Moodna Creek Watershed and Flood Mitigation Assessment Final Report

Orange County, NY

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Introduction

The greater Moodna Creek watershed covers 115,600 acres, or 180 square miles, of eastern Orange County, NY. The watershed includes 22 municipalities and hundreds of streams before joining the Hudson River, just north of the Village of Cornwall-on-Hudson. This region has seen tremendous growth in recent years with the expansion of regional transit networks and critical infrastructure. The Moodna Creek watershed can be split into two sub-basins, referred to herein as the Upper Moodna and the Lower Moodna watersheds (Figure 1). Both sub-basins have noted a concern about flood risk as the watershed continues to develop. In the span of 1515-months, Hurricane Irene, Tropical Storm Lee and Hurricane Sandy caused significant flooding throughout the Moodna Creek watershed, damaging a number of public facilities, roadways, and private properties.

The arrival of three extreme weather events within a 15-month period may be a highly unusual anomaly for the Hudson Valley that doesn't repeat itself, but even one of these storm events has the potential to cause severe and damaging flooding. Furthermore, based on a general warming of global temperatures there are indications that these types of large storm events may occur more often than they have in the past. Additionally, the recent extreme flood events have amounted to "valley-forming flows", which drastically re-align channels, re-work floodplains, and in some instances, widen valley walls through riverine erosion that induces massive valley wall failures and long-term slope instability. As global temperatures increase, climate models are predicting more intense rainfall events, with a higher volume of water per event for this region, as compared to past storm events. Given these changing trends in climate and increases in rainfall, the risk from extreme rainfall events for communities along waterways that are prone to flooding—like the Lower Moodna watershed—will only increase as time passes.

As part of the 2014 New York Rising Community Reconstruction Program, communities within the Upper Moodna watershed (Blooming Grove, Washingtonville, and South Blooming Grove) received funding to complete a flood risk assessment and flood mitigation analysis of the Upper Moodna. However, this analysis does not extend to areas within the Lower Moodna Watershed. Using funds from a 2016 grant program sponsored by the New England Interstate Waters Pollution Control Commission (NEIWPCC) and the New York State Department of Environmental Conservation-Hudson River Estuary Program (HREP), this report details a complementary flood assessment and flood mitigation analysis for the communities within the Lower Moodna watershed (Cornwall, New Windsor, Cornwall-on-Hudson, and Woodbury). The analyses and recommendations described in this report in conjunction with the modeling and conclusions developed for the Upper Moodna, create a fully developed flood assessment master plan and flood mitigation plan that can serve as a roadmap for reducing flooding issues within the entire Moodna Watershed.

The first step in managing flood risk is to understand what type of exposure the communities face. This project modeled flooding within the watershed during normal rain events, extreme rain events, and future rain events with the following goals in mind. First, assessing the facilities, infrastructure, and urban development that are at risk from flooding along the Moodna Creek and its tributaries within the study area; and second, developing a series of hydrologic and hydraulic models to assess the extent of potential flooding from the 10 percent, 1 percent, and 0.2 percent, often referred to as the 10-year, 100-year, and 500-year, respectively, storm recurrence intervals within the study area. The modeling included flows for these storm events under existing conditions and also hypothetical scenarios with predicted increases in precipitation and population growth.

The project team used these models and data to propose and evaluate a series of design measures that can help reduce and mitigate existing and anticipated flood risk within the study area. Where possible, the proposed solutions prioritized approaches that protect and/or mirror natural flood protection mechanisms within the watershed such as floodplain reconnection and wetland establishment. These “softer” and more nature-based approaches are often referred to as a type of “green infrastructure.” in contrast to a flood wall or other structural approaches, these projects also provide water quality protection, aesthetics and recreation, pollutant reduction, and/or wildlife habitat.

