APPENDICES

Appendix 1: Geomorphology Assessment

TECHNICAL MEMORANDUM

To: Russell Urban-Mean, The Chazen Companies

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

Date: May 10, 2019

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

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Executive Summary

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

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

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

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

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

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

Introduction

BACKGROUND

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

ASSESSMENT SCOPE

The scope of our assessment includes:

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

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

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

Existing Data Review and Basin-Scale Analysis

GEOLOGICAL SETTING

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

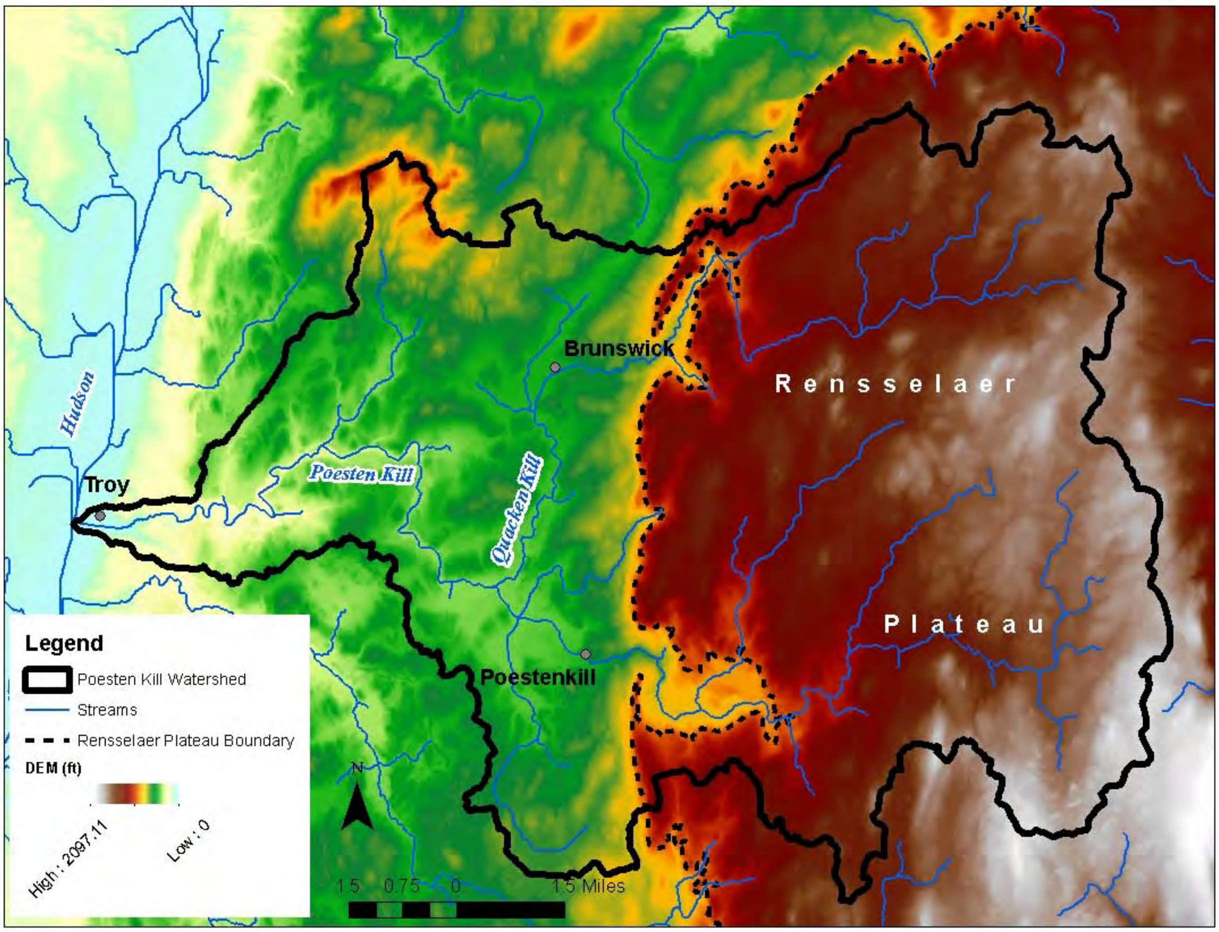

Figure 1. Map of Poesten Kill watershed with digital elevation model (DEM) and shaded relief map. The watershed is outlined in black. The Rensselaer Plateau is the elevated land (colored red/white) delineated by a dashed black line. DEM from USGS/CUGIR.

