed structural issues that raise concerns about the possibility of a future breach and sudden inundation of downstream areas (Schnabel Engineering, 2018). In the short term, the lake will be drained in a controlled manner by removing the central portion of the spillway to avoid sudden failure. The City is exploring long-term options including; dam removal, replacement with a more resilient, non-timber structure, and replacement with a more resilient structure at a lower elevation[15].

Summary and Recommendations

The watershed's location on either side of the edge of the Rensselaer Plateau is the primary influence on the flood dynamics in the watershed. The upper watershed is a source of runoff that is rapidly conveyed through narrow valleys incised into the face of the steep escarpment forming the western boundary of the plateau. Sediment mobilized along the escarpment is deposited at the base of the escarpment during large flood events, forcing flow out of banks.

Land-use modifications and human activities further affect flooding and its consequences. Development within the narrow valleys of the escarpment has constrained the Quacken Kill and Poesten Kill, reduced riparian buffers, increased runoff, and increased potential for flood damages. Roads crossings frequently restrict flows and are vulnerable to failure when blocked or overtopped. In lowland areas, development and agricultural practices occupy floodplains and encroach into riparian buffers, and channel maintenance practices have left channels disconnected from floodplains reducing flood storage and increasing conveyance of flood flows further downstream.

We recommend an approach to increasing flood resilience that is tailored to the landscape and the different processes dominating various parts of the watershed. This "nature-based" strategy is ecologically sound and results in lasting, cost-saving solutions because it focuses on working with natural stream processes rather than trying to suppress or control them through post-flood maintenance actions.

In the headwaters on the plateau, opportunities should be sought to store water on floodplains, in wetlands, and utilizing existing flood storage of existing dam infrastructure. Forest cover should be

[15] More information about the Ida Lake Dam Project can be found on the City's project website: http://www.troyny.gov/departments/engineering-department/engineering-projects/mount-ida-dam-project/

maintained and expanded to help maximize interception and evapotranspiration and slow runoff. Riparian buffers should be encouraged to help stabilize banks and slow flood flows.

In the steep reaches on the plateau and along the escarpment, efforts should focus on improving the ability of roads, road crossings, and other infrastructure to withstand the passage of large floods without extensive damage or catastrophic failure and on slowing flows and reducing erosion. Road crossings should be upsized to pass larger flows and debris to avoid catastrophic failure. Relic or redundant structures such as dams, weirs, and culverts that no longer serve a purpose should be removed, prioritizing those that could fail catastrophically. Best management practices (BMPs) should be implemented to intercept road drainage, slow runoff, and reduce gullying and erosion along steep road sections. Roughness should be added to the channel in the form of large wood grade control structures where appropriate to slow flows, enhance the limited floodplain storage that is available, and trap coarse sediment. Finally, if significant point sources of coarse sediment are identified, ecologically sensitive bank stabilization projects should be implemented as appropriate.

In the western lowlands, vulnerable development types should be encouraged to relocate outside flood-prone areas where possible, and future development should be restricted to higher ground. In reaches within natural zones of deposition, steps should be taken to give the channel room to aggrade, build bars, and shift position. Repeated dredging operations should be minimized to reduce adverse impacts to in-stream habitat and maintain more natural cross-section conditions. Overwide channels formed by dredging can cause further instability by exacerbating aggradation through reduced flow depths and velocities compared with a naturally formed channel. Floodplains and wetlands should be maintained, protected, and enhanced to store and slow floodwaters. Artificial barriers and restrictions that elevate upstream flood levels should be removed.

Table 2 provides examples of the strategy described above that are focused on the sites included in the field assessment in addition to watershed-wide recommendations. Sketches for selected projects are provided in Appendix B. The concepts may and should, however, be applied as appropriate to other opportunities and problem areas within the watershed to achieve a comprehensive approach that is expected to have a measurable effect.

The following projects are limited to resilience alternatives related to channel and floodplain geomorphology and function; other alternatives, including reservoir operations and other infrastructure-related work will be presented in the wider report by Chazen. We recognize that the project list is by nature incomplete in that it does not cover all possible actions that could be taken at every site within the watershed. These project examples have been provided as a starting point, and the list should be expanded as more information is gathered and opportunities are identified.

Table 2. Project alternatives to improve resilience by addressed channel and floodplain geomorphology and function

Location of example project	Description	Figure in Appendix B
Route 2/ Roark Road (escarpment)	Replace the Route 2 and Roark Road tributary crossings with structures sized to the channel and adequate to pass extreme floods, including debris generated during extreme floods. Remove relic culvert at disused crossing between Route 2 and Roark Road. Project would reduce the risk of flood damages, improve local resilience to flooding, and reduce risk of public safety.	
Quacken Kill Reservoir Dam (escarpment)	Confirm structural integrity of dam and investigate feasibility of removal to eliminate maintenance and the risk of failure and to restore the channel and aquatic organism passage. Alternatively, maintain a robust inspection schedule and make repairs as necessary to ensure the integrity of the structure.	
Quacken Kill along Route 2 (escarpment)	Evaluate low-lying stretches of Route 2 for flooding issues and raise the road if necessary to reduce risk and eliminate need for dredging. Install valley-spanning engineered large wood structures where opportunities exist to increase floodplain storage, slow flows, control grade in the channel, and trap coarse sediment. Implement bioengineered bank erosion control projects where appropriate to stabilize coarse sediment.	
South Road (escarpment)	Install regularly spaced ditch relief culverts to intercept road drainage and route flows into an existing wetland. Regrade and repair the road ditch. Replace the culvert under South Road at the outlet to the wetland with an appropriately sized structure and construct a berm to prevent overflow from the wetland onto the road. Consider raising the road over approximately 300 feet at the crossing to prevent overtopping. Confirm adequate sizing of downstream culverts. The project would reduce flood damages, increase the resilience of the road, and slow runoff.	Concept 1

Location of example project	Description	Figure in Appendix B
Tamarac Road area (lowlands)	Relocate the Brunswick Soccer Complex away from the toe of the escarpment and the main Quacken Kill channel. Remove the berm at the existing complex and restore floodplain connectivity. Enhance the existing floodplain to increase flood storage and conveyance. Relocate power lines outside of floodplain enhancement area. Relocation and floodplain enhancement would require land purchase and should be supported by further investigation and hydraulic study.	
Campfire Girls Dam (plateau)	Remove Campfire Girls Dam and replace culvert under North Road with a larger structure to improve resilience, reduce the risk of failure, and reduce risk to public safety.	
Fifty Six Road (plateau)	Replace twin culverts with an appropriately sized structure to improve resilience of the road.	
Plank Road (plateau/escarpment)	Carry out a more detailed geomorphic assessment to investigate point sources of coarse sediment and define limits of depositional reaches. Address sediment generation at source using ecologically sensitive methods. Establish and enhance riparian buffers. Design crossings to pass debris and use bioengineering techniques to stabilize the streambanks at road embankments. Inform residents of options for buy outs or individual property protection.	
Bonesteel Creek wetlands (plateau)	Increase flood retention in existing wetlands by blocking artificial drainage ditches, re-meandering channels, and/or installing wood or boulders and enhancing floodplain roughness to slow outflow. Lateral and longitudinal extents should be designed to prevent outflanking during high flows. Expand the existing conservation easement to include the entire wetland.	Concept 2 (two options)

Location of example project	Description	Figure in Appendix B
Poestenkill Village (lowlands)	Buy out properties susceptible to repeat flooding, and rehabilitate the channel through re-meandering, appropriate sizing, and installation of measures to introduce hydraulic complexity and facilitate sediment transport. Remove berms, reconnect floodplains, and expand riparian buffers. Channel design should be supported by further investigation and hydraulic study. Concept 3 as shown in Appendix B is focused on the land immediately adjacent to the Poestenkill Fire Company. Extending the concept upstream to Route 351 will require property acquisition.	Concept 4
Mcchesney Ave Extension (lowlands)	Establish a monitoring program and carry out a geotechnical investigation to assess the risk of failure. Depending on the results, consider options for eliminating the hazard such as implementing a bluff stabilization project or relocating the road.	
Watershed-wide	Educate the community about the watershed's geologic, geomorphic, and hydrologic context. Explain the natural processes at work and how these are likely to be exacerbated with climate change. Work with landowners to curb unsustainable practices such as dredging and berming.	
Watershed-wide	Complete additional field-based geomorphic assessments along reaches of the Quacken Kill, Poesten Kill, and tributaries not included in this study to identify point sources of coarse sediment and additional opportunities for restoration and enhancement. Address sediment generation at source, where appropriate, using ecologically sensitive methods.	
Watershed-wide	Create an inventory of roads that contribute to flood peaks by intercepting and concentrating runoff. Systematically develop and implement BMPs to slow runoff and reduce erosion.	

Location of example project	Description	Figure in Appendix B
Watershed-wide	Expand and formalize training and resources for the public and county and municipal staff that focus on flood resilience and natural systems solutions and management practices that support watershed resilience. Among other sources of information and ideas are Vermont's Rivers and Roads and Flood Ready Vermont programs, or Maine Audubon's Stream Smart program.	
Watershed-wide	Establish and advertise a stream buffer program or advertise existing programs such as the Hudson River Estuary Program's Trees for Tribs to assist private landowners in developing and implementing planting plans.	
Watershed-wide	Establish conservation easements to protect and restore priority riparian corridors, wetlands, and forested areas. Support the program with a study that prioritizes parcels for easement acquisition.	
Watershed-wide	Via the New York State Hemlock Initiative, partner with NYS DEC and Cornell University Cooperative Extension to hold a Hemlock Woolly Adelgid (HWA) workshop to educate public and private landowners and managers on the importance of hemlock trees in local forests, the threat presented by HWA, and how landowners can identify and manage HWA infestations.	

Location of example project	Description	Figure in Appendix B
Watershed-wide	Establish a watershed alliance to lead the development of a watershed plan that dovetails with the Hudson River Comprehensive Restoration Plan (Partners Restoring the Hudson, 2018), incorporates the recommendations from this study, and expands recommendations beyond flood risk management. The role of an alliance may also include raising awareness about critical issues, educating the public, monitoring streams, and completing stream improvement and clean-up projects. RPA has established a committee to assist with the current project; the possibility of transitioning this committee into a watershed organization should be explored.	

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Partners Restoring the Hudson, 2018. Hudson River Comprehensive Restoration Plan: Recommendations for the New York-New Jersey Harbor & Estuary Program Action Agenda and the New York State Hudson River Estuary Action Agenda. New York, NY. The Nature Conservancy.

Schnabel Engineering, 2018. Letter to Chris Wheland, Superintendent of Public Utilities, City of Troy, Subject: Recommendation for Lake Lowering, Ida Lake Dam Structure Inspection, NYS ID: 226-1391. September 19, 2018.

Appendix A – Existing Data

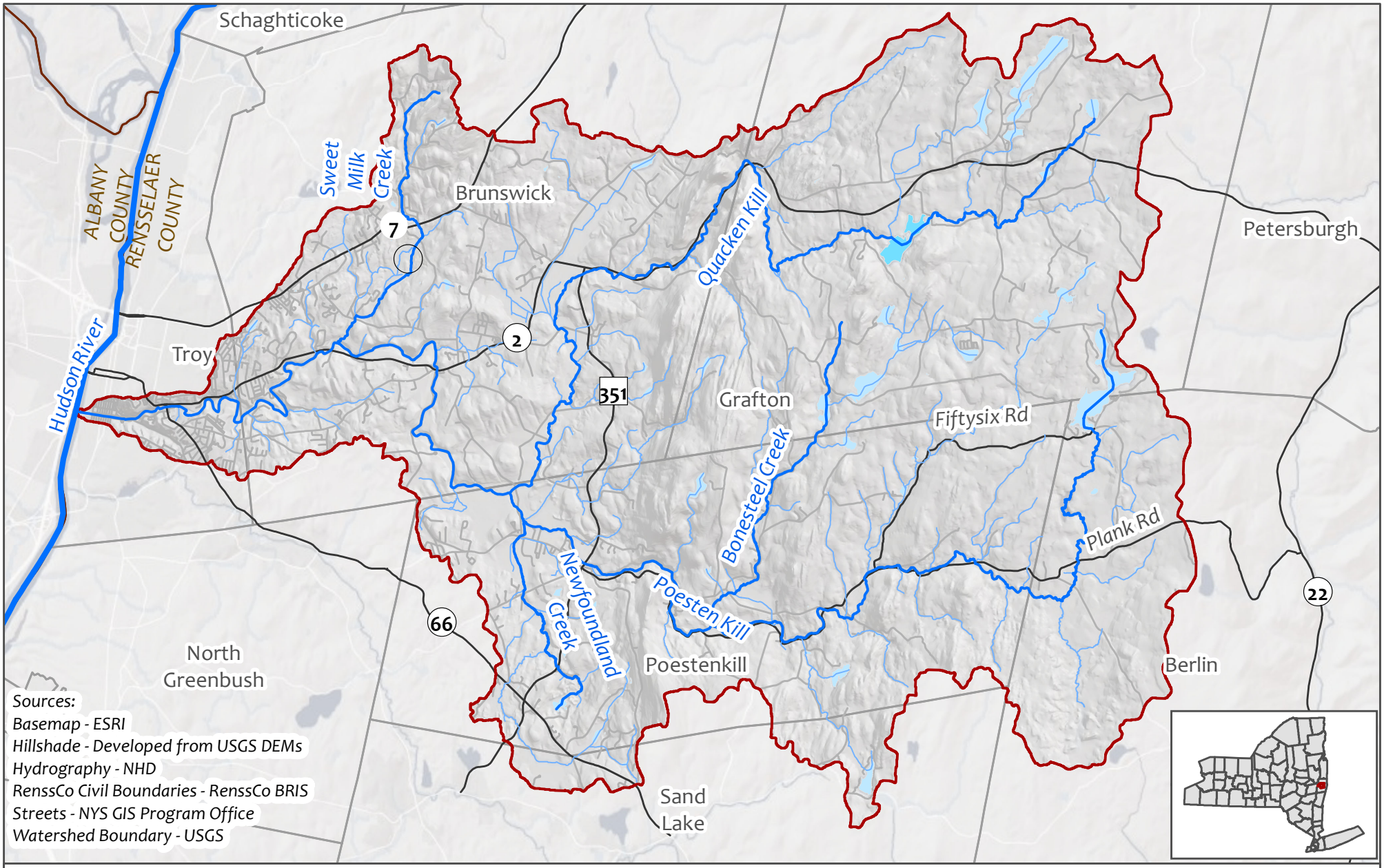


Figure 1a. Watershed Overview

N

0 1 2 4 Miles

Poesten Kill Watershed
Waterbodies
Streams/Rivers
Streets
Town Boundaries

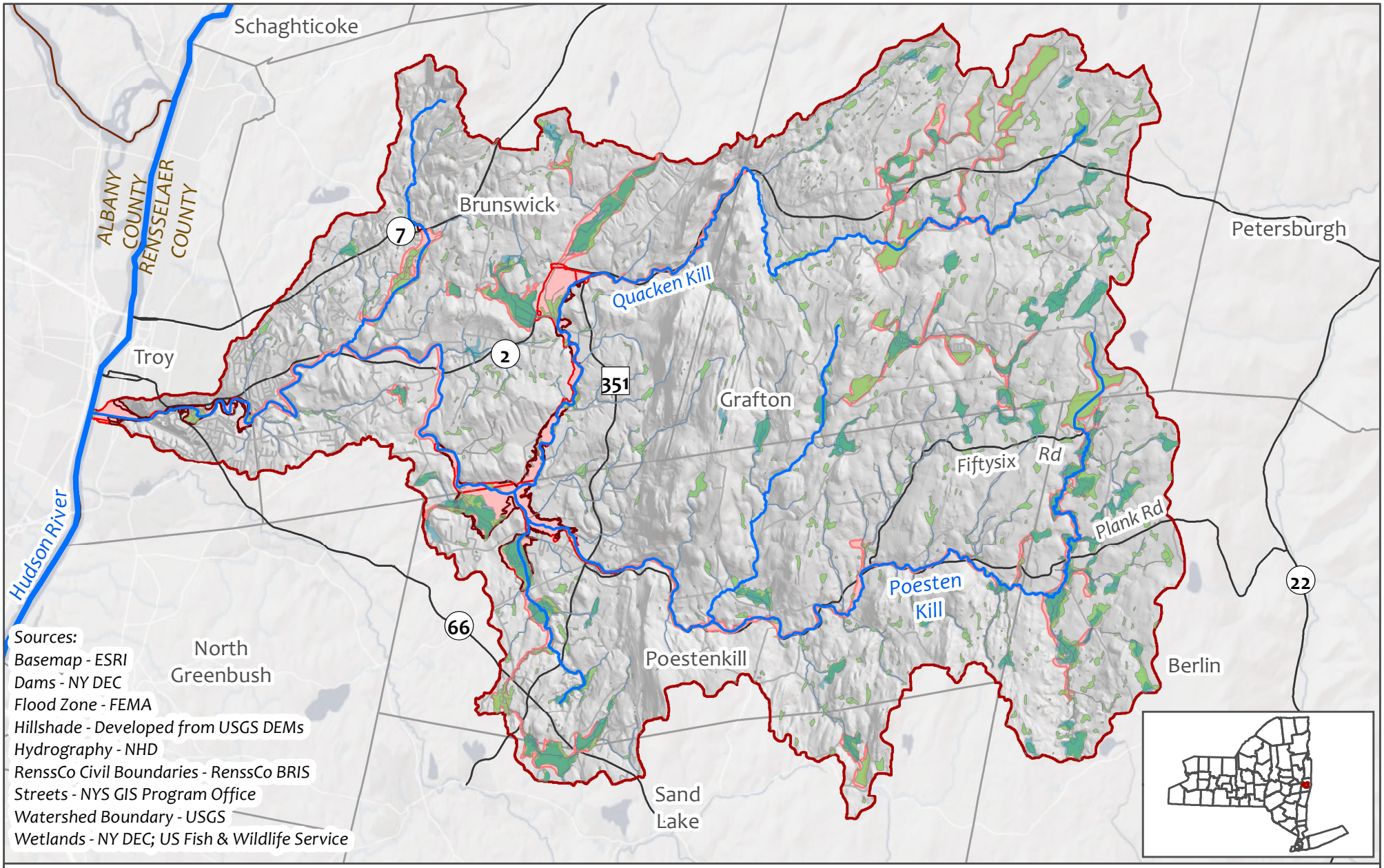


Figure 2b. NWI and NY DEC Wetlands

N

0 1 2 4 Miles

FEMA Flood Zone

- 100-yr Flood Zone *BFE not determined*
- 100-yr Flood Zone *BFE determined*
- 500-yr Flood Zone
- NWI Wetlands
- DEC Wetlands
- Poesten Kill Watershed
- Streams/Rivers
- Streets
- Town Boundaries

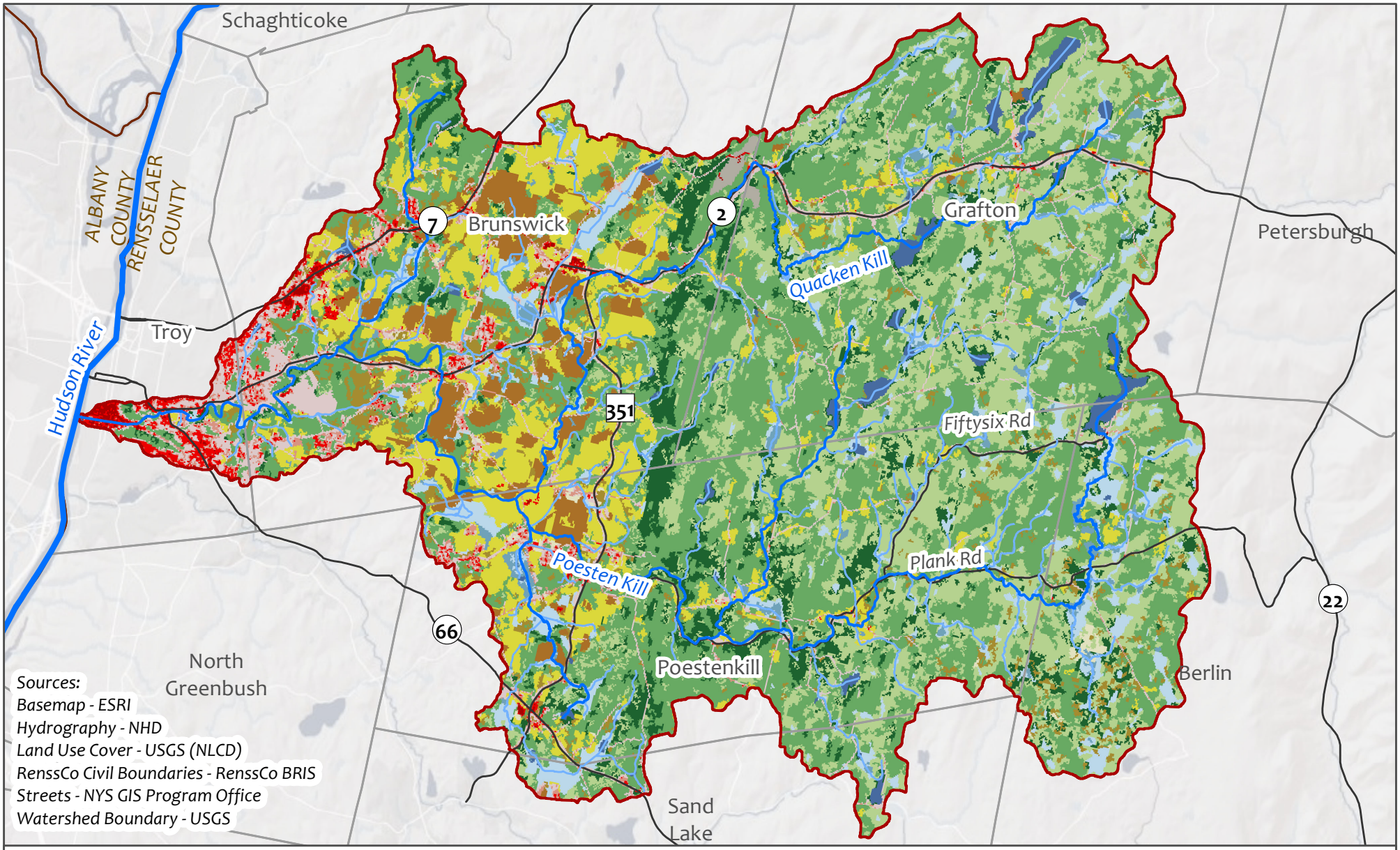


Figure 3. Land Use Cover

N

0 1 2 4 Miles

Open Water	Barren Land (Rock/Sand/Clay)	Grassland/Herbaceous
Developed, Open Space	Deciduous Forest	Pasture/Hay
Developed, Low Intensity	Evergreen Forest	Cultivated Crops
Developed, Medium Intensity	Mixed Forest	Woody Wetlands
Developed, High Intensity	Shrub/Scrub	Emergent Herbaceous Wetlands

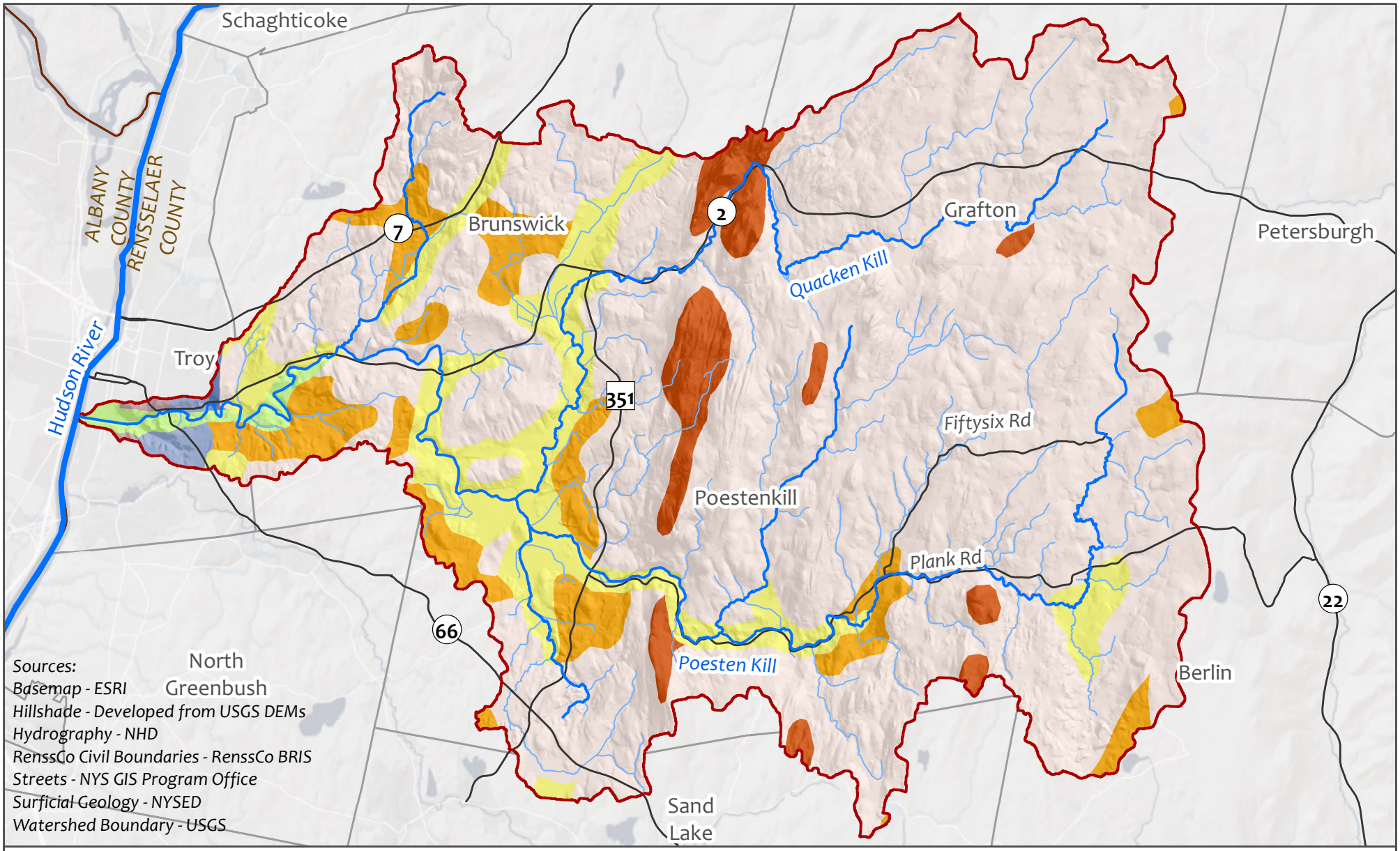


Figure 4. Surficial Geology

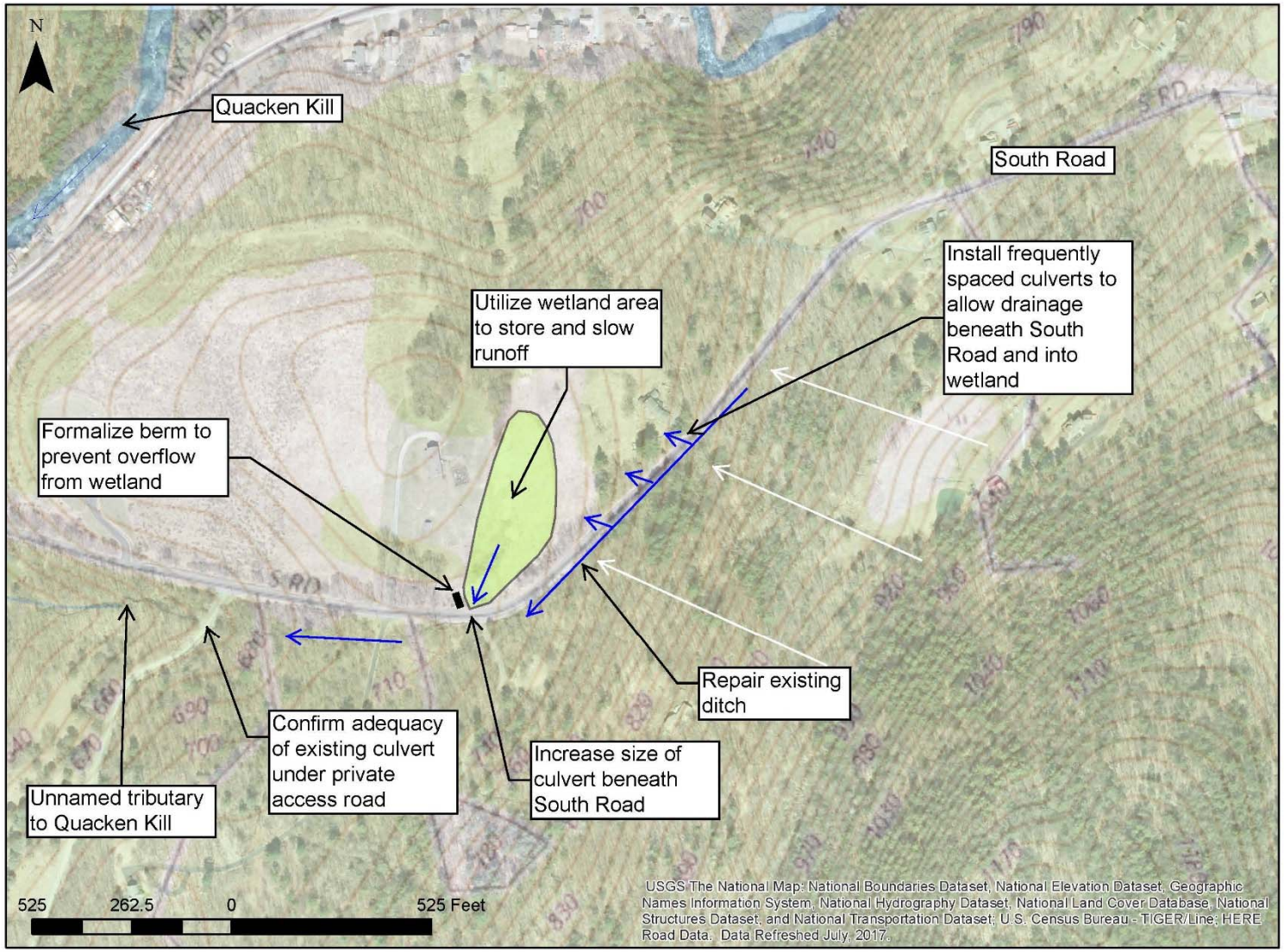
N

0 1 2 4 Miles

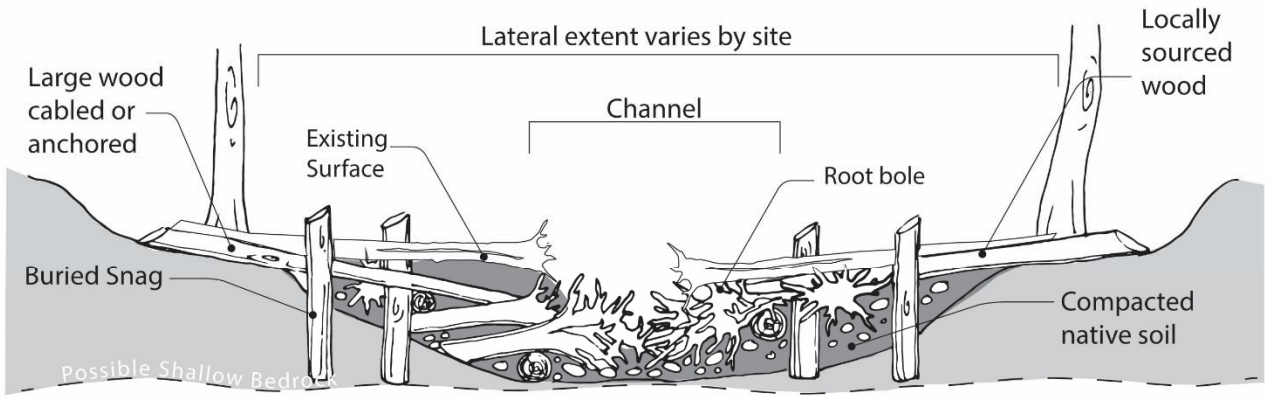
Material

- Alluvium
- Bedrock
- Kame deposits
- Lacustrine beach
- Lacustrine delta
- Lacustrine silt and clay
- Outwash sand and gravel
- Till
- Poesten Kill Watershed
- Streams/Rivers
- Streets
- Town Boundaries

Appendix B – Recommendations

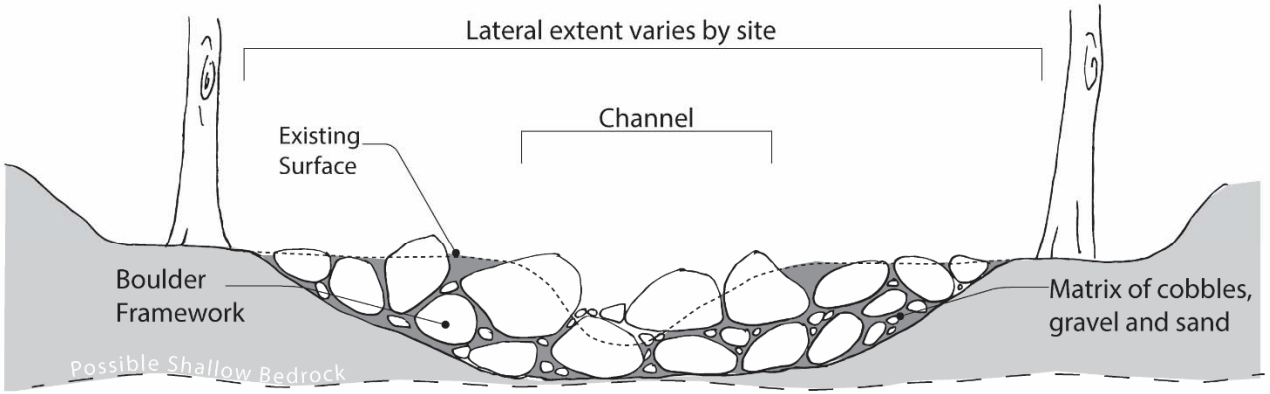


Concept 1. Road drainage improvements at South Road, Brunswick, to reduce interception of flow by road, utilize natural wetland area, and reduce the rate of runoff. Data sources: 2017 Rensselaer County high-resolution digital orthoimagery (NYS Office of Information Technology Services, GIS Program Office, 2017) and USGS topo map (source data listed on map).



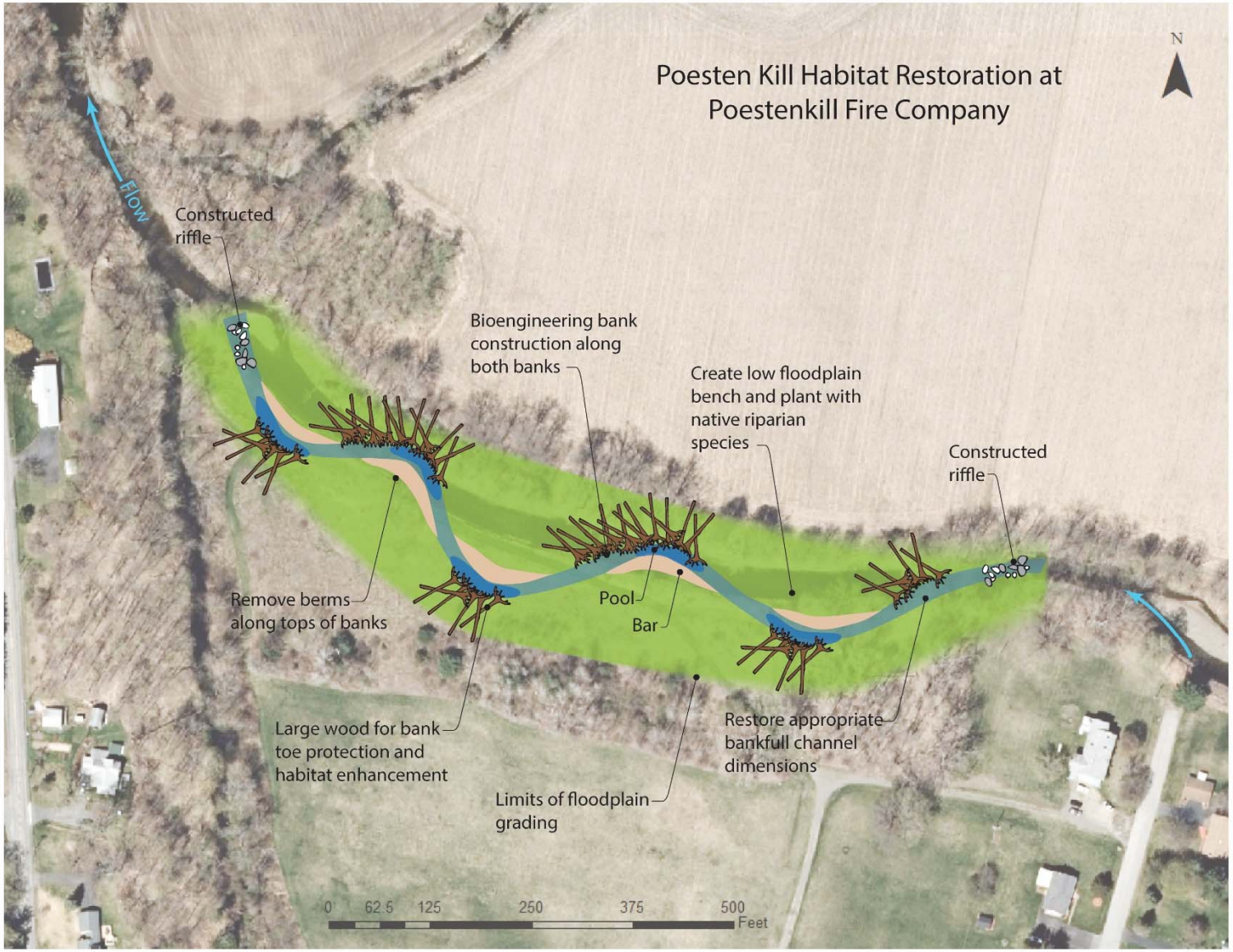
2a- Large Wood Cross-Sections N.T.S.
Replace native bed and bank material with large wood and root boles within a matrix of native soil

Concept 2. Option a: Measure to increase flood retention within wetlands on Bonesteel Creek using large wood



2b- Boulder Cross-section N.T.S.
Replace native bed and bank material with well-graded mixture of river rock, boulder and sand

Concept 3. Option b: Measure to increase flood retention within wetlands on Bonesteel Creek using rock



Concept 4. Measures to improve resilience, enhance floodplain function, and restore in-stream habitat in the Poesten Kill at the Poestenkill Fire Company. 2017 aerial imagery of Rensselaer County from NYS Office of Information Technology Services, GIS Program Office.

Appendix C – Field Data Collection Sheets

Channel Reconnaissance Form

inter·fluve

Date	8/21/18
Stream/Drainage	Poesten Kill
Stream Reach ID	Behind Firehouse
Field Team	CC KK

Station | | **to** |

General Channel Conditions

Channel Shape (check)
- ☐ Rectangular
- ☐ Shallow Rectangular
- ☐ Irregular
- ☑ Trapezoidal
- ☐ Parabolic
- ☐ Other _____

Sediment Particle Size Estimate		
	D_{50}	D_{max}
Banks	silt/clay to	dredge spoils of cobble / gravel
Bars	N/A	
Bed	1-2 inches	

Bar Types (circle): Alternate lateral | Point / transverse | None — At moderate flow.
Mid-channel | Point / mid | Point / alternate — At low flow, some alternate bars

Fluvial Geomorphic Conditions

Vertical Stability *degradation/aggradation*	Dredged
Lateral stability *deposition, erosion*	Stable
Channel evolution (Schumm) Stage/description:	
Erosion (excessive/site specific)	Some localized erosion of dredged material piled on left bank

Dominant bank erosion types (circle any that apply)					
	Fluvial	Undercut / cantilever	Selective erosion of noncohesive laters	Dry flow	Seepage
	Gravitational	Rotational	Planar	Wedge	

Bank composition	*Notes (shape/character)*: left bank is steep. Dredged material piled up here	*Consolidation / Aggregation*:
Terrace/Valley	*Valley form* – Wide valley unconfined.	*Condition* –
Altered state (human) - dams, bridges, canoe landings, parks, etc.	Bridges. widespread dredging	
Bankfull/Channel forming flow indication	line of active erosion on left bank, bench on right bank	

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Sediment Impacts			
Riffle sediment type		Pool sediment type	
Sorting / Imbrication	Imbricated		
Bars / depositional features			
Sediment type/size	Cobble / gravel		
Mid, alternate, braided			
Bar vegetation (type, age)	Sedges		
Floodplain soils	Sandy loam		
Overbank deposition	Entrenched since dredging. No recent evidence		

Riparian Vegetation and Floodplain

Root coverage of banks (%)	<50
Width of veg. riparian corridor*	10-20 ft
Canopy coverage (%)	25 (within corridor)

** Verify with orthoquad data*

Canopy structure: (check one)

none = anthro / maintained (lawn, field, pasture)	✓
low = single canopy layer	✓ (within corridor)
medium = at least two canopy layers	
high = multiple canopy layers	

Primary veg forms present: (%)

grasses/forbs	50
woody species	50
bare/other	
exotic/invasive species	Japanese Knotweed

Woody species present	% of total tree community
Cottonwood, sycamore, maple	

Tree Stand Age (if applicable)

Station	*Species*	*Age*	*Notes / Location within XS*

Habitat

LWD density (pieces / 100 ft)	0	General habitat notes: little diversity. straight reach with thalweg and infrequent lateral bars wood has been removed
Residual pool	None	
Undercut bank	very few	
Riffle / Other	one approx 300-400 ft upstream	***SVAP Score =***

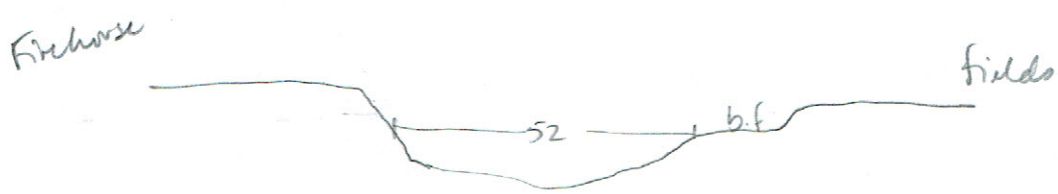
Channel Stability Form

Reach stability		1-2 Degrading		3 Stable		4-5 Aggrading
Estimated sediment mobility (D50 moves at:)	<2yr Q		2-10 yr		>10 yr	
Substrate consolidation	Strong, gravels/cobble		Strong, gravels		Weak, sand/silt	
Bank failure mechanism	High banks, grav. collapse, variable channel width		Localized surficial erosion, constant width		Low banks, overflows, surficial erosion	
Bar development	Poorly formed		Narrow, vegetated		Wide (>1/2 channel length), unveg.	
Bank erosion extent	Extensive		Local erosion/pools		Extensive bar pressure	
Relative Width:Depth ratio	Low		Average		High	
Channel pattern	Single thread		Single thread		Multiple thread/braided	
Average bank slope	<3:1		>3:1			
Vegetative bank protection	Poor		Extensive		Poor	
Field stability rating (add all cells)/9		=				

Representative cross-section sketch

Bankfull width = 52 ft	Floodplain width = See LiDAR	Water depth (at survey) = 1.9 ft @ thalweg
Bankfull depth = 3.6 ft.	Channel Class =	Water width (at survey) = 36 ft

Station:



Station:

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Channel Reconnaissance Form

inter·fluve

Date	8/21/2018
Stream/Drainage	Quackenkill
Stream Reach ID	Mainstem u/s of White Church
Field Team	CC, KK

200' D/s of Tam Junct.

Station | | to |

General Channel Conditions

Channel Shape (check)
- ☐ Rectangular
- ☐ Shallow Rectangular
- ☐ Irregular
- ☑ Trapezoidal
- ☐ Parabolic
- ☐ Other _____

Sediment Particle Size Estimate		
	D_{50}	D_{max}
Banks	silt-gravel	3"
Bars		
Bed	1-2"	6-8"

cobble-sand

Bar Types (circle): Alternate lateral | Point / transverse | None | Mid-channel | Point / mid | Point / alternate

Fluvial Geomorphic Conditions

Vertical Stability *degradation/aggradation*	stable or mildly aggrading
Lateral stability *deposition, erosion*	Stable
Channel evolution (Schumm) Stage/description:	
Erosion (excessive/site specific)	Localized, e.g. cut bank at jct.