Watershed Profile

The Lower Moodna watershed (herein referred to as Lower Moodna) covers approximately 35,200 acres, or less than one-third of the greater Moodna watershed, in eastern Orange County. Similar to other parts of the region, the Lower Moodna contains varying topography with steep slopes, elevation changes, and channelized streambeds. The Lower Moodna drains land within the towns of Cornwall, New Windsor, Woodbury, Highlands, and the Village of Cornwall-on-Hudson. Its major creeks and streams include the main stem of the Moodna Creek (downstream of Beaverdam Lake), Silver Stream, Idlewild Creek, and Woodbury Creek (Figure 1). These watercourses, plus dozens of headwater streams and tributaries, combine for approximately 98 miles of stream length within the Lower Moodna. The highest elevation within the Lower Moodna, at the peak of Schunnemunk Mountain, is approximately 1,677 feet (NAVD88).

The Lower Moodna can be further broken down into five subwatersheds. Figure 2 shows the location of these subwatersheds. Subwatershed 1 is the drainage area for Silver Stream. It covers 4,524 acres and includes Stewart International Airport, Stewart Air National Guard, Browns Pond, and a stretch of the NY Thruway. To the east, approximately 1,226 acres within the Town of New Windsor, subwatershed 2 encompasses only 3 percent of the land within the Lower Moodna. Tucked between two ridgelines, this subwatershed has less variability in its topography than the other watersheds in the Lower Moodna; generally, it is flatter. Consequently, it has more concentrated development including the Heritage Middle School, the commercial area at the junction of Windsor Highway and Union Ave, as well as the neighborhoods between Union Avenue and Blooming Grove Turnpike. This subwatershed is approximately 22 percent covered by impervious surfaces. It has the highest percent of its land covered by impervious surfaces of all five subwatersheds. Subwatershed 3 surrounds the Moodna Creek as it flows downstream of Beaverdam Lake. This subwatershed accounts for one-third of the land within the Lower Moodna. Subwatershed 4 lies just west of Storm King State Park and includes most of the Town of Cornwall and the unincorporated land south of Route 9W. It drains about 4,349 acres into Idlewild Creek that enters the Moodna just upstream of the mouth near the New York Military Academy. The fifth subwatershed, the largest within the Lower Moodna, encompasses the drainage area for Woodbury Creek. It includes 14,151 acres north of Route 6 in Woodbury, between the southeastern face of Schunnemunk Mountain and the ridge line west of Angola Road. Woodbury Creek joins the Moodna near the Pleasant Hill Road (Route 79) crossing.

The upper portion of the Lower Moodna is located in the Hudson Valley Lowlands (of the Valley and Ridge Physiographic Province); however, the Moodna Creek then encounters Schunnemunk Mountain as it enters the Hudson Highlands (of the New England Section of the New England Physiographic Province) near the Interstate 87 corridor. As the names imply, the Hudson Valley Lowlands are characterized by lower relief and broader floodplains, in contrast to the Hudson Highlands that have a more rugged topography and narrow valleys. The primary tributary from the south, Woodbury Creek, emanates from the Hudson Highlands. The main stem of Moodna Creek within the watershed study area is generally characterized by moderate gradient, cobble-boulder riffles/rapids, extended pools, and narrow floodplains confined by steep, erodible valley walls. Surficial materials within the Moodna Creek corridor are predominantly glacial outwash sand and gravel with multiple localized kame deposits; at the confluence with the Hudson River, materials are identified as lacustrine delta.

The Lower Moodna is entirely contained within Orange County; which has experienced periods of moderate and rapid growth over the past few decades. The Orange County Hazard Mitigation Plan (HMP) reported a 21.7 percent growth overall between 1990 and 2014. Within the watershed, the growth has been concentrated in the northeastern portion. This area provides close access to Interstate 84, the Thruway, and regional rail transit lines. According to the HMP, the Town of New Windsor grew about 12.1 percent, the Town of Cornwall 11.5%, and the Village of Cornwall on the Hudson declined by 3.1 percent between 1990 and 2014. The Town of Highlands also saw a decline of 9.8 percent. The Town of Woodbury saw the greatest growth rate at 38.3 percent. According to the Moodna Creek Watershed Management Plan (WMP), the focus of the growth has been contained to areas that are already populated. In addition to these areas, the population growth cited in the HMP indicates Woodbury is an area that is growing rapidly, which likely correlates with an increase in development interest. Additionally, the WMP highlights the Silver Stream Reservoir subwatershed as an area that is experiencing development pressure.