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

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

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

LAND USE / LAND COVER

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

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

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

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

FLOOD AND CHANNEL DYNAMICS

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

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

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

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

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

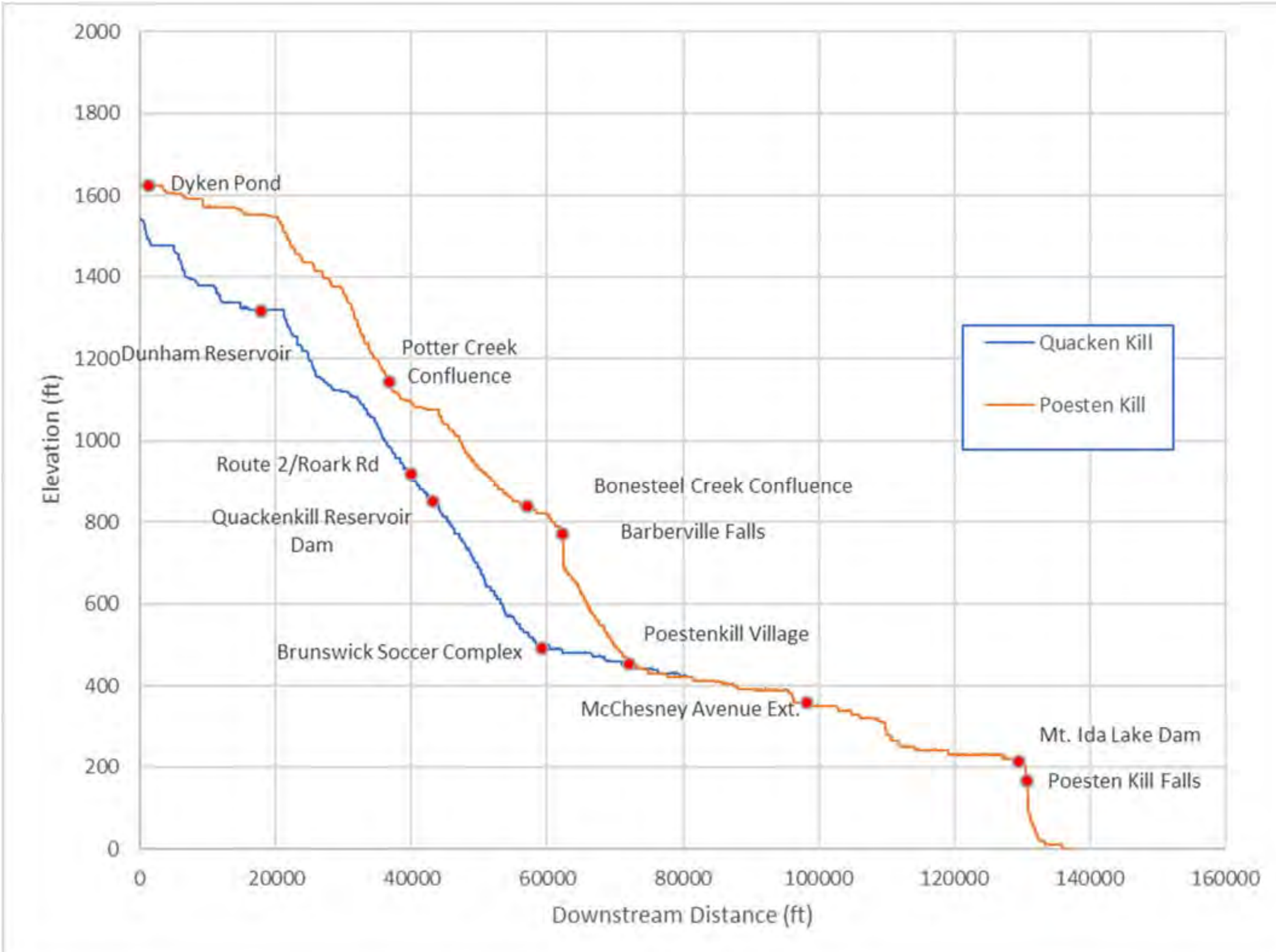

Figure 2. Longitudinal profiles of the Poesten Kill and Quacken Kill, from the headwaters to the confluence with the Hudson River. Points of interest referenced in the report are shown along the profile as red dots. Elevation data derived from 10-meter DEM (CUGIR).

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

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

Studies of climate change impacts in the northeastern U.S. have documented and continue to anticipate a shift toward more extreme precipitation events and higher peak flood flows. For example, Horton et al. (2014) found that the amount of precipitation falling in the heaviest storm events increased by over 70% between 1958 and 2010. Thus, under current climate change projections, flooding and flood-related impacts in the watershed are likely to intensify. Adaptation is necessary to avoid increasingly significant impacts.