Dominant bank erosion types (circle any that apply)					
	Fluvial	Undercut / cantilever	Selective erosion of noncohesive laters	Dry flow	Seepage
	Gravitational	Rotational	Planar	Wedge	___

Bank composition	*Notes (shape/character)*: silt - gravel	*Consolidation / Aggregation*:
Terrace/Valley	*Valley form* – broad flood plain	*Condition* –
Altered state (human) - dams, bridges, canoe landings, parks, etc.	Bridge @ white church rd, wall along cut bank leading into bridge	
Bankfull/Channel forming flow indication		

Velocity 20' in 5 sec → 4 ft/sec (approx)

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Sediment Impacts

Riffle sediment type		Pool sediment type	
Sorting / Imbrication	Bed is imbricated, sand beneath light armor. all mobile in Q2		

Bars / depositional features	
Sediment type/size	
Mid, alternate, braided	
Bar vegetation (type, age)	
Floodplain soils	
Overbank deposition	

Riparian Vegetation and Floodplain

Root coverage of banks (%)	75
Width of veg. riparian corridor*	100-200'
Canopy coverage (%)	40%

** Verify with orthoquad data*

Canopy structure: (check one)

none = anthro / maintained (lawn, field, pasture)	
low = single canopy layer	
medium = at least two canopy layers	✓
high = multiple canopy layers	

Primary veg forms present: (%) ~~typ~~ mature trees, with forbs

grasses/forbs	
woody species	
bare/other	
exotic/invasive species	

Woody species present	% of total tree community
maple, black walnut	

Tree Stand Age (if applicable)

Station	*Species*	*Age*	*Notes / Location within XS*

Habitat

LWD density (pieces / 100 ft)	<1	General habitat notes:
Residual pool	few	pools on channel bends, not otherwise. some banks undercut
Undercut bank		
Riffle / Other	sporadic gentle riffle	**SVAP Score =**

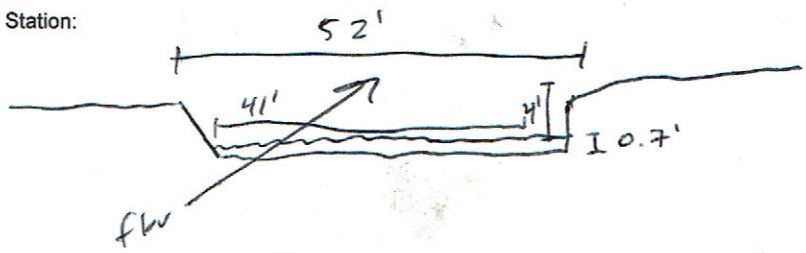
Channel Stability Form

Reach stability		1-2 Degrading		3 Stable		4-5 Aggrading
Estimated sediment mobility (D50 moves at:)	<2yr Q		2-10 yr		>10 yr	
Substrate consolidation	Strong, gravels/cobble		Strong, gravels		Weak, sand/silt	
Bank failure mechanism	High banks, grav. collapse, variable channel width		Localized surficial erosion, constant width		Low banks, overflows, surficial erosion	
Bar development	Poorly formed		Narrow, vegetated		Wide (>1/2 channel length), unveg.	
Bank erosion extent	Extensive		Local erosion/pools		Extensive bar pressure	
Relative Width:Depth ratio	Low		Average		High	
Channel pattern	Single thread		Single thread		Multiple thread/braided	
Average bank slope	<3:1		>3:1			
Vegetative bank protection	Poor		Extensive		Poor	
Field stability rating (add all cells)/9		=				

Representative cross-section sketch

Bankfull width = 52'	Floodplain width =	Water depth (at survey) = 0.7
Bankfull depth = 4'	Channel Class =	Water width (at survey) = 41'

Station:



consistent depth across channel, no defined thalweg or low flow channel

41 x 0.7 x 4 ~ 50-100 cfs

4 days post 2" rain event

Station:

Channel Reconnaissance Form

inter·fluve

Date	8/21/18
Stream/Drainage	trib to Quackenkill
Stream Reach ID	Roark Rd.
Field Team	CC KK

Station | | **to** |

General Channel Conditions

Channel Shape (check)
- ☐ Rectangular
- ☑ Shallow Rectangular
- ☐ Irregular
- ☑ Trapezoidal
- ☐ Parabolic
- ☐ Other _____

Sediment Particle Size Estimate		
	D_{50}	D_{max}
Banks		
Bars		
Bed	Boulder to gravel	

Bar Types (circle): Alternate lateral | Point / transverse | None | Mid-channel limited | Point / mid | Point / alternate

Fluvial Geomorphic Conditions

Vertical Stability *degradation/aggradation*	No evidence
Lateral stability *deposition, erosion*	Stable
Channel evolution (Schumm) Stage/description:	
Erosion (excessive/site specific)	None

Dominant bank erosion types (circle any that apply)					
	Fluvial	Undercut / cantilever	Selective erosion of noncohesive laters	Dry flow	Seepage
	Gravitational	Rotational	Planar	Wedge	

Bank composition	*Notes (shape/character)*: Root-bound boulders & cobbles	*Consolidation / Aggregation*:
Terrace/Valley	*Valley form* – Confined	*Condition* –
Altered state (human) - dams, bridges, canoe landings, parks, etc.	culverts u/s Rte 2 & d/s Roark Rd.	
Bankfull/Channel forming flow indication	undercutting of ~~bank~~ bank; top of right bank at floodplain	

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Sediment Impacts			
Riffle sediment type	Boulders, cobble	Pool sediment type	gravel
Sorting / Imbrication	Imbrication		

Bars / depositional features	
Sediment type/size	Boulders, cobble
Mid, alternate, braided	
Bar vegetation (type, age)	
Floodplain soils	thin & rocky
Overbank deposition	gravels & woody debris on right bank floodplain

Riparian Vegetation and Floodplain

Root coverage of banks (%)	80
Width of veg. riparian corridor*	20ft either side
Canopy coverage (%)	75%

** Verify with orthoquad data*

Canopy structure: (check one)

none = anthro / maintained (lawn, field, pasture)	
low = single canopy layer	
medium = at least two canopy layers	✓
high = multiple canopy layers	

Primary veg forms present: (%)

		Woody species present	% of total tree community
grasses/forbs	✓	maple, oak	
woody species	✓		
bare/other			
exotic/invasive species	None		

Tree Stand Age (if applicable)

Station	*Species*	*Age*	*Notes / Location within XS*

Habitat

		General habitat notes:
LWD density (pieces / 100 ft)	3-5	High variability in flow & sediment types
Residual pool	✓	not-band undercut banks.
Undercut bank	✓	Residual pools ~~1ft~~ 0.5 ft. - 1 ft
Riffle / Other	✓	riffles & step pools. **SVAP Score =**

Channel Stability Form

Reach stability		1-2 Degrading		3 Stable		4-5 Aggrading
Estimated sediment mobility (D50 moves at:)	<2yr Q		2-10 yr	✓	>10 yr	
Substrate consolidation	Strong, gravels/cobble	✓	Strong, gravels		Weak, sand/silt	
Bank failure mechanism	High banks, grav. collapse, variable channel width		Localized surficial erosion, constant width	✓	Low banks, overflows, surficial erosion	
Bar development	Poorly formed		Narrow, vegetated	✓	Wide (>1/2 channel length), unveg.	
Bank erosion extent	Extensive		Local erosion/pools	✓	Extensive bar pressure	
Relative Width:Depth ratio	Low		Average	✓	High	
Channel pattern	Single thread		Single thread	✓	Multiple thread/braided	
Average bank slope	<3:1	✓	>3:1			
Vegetative bank protection	Poor		Extensive	✓	Poor	
Field stability rating (add all cells)/9		=				

Representative cross-section sketch

Bankfull width = 27.5 ft	Floodplain width = 20 ft (right bank)	Water depth (at survey) = 0.5 ft
Bankfull depth = 1.8 ft	Channel Class =	Water width (at survey) = 21.5 ft

Station:

b.f. = width 19 ft

f.p. w = 10 ft

w. d. = 0.5 ft

ww. = 16 ft

b.f. d. = 1.5 ft

Station: 4.5 ft wide by 5 ft deep. - relict box culvert b/t Rte 2 & Roark Rd.

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Channel Reconnaissance Form

inter·fluve

Date	8/21/18
Stream/Drainage	trib to Overlen Kill
Stream Reach ID	Sports Complex
Field Team	CC KK

Station | | **to** |

General Channel Conditions

Channel Shape (check)
- ☐ Rectangular
- ☐ Shallow Rectangular
- ☐ Irregular
- ☐ Trapezoidal
- ☐ Parabolic
- ☐ Other _____

Sediment Particle Size Estimate		
	D_{50}	D_{max}
Banks		
Bars		
Bed		

Bar Types (circle): Alternate lateral | Point / transverse | None | Mid-channel | Point / mid | Point / alternate

Fluvial Geomorphic Conditions

Vertical Stability *degradation/aggradation*	Dredged / incised and stable
Lateral stability *deposition, erosion*	stable banks
Channel evolution (Schumm) Stage/description:	
Erosion (excessive/site specific)	None

Dominant bank erosion types (circle any that apply)					
	Fluvial	Undercut / cantilever	Selective erosion of noncohesive laters	Dry flow	Seepage
	Gravitational	Rotational	Planar	Wedge	

Bank composition	*Notes (shape/character)*:	*Consolidation / Aggregation*:
Terrace/Valley	*Valley form* – wide, flat valley	*Condition* –
Altered state (human) - dams, bridges, canoe landings, parks, etc.	Sports complex, farm fields	
Bankfull/Channel forming flow indication		

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Sediment Impacts			
Riffle sediment type	N/A	Pool sediment type	
Sorting / Imbrication	No bedforms		
Bars / depositional features			
Sediment type/size			
Mid, alternate, braided			
Bar vegetation (type, age)			
Floodplain soils			
Overbank deposition	Incised / dredged N/A		

Riparian Vegetation and Floodplain

Root coverage of banks (%)	100
Width of veg. riparian corridor*	None
Canopy coverage (%)	0

** Verify with orthoquad data*

Canopy structure: (check one)

none = anthro / maintained (lawn, field, pasture)	✓
low = single canopy layer	
medium = at least two canopy layers	
high = multiple canopy layers	

Primary veg forms present: (%)

grasses/forbs	100
woody species	
bare/other	
exotic/invasive species	

Woody species present	% of total tree community
N/A	

Tree Stand Age (if applicable)

Station	*Species*	*Age*	*Notes / Location within XS*

Habitat

LWD density (pieces / 100 ft)		General habitat notes:
Residual pool		
Undercut bank		
Riffle / Other		***SVAP Score =***

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Channel Stability Form N/A

Reach stability		1-2 Degrading		3 Stable		4-5 Aggrading
Estimated sediment mobility (D50 moves at:)	<2yr Q		2-10 yr		>10 yr	
Substrate consolidation	Strong, gravels/cobble		Strong, gravels		Weak, sand/silt	
Bank failure mechanism	High banks, grav. collapse, variable channel width		Localized surficial erosion, constant width		Low banks, overflows, surficial erosion	
Bar development	Poorly formed		Narrow, vegetated		Wide (>1/2 channel length), unveg.	
Bank erosion extent	Extensive		Local erosion/pools		Extensive bar pressure	
Relative Width:Depth ratio	Low		Average		High	
Channel pattern	Single thread		Single thread		Multiple thread/braided	
Average bank slope	<3:1		>3:1			
Vegetative bank protection	Poor		Extensive		Poor	
Field stability rating (add all cells)/9		=				

Representative cross-section sketch

Bankfull width = 22 ft	Floodplain width = wide, see LiDAR	Water depth (at survey) = 1.7 ft
Bankfull depth = 3.8 ft	Channel Class =	Water width (at survey) = 12.5 ft

Station: bankfull not really applicable.
dredged canal through fields
left bank floodplain elev. approx 1-2 ft higher than bankfull
along [illegible]

Station:

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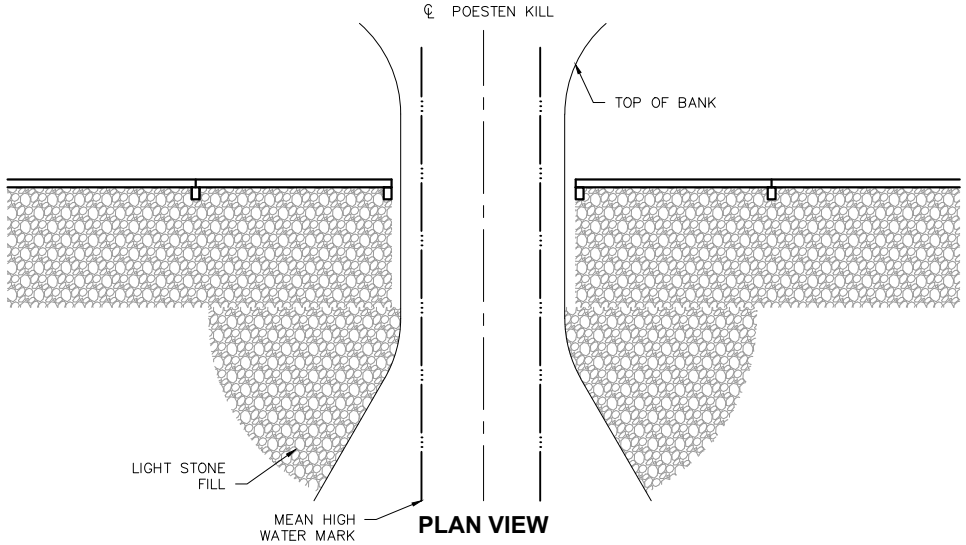
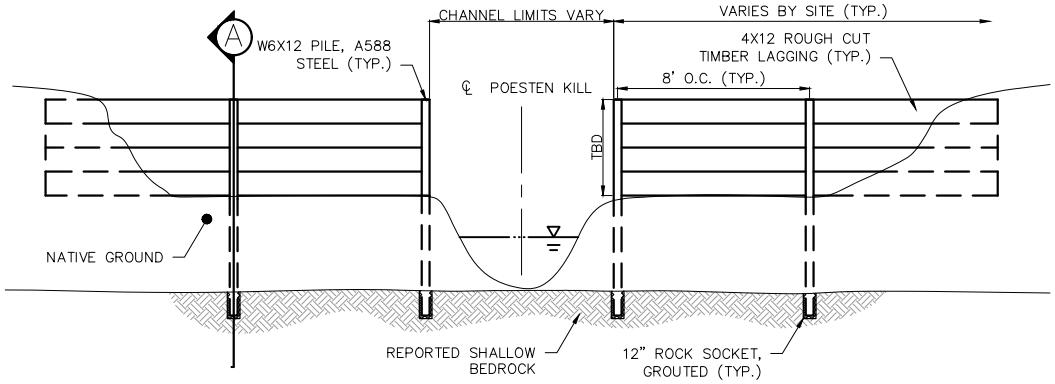
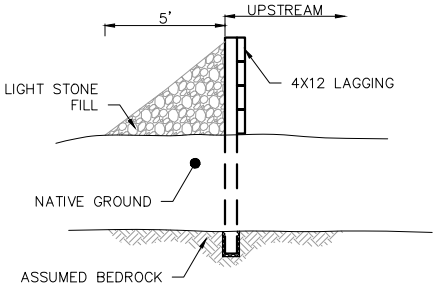
Appendix 2: Conceptual Wetland Detention Structure Designs and Budgets



PLAN VIEW





SECTION A-A

A **STREAM SECTION - DIKE ELEVATION**

SCALE: NOT TO SCALE

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Chattanooga, Tennessee 37403
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RPA POESTEN KILL FLOOD MITIGATION STUDY

PILE & LAGGING / NO BERM

POESTEN KILL WATERSHED, RENSSELAER COUNTY, NEW YORK

design FBM	chked MAC
date 6/21/19	scale N.T.S.
project no. 41822.00	
sheet no. **DETAIL A**	

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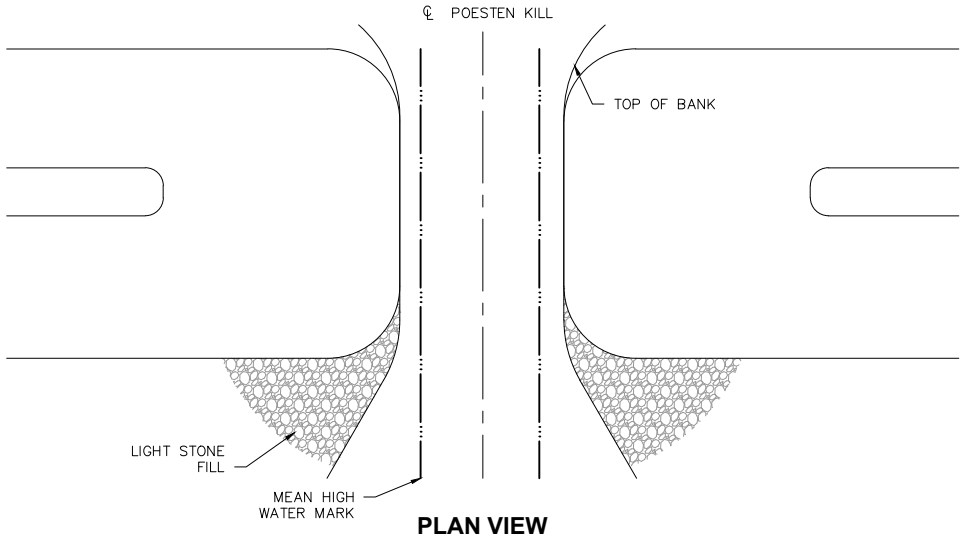
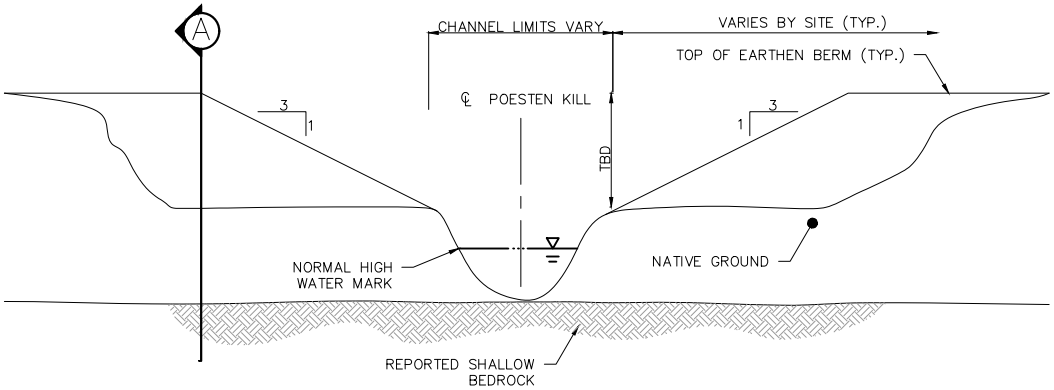
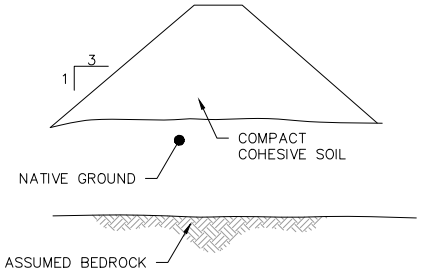
Drawing Name: Z:\projects\41800-41899\41822_00 RPA Poesten Kill Flood Management Study\DWG\DETAILS-BERM.dwg Date Printed: Jul 22, 2019, 2:24pm



PLAN VIEW





SECTION A-A

B **STREAM SECTION - DIKE ELEVATION**

SCALE: NOT TO SCALE

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Chattanooga Tennessee Office:
427 E. 5TH ST. (Suite 201)
Chattanooga, Tennessee 37403
Phone: (423) 241–6575

RPA POESTEN KILL FLOOD MITIGATION STUDY

EARTHEN BERM (NO CORE)

POESTEN KILL WATERSHED, RENSSELAER COUNTY, NEW YORK

design	chked
FBM	MAC
date	scale
6/21/19	N.T.S.

project no. 41822.00

sheet no. **DETAIL B**

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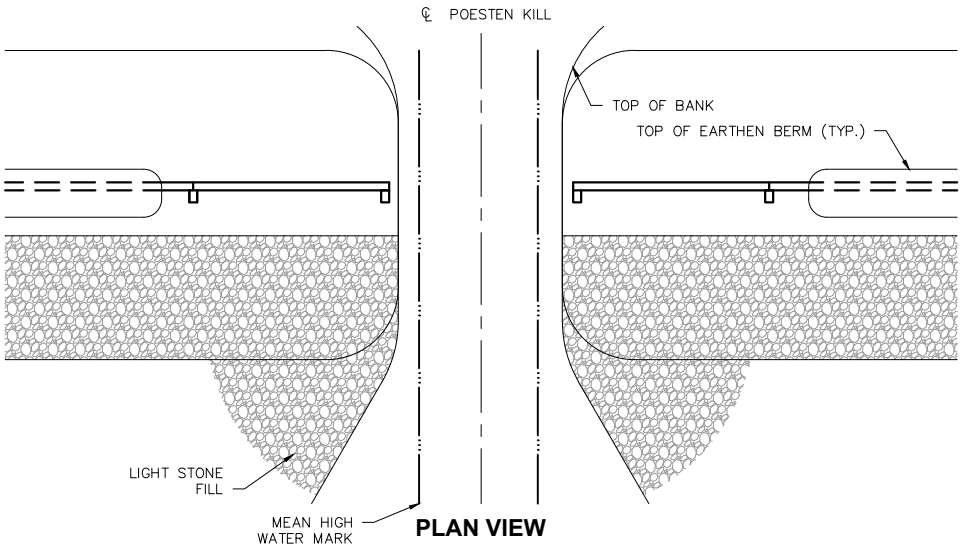
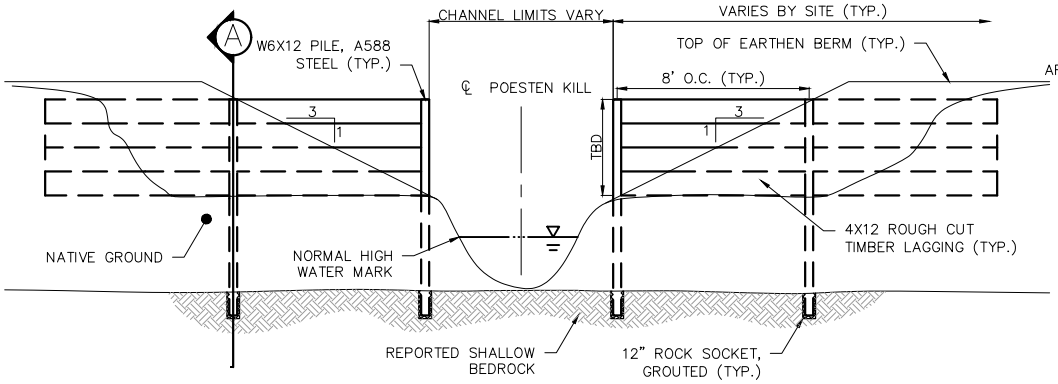
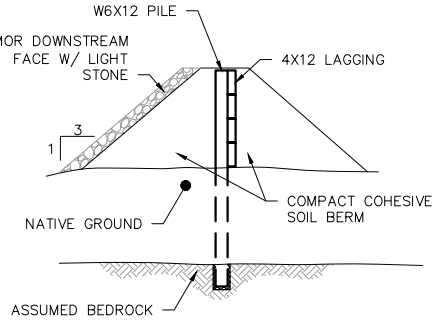


PLAN VIEW





SECTION A-A

C **STREAM SECTION - DIKE ELEVATION**

SCALE: NOT TO SCALE

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Chattanooga, Tennessee 37403
Phone: (423) 241-6575

RPA POESTEN KILL FLOOD MITIGATION STUDY

PILE & LAGGING / WITH BERM

POESTEN KILL WATERSHED, RENSSELAER COUNTY, NEW YORK

design FBM	chked MAC
date 6/21/19	scale N.T.S.
project no. 41822.00	
sheet no. **DETAIL C**	

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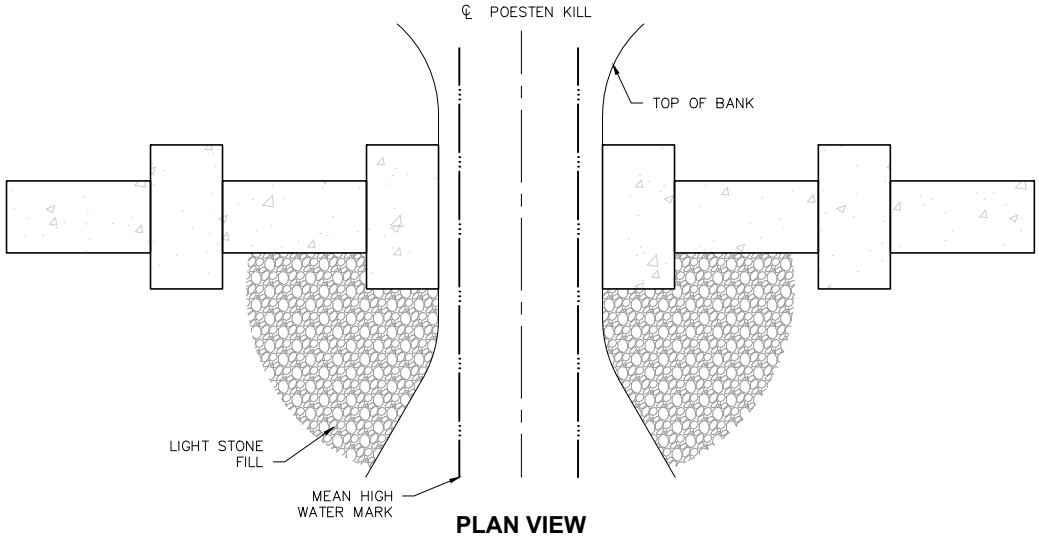
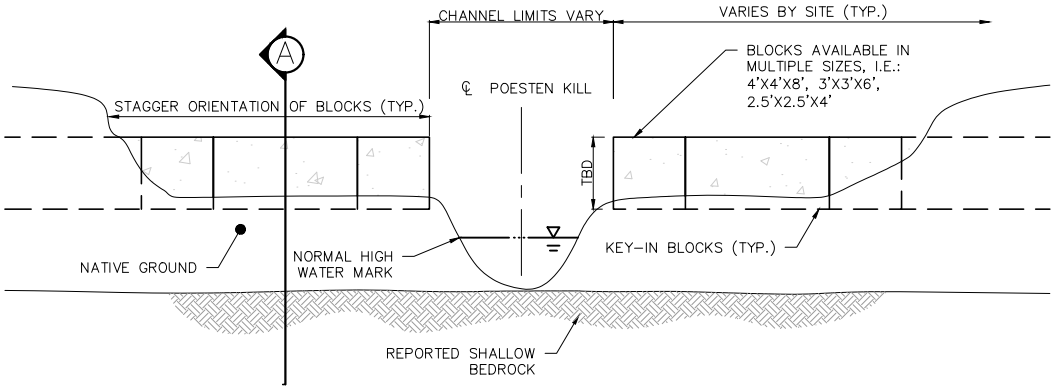
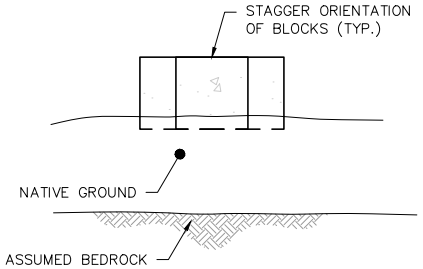


PLAN VIEW





SECTION A-A

D **STREAM SECTION - DIKE ELEVATION**

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Phone: (423) 241-6575

RPA POESTEN KILL FLOOD MITIGATION STUDY

PRE-CAST CONCRETE GRAVITY BLOCK

POESTEN KILL WATERSHED, RENSSELAER COUNTY, NEW YORK

design FBM	chked MAC
date 6/21/19	scale N.T.S.
project no. 41822.00	
sheet no. **DETAIL D**	

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RPA - Poestenkill NEWIIPIC

41822.00

Date: April 24, 2019
REVISED June 28, 2019

WETLAND RESTRICTING DIKES (Each)				
Description	QTY	Unit	Unit Price	Total Cost
Method A - Pile & Lagging/No Berm				
Mobilization	1	LS	$2,000.00	$2,000.00
14 - W6x12 Posts @ 6' long = 72 lb ea.	1,008	LB	$3.00	$3,024.00
Timber Lagging -	1,400	Bd. Ft	$5.00	$7,000.00
Install Piles	2	Day	$2,500.00	$5,000.00
Light Stone Fill	80	CY	$50.00	$4,000.00
Erosion & Sediment Control	1	LS	$1,500.00	$1,500.00
			Total Method A	***$22,524.00***
Method B - Earthen Berm w/ No Core				
Mobilization	1	LS	$2,000.00	$2,000.00
Light Stone Fill	20	CY	$50.00	$1,000.00
Earthen Embankment-in-Place	100	CY	$60.00	$6,000.00
Seed & Mulch	1	LS	$250.00	$250.00
Plantings	8	LS	$400.00	$3,200.00
Topsoil	150	SY	$40.00	$6,000.00
Erosion & Sediment Control	1	LS	$1,500.00	$1,500.00
			Total Method B	**$19,950.00**
Method C - Pile & Lagging w/ Berm				
Mobilization	1	LS	$2,000.00	$2,000.00
14 - W6x12 Posts @ 6' long = 72 lb ea.	1,008	LB	$3.00	$3,024.00
Timber Lagging -	1,400	Bd. Ft	$5.00	$7,000.00
Install Piles	2	Day	$2,500.00	$5,000.00
Light Stone Fill	35	CY	$50.00	$1,750.00
Earthen Embankment-in-Place	100	CY	$60.00	$6,000.00
Seed & Mulch	1	LS	$250.00	$250.00
Plantings	8	LS	$400.00	$3,200.00
Topsoil	150	SY	$40.00	$6,000.00
Erosion & Sediment Control	1	LS	$1,500.00	$1,500.00
			Total Method C	**$35,724.00**
Method D - Pre-Cast Concrete Gravity Block				
Mobilization	1	LS	$2,000.00	$2,000.00
36x36x72 block, In-Place	18	Each	$300.00	$5,400.00
Light Stone Fill	20	CY	$50.00	$1,000.00
Site Prep	1	LS	$2,000.00	$2,000.00
Erosion & Sediment Control	1	LS	$1,500.00	$1,500.00
			Total Method D	***$11,900.00***
			Annual Maintenance - All Options (Each) - (2 man-days+time on equipment)	**$1,300.00**
			Engineering Design & Environmental Permitting (Each Site)	***$18,000.00***
AVERAGE PROJECT BUDGET, EACH SITE				***$40,524.50***

[1] *Estimate is an opinion of probable construction costs based on approximate dimensions from the final design drawings.*
[2] *Assumes a mean length of dyke = 100'*
[3] *Assumes that the work of each site will not require a publicly bid contract*
[4] *Assumes that the average height of the dyke is 3.5'*

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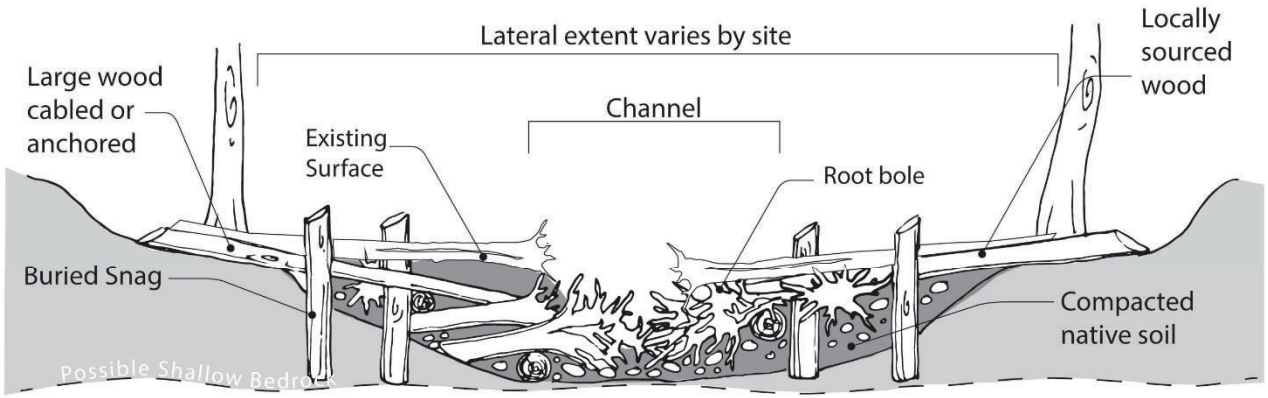
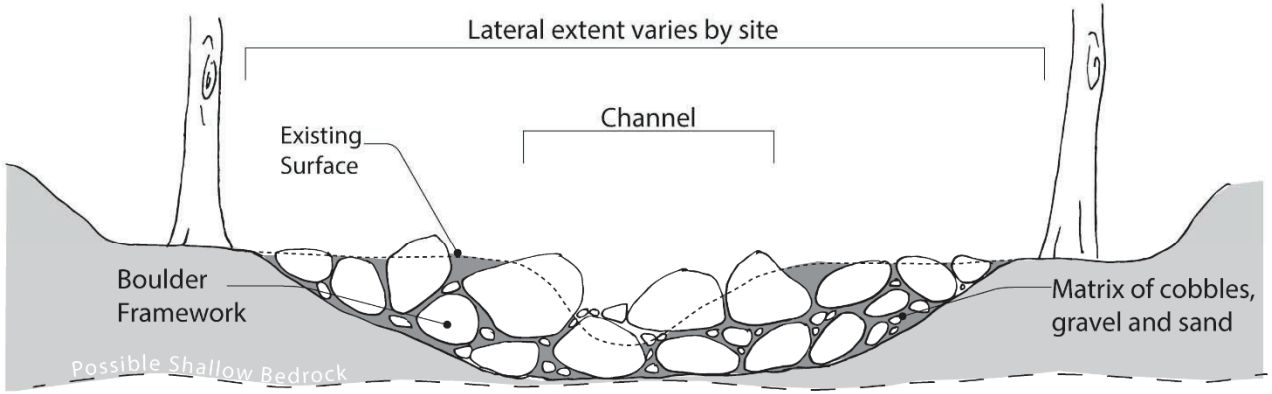


2a- Large Wood Cross-Sections N.T.S.
Replace native bed and bank material with large wood and root boles within a matrix of native soil

Concept 2. Option a: Measure to increase flood retention within wetlands on Bonesteel Creek using large wood

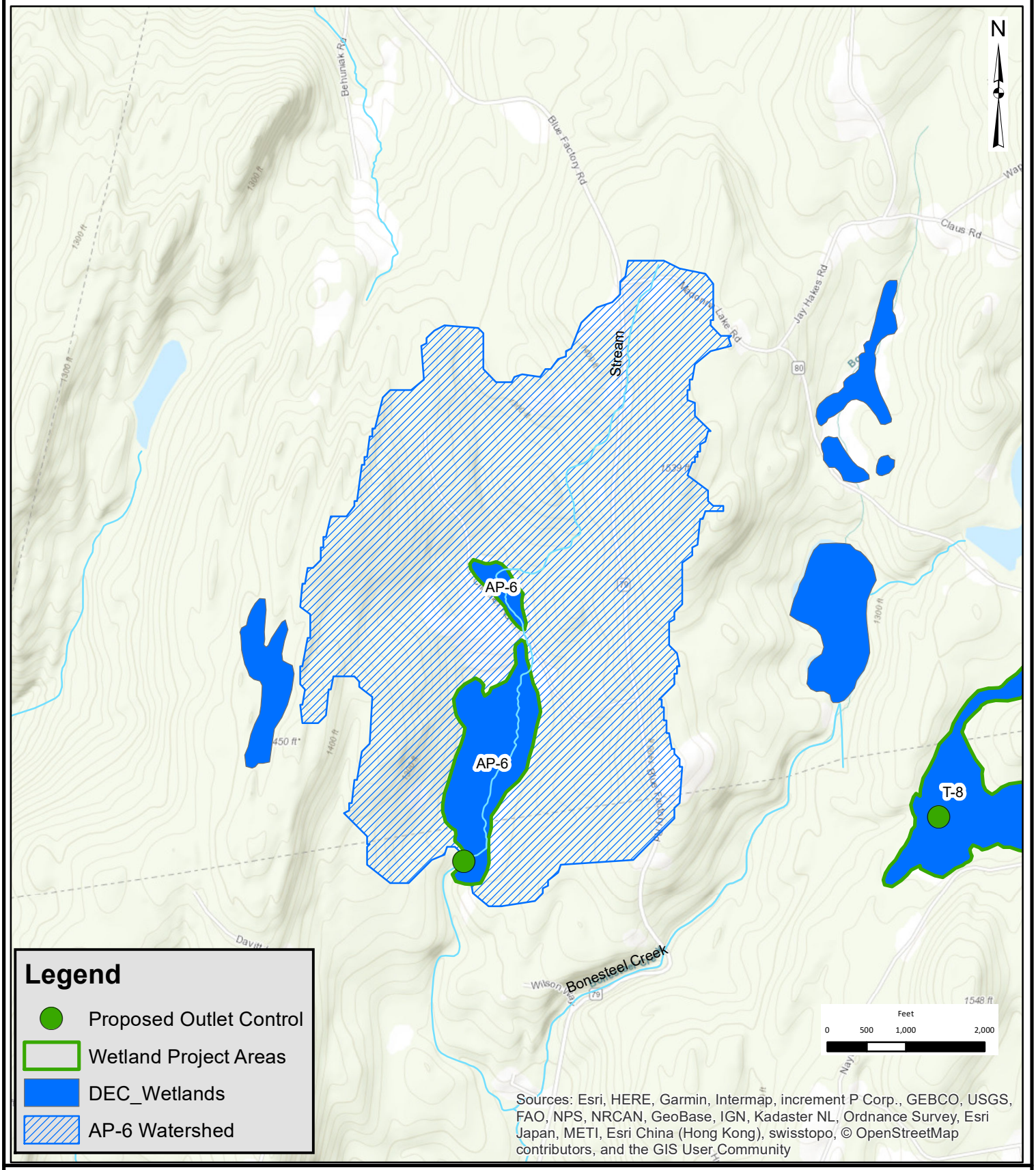


2b- Boulder Cross-section N.T.S.
Replace native bed and bank material with well-graded mixture of river rock, boulder and sand

Interfluve Design 2

Concept 3. Option b: Measure to increase flood retention within wetlands on Bonesteel Creek using rock

Appendix 3: Wetland Control Outlet Location Maps and Associated Sub-Watersheds



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AP-6 Wetland

Poesten Kill Watershed, Rensselaer County, New York

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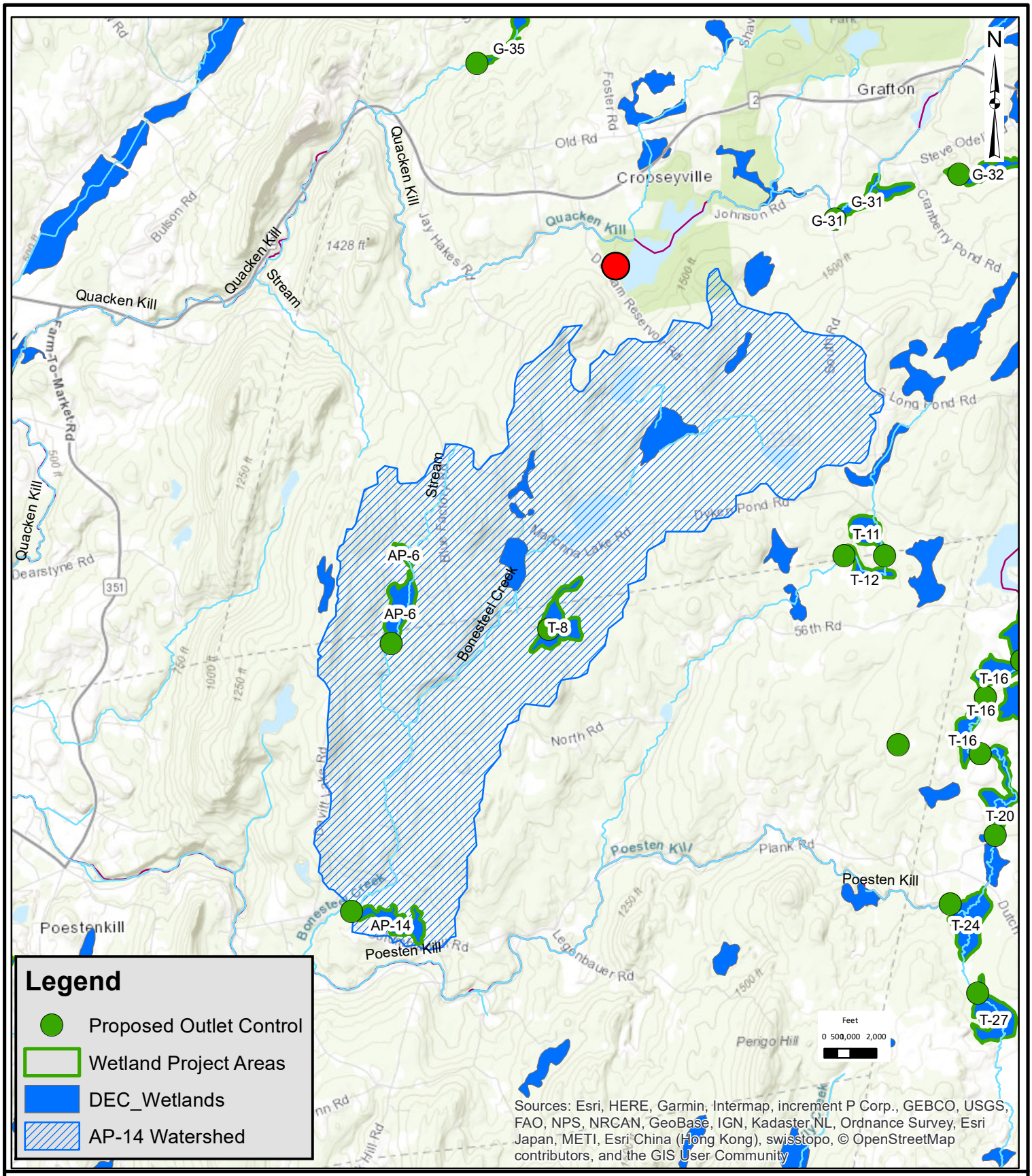

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AP-14 Wetland

Poesten Kill Watershed, Rensselaer County, New York

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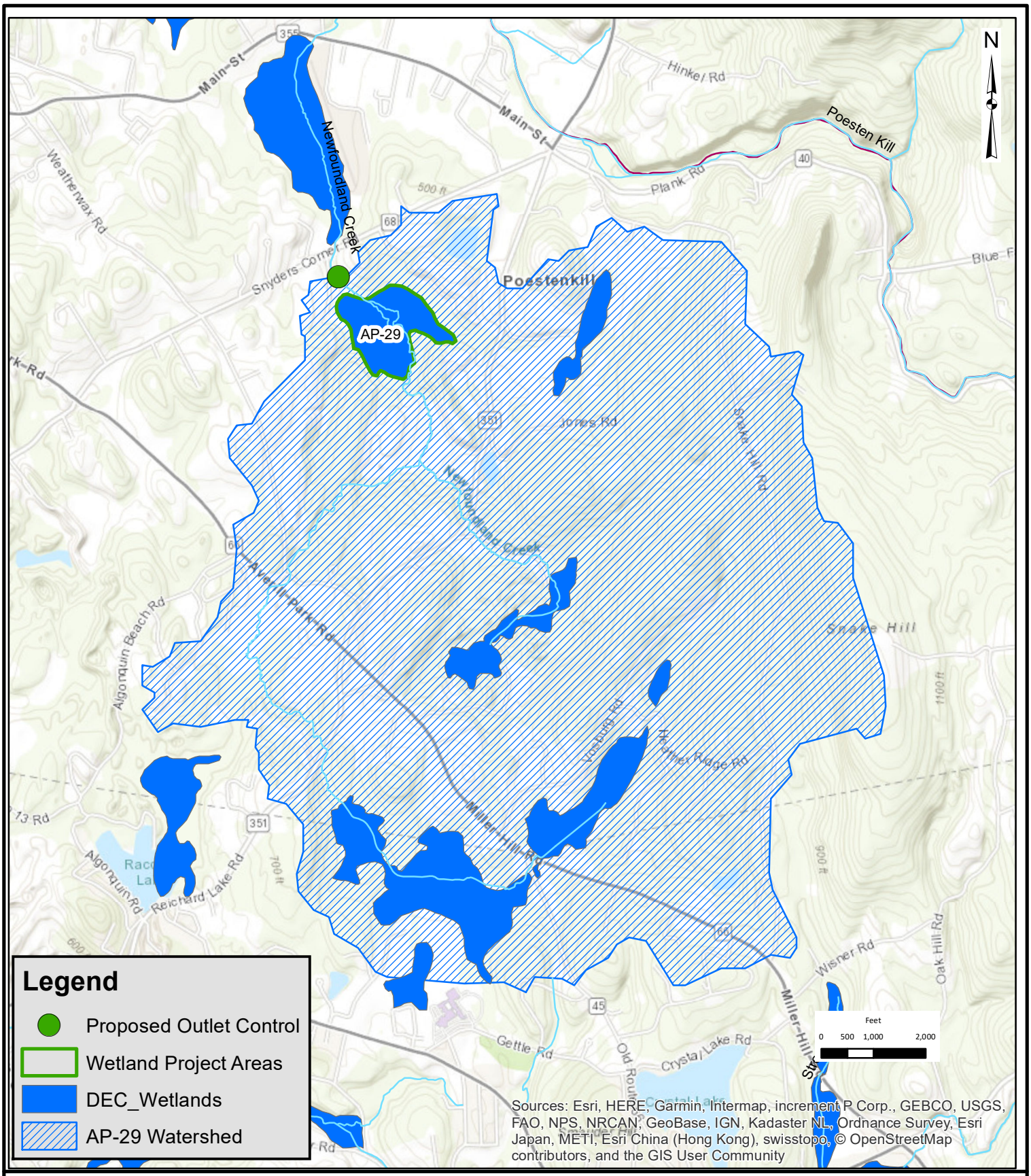

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AP-29 Wetland

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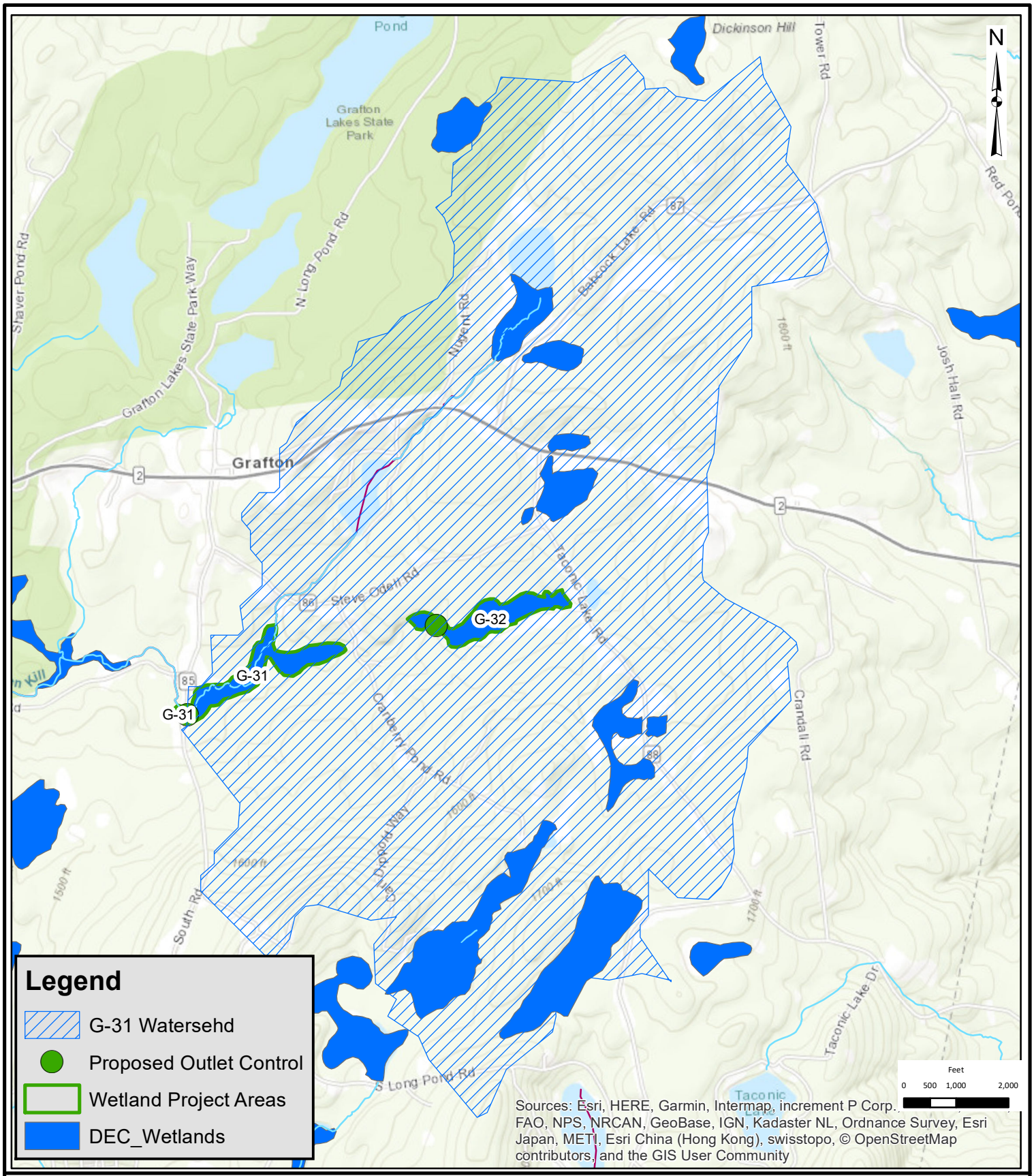