Land Use and Zoning

According to the National Land Cover Dataset (NLCD) 62 percent of the watershed is covered by forests. Only 6 percent is wetland area and 24 percent can be described as 'urban'. Subwatershed 2 has the greatest percentage of its land classified as 'urban', with 64 percent. Silver stream watershed, subwatershed 1, is 45 percent 'urban'. This classification includes all uses such as residential, industrial, and commercial.

Zoning is powerful tool that determines a region's exposure to hazards and risk. Zoning determines which uses are permitted, or encouraged, to be built in moderate and high-risk areas. It also prevents certain uses, such as critical facilities, from being built in those areas. Zoning is also a determinant of a region's character and identity. Overall, the Lower Moodna is largely zoned as a residential area; over 82 percent of the land within the watershed is zoned for residential use. This is based on the data for Cornwall, New Windsor, Cornwall-on-Hudson, Washingtonville, and Woodbury. Approximately 8 percent of the watershed had no zoning data, which includes Blooming Grove, Highlands, and Newburgh. Where the data are available, less than 3.62 percent of area is set aside for commercial uses and 3.74 percent for industrial uses. Agricultural uses were absorbed in residential lands for the purposes of this analysis.

Generally, within the Lower Moodna, there is a higher ratio of areas zoned for non-residential uses in flood-prone areas than in other developable land. Within the 10 percent floodplain, 30 percent of the land is zoned for industrial use. This is likely because several facilities such as wastewater treatment plants and mills require immediate proximity to the river. Within the 1 percent floodplain approximately 60 percent of the land is zoned for residential use, which in contrast to the overall Lower Moodna trend of 82 percent, demonstrates a general preference to limit residential use of flood-prone areas.

However, this preference is not universal across all the subwatersheds. Subwatershed 1 has the greatest number of acres of non-residential land within the 0.2 percent floodplain with 304 acres of land zoned for industrial use. This accounts for 85 percent of the 0.2 percent floodplain within Subwatershed 1 and does not include the 19 acres of land that are zoned for airport. In contrast, the floodplains in Subwatershed 2 are zoned only for residential uses. The subwatershed for the main stem of the Moodna Creek has zoning that mirrors the overall watershed composition, with approximately 84 percent of the 0.2 percent floodplain reserved for residential uses. Subwatershed 4, which covers the Town of Cornwall has only 1 acre of non-residential use within its 0.2 percent floodplain. The Woodbury Creek subwatershed has the greatest amount of commercial land within its floodplains with 93 acres, or 18 percent of the 0.2 percent floodplain (Insert Table). There was minimal difference between the zoning for the 1 percent floodplain and the 0.2 percent floodplain across the watershed. This is likely because the extent of both flood zones are very close throughout the watershed. The floodplain is frequently constricted by topography and the 1 percent and 0.2 percent floodplains are very similar in footprint throughout the watershed. It also indicates that the type of exposure each community faces will not be dramatically different under future conditions.

Preserved Land

Nearly 30 percent of the land within the Lower Moodna is preserved by private entities, government agencies, and non-government organizations. This includes large preserves like Schunnemunk Mountain State Park, as well as small tracts preserved through easements. Conservation easements held by non-governmental organizations are the largest source of preserved land with a total just over 3,900 acres at the time of this report. The state owns over 3,800 acres within the Lower Moodna. Approximately 18 percent of the total preserved land in the data provided by the County did not have ownership information. Similar to the development patterns, the distribution of preserved land is not uniform throughout the Lower Moodna; some subwatersheds have a greater percentage of preserved land than others.