ECOLOGY

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

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

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

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

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

Geomorphic Field Assessment

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

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

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

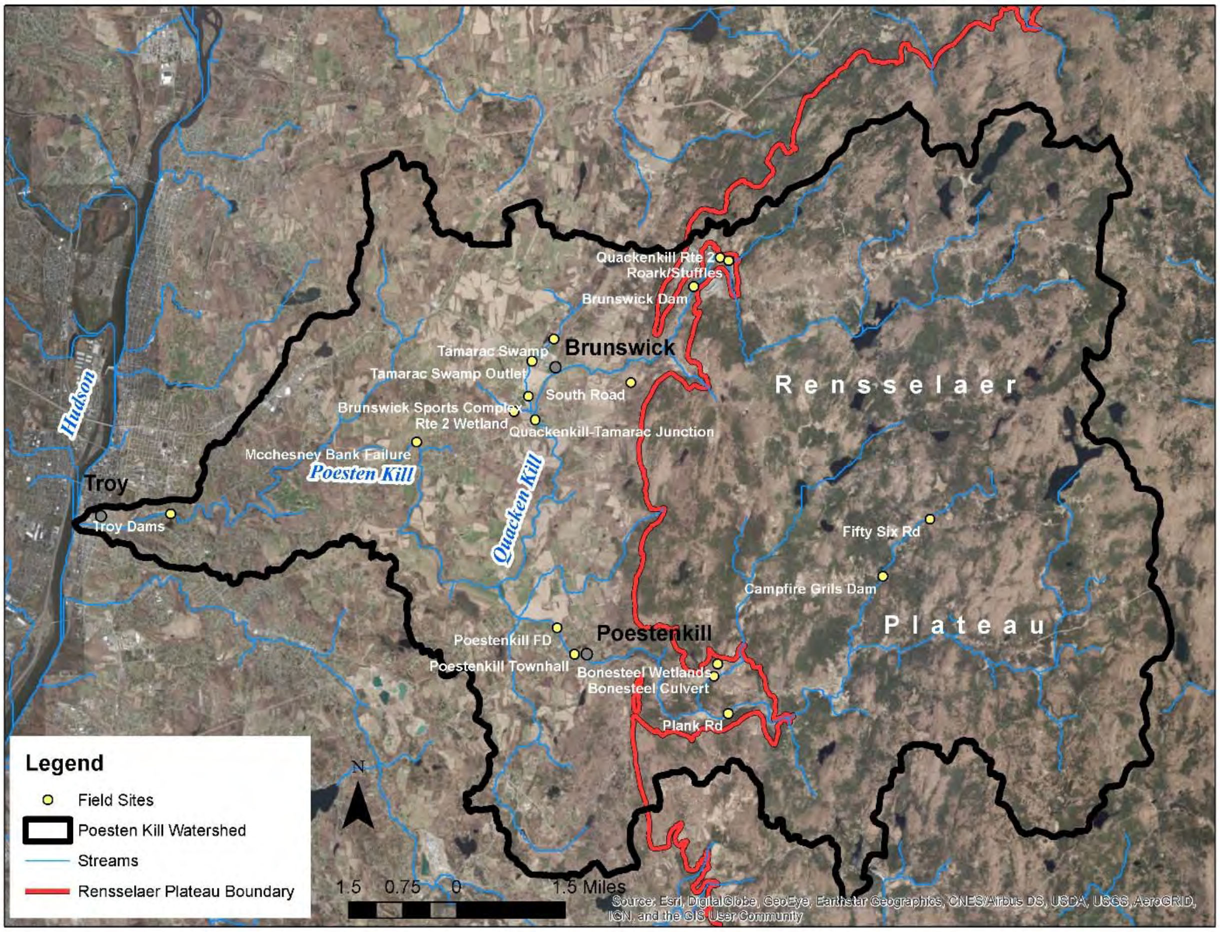

Figure 3. Map of Poesten Kill watershed with field sites labeled. The Rensselaer Plateau escarpment is delineated by a red line.