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Wetland G-31

Poesten Kill Watershed, Rensselaer County, New York

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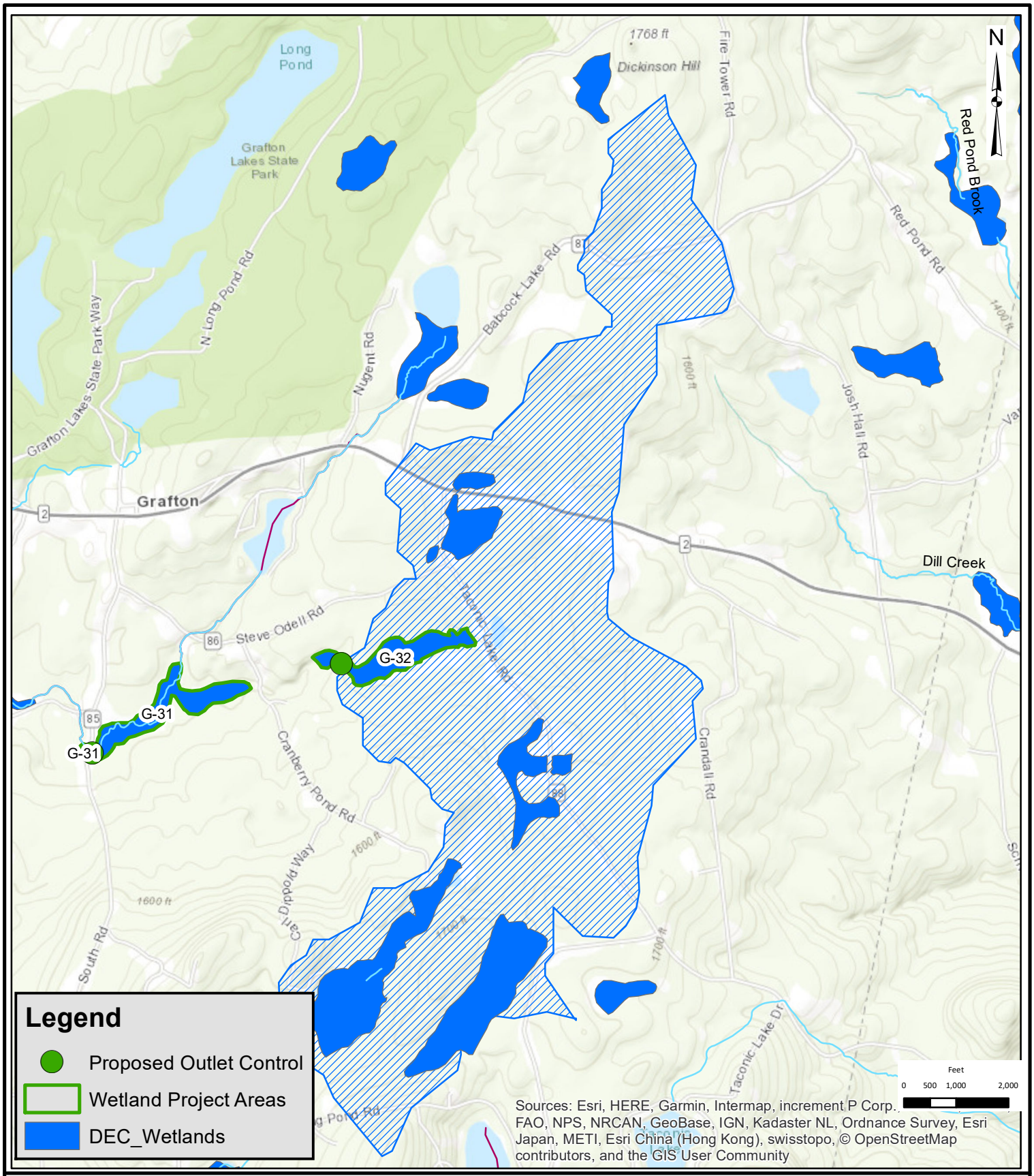

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Wetland G-32

Poesten Kill Watershed, Rensselaer County, New York

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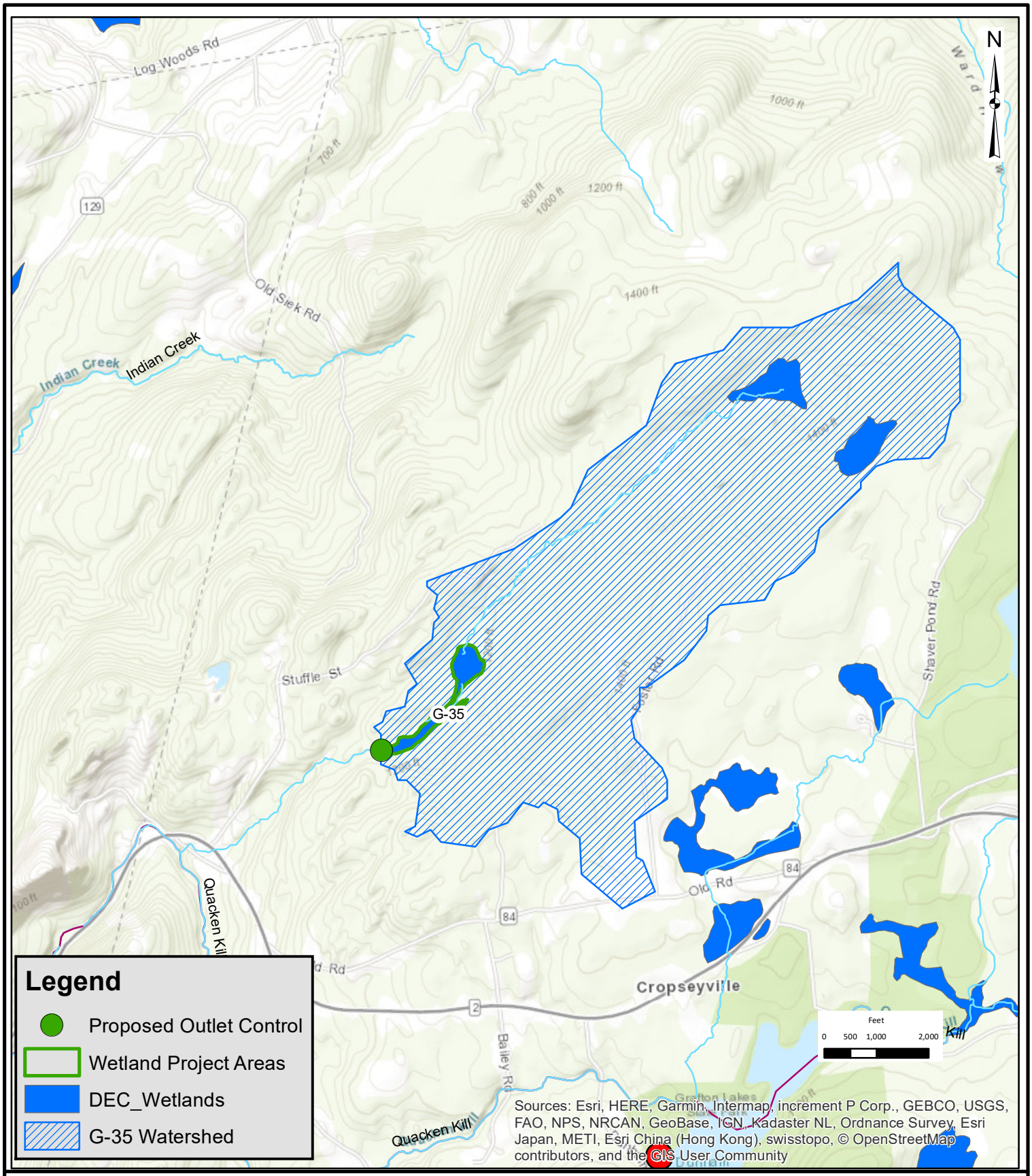

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RPA Poesten Kill Flood Mitigation Study

G-35 Wetland

Poesten Kill Watershed, Rensselaer County, New York

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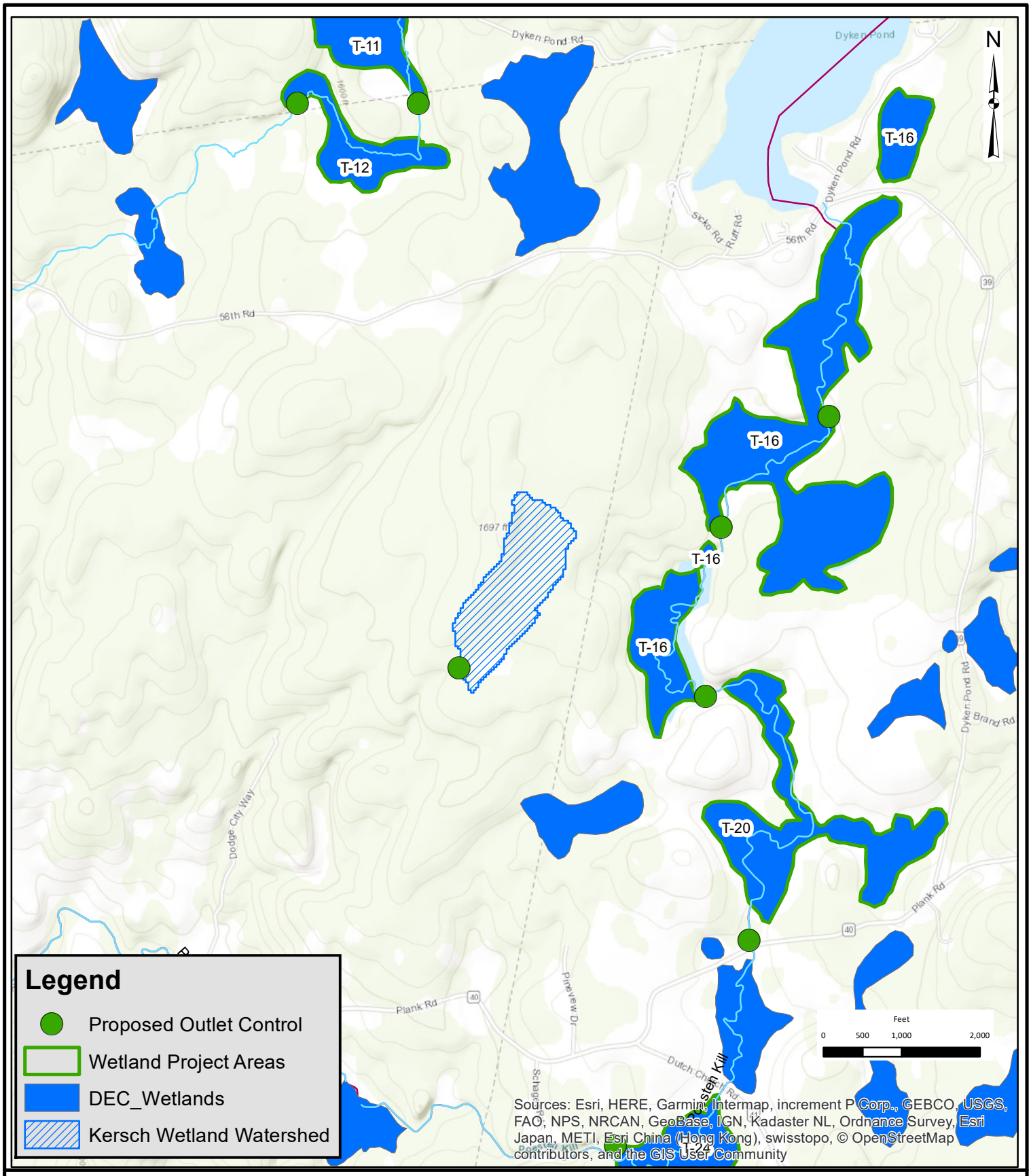

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RPA Poesten Kill Flood Mitigation Study

Kersch Wetland

Poesten Kill Watershed, Rensselaer County, New York

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Date:	06/20/19
Scale:	1:20,000
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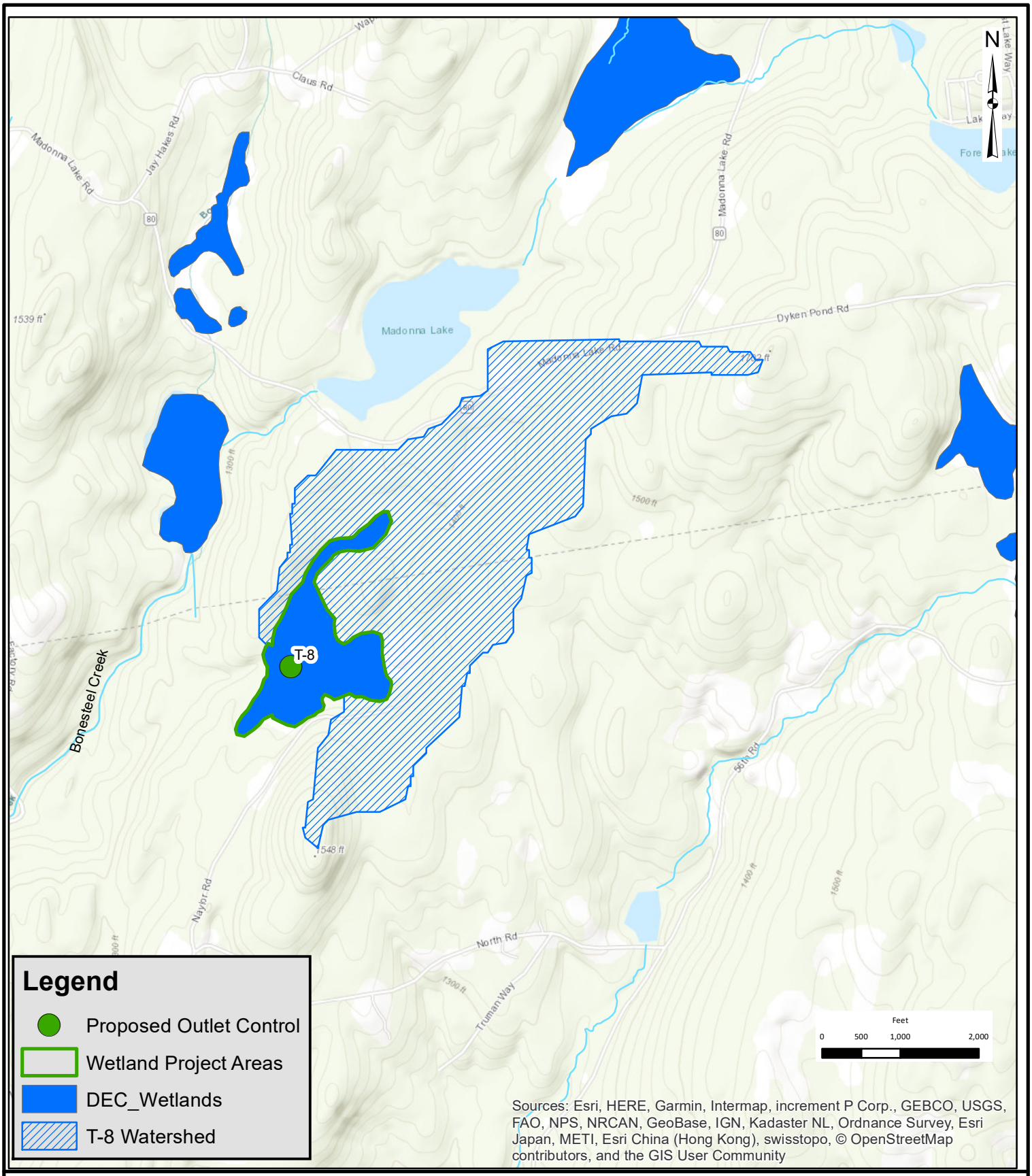

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RPA Poesten Kill Flood Mitigation Study

T-8 Wetland

Poesten Kill Watershed, Rensselaer County, New York

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Date:	06/20/19
Scale:	1:20,000
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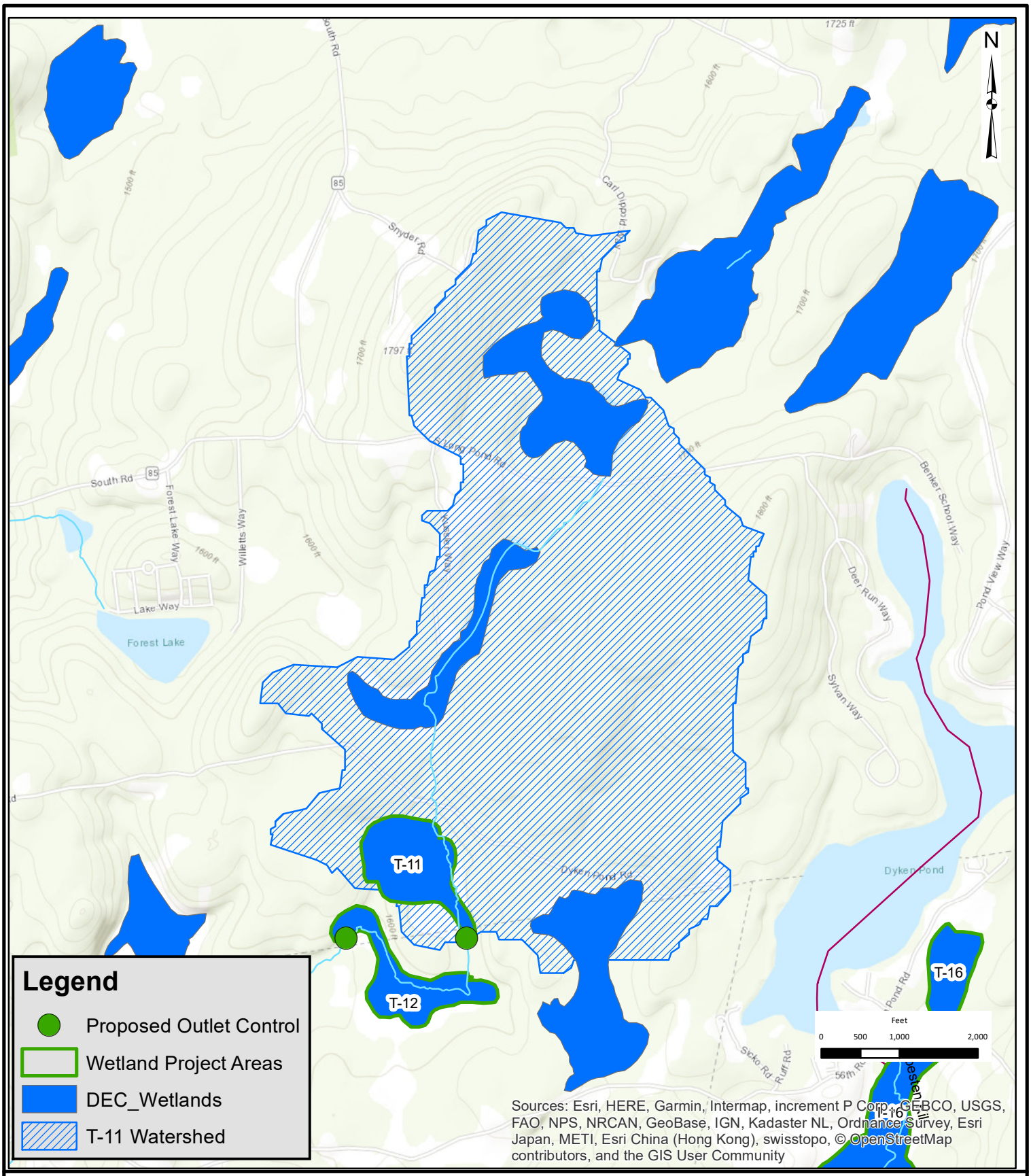

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RPA Poesten Kill Flood Mitigation Study

T-11 Wetland

Poesten Kill Watershed, Rensselaer County, New York

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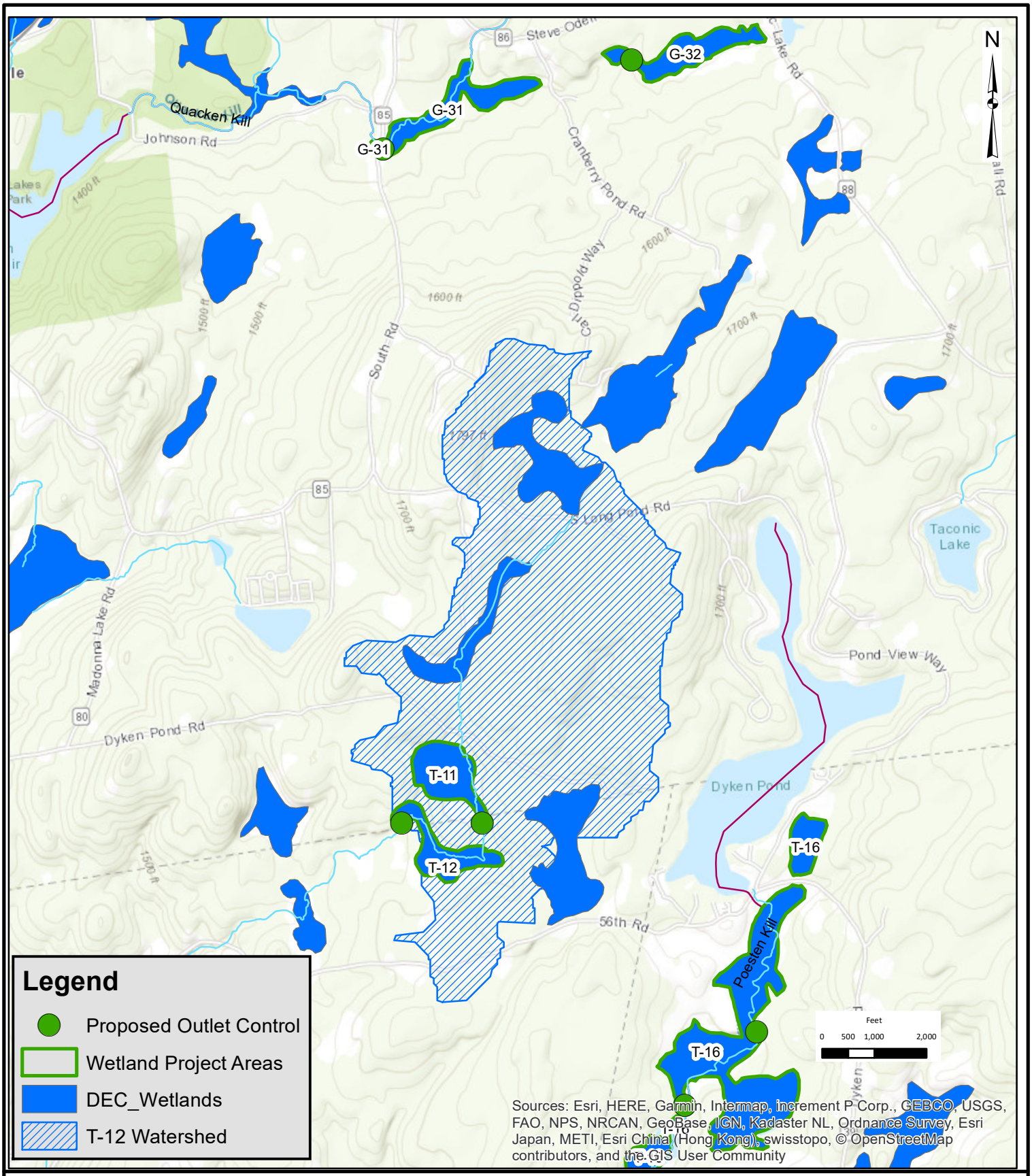

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Phone: (845) 454-3980

Capital District Office:
547 River Street, Troy, NY 12180
Phone: (518) 273-0055

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RPA Poesten Kill Flood Mitigation Study

T-12 Wetland

Poesten Kill Watershed, Rensselaer County, New York

Drawn:	JLB
Date:	06/20/19
Scale:	1:30,000
Project:	41822.00
Figure:	1

Map Document: (R:\0\standards\Gis\ChazenGIS\8X11P_MinimalChazenAddress.mxt)
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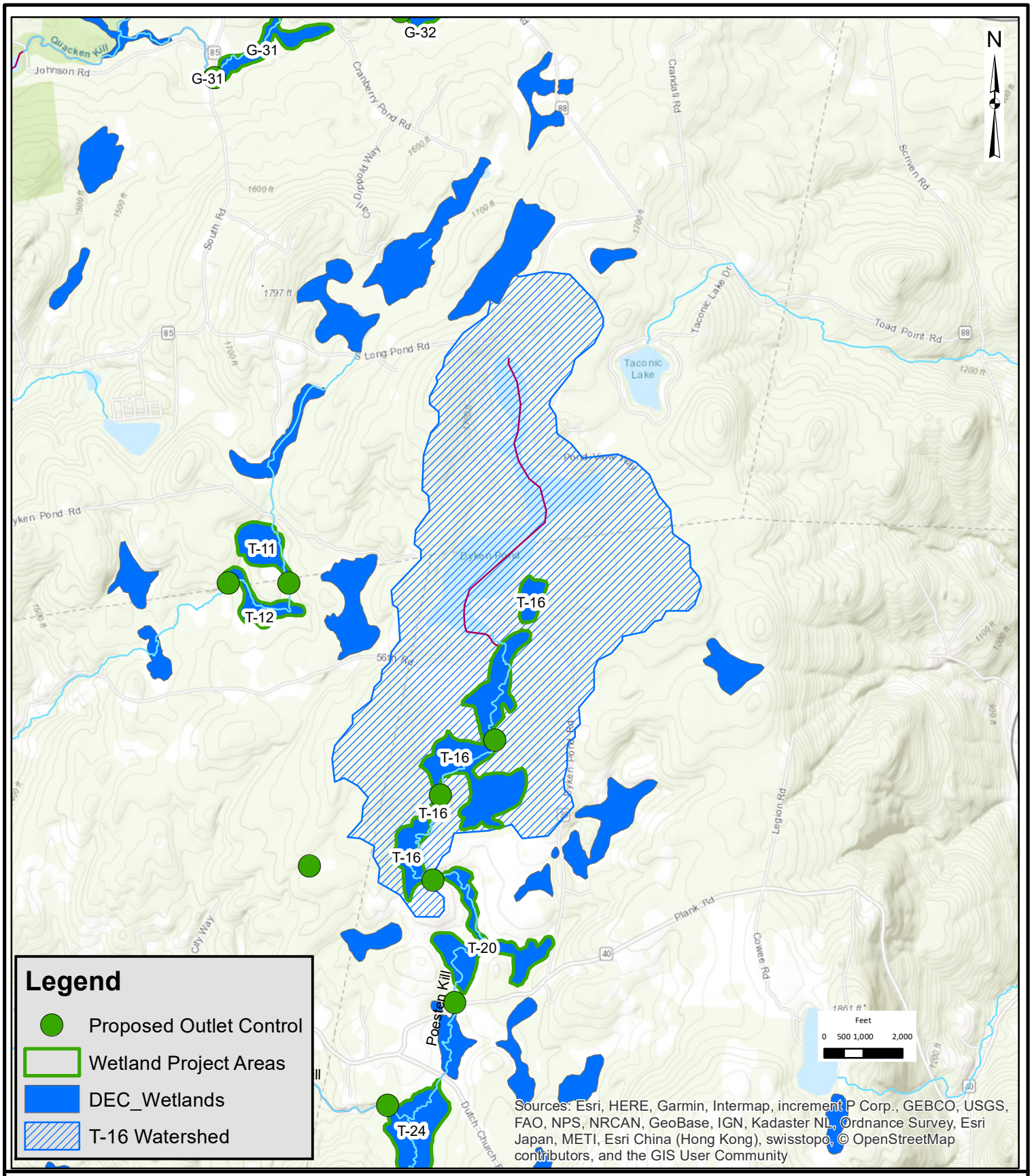

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RPA Poesten Kill Flood Mitigation Study

T-16 Wetland

Poesten Kill Watershed, Rensselaer County, New York

Drawn:	JLB
Date:	06/20/19
Scale:	1:40,000
Project:	41822.00
Figure:	1

Map Document: (R:\0\standards\Gis\ChazenGIS\8X11P_MinimalChazenAddress.mxt)
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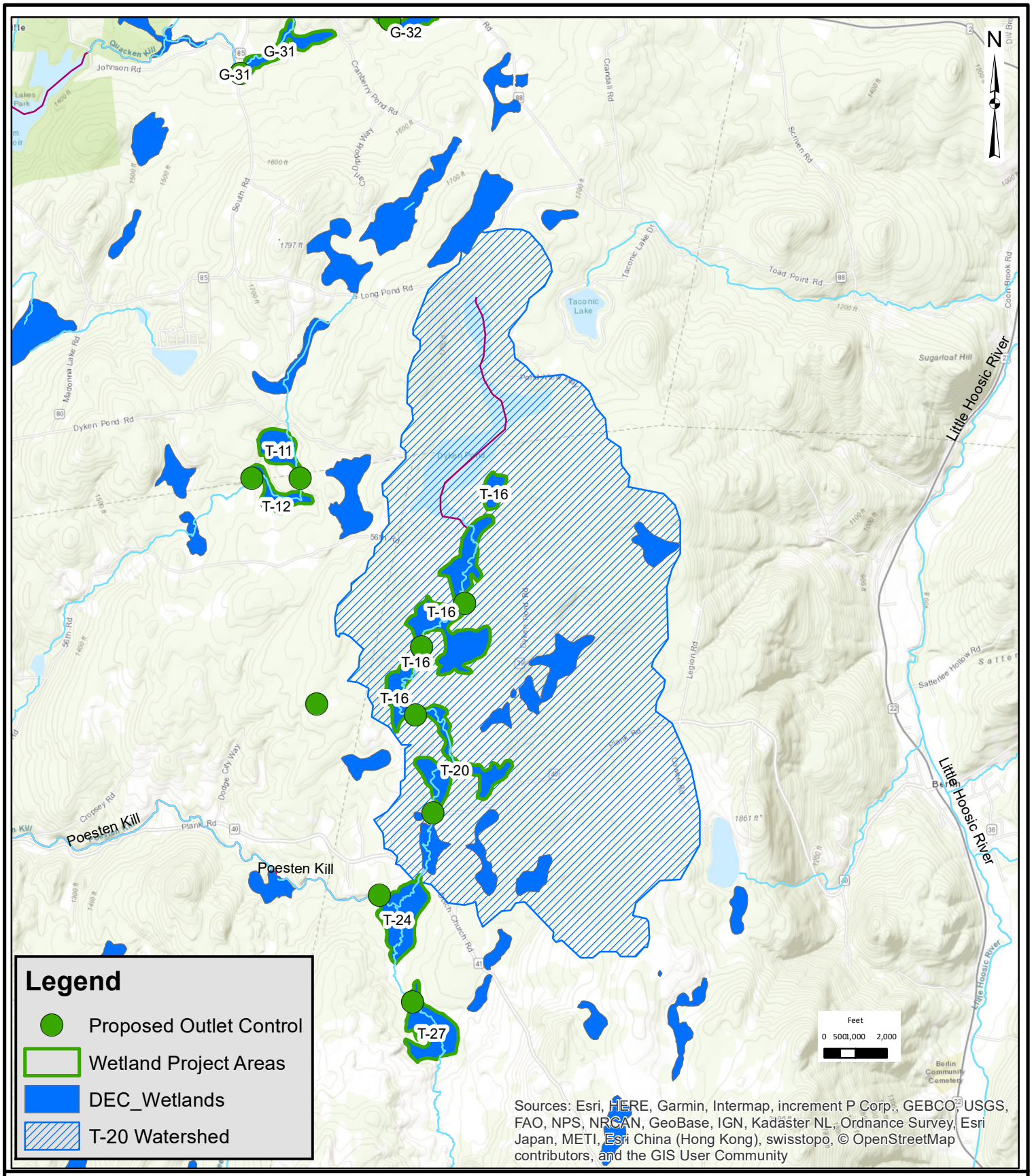

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RPA Poesten Kill Flood Mitigation Study

T-20 Wetland

Poesten Kill Watershed, Rensselaer County, New York

Drawn:	JLB
Date:	06/20/19
Scale:	1:50,000
Project:	41822.00
Figure:	1

Map Document: (R:\0\standards\Gis\ChazenGIS\8X11P_MinimalChazenAddress.mxt)
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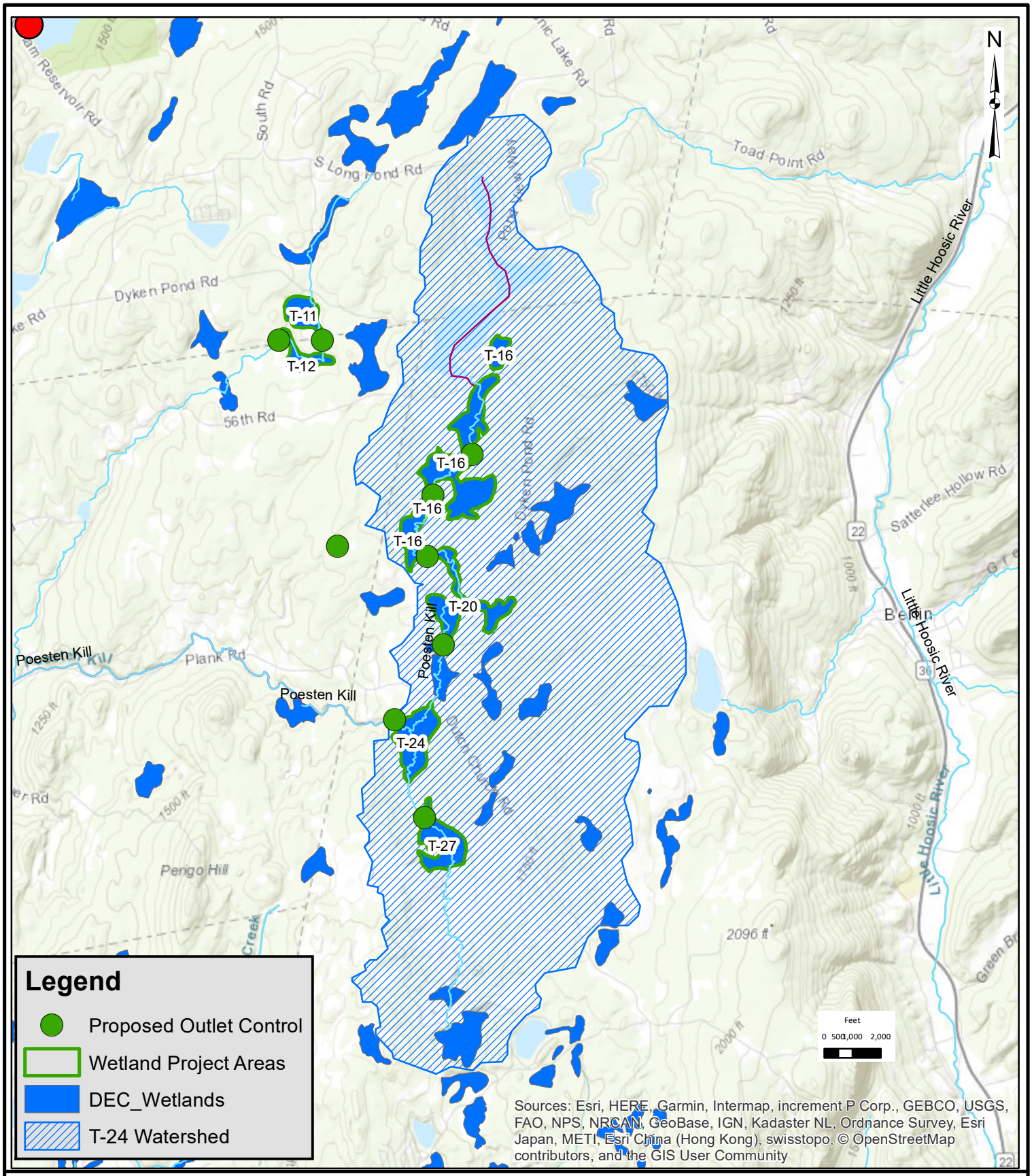

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RPA Poesten Kill Flood Mitigation Study

T-24 Wetland

Poesten Kill Watershed, Rensselaer County, New York

Drawn:	JLB
Date:	06/20/19
Scale:	1:55,000
Project:	41822.00
Figure:	1

Map Document: (R:\0\standards\Gis\ChazenGIS\8X11P_MinimalChazenAddress.mxt)
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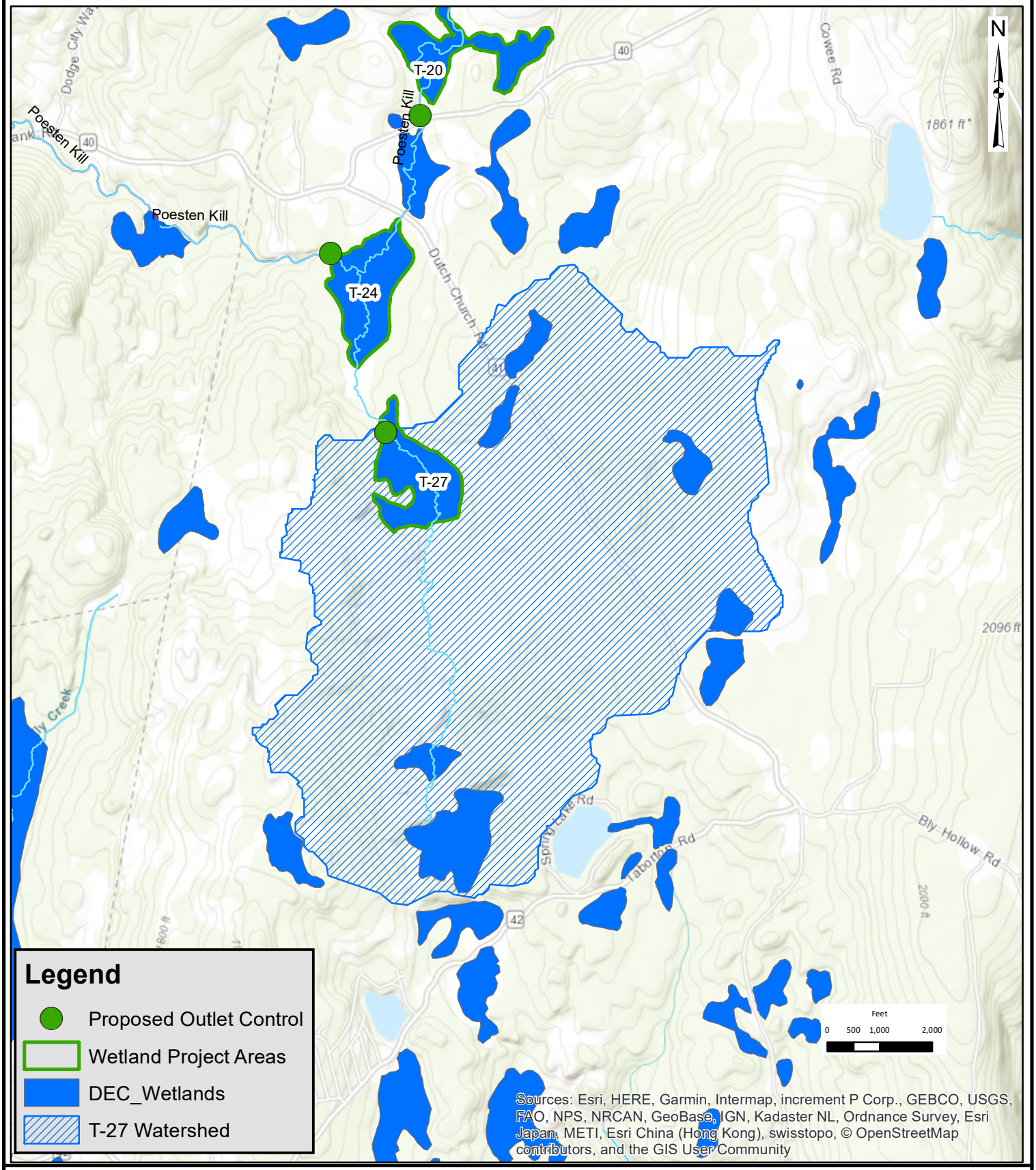

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RPA Poesten Kill Flood Mitigation Study

T-27 Wetland

Poesten Kill Watershed, Rensselaer County, New York

Drawn:	JLB
Date:	06/20/19
Scale:	1:30,000
Project:	41822.00
Figure:	1

Map Document: (R:\0\standards\Gis\ChazenGIS\8X11P_MinimalChazenAddress.mxt)
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Appendix 4: Public Participation Meeting Attendance

Sign-in / Attendance Lists for RPA Poesten Kill Watershed Flood Management Project Meetings

A. June 28, 2018 sign in list
B. December 11, 2018 sign in list
C. April 24, 2019 attendance list
D. May 23, 2109 attendance list (NYSDEC and Chazen additional; not listed)
E. July 18 2019 sign in list

Name	Organization	phone	email
BOB CROWLEY	RENSSELAER LAND TRUST	518-283-7364	CROWLEYRH@AOL.COM
Sarah Parks	RPA	302-584-7748	sparks@amalaconsulting.com
Jim Bonestoel	RPA	518-712-9211	jim@rensselaerplateau.org
Bob DAVIS	HOMEWATERS TROUT UNLIMITED	518-441-7306	twodavis1979@yahoo
Dorothy Surprise	Homewaters - trout unlimited	518-641-9660	Homewatersfu@gmail.com
INGRID GUNDRUM	SUPERVISOR TOWN of GRAFTON	518 788 5100	supervisorgundrum@albany-twelve.com
Pat Poleto	ASSIST. TO SUPERVISOR TOWN of BRUNSWICK	518 279-3461	pdeto@TownofBrunswick.com
Linda Vonder Heide	Rensselaer County Planning	518-270 2921	LvonderHeide@rensco.com
Steve Strichman	CITY of TROY	518-279-7166	steven.strichman@troyny.gov
Jeff Briggs	RPA	518-283-1926	jbriggs200@nycap.rr.com
Megan Lung	Hudson River Estuary Program / NEIWPCC	845-633-5449	megan.lung@dec.ny.gov
Candice Constantine	Inter-Fluve	617-909-7569	cconstantine@interfluve.com
Russell Urban-Mead	Chazen	845 486 1551	rum@chazencompanies.com
Jessica Brown	Chazen	(518) 266-7344	jbrown@chazencomp.com

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Please Sign In (Please print clearly)

1	Name: Russell Urban-Mead How did you hear about us? email	☐ I want to stay in touch e-mail: rum@chazencompanies.com phone: 914 956 1995	Address: 284 Mills Corners Rd Slatsburg NY 12580
2	Name: Chris von Schilgen How did you hear about us? email	☐ I want to stay in touch e-mail: phone:	Address: 308 Dunham Rd Coopseyville, NY 12052
3	Name: Don von Schilgen How did you hear about us? email	☐ I want to stay in touch e-mail: phone:	Address:
4	Name: Alene Orion How did you hear about us?	☒ I want to stay in touch e-mail: lene.orion@gmail.com phone: 3149102334	Address: 27 Holloway Ave all Park NY 12018
5	Name: MARK Russo How did you hear about us? via Mark Hufford / Friends of Poa lake	☒ I want to stay in touch e-mail: russomc@gmail.com phone: 646-226-1201	Address: 12 linden Ave Troy 12180
6	Name: Linda von der Hude How did you hear about us? Jim's e-mail	☐ I want to stay in touch e-mail: phone:	Address: 1600 Seventh Avenue Troy NY 12182
7	Name: Anasha Cummings How did you hear about us? Facebook	☒ I want to stay in touch e-mail: anasha.cummings@troyny.gov phone: (518) 406-8636	Address: 16 Hutton St. Troy NY 12180
8	Name: How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:
9	Name: How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:
10	Name: How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:

committee

russomc@gmail.com

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1	Name: Jim Bonesteel How did you hear about us? post card	☑ I want to stay in touch e-mail: jim@bonesteel.com phone: (518) 712-9211	Address: 167 Brainard Rd Averill Park, NY 12018
2	Name: Jessica Brown How did you hear about us? Post card	☒ I want to stay in touch e-mail: Jbrown@chazencompanies.com phone: (518) 266-7344	Address: 547 River St. Troy, NY 12180
3	Name: Alicia Flint How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:
4	Name: Amelia Flint How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:
5	Name: Harold VanSlyke How did you hear about us? ?	☒ I want to stay in touch e-mail: vanslykebelle@gmail.com phone:	Address:
6	Name: Ashley Albano How did you hear about us? Post Card	☐ I want to stay in touch e-mail: phone:	Address:
7	Name: Tom Russell How did you hear about us?	☒ I want to stay in touch e-mail: HoBIEYo@AOL.COM phone:	Address:
8	Name: How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:
9	Name: How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:
10	Name: How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:

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1	Name: MARCIA HOPPLE How did you hear about us? email	☐ I want to stay in touch e-mail: mhopple@nycap.rr.com phone: 518 283 5353	Address: 174 Hinkelkill Poestenkill NY 12140
2	Name: Robert Renee Kardelky How did you hear about us? Advertiser	☐ I want to stay in touch e-mail: Kardelky1@yahoo.com phone: (518) 324-3020	Address: 900 Plank Rd Averill Park NY 12018
3	Name: Robert Morrell How did you hear about us? Advertiser	☐ I want to stay in touch e-mail: phone:	Address:
4	Name: Walter Kersch How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:
5	Name: Luke Reiter How did you hear about us? FaceBook	☐ I want to stay in touch e-mail: phone:	Address: 693 Blue Factory Rd Averill Park NY
6	Name: Dorothy Surprise How did you hear about us? email	☒ I want to stay in touch e-mail: QuiltBugtoo@gmail.com phone: 518.641.9660	Address: 39 McKinley Way Apt C9 Wynantskill, NY 12198
7	Name: Bob DAVIS How did you hear about us? email	☒ I want to stay in touch e-mail: RWDAVIS1979@gmail.com phone: 518-441-7306	Address: 486 N. Nassau Rd Averill Park, NY 12018
8	Name: ROBERT WAGNER How did you hear about us? BOB DAVISE	☐ I want to stay in touch e-mail: phone: 852 2836	Address: 79 GARFIELD RD POESTENKILL NY 12140
9	Name: Howie Cushing How did you hear about us? Advertisin	☐ I want to stay in touch e-mail: CCSHNG3@AOL.COM phone: 5186942961	Address: 96 JONES RD POESTENKILL N.Y. 12140
10	Name: How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:

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1	Name: Shari Gibbs How did you hear about us? RPA	☑ I want to stay in touch e-mail: sdgibbs66@gmail.com phone: 518 928-8877	Address: 287 Hidley Rd Wynantskill, NY 12198
2	Name: Dick Gibbs How did you hear about us? RPA	☑ I want to stay in touch e-mail: dickgibbshs@gmail.com phone: 518 225-7371	Address: " ↑
3	Name: Jeff Briggs How did you hear about us? RPA	☐ I want to stay in touch e-mail: jbriggs200@nycap.rr.com phone: (518) 283-1926	Address: 332 Weatherway Rd Poestenkill, NY
4	Name: PAUL BARRINGER How did you hear about us? ADVERTISER	☐ I want to stay in touch e-mail: PBARRINGER@POESTENKILLNY.COM phone: 518 283-5100 x102	Address: 38 DAVIS DR. POESTENKILL NY 12144
5	Name: Megan Lung How did you hear about us? NYS DEC	☑ I want to stay in touch e-mail: phone:	Address:
6	Name: A. Hohenstein How did you hear about us? friend	☐ I want to stay in touch e-mail: phone:	Address: Troy
7	Name: T. J. Kennedy How did you hear about us? Facebook	☑ I want to stay in touch e-mail: TKeann56@gmail.com phone: 5184290489	Address: 235 Stow Ave Troy NY
8	Name: How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:
9	Name: How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:
10	Name: How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:

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Please Sign In (Please print clearly)

1	Name: Rinde Weal Maleff How did you hear about us? e mail	☐ I want to stay in touch e-mail: dewealmaleff@gmail.com phone:	Address: 5 Bayberry Circle Westerlkill
2	Name: Louis Wagner How did you hear about us? Mark	☐ I want to stay in touch e-mail: phone:	Address:
3	Name: KEITH WAGNER How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address: 185 GARFIELD RD POESTENKILL, NY 12140
4	Name: How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:
5	Name: How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:
6	Name: How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:
7	Name: How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:
8	Name: How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:
9	Name: How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:
10	Name: How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:

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RPA Poesten Kill committee meeting, April 24, 2019

Attendees

- Jim Bonesteel, RPA
- Dan Morse, RPA
- Bob Davis (Trout Unlimited)
- Marcia Hopple, assisting with Poestenkill NRI update
- Jeff Briggs (RPA)
- Linda VonDerHeide (Rensselaer County)
- Jim de Waal Malefyt (RPA)
- Rob Morrell (DEC)
- Trevor Brady (DEC)
- Kristina Younger (Rensselaer Land Trust)
- Brian Buchanan (Hudson Estuary Program)
- Russell Urban-Mead, Chazen

entered 5/24/19 DM

Rensselaer Plateau Alliance

Conservation Through Community

Community Meeting - Poesten Kill Flood Mitigation Study - May 23, 2019

Please sign in (please print clearly) – thank you!

