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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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, to Sarah Parks at Amala Consulting (www.amalaconsulting.com) who assisted RPA and Chazen with many of this report's Figures, 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:

- <u>Land Preservation</u> 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.
- <u>Enhanced land use guidance or regulations</u> 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.

Public Involvement: 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.

Upper Poesten Kill (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.

Key Hydrology and Climate Points: 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

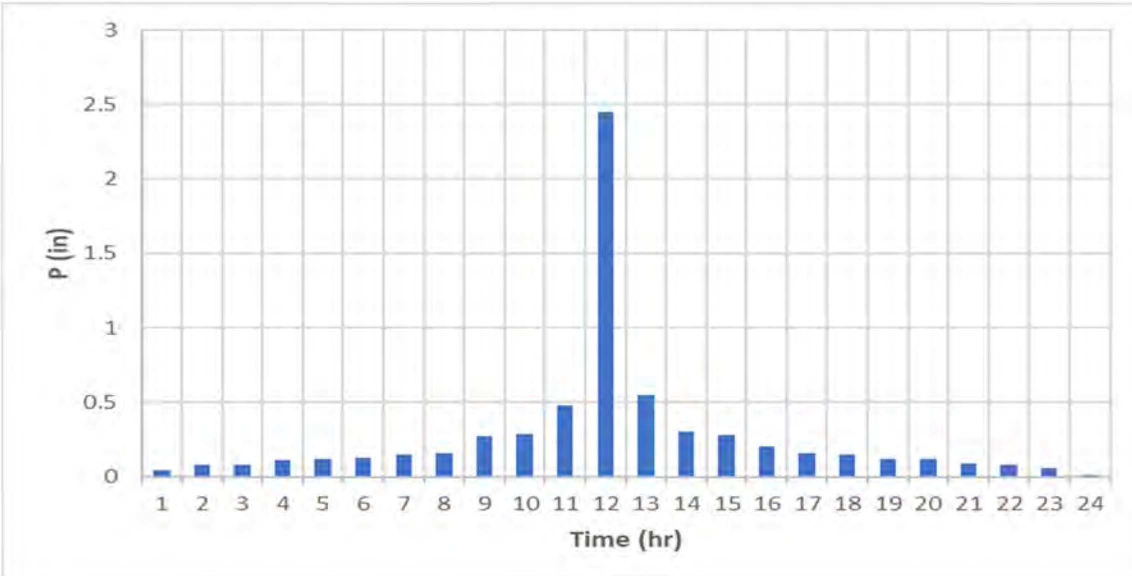

Image 1. 100-yr Design Hyetograph

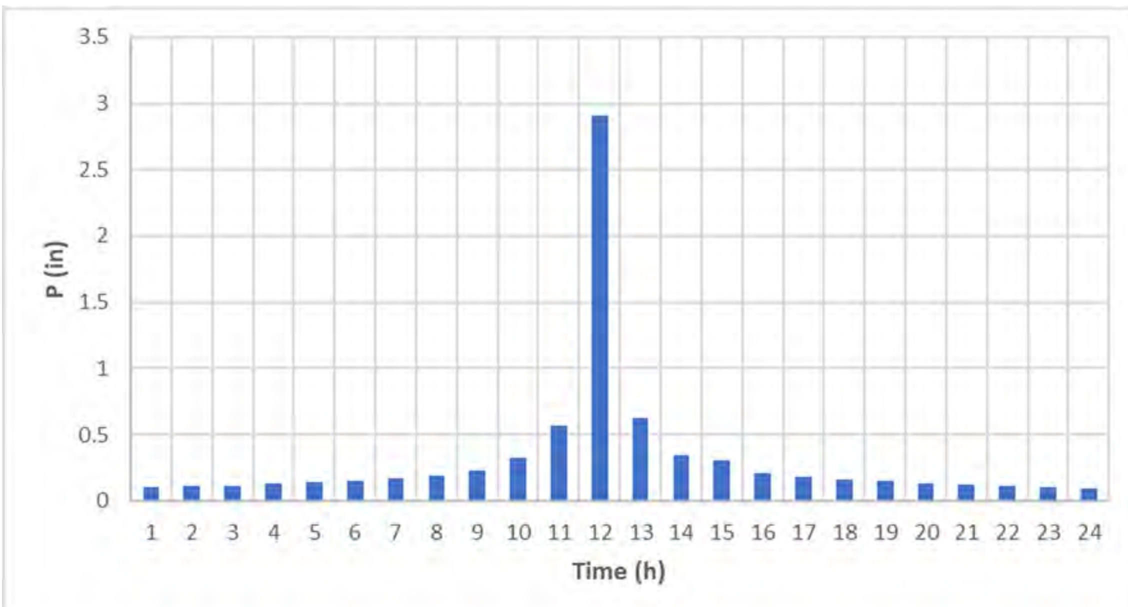

Image 2. 200-yr Design Hyetograph

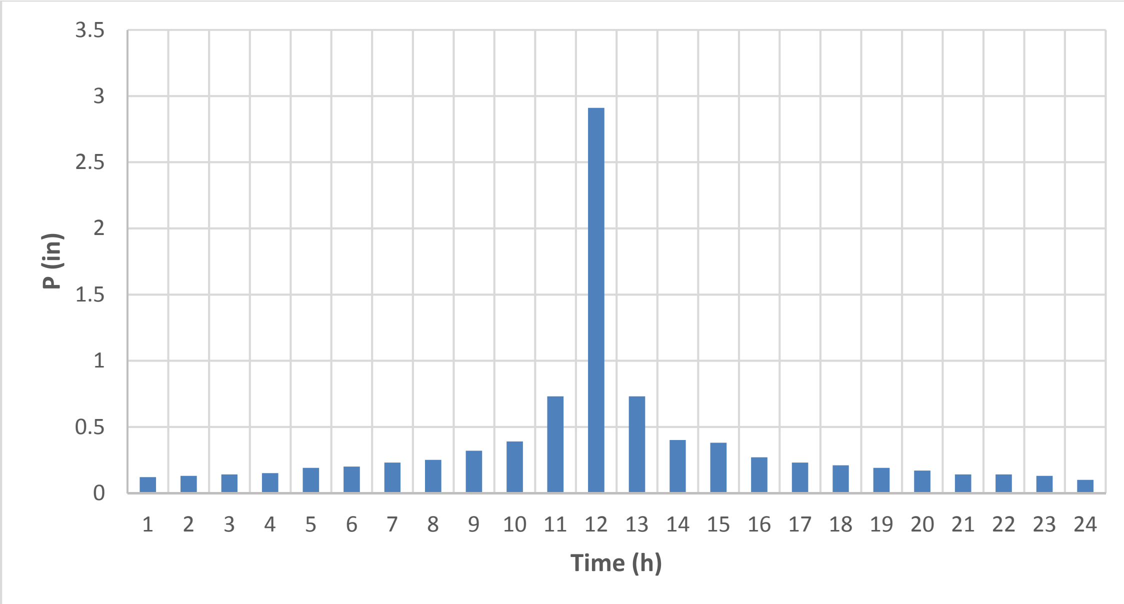