Subwatershed 2 has only 2 documented acres of protected lands, both owned by the state. Although this is a small subwatershed in the Moodna, less than half of one percent of land is protected. Subwatershed 4, which drains land from the Town of Cornwall and west of the Storm King State Park, has the greatest percentage of preserved land with nearly 63 percent of its 4,300 acres protected. This area is the source for several headwater streams, which form tributaries to the Moodna within the Town of Cornwall. The remaining subwatersheds are similar to the overall trends within the Lower Moodna. Subwatershed 5, which includes a large portion of Schunnemunk Mountain State Park, has approximately 36 percent protection. Subwatershed 3 has about 16 percent of its land preserved. The Silver Stream subwatershed, subwatershed 1, has only 8 percent protection, which is notable because of the perceived development pressure noted in the WMP.

In addition to its ecological benefits, land preservation protects the watershed from certain risks of development including increased runoff, changes in the time of concentration, destabilization of steep slopes, and increased erosion. In terms of risk, preserving land within the floodplain is the best mechanism to limit the amount of development exposed to damage from flooding. Risk is a calculation of rate exposure and the value of the potential damage. Simply, property that is located in areas without flooding potential has minimal exposure and therefore limited risk. Alternatively, a highly floodprone area that has no structures will face little expense from damage in a flood event. For this reason, preservation is an important tool for limiting risk to flooding on undeveloped properties. This does not mean there should be no development in the watershed, but that the location of that development should be carefully considered in terms of its implication for how it changes the communities risk of floods.

Within the mapped floodplains there appears to be a slight priority for preserving land most at-risk for flooding. This is likely a consequence of prioritizing land that is closest to riparian areas and preserving wetland areas, as these lands are the most likely to experience flooding. Within the floodplains for the 10 percent storm, approximately 22.7 percent is preserved. For the 1 percent storm, approximately 21.2 percent of the land is preserved. Within the 0.2 percent storm, this number drops slightly to 20.3 percent. These numbers are so close in part because the difference between the 10 percent, 1 percent, and 0.2 percent floodplains are small in many areas of the watershed.

Existing Buildings

Relative to other developed watersheds, including the Upper Moodna, the Lower Moodna does not currently have a lot of development within the floodplain. Based on the building data provided by the County, which the project team updated using aerial imagery, there are only 240 buildings within the 1 percent flood zone. It is estimated that 100 of these structures actually lie within the 10 percent zone. This means 41 percent of the buildings in mapped floodplains have a 96 percent chance of experiencing flooding within a 30-year period. An additional 79 buildings are located within the 0.2 percent flood zone. These structures do not fall within the federal mandate to carry flood insurance if they have a federally-backed mortgage. As floodplains expand and water surface elevations change due to climate change and shifts within the watershed, all structures within flood-prone areas may see an increase in flood risk. Additionally, a small number of homes and businesses throughout the watershed that are not currently within a mapped floodplain may experience flooding or be included in the regulatory floodplain in the future.

The HMP details that there are a total of 179 National Flood Insurance Program policies for all the towns that have land within the Lower Moodna. It is unknown from the data if these policies are all within the Lower Moodna watershed, as the towns also drain to other basins. It is also unknown if these policies are for structures within the Lower Moodna. However, this statistic does demonstrate that there are structures within the regulatory floodplain that do not carry flood insurance.

There are only three facilities identified as *Critical Facilities* that fall within the mapped floodplains in the project area. The Salisbury Mills Fire Department, the Town of Cornwall Wastewater Treatment Plant, and the New Windsor Wastewater Treatment Plant. All three facilities are mapped within the existing 10-year floodplain and all three experienced flooding in 2011. The Fire Department had approximately three feet of water within the building, which had been built in 2005. The flooding did not force the department to cease operation, however. The Fire Department and the New Windsor plant continued serving the community through the storm events, despite their own damage. The Town of Cornwall plant was taken offline, which resulted in untreated sewage passing through to the Hudson.