1	Name: PAUL BARRINGER How did you hear about us?	☐ I want to stay in touch e-mail: PBARRINGER@POESTENKILLNY.COM phone: 518 288-5100 X102	Address: 38 DAVIS DR. POESTENKILL NY 12140
2	Name: KIM HOPPER How did you hear about us?	☐ I want to stay in touch e-mail: kimhopper46@gmail.com phone:	Address: 32 Balsam Way Cropseyville, NY 12052
3	Name: JIM LENNON How did you hear about us?	☑ I want to stay in touch e-mail: JIM.LENN49@GMAIL.COM phone:	Address: 41 BALSAM WAY CROPSEYVILLE NY 12052
4	Name: JUDE BUTLER How did you hear about us?	☐ I want to stay in touch e-mail: ROSS4JB@JUNO.COM phone: 518-283-1373	Address: 181 FIFTY-SIX RD AVERILL PARK 12018
5	Name: MARCIA HOPPLE How did you hear about us?	☐ I want to stay in touch e-mail: You have phone:	Address: You have
6	Name: How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:
7	Name: How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:
8	Name: How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:
9	Name: How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:
10	Name: How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:

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Please sign in (please print clearly) – thank you!

1	Name: Ray Morris How did you hear about us? e-mail	☐ I want to stay in touch e-mail: phone:	Address: Morris way & 4 Spring landing blvd. Wyman Sky NY 12198
2	Name: Angela + Nick Petitti How did you hear about us? e-mail	☐ I want to stay in touch e-mail: apetitti@nycap.rr.com phone:	Address: 259 Madonna Lake Rd Cropseyville, NY 12052
3	Name: MIKE HOGAN How did you hear about us? BOB DAVIS	☑ I want to stay in touch e-mail: MMHFLP@AOL.COM phone: 518 2793821	Address: 426 GARFIELD RD TROY NY 12180
4	Name: BOB DAVIS How did you hear about us? HOMEWATERS TU.	☐ I want to stay in touch e-mail: phone:	Address: 486 NO. NASSAU RD. AVERILL PARK N.Y.
5	Name: Joe Auslander How did you hear about us? Home Waters TU	☒ I want to stay in touch e-mail: reuphysherman@twc.com phone: 518-545-1771	Address: P.O. Box 388 West Sand Lake NY 12196
6	Name: How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:
7	Name: How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:
8	Name: How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:
9	Name: How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:
10	Name: How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:

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Community Meeting - Poesten Kill Flood Mitigation Study - May 23, 2019

Please sign in (please print clearly) – thank you!

2 1	Name: Mofie How did you hear about us? Advertisin	☐ I want to stay in touch e-mail: GennyA597@aol.com phone:	Address:
2	Name: Brant Caird How did you hear about us? meetings	☐ I want to stay in touch e-mail: brantcaird@msn.com phone: 209-8684	Address: 50 Pawling Ave Troy
3	Name: Dorothy Sweeney How did you hear about us?	☐ I want to stay in touch e-mail: QUILTBUGtroe@gmail.com phone:	Address: 39 McKinley WAY C9 Wynantskill, NY 12198
4	Name: Matter Kersel How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:
5	Name: Julia Cavicchi How did you hear about us? Garrett	☒ I want to stay in touch e-mail: jcavicch@skidmore.edu phone: 240-888-0209	Address:
6	Name: How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:
7	Name: How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:
8	Name: How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:
9	Name: How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:
10	Name: How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:

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Community Meeting - Poesten Kill Flood Mitigation Study - May 23, 2019

Please sign in (please print clearly) – thank you!

1	Name: Chris von Schilgen How did you hear about us? e-mail	☐ I want to stay in touch e-mail: phone:	Address:
2	Name: Linda vonderHerr How did you hear about us? E-Mail	☐ I want to stay in touch e-mail: phone:	Address:
3	Name: Jeff Briggs How did you hear about us? word of mouth	☐ I want to stay in touch e-mail: phone: 283-1926	Address: Weatherwax Rd Poestenkill
4	Name: How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:
5	Name: How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:
6	Name: How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:
7	Name: How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:
8	Name: How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:
9	Name: How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:
10	Name: How did you hear about us?	☐ I want to stay in touch e-mail: phone:	Address:

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7-18-2019 Poesten Kill watershed Committee Meeting

Name	e-mail
Jim Bonestoel	jim@rensselaerplateau.org
Bob Davis	rwdavis@e-mail.com
RANDOLPH FRANKLIN	RENSPLAT@WRFRANKLIN.ORG
Linda von der Heide	Lvonderheide@rensco.com
Walter Kersch	walterkersch@aol.com
Jeff Briggs	jbriggs200@nycap.rr.com
Russell Urban-Mead	rum@chazecompanies.com
Megan Lung	Megan.Lung@dec.ny.gov
Brian Buchanan	brian.buchanan@dec.ny.gov

Appendix 5: Wetland Detention Permitting Memorandum & Email

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Meeting Summary

Project Title: Rensselaer Plateau Alliance – Posten Kill Watershed Green Design Flood Mgt.
Chazen Project Number: 41822.00

Meeting Date, Time: Friday February 1, 2019 at 1-2:30PM
Meeting Location: NYSDEC Region 4 Offices, with HREP staff participating by phone
Summary Writer: Barbara Beall
Issue Date: February 14, 2019
Attending:

Attendee:	Representing:
Jeff Briggs	Rensselaer Plateau Alliance (RPA)
Russell Urban-Mead	The Chazen Companies
Barbara Beall	The Chazen Companies
Andy Dangler	US Army Corps of Engineers Upstate Field Office
Kate Kornak	NYSDEC Region 4 Deputy Regional Permit Admin.
Derek Thorsland	NYSDEC Region 4 Water Quality/Stream Engineer
Tom Blanchard	NYSDEC Region 4 Floodplain Mgt. Dam Safety
Georgette Walters	NYSDEC Region 4 Wetland Permits
Trevor Brady	NYSDEC Region 4 Stream Permits
Scott Cuppett	HREP
Megan Lung	HREP/NEIWPCC

Summary:

Discussion

- Project Overview: Russell Urban-Mead began with a discussion of the project. Project is to explore options to manage the next big flood in the Posten Kill Watershed. Hurricane Irene beat the watershed up. Have a grant to study how landscape features might be used to management flood. There may be a dam/relocation function of the floodplain. The Rensselaer Plateau has a unique geography with 2,000 acres of wetlands at higher elevations in the floodplain. They are wetland areas generally constrained by an outlet that links by small streams in a forested landscape. Goal is to work with nature to provide greater detention and drain out time in order to desynchronize flooding. There is not a single wetland that can solve this problem. When the flow comes down the watershed, it becomes a much larger problem in Troy and downstream in the watershed when the Posten Kill jumps its banks and floods.

- Jeff Briggs and Rensselaer Plateau Alliance: Jeff lives in the watershed. He is a retired wetland professional. He is looking at a way to detain water in a wetland with sidewall control device. While retaining water in one wetland may not make a large difference, retaining water in a series

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of wetlands will likely make a large difference. Retaining water over 25 acres for a 25-year storm event made a 40% reduction in flows.

- Modeling to Date: One model was run using a wingwall constrained to a 25-year flood flow resulting in 3 to 4 days of inundation by a couple of feet. It is hoped that the there can be a series of these projects in the floodplain. This is a blue-sky discussion of whether this represents a possible solution to downstream flooding. Doing this on 12 wetlands would make a meaningful impact based on modeling. It could then become a repeatable cost-effective action that everyone understands from a permitting perspective. Model used Dyken Pond and NYSDEC Wetland T-16 as an example. Would use wingwalls at the downstream outlet of the wetland to narrow the outlet. There are existing steep sidewalls in this area. Would have the wingwall marry into the landscape. NYSDEC asked what about downstream flow over the temporary spillway. What does this mean to the stream downstream of the spillway. Jeff explained that at the Heckleman Site, the project is a sill on bedrock, and throughout most of the Bonesteel Creek, the wetlands outlet on a bedrock sill – most outlets of wetlands above 1,000 feet appear to be bedrock control features at stream outlet. Newfoundland Creek is a bit broader and flatter but may have a rocky bottom in the stream. NYSDEC concerned about anything that concentrates flow and causes downcutting in the channel. Explained that the outlet would be somewhere in the 2-foot tall detention wall, so there is not significant erosive threat. It was noted that at least around NYSDEC Wetland T-16, the land rises quickly from the wetland, so increased area of flooded land may not be that large.

- Non-Regulation by Dam Safety and Corps of Engineers: It is a shallow structure. It is not tall enough to be a "dam" under NYSDEC Dam Safety Regulations (dams are at 6 foot). Corps stated that if the structure is in uplands outside of any wetland area or any Ordinary High Water Mark (OHWM) of a stream, the activity is not regulated by the US Army Corps of Engineers. The OHWM typically/often forms around the 2-year flow line.

- Owner Permission: The RPA will need to have property owner's permission for this work. Discussed the need to research the flooding limits under different scenarios to ensure that individuals upstream of the structure know that there may be a larger area of their property flooded at a lower storm interval to obtain permission for this work. There may be additional floodplain areas upstream of the weirs. FEMA or other agencies may need to evaluate downstream flood zones. Group recommended use of beaver pipes to keep beaver from enhancing dam aspect of weir following construction.

- NYSDEC Permits: Kate mentioned that there will be a need for Article 15 and Article 24 permits for this work (protected streams and Freshwater Wetlands). Landowner sign-off on permit applications. Need to ensure that there are no homes that would be impacted by inundation.

- Donation of Lands to NYS: Some of these lands may become the NYSDEC ownership as a result of conservation deeds to the State. There needs to be a discussion of maintenance requirements if the weirs and lands will ultimately be owned by the NYSDEC.

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- Watersheds of Quacken Kill and Posten Kill Stem: Those have different watersheds, but during Hurricane Irene they peaked at the same time, with two flooding streams coming together creating a downstream super flood. This project may desynchronize the release of these two streams, reducing downstream damage. A lot of rain in one part of the overall Posten Kill Watershed versus in another part of the watershed has much different results on downstream flooding. They way they come together varies. In Hurricane Irene there was a "perfect storm" where everything broke loose.

- Unintended Consequences – Aquatic Fauna Movement: Scott Cuppett asked if this would result in unintended consequences or be detrimental to rock stabilization. Will the project funnel water into a narrow channel? Will the project create unintended barriers between different wetlands? There is the potential for the weir to serve as a deterrent to aquatic life movement. Identified Georgette Walters in Region 4 as someone to speak to. Chris Edmare also would be involved in reviewing potential impacts to Dyken Pond, the outlet trout stream and regulated wetland.

- Factors to be Reviewed in Permitting: Trevor is an Article 15 specialist. The following factors were identified for review in permitting a small model project:

    - Models – understand the flows upstream and downstream of the location.

    - Individual Group of Projects versus Whole Watershed - 95 square miles, 45 square miles 5% impoundment. There is a cumulative beneficial impact downstream from a group of projects. Any one project is insufficient to make a difference. Should there be a concentrated effort on 6 to 12 projects or

    - Local public interest benefit that outweighs detriment to wetland - If there is no great retention for flood abatement overall in the floodplain, what is the abatement. Should the project review more micro-scale benefits such as the downstream road which was blown out in Hurricane Irene during the flood event.

    - Blockage of Aquatic Organisms - Will the weir act as a debris trap? Will they encourage beaver to create a blockage to aquatic organism passage? Is there a way to raise the elevation to not block movement?

    - Custody - Who will evaluate, maintain, watch for barrier issues over the long-term.

    - Adjacent wetlands – In the surrounding upland woods, are there depressional wetlands that serve as vernal pools. Will those areas now be open for flooding and fish predation. Will some wetlands like that be stranded?

    - Grade Control/Scour protection/Changes in Wetland and Stream Function - Will there be a change in flow dynamics that could increase erosive factors at the weir. Would there be a head cut at the wetland? Need to identify if there will be changes in wetland functions

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from an increased frequency/duration of flooding? Is the substrate bedrock or soil? Is there a need for erosion control?

- Article 15 (Stream Disturbance) Permitting Standards: Reasonable and necessary. Will the project meet the standard if there is a subset of mitigation areas versus all the mitigation areas?

- Article 24 Freshwater Wetland) Permitting Standards: Under the Uniform Procedures Act, this would be a major project. Would need to review and issue permits in 60 days or so. Loot at the entire project in global scope or pieces at time. Will the permits be issued for a long-enough time frame to allow them to be constructed? Need to look at Posten Kill benefits versus Troy benefits. Georgette on Article 24"

    - Not a typical project.

    - Open-minded with all questions.

    - Trevor agreed. Modeling to understand S&E issues

    - Regulatory standpoint – Will this increase effluent in wetlands. Will the flood retention modify the Dissolved Oxygen in streams? Is there a difference between a natural and an enhanced function? Is there aquatic organism impediment issues? Provide enough information to analyze.

    - Trevor stated that frequency of storm events helpful to have so one can make a reasonable prediction of how often the weir structure will be activated. Will it be every 25 years or 4x/year? Historical data for frequency of storms.

    - Russell asked if the concept for a 100 year to a 25-year storm flows – if we modify 25-year flows, don't see impacts, increase to 50- or 100-year events. It is still a huge benefit. Model to find out storm events and what happens. Use in a pragmatic way. Make sure you are evaluating the migratory corridors not just in the stream but in the areas of the weir.

    - Megan Lung stated not opposed to effluent into wetland due to dissipation factors up to a 50-year storm. Look at the benefit of a multi-factor hydraulic model, and seek to avoid disconnecting or degrading habitats. Be aware of maintenance costs.

- Discuss maybe modeling one system, where there is a good handle on existing conditions, look at storm events, sediment load on wetlands, cuts in stream channel, vegetation dying back? Model and implement one system and watch what happens. Have the first project be a demonstration project.

Meeting adjourned (2:15 PM)

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From: Brady, Trevor M (DEC) [mailto:trevor.brady@dec.ny.gov]
Sent: Monday, May 06, 2019 8:16 AM
To: Jim Bonesteel <jim@rensselaerplateau.org>
Cc: Jacobson, Roy (DEC) <roy.jacobson@dec.ny.gov>
Subject: Rensselaer Plateau Alliance Meeting

Hi Jim,

Thank you for providing me with the opportunity to attend the April 24, 2019 meeting of the Poesten Kill Watershed Flood Mitigation Committee. To recap, the purpose of the meeting was to discuss the Poesten Kill Watershed Flood Mitigation projects currently under evaluation by Chazen Companies and the Renssalaer Plateau Alliance. As I stated during the meeting the Region 4 Bureau of Ecosystem Health's (R4 BEH) role in this process will be to provide regulatory review if, and when the projects reach the application for permit stage. Currently, Chazen Companies has identified 15 unique potential locations for the proposed "dry dam" flood retention devices. The identified locations are situated within multiple New York State Department of Environmental Conservation protected resources including 13 Fresh Water Wetlands and multiple Protected Streams. The R4 BEH has not to date received any official application materials or preliminary plans for review. As such, The R4 BEH has not developed any opinion on the potential benefit or impacts of the proposed devices.

During the meeting I also reiterated (originally detailed during the February 1, 2019 pre-application meeting) some of the elements that the R4 BEH would be looking for in any eventual application packet for one of these projects. These include:

What alternatives to the proposed project were evaluated, and the outcome.

A description of the anticipated benefit of each of these structures.

Hydraulic/Sediment Modeling that demonstrates and predicts the before and after conditions of the stream (upstream and downstream) and wetland in relation to the addition of the flood retention devices.

Flood frequency data and the anticipated frequency and duration of artificial retention of flood waters.

Predictive Inundation Mapping which demonstrates what level of flood abatement will be achieved through the addition of the devices.

Evaluate and describe the need for grade control near the proposed "dry dams".

“Dry Dam’ inspection and maintenance methods and schedules.

Please understand that this list is by no means exhaustive and the review process may likely identify the need for more details. Thank you again for the opportunity to discuss these details in person. Please don’t hesitate to contact the Region 4 Bureau of Ecosystem Health with any questions or concerns that you may have.

Trevor Brady
Biologist 1 (Ecology)

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Appendix 6: Storm Preparation and Watershed Restoration Recommendations

Dutchess Area Environmental Science Advisory Network (ESAN)

Recommendations for Stream & Flood Management in Dutchess County

Compiled by the
Dutchess Area Environmental Science Advisory Network

September 2008

Dutchess Area Environmental Science Advisory Network (ESAN)

September 5, 2008

Dear Local Officials and Interested Parties:

The Dutchess Area Environmental Science Advisory Network (ESAN) is pleased to provide you with a copy of a new ESAN report on *Recommendations for Stream & Flood Management in Dutchess County*. Primary authors of the report are David Burns and Thomas Lynch, with input from several other authors identified in the report. The ESAN is a non-advocacy network of environmental scientists who are available to provide non-biased, scientific input on important issues surrounding the use and management of natural resources and humans' interactions with the environment.

While recognizing that protection of life and property is the highest priority during extreme weather events, the attached recommendations seek such protection while also considering long-term risk abatement, ecological habitat preservation, infrastructure investments which will reduce flooding harm, and storm pre-planning measures. Two important steps are assessing where the risks for floods are the greatest in our municipalities and where there are opportunities for mitigating potential problems. We envision the document being useful to planners, engineers, and municipal leaders seeking general guidance; these general recommendations can be adopted at the local level based on site specific knowledge in particular areas about flood histories, risks, and preparedness.

For more information on this report, or the ESAN, please contact me at 845.677.5343 or findlays@ecostudies.org. The report is available online through the Cornell Cooperative Extension Dutchess County Environment Program website at http://counties.cce.cornell.edu/dutchess/002_environment/003_our_water_resources/. ESAN members are available to present these recommendations for stream & flood management to local boards and in public forums, and welcome suggestions about other critical environmental issues that need similar analysis by the Network in the future.

Sincerely,

Dr. Stuart Findlay
Cary Institute of Ecosystem Studies *and*
Chair of the Dutchess Area ESAN

DUTCHESS COUNTY ENVIRONMENTAL SCIENCE ADVISORY NETWORK (ESAN)
STUART FINDLAY (CHAIR) • DAVID BURNS • SCOTT CHASE
ALLISON CHATRCHYAN • CAROLYN KLOCKER • THOMAS LYNCH • GARY LOVETT
CATHY MCGLYNN • KIRSTEN MENKING • CATHERINE O'REILLY • RUSSELL URBAN-MEAD

Foreword

The Dutchess Area Environmental Science Advisory Network (ESAN) is a network of local environmental scientists and professionals who work to promote the improved scientific understanding of critical environmental issues by the public and local municipal officials through the collection, analysis, sharing, and diffusion of reliable and unbiased scientific information. ESAN works to provide a forum to infuse scientific knowledge into environmental decision-making; convey ecological science to the media and the general public; and provide a collaborative network for the environmental science community. To accomplish this mission, and to be able to work with all stakeholders, ESAN is an independent, apolitical and non-advocacy organization, and will draw on all available resources to present the state of our understanding of various environmental issues.[1]

This document was generated through the collaborative efforts of the Dutchess Area ESAN and is not meant as a panacea, but rather a logical approach towards the development of solutions to the complicated and recurring problem of flooding and subsequent calls for in-stream modifications. This document is organized into a series of recommendations encompassing stream management, floodplain planning and management, and needed research, as well as a section dealing with supporting technical background material.

The ESAN would particularly like to thank lead authors David Burns and Thomas Lynch for compiling the document, and Mark Vian and the New York City Department of Environmental Protection for providing assistance. Finally, the ESAN would like to thank the following individuals for their technical review and comments: Roy Budnik, Scott Chase, Allison Chatrchyan, Stuart Findlay, Nat Gillespie, Ed Hoxsie, Carolyn Klocker, Cathy McGlynn, Kirsten Menking, Rebecca Schneider, Russell Urban-Mead, and several anonymous reviewers.

Introduction

In response to the recent flooding events and damage in Dutchess County, there has been increased concern by the general public and several courses of action proposed by various local officials. The Dutchess Area Environmental Science Advisory Network (ESAN) felt it would be beneficial to develop a set of recommendations based on existing knowledge, and sound geomorphic and ecological science, to assist communities as they consider various options and potential stream management. The

[1] For information on the ESAN, contact Dr. Stuart Findlay, Cary Institute of Ecosystem Studies, at 845 677-7600 Ext. 138, or findlays@ecostudies.org.

following recommendations and background material are intended to protect human life and critical infrastructure, while preserving the ecological functions and value of streams and floodplains.

Recommendations

These recommendations are intended to be used in conjunction with one another to form a successful flood management strategy:

Stream Management

1) **The County and/or its various municipalities should identify specific infrastructure threatened by flooding or erosion through the stream feature inventory (see page 8) and interviews with local highway superintendents**. Undersized culverts and bridges should be replaced as opportunities arise (routine replacement, FEMA funding); undersized bridges should be replaced with single span bridges where practical. For road and bridge sites identified by the highway superintendents as repeatedly damaged, proper channel dimensions based on hydraulic geometry regional curves should be utilized when making both emergency and permanent repairs. Emerging geomorphic science allows for the determination of a stream channel's cross-sectional dimension for a given drainage area. A reasonable stream slope and geometric pattern can also be determined. This approach closely replicates how a stream naturally behaves and allows it to return to a healthier and more stable condition while improving water quality and aquatic habitat. Higher peak flows due to an anticipated increase in the amount of impervious surfaces and more intense precipitation events associated with global climate change should be considered when calculating the proper size of infrastructure.

2) **Municipalities should facilitate the development of a GIS-based flood damage reporting system and database to track types of flooding, their location, and the costs associated with flood damage.** An inventory of areas likely to flood at various flows should be developed. The flood tracking database should be maintained in a uniform format by the County.

3) **Stormwater run-off and the need for infrastructure should be minimized where possible.** Where appropriate, retrofits and new construction should seek to maximize onsite infiltration and slow run-off. Wherever possible, runoff generated from impervious surfaces of rooftops, parking

lots, and walkways should be retained on-site and not routed to the roadside ditches via pipes, ditches, etc.; roadside ditches should not be scraped and left with exposed substrates. Ideally, ditches should be reconfigured to allow for regular mowing instead of scraping as the primary form of management and where scraping is necessary, a small patch of vegetated ditch should be left intact at the downstream end of the ditch to capture any eroding sediments and the ditch should be hydroseeded immediately after scraping. Finally, ditches should be disconnected from the stream channel system. Instead, infiltration basins, detention ponds or constructed wetlands should be used as ditch collection points in order to allow the water to re-infiltrate and recharge the groundwater. There are many additional proven techniques for treating, infiltrating, and storing stormwater. The Hudson River Estuary Program is a good starting point for information: http://www.dec.ny.gov/lands/5098.html.

4) **Deepening and straightening of stream channels should be avoided as these practices typically result in increased erosion and stream instability.** The slope of the stream bed is one of the factors affecting current velocity. By shortening the distance between two points while maintaining the same vertical drop, the slope and, in turn, the current velocity is increased, resulting in higher energy and more erosion downstream. Deepening the channel will cause undercutting of the steeper banks, ultimately resulting in bank failure and greater deposition of sediments at downstream locations.

5) **Removal of woody debris from the stream channel should generally be avoided.** In many Dutchess County streams, the woody debris provides prime habitat for stream fishes and aquatic invertebrates that are an important part of the food chain. Woody debris also plays a critical role in stream stability by providing roughness and capturing bedload (see page 13). Removal of woody material should only occur after consideration of the viewpoints of multiple stakeholders. Wood removal at sites posing an ***imminent threat*** to critical infrastructure, such as bridge footings and culverts, could be considered on a case-by-case basis. Such actions in regulated streams require consultation with the New York State Department of Environmental Conservation, Region 3 Permitting Office at Tel: 845-256-3054. For more information on the importance of maintaining wood in streams visit: http://anrcatalog.ucdavis.edu/Items/8157.aspx and download the report "*Maintaining Wood in Streams: A Vital Action for Fish Conservation.*"

6) **Because gravel is highly mobile and provides valuable ecological habitat, its removal should generally be discouraged.** All rivers and streams, including those in Dutchess County, carry massive amounts of water and sediment during flood flows. Gravel bars form when the flood waters begin to drop, but they generally move the next time the water rises, and typically are not the root cause of increased flooding. Furthermore, the existence of a gravel bar is likely due to the stream's hydraulic characteristics, so the deposit is likely to reform if it has been excavated as a short term fix. Thus, removing a gravel bar may temporarily treat a symptom, but it doesn't solve the problem, and may cause additional bank erosion as the stream finds an alternate supply of sediment to replace what was removed. Gravel removal in regulated streams also requires permits from the New York State Department of Environmental Conservation Region 3 Permitting Office at Tel: (845)-256-3054.

Floodplain Planning and Management

1) **Municipalities should conduct a review of current floodplain ordinances and adopt revisions as appropriate**. Revisions should reflect current building trends, new technologies, compliance with regulations, and integration with broader community plans as appropriate. Municipalities should make every effort to not allow any new structures in the 100-year floodplain and should work to remove existing structures over time as opportunities arise.

2) **Communities are encouraged to participate in the development of a county-wide All Hazards Mitigation Plan.** The Disaster Mitigation Act (DMA) of 2000 resulted in significant changes in the mitigation programs offered by FEMA. Under the 2000 DMA, local communities seeking funding under the Hazard Mitigation Grant Program and Flood Mitigation Assistance Program will be required to have an All Hazards Mitigation Plan approved by FEMA to be eligible for these funds. These plans are designed to reduce repeated flood damages within a community and can improve a community's Community Rating within the National Flood Insurance Program. Several communities are currently developing plans. FEMA has Mitigation Planning Guidance Documents available at http://www.fema.gov/plan/mitplanning/index.shtm.

3) **Identify and protect flood storage areas – this includes protecting wetlands, forested riparian buffers, uplands and floodplains**. Floodplains that are connected to the stream should be protected as flood storage areas. This will help to alleviate downstream flooding by providing a

location for the floodwaters to spread out thereby reducing their velocity and destructive energy while also lowering the flood crests. Additionally, identify floodplains suitable for restoration to encourage storage of floodwaters and sediment, including berm removal, excavation of fill previously placed in the floodplain, and creation of floodplain benches. Natural impoundments including beaver ponds should also be identified and effects on storage capacity determined.

4) **Dutchess County open space funds should be utilized for a flood buyout program for repeatedly flooded properties**. To maximize the effectiveness of the funds, they could be leveraged as the local cost-share with FEMA buyout funding following a declared disaster. Once the property is purchased, any buildings should be removed and the property should be reforested and utilized for flood storage if possible.

5) **Re-establish floodplain wetlands and forests where possible.** Wetlands act as water storage locations during heavy precipitation events and release the water slowly over time. Homeowners throughout the watersheds should be encouraged to reduce lawn size by the replanting of trees since lawns provide less erosion protection and generate more runoff than forests. The Dutchess County Soil and Water District [http://dutchessswcd.org/ or 845-677-8011, ext. 3] can help homeowners obtain appropriate seedlings. The Hudson River Estuary Program's *"Trees for Tribs"* Program also provides planting materials and technical assistance to interested organizations and homeowners. Contact information is available at http://www.dec.ny.gov/lands/43668.html.

6) **Encourage landowners through multiple approaches (including tax abatements) to maintain a healthy forested riparian stream buffer.** Healthy, robust riparian zones slow erosion of stream banks, help keep streams cooler by shading, serve as an important source of organic matter for stream ecosystems, and provide habitat for wildlife. See the Cornell University, *"Stand by Your Stream"* Fact Sheet Series for more information, at http://strmhlth.cfe.cornell.edu/index.html.

Education and Outreach

1) **Dutchess County (perhaps in cooperation with Dutchess County Soil and Water Conservation District and/or Cornell Cooperative Extension Dutchess County) should**

collect information regarding flood prevention/protection. Access to current information should be established for the public at multiple repositories in Dutchess County. This would include reference materials, floodplain maps and guidance documents that should be continually updated.

2) **Municipalities should facilitate periodic notification to landowners who have special flood hazard areas (SFHA) located on their property.**

3) **Municipalities and watershed organizations should work with local and state agencies to provide periodic training sessions on flood related issues.** The audience should include municipal leaders, code enforcement staff, planning boards, landowners, realtors, highway crews, lending institutions and others.

4) **Dutchess County and municipalities should identify trained professionals to provide on-site guidance for stream modifications.** In particular, this guidance should be available immediately following floods. The existing approach to flood management of patching flood damage without stream process knowledge wastes limited funding, may leave localities more vulnerable to future floods, often makes a bad situation worse, and may create liability for already devastated communities. Minimal stream disturbance to repair immediate infrastructure problems should be the short-term goal following flooding. A long-term flood response program is needed, one that is based upon current river science and is designed to achieve channel stability while meeting human and infrastructure needs. The stream professionals will provide for rapid and coordinated expert review and guidance on a regional basis during planning, funding, permitting and construction phases of flood remediation.

5) **Dutchess County should develop a training program to include workshops, demonstrations, simulations, site visits and possibly a certification process for contractors and highway departments interested in performing natural channel design work**. The multiple agencies involved (Transportation, Health, etc.) should coordinate more closely in setting goals and laying out desirable approaches to stream management. In addition, a Stream Table can provide a great hands-on tool to illustrate how streams function and the underlying stream

morphology (*The Cornell Cooperative Extension Dutchess County Environment Program owns a stream table that is used for education and outreach*).

Research

1) **A stream feature inventory should be conducted**. The inventory provides a basic familiarity with the stream corridor and surrounding watershed and can reveal trends important to understanding the stream system. The stream feature inventory should provide the following information: a) conditions that affect hydraulic function, particularly sediment transport function such as bedrock sills and banks, cultural and natural grade controls, berms, and rip-rap or other revetment, and inadequate riparian vegetation; b) potential sources of water quality impairment in the corridor, especially eroding banks, road runoff outfalls, dump sites, and exposed septic leach fields or other hazards; c) locations of bank erosion sites that need to be documented and surveyed regularly for study of bank erosion rates; d) infrastructure, including road crossings, bridge abutments, culverts and outfalls, and utility lines or poles; e) other features such as tributary confluences, water intakes, springs, wells, diversions, and invasive species. This effort can be accomplished by trained staff utilizing a Global Positioning System (GPS) and a stream feature inventory data dictionary at a rate of approximately one mile/day.

2) **Historical records for precipitation amount, intensity and resulting stream flow response should be analyzed**. With impending climate change there is a need to document current trends (if any) in precipitation amount, intensity, timing of snowmelt and other forces potentially affecting flood frequency and magnitude. Dutchess County and the nearby Hudson Valley have several long-term weather monitoring sites suitable for analysis.

3) **Aerial photography should be geo-referenced and used to digitize stream channel alignments and overlayed to detect historical stream channel alignments.** These historical alignments can determine the frequency and magnitude of channel migrations, typically over the last 50-60 years. The DCSWCD has historical photos and additional photos can be purchased from: http://www.apfo.usda.gov/.

Background for Further Reading on Stream Functions and Hydrology

Hydrology is the study of the properties, distribution, and effects of water on the earth's surface, in the soil and underlying rocks (groundwater), and in the atmosphere. The hydrologic cycle includes all of the ways in which water cycles from the landscape (both underground and in streams and water bodies) to the atmosphere (as water vapor and clouds) and back to the landscape (as snow, rain and other forms of precipitation) (Figure 1). Understanding the hydrology within Dutchess County will; a) assist managers in land use decisions that work within the constraints of the hydrologic cycle and, b) help to avoid exacerbating flooding or further water quality impairment.

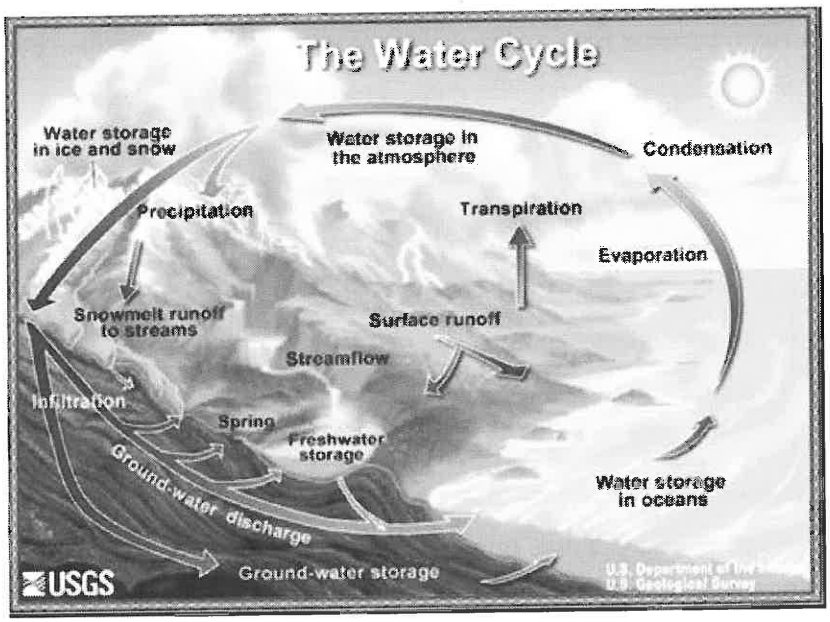

Figure 1. The Hydrologic (water) Cycle. Source: http://ga.water.usgs.gov/edu/watercyclesummary.html.

Water flowing through the streams and rivers in the County reflects the integrated effects of all watershed characteristics that influence the hydrologic cycle. Characteristics include climate of the drainage basin (type and distribution patterns of precipitation and temperature regime), geology and land use/cover (permeable or impermeable surfaces and materials affecting timing and amount of infiltration and runoff, and human-built drainage systems), and vegetation (uptake of water by plants, protection against erosion, and influence on infiltration rates). These factors affect timing and amount of stream flow, referred to as the stream's hydrologic regime. For example, a stream with an urbanized watershed where water runs off hardened surfaces directly into the stream will have higher peak discharges following storms than a watershed of similar size which is predominantly forested and allows a higher percentage of

rain water to infiltrate into the ground, releasing the water slowly over time. Understanding the hydrology of a drainage basin is important to the stream manager because stream flow patterns affect aquatic habitat, flood behavior, recreational use, and water supply and quality.

There are two general categories of stream flow between which streams fluctuate over time: storm flow (also called flood flow) and base flow. Storm flow fills the stream channel in direct response to precipitation (rain or snow) or snowmelt, whereas base flow originates primarily from groundwater and sustains stream flow between storms and during subfreezing or drought periods. A large portion of storm flow is made up of overland flow, runoff that occurs over and just below the soil surface during a rain or snowmelt event. This surface runoff appears in the stream relatively quickly and recedes soon after the event. In general, higher stream flows are more common during spring due to rain, snowmelt and combination events, and during hurricane season in the fall. During summer months, actively growing vegetation on the landscape draws vast amounts of water from the soil through evapotranspiration. This demand for groundwater by vegetation can significantly delay and reduce the amount of runoff reaching streams during a rain storm.

Base flow consists of water that seeps or rises from the ground and sustains stream flow during dry periods and between storm flows. The source of base flow is groundwater that flows through unsaturated and saturated soils and cracks or layers in bedrock adjacent to the stream. In this way, streams can sustain flow for weeks or months between precipitation events and through the winter when the ground surface and all precipitation is otherwise frozen. Stable-temperature groundwater inputs keep stream water warmer than the air in winter and cooler than the air in summer – this enables fish and other aquatic life to survive in streams year-round. For these reasons it is important to protect these groundwater inputs.

Hydrologists use a hydrograph, which is a graph showing the volume of flow (discharge) in a stream over time, to analyze flow patterns and trends such as flood frequency or drought cycles. A stream gage, a device that primarily measures water level, is necessary to monitor stream discharge and develop a hydrograph. The United States Geological Survey (USGS) maintains two continuously recording stream gages on streams that flow through Dutchess County: Wappinger (established in 1928 with some earlier data, drainage area of 181 mi^2, USGS ID# 01372500) and Tenmile (established in 1938, drainage area of 203 mi^2, USGS ID# 01200000). Prior to 1996, a crest stage gage was maintained at Lexington starting in 1929. All gage information is available online at the USGS website:

1) for the Wappinger Creek at (http://waterdata.usgs.gov/ny/nwis/uv/?site_no=01372500&PARAmeter_cd=00065,00060) and
2) for the Tenmile River at Gaylordsville, CT at

(http://waterdata.usgs.gov/ny/nwis/uv/?site_no=01200000&PARAmeter_cd=00065,00060).

3) In addition, the Cary Institute of Ecosystem Studies has operated a gage on the East Branch of the Wappinger Creek near Millbrook, NY; and
4) Faculty of Vassar College have recently installed a gage on the Casperkill Creek in Poughkeepsie, NY.
5) There are also several historic gages with varying levels of information. They can be accessed at: http://waterdata.usgs.gov/ny/nwis/nwis.

These stream gages measure the stage, or height, of the water surface at a specific location, typically updating the measurement every 15 minutes. By knowing the stage we can calculate the magnitude of the discharge, or volume of water flowing by that point, using the relationship between stage and discharge called a rating curve. Using this rating curve, the volume of flow in the stream at the gage location can be determined at any time just by knowing the current stage. Discharge can also be calculated for any other stage of interest. Additionally, we can use the historic record of constantly changing stage values to construct a picture of stream response to rain storms, snow melt or extended periods of drought, and to analyze seasonal patterns or flood characteristics.

The Wappinger gage at Red Oaks Mill has a period of record covering almost 80 years. Data gathered over long time periods can be analyzed to see seasonal trends, changes from year to year, or changes in long-term averages for the entire length (period) of the gage record. The gages provide information that can be analyzed to determine whether or not recent flood damage might be due to increased intensity of storm events, ongoing development in watersheds and its attendant change in hydrology, or a combination of these and other factors. The hydrograph below of the April 2007 illustrates flood flows that caused damage in Dutchess County (Figure 2).

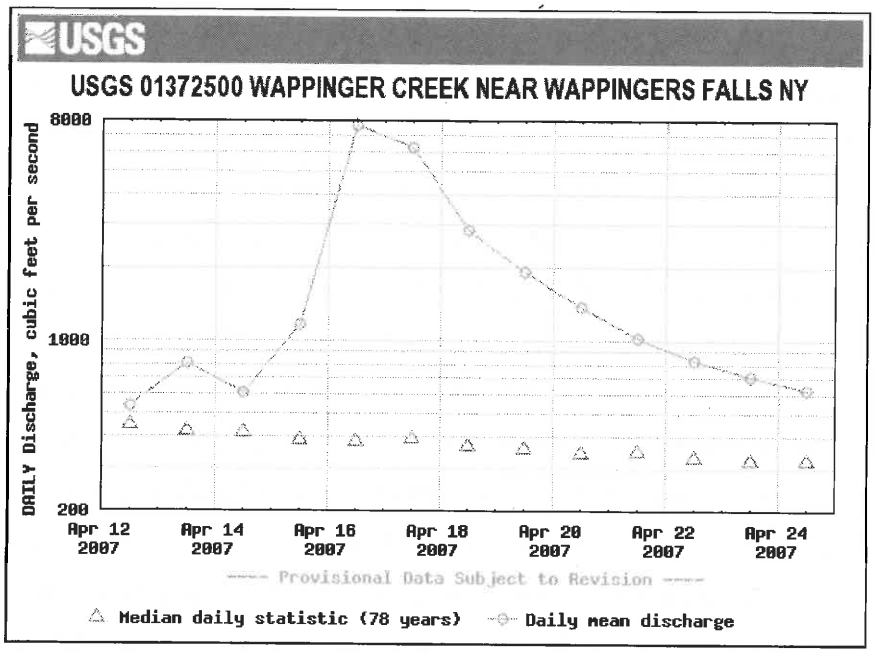

Figure 2. Daily average flow during the flood of April 2007 on Wappinger Creek.

The Wappinger Creek rose from a daily average of 613 cubic feet per second (CFS) to 7,640 CFS in approximately 48 hours. This event was not unique in that this daily average was exceeded by higher flows (and flooding) in 1938, 1949, 1955, 1973 and 1984 (Figure 3). Following 1984 there was a period of relatively lower flows (perhaps due to lower average precipitation) until 2006 and 2007. At the same time that Dutchess County was experiencing lower precipitation and stream flows, there was a dramatic increase in development with its attendant increase in impervious surface. Some of this development unfortunately took place in floodplains.

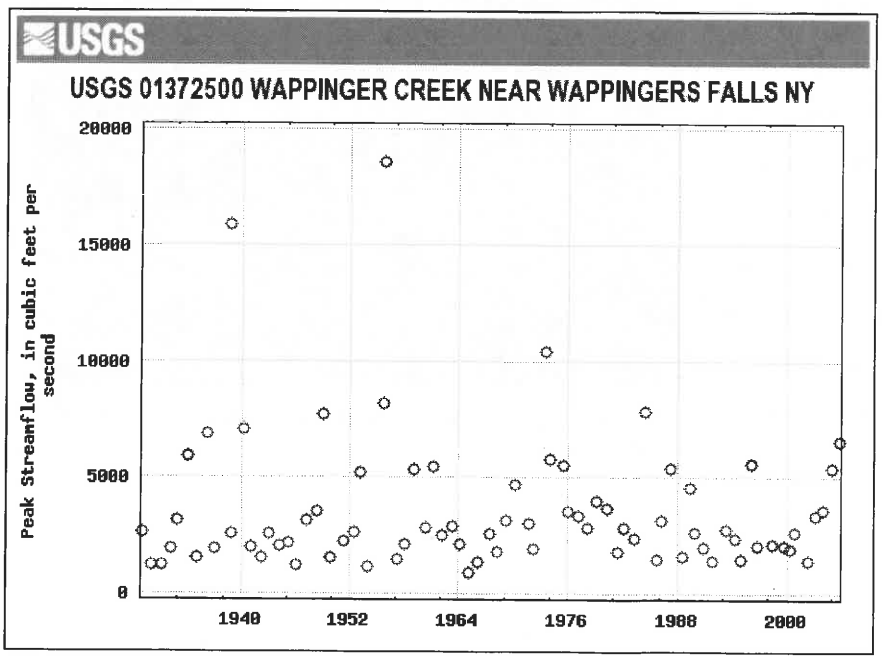

Figure 3. Peak stream flows on Wappinger Creek for the period 1929 to 2006.

Another approach to interpreting flooding magnitudes and patterns uses analysis of flood frequency distributions that indicate the probability of floods of different magnitudes. In other words, how likely is it that a flood of a given size will occur in any one year, or over a period of years? For example, each year it is possible, but not likely, that we will see a large flood (a flood so large it might recur once every 100 years on average) and almost a certainty we will see a small one (1-2 year recurrence). This value is actually calculated as a percent likelihood, but is most often converted to a number of years (e.g. the 100-year flood). This number of years is called the "recurrence interval" (RI) or "return period" of an event of certain size. For example, the flood with a 20% chance of occurring or being exceeded in any single year corresponds to what is commonly referred to as a "5-year flood" (each of these values is the inverse of the other - just divide 1 by % probability to get RI in years, or divide 1 by RI in years to get % probability). This simply means that on average, for the period of record, a flood of this magnitude will occur about once every 5 years. This probability remains the same year to year over time for a particular size flood to occur, although the actual distribution of flood events in time is not regular. Many years may go by without a certain magnitude flood or a flood of a particular magnitude may occur several times in a single year. For example, we might expect to see about 2 "5-year floods" for every 10 years of record, but any particular 10 year period may contain more or fewer floods of this size.

Introduction to Stream Processes

Living near a stream or river involves both benefits and risks; to enjoy the benefits, the risks are accepted. Both the pleasures as well as the dangers of living near streams stem in part from their ever-changing nature. Icy spring flood-flows are exciting and beautiful until they flow over their banks and run across yards into the basement windows or suddenly tear out a stream bank and begin flowing down the only access road to homes. For many reasons, the relatively flat land in the

Figure 4. The Fishkill Creek in Beacon, NY. *Photo courtesy of Dave Burns.*

floodplain of a stream may be an inviting place to build a home or road –in fact, it may be the only place. However, long-time residents of floodplains know only too well that it is not a matter of *if* they will see floodwaters, but of *when.*

Even though streams are dynamic systems, their changes are predictable based on season or storm event. If we take the time to observe them carefully, we can begin to understand patterns of stream behavior and, more importantly, learn how to make proximity to streams and rivers more beneficial and less risky.

Streams drain water from the landscape, but they also carry bedload - gravel, cobble, and even boulders, that have been eroded from streambeds and banks upstream. During a storm event the water begins to rise in the stream channel. At some point the force of the water begins to move the material on the bottom of the channel. The gravel, cobble and boulders tumble against each other as they are pushed downstream by the force of the floodwaters and the stream banks vibrate with the force of these collisions. As the storm waters recede, the force decreases and the gravel and cobble stop moving.

The shape and size of a stream channel are determined by the amount of water and bedload it carries. Within certain limits, the form (morphology) of a stream is self-adjusting, self-stabilizing and self-sustaining. If stream managers alter the ability of a stream to self-regulate, the stream may remain unstable for a long time as its channel erodes and meanders in an attempt to reach a new state of stability.

Over the period since the last glaciers retreated some 12,000 years ago, Dutchess County streams have been shaped by regional conditions. Climate, topography, geology and vegetation of a region usually change only very slowly over time. Therefore the amount of water moving through a stream from year to year, or streamflow regime, is variable but somewhat predictable within broad limits at any given location.[2] This stream flow regime, in turn, defines when and how much bedload will be moving through the stream channel from year to year. Together, the movement of water and bedload carve the form of the stream channel into the landscape. In the absence of human influence, streamflow regime tends to be fairly consistent year after year which provides for relatively slow changes in stream channels. Over the 120 centuries since glaciers covered the region, the stream channel and the landscape conditions evolved in a dynamic balance.