Image 3. 500-yr Design Hyetograph

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

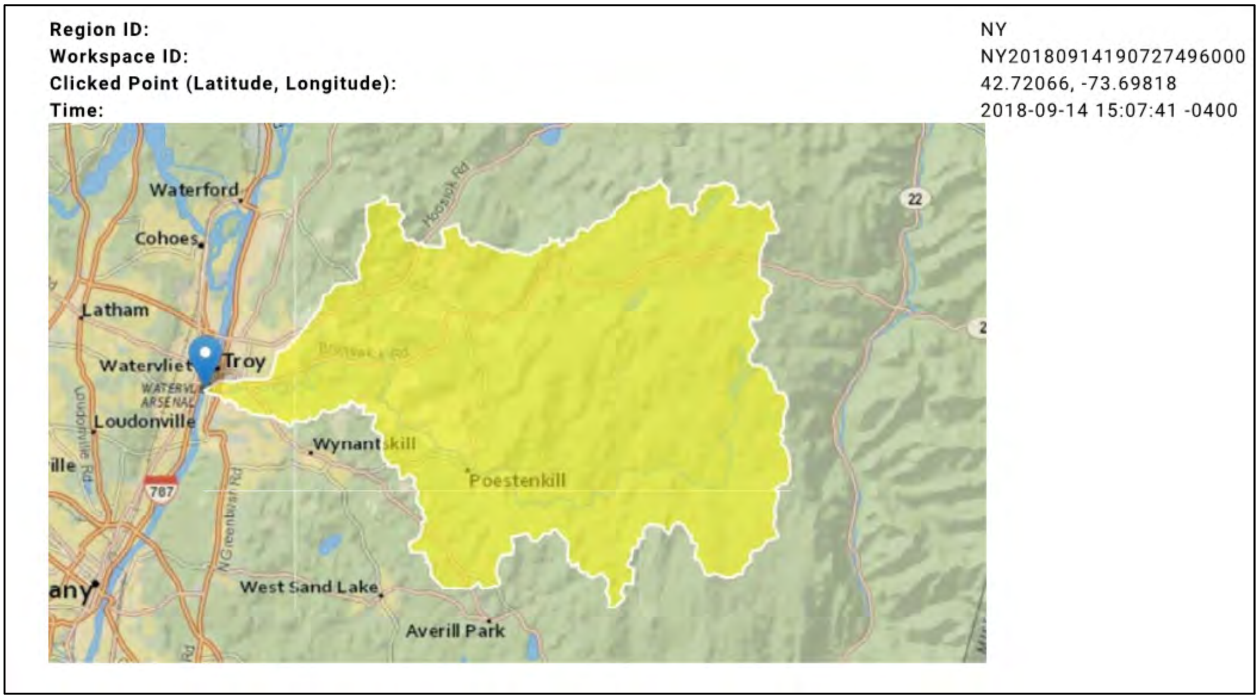

Image 4. Watershed at Calibration Location

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.

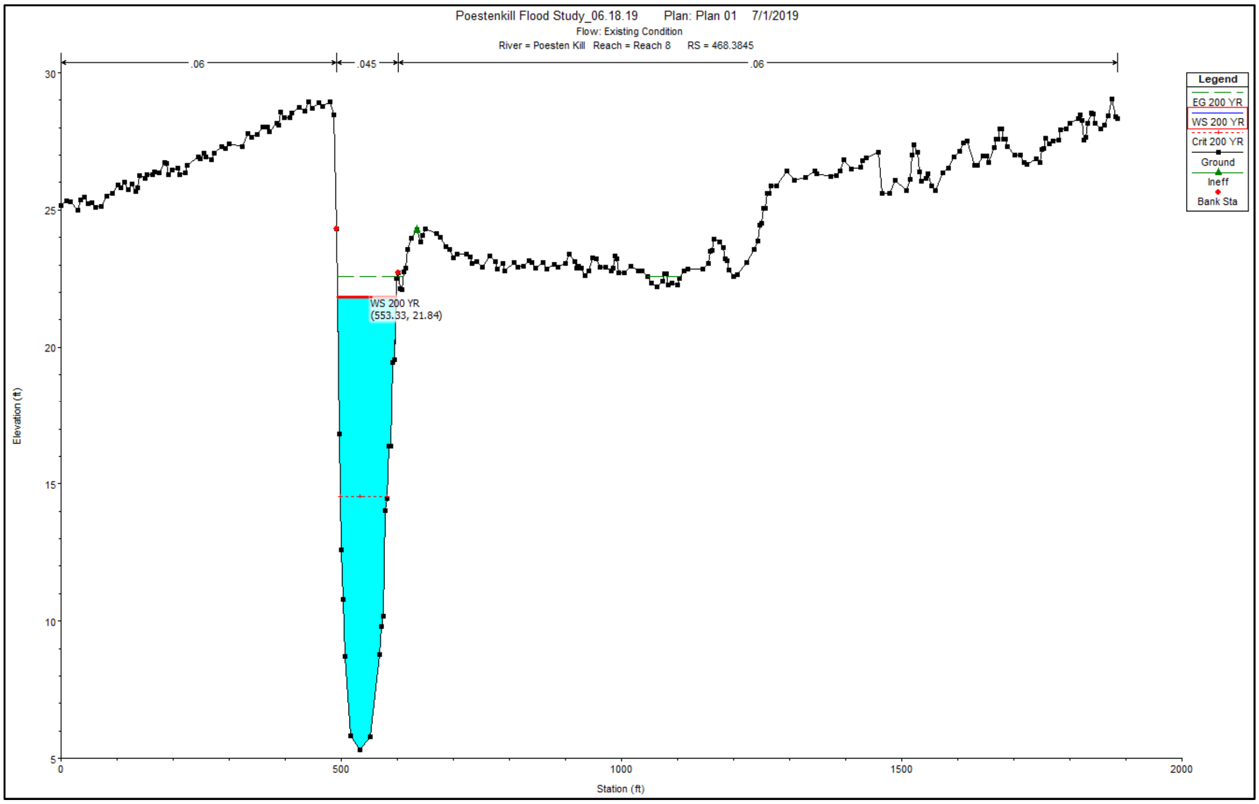

Image 5. HEC-RAS Calibration Water Level Results (Cross Section 486.3845)

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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