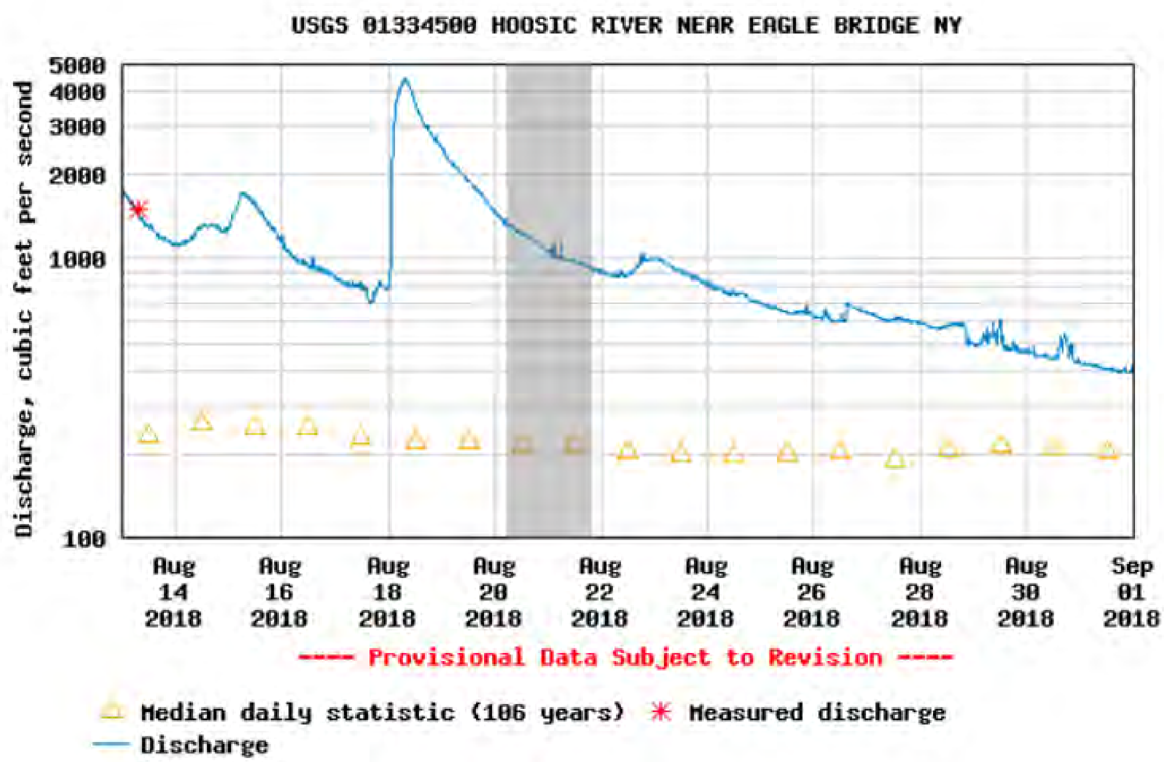

Figure 4. Hydrograph of the Hoosic River in Rensselaer County, a representative gage near the Poestenkill watershed. An approximately 2-inch rain storm produced the high flow event on August 18, 2018. The field survey occurred on August 20 and 21 (shaded in grey) while flows remained well above the median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