The Salisbury Mills Fire Company has identified three projects within the 2017 Orange County Hazard Mitigation Plan to address its flood vulnerability. These projects were not evaluated as part of this report, though it is recommended that all critical facilities consider future climate projections when evaluating mitigation strategies.

Hydrology and Hydraulics

As part of this flood assessment, a series of hydrologic and hydraulic (H&H) models were developed to assess the extent of potential flooding from the 10 percent (10-year), 1 percent (100-year), and 0.2 percent (500-year) storm recurrence intervals within the Lower Moodna. The modeling included flows for these storm events under existing conditions and future conditions based on predicted increases in precipitation and population growth.

The foundation of the H&H models used FEMA data including channel geometry, bridge crossings, and storm flows. FEMA data existed for Moodna Creek, Idlewild Creek, Woodbury Creek, and two un-named tributaries in subwatershed 2. However, much of these data had been created from studies performed in the 1980's. The technology and methods since the studies were performed have greatly advanced in accuracy and ease of use. Additionally, the data available was insufficient for use with the preferred software to create models for this project. Given the limitation of the available data, Princeton Hydro determined it was best to create new models that would allow the greatest depth of analysis within the funding and time constraints of the project. Additionally, Silver Stream, which has not been previously studied by FEMA, was studied. All hydraulic computations were completed using United States Army Corps of Engineers (USACE) HEC-RAS computer program, Version 5.0. The final model for the Lower Moodna watershed is a combination of the previous flood studies and new data generated for this project. A detailed methodology of the modeling is included in Appendix B.

The FEMA data that were used included constrictions such as bridges and culverts and channel geometry such as channel shape and bottom elevation. Floodplain topography outside of the stream channel was interpolated from 2014 LiDAR data. Where FEMA data was unavailable, orthoimagery, LiDAR, and field observations were used. The Project Team also included buildings that may obstruct the flow of water during a flood. The building outlines had been created by the County in GIS in 1994. This dataset was compared to imagery for accuracy and new structures were manually added to be included in the modeling.

Peak discharges, also known as flow, for the hydraulic modeling were a combination of FEMA data and regression-based computations. In order to develop a baseline condition, Princeton Hydro believed that flood mapping of the existing conditions should be consistent with existing FEMA flood studies. As a result, many of the discharges from streams came directly from the FEMA flood insurance study and hydraulic models for Orange County. Other stream discharges were computed using the USGS StreamStats computer program.

In the original proposal for the project, Princeton Hydro was tasked with coordinating with the Upper Moodna Watershed project team, in order to tie in the two flood studies. Most importantly, Princeton Hydro would use the discharges and water surface elevations for Moodna Creek at the tie in location immediately downstream of the Beaverdam Lake tributary. This was to ensure that floodplain delineation would be more consistent for the entire scope of the Moodna watershed. However, the discharges provided by the Upper Moodna watershed project team were significantly greater than the discharges used in the FEMA flood study. Using the Upper Moodna discharges in the hydraulics modeling would produce significantly higher water surface elevations and wider floodplains compared to the FEMA model. By using the FEMA discharges, Princeton Hydro was able to produce floodplains that more closely match the FEMA regulatory floodplains. In this manner, it is easier to assess what new areas are impacted in the future.

Future Conditions

One core objective of this project is to analyze how flooding within the watershed may be affected by changes in land use, precipitation, and mitigation efforts. To achieve this effort, the hydraulic model was used to evaluate scenarios based on projected population growth and predicted changes in river flows associated with climate change. The model was then adjusted for individual mitigation projects such as culvert enlargement, floodplain storage, or bridge expansion. The project team also explored the impact developing certain remaining wetland and unimproved areas would have on flooding. Each project was analyzed individually in terms of its impact on peak flows, as well as potential downstream and upstream effects.