However, as human activity altered the landscape (e.g. clearing forests for pastures or straightening stream channels to avoid having to build bridges), the balance between streams and their landscapes was changed. Some parts of streams seem to change form very quickly, while others parts remain much the

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[2] One exception is when the vegetation changes quickly, such as can happen during forest fires, volcanic eruptions or even rapid commercial or residential development.

same year after year, even after great floods. Why is this? Streams that are in dynamic balance with their landscapes develop forms that can pass the water and bedload associated with both small and large floods, often regaining their previous forms (although specific locations may shift) after the flood passes. This is the definition of stability. In many situations, however, stream reaches become unstable when some human activity on the watershed has upset that balance and altered the stream's ability to move its water and bedload effectively. Due to the increase in impervious surfaces associated with development, increase in ditches and the drainage network, and /or increased erosion from soils in the watershed, the volume of water or sediment that the stream must carry increases. To compensate, the stream must widen or deepen its channel.

The potential force generated by water that moves its bedload is determined by its slope and its depth: the steeper and deeper the stream, the more force it exerts. For example, if changes made to a stable reach of stream reduce its slope and/or depth, the stream may not be able to effectively move the bedload supplied to it from upstream. The likely result will be that the material will be deposited in that section and the streambed will start building up or aggrading. This can often be seen upstream of bridges.

Changes in the length of a stream also affect its ability to move its bedload. When a stream is straightened it becomes shorter; this means that its slope is increased resulting in an increase in its potential force to move its bedload. Road encroachment narrows and deepens many streams which increases potential force to the point of stream bed degradation. In these cases streams become deeply incised within their valleys. Both aggradation and degradation result in a stream reach that has become unstable. Rapid bank erosion, as well as impairment of water quality and stream health, is likely to occur. Unfortunately these local changes can spread upstream and downstream causing great lengths of stream to become unstable.

The stream pattern we now see throughout Dutchess County is the result of millions of years of landscape evolution. Fractured bedrock was chiseled repeatedly by rivers and then glaciers and then rivers again. As glacial ages came and went, the valleys were eroded out of the mountains and their remnants washed out to sea. As the steeper streams coming off the mountainsides flowed into more gently sloped channels running through the main valley, the streams became wider and shallower. The valleys developed floodplains and the streams flowing through them became less steep. Stream pattern and shape progressively adjusted to assume new stable forms in balance with the new landscape. This adjustment often causes the river to meander over its floodplain. As time progresses, the meanders will increase in amplitude as erosion occurs on the outside of bends and deposition takes place on the inside. Streams, particularly in low gradient floodplains, are constantly changing the location of their channels. This is

completely natural and should be anticipated. Failure to give the stream "room to roam" will produce ongoing problems that will require large and reoccurring expenditures over time.

As the earth's climate warmed, grasses and trees returned to the floodplains and the conditions that determined the balance between stream shape and the landscape changed once again. Stream banks that had a dense network of tree and shrub roots anchoring the soil were better able to resist the erosive power of flood flows and consequently a new stable stream form emerged; a new balance was struck between resistive and erosive forces. Dense mats of woody roots are essential for maintaining stable stream banks. If streamside trees and shrubs are removed, banks will often begin to erode resulting in water quality impairment or loss of habitat.

Summary

The hydrology of Dutchess County affects how the stream corridor should be managed. Flood history and dynamics play a large role in determining the shape, or morphology, of stream channels and the hazards associated with land uses on the banks and in the floodplain. For example, the number of applications for stream disturbance permits (from NYS DEC) typically increases following floods as landowners and municipalities attempt to repair damage caused by flooding. If we want to minimize flooding impacts on property and infrastructure, it is critical that we understand that flooding of variable severity is inevitable and we should plan accordingly. Historically, this "planning" has emphasized constraining and controlling stream channels. Results of this type of planning are often costly and sometimes catastrophic, such as when berms or levees fail or bridges wash out. These "control" approaches typically result in ongoing maintenance costs that can draw valuable community resources away from other projects. With a better understanding of stream and floodplain processes, we can reduce these costs.

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Post-Flood Stream Reconstruction

Guidelines and Best Practices

Post-Flood Stream Repair Guidelines

DEC has developed guidelines to assist with stream repairs, or "interventions," after a major storm. This includes priority repairs when public health and safety are immediately threatened, such as removing flood debris from plugged culvert pipes and bridges; opening up clogged stream channels; repairing or replacing critical infrastructure; and reopening roads.

- **DEC Guidelines for Post-Flood Stream Construction (PDF)** (815 KB)
- **DEC Guidelines for Post-Food Stream Construction Large Format (PDF)** (775 KB) *You must set your printer to 11" x 17" paper.

Educational Materials for Landowners

See the Cuyahoga Soil and Water Conservation District's publication *"Life at the Water's Edge - Living in harmony with your backyard streams"* and other informative publications. Use the link to the Cuyahoga SWCD at right and scroll down to "Educational Materials" on their site.

Post-Flood Stream Repair Training

DEC and the Delaware County Soil and Water Conservation District have developed a training program and manual to help municipal officials, contractors and machine operators respond to flood damage. The training is based on sound stream science and processes. Following the guidelines and recommended procedures will eliminate the need for communities to go back and repair mistakes, saving time, money and resources.

DEC in partnership with NYS soil and water conservation districts are offering trainings at selected locations around the state. Trainings offered may include three day trainings, comprised of one day of classroom instruction and two days of field study or shorter 4 (four) hour or 6 (six) hour trainings. See a list of scheduled trainings or contact the DEC at (518) 402-8044 for more information.

The training manual can be viewed using these links:

Post-Flood Emergency Stream Intervention Training Manual (PDF) (4.89 MB)

Appendices to the Stream Intervention Training Manual (PDF) (2.8 MB)

Post-Flood Emergency Stream Intervention Trained Contacts

The link below provides contacts and locations from New York Soil and Water Conservation Districts trained in the Post-Flood Emergency Stream Intervention (ESI) Program. Please feel free to contact these individuals for technical assistance and/or questions related to the ESI program within your county.

Post-Flood Emergency Stream Intervention Trainer Contact List and Watershed Map

If you have additional questions with regard to the ESI program, please feel free to contact Tom Snow, DEC's New York City Watershed Coordinator at 518-402-9395.

Interagency Post-Flood Stream Intervention Training

In response to storm damage to streams following Tropical Storm Irene, DEC working with the Delaware County Soil and Water Conservation District, recently provided a Post-Flood Stream Intervention training. On January 8, 2013, DEC held this training with over 200 participants video-cast to 17 DEC office locations statewide.The Delaware County Soil and Water Conservation District instructed the class.

Participants included staff from DEC, Cornell Cooperative Extension, Soil and Water Conservation Districts, Department of Transportation, Department of Agriculture and Markets, Army Corp of Engineers, Lower Hudson Coalition of Conservation Districts, and Lake George and Ausable River Associations.

This one-day condensed format training complemented a more comprehensive three-day training being developed for municipal officials, contractors, and the machine operators that typically respond to flood damage. The full training has already taken place in Delaware County with over 400 participants. Overviews of the program have been provided in a number of other forums, including an Association of General Contractors meeting. The full three-day training will be offered at selected locations around the state this coming summer. DEC is developing partnerships with staff from the Soil and Water Conservation Districts as well as the various Cornell Cooperative Extension offices, to provide this training.

Post-Flood Emergency Stream Intervention Training

Part 1 (PDF) 3.49 MB (Overview, Stream Mechanics, Stream Types, Floodplains, Stream Instability)

Part 2 (PDF) 4.62 MB (Stream Table, Unstable Channels, Flood Response, Channel Sizing)

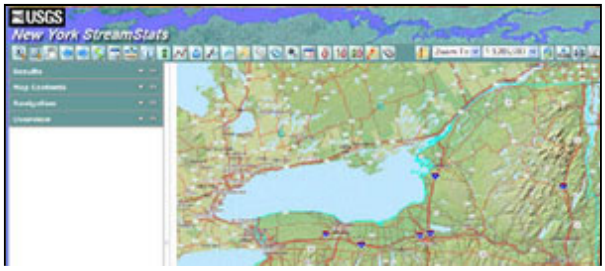
Part 3 (PDF) 4.9 MB (Classroom Examples, Work Methods, De-watering)

Part 4 (PDF) 4.6 MB (Project Sites - before and after examples)

Part 5 (PDF) 1.47 MB (Bioengineering techniques, Hydraulic structures)

How to Determine Proper Channel/Bankfull Dimensions

1. Determine the watershed area using the USGS Streamstats web tool



In order to determine proper channel dimensions, you must know the watershed area in square miles. The watershed area can be determined using the USGS Streamstats web tool. (See "Links Leaving DEC's

Website" at right) Instructions on how to use the USGS streamstats tool are in Appendix D of the training manual.

The USGS Streamstat web tool will allow you to quickly determine watershed area.

2. Look up the required channel dimensions for your drainage area

Once you've determined the watershed area, you can use the Bank-full Hydraulic Geometry Tables (PDF) 88 KB, to determine proper stream channel construction dimensions. While this may sound complicated, it is actually fairly easy and straight forward. Examples of how to use the bankfull hydraulic geometry tables are included in the training manual.

More about Post-Flood Stream Reconstruction:

Post-Flood Stream Contacts - A map and list of contacts trained in post-flood emergency stream response across NY state.

Woody Debris Removal from Rivers and Streams - Guidelines on when you should and should not remove woody debris

Post-Flood Emergency Stream Intervention Trainings - A schedule of upcoming post-flood emergency stream intervention trainings for municipal officials, environmental organizations, contracotrs, and county legislators.

Permits Information

For information on the necessary permits to conduct work in and around waterbodies, please contact the NYSDEC regional office for your county and the U.S. Army Corp of Engineers:

Region 1	Nassau and Suffolk **(631) 444-0365**
Region 2	New York, Kings, Queens, Bronx, Richmond **(718) 482-4997**
Region 3	Dutchess, Orange, Putnam, Rockland, Sullivan, Ulster and Westchester **(845) 256-3054**
Region 4	Albany, Columbia, Delaware, Greene, Montgomery, Otsego, Rensselaer, Schenectady, Schoharie **(518) 357-2069**
Region 5	Clinton, Essex, Franklin, Fulton, Hamilton, Saratoga, Warren and Washington **(518) 897-1234**
Region 6	Herkimer, Jefferson, Lewis, Oneida and St. Lawrence **(315) 785-2245**
Region 7	Broome, Cayuga, Chenango, Cortland, Madison, Onondaga, Oswego, Tioga and Tompkins **(315) 426-7438**
Region 8	Chemung, Genesee, Livingston, Monroe, Ontario, Orleans, Schuyler, Seneca, Steuben, Wayne, Yates **(585) 226-2466**
Region 9	Allegany, Chautauqua, Cattaraugus, Erie, Niagara and Wyoming **(716) 851-7165**

U.S. Army Corps of Engineers Contact Information

Covering DEC Regions 1, 2 and 3:
US Army Corps of Engineers NY District
ATTN: Regulatory Branch
26 Federal Plaza, Room 1937
New York, NY 10278-0090
For DEC Regions 1 & 2 and Westchester and Rockland counties in Region 3, call **(917) 790-8511.** For other counties in Region 3, call **(917) 790-8411**.
E-mail: **CENAN.PublicNotice@usace.army.mil**

Covering DEC Regions 4 & 5:
Department of the Army
ATTN: CENAN-OP-R
NY District, Corps of Engineers
1 Buffington Street
Building 10, 3rd Floor
Watervliet, NY 12189-4000
Call **(518) 266-6350** - Permits Team Call **(518) 266-6360** - Compliance Team
E-mail: **cenan.rfo@usace.army.mil**

Covering DEC Regions 6, 7, 8 & 9:
US Army Corps of Engineers
Buffalo District
ATTN: Regulatory Branch
1776 Niagara Street
Buffalo, NY 14207-3199
Call **(716) 879-4330**
E-mail: **LRB.Regulatory@usace.army.mil**

NEW YORK STATE
Department of Environmental Conservation

Guidelines for Post-flood Stream Construction

What to do and not do after a major storm

When communities are hit by major floods, roadways, bridges and culverts suffer severe damage and need to be repaired quickly. These guidelines have been developed to assist in post-flood stream repairs, or "interventions," after a major storm. These include priority repairs when public health and safety are immediately threatened, such as:

- Removing flood debris from plugged culvert pipes and bridges
- Opening up clogged stream channels
- Repairing or replacing critical infrastructure
- Reopening roads

To rescue people and keep them safe after a flood, emergency repairs are often necessary in order to re-establish vital community access routes and services. Sometimes emergency repairs leave stream conditions that, if not subsequently addressed, will cause further problems. These guidelines will help you minimize adverse impacts and the need for subsequent repairs.

NOTE: The activities described in this publication require permits from the New York State Department of Environmental Conservation (NYSDEC) and United States Army Corps of Engineers. See "Permits Information" for contacts. ***These guidelines are not intended to apply to routine or non-emergency stream work, which must follow the normal administrative and regulatory review and approval process.***

Emergency Repairs

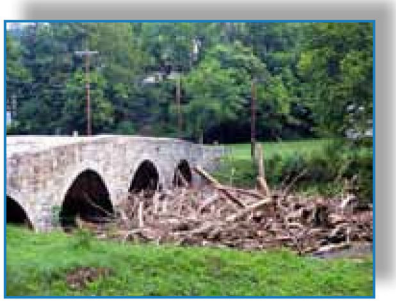
General Considerations

Emergency stream repairs should:

- Be done in a timely manner;
- Consider factors that have a long-term effect on the economic well-being of your community, such as fish habitat protection and
- Avoid contributing to future flooding problems. If done incorrectly, work in a stream can create worse problems for you and your downstream neighbors.

Repair Recommendations

NYSDEC recommends the following steps to properly repair streams.



1. **Clear debris and log jams at bridges and culverts:**
   - Remove only the debris necessary to re-establish original stream-channel dimensions.
   - Do not use cleared debris to build berms on top of stream banks.
2. **Clear gravel deposits clogging the stream:**
   - Remove gravel deposits to pre-flood grade level only.
   - When possible, relocate gravel deposits to areas where gravel was scoured away.

3. **Reconstruct the stream channel**
   - Do not build permanent berms on top of stream banks. If you need to pile material on banks temporarily, be sure to remove it before you are done. Berms block streams from spilling into their natural floodplains and may result in increased flooding, channel scouring, or erosion caused by higher streamflow velocities and flood elevations. Also, berms are generally not engineered to withstand flood forces and will likely blow out during the next flood, increasing damage and erosion in adjacent areas.

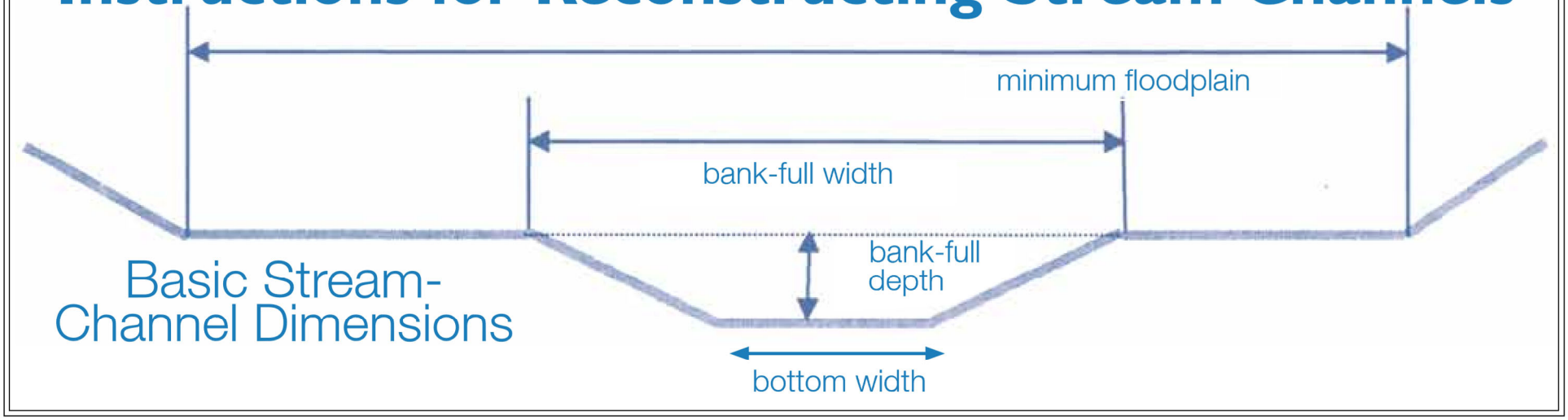
   - Do not attempt to deepen or widen the channel. Over-excavating the stream channel will have the same effects as berms, increasing flood risks to the site or downstream areas by increasing streamflow velocities and bank erosion, or sediment deposits in the channel.
   - Only remove the amount of debris necessary to re-establish original stream-channel dimensions. See "Reconstruct the stream channel to pre-flood, bank-full dimensions" in the next section.

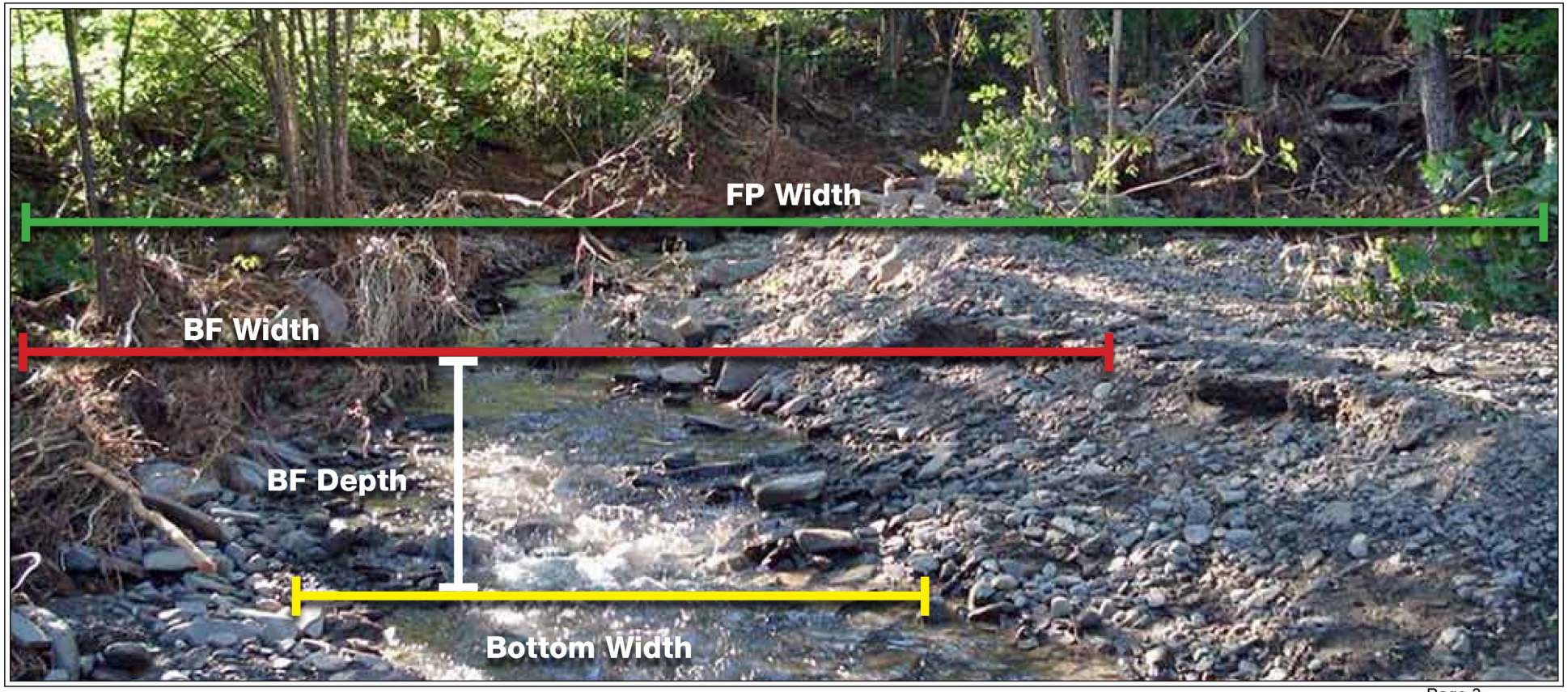
Post-Emergency Repairs

After the emergency response, more measured and deliberate stream repair work should begin in order to return the channel to pre-flood conditions.

The best model for managing high volumes of floodwater in a stream channel is one that slows the flow of floodwaters and increases their retention over an entire watershed, spreading them out instead of concentrating them in one area. Delaware County Soil and Water Conservation District's (DCSWCD) *Post-Flood Emergency Stream Intervention Training Manual,* available on DEC's website at **www.dec.ny.gov/lands/86450.html**, is an excellent source of information on this subject.

Instructions for Reconstructing Stream Channels





1. Reconstruct the stream channel to pre-flood, bank-full dimensions

- Proper stream-channel dimensions can be obtained by measuring an undamaged or "reference" stream reach immediately upstream or downstream of the planned worksite.

  Reconstruct the damaged channel using the bank-full depth, bank-full width, and floodplain width measurements from a comparable reach. See the Basic Stream- Channel Dimensions diagram for where to measure these dimensions.

- After severe flooding, an undamaged stream reach comparable to a damaged section may be difficult to find. In these circumstances, stream-channel dimensions can be calculated using the Bank-full Hydraulic Geometry Tables for Selected Hydrologic Regions (Regional Tables). Find directions for using Regional Tables on DEC's website at **www.dec.ny.gov/lands/86450.html**

2. Avoid creating a head cut (an abrupt vertical drop)

- Installing rock cross-vanes, or another similar in-stream structure, may be required to prevent head cutting.
- Please seek technical assistance from your county's soil and water conservation district or NYSDEC.

3. Avoid scouring/down-cutting (increasing channel depth)

- Reconstructing the channel to bank-full dimensions, the appropriate grade, and with as much floodplain access or bench as available room allows should minimize channel scouring and bank erosion afterwards.
- Often, flooding causes an alternating damage pattern of scouring/down-cutting and gravel deposits in a stream. Therefore, a source of material for filling scour holes may be located downstream of the scoured/down-cut reach.

4. Repair eroded banks

- If space allows, slope eroding banks to a stable slope, such as 3:1 (units of width to units of elevation) or flatter. Slope protection or erosion-control methods may be required. Slopes of as much as 2:1 may be considered when using rocks or other stable materials.
- To prevent future erosion on a river bend, incorporate rock vanes to deflect current away from the bank.

Important Notes on Water Quality When Working Near Streams

- All actions that cause erosion or affect water quality should be minimized to the greatest extent practicable, including the release of turbid (muddy) water.
- Machinery should be operated from the stream banks, avoiding use in flowing water to the greatest extent practicable.
- To avoid disruption of trout spawning, in-stream work should be avoided to the greatest extent practicable from November 1 - June 15.

NOTE: County soil and water conservation districts can be a great resource for information, training and help when working in and around waterbodies. Find a complete list of county contacts on the New York State Soil and Water Conservation Committee's website:
www.nys-soilandwater.org/contacts/county_offices.html

Post-Flood Emergency Stream Intervention

Before repairs

After repairs

Training Manual

Originally prepared by:
Delaware County Soil and Water Conservation District
Delaware County Planning Department

In cooperation with:
The New York City Department of Environmental Protection,
Bureau of Water Supply, Stream Management Program

With permission, this document was edited and expanded for state-wide application by:
New York Department of Environmental Conservation

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~ I. Foreword ~

After a flood event, streams may look unraveled with gravel and debris strewn all over the place. Our first reaction is to put everything back to the way it was and maybe do some extra work. Typically this extra work consists of widening and dredging the channel to increase capacity. While the pressure to get into the area and move material to protect the public is understood, it is important to understand how the stream has changed as a result of the flood. Quick assessment can give the contractor or highway superintendent valuable information that will help determine how much work needs to be done and how the problem can be best resolved. Because the damage is widespread, the objective is to do the most good with the least effort. This is accomplished by addressing the most pressing problem areas and phasing the work so more complex work is left to the later stage of flood recovery. The process is akin to First Aid where the first responder must assess the scene, decide who the priority for treatment is and only do what is required to stabilize the situation until additional assistance arrives. This training material will provide information on how to assess the situation, decide where to work and what the right approach to be under and emergency response condition.

The development of this training program was initially funded in part by a grant from the New York State Department of Environmental Conservation's Water Quality Improvement Program and in part through the Delaware County Soil and Water Conservation District Stream Management Program contract with the New York City Department of Environmental Protection's Bureau of Water Supply. Subsequent edits were made to this manual by DEC to facilitate its use state-wide.

~ II. Introduction to Streams ~

Understanding the stream mechanics is important when conducting stream management practices because there can be an impact upstream and downstream of your project site. In the course of transporting water from the tops of mountains to the ocean, streams also transport sediment scoured from their own beds and banks. Streams and rivers are never constant, and it is important to understand how and why streams change. An understanding of how streams work is essential when approaching stream management at any level. This section is intended to serve as an overview of stream science, as well as its relation to management practices past and present.

Watershed

Streams reflect the regional climate, biology and geology. The water flowing through the drainage system reflects the watershed characteristics that influence the hydrologic cycle (**Figure 2.1**). These characteristics include the climate of the drainage basin, geology, topography, land use/land cover, infrastructure and vegetation.

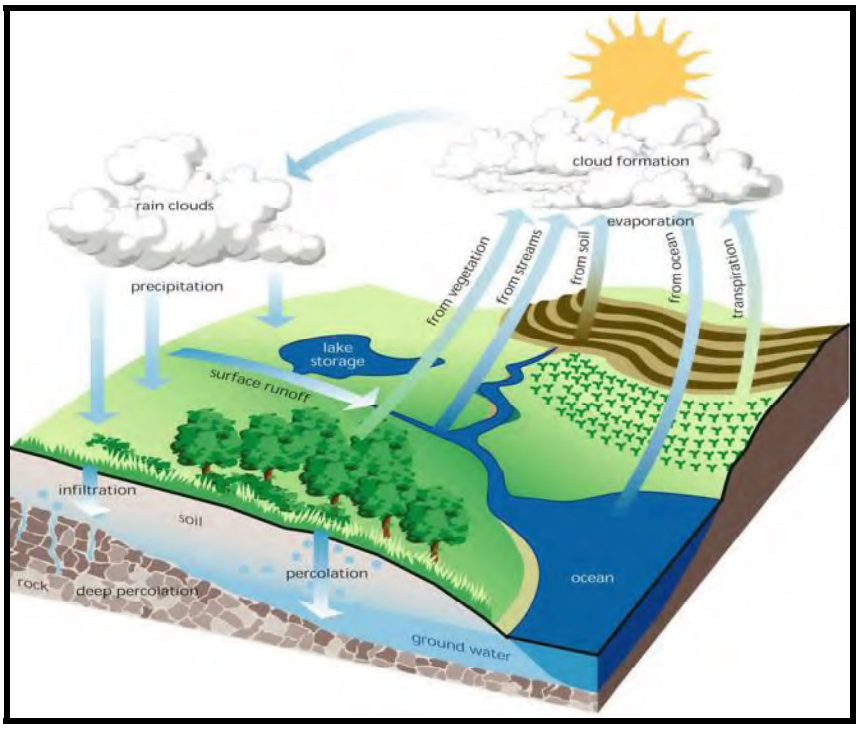


Figure 2.1 The Hydrologic Cycle (USDA-NRCS, 1998)

Drainage area or watershed size is part of the physical characteristics of the watershed. The size of the watershed is defined by the amount of land area that has the potential to drain stormwater runoff into the stream network. The shape of the watershed also plays a key role in the stream network; if two watersheds have the same size but different shapes, they will have different peak discharges and times of concentration resulting from the same storm event. Travel time for runoff to move through the stream network varies with watershed topography. A steep watershed typically exhibits a higher peak discharge than a flatter watershed. Climate, geology, topography, vegetation, etc. affect timing and amount of stream flow, referred to as the stream's hydrologic regime. **Figure 2.2** is a drainage area map for Chambers Hollow in the Town of Hamden, produced using StreamStats; a water resource program developed by the United States Geological Survey (USGS).

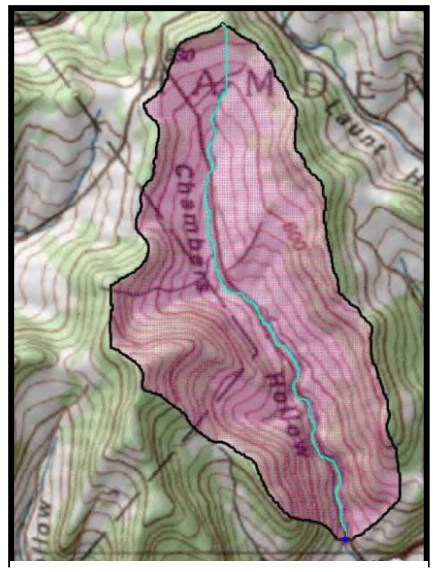


Figure 2.2 Drainage area map from USGS StreamStat

Stream Flow

Streams flow at many different levels over the course of a year, ranging from the small trickle of a dry summer to the raging torrent associated with the rapid thaw of a thick snowpack. There are essentially three basic types of stream flow: base flow, storm flow, and flood flow. Base flow sustains stream flow between storms, during subfreezing, or during drought periods and is largely the water flowing into the stream from groundwater springs and seeps. Storm flow, also known as bank full flow, appears in the channel in direct response to precipitation and/or snowmelt. Flood flow is water that gets outside of the stream banks. **Figure 2.3** illustrates the basic stream flow patterns in a typical stream cross section.

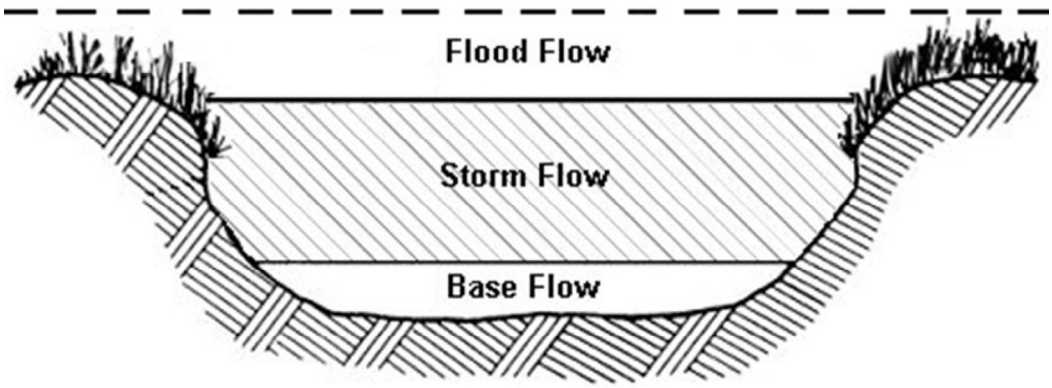


Figure 2.3 Illustration of a typical stream cross section showing stream flows.

A daily mean discharge curve for the stream gage at Margaretville, NY for the period from September 2006 to August 2007 is provided below in **Figure 2.4**. Note that the brown line indicates the average daily mean discharge (stream flow measured in cubic feet per second) for

the 69 years of gage records, and the light blue line shows the daily mean discharge for the 2006-2007 period. United States Geological Survey (USGS)[1] graph also shows that most of the runoff for the watershed occurs between mid March and mid May, with a second period of runoff in the fall in November and December. This is a period when the ground is often bare and evapo-transpiration from plants is low. The precipitation that falls during this period quickly runs off and the streams are full.

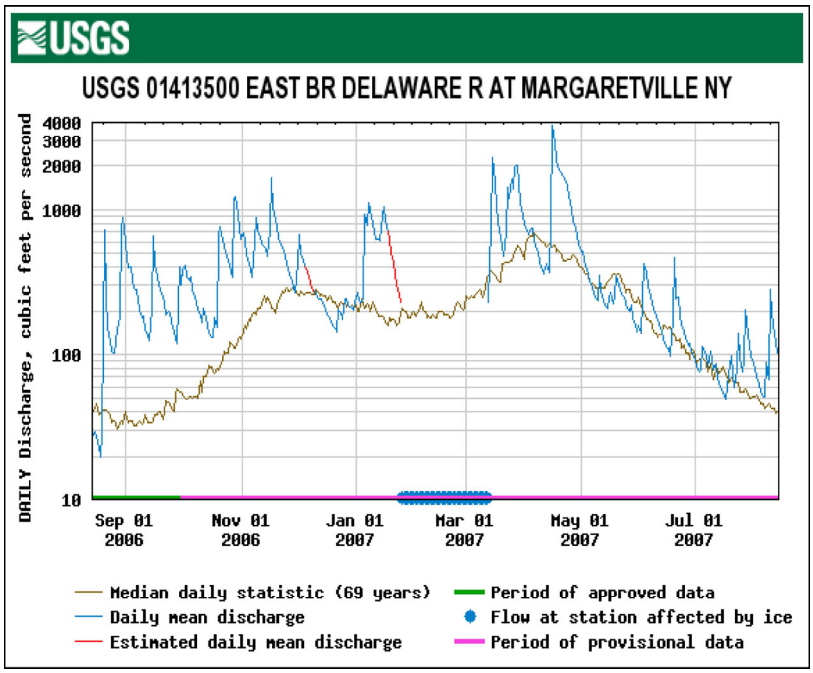


Figure 2.4 Daily Mean Discharge Curve

Stream Stability

The definition of a stable stream is: "The tendency of a stream to maintain its cross-section, plan form and profile geometry over time, effectively transporting its water and sediment supply without aggrading (building up), degrading (down cutting), or adjusting laterally (eroding its banks)." (Rosgen, 1996)

Streams that are in balance with their landscape adapt a form that can pass the water and sediment through both small and large floods, regaining their previous form after the flood passes. In many situations, however, stream reaches become unstable when some management activity has upset that balance, altering the stream's ability to move its water and sediment effectively.

The form of a stream that is considered "stable" varies with topography. When it is in balance with mountainous terrain, a stable stream will look different than one that is in balance with rolling hills or broad floodplains. Stable streams are less likely to experience bank erosion, water quality and habitat problems. A number of factors can change the stability of streams such as changes in flow input, sediment, and land use. Channelization of the stream and placement of berms, culverts and bridges can also have a negative impact on stream stability.

Sediment Balance

Sediment discharge has long been recognized as one of the primary variables that determine the characteristics of a stream. **Figure 2.5** below illustrates the relationship between a set of four primary physical variables (sediment size, sediment load, stream discharge and stream slope) and two opposing processes (stream bed aggradation and degradation) that determine stream

[1] USGS stream gage information can be found on their website http://nwis.waterdata.usgs.gov/ny/nwis/rt

sediment and channel characteristics and balance. The figure suggests that a change in one of four physical variables will trigger a response in the two process variables. This in turn creates changes in stream characteristics. See **Figure 2.5a** and **Figure 2.5b**. Streams are said to be in equilibrium when the volume of water is enough to transport the available sediment without building up in the channel (also known as aggradations) or cutting down the channel bed (known as degradation). Streams will adjust their shape, size, and slope in order to transport the sediment.

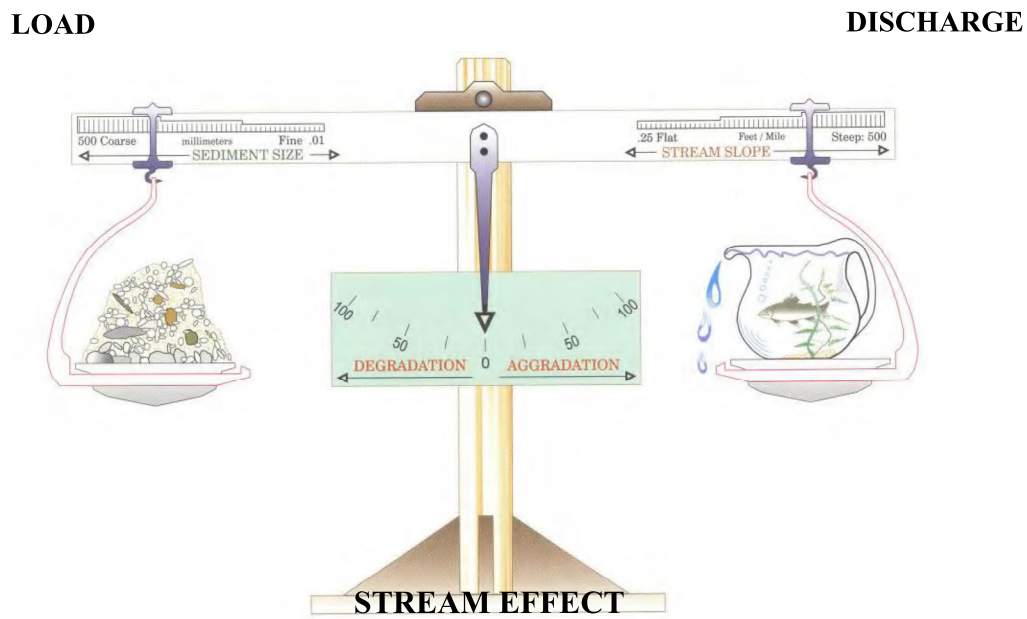


Figure 2.5 Sediment Balance (Sediment LOAD) x (Sediment SIZE) is proportional to (Stream SLOPE) x (Stream DISCHARGE) **(Rosgen, 1996)**

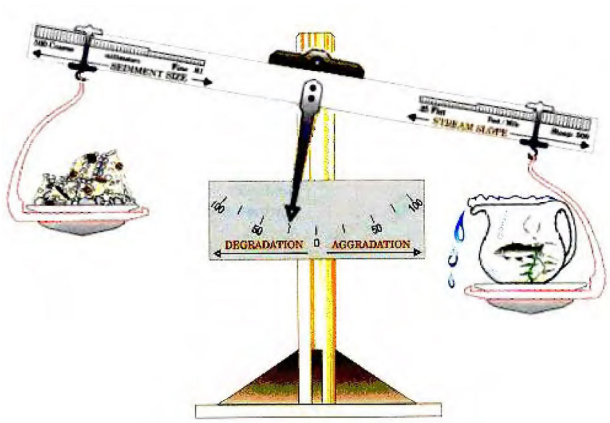


Figure 2.5a If the supply of sediment decreases or the supply of water increases, the stream will begin to erode the stream bed or degrade. (After Rosgen, 1996)

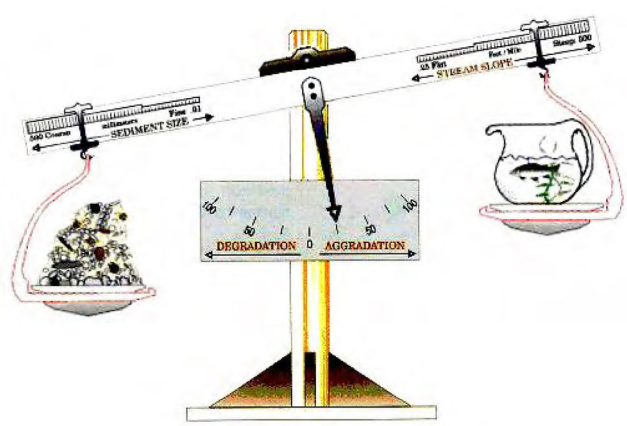


Figure 2.5b If the supply of sediment increases or the supply of water decreases, the stream will begin to fill in with gravel or aggrade. (After Rosgen, 1996)

Stream Features

The features of a stream are described in terms of their planform dimensions, their longitudinal dimensions, and their cross-sectional dimension.

The overhead or "planform" view of the stream focuses on the path that the stream follows within its valley (**Figure 2.6**). Stream managers speak of a stream's sinuosity as they describe the coverage the stream meanders across the valley. Sinuosity is related to slope and energy. A stream that has sinuosity has a longer distance than a stream that is straight. The associated elevations will also differ whereas the greater the sinuosity the lower the average slope. The sinuosity of a stream is generally greater at the lower end of the valley closer to the mouth of the watershed.

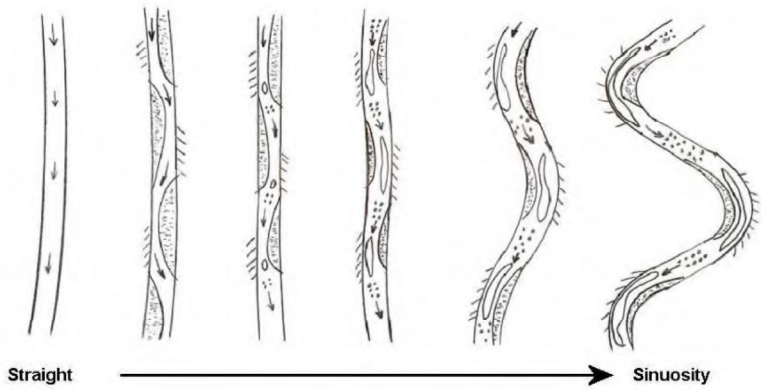


Figure 2.6 Planform of a Stream with Increasing Sinuosity (After Keller, 1972)

Longitudinal dimensions of a stream are used to describe how the stream changes from the top of the watershed to the mouth of the stream. The most important factor is the slope of the stream. Slope is a critical contributor to the energy of the stream. The energy of water flowing down a slope is needed to move sediment. A stream's slope can vary from high gradient (slope greater than 4%) to medium gradient (2%-4%) to low gradient (less than 2%)(see **Figure 2.7**). The slope of the stream typically is greatest at the top of the watershed (high gradient stream) and gradually declines as the stream flows down the valley (medium gradient stream) and makes its way to the bottom of the watershed (low gradient streams).

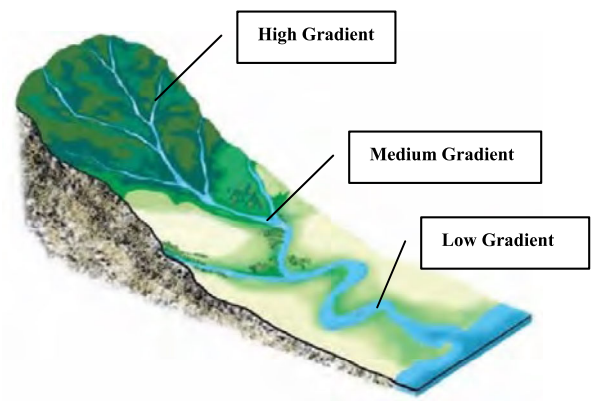


Figure 2.7 Stream's slope from high gradient to low

In terms of its cross-sectional dimension, a stream has a primary channel that conveys most of the flow throughout the year. Secondary conveyance of flow is the floodplain. Floodplains are the flat area of a stream system located above the top of the stream bank that is inundated with slower flowing water during and following flood flow events. Flood flows in some streams sections may not rise over the top of the banks and therefore may lack or are disconnected from their historic floodplain. Such stream channels are commonly called entrenched channels (**Figure 2.8**). Maximum depth is the distance from the top of the water at bank full elevation to the deepest part of the channel. If at twice maximum depth the stream cannot access it's floodplain it is considered to be entrenched.

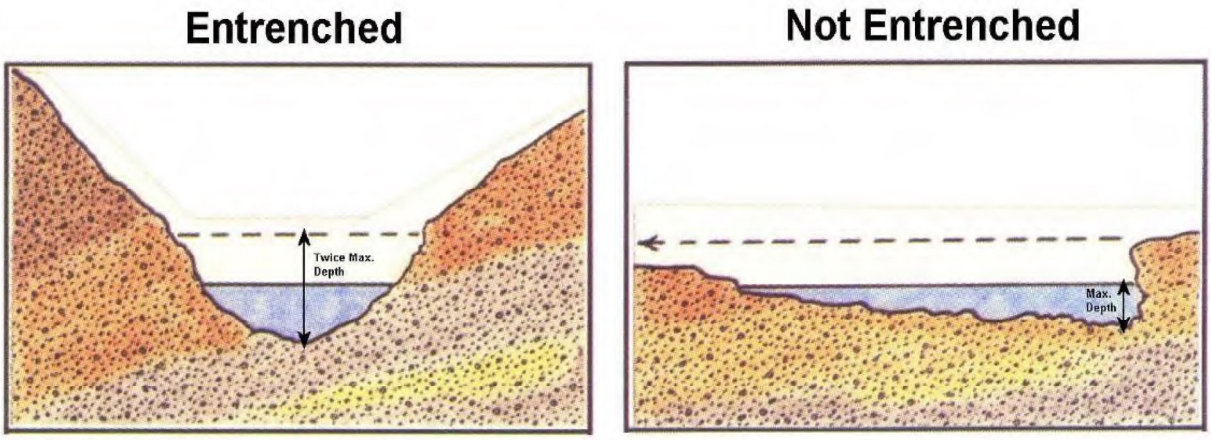


Figure 2.8 Shows entrenched channel (After Rosgen, 1996)

"The floodplain is defined as the flat area bordering a stream, constructed by the river in the present climate and inundated during periods of high flow" (Leopold, 1997). The floodplain is a critical component of stream function. The floodplain serves as an energy dissipater and depository of finer sediments during high flows. **Figure 2.9** shows a typical cross section of a stream system with bank full and floodplain. Notice that a bank full event is not considered a flood event until it over tops the banks. Bank full happens on average, every 1.2 to 2.0 years. This discharge, from relatively frequent storms, is largely responsible for the shape of the stream channel within the floodplain.

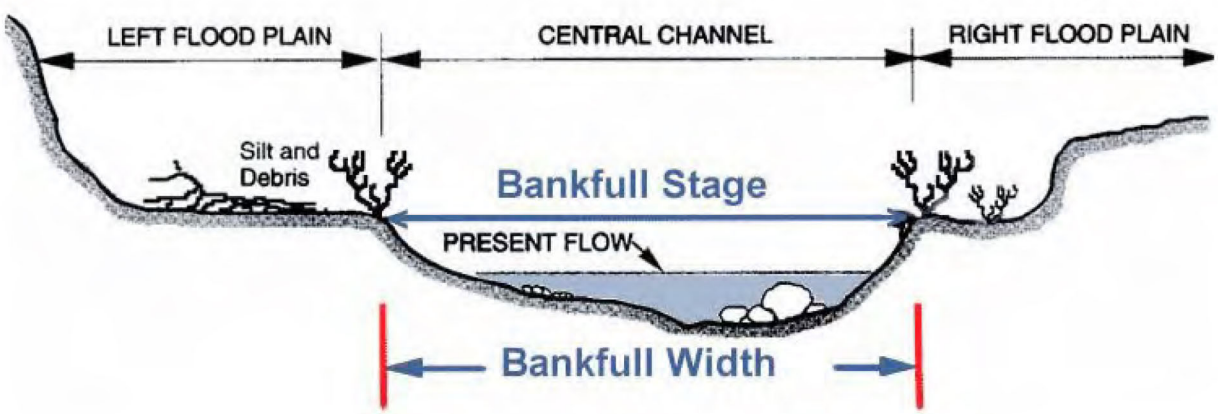


Figure 2.9 Shows a typical cross section of a stream system (After Newbury & Gaboury, 1993))

Stream Type

There are two basic stream types that can be identified in the field. One is the riffle-pool sequence illustrated in **Figure 2.10**. Typically a stable stream reach will maintain a balance in the ratio of the length of riffles to the length of pools. This balance helps regulate the velocity of water when it speeds up in riffles and slows down in the pools. Pools are important features in the stream since their low slope acts to slow the velocity (hence reduce the energy of the stream). Pools are found on the stream bends and the water enters the bend into a vortex pattern dissipating the energy in the deep water. Gravel can be found on the inside of the bend (point bar), which is a characteristic of a stable stream.