ROUTE 2 AT INTERSECTION WITH STUFFLE STREET AND ROARK ROAD CROSSING

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

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

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

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

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

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

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

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

QUACKEN KILL RESERVOIR DAM

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

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

ROUTE 2 DOWNSTREAM OF QUACKEN KILL RESERVOIR DAM

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

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

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

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

Figure 8. Quacken Kill Reservoir Dam

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

SOUTH ROAD

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

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

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

Figure 10. Incised ditch along South Road, Brunswick

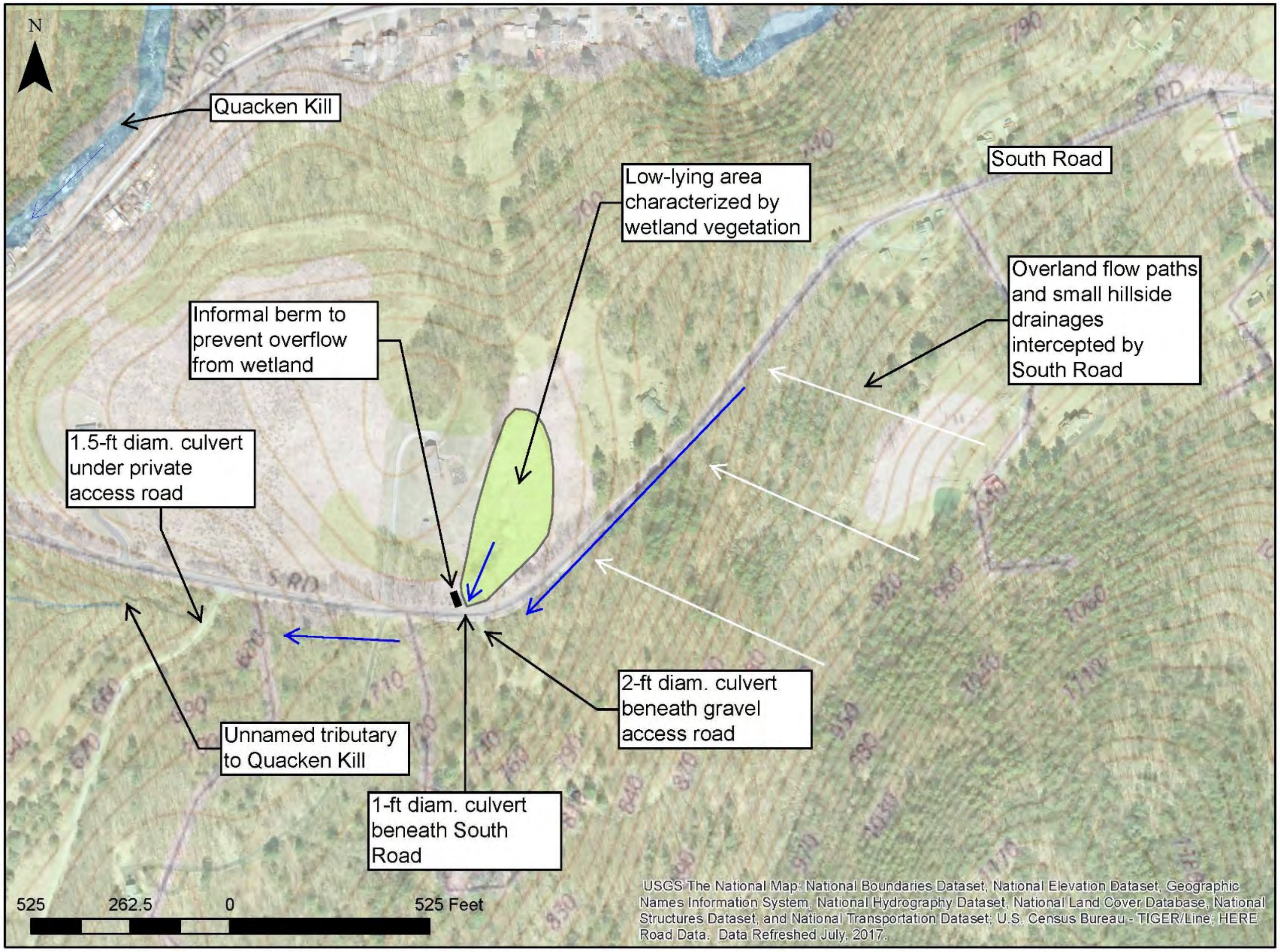

Figure 11. South Road, Brunswick, showing interception of overland flow paths and intermittent hillside channels by South Road, channelized flow along the road ditch (blue arrows) and into an unnamed tributary to the Quacken Kill. Approximate extent of low-lying area of wetland vegetation shown in green.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

TAMARAC ROAD AREA

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

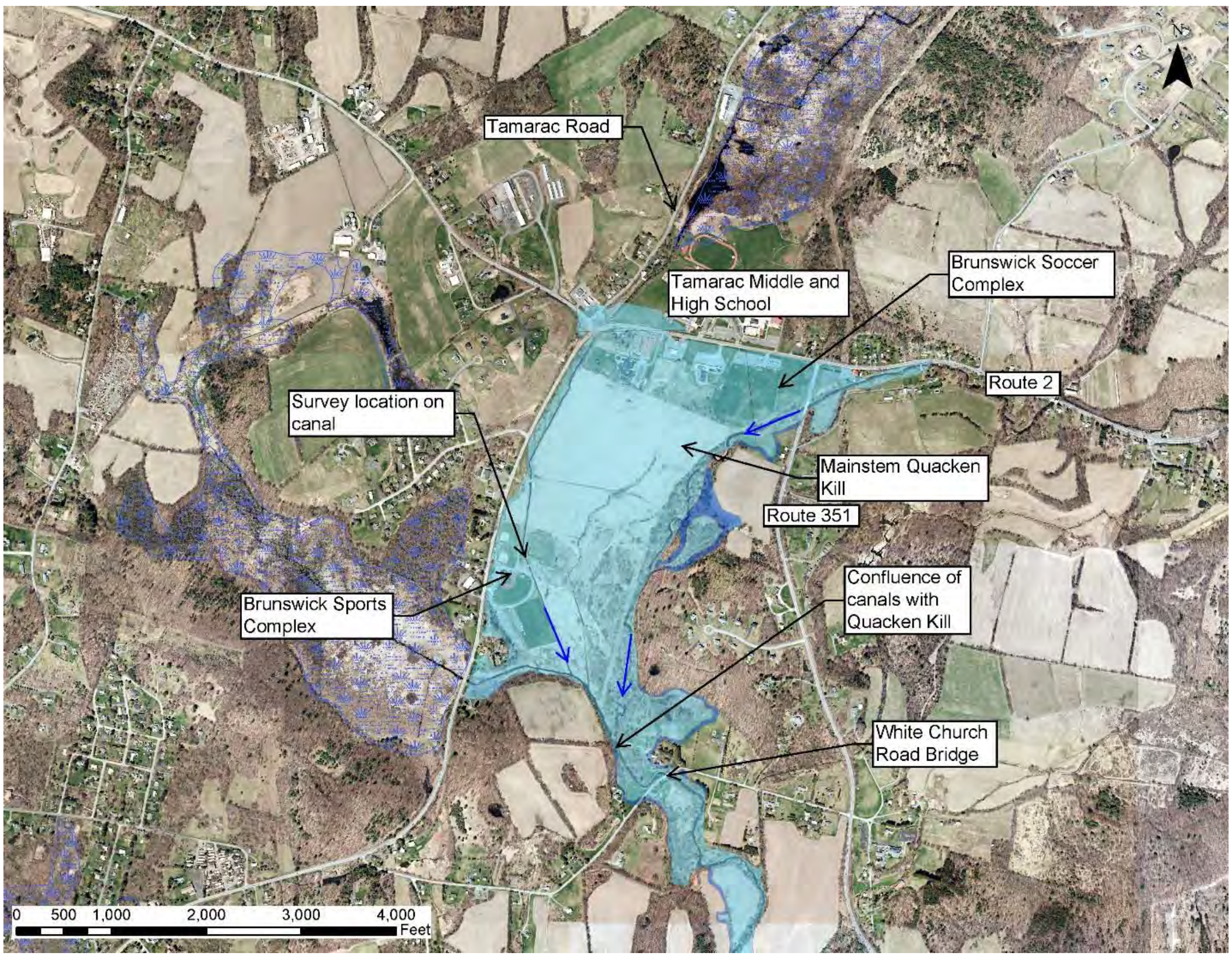

Figure 12. Tamarac Road area in Brunswick showing mainstem Quacken Kill, wetlands and drainage canals. Blue arrows indicate flow direction. Freshwater wetlands mapped by the New York Department of Environmental Conservation (NYS DEC wetlands) and FEMA 1% annual chance (light blue) and 0.5% annual chance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