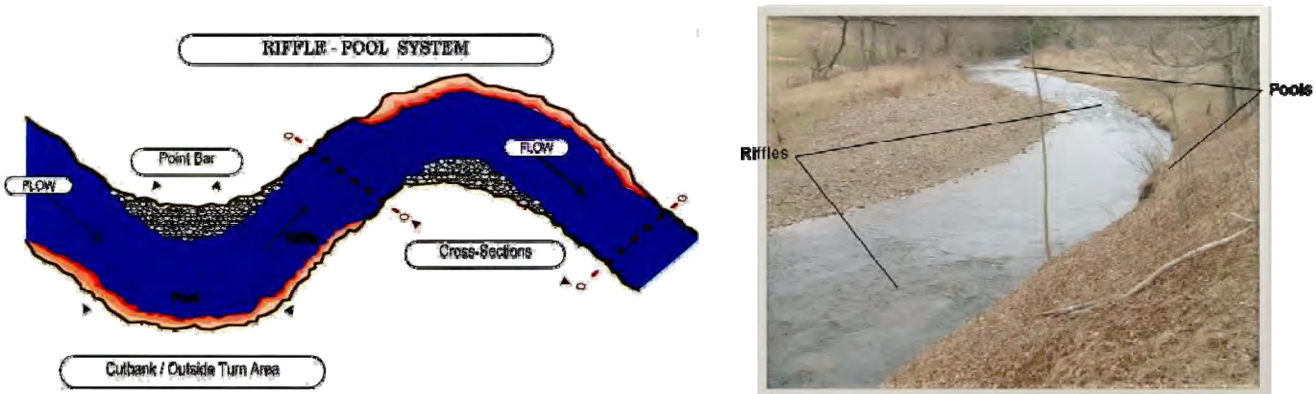


Figure 2.10 Typical Riffle-Pool Sequence (Rosgen, 1996)

The second stream type is called a step-pool sequence which is illustrated in **Figure 2.11**. The energy is dissipated through the stepped pools much like a series of speed bumps would slow down a car. This stream type is typically found in the headwaters or in steep narrow valleys.

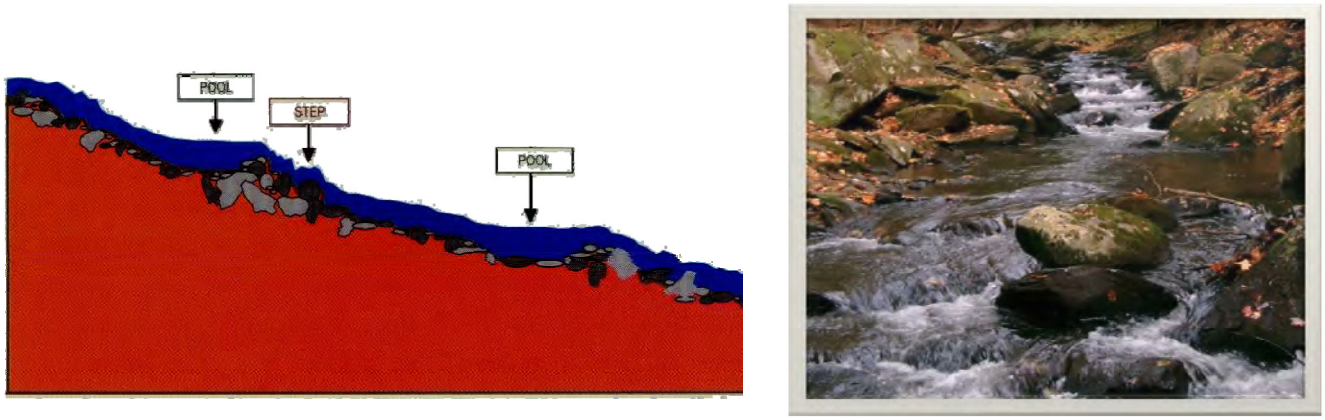


Figure 2.11 Typical Step-Pool Sequence (Rosgen, 1996)

Channel Disturbance – Evolutionary Sequence

Channels that have been disturbed by dredging, incision, or channelization follow a systematic path to recovery. This process has been documented in six classes described by Simon and Hupp (1992) in **Figure 2.12**. This process can happen naturally.

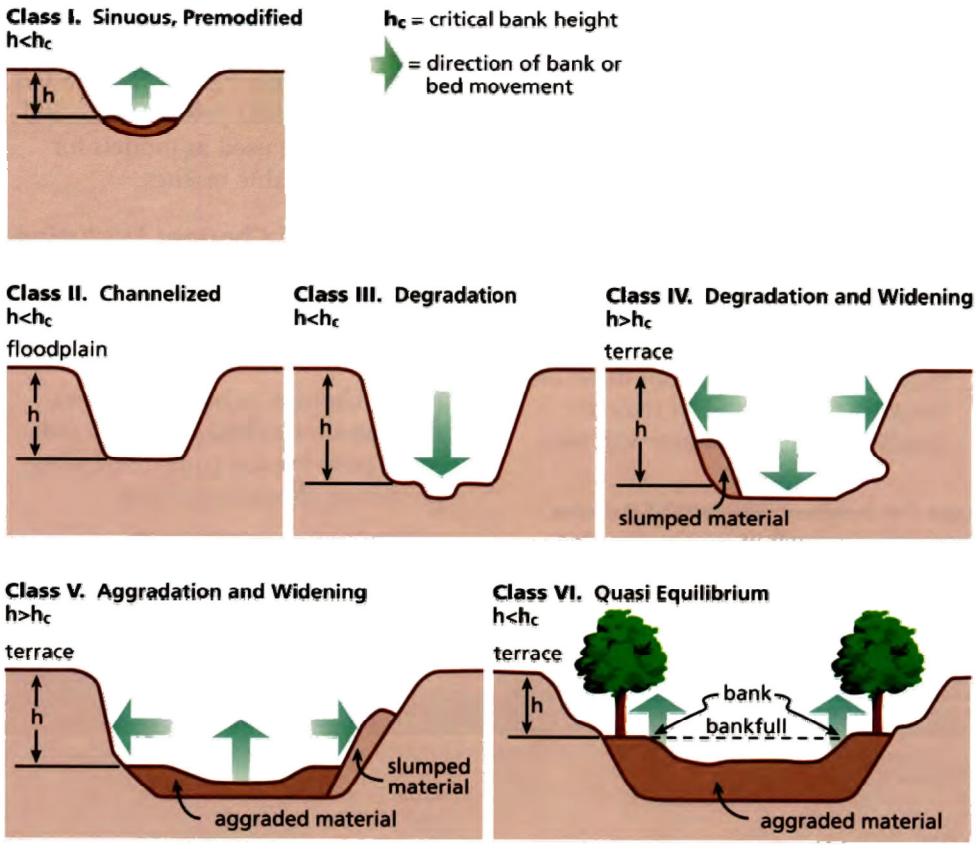


Figure 2.12 Stream Evolutionary Sequence (Simon and Hupp, 1992)

- Class I, is the channel in its natural pre-disturbed state.
- Class II, is the channel immediately after being disturbed (in this case, channelized, presumably straightened and steepened in addition to over-widened).
- Class III, is the channel eroding down (degrading) due to the flood waters being confined because channel is lower and out of contact with the former floodplain.
- Class IV, the channel continues to degrade, the banks become unstable, and the channel erodes laterally.
- Class V, the channel begins to deposit eroded material in the over-wide channel, and the newly developing floodplain continues to widen.
- Class VI, and a new channel is established and becomes relatively stable. A new floodplain is established within the original channel, and the former floodplain becomes a terrace (abandoned or inactive floodplain).

Immediate Effects of Dredging

Dredging is often proposed as a means of increasing channel capacity after a flood. On the previous page we have shown the evolutionary sequence that the stream must go through when channelization occurs. The immediate consequences of dredging are illustrated below:

Figure 2.13 (after R. Hey, 2003) shows a stream in profile view that has just been dredged. This corresponds to Simon and Hupp's Class II in Figure 2.12.

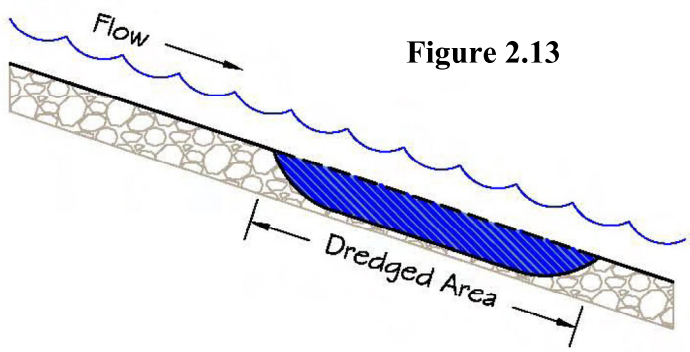


Figure 2.13

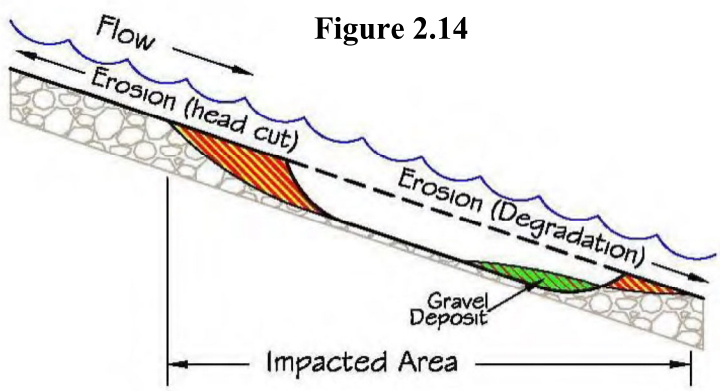


Figure 2.14

Within days, certainly no longer than weeks, the disturbances illustrated in **Figure 2.14** (after R. Hey, 2003) will be seen on the dredged stream.

Three things are occurring in the stream when it is dredged:

- A headcut occurs as a steep abrupt change in elevation in the stream bottom which forms upstream of the dredged area. The headcut will continue to move upstream releasing a huge amount of sediment supply from the bed and banks.
- This new sediment will be deposited at the location shown in the sketch labeled gravel deposit.
- Since the headcut is in effect lowering the elevation of the channel, erosion will occur downstream of the gravel deposit and outside of the area dredged. This occurs because the stream is trying to achieve equilibrium with a new bottom elevation and slope. In short, it is trying to match downstream with what is happening upstream.

Figure 2.15 is an illustration of a headcut that shows the instability that progresses upstream and the impacts that happen downstream.

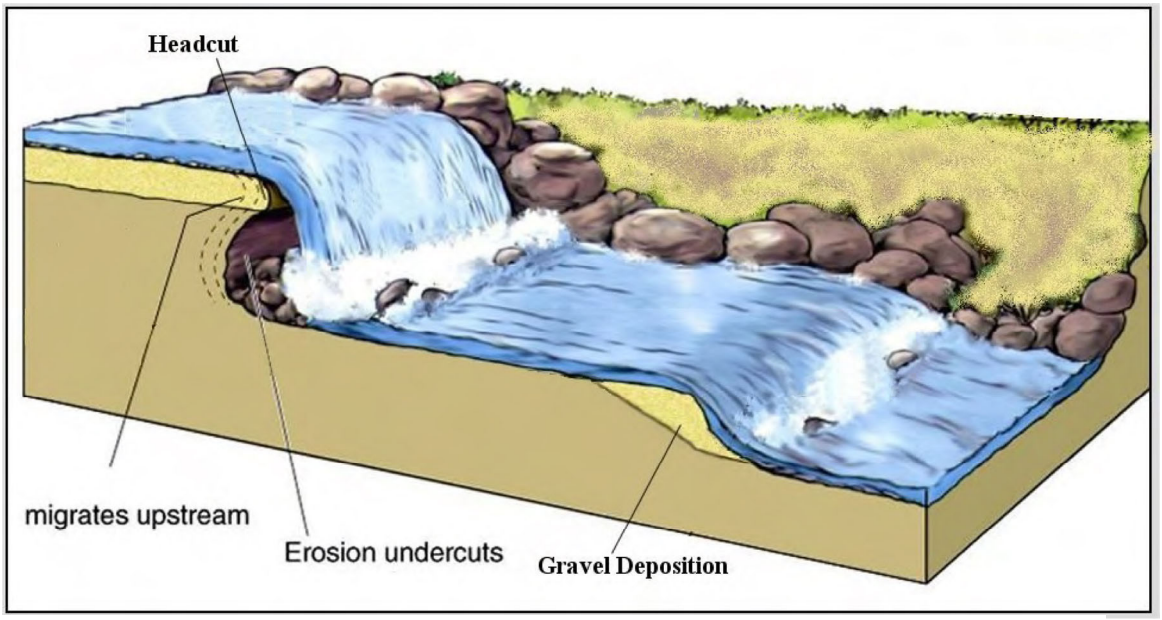


Figure 2.15 Headcut illustration showing instability of the stream channel

All of this leads to serious instabilities in the reach. Unfortunately, that is not all that can happen. The headcut, if left unchecked, will proceed upstream and destabilize more of the stream. The erosion and gravel deposition will proceed downstream and destabilize the downstream reach. If the upstream and downstream reaches are stable then this chain reaction will result in an unstable reach. If the unstable reach was further compromised with improper stream management such as dredging, the impact will further destabilized the reach resulting in steeper bank erosion. This will be greater nuisance to the municipality or landowner which may be a danger to public safety and may cost additional funding to correct the situation. The example shown in **Figure 2.16,** shows a headcut moving upstream on Third Brook in Walton, NY after post-flood work using traditional deeper -wider u-shape (parabolic) stream channel was completed to repair damages from the 2006 storm event. This headcut eroded the streambed down 6 feet which has compromised existing high eroding banks within the reach. The municipality has received funding to repair some areas of the reach and is currently in the process of developing a stream management plan to address several mass slope failures within the reach.

Figure 2.16 Headcut on Third Brook in Walton, NY

Human Activities and Impacts on Stream Health

The distinction between natural and human disturbances is important to understand. Human disturbances often significantly alter natural conditions and can have a longer lasting impact on the capability of the stream to function. These disturbances can include logging practices, livestock overgrazing, cropping practices, construction and maintenance of highway infrastructure, real estate development, gravel mining, dredging, channelization, berming, and introduction of non-native species in the riparian corridor. All of these practices have impacted stream stability on a watershed scale.

Highway/Public Utility Infrastructure Influence

Some of the most easily visible impacts to stream stability result from the construction or maintenance of highway infrastructure. Roads are commonly located close to streams, especially in mountainous regions that typically have narrow and winding valleys. Road encroachment has narrowed and deepened many streams, resulting in increased velocity. This causes the bed of the stream to degrade and, ultimately, to become incised, like a gully in its valley. This means that the stream reach has become unstable, which can lead to rapid streambank erosion as well as impairment of the water quality and stream health. Worse yet, these local changes can spread upstream and downstream, causing great lengths of stream to become unstable.

Roadside ditches collect stormwater runoff, carrying it away from the road and sometimes directly into streams. Roadside ditches have an impact on water quality and quantity. Without stormwater retention and/or filtration, runoff may impact streams by transporting contaminants, excess sediment, and excess nutrients as well as carrying excess water. The re-direction of water away from property, fields or roads without giving the water the chance to absorb into the ground, will increase runoff into the streams which raises water levels during storm events. If ditches are maintained without re-seeding, their discharge to streams can increase sediment (turbidity) in the stream system. This can aggravate gravel deposition problems.

Proper culvert installation and sizing is also important for stream stability (see **Figure 2.17**). Culvert installation that utilizes improper size, slope, and headwall can lead to streambank erosion and/or gravel deposition both upstream and downstream of the culvert.

Figure 2.17 Culvert Conveying on Holliday Brook Colchester, NY

Orientation, size and approaches for bridges have had a considerable impact on stream system stability. Bridges built wider than the stream's natural dimensions will lead to the deposition of sediment under and near the structure during periods of low or base flow. Localized scour may also be present. Sediment that is deposited under the bridge

may affect the designed flow capacity of the channel beneath the bridge. In many instances, the sediment must be excavated to maintain the design capacity. Bridges built narrower than the stream's natural dimensions will exhibit a depositional wedge upstream of the structure. This may lead to water to become backed up behind the bridge, resulting in local flooding upstream. Bridge approaches are usually built across floodplains in order to have a gradual transition onto the bridge. These become a floodplain block (see Figure 2.18).

Figure 2.18 Bridge results in elimination of Floodplain

Bridges can force water and debris that would normally be on the floodplain through a narrow opening, concentrating energy that can cause problems downstream of the bridge, such as streambank and stream bed erosion or debris plugging bridge openings. Allowing the water to convey thru floodplain culverts placed in bridge approaches will allow water to access the floodplain and reduce the risk of water backing up behind the bridge debris jams under bridges (**Figure 2.19)**.

Figure 2.19 Floodplain culverts along Delaware County Route 2 Hamden, NY

Residential and Commercial Development Influence

Development of new residential and commercial districts can have a significant impact on the watershed and on the ecology of the riparian (streamside) area. Developments require access roads and utility lines that often are required to cross streams. Stormwater runoff in a natural landscape is compared to runoff in a developed landscape in **Figure 2.20**. Homeowners who enjoy their stream and desire to be close

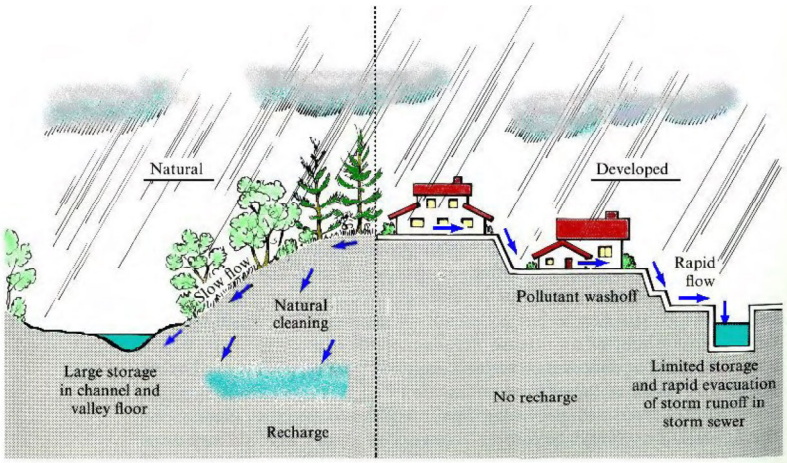


Figure 2.20 Natural vs. Developed Runoff (Dunne & Leopold, 1978)

to it may clear all the trees and shrubs along it to provide views and access. They may replace natural conditions with an un-natural mowed lawn that provides little benefit to stream health or local wildlife. Mowed lawn will increase stormwater runoff that would normally be a slow flow that would be absorbed by the trees, shrubs and ground. This leads to increase water to the stream system that may produce new streambank erosion or increase existing erosion issues. Landowners that live close to a stream and desire access to the water can minimize the destabilization of the streambank. Careful selection of a route to the stream and locating access where the water's force on the bank is lower, a landowner can minimize disturbance to riparian vegetation and the streambank. Minimizing the disturbance in the flood prone area and promoting a dense natural buffer provide property protection, aesthetic value and wildlife habitat. Landowners should be aware of planting appropriate riparian species along the stream to maximize streambank stability.

Impervious surfaces such as houses, buildings, paved parking lots or driveways will not allow for water to be absorbed into the ground. This water will become surface water runoff that is directed into ditches or swales to be removed from the property and directed towards the stream. The increase stormwater runoff to the streams will raise water levels and will reduce groundwater recharge.

Agricultural Influence

The abundance of water and cold-hardy grasses have supported agricultural industries for centuries. As fields were created to obtain the most profitable land for growing crops or grazing cattle, the streams were moved to maximize property. Streams were pushed to the sides of valleys which are no longer the lowest point of elevation. These streams are traditionally maintained and reinforced to stay in place by berms, riprap or other stabilization methods. **Figure 2.21** illustrates the stream reaction to the displacement where the channel bed is filled with gravel and erosion on the streambank occurs. When water flows over the streambanks during storm events the water will flow to the lowest elevation of the valley.

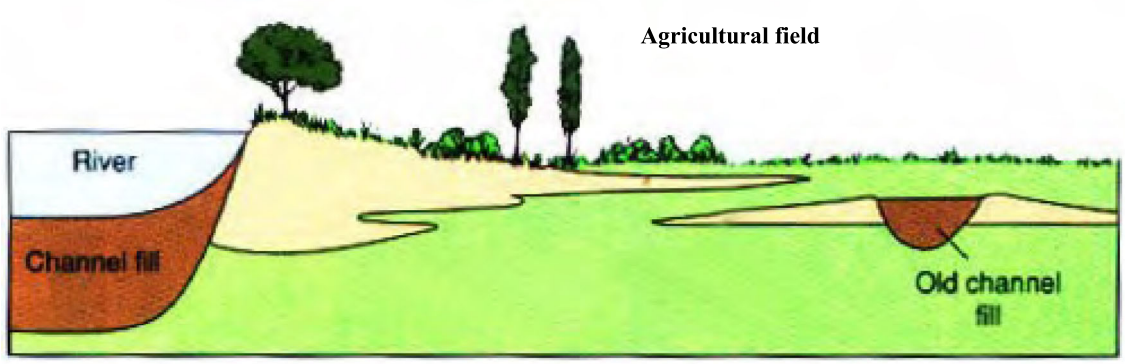


Figure 2.21 Stream that has been moved to higher elevation in a valley.

~ III. Flood Response~

After a flood event, streams may look unraveled with all the gravel and debris all over the place. A first reaction is to put everything back to the way it was and maybe do some extra work. Some of these attempts at fixing the streams have been "band-aid" solutions for spot problems and have often created additional problems. Understanding the stream conditions and using stream friendly techniques can help contractors and municipalities prioritize post-flood unstable reaches for treatment. Identifying areas that are in most need of help is essential. Often looking upstream and downstream can help a contractor determine the best fit channel shape. Allowing the stream to be re-connected to the floodplain will help maintain the new constructed channel. Remember that what you do at a given site should not significantly affect areas upstream and downstream. A variety of management strategies can be provided to address post-flood issues problems on both short and long-term bases.

Protocol

There is a need to develop a protocol for flood response to ensure the best results with minimal adverse impacts. Developing an emergency plan can help with organization of resources and determine where work is needed. Assessing and correcting stream channel conditions on a short-term basis can be completed with minimum adverse effect on the streams and can save time and money in the long run.

Immediate Priority

During and after a flood certain things need to be completed and they must be done immediately. Immediate priority items include, but are not limited to:

- Opening clogged bridges
- Opening closed roads
- Keeping important installations functioning, such as:
    - Power plants
    - Fire stations
    - Rescue centers
    - Water wells and systems
    - Sewage treatment plants and systems
    - Hospitals

Immediate priority items are those facilities and infrastructure which need to be repaired and/or kept open in order that further recovery may be allowed to continue, or to prevent immediate loss of human life.

High Priority

High priority items are those items of work that are necessary for the first part of the cleanup process. Generally, one of the first high priority items is to get the stream channels back into some sort of a functioning condition. The reason this needs to be accomplished is to:

- Open up clogged channels so they can convey their normal flow.
- Put channels back in place to prevent continued flooding.
- Open up clogged bridges to prevent additional flooding should there be another storm.
- Stabilize streambanks to prevent erosion. If left unchecked this can lead to deposition, which in turn can lead to more localized flooding.
- Attempt to stabilize landslides, at least on a temporary basis, so they do not slide into the channel and trigger an avulsion and/or localized flooding.
- Get the channel into a condition such that the natural processes of streams can begin to return the stream to its pre-flood condition.

Other work may also qualify as high priority. This training guide is intended to describe an efficient method that may be used for the emergency repair of impaired stream channels after a flood. The material which follows concentrates primarily, although perhaps not exclusively, on post-flood emergency channel repair.

Assess the Stream Reach

Knowing where to work and where not to work in a stream will help save time and money. Not all streams will need to have work done to them after a flood, even if at first glance, they appear to be in bad condition. In many cases the stream will have created a new, stable condition. Therefore, the first thing to do is assess the condition of the stream.

Appendix A is the "Problem Itemization Sheet". It is a check list of problems commonly found after a flood. It is highly recommended to take copies of this sheet out in the field, to be used in the assessment of streams. The sheet can be used to:

- Identify the number of problem sites
- Itemize the number and type of problems on a given reach
- Identify the most severely impacted reaches
- Prioritize reaches with more severe problems
- Determine manpower and equipment needs
- Serve as documentation for state or federal reimbursement
- Help document work done under an emergency permit
- Serve as documentation for additional permits

When a damaged reach is assessed, the upstream and downstream reaches should be assessed as well. For example, the upstream reach is not damaged, it is possible to measure certain physical features and then "duplicate" that reach at the damaged reach.

Perform the Work

When the assessment is complete and priorities have been established, work can begin to restore the damaged steam reaches.

Assess and Document Further Needs

Documentation is important for any project. This information can be used for flood aid reimbursement and/or future long term mitigation planning. A stream manager/contractor should provide the following:

- Project sketch or drawing
- Before and after photos
- Written description of work
    - Date
    - Time
    - Equipment
    - Material
    - Labor force

Note any future work that needs to be done. Even though the channel may be reformed to the approximate correct size, long term mitigation may be required. Such as:

- Vegetation that may need to be planted
- Structures that may be required to permanently stabilize the stream

A post construction assessment should be made. Staff from your local SWCD and DEC offices can be asked to provide technical assistance and to help with a monitoring plan.

Improper Sizing of Channels

Over-sizing or under-sizing a stream may create future problems for the area and should be avoided. Dredging the entire stream from top to bottom creates more problems. If the stream is disconnected from its floodplain, the stream will begin to down-cut, causing the streambanks to be taller, steeper, and more unstable. This can create a whole new set of problems that will end up costing more money in the end.

An example of improper stream sizing is the classic parabolic shape, or u-shape, channels. This technique is highly discouraged due to the fact that the parabolic shape concentrates the water flow with no energy dissipation and the smooth surface increases the water velocity. The series of figures below show the sequence of stream evolution after the Third Brook stream located in Walton, NY was fixed after the 2006 flood event using the parabolic design.

Figure 3.1 shows an area of stream directly after a flood event. This area appears to be in bad condition, but it is in relatively stable form. The sediment after a flood flow settles out into an overlapping or shingle-like effect wedging sediment material together. This interlocked material is less likely to move in a smaller storm event.

Figure 3.1 Section of stream that has been flooded.

Figure 3.2 The classic parabolic stream channel shape.

Figure 3.2 is in the same location as in Figure 3.1 after some stream construction was conducted. Notice the classic parabolic shape stream channel. Re-arranging the stream bed and banks loosened the sediment material which allows this material to be more transportable. The smooth bank and rounded streambed allows for the water to speed up.

Figure 3.3 shows the stream channel two months later. Notice that the stream has begun to erode its streambanks and become wider. The loose sediment is easily transported downstream.

Figure 3.3 Two months of stream channel evolution.

Figure 3.4 shows the stream channel three months after construction. The stream has continued to adjust, further eroding its streambanks and creating a floodplain. The original floodplain is so high that it is now a terrace.

Figure 3.4 Three months of stream channel evolution.

Proper Sizing of Channels

To avoid situations such as described on the previous pages, it is necessary to work with the stream and to have an understanding of how streams work. The simplest solution is to do nothing and allow natural processes to do the work. But in most situations this cannot happen due to existing infrastructure such as homes, bridges, or roads that are threatened.

Various solutions are provided in the next few pages as an alternative to just going into a stream and "winging it". There is no one answer that fits all streams, and in some cases technical assistance may be needed. In these cases, contact your SWCD or regional DEC staff for any assistance.

There are two ways to properly size channels:

- The Stable Riffle Reach Concept
- Using Regional Bank Full Hydraulic Geometry Tables

The Stable Riffle Reach Concept:

This is the preferred method. In some cases only a section of stream is damaged, typically associated with riffles. The simplest solution in this case is to look upstream and/or downstream of the area to find a relatively undisturbed "stable" riffle section. Measure the width, depth, and slope of this area and duplicate these measurements at the impacted area. A suggested method of surveying the cross section is shown in **Figure 3.5**. These measurements should be checked using the Regional Bank Full Hydraulic Geometry Tables as the example table is shown in **Figure 3.9**. This "duplicating" method will allow for natural processes to adjust the stream and have minimal adverse impact to the stream health. It will also give you information about the presence and size of important features of the stream, such as the floodplain benches, pool depths, or the stream's meander geometry.

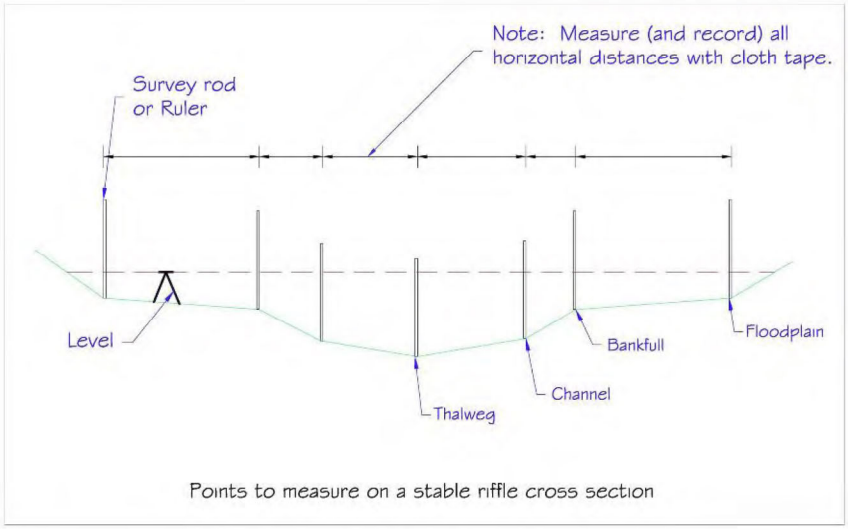


Figure 3.5 Surveying A Stable Riffle Cross Section

When you have finished your survey your sketch of the riffle cross section should approximate something like **Figure 3.6**.

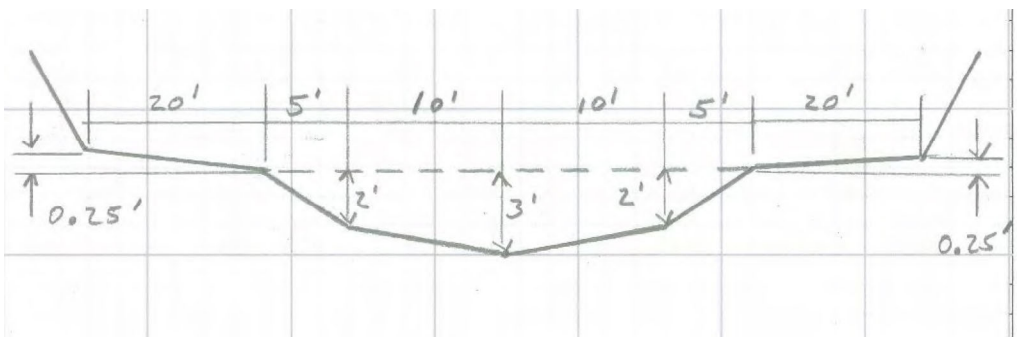


Figure 3.6 Sketch of Stable Riffle Cross Section

Using Regional Bank Full Hydraulic Geometry Tables:

In cases where the stream was completely devastated by a flood event a determination of the bank full hydraulic geometry can be used to determine stream channel dimensions. Regional bank full discharge and channel-characteristic models have been developed by the USGS using linear regression equations to relate bank full discharge and bank full channel dimensions (width, depth, and cross-sectional area) to drainage-area size. Regional Bank Full Hydraulic Geometry Tables for use throughout New York State were developed by DEC using information gathered from USGS stream gaging stations. New York's highly variable physiographic features and climate necessitated that the state be divided into hydrologic regions on the basis of the physiographic and geologic characteristics that affect streamflow. The resulting tables are therefore specific to eight distinct geographic regions in the state as shown below in **Figure 3.7**.

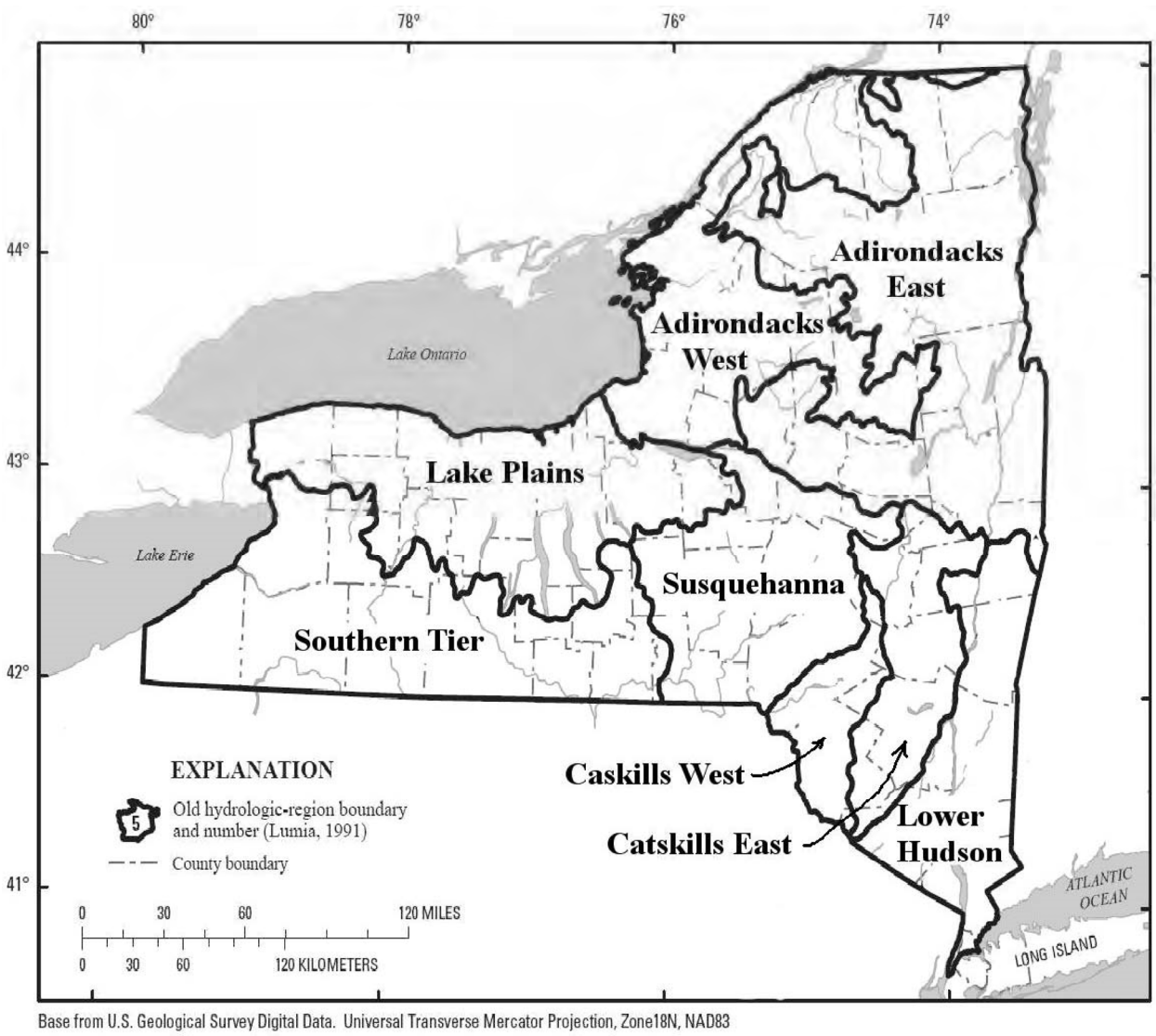


Figure 3.7 Hydrologic Regions in New York State

Bank Full Hydraulic Geometry vs. Drainage Area for Selected Hydrologic Regions

Bank Full Hydraulic Geometry Tables have been produced for each of eight geographic regions of the State: 1) Western Adirondacks, 2) Eastern Adirondacks, 3) Lower Hudson, 4) Catskills East, 4a) Catskills West, 5) Susquehanna, 6) Southern Tier, and 7) Lake Plains. Regional boundaries were established based on variability in the physiographic features and climate between each region. If the drainage area is known, the tables found in Appendix C give dimensions that can be used for the emergency reconstruction of stream channels.

The drainage area (D.A.) and can be found by:

- Using the USGS *StreamStats* website found at: http://water.usgs.gov/osw/streamstats. Instructions for use are found on the left side of the web page. Click on "State

Applications" to access New York. Additional instructions for using the USGS NY State site are in **Appendix D.**

- Using maps created by DEC, available for each county, to be made available on the DEC website.

Note: The Bank Full Stream Channel Statistics can also be calculated using *StreamStats;* however, presently the USGS website does not calculate the necessary construction dimensions that can be found in the Bank Full Hydraulic Geometry Tables found in Appendix C.

Based on the Regional Bank Full Hydraulic Geometry Tables, SWCD staff can design a typical cross section that can be used for the emergency reconstruction of a severely damaged stream. These tables are to be used for emergencies only! An example Regional Bank Full Hydraulic Geometry Table is shown below in **Figure 3.8.** A typical stream channel cross-section would look much like the one shown below in **Figure 3.9**.

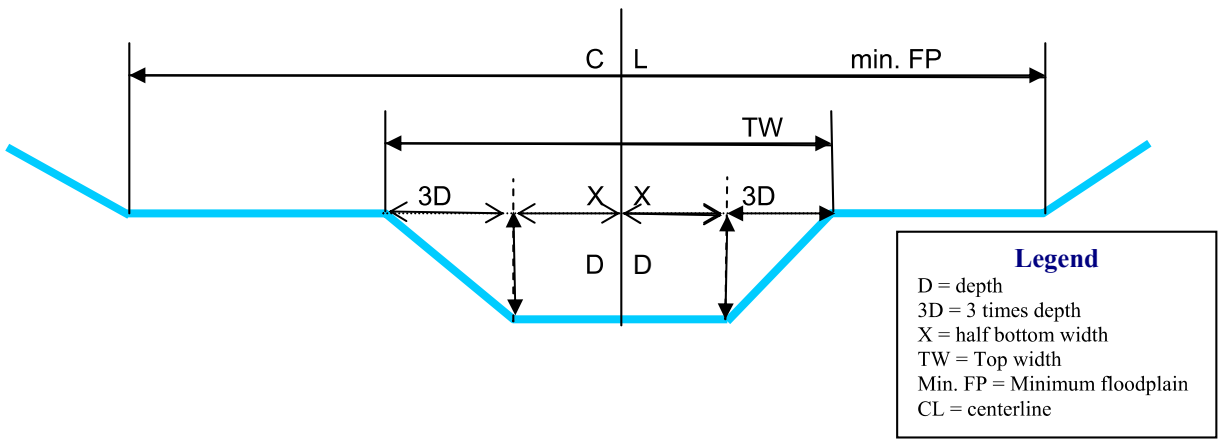
Figure 3.8 Example Regional Bank full Hydraulic Geometry Table

				Construction Dimensions					
DA (sq. mile)	Bank-Full Area (sq. ft)	Bank -Full Width (ft)	Bank-Full Depth (ft)	channel bank side slope	D (ft)	3D (ft)	X (ft)	TW (ft)	Min. FP (ft)
1	7	8.1	0.9	**2:1**	1.3	2.6	1.5	8.1	18
2.5	16	13.9	1.2	**2:1**	1.5	3.0	4.0	13.9	31
5	31	21.1	1.5	3:1	2.1	6.3	4.3	21.1	46
7.5	46	27.0	1.7	3:1	2.3	6.8	6.7	27.0	59
10	60	32.0	1.9	3:1	2.4	7.3	8.7	32.0	70
12.5	73	36.6	2.0	3:1	2.5	7.5	10.8	36.6	81
15	87	40.9	2.1	3:1	2.6	7.9	12.5	40.9	90
17.5	100	44.8	2.2	3:1	2.7	8.2	14.2	44.8	99
20	114	48.6	2.3	3:1	2.8	8.5	15.8	48.6	107
22.5	127	52.1	2.4	3:1	2.9	8.8	17.3	52.1	115
25	140	55.5	2.5	3:1	3.0	9.0	18.7	55.5	122
27.5	153	58.8	2.6	3:1	3.1	9.3	20.1	58.8	129
30	166	62.0	2.7	3:1	3.2	9.5	21.5	62.0	136
32.5	179	65.0	2.7	3:1	3.2	9.7	22.8	65.0	143
35	191	68.0	2.8	3:1	3.3	9.8	24.2	68.0	150
37.5	204	70.8	2.9	3:1	3.4	10.1	25.3	70.8	156
40	217	73.6	2.9	3:1	3.4	10.3	26.5	73.6	162
42.5	229	76.4	3.0	3:1	3.5	10.4	27.8	76.4	168
45	242	79.0	3.1	3:1	3.5	10.6	28.9	79.0	174
47.5	254	81.6	3.1	3:1	3.6	10.8	30.0	81.6	180
50	267	84.2	3.2	3:1	3.6	10.9	31.2	84.2	185

To determine the dimensions of a typical stream cross-section that can be used for the emergency reconstruction:

1) Select the table for the drainage basin that your project is in.
2) Select the drainage area (DA) in the selected table that most closely matches the DA at your project site.
3) Under "Construction Dimensions" read the channel dimensions tabulated.
4) Build the channel to these "approximately bank full" channel dimensions.

Figure 3.9 Typical Stream Cross Section for Emergency Stream Intervention



Classroom Examples on How to Use Bank Full Hydraulic Geometry Tables

Some examples are provided below using the tables. The answers are provided below each example with a detailed explanation.

Example 1:

Flooding has occurred in Woodhull, NY in the south Branch of Tuscarora Creek and repairs work is needed on a small stretch of stream. There is a bridge ¼ mile downstream of the affected area with a drainage area of 19.6 square miles. Using the appropriate Regional Bank Full Hydraulic Geometry Table from Appendix C, find the following:

a) Bank full width b) Bank full depth
c) Bank full area d) Floodplain width

Answer to Example 1:

- Determine the geographic region in which the site is located. In this case, it is in the Southern Tier Region (see figure 3.7). Use the Southern Tier table.
- Locate in the table the drainage area (DA) for the site. If there isn't an exact match, use the table value that is slightly higher than the actual site value. In this case, the closest DA is 20.0 square miles.
- The answers are highlighted in the table below:
  - Bank full width = 59.3 ft. Bank full depth = 2.47 ft.
  - Bank full area = 127.88 ft^2 Floodplain width (FP) = 130.45 ft.

Southern Tier Region

Bank Full Hydraulic Geometry vs. Drainage Area for Selected Hydrologic Regions

				Construction Dimensions					
DA (sq. mile)	Bank-Full Area (sq. ft)	Bank -Full Width (ft)	Bank-Full Depth (ft)	channel side slope	D (ft)	3D (ft)	X (ft)	TW (ft)	Min. FP (ft)
1.0	17.60	16.90	1.04	3:1	1.38	4.13	4.32	16.90	37.18
2.5	32.28	24.81	1.30	3:1	1.62	4.85	7.56	24.81	54.58
5.0	51.08	33.17	1.54	3:1	1.85	5.55	11.04	33.17	72.98
7.5	66.80	39.31	1.70	3:1	2.01	6.02	13.63	39.31	86.49
10.0	80.82	44.35	1.82	3:1	2.13	6.39	15.78	44.35	97.57
12.5	93.68	48.70	1.93	3:1	2.23	6.70	17.65	48.70	107.13
15.0	105.70	52.56	2.01	3:1	2.32	6.96	19.32	52.56	115.64
17.5	117.06	56.07	2.09	3:1	2.40	7.20	20.84	56.07	123.35
20.0	127.88	59.30	2.16	3:1	2.47	7.41	22.24	59.30	130.45

Example 2:

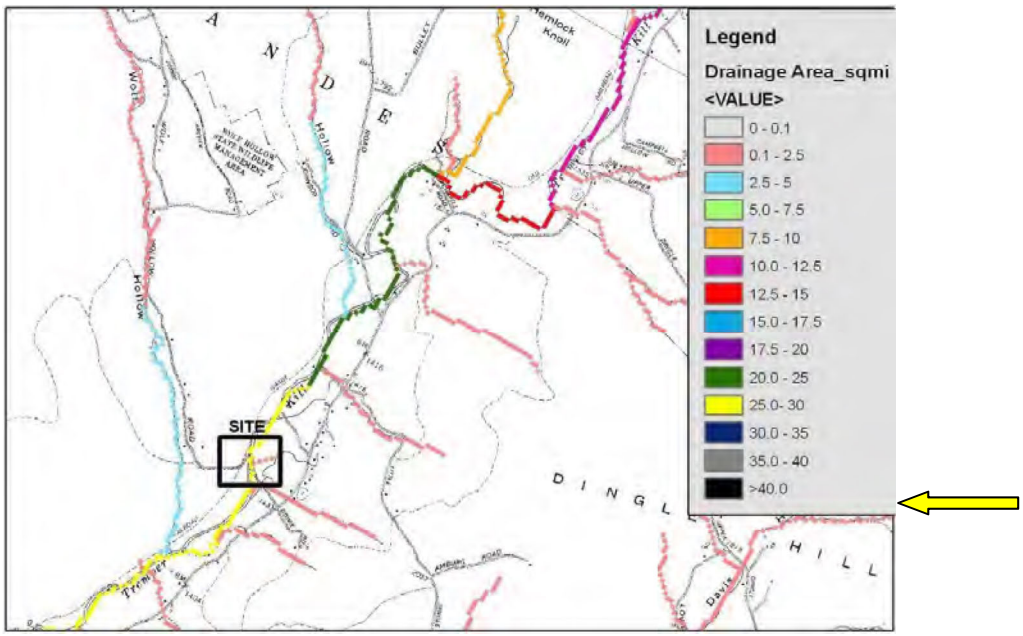
Flooding has occurred in Andes, NY on a portion of the Tremper Kill stream near Wolf Hollow Road. From the map provided below, determine the approximate Drainage Area (DA), then use the appropriate table to determine the approximate construction dimensions.

Answer to Example 2:

- On the map below, the reach in question is color-coded yellow. The key tells us that this means that the DA is between 25 and 30 square miles; therefore we will use the values for the 30 square mile drainage area.
- The project is located in the East Branch Delaware River basin, and falls within the "Catskill West" region. Use the table for this physiographic region.

- Under D.A. we find 30, then reading across under the heading Construction Dimensions we get the following answers:
    - D = 3.1 ft
    - 3D = 9.3 ft
    - X = 19.8 ft
    - TW (top width) = 58.1 ft
    - Min. FP (minimum floodplain) = 127.8 ft

It is best practice to make a sketch of the cross section using these dimensions, and then refer to the sketch during stakeout and construction.



Re-connecting Floodplains

When streams are disconnected from floodplains by berming or dredging, the natural balance is disrupted – often with undesirable impacts. Berms are described as an earthen embankment or wall, usually built to provide protection or a result of side casting during stream channel dredging. **Figure 3.10** shows the same flood event occurring in both diagrams. The diagram on the left depicts slow, shallow water on the floodplain. The diagram on the right shows the same water volume, but the floodplain access has been blocked with a berm. There is a lot of water and energy that is stored behind the berm. If the structure fails it could cause devastation in its path. It is, therefore, an important component of any long-term restoration project to give prioritization to floodplain re-connection.