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

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

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

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

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

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

FIFTY SIX ROAD AND THE CAMPFIRE GIRLS DAM

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

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

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

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

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

PLANK ROAD

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

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

BONESTEEL CREEK WETLANDS

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

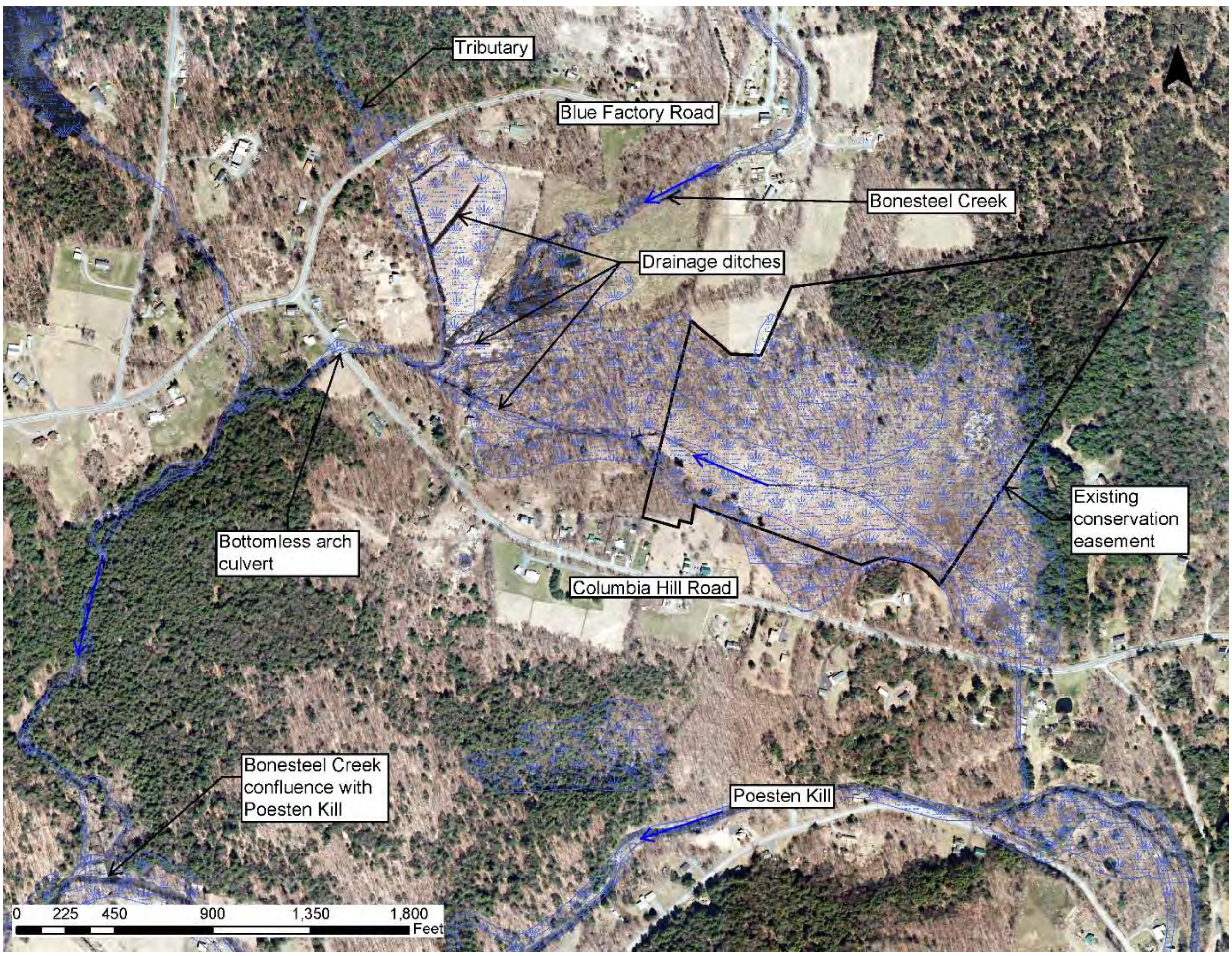

Figure 18. Wetlands (light blue shading) along Bonesteel Creek upstream of Columbia Hill Road showing drainage ditches. Black polygon is an existing conservation easement held by NRCS. Data sources: 2017 Rensselaer County high-resolution digital orthoimagery (NYS Office of Information Technology Services,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

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

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

POESTENKILL VILLAGE

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

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

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

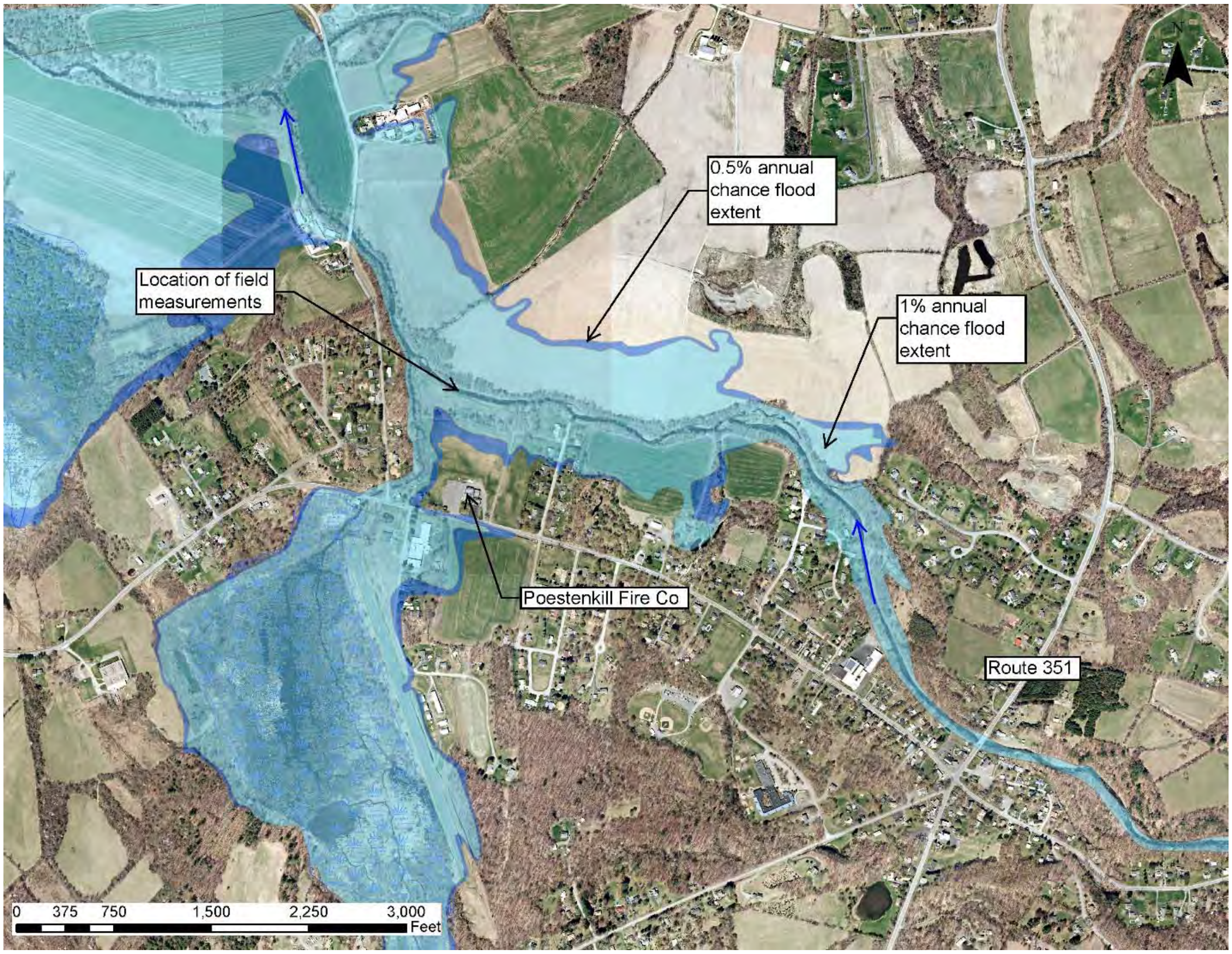

Figure 20. Mapped flood extents along the Poesten Kill at the Poestenkill Fire station. Data sources: 2017 Rensselaer County high-resolution digital orthoimagery (NYS Office of Information Technology Services, GIS Program Office, 2017) and FEMA flood extents.

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

MCCHESNEY AVE EXTENSION BLUFF EROSION

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

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

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

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

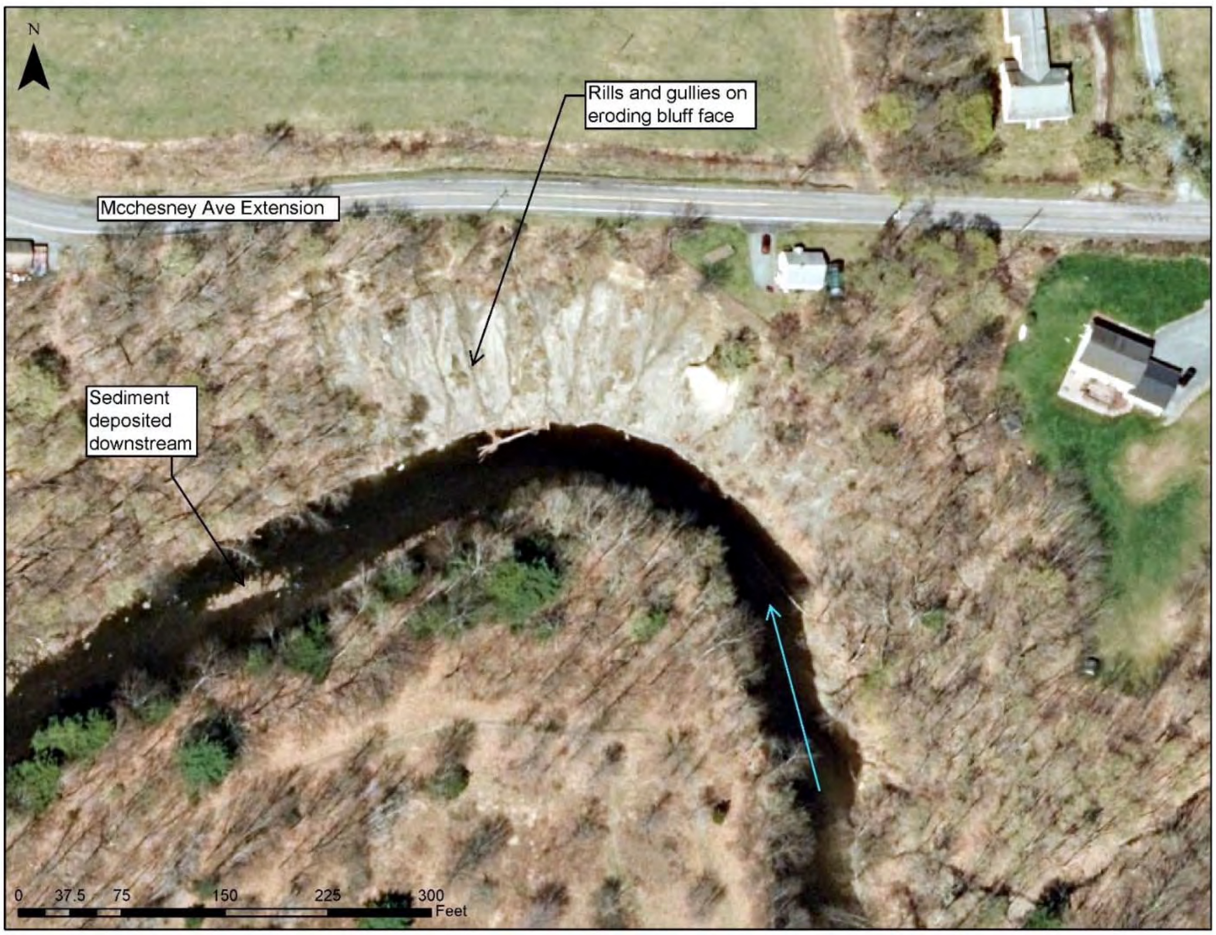

Figure 22. Eroding bluff at Mcchesney Ave Extension in Brunswick. Blue arrow indicates flow direction in the Poesten Kill. Data source: 2017 Rensselaer County high-resolution digital orthoimagery (NYS Office of Information Technology Services, GIS Program Office, 2017).

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

IDA LAKE DAM

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

Summary and Recommendations

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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