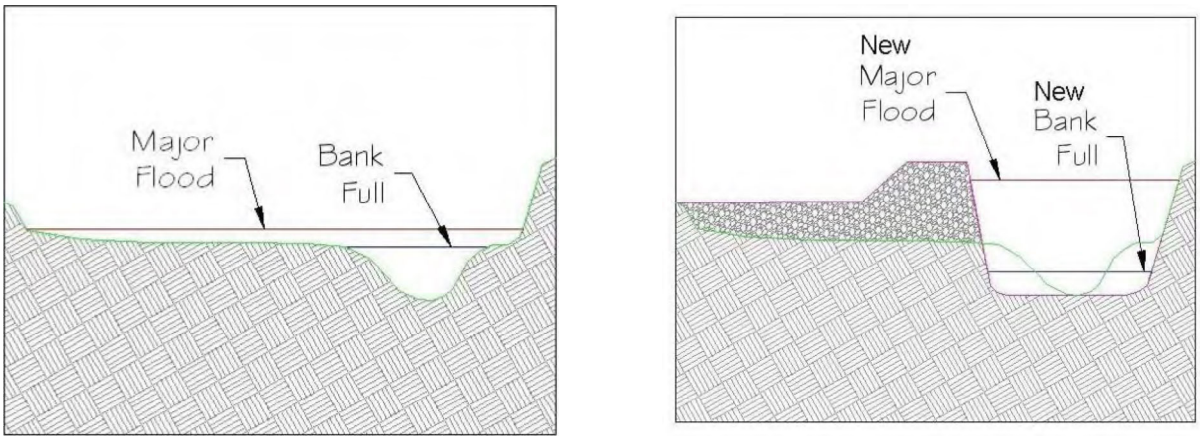


Figure 3.10 Shows the same flood situation on a fully functional floodplain vs. a filled in floodplain and berm.

Figure 3.11 is picture of a functioning floodplain during a storm event. Notice the slow moving water with low energy moving on the floodplain. **Figure 3.12** is picture of a berm protecting a corn field that was breached during a storm event. Notice the high energy that was released when the berm was compromised and destroyed the field.

Figure 3.11 Functioning Floodplain

Figure 3.12 Berm that was breached in 2005 storm event

Post-Flood Intervention using Bank Full Hydraulic Geometry Tables

SWCD utilized the Regional Tables during the 2006 flood event in the Town of Walton. The photographs below are before and after channel re-construction efforts.

Figure 3.13 is a picture taken after the flood and before any stream construction has begun. The stream was filled with debris and sediment. Construction consisted of excavating the stream channel using dimensions determined from the Regional Tables.

Figure 3.13 Shows stream channel after flood event.

Figure 3.14 is a picture at the same location taken after stream channel construction. Notice a floodplain was constructed.

Figure 3.14 Stream channel after Post Flood Intervention.

Figure 3.15 was taken two years later at the same location. The stream has kept the general form of the cross section with a few natural adjustments. The stream is stable with minimum efforts.

Figure 3.15 Two years after Post Flood Intervention.

Effect of Slope on Post-flood Emergency Reconstruction

If the stream slope is found to be 4% or greater in the mountainous regions of New York, the stream *will* almost inevitably have a step-pool sequence. If the stream slope is 2% - 4% the stream *could* be a step-pool sequence. Step-pool sequence requires special construction measures and designs, such as cross-vanes or other structures designed to mimic the operation of step-pools. In post-flood emergencies, there is not enough time for such design and implementation. In an emergency, immediate priority requires the channel be constructed as has been previously described using the Regional Tables. Stream work on a steep grade will require careful monitoring. Contact SWCD or DEC to monitor the repair work, and if necessary, devise and implement a long-term stabilization program. If it is not an immediate priority or you are not sure how to proceed, please contact SWCD or DEC.

Consideration of Upstream and Downstream Impacts

Impacts upstream and downstream of a stream restoration project always need to be considered. For example, if a streambank is to be armored with rip rap or other hard material, consideration must be given to increased velocities and erosion potential on an opposing downstream bank. Likewise, if a restoration project is designed to improve sediment transport through a reach, deposition potential downstream must be assessed. It is a goal with natural stream channel design to not only repair an impacted reach but to *not* create undue stress elsewhere in the stream system.

Using Vegetation and Natural Channel Design Structures

Woody debris can be found in abundance after a flooding event. The large amount of debris poses huge problems such as difficulty removing the debris from the stream, disposal once removed, and the cost of disposal. The simplest solution is to utilize the woody debris onsite for streambank stabilization.

Woody debris can be utilized in post-flood intervention saving time and money to implement additional projects. Placing a large tree into the streambank oriented so that the root mass is facing the water pointing upstream and the trunk is buried into the bank, is referred to as a root wad (see **Figure 3.16**). The bottom of the root ball should be below the channel grade to avoid the toe of the root wad to be washed out and be braced with boulders or crisscrossed with other logs. Several layers maybe necessary to get the depth of the structure below the stream channel bed. The exposed root mass dissipates water, protects the streambank and provides good aquatic habitat. Root wad details can be found in **Appendix-E**.

Figure 3.16 Root wads were placed in two layers with large boulders or logs to hold them in place

Figure 3.17 shows a stream that has been impacted by the 2006 flood event. The stream's original channel was to the left of the willow tree and an agricultural field is located on the right where the stream is now flowing. Note the location of the willow in both pictures. **Figure 3.18** shows the stream placed back into the original channel using the Regional Hydraulic Geometry Tables and typical cross-sections. The large woody debris found on-site was used as root wads to protect the streambank and newly formed floodplain.

Figure 3.17 Stream impacted by the 2006 Flood.

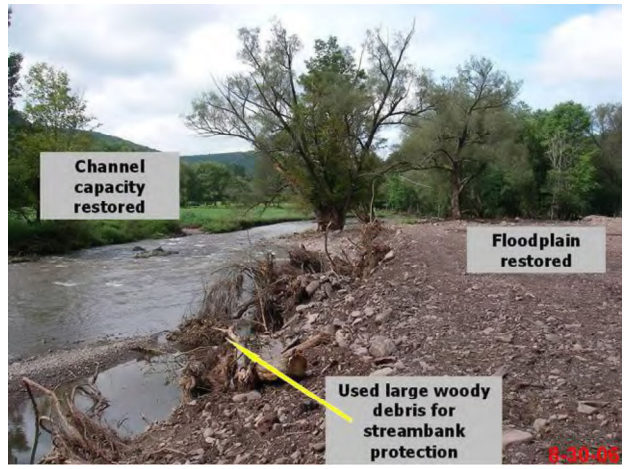


Figure 3.18 Stream construction using Regional Bank full Hydraulic Geometry values, typical cross-section and root wad.

Natural channel structures can be used to reduce stress on the streambank by re-directing stream flow toward the center of the stream. These typically include single arm vanes or cross-vanes that are made out of large rocks but logs maybe used in some small streams. Rock vane structures are built with layers of large rocks, one layer that is well-footed below the stream bed, and well-tied into the stream bank. The vane arm slopes from the top of the stream bank to the stream bed. A rock cross-vane is simply two single arm vanes with a throat in the center (**Figure 3.19**). Vegetative plantings are done around both at the ends of the vane arms (where they are tied into the stream bank). There is, however, a standard design for using them in restoration projects requiring technical data and they are expensive to be placed, so this option may not be feasible without funding.

Figure 3.19 Rock Cross-Vane

Limiting Gravel Removal

As storm flows subside, bed material overlaps and becomes wedged together like shingles; this process is called imbrication. Bed material mobilizes during high water events, and when the water velocity slows down, the material drops out. This interlocking material becomes less mobile. Rearranging the stream bed and banks loosens the interlocking material, and allows the material to become more transportable in the next highwater event. **Figure 3.20** is an example of imbrication after the June 2006 food. Gravel removal at a project site should be given careful consideration. Some gravel bars, such as transverse bars (those bars across a stream that direct flow toward a stream bank), center bars (those in the center of a stream with flow on both sides), or deposition near drainage structures should be considered for removal. Point bars (those on the inside of a bend) actually serve a hydraulic function (**Figure 3.21**). Point bars are formed by lack of stream energy on the inside of a bend and are partially eroded away during flood events, then are re-deposited as flood flows subside. Removing point bars will reduce stream energy at low flows, thereby creating potential for increased deposition in the form of transverse and/or center bars.

Figure 3.20 shows imbrication after the 2006 flood.

Figure 3.22 shows downcutting after dredging.

A straightened stream will also adjust itself. Notice in **Figure 3.22**, how the stream was manipulated into the classic parabolic shape. This adjustment was made after the June 2006 flood event, and this photo was taken in October 2006. The stream has adjusted itself by downcutting approximately 6 feet and eroding the streambanks. The stream will continue to adjust by transporting loosened sediment downstream until it reaches equilibrium and re-builds a floodplain at a new elevation.

Figure 3.21 Looking upstream at a point bar in the Tremper Kill Sub-basin

Environmental Permitting

Compliance with State and Federal Environmental Permitting Laws will need to be established before work can commence. This compliance will need to be documented prior to receiving any Federal Emergency Management Agency (FEMA) or State Office of Emergency Management (SOEM) disaster relief funds. Work without the necessary permits can lead to significant fines and the need to redo the project and possible no reimbursement from funding agencies.

The DEC regulates activities in and around the water resources of New York State pursuant to the Environmental Conservation Law (ECL) Article 15, Title 5, Protection of Waters Program and the federal Clean Water Act, Section 401 Water Quality Certification (WQC) Program. An Article 15 Permit is required for temporary or permanent disturbances to the bed or banks of a stream with a classification and standard of C(T) or higher and for excavation and fill in Navigable Waters. An Article 24 Freshwater wetland permit may also be needed if State protected Wetlands are present.

Examples of activities requiring this permit are:

- Placement of structures in or across a stream (i.e., bridges, culverts or pipelines);
- Fill placement for bank stabilization or to isolate a work area (i.e., riprap or other forms of revetment);
- Excavations for gravel removal or as part of a construction activity;
- Lowering streambanks to establish a stream crossing;
- Use of heavy equipment in a stream to remove debris or to assist in-stream construction.

A state Water Quality Certification is required for any project that required Federal permitting or funding (*e.g.* FEMA funds).

DEC Permit Procedures

In addition to normal permitting procedures, the DEC has two expedited permitting processes available to respond to emergency and disaster situations.

<u>Emergency Authorizations (EA)</u>

- Issued for emergency actions to protect life, health, property and natural resources
- Written pre-notification & plan required (For municipalities, notification within 24 hours if pre-notification is not possible)
- DEC must certify or deny the EA within 2 business days
- Expire in 30 days; ca be renewed for an additional 30 days

<u>General Permits for Disaster Recovery</u>

- Expedited review process
- Valid for all restoration work not just Emergencies
- Available for a set period after a Natural Disaster (i.e. 6 months)
- Expiration date is variable
- These permits can be issued during a site visit or in response to an application received at the DEC office

- For more information see **Appendix F** – Stream Disturbance Permit Regulations in Natural Disasters

Emergency Authorizations (EA) and Permit Conditions

All Emergency Authorizations and Permits will contain enforceable conditions designed to ensure that the project will not impact adjacent landowners, protect natural resources and maintain state water quality standards. These conditions will include:

- Isolating and dewatering the work area
- June 15 – September 30 work windows for trout waters where practicable
- Proper bedding of culverts
- No discharge of turbid waters
- Proper stabilization and re-vegetation of work site

For permit applications and any questions regarding the permit process, contact the Regional Permit Administrator at your local regional DEC office as listed on the DEC website at: http://www.dec.ny.gov/about/39381.html.

Protection of Waters permit information is also available on the DEC website: http://www.dec.ny.gov/permits/6042.html.

Local Municipal Floodplain Development Permits

Nearly every municipality in New York State participates in the National Flood Insurance Program. A condition of program participation is that any development within a mapped Special Flood Hazard Area (area that has a one percent or greater chance of being flooded every year, often called the 100-year floodplain) must receive a floodplain development permit from the municipality. The definition of "development" is:

"any man-made change to improved or unimproved real estate, including but not limited to buildings or other structures, mining, dredging, filling, grading, paving, excavation or drilling operations or storage of equipment or materials." (FEMA regulations, 44 CFR 59.1)

Prior to any excavation, dredging, or grading, the local floodplain administrator, usually a building code or zoning official, must approve the plan. Approval is based on a determination that the development will not result in physical damage to other property, such as stream bank erosion and increased flood velocities.

Some locations have detailed flood maps that include regulatory floodways. The floodway is a narrower portion of the floodplain that must be kept free of encroachment in order to pass the base flood flow without causing any increase in flood elevations. They are shown on Flood Insurance Rate Maps as cross hatched areas within the floodplain, or for maps published prior to 1988, they are shown on separate Flood Boundary and Floodway Maps. No encroachment into any regulatory floodway is allowed by local laws passed to comply with FEMA regulations unless an engineering analysis is performed that concludes that the encroachment will not

increase the base flood elevation (elevation of the one percent annual chance flood) by any measurable amount.

The Department of Environmental Conservation serves as the state National Flood Insurance Program coordinating agency and in the role, provides technical assistance to local communities and others on how to comply with floodplain development requirements. The Floodplain Management Section of DEC can be reached the DEC's regional offices, or at 518-402-8185, or by e-mail at fldplain@gw.dec.state.ny.us.

U. S. Army Corps of Engineers (USACE) Permit Requirements

Section 10 of the Rivers and Harbors Act requires a permit from the USACE for any work (including structures) in or affecting navigable waters of the United States.

Section 404 of the Clean Waters Act requires a permit for any activities that involve or result in the discharge of fill material into waters of the United States. Waters of the United States include: 1) navigable waters and adjacent wetlands, 2) tributaries to navigable waters and wetlands, regardless of their DEC classification.

Typical flood response actions that require a permit are:

- Channel shaping
- Sediment removal
- Bank stabilization
- Culvert and bridge repair or replacement
- Road repair or replacement that takes place in water
- Cofferdams or temporary fills required to complete the work

Minor projects with minimal individual and cumulative impacts may be authorized under general permits including Nationwide Permits. Many Nationwide Permits require pre-construction notification to the USACE prior to the commencement of work, especially if the activities:

- Are located in or near wetlands
- Are located in or near riffle pool complexes
- May affect historic property
- May affect endangered species

All terms and conditions of the Nationwide Permit must be complied with even if pre-construction notification or prior written approval of the USACE is not required. Special conditions, such as monitoring requirements, may be added to a permit by the USACE to assure that impacts are minimal.

The U.S. Army Corps of Engineers also has emergency procedures (33 CFR Part 325.2), which may be used to authorize work when their existing permit processing procedures are not timely enough for responding to emergency work.

DEC ***no longer forwards permit applications to the Army Corps***. The applicant must send a copy of the application to the Army Corps. If the emergency is a federal declared disaster, the

USACE will accept complete jurisdictional inquiry forms which are available from State Office of Emergency Management (SOEM).

Nationwide permits may be used to authorize the types of activities typically done in response to flooding events:

- Nationwide Permits 3 – Maintenance
- Nationwide Permit 13 – Bank Stabilization
- Nationwide Permit 27 – Aquatic Habitat Restoration, Establishment, and Enhancement Activities
- Nationwide Permit 33 – Temporary Construction, Access and Dewatering
- Nationwide Permit 37 – Emergency Watershed Protection and Rehabilitation
- Nationwide Permit 45 – Repair of Uplands Damaged by Discrete Events

Nationwide Permits, like all permits from the USACE, require compliance with:

- Wild and Scenic River Act (Delaware River)
- Section 7 of the Endangered Species Act
- Section 106 of the National Historic Preservation Act

If a project would affect any of these conditions then notification will be triggered.

For more information contact the regional USACE office at:

For DEC Regions 1, 2 and 3
US Army Corps of Engineers NY District
ATTN: Regulatory Branch
26 Federal Plaza, Room 1937
New York, NY 10278-0090
email: CENAN.PublicNotice@usace.army.mil

For DEC Regions 1, 2,
Westchester County and
Rockland County - (917) 790-8511

For the other counties
of DEC Region 3 -(917) 790-8411

For DEC Regions 4, 5
Department of the Army
ATTN: CENAN-OP-R
NY District, Corps of Engineers
1 Buffington Street
Building 10, 3rd Floor
Watervliet, NY 12189-4000
(518) 266-6350 - Permits team
(518) 266-6360 - Compliance Team
email: cenan.rfo@usace.army.mil

For DEC Regions 6, 7, 8, 9
US Army Corps of Engineers
Buffalo District
ATTN: Regulatory Branch
1776 Niagara Street
Buffalo, NY 14207-3199
(716) 879-4330
email: LRB.Regulatory@usace.army.mil

~ IV. References ~

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Keller, E.A., 1972. Development of alluvial streams: a five stage model. *Geological Society of America Bulletin* 83, 1531-1536.

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Simon, A. and C.R. Hupp. 1992. Geomorphic and Vegetative Recovery Processes Along Modified Stream Channels of West Tennessee. U.S. Geological Survey, Open File Report 91-502.

Appendix 7: Watershed Hydraulic Model and Benefit Assessment

HEC-HMS Peak Discharge Summary Table - Existing Condition

Hydrologic Element	Drainage Area	100 yr Peak Discharge	200 yr Peak Discharge	500 yr Peak Discharge
Bonesteel Creek Reach 1	5	413.8	554.5	702.9
Bonesteel Creek Reach 2	2.24	178	235.2	293.9
Bonesteel Trib-Trib 1	1.46	169.2	227.2	285.2
Junction-11	36.86	2916.4	3863.3	4892.8
Junction-15	3.8	342.3	445.1	559.6
Junction-19	49.48	3819.3	5053	6384.2
Junction-20	80.57	5669.9	7495.7	9464.9
Junction-21	7.87	797.1	1065.7	1343.1
Junction-22	24.77	1662.8	2191.6	2763.7
Junction-24	92.07	6371.3	8416.1	10616.1
Junction-25	97.47	6445.8	8515.8	10742.6
Junction-5	19.72	1698.2	2268	2866.8
Junction-5A	9.21	1041.3	1396.8	1754.5
Junction-7	34.7	2753.4	3650	4626.2
Junction-9	6.46	548.1	729.5	926.4
Newfoundland Creek Reach1	1.13	230.4	307.5	371.5
Poesten Kill Reach 4	1.3	65.7	87.5	109.8
Poesten Kill Reach 5	3.54	116.1	155.3	195.7
Poesten Kill Trib-Trib5	0.86	103.4	135.5	167.8
Poestenkill Reach 1	6.11	682.8	911.8	1147.1
Poestenkill Reach 2	5.59	391.2	526.9	668.8
Poestenkill Reach 3	6.28	376.9	500.7	627.2
Poestenkill Reach 6	0.09	2.7	3.6	4.5
Poestenkill Reach 8	5.4	74.5	99.7	126.5
Poestenkill Reach7	6.3	144.2	193	244.3
Poestenkill Trib - Trib 6	4.92	395.3	530.4	672.5
Poestenkill Trib Trib 1	2.98	244.5	322.6	403.1
Poestenkill Trib Trib2	2.3	205.4	270.5	337.7
Poestenkill Trib Trib3	2.67	265.6	348.3	434.4
Poestenkill Trib-Trib 7	3.1	361.4	485	608.9
Quacken Kill - Reach 1	6.02	596.2	796.8	1006.1
Quacken Kill - Reach 2	13.33	511.5	683.2	859.9
Quackenkill Reach2A	6.23	185	247.5	312.4
Quackenkill Trib-Trib A	1.85	226.1	304.5	381.1
Quackenkill Trib-Trib1	3.57	424.7	555.4	689.4
Sweet Mill Creek	5.2	558.4	731.7	910.6

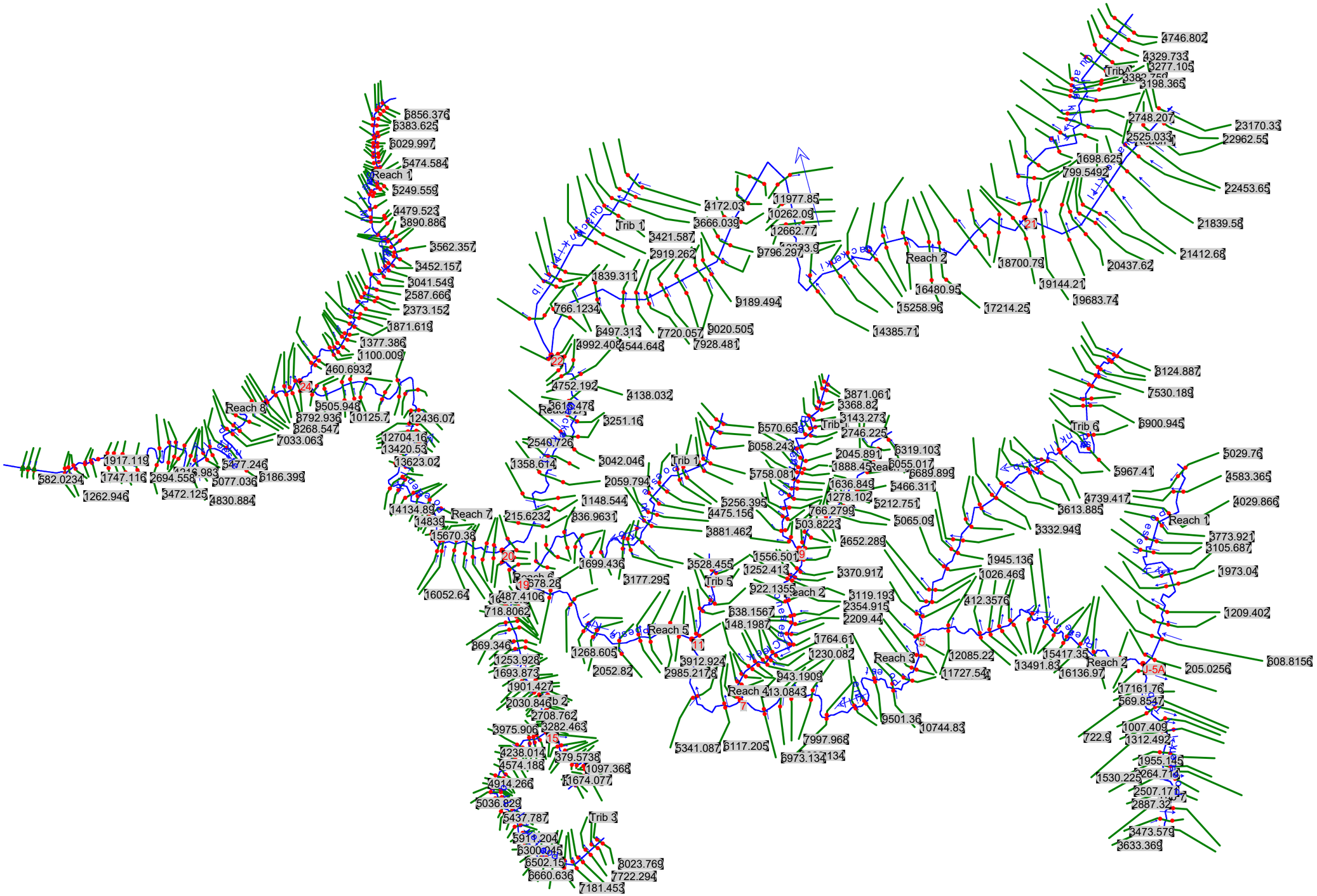
HEC-HMS Peak Discharge Summary Table - Post Condition (Wetland Control Devices and Dunham Reservoir Management)

Hydrologic Element	Drainage Area	100 yr Peak Discharge	200 yr Peak Discharge	500 yr Peak Discharge
AP-14	8.33	317.9	740.1	1089.3
AP-14 Watershed	8.33	718.6	947.1	1183.1
AP-29	5.24	132.6	169.9	214.2
AP-29 Watershed	5.24	171.9	229.8	289.7
AP-6	1.06	56.7	82.7	109.7
AP-6 Watershed	1.06	122.3	164.3	206.3
Bonesteel Creek Reach 1	4.45	368.3	493.5	625.6
Bonesteel Creek Reach 2	0.37	29.4	38.8	48.5
Bonesteel Trib-Trib 1	0.4	46.3	62.2	78.1
Dunham Reservoir	10.28	52.4	61.5	92
Dunham Watersehd	2.41	39	53.3	68.4
G-31	5.2	150.5	197.2	250.8
G-31 Watershed	2.55	93.1	126.9	161.7
G-32	2.65	110.2	144.4	183.3
G-32 Watershed	2.65	169	228.2	289.7
G-35	1.93	183.7	242.7	303.2
G-35 Watershed	1.93	190	249.3	310.9
Junction-11	43.2856	2320	3437.1	4685.6
Junction-15	3.8	342.3	445.1	559.6
Junction-19	59.6556	3222.5	4621.5	6172.3
Junction-20	91.5256	4424.8	6200.1	8165.9
Junction-21	7.87	397.2	514.3	655.2
Junction-22	25.55	1014.6	1327.6	1676.7
Junction-24	103.0256	5132.8	7127.3	9324.1
Junction-25	108.4256	5207.3	7227	9450.5
Junction-5	19.6856	951.3	1290.2	1816.1
Junction-5A	9.2	190.9	267.1	431
Junction-7	41.1256	2157.1	3223.9	4419
Junction-9	6.46	481.5	654.1	837.9
Kersch	0.0656	11.4	16.6	20.9
kersch watershed	0.0656	21.3	29.7	35.5
Newfoundland Creek Reach1	1.13	230.4	307.5	371.5
Poesten Kill Reach 4	1.3	65.7	87.5	109.8
Poesten Kill Reach 5	3.54	116.1	155.3	195.7
Poesten Kill Trib-Trib5	0.86	103.4	135.5	167.8
Poestenkill Reach 2	5.5	384.9	518.4	658
Poestenkill Reach 3	6.28	376.9	500.7	627.2
Poestenkill Reach 6	0.09	2.7	3.6	4.5
Poestenkill Reach 8	5.4	74.5	99.7	126.5
Poestenkill Reach7	6.3	144.2	193	244.3
Poestenkill Trib - Trib 6	3.37	270.8	363.3	460.6
Poestenkill Trib Trib 1	2.98	244.5	322.6	403.1
Poestenkill Trib Trib2	0.81	72.3	95.3	118.9
Poestenkill Trib Trib3	2.67	265.6	348.3	434.4
Quacken Kill - Reach 1	0.82	81.2	108.5	137
Quacken Kill - Reach 2	9.77	374.9	500.7	630.2
Quackenkill Reach2A	6.23	185	247.5	312.4
Quackenkill Trib-Trib A	1.85	226.1	304.5	381.1
Quackenkill Trib-Trib1	3.57	424.7	555.4	689.4
Sweet Mill Creek	5.2	565.5	739	918
T-11	1.31	134.3	176.2	240.6
T-11 Watershed	1.31	154.5	202.2	251
T-12	1.55	101.4	137	260.8
T-12 Watershed	0.24	20.8	27.8	35.2
T-16 Watershed	2.73	206.3	277.3	351.9
T-16A	2.73	156.1	198.3	248.3
T-16B	2.73	79.9	118.2	152.2
T-16C	2.73	35.6	64.7	95.2
T-20	4.53	81	126.5	177.3
T-20 Watershed	1.8	76.3	103.7	132.1
T-24	9.2	190.9	267.1	431
T-24 Watershed	2	64.5	88	112.3
T-27	2.67	217.4	295.8	359.2
T-27 Watershed	2.67	248.2	331.4	419.4
T-8	0.55	19.7	29.9	41.4
T-8 Watershed	0.55	55.6	74.3	93.8

HEC-HMS Peak Discharge Summary Table - Post Condition (Wetland Control Devices Only)

Hydrologic Element	Drainage Area	100 yr Peak Discharge	200 yr Peak Discharge	500 yr Peak Discharge
Junction-20	91.5256	4738.2	6640.2	8722.1
Kersch	0.0656	11.4	16.6	20.9
T-12 Watershed	0.24	20.8	27.8	35.2
T-27 Watershed	2.67	248.2	331.4	419.4
Poestenkill Trib - Trib 6	3.37	270.8	363.3	460.6
T-20 Watershed	1.8	76.3	103.7	132.1
T-16B	2.73	79.9	118.2	152.2
T-16C	2.73	35.6	64.7	95.2
T-20	4.53	81	126.5	177.3
Junction-5A	9.2	190.9	267.1	431
T-16A	2.73	156.1	198.3	248.3
kersch watershed	0.0656	21.3	29.7	35.5
T-27	2.67	217.4	295.8	359.2
T-24 Watershed	2	64.5	88	112.3
T-11 Watershed	1.31	154.5	202.2	251
Poestenkill Reach 2	5.5	384.9	518.4	658
T-12	1.55	101.4	137	260.8
T-24	9.2	190.9	267.1	431
T-16 Watershed	2.73	206.3	277.3	351.9
T-11	1.31	134.3	176.2	240.6
Junction-5	19.6856	951.3	1290.2	1816.1
AP-14 Watershed	8.33	718.6	947.1	1183.1
AP-14	8.33	317.9	740.1	1089.3
T-8 Watershed	0.55	55.6	74.3	93.8
AP-6	1.06	56.7	82.7	109.7
AP-6 Watershed	1.06	122.3	164.3	206.3
Bonesteel Creek Reach 1	4.45	368.3	493.5	625.6
Bonesteel Trib-Trib 1	0.4	46.3	62.2	78.1
T-8	0.55	19.7	29.9	41.4
Junction-9	6.46	481.5	654.1	837.9
Poestenkill Reach 3	6.28	376.9	500.7	627.2
Junction-7	41.1256	2157.1	3223.9	4419
Poesten Kill Reach 4	1.3	65.7	87.5	109.8
Bonesteel Creek Reach 2	0.37	29.4	38.8	48.5
Poesten Kill Trib-Trib5	0.86	103.4	135.5	167.8
Junction-11	43.2856	2320	3437.1	4685.6
AP-29 Watershed	5.24	171.9	229.8	289.7
AP-29	5.24	132.6	169.9	214.2
Newfoundland Creek Reach1	1.13	230.4	307.5	371.5
Poestenkill Trib Trib3	2.67	265.6	348.3	434.4
Junction-15	3.8	342.3	445.1	559.6
Poesten Kill Reach 5	3.54	116.1	155.3	195.7
Poestenkill Trib Trib 1	2.98	244.5	322.6	403.1
Poestenkill Trib Trib2	0.81	72.3	95.3	118.9
Junction-19	59.6556	3222.5	4621.5	6172.3
G-35 Watershed	1.93	190	249.3	310.9
G-31 Watershed	2.55	93.1	126.9	161.7
Quackenkill Trib-Trib A	1.85	226.1	304.5	381.1
G-32 Watershed	2.65	169	228.2	289.7
G-31	5.2	150.5	197.2	250.8
Quacken Kill - Reach 1	0.82	81.2	108.5	137
G-32	2.65	110.2	144.4	183.3
Dunham Watersehd	2.41	39	53.3	68.4
Junction-21	7.87	397.2	514.3	655.2
Dunham Reservoir	10.28	365.9	501.6	648.2
Quacken Kill - Reach 2	9.77	374.9	500.7	630.2
G-35	1.93	183.7	242.7	303.2
Quackenkill Trib-Trib1	3.57	424.7	555.4	689.4
Junction-22	25.55	1328.1	1767.7	2232.9
Quackenkill Reach2A	6.23	185	247.5	312.4
Poestenkill Reach 6	0.09	2.7	3.6	4.5
Poestenkill Reach7	6.3	144.2	193	244.3
Sweet Mill Creek	5.2	558.4	731.7	910.6
Junction-24	103.0256	5439.7	7560.6	9873.4
Poestenkill Reach 8	5.4	74.5	99.7	126.5
Junction-25	108.4256	5514.1	7660.3	9999.9

HEC-HMS Peak Discharge Summary Table - Post Condition (Dunham Reservoir Management Only)				
Hydrologic Element	Drainage Area	100 yr Peak Discharge	200 yr Peak Discharge	500 yr Peak Discharge
Junction-20	82.98	5175.8	7237.1	9346
Junction-5	19.72	1698.2	2268	2866.8
Poestenkill Trib-Trib 7	3.1	361.4	485	608.9
Junction-7	34.7	2753.4	3650	4626.2
Poesten Kill Reach 5	3.54	116.1	155.3	195.7
Poestenkill Trib - Trib 6	4.92	395.3	530.4	672.5
Newfoundland Creek Reach1	1.13	230.4	307.5	371.5
Junction-15	3.8	342.3	445.1	559.6
Poesten Kill Reach 4	1.3	65.7	87.5	109.8
Poestenkill Trib Trib3	2.67	265.6	348.3	434.4
Poestenkill Trib Trib2	2.3	205.4	270.5	337.7
Junction-11	36.86	2916.4	3863.3	4892.8
Junction-5A	9.21	1041.3	1396.8	1754.5
Bonesteel Creek Reach 1	5	413.8	554.5	702.9
Bonesteel Creek Reach 2	2.24	178	235.2	293.9
Poesten Kill Trib-Trib5	0.86	103.4	135.5	167.8
Junction-9	6.46	548.1	729.5	926.4
Poestenkill Trib Trib 1	2.98	244.5	322.6	403.1
Bonesteel Trib-Trib 1	1.46	169.2	227.2	285.2
Poestenkill Reach 3	6.28	376.9	500.7	627.2
Poestenkill Reach 2	5.59	391.2	526.9	668.8
Poestenkill Reach 1	6.11	682.8	911.8	1147.1
Junction-19	49.48	3819.3	5053	6384.2
Quacken Kill - Reach 2	13.33	511.5	683.2	859.9
Quackenkill Trib-Trib A	1.85	226.1	304.5	381.1
Quacken Kill - Reach 1	6.02	596.2	796.8	1006.1
Junction-21	7.87	797.1	1065.7	1343.1
Dunham Reservoir	10.28	253.7	727.2	1133.8
Dunham Watershed	2.41	39	53.3	68.4
Quackenkill Trib-Trib1	3.57	424.7	555.4	689.4
Junction-22	27.18	1168.8	1933	2644.9
Quackenkill Reach2A	6.23	185	247.5	312.4
Sweet Mill Creek	5.2	558.4	731.7	910.6
Poestenkill Reach7	6.3	144.2	193	244.3
Poestenkill Reach 6	0.09	2.7	3.6	4.5
Junction-24	94.48	5877.2	8157.5	10497.3
Poestenkill Reach 8	5.4	74.5	99.7	126.5
Junction-25	99.88	5951.7	8257.2	10623.8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4475.156
766.2799
503.8223
5065.09
3881.462
4652.289
1556.501
1252.413
3370.917
3528.455
3177.295
922.1355
3119.193
2354.915
2209.44
638.1567
148.1987
1764.61
1230.082
1268.605
2052.82
3912.924
2985.217
943.1909
413.0843
5341.087
6117.205
7997.968
6973.134
134
9501.36
10744.83
12085.22
11727.54
1945.136
1026.469
412.3576
3332.949
3613.885
4739.417
5967.41
5029.76
4583.365
4029.866
3773.921
3105.687
1973.04
1209.402
608.8156
205.0256
15417.35
13491.83
16136.97
8124.887
7530.189
6900.945
17161.76
569.8547
722.9
1007.409
1312.492
1955.145
1530.225
3264.714
2507.171
2887.32
3473.579
3633.369

HEC-RAS Summary Table - Post Condition Reach 8 (w/o Dunham Reservoir)													
Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width		WS. Elevation Benefit
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)		(ft)
Reach 8	9084.866	100 YR	5439.7	328.97	340.54	335.49	340.57	0.00017	1.4	3879.23	653.48		-0.76
Reach 8	9084.866	200 YR	7560.6	328.97	342.19	336.05	342.22	0.000147	1.52	4963.31	661.32		-0.59
Reach 8	9084.866	500 YR	9873.4	328.97	343.74	336.44	343.79	0.000135	1.65	5997.52	666.58		-0.47
Reach 8	8904.993	100 YR	5439.7	324.05	340.2		340.37	0.000683	3.36	1619.79	204.11		-0.74
Reach 8	8904.993	200 YR	7560.6	324.05	341.81		342.03	0.000915	3.77	2004.57	266.24		-0.58
Reach 8	8904.993	500 YR	9873.4	324.05	343.34		343.6	0.000896	4.06	2429.41	283.94		-0.47
Reach 8	8792.936	100 YR	5439.7	322.64	340.21		340.24	0.000127	1.4	3884.43	525.96		-0.74
Reach 8	8792.936	200 YR	7560.6	322.64	341.83		341.87	0.000129	1.59	4746.53	533.89		-0.6
Reach 8	8792.936	500 YR	9873.4	322.64	343.39		343.44	0.00013	1.77	5579.1	538.32		-0.47
Reach 8	8546.203	100 YR	5439.7	318.6	326.24		326.67	0.002369	5.26	1034.16	171.68		-0.67
Reach 8	8546.203	200 YR	7560.6	318.6	327.73		328.26	0.002292	5.84	1293.77	178.33		-0.54
Reach 8	8546.203	500 YR	9873.4	318.6	329.17		329.8	0.00223	6.34	1556.19	185.27		-0.45
Reach 8	8339.744	100 YR	5439.7	315.29	320.7	320.7	323.01	0.018456	12.17	446.81	97.86		-0.54
Reach 8	8339.744	200 YR	7560.6	315.29	321.86	321.86	324.68	0.017472	13.47	561.32	100.62		-0.45
Reach 8	8339.744	500 YR	9873.4	315.29	323.01	323.01	326.3	0.016598	14.54	679.04	103.75		-0.34
Reach 8	8268.547	100 YR	5439.7	304.66	313.47	314.47	317.63	0.027594	16.35	332.73	60.62		-0.83
Reach 8	8268.547	200 YR	7560.6	304.66	315.46	316.43	319.44	0.028683	16	472.58	92.56		-0.47
Reach 8	8268.547	500 YR	9873.4	304.66	316.46	317.52	321.06	0.030202	17.21	573.81	104.8		-0.26
Reach 8	8134.045	100 YR	5439.7	283.79	288.66	291.18	297.26	0.086827	23.53	231.2	58.57		-0.45
Reach 8	8134.045	200 YR	7560.6	283.79	289.85	292.7	299.42	0.07638	24.82	304.58	63.88		-0.48
Reach 8	8134.045	500 YR	9873.4	283.79	291.01	294.18	301.5	0.066009	25.98	380.04	65.77		-0.33
Reach 8	8031.935	100 YR	5439.7	280.22	287.23	287.23	289.88	0.017843	13.06	416.41	78.69		-0.61
Reach 8	8031.935	200 YR	7560.6	280.22	288.59	288.59	291.81	0.016947	14.4	525.11	81.55		-0.49
Reach 8	8031.935	500 YR	9873.4	280.22	289.96	289.95	293.66	0.016295	15.45	639.06	86.05		-0.4
Reach 8	7403.166	100 YR	5439.7	253.84	270.44	258.83	270.48	0.000081	1.48	3680.42	321.55		-1.11
Reach 8	7403.166	200 YR	7560.6	253.84	272.85	259.52	272.89	0.00009	1.69	4483.71	346.95		-0.82
Reach 8	7403.166	500 YR	9873.4	253.84	275.25	260.22	275.31	0.000099	1.84	5362.77	390.62		-0.63
Reach 8	7175.604	100 YR	5439.7	251.87	260.89		261.29	0.00227	5.06	1074.98	183.97		-0.93
Reach 8	7175.604	200 YR	7560.6	251.87	262.95		263.37	0.001681	5.16	1464.33	193.37		-0.76
Reach 8	7175.604	500 YR	9873.4	251.87	265.02		265.45	0.001368	5.26	1878.18	206.42		-0.63
Reach 8	7033.063	100 YR	5439.7	250.07	260.16		260.46	0.001315	4.43	1228.32	167.87		-1.01
Reach 8	7033.063	200 YR	7560.6	250.07	262.37		262.71	0.001108	4.7	1607.75	175.19		-0.79
Reach 8	7033.063	500 YR	9873.4	250.07	264.52		264.9	0.000976	4.96	1989.8	180.45		-0.64
Reach 8	6186.399	100 YR	5439.7	244.23	258.96		258.96	0.00001	0.47	11548.02	1240.15		-1.08
Reach 8	6186.399	200 YR	7560.6	244.23	261.31		261.32	0.00001	0.52	14489	1257.39		-0.81
Reach 8	6186.399	500 YR	9873.4	244.23	263.54		263.54	0.000009	0.57	17316.07	1282.93		-0.66
Reach 8	5477.246	100 YR	5439.7	240.03	258.33		258.39	0.000161	1.87	2908.72	300.32		-1.1
Reach 8	5477.246	200 YR	7560.6	240.03	260.71		260.78	0.000157	2.07	3643.72	315.17		-0.8
Reach 8	5477.246	500 YR	9873.4	240.03	262.94		263.02	0.000158	2.26	4360.9	332.81		-0.65
Reach 8	5291.141	100 YR	5439.7	237.73	249.13		249.75	0.002167	6.3	862.84	97.16		-1.33
Reach 8	5291.141	200 YR	7560.6	237.73	251.33		252.08	0.002432	6.96	1085.86	114.77		-0.49
Reach 8	5291.141	500 YR	9873.4	237.73	252.68		253.63	0.003496	7.82	1261.97	148.29		-0.38
Reach 8	5077.036	100 YR	5439.7	237.53	249.13		249.19	0.000251	1.94	2797.35	385.82		-1.42
Reach 8	5077.036	200 YR	7560.6	237.53	251.48		251.54	0.000195	2.04	3713.99	394.34		-0.53
Reach 8	5077.036	500 YR	9873.4	237.53	252.9		252.98	0.000215	2.31	4279.56	404.66		-0.4
Reach 8	4830.884	100 YR	5439.7	235.14	248.23		248.24	0.000023	0.66	8270.51	982.93		-1.6
Reach 8	4830.884	200 YR	7560.6	235.14	250.72		250.73	0.00002	0.7	10841.03	1079.41		-0.48
Reach 8	4830.884	500 YR	9873.4	235.14	252.03		252.04	0.000024	0.81	12276.15	1115.38		-0.36
Reach 8	4216.983	100 YR	5439.7	231.5	246.96		247.06	0.000662	2.49	2181.69	426.95		-1.92
Reach 8	4216.983	200 YR	7560.6	231.5	249.72		249.8	0.000318	2.21	3422.12	462.86		-0.41
Reach 8	4216.983	500 YR	9873.4	231.5	250.87		250.96	0.000349	2.49	3962.29	479.17		-0.31
Reach 8	4059.872	100 YR	5439.7	230.41	246.84	236.09	246.91	0.000148	2.05	2655.83	222.12		-1.89
Reach 8	4059.872	200 YR	7560.6	230.41	249.58		249.64	0.000281	1.96	3848.9	565.79		-0.41
Reach 8	4059.872	500 YR	9873.4	230.41	250.71		250.79	0.000319	2.19	4508.24	619.83		-0.31

Reach 8	3942.972	100 YR	5439.7	230.25	243.9		243.92	0.000206	1.33	4187.73	871.37		-0.54
Reach 8	3942.972	200 YR	7560.6	230.25	245.16		245.19	0.00024	1.42	5455.12	1158.39		-0.35
Reach 8	3942.972	500 YR	9873.4	230.25	246.07		246.1	0.000236	1.55	6522.84	1199.12		-0.26
Reach 8	3472.125	100 YR	5439.7	227.99	239.72		239.78	0.00049	1.86	2918.11	711.43		-0.51
Reach 8	3472.125	200 YR	7560.6	227.99	240.83		240.9	0.00043	2.04	3710.81	717.2		-0.45
Reach 8	3472.125	500 YR	9873.4	227.99	241.97		242.05	0.000383	2.18	4538.22	728.71		-0.34
Reach 8	2694.558	100 YR	5439.7	227.07	235.14		235.17	0.000167	1.44	3845.03	634.63		-0.56
Reach 8	2694.558	200 YR	7560.6	227.07	236.64		236.68	0.000157	1.61	4807.18	650.4		-0.45
Reach 8	2694.558	500 YR	9873.4	227.07	237.81		237.86	0.000166	1.81	5573.07	654.42		-0.36
Reach 8	2381.125	100 YR	5439.7	226.84	232.8		232.82	0.00017	1.14	4803.1	1115.91		-0.8
Reach 8	2381.125	200 YR	7560.6	226.84	235.13		235.14	0.000081	1.02	7469.08	1175.03		-0.44
Reach 8	2381.125	500 YR	9873.4	226.84	236.26		236.28	0.000082	1.13	8811.39	1215.76		-0.33
Reach 8	2233.088	100 YR	5439.7	213.62	232.75		232.77	0.000085	1.02	5569.02	931.13		-0.8
Reach 8	2233.088	200 YR	7560.6	213.62	235.1		235.11	0.000064	0.98	7983.1	1104.81		-0.43
Reach 8	2233.088	500 YR	9873.4	213.62	236.22		236.24	0.000068	1.11	9243.24	1128.08		-0.34
Reach 8	2107.736	100 YR	5439.7	213.48	229.33		229.49	0.000731	3.14	1732.99	254.89		-0.87
Reach 8	2107.736	200 YR	7560.6	213.48	232.35		232.46	0.000782	2.63	2879.13	591.96		-0.37
Reach 8	2107.736	500 YR	9873.4	213.48	233.33		233.46	0.000749	2.85	3469.48	611.93		-0.31
Reach 8	1917.119	100 YR	5439.7	199.21	207.04	204.96	207.99	0.005292	7.81	696.24	114.57		-0.59
Reach 8	1917.119	200 YR	7560.6	199.21	208.35	206.02	209.59	0.005519	8.9	849.03	117.62		-0.51
Reach 8	1917.119	500 YR	9873.4	199.21	209.64	207.09	211.15	0.005648	9.85	1002.24	120.61		-0.38
Reach 8	1747.116	100 YR	5439.7	74.28	78.78	78.78	80.68	0.019643	11.06	491.94	131.3		-0.44
Reach 8	1747.116	200 YR	7560.6	74.28	79.73	79.73	82.06	0.018247	12.26	616.91	132.53		-0.33
Reach 8	1747.116	500 YR	9873.4	74.28	80.63	80.63	83.42	0.017576	13.4	736.85	133.69		-0.28
Reach 8	1615.422	100 YR	5439.7	51.25	55.68	58.19	64.09	0.095581	23.27	233.73	66.24		-0.43
Reach 8	1615.422	200 YR	7560.6	51.25	56.66	59.64	66.53	0.085836	25.21	299.96	69.05		-0.41
Reach 8	1615.422	500 YR	9873.4	51.25	57.64	60.93	68.62	0.080776	26.59	371.36	75.07		-0.31
Reach 8	1382.411	100 YR	5439.7	27.13	46.43	33.78	46.49	0.000144	2.05	2650.85	213.43		-1.29
Reach 8	1382.411	200 YR	7560.6	27.13	49.17	35.38	49.26	0.000149	2.33	3244.68	219.67		-1.19
Reach 8	1382.411	500 YR	9873.4	27.13	51.84	36.86	51.94	0.000154	2.57	3843.38	228.63		-0.64
Reach 8	1262.946	100 YR	5439.7	20.83	43.57		43.67	0.0003	2.63	2069.3	196.41		-1.19
Reach 8	1262.946	200 YR	7560.6	20.83	46.08		46.21	0.000346	2.88	2626.92	244.87		-1.12
Reach 8	1262.946	500 YR	9873.4	20.83	48.54		48.67	0.000397	2.94	3359.18	341.23		-0.6
Reach 8	1171.695	100 YR	5439.7	17.36	36.6		36.74	0.000565	3.01	1804.24	223.08		-1.09
Reach 8	1171.695	200 YR	7560.6	17.36	38.89		39.05	0.000508	3.24	2333.3	238.71		-0.75
Reach 8	1171.695	500 YR	9873.4	17.36	40.78		40.97	0.000505	3.53	2797	250.44		-0.56
Reach 8	582.0234	100 YR	5439.7	6.23	22.98		23.41	0.001028	5.3	1068.99	238.87		-0.49
Reach 8	582.0234	200 YR	7560.6	6.23	24.05		24.68	0.001465	6.54	1468.34	528.04		-0.35
Reach 8	582.0234	500 YR	9873.4	6.23	24.94		25.71	0.001763	7.47	2057.87	822.33		-0.25
Reach 8	468.3845	100 YR	5439.7	5.29	22.84		23.08	0.000556	3.94	1421.69	311.41		-0.47
Reach 8	468.3845	200 YR	7560.6	5.29	23.86		24.21	0.00077	4.85	2007.78	684.34		-0.34
Reach 8	468.3845	500 YR	9873.4	5.29	24.71		25.14	0.000933	5.55	2633.27	760.09		-0.23
Reach 8	363.373	100 YR	5514.1	3.57	22.52	13.94	22.82	0.001001	4.81	1904	813.87		-0.51
Reach 8	363.373	200 YR	7660.3	3.57	23.61	15.86	23.89	0.001002	5	2869.07	937.75		-0.35
Reach 8	363.373	500 YR	9999.9	3.57	24.49	17.58	24.75	0.001002	5.16	3821.69	1275.17		-0.25

HEC-RAS Summary Table - Post Condition Reach 8 (w/Only Dunham Reservoir Management)													
River	Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	WS. Elevation Benefit
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)		(ft)
Reach 8	9084.866	100 YR	5877.2	328.97	340.9	335.67	340.93	0.000163	1.43	4117.14	654.82	0.1	-0.4
Reach 8	9084.866	200 YR	8157.5	328.97	342.61	336.16	342.64	0.000144	1.56	5240.96	663.9	0.1	-0.17
Reach 8	9084.866	500 YR	10497.3	328.97	344.14	336.55	344.18	0.000132	1.68	6262.53	667.24	0.1	-0.07
Reach 8	8904.993	100 YR	5877.2	324.05	340.55		340.74	0.000743	3.47	1693.47	216.71	0.22	-0.39
Reach 8	8904.993	200 YR	8157.5	324.05	342.22		342.45	0.000921	3.86	2115.81	273.3	0.24	-0.17
Reach 8	8904.993	500 YR	10497.3	324.05	343.73		344	0.000884	4.13	2541.5	286.88	0.24	-0.08
Reach 8	8792.936	100 YR	5877.2	322.64	340.57		340.6	0.000128	1.44	4072.18	528.15	0.09	-0.38
Reach 8	8792.936	200 YR	8157.5	322.64	342.25		342.29	0.000129	1.64	4969.52	535.08	0.09	-0.18
Reach 8	8792.936	500 YR	10497.3	322.64	343.78		343.84	0.00013	1.81	5793.24	539.45	0.1	-0.08
Reach 8	8546.203	100 YR	5877.2	318.6	326.57		327.02	0.002351	5.39	1089.81	173.12	0.38	-0.34
Reach 8	8546.203	200 YR	8157.5	318.6	328.11		328.67	0.002279	5.99	1362.04	180.04	0.38	-0.16
Reach 8	8546.203	500 YR	10497.3	318.6	329.55		330.2	0.002222	6.45	1627.11	188.31	0.39	-0.07
Reach 8	8339.744	100 YR	5877.2	315.29	320.95	320.95	323.37	0.018281	12.48	470.8	98.44	1.01	-0.29
Reach 8	8339.744	200 YR	8157.5	315.29	322.17	322.17	325.11	0.017125	13.75	593.3	101.38	1	-0.14
Reach 8	8339.744	500 YR	10497.3	315.29	323.29	323.29	326.7	0.016523	14.81	708.74	104.86	1	-0.06
Reach 8	8268.547	100 YR	5877.2	304.66	313.83	315.16	318.1	0.026685	16.58	354.56	61.51	1.22	-0.47
Reach 8	8268.547	200 YR	8157.5	304.66	315.84	316.69	319.82	0.029896	16.01	509.43	103.17	1.27	-0.09
Reach 8	8268.547	500 YR	10497.3	304.66	316.67	317.79	321.48	0.030229	17.59	596.7	105.37	1.3	-0.05
Reach 8	8134.045	100 YR	5877.2	283.79	288.84	291.51	298.01	0.088112	24.29	241.92	58.94	2.11	-0.27
Reach 8	8134.045	200 YR	8157.5	283.79	290.2	293.11	299.84	0.071081	24.91	327.51	64.46	1.95	-0.13
Reach 8	8134.045	500 YR	10497.3	283.79	291.29	294.62	302.07	0.064582	26.34	398.49	66.23	1.89	-0.05
Reach 8	8031.935	100 YR	5877.2	280.22	287.51	287.53	290.3	0.017824	13.42	438.04	79.27	1.01	-0.33
Reach 8	8031.935	200 YR	8157.5	280.22	288.93	288.94	292.31	0.016874	14.76	552.86	82.26	1	-0.15
Reach 8	8031.935	500 YR	10497.3	280.22	290.3	290.3	294.13	0.016223	15.7	668.77	87.57	1	-0.06
Reach 8	7403.166	100 YR	5877.2	253.84	270.98	258.98	271.02	0.000083	1.52	3855.15	327.65	0.08	-0.57
Reach 8	7403.166	200 YR	8157.5	253.84	273.43	259.72	273.48	0.000092	1.74	4686.51	350.29	0.08	-0.24
Reach 8	7403.166	500 YR	10497.3	253.84	275.78	260.39	275.84	0.0001	1.88	5570.85	395.3	0.09	-0.1
Reach 8	7175.604	100 YR	5877.2	251.87	261.34		261.74	0.002095	5.07	1158.9	185.94	0.36	-0.48
Reach 8	7175.604	200 YR	8157.5	251.87	263.48		263.9	0.001597	5.2	1567.34	196.7	0.33	-0.23
Reach 8	7175.604	500 YR	10497.3	251.87	265.55		265.99	0.001308	5.28	1988.17	209.75	0.3	-0.1
Reach 8	7033.063	100 YR	5877.2	250.07	260.66		260.97	0.00125	4.48	1312.52	169.52	0.28	-0.51
Reach 8	7033.063	200 YR	8157.5	250.07	262.92		263.28	0.001076	4.79	1704.18	176.53	0.27	-0.24
Reach 8	7033.063	500 YR	10497.3	250.07	265.06		265.45	0.000951	5.03	2088.03	181.78	0.26	-0.1
Reach 8	6186.399	100 YR	5877.2	244.23	259.51		259.51	0.00001	0.48	12233.07	1244.12	0.03	-0.53
Reach 8	6186.399	200 YR	8157.5	244.23	261.87		261.87	0.00001	0.54	15193.13	1264.11	0.03	-0.25
Reach 8	6186.399	500 YR	10497.3	244.23	264.09		264.1	0.000009	0.58	18031.84	1291.24	0.03	-0.11
Reach 8	5477.246	100 YR	5877.2	240.03	258.9		258.95	0.000159	1.91	3080.27	305.91	0.11	-0.53
Reach 8	5477.246	200 YR	8157.5	240.03	261.26		261.34	0.000158	2.14	3819.13	318	0.11	-0.25
Reach 8	5477.246	500 YR	10497.3	240.03	263.49		263.57	0.00016	2.31	4546.88	339.5	0.11	-0.1
Reach 8	5291.141	100 YR	5877.2	237.73	250.08		250.66	0.00187	6.15	955.74	99.48	0.35	-0.38
Reach 8	5291.141	200 YR	8157.5	237.73	251.67		252.49	0.00257	7.25	1125.39	116.65	0.41	-0.15
Reach 8	5291.141	500 YR	10497.3	237.73	253		254	0.003733	8.01	1310.87	156.5	0.49	-0.06
Reach 8	5077.036	100 YR	5877.2	237.53	250.14		250.19	0.000192	1.84	3189.41	389.49	0.11	-0.41
Reach 8	5077.036	200 YR	8157.5	237.53	251.85		251.92	0.000201	2.11	3860.77	395.69	0.12	-0.16
Reach 8	5077.036	500 YR	10497.3	237.53	253.23		253.32	0.00022	2.38	4415.98	406.03	0.13	-0.07
Reach 8	4830.884	100 YR	5877.2	235.14	249.44		249.45	0.000018	0.62	9487.82	1034.23	0.04	-0.39
Reach 8	4830.884	200 YR	8157.5	235.14	251.06		251.07	0.000021	0.73	11207.03	1088.76	0.04	-0.14
Reach 8	4830.884	500 YR	10497.3	235.14	252.34		252.35	0.000025	0.84	12621.71	1120.69	0.04	-0.05
Reach 8	4216.983	100 YR	5877.2	231.5	248.53		248.59	0.000333	2.04	2875.13	452.41	0.14	-0.35
Reach 8	4216.983	200 YR	8157.5	231.5	250.01		250.09	0.000329	2.29	3555.41	465.97	0.15	-0.12
Reach 8	4216.983	500 YR	10497.3	231.5	251.13		251.24	0.000358	2.57	4089.34	482.16	0.16	-0.05
Reach 8	4059.872	100 YR	5877.2	230.41	248.37		248.43	0.000298	1.85	3181.1	535.62	0.13	-0.36
Reach 8	4059.872	200 YR	8157.5	230.41	249.86		249.93	0.000289	2.03	4009.8	570.99	0.14	-0.13
Reach 8	4059.872	500 YR	10497.3	230.41	250.97		251.05	0.000329	2.25	4672.19	632.42	0.15	-0.05

Reach 8	3942.972	100 YR	5877.2	230.25	244.14		244.17	0.00021	1.36	4398.51	890.13	0.11	-0.3
Reach 8	3942.972	200 YR	8157.5	230.25	245.41		245.44	0.000238	1.45	5737.61	1166.44	0.12	-0.1
Reach 8	3942.972	500 YR	10497.3	230.25	246.29		246.33	0.000234	1.58	6786.71	1199.7	0.12	-0.04
Reach 8	3472.125	100 YR	5877.2	227.99	239.97		240.02	0.000472	1.9	3091.57	712.45	0.16	-0.26
Reach 8	3472.125	200 YR	8157.5	227.99	241.15		241.21	0.000416	2.07	3937.18	723.87	0.16	-0.13
Reach 8	3472.125	500 YR	10497.3	227.99	242.26		242.34	0.000373	2.21	4746.5	729.83	0.15	-0.05
Reach 8	2694.558	100 YR	5877.2	227.07	235.41		235.44	0.000169	1.49	4014.48	636.19	0.1	-0.29
Reach 8	2694.558	200 YR	8157.5	227.07	236.95		237	0.000159	1.66	5012.22	651.45	0.1	-0.14
Reach 8	2694.558	500 YR	10497.3	227.07	238.11		238.17	0.000168	1.86	5769.76	655.83	0.11	-0.06
Reach 8	2381.125	100 YR	5877.2	226.84	233.21		233.23	0.000148	1.12	5258.72	1125.03	0.09	-0.39
Reach 8	2381.125	200 YR	8157.5	226.84	235.44		235.46	0.00008	1.05	7833.29	1176.35	0.07	-0.13
Reach 8	2381.125	500 YR	10497.3	226.84	236.54		236.56	0.000083	1.15	9156.24	1233.83	0.07	-0.05
Reach 8	2233.088	100 YR	5877.2	213.62	233.16		233.18	0.000083	1.03	5956.11	955.78	0.07	-0.39
Reach 8	2233.088	200 YR	8157.5	213.62	235.4		235.42	0.000065	1.02	8326.68	1115.12	0.07	-0.13
Reach 8	2233.088	500 YR	10497.3	213.62	236.5		236.52	0.000069	1.14	9561.65	1132.17	0.07	-0.06
Reach 8	2107.736	100 YR	5877.2	213.48	229.82	219.06	229.97	0.000735	3.16	1860.11	272.45	0.21	-0.38
Reach 8	2107.736	200 YR	8157.5	213.48	232.61		232.73	0.000773	2.69	3035.07	597.3	0.21	-0.11
Reach 8	2107.736	500 YR	10497.3	213.48	233.59		233.72	0.00074	2.9	3625.03	617.8	0.21	-0.05
Reach 8	1917.119	100 YR	5877.2	199.21	207.33	205.18	208.34	0.005336	8.05	729.7	115.24	0.56	-0.3
Reach 8	1917.119	200 YR	8157.5	199.21	208.7	206.33	210.01	0.00556	9.17	889.7	118.42	0.59	-0.16
Reach 8	1917.119	500 YR	10497.3	199.21	209.96	207.36	211.54	0.005686	10.09	1040.88	121.35	0.61	-0.06
Reach 8	1747.116	100 YR	5877.2	74.28	78.98	78.98	80.98	0.019353	11.34	518.36	131.56	1.01	-0.24
Reach 8	1747.116	200 YR	8157.5	74.28	79.97	79.97	82.43	0.018023	12.57	649.2	132.84	1	-0.09
Reach 8	1747.116	500 YR	10497.3	74.28	80.86	80.86	83.77	0.017384	13.66	768.22	133.99	1.01	-0.05
Reach 8	1615.422	100 YR	5877.2	51.25	55.88	58.49	64.65	0.093646	23.76	247.38	66.83	2.18	-0.23
Reach 8	1615.422	200 YR	8157.5	51.25	56.95	59.99	67.01	0.08449	25.44	320.68	71.9	2.12	-0.12
Reach 8	1615.422	500 YR	10497.3	51.25	57.9	61.25	69.09	0.077998	26.83	391.3	75.91	2.08	-0.05
Reach 8	1382.411	100 YR	5877.2	27.13	47.08	34.07	47.15	0.000144	2.11	2791.12	214.83	0.1	-0.64
Reach 8	1382.411	200 YR	8157.5	27.13	49.99	35.96	50.07	0.000148	2.38	3424.44	222.21	0.11	-0.37
Reach 8	1382.411	500 YR	10497.3	27.13	52.37	37.13	52.48	0.000158	2.65	3965.12	229.65	0.11	-0.11
Reach 8	1262.946	100 YR	5877.2	20.83	44.18		44.29	0.000314	2.68	2194.73	210.5	0.15	-0.58
Reach 8	1262.946	200 YR	8157.5	20.83	46.84		46.97	0.000368	2.88	2831.02	277.76	0.16	-0.36
Reach 8	1262.946	500 YR	10497.3	20.83	49.03		49.17	0.000393	2.97	3529.11	350.21	0.17	-0.11
Reach 8	1171.695	100 YR	5877.2	17.36	37.13		37.28	0.000546	3.05	1924.54	227.35	0.19	-0.56
Reach 8	1171.695	200 YR	8157.5	17.36	39.42		39.59	0.000503	3.31	2461.89	242.02	0.18	-0.22
Reach 8	1171.695	500 YR	10497.3	17.36	41.25		41.45	0.000514	3.6	2914.65	256.96	0.19	-0.09
Reach 8	582.0234	100 YR	5877.2	6.23	23.22		23.7	0.001131	5.6	1133.15	298.48	0.27	-0.25
Reach 8	582.0234	200 YR	8157.5	6.23	24.29		24.98	0.001559	6.82	1606.85	583.66	0.32	-0.11
Reach 8	582.0234	500 YR	10497.3	6.23	25.16		25.94	0.00179	7.6	2243.32	848.7	0.34	-0.03
Reach 8	468.3845	100 YR	5877.2	5.29	23.06		23.33	0.00061	4.17	1513.17	495.5	0.21	-0.25
Reach 8	468.3845	200 YR	8157.5	5.29	24.1		24.47	0.00082	5.06	2173.68	716.22	0.24	-0.1
Reach 8	468.3845	500 YR	10497.3	5.29	24.91		25.35	0.000967	5.7	2785.67	761.47	0.26	-0.03
Reach 8	363.373	100 YR	5951.7	3.57	22.77	14.36	23.06	0.001002	4.86	2108.18	834.03	0.25	-0.26
Reach 8	363.373	200 YR	8257.2	3.57	23.86	16.31	24.13	0.001001	5.05	3107.13	1012.08	0.25	-0.1
Reach 8	363.373	500 YR	10623.8	3.57	24.7	18.09	24.96	0.001	5.2	4099.07	1410.29	0.26	-0.04

HEC-RAS Summary Table - Post Condition Reach 8														
River	Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width		WS. Elevation Benefit
				(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)		(ft)
Poesten Kill	Reach 8	9084.866	100 YR	5132.8	328.97	340.28	335.33	340.31	0.000176	1.38	3708.35	652.98		-1.02
Poesten Kill	Reach 8	9084.866	200 YR	7127.3	328.97	341.87	335.98	341.91	0.00015	1.5	4756.36	658.55		-0.91
Poesten Kill	Reach 8	9084.866	500 YR	9324.1	328.97	343.39	336.36	343.43	0.000138	1.62	5759.88	665.98		-0.82
Poesten Kill	Reach 8	8904.993	100 YR	5132.8	324.05	339.94		340.11	0.000661	3.27	1568.26	200.45		-1
Poesten Kill	Reach 8	8904.993	200 YR	7127.3	324.05	341.5		341.71	0.00091	3.71	1923.25	260.96		-0.89
Poesten Kill	Reach 8	8904.993	500 YR	9324.1	324.05	342.99		343.24	0.000907	4	2329.8	281.31		-0.82
Poesten Kill	Reach 8	8792.936	100 YR	5132.8	322.64	339.95		339.98	0.000127	1.37	3748.45	524.34		-1
Poesten Kill	Reach 8	8792.936	200 YR	7127.3	322.64	341.52		341.56	0.000129	1.56	4579.94	533		-0.91
Poesten Kill	Reach 8	8792.936	500 YR	9324.1	322.64	343.03		343.08	0.00013	1.73	5387.29	537.3		-0.83
Poesten Kill	Reach 8	8546.203	100 YR	5132.8	318.6	326.01		326.42	0.002384	5.16	994.18	170.63		-0.9
Poesten Kill	Reach 8	8546.203	200 YR	7127.3	318.6	327.44		327.95	0.002306	5.74	1242.48	177.03		-0.83
Poesten Kill	Reach 8	8546.203	500 YR	9324.1	318.6	328.83		329.44	0.002245	6.24	1493.92	183.29		-0.79
Poesten Kill	Reach 8	8339.744	100 YR	5132.8	315.29	320.52	320.52	322.74	0.01865	11.96	429.18	97.42		-0.72
Poesten Kill	Reach 8	8339.744	200 YR	7127.3	315.29	321.63	321.63	324.35	0.017633	13.23	538.83	100.08		-0.68
Poesten Kill	Reach 8	8339.744	500 YR	9324.1	315.29	322.75	322.75	325.93	0.016679	14.29	652.42	102.76		-0.6
Poesten Kill	Reach 8	8268.547	100 YR	5132.8	304.66	313.22	314.11	317.28	0.028296	16.18	317.29	59.98		-1.08
Poesten Kill	Reach 8	8268.547	200 YR	7127.3	304.66	315.03	316.19	319.19	0.02701	16.37	435.43	78.21		-0.9
Poesten Kill	Reach 8	8268.547	500 YR	9324.1	304.66	316.27	317.26	320.66	0.029926	16.81	554.74	104.32		-0.45
Poesten Kill	Reach 8	8134.045	100 YR	5132.8	283.79	288.53	290.96	296.72	0.085767	22.96	223.57	58.31		-0.58
Poesten Kill	Reach 8	8134.045	200 YR	7127.3	283.79	289.54	292.41	299.26	0.083485	25.02	284.88	63.38		-0.79
Poesten Kill	Reach 8	8134.045	500 YR	9324.1	283.79	290.75	293.85	301.01	0.067794	25.69	362.88	65.35		-0.59
Poesten Kill	Reach 8	8031.935	100 YR	5132.8	280.22	287.02	287.02	289.58	0.018034	12.84	399.65	78.24		-0.82
Poesten Kill	Reach 8	8031.935	200 YR	7127.3	280.22	288.32	288.32	291.44	0.017098	14.15	503.67	80.99		-0.76
Poesten Kill	Reach 8	8031.935	500 YR	9324.1	280.22	289.63	289.63	293.25	0.016467	15.26	611.1	84.58		-0.73
Poesten Kill	Reach 8	7403.166	100 YR	5132.8	253.84	270.05	258.73	270.09	0.00008	1.44	3555.55	317.12		-1.5
Poesten Kill	Reach 8	7403.166	200 YR	7127.3	253.84	272.39	259.39	272.44	0.000089	1.65	4327.5	342.88		-1.28
Poesten Kill	Reach 8	7403.166	500 YR	9324.1	253.84	274.73	260.07	274.78	0.000097	1.81	5160.05	381.03		-1.15
Poesten Kill	Reach 8	7175.604	100 YR	5132.8	251.87	260.57		260.96	0.002411	5.05	1016.26	182.58		-1.25
Poesten Kill	Reach 8	7175.604	200 YR	7127.3	251.87	262.54		262.95	0.001769	5.15	1385.22	191.14		-1.17
Poesten Kill	Reach 8	7175.604	500 YR	9324.1	251.87	264.55		264.97	0.001429	5.24	1780.57	203.41		-1.1
Poesten Kill	Reach 8	7033.063	100 YR	5132.8	250.07	259.81		260.11	0.001336	4.38	1170.82	164.41		-1.36
Poesten Kill	Reach 8	7033.063	200 YR	7127.3	250.07	261.94		262.27	0.001141	4.65	1532.05	173.75		-1.22
Poesten Kill	Reach 8	7033.063	500 YR	9324.1	250.07	264.03		264.4	0.001001	4.9	1901.54	179.25		-1.13
Poesten Kill	Reach 8	6186.399	100 YR	5132.8	244.23	258.58		258.58	0.000011	0.46	11083.24	1237.94		-1.46
Poesten Kill	Reach 8	6186.399	200 YR	7127.3	244.23	260.85		260.86	0.00001	0.51	13914.55	1253.8		-1.27
Poesten Kill	Reach 8	6186.399	500 YR	9324.1	244.23	263.03		263.04	0.000009	0.56	16671.37	1275.4		-1.17
Poesten Kill	Reach 8	5477.246	100 YR	5132.8	240.03	257.95		258	0.00016	1.84	2795.16	295.8		-1.48
Poesten Kill	Reach 8	5477.246	200 YR	7127.3	240.03	260.25		260.31	0.000158	2.04	3498.89	312.82		-1.26
Poesten Kill	Reach 8	5477.246	500 YR	9324.1	240.03	262.44		262.51	0.000157	2.22	4195.51	326.74		-1.15
Poesten Kill	Reach 8	5291.141	100 YR	5132.8	237.73	248.86		249.44	0.002118	6.14	836.24	96.48		-1.6
Poesten Kill	Reach 8	5291.141	200 YR	7127.3	237.73	251.05		251.76	0.002209	6.76	1054.89	108.13		-0.77
Poesten Kill	Reach 8	5291.141	500 YR	9324.1	237.73	252.35		253.27	0.003367	7.68	1214.81	142.76		-0.71
Poesten Kill	Reach 8	5077.036	100 YR	5132.8	237.53	248.83		248.89	0.000256	1.91	2681.97	384.74		-1.72
Poesten Kill	Reach 8	5077.036	200 YR	7127.3	237.53	251.19		251.25	0.000192	1.98	3598.35	393.28		-0.82
Poesten Kill	Reach 8	5077.036	500 YR	9324.1	237.53	252.56		252.64	0.000212	2.25	4142.82	401.82		-0.74
Poesten Kill	Reach 8	4830.884	100 YR	5132.8	235.14	247.93		247.94	0.000023	0.64	7975.93	974.4		-1.9
Poesten Kill	Reach 8	4830.884	200 YR	7127.3	235.14	250.45		250.46	0.00002	0.68	10548.56	1071.88		-0.75
Poesten Kill	Reach 8	4830.884	500 YR	9324.1	235.14	251.71		251.72	0.000023	0.79	11920.33	1106.74		-0.68
Poesten Kill	Reach 8	4216.983	100 YR	5132.8	231.5	246.65		246.75	0.000706	2.5	2051.15	419.16		-2.23
Poesten Kill	Reach 8	4216.983	200 YR	7127.3	231.5	249.48		249.55	0.000313	2.15	3311.27	460.47		-0.65
Poesten Kill	Reach 8	4216.983	500 YR	9324.1	231.5	250.57		250.67	0.000347	2.44	3821.51	475.84		-0.61

Poesten Kill	Reach 8	4059.872	100 YR	5132.8	230.41	246.54		246.6	0.000143	1.98	2588.33	221.17		-2.19
Poesten Kill	Reach 8	4059.872	200 YR	7127.3	230.41	249.34		249.4	0.000279	1.92	3713.8	563.05		-0.65
Poesten Kill	Reach 8	4059.872	500 YR	9324.1	230.41	250.42		250.49	0.000303	2.15	4332.45	588.25		-0.6
Poesten Kill	Reach 8	3942.972	100 YR	5132.8	230.25	243.69		243.72	0.0002	1.31	4011.14	834		-0.75
Poesten Kill	Reach 8	3942.972	200 YR	7127.3	230.25	244.96		244.98	0.000238	1.39	5218.54	1124.46		-0.55
Poesten Kill	Reach 8	3942.972	500 YR	9324.1	230.25	245.87		245.9	0.000238	1.52	6286.16	1197.94		-0.46
Poesten Kill	Reach 8	3472.125	100 YR	5132.8	227.99	239.54		239.6	0.000504	1.84	2791.79	710.62		-0.69
Poesten Kill	Reach 8	3472.125	200 YR	7127.3	227.99	240.6		240.67	0.000442	2.01	3545.97	714.88		-0.68
Poesten Kill	Reach 8	3472.125	500 YR	9324.1	227.99	241.72		241.79	0.000392	2.14	4350.79	727.7		-0.59
Poesten Kill	Reach 8	2694.558	100 YR	5132.8	227.07	234.96		234.99	0.000164	1.4	3729.28	633.56		-0.74
Poesten Kill	Reach 8	2694.558	200 YR	7127.3	227.07	236.4		236.44	0.000155	1.56	4651.65	649.25		-0.69
Poesten Kill	Reach 8	2694.558	500 YR	9324.1	227.07	237.55		237.6	0.000164	1.76	5400.51	653.5		-0.62
Poesten Kill	Reach 8	2381.125	100 YR	5132.8	226.84	232.36		232.38	0.000214	1.2	4308.35	1105.92		-1.24
Poesten Kill	Reach 8	2381.125	200 YR	7127.3	226.84	234.89		234.9	0.000081	1	7186.85	1173.45		-0.68
Poesten Kill	Reach 8	2381.125	500 YR	9324.1	226.84	236		236.02	0.000082	1.1	8504.34	1203.68		-0.59
Poesten Kill	Reach 8	2233.088	100 YR	5132.8	213.62	232.3		232.31	0.000092	1.04	5158.53	887.59		-1.25
Poesten Kill	Reach 8	2233.088	200 YR	7127.3	213.62	234.86		234.87	0.000063	0.96	7718.31	1099.48		-0.67
Poesten Kill	Reach 8	2233.088	500 YR	9324.1	213.62	235.97		235.99	0.000067	1.08	8958.12	1124.26		-0.59
Poesten Kill	Reach 8	2107.736	100 YR	5132.8	213.48	228.73		228.89	0.000716	3.23	1588.14	219.17		-1.47
Poesten Kill	Reach 8	2107.736	200 YR	7127.3	213.48	232.14	219.78	232.24	0.000789	2.59	2752	581.31		-0.58
Poesten Kill	Reach 8	2107.736	500 YR	9324.1	213.48	233.11		233.23	0.000755	2.8	3333.46	607.39		-0.53
Poesten Kill	Reach 8	1917.119	100 YR	5132.8	199.21	206.82	204.8	207.73	0.005269	7.64	671.78	114.07		-0.81
Poesten Kill	Reach 8	1917.119	200 YR	7127.3	199.21	208.1	205.81	209.27	0.005486	8.7	818.82	117.03		-0.76
Poesten Kill	Reach 8	1917.119	500 YR	9324.1	199.21	209.34	206.83	210.79	0.005639	9.65	966.01	119.91		-0.68
Poesten Kill	Reach 8	1747.116	100 YR	5132.8	74.28	78.64	78.64	80.47	0.019793	10.85	473.1	130.8		-0.58
Poesten Kill	Reach 8	1747.116	200 YR	7127.3	74.28	79.55	79.55	81.79	0.018429	12.02	592.93	132.29		-0.51
Poesten Kill	Reach 8	1747.116	500 YR	9324.1	74.28	80.43	80.43	83.11	0.017608	13.12	710.62	133.43		-0.48
Poesten Kill	Reach 8	1615.422	100 YR	5132.8	51.25	55.54	57.96	63.66	0.096288	22.86	224.58	65.84		-0.57
Poesten Kill	Reach 8	1615.422	200 YR	7127.3	51.25	56.46	59.34	66.08	0.087743	24.88	286.52	68.49		-0.61
Poesten Kill	Reach 8	1615.422	500 YR	9324.1	51.25	57.44	60.63	68.07	0.081467	26.15	356.54	74.45		-0.51
Poesten Kill	Reach 8	1382.411	100 YR	5132.8	27.13	44.01	33.57	44.1	0.000251	2.4	2140.44	208.05		-3.71
Poesten Kill	Reach 8	1382.411	200 YR	7127.3	27.13	48.66	34.98	48.74	0.000148	2.27	3133	218.07		-1.7
Poesten Kill	Reach 8	1382.411	500 YR	9324.1	27.13	51.32	36.66	51.41	0.000151	2.5	3723.36	227.61		-1.16
Poesten Kill	Reach 8	1262.946	100 YR	5132.8	20.83	40.13		40.29	0.000296	3.19	1610.69	108.83		-4.63
Poesten Kill	Reach 8	1262.946	200 YR	7127.3	20.83	45.62		45.74	0.000339	2.83	2515.67	235.91		-1.58
Poesten Kill	Reach 8	1262.946	500 YR	9324.1	20.83	48.06		48.19	0.000392	2.92	3197.55	325.37		-1.08
Poesten Kill	Reach 8	1171.695	100 YR	5132.8	17.36	34		34.2	0.00043	3.58	1433.41	104.81		-3.69
Poesten Kill	Reach 8	1171.695	200 YR	7127.3	17.36	38.47		38.63	0.000514	3.19	2234.24	236.13		-1.17
Poesten Kill	Reach 8	1171.695	500 YR	9324.1	17.36	40.38		40.57	0.000501	3.46	2697.4	247.97		-0.96
Poesten Kill	Reach 8	582.0234	100 YR	5132.8	6.23	22.79		23.19	0.000956	5.09	1028.76	188.65		-0.68
Poesten Kill	Reach 8	582.0234	200 YR	7127.3	6.23	23.86		24.46	0.001382	6.32	1376.12	477.53		-0.54
Poesten Kill	Reach 8	582.0234	500 YR	9324.1	6.23	24.74		25.49	0.001721	7.31	1900.15	765.26		-0.45
Poesten Kill	Reach 8	468.3845	100 YR	5132.8	5.29	22.66		22.88	0.000515	3.78	1379.25	195.53		-0.65
Poesten Kill	Reach 8	468.3845	200 YR	7127.3	5.29	23.68		24.02	0.000731	4.69	1888.37	664.72		-0.52
Poesten Kill	Reach 8	468.3845	500 YR	9324.1	5.29	24.53		24.94	0.000902	5.4	2492.22	758.81		-0.41
Poesten Kill	Reach 8	363.373	100 YR	5207.3	3.57	22.32	13.63	22.63	0.001002	4.78	1746.63	801.82		-0.71
Poesten Kill	Reach 8	363.373	200 YR	7227	3.57	23.42	15.52	23.71	0.001002	4.97	2696.72	923.35		-0.54
Poesten Kill	Reach 8	363.373	500 YR	9450.5	3.57	24.3	17.15	24.56	0.001001	5.12	3588.22	1164.45		-0.44

HEC-RAS Summary Table - Existing Condition Reach 8													
River	Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
				(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Poesten Kil	Reach 8	9084.866	100 YR	6371.3	328.97	341.3	335.81	341.33	0.000157	1.45	4378.93	656.32	0.1
Poesten Kil	Reach 8	9084.866	200 YR	8416.1	328.97	342.78	336.21	342.82	0.000142	1.57	5358.79	664.54	0.1
Poesten Kil	Reach 8	9084.866	500 YR	10616.1	328.97	344.21	336.56	344.26	0.000132	1.68	6310.83	667.36	0.1
Poesten Kil	Reach 8	8904.993	100 YR	6371.3	324.05	340.94		341.14	0.000835	3.58	1780.71	238.28	0.23
Poesten Kil	Reach 8	8904.993	200 YR	8416.1	324.05	342.39		342.63	0.000922	3.89	2163.86	276.08	0.24
Poesten Kil	Reach 8	8904.993	500 YR	10616.1	324.05	343.81		344.07	0.000882	4.14	2561.95	287.41	0.24
Poesten Kil	Reach 8	8792.936	100 YR	6371.3	322.64	340.95		340.99	0.000128	1.49	4278.35	530.38	0.09
Poesten Kil	Reach 8	8792.936	200 YR	8416.1	322.64	342.43		342.47	0.000129	1.66	5064.24	535.59	0.1
Poesten Kil	Reach 8	8792.936	500 YR	10616.1	322.64	343.86		343.91	0.00013	1.82	5832.15	539.65	0.1
Poesten Kil	Reach 8	8546.203	100 YR	6371.3	318.6	326.91		327.39	0.002339	5.54	1149.98	174.68	0.38
Poesten Kil	Reach 8	8546.203	200 YR	8416.1	318.6	328.27		328.84	0.002271	6.05	1391.54	180.77	0.38
Poesten Kil	Reach 8	8546.203	500 YR	10616.1	318.6	329.62		330.27	0.002219	6.47	1640.77	188.89	0.39
Poesten Kil	Reach 8	8339.744	100 YR	6371.3	315.29	321.24	321.24	323.77	0.017824	12.75	499.75	99.14	1
Poesten Kil	Reach 8	8339.744	200 YR	8416.1	315.29	322.31	322.31	325.3	0.017008	13.87	606.72	101.69	1
Poesten Kil	Reach 8	8339.744	500 YR	10616.1	315.29	323.35	323.35	326.78	0.016512	14.86	714.29	105.07	1
Poesten Kil	Reach 8	8268.547	100 YR	6371.3	304.66	314.3	315.76	318.58	0.026068	16.59	384.09	65.41	1.21
Poesten Kil	Reach 8	8268.547	200 YR	8416.1	304.66	315.93	316.8	320.01	0.029916	16.2	519.58	103.43	1.27
Poesten Kil	Reach 8	8268.547	500 YR	10616.1	304.66	316.72	317.84	321.56	0.030219	17.66	601.1	105.48	1.3
Poesten Kil	Reach 8	8134.045	100 YR	6371.3	283.79	289.11	291.9	298.57	0.090501	24.67	258.26	62.69	2.14
Poesten Kil	Reach 8	8134.045	200 YR	8416.1	283.79	290.33	293.28	300.11	0.07029	25.09	335.45	64.66	1.94
Poesten Kil	Reach 8	8134.045	500 YR	10616.1	283.79	291.34	294.71	302.18	0.064345	26.41	401.94	66.31	1.89
Poesten Kil	Reach 8	8031.935	100 YR	6371.3	280.22	287.84	287.85	290.76	0.017492	13.71	464.55	79.97	1
Poesten Kil	Reach 8	8031.935	200 YR	8416.1	280.22	289.08	289.09	292.52	0.016783	14.89	565.38	82.58	1
Poesten Kil	Reach 8	8031.935	500 YR	10616.1	280.22	290.36	290.36	294.21	0.016187	15.74	674.27	87.7	1
Poesten Kil	Reach 8	7403.166	100 YR	6371.3	253.84	271.55	259.17	271.59	0.000086	1.58	4044.83	333.71	0.08
Poesten Kil	Reach 8	7403.166	200 YR	8416.1	253.84	273.67	259.8	273.72	0.000093	1.76	4772.85	351.7	0.08
Poesten Kil	Reach 8	7403.166	500 YR	10616.1	253.84	275.88	260.42	275.93	0.000101	1.89	5607.96	395.62	0.09
Poesten Kil	Reach 8	7175.604	100 YR	6371.3	251.87	261.82		262.22	0.001955	5.11	1247.76	188	0.35
Poesten Kil	Reach 8	7175.604	200 YR	8416.1	251.87	263.71		264.13	0.001562	5.22	1612.75	198.15	0.32
Poesten Kil	Reach 8	7175.604	500 YR	10616.1	251.87	265.65		266.08	0.001298	5.29	2008.72	210.36	0.3
Poesten Kil	Reach 8	7033.063	100 YR	6371.3	250.07	261.17		261.49	0.001206	4.55	1399.1	171.2	0.28
Poesten Kil	Reach 8	7033.063	200 YR	8416.1	250.07	263.16		263.52	0.001061	4.82	1746.41	177.12	0.27
Poesten Kil	Reach 8	7033.063	500 YR	10616.1	250.07	265.16		265.56	0.000947	5.04	2106.23	182.03	0.26
Poesten Kil	Reach 8	6186.399	100 YR	6371.3	244.23	260.04		260.04	0.00001	0.49	12896.47	1247.95	0.03
Poesten Kil	Reach 8	6186.399	200 YR	8416.1	244.23	262.12		262.12	0.00001	0.54	15504.31	1267.07	0.03
Poesten Kil	Reach 8	6186.399	500 YR	10616.1	244.23	264.2		264.2	0.000009	0.58	18163.65	1292.77	0.03
Poesten Kil	Reach 8	5477.246	100 YR	6371.3	240.03	259.43		259.49	0.000159	1.96	3244.13	308.64	0.11
Poesten Kil	Reach 8	5477.246	200 YR	8416.1	240.03	261.51		261.58	0.000158	2.16	3897.17	319.25	0.11
Poesten Kil	Reach 8	5477.246	500 YR	10616.1	240.03	263.59		263.68	0.00016	2.32	4581.31	340.73	0.11
Poesten Kil	Reach 8	5291.141	100 YR	6371.3	237.73	250.46		251.09	0.00196	6.41	993.59	100.42	0.36
Poesten Kil	Reach 8	5291.141	200 YR	8416.1	237.73	251.82		252.66	0.002667	7.36	1142.92	119.02	0.42
Poesten Kil	Reach 8	5291.141	500 YR	10616.1	237.73	253.06		254.06	0.003772	8.04	1319.97	157.83	0.49
Poesten Kil	Reach 8	5077.036	100 YR	6371.3	237.53	250.55		250.6	0.000193	1.9	3348.42	390.97	0.11
Poesten Kil	Reach 8	5077.036	200 YR	8416.1	237.53	252.01		252.08	0.000203	2.14	3923.87	396.27	0.12
Poesten Kil	Reach 8	5077.036	500 YR	10616.1	237.53	253.3		253.38	0.000221	2.39	4440.75	406.28	0.13
Poesten Kil	Reach 8	4830.884	100 YR	6371.3	235.14	249.83		249.83	0.000019	0.65	9888.61	1049.73	0.04
Poesten Kil	Reach 8	4830.884	200 YR	8416.1	235.14	251.2		251.21	0.000022	0.74	11366.35	1092.8	0.04
Poesten Kil	Reach 8	4830.884	500 YR	10616.1	235.14	252.39		252.4	0.000025	0.84	12683.63	1121.46	0.04
Poesten Kil	Reach 8	4216.983	100 YR	6371.3	231.5	248.88		248.95	0.000329	2.1	3035.34	455.39	0.14
Poesten Kil	Reach 8	4216.983	200 YR	8416.1	231.5	250.13		250.22	0.000335	2.33	3613.83	469.21	0.15
Poesten Kil	Reach 8	4216.983	500 YR	10616.1	231.5	251.18		251.28	0.00036	2.58	4111.72	482.68	0.16
Poesten Kil	Reach 8	4059.872	100 YR	6371.3	230.41	248.73		248.78	0.000294	1.89	3372.97	543.18	0.13
Poesten Kil	Reach 8	4059.872	200 YR	8416.1	230.41	249.99		250.05	0.000292	2.06	4080.29	574.34	0.14
Poesten Kil	Reach 8	4059.872	500 YR	10616.1	230.41	251.02		251.1	0.00033	2.26	4701.17	633.43	0.15

Poesten Kil	Reach 8	3942.972	100 YR	6371.3	230.25	244.44		244.46	0.000219	1.39	4675.64	946.76	0.11
Poesten Kil	Reach 8	3942.972	200 YR	8416.1	230.25	245.51		245.54	0.000238	1.47	5854.09	1169.84	0.12
Poesten Kil	Reach 8	3942.972	500 YR	10616.1	230.25	246.33		246.37	0.000233	1.59	6836.7	1199.81	0.12
Poesten Kil	Reach 8	3472.125	100 YR	6371.3	227.99	240.23		240.29	0.000456	1.94	3282.2	713.47	0.16
Poesten Kil	Reach 8	3472.125	200 YR	8416.1	227.99	241.28		241.35	0.00041	2.09	4032.45	725.99	0.16
Poesten Kil	Reach 8	3472.125	500 YR	10616.1	227.99	242.31		242.39	0.000372	2.22	4785.83	730.04	0.15
Poesten Kil	Reach 8	2694.558	100 YR	6371.3	227.07	235.7		235.74	0.000171	1.54	4201.65	637.91	0.1
Poesten Kil	Reach 8	2694.558	200 YR	8416.1	227.07	237.09		237.13	0.00016	1.69	5100.3	651.9	0.1
Poesten Kil	Reach 8	2694.558	500 YR	10616.1	227.07	238.17		238.23	0.000168	1.87	5809.07	656.21	0.11
Poesten Kil	Reach 8	2381.125	100 YR	6371.3	226.84	233.6		233.62	0.000135	1.12	5695.94	1133.72	0.09
Poesten Kil	Reach 8	2381.125	200 YR	8416.1	226.84	235.57		235.58	0.00008	1.06	7984.75	1180.62	0.07
Poesten Kil	Reach 8	2381.125	500 YR	10616.1	226.84	236.59		236.61	0.000083	1.16	9223.03	1241.19	0.07
Poesten Kil	Reach 8	2233.088	100 YR	6371.3	213.62	233.55		233.57	0.000083	1.05	6334.39	984.54	0.07
Poesten Kil	Reach 8	2233.088	200 YR	8416.1	213.62	235.53		235.55	0.000066	1.03	8469.95	1117.69	0.07
Poesten Kil	Reach 8	2233.088	500 YR	10616.1	213.62	236.56		236.58	0.00007	1.14	9622.58	1132.91	0.07
Poesten Kil	Reach 8	2107.736	100 YR	6371.3	213.48	230.2	219.35	230.36	0.000732	3.24	1965.31	276.08	0.21
Poesten Kil	Reach 8	2107.736	200 YR	8416.1	213.48	232.72		232.84	0.00077	2.71	3100.86	599.54	0.21
Poesten Kil	Reach 8	2107.736	500 YR	10616.1	213.48	233.64		233.77	0.000739	2.9	3655.72	619.45	0.21
Poesten Kil	Reach 8	1917.119	100 YR	6371.3	199.21	207.63	205.45	208.71	0.005415	8.33	764.95	115.95	0.57
Poesten Kil	Reach 8	1917.119	200 YR	8416.1	199.21	208.86	206.45	210.19	0.00555	9.26	908.46	118.79	0.59
Poesten Kil	Reach 8	1917.119	500 YR	10616.1	199.21	210.02	207.41	211.61	0.005694	10.13	1048.11	121.49	0.61
Poesten Kil	Reach 8	1747.116	100 YR	6371.3	74.28	79.22	79.22	81.31	0.018851	11.6	549.3	131.87	1
Poesten Kil	Reach 8	1747.116	200 YR	8416.1	74.28	80.06	80.06	82.58	0.018094	12.73	661.1	132.95	1.01
Poesten Kil	Reach 8	1747.116	500 YR	10616.1	74.28	80.91	80.91	83.83	0.017348	13.71	774.13	134.05	1.01
Poesten Kil	Reach 8	1615.422	100 YR	6371.3	51.25	56.11	58.82	65.24	0.091309	24.24	262.86	67.49	2.17
Poesten Kil	Reach 8	1615.422	200 YR	8416.1	51.25	57.07	60.14	67.22	0.08438	25.55	329.4	73.29	2.12
Poesten Kil	Reach 8	1615.422	500 YR	10616.1	51.25	57.95	61.32	69.18	0.077651	26.89	394.82	76.05	2.08
Poesten Kil	Reach 8	1382.411	100 YR	6371.3	27.13	47.72	34.4	47.79	0.000145	2.18	2928.17	216.11	0.1
Poesten Kil	Reach 8	1382.411	200 YR	8416.1	27.13	50.36	36.08	50.45	0.000146	2.4	3508.24	223.05	0.11
Poesten Kil	Reach 8	1382.411	500 YR	10616.1	27.13	52.48	37.19	52.59	0.000159	2.66	3990.62	229.87	0.11
Poesten Kil	Reach 8	1262.946	100 YR	6371.3	20.83	44.76		44.87	0.000323	2.75	2319.41	219.21	0.15
Poesten Kil	Reach 8	1262.946	200 YR	8416.1	20.83	47.2		47.33	0.000381	2.87	2934.52	298.77	0.16
Poesten Kil	Reach 8	1262.946	500 YR	10616.1	20.83	49.14		49.28	0.000393	2.98	3567.25	353.4	0.17
Poesten Kil	Reach 8	1171.695	100 YR	6371.3	17.36	37.69		37.84	0.000529	3.1	2053.29	231.34	0.18
Poesten Kil	Reach 8	1171.695	200 YR	8416.1	17.36	39.64		39.81	0.000503	3.35	2514.64	243.36	0.18
Poesten Kil	Reach 8	1171.695	500 YR	10616.1	17.36	41.34		41.55	0.000516	3.61	2940.04	259.09	0.19
Poesten Kil	Reach 8	582.0234	100 YR	6371.3	6.23	23.47		24	0.001241	5.92	1213.24	333.91	0.28
Poesten Kil	Reach 8	582.0234	200 YR	8416.1	6.23	24.4		25.09	0.001593	6.93	1667.91	616.9	0.32
Poesten Kil	Reach 8	582.0234	500 YR	10616.1	6.23	25.19		25.97	0.001798	7.63	2274.44	850.65	0.34
Poesten Kil	Reach 8	468.3845	100 YR	6371.3	5.29	23.31		23.6	0.000664	4.4	1646.42	594.61	0.21
Poesten Kil	Reach 8	468.3845	200 YR	8416.1	5.29	24.2		24.58	0.00084	5.14	2244.48	732.52	0.24
Poesten Kil	Reach 8	468.3845	500 YR	10616.1	5.29	24.94		25.39	0.000975	5.73	2810.9	761.7	0.26
Poesten Kil	Reach 8	363.373	100 YR	6445.5	3.57	23.03	14.81	23.32	0.001002	4.9	2337.39	890.82	0.25
Poesten Kil	Reach 8	363.373	200 YR	8515.8	3.57	23.96	16.49	24.23	0.001002	5.06	3211.73	1048.25	0.26
Poesten Kil	Reach 8	363.373	500 YR	10742.6	3.57	24.74	18.17	24.99	0.001	5.21	4148.32	1433.6	0.26