Growth and Development

It is extremely difficult and resource intensive to accurately predict where future development will occur, even with detailed understanding of zoning. The Project Team considered several approaches to calculating the future population and the footprint this development would encompass. Using data from the census and the NLCD from USGS the project team looked at the relationship between population growth and the percent of impervious cover. Decennial census data from 1980 to 2010 for Orange County were downloaded from United States Census. 2001, 2006, and 2011 NLCD data were downloaded from the USGS's National Map website. Land cover data after 2011 were not available. A summary of the data between 2000 and 2011 are shown below:

Table 1. Population and NLCD Percent Impervious Cover

Time Period	Population	Percent Impervious
2000 - 2001	341,367	14.85
2005 - 2006	357,090 [1]	15.63
2010 – 2011	372,813	16.36

[1] This estimate was a linear interpolation between 2000 and 2010.

Based on the historic population trends and projected growth rate as reported by the Cornell Program on Applied Demographics, the projected population for Orange County in 2040 is 444,322 people. The Cornell projections did not project beyond 2040, therefore 2040 was used as an analog for 2050. After reviewing several methods, it was decided that a linear correlation between population and percent impervious, which likely overestimates the impact of development associated with the growth, was best for the purposes of the project. The model also assumes population density is even across the entire watershed. In reality, impervious cover will increase throughout a range of different land uses and the various tributaries in the watershed will have different responses to those land use changes. Although, those with knowledge of the history and current conditions in the watershed can attest that these assumptions are flawed, they were selected in order to provide the greatest assessment of potential risk. Under a linear relationship between population growth and impervious cover there will likely be an increase of 21 percent impervious cover by 2050. Consequently, the impervious cover area will increase by 18,436 acres. This increase in impervious cover was integrated into the modeling by replacing existing forested areas, which will increase runoff within the watershed. In order to compare how this would affect flooding, each storm event was calculated independently. As the return period increases (10 to 0.2 percent) and, thus, peak discharges increase, the influence of the increase in runoff is less prominent as illustrated in Table 2.

Table 2. Percent Increase in Runoff Due to Changes in Impervious Cover from 2017 to 2050

Return Period	Runoff Percent Increase
10%	9.8
1%	6.3
0.2%	4.5

Changes in Precipitation and Flows

It is likely that the Moodna watershed will experience greater precipitation amounts by 2050 due to climate change. To help prepare for the potential impacts of climate change, USGS, in collaboration with the New York State Department of Transportation, developed a web-based tool to calculate the increase in flows projected for the future. Using StreamStats, this estimate can be used to calculate future conditions within watersheds to better understand how flows may change. The tool does not take land use, stormwater management, or storage into account. For this project the Project Team used the USGS tool to calculate a percent increase in discharge for each storm event. These percent increases due to climate change were then applied to the discharges in the model to predict discharges for 2050. The final future discharges are the product of the current discharges, the percent increase due to land use change, and the percent increase due to climate change.

Future Floodplains within the Moodna

The forecasted discharges were used to compute future water surface elevations, which in turn was used to map the floodplains. The project team looked at where floodplains may change in 2050 given changes in impervious cover and precipitation. Other inputs such as terrain, blocked obstructions, and roughness coefficients were not altered. Although, this data will likely change as development continues in the Moodna watershed.

Risk-Reduction Strategy

Understanding the existing and anticipated conditions for flooding within a watershed is a critical step to reducing risk. Flood risk in the Lower Moodna is predominantly driven by high-velocity flows that cause erosion, scouring, and damage to in-stream structures. The second cause of risk is back-flooding due to constrictions within the channel, both naturally formed constrictions and man-made structures. There are other factors that have influenced flood risk within the watershed such as development within the floodplain, stormwater management, as well as erosion and steep slope protections. All of these factors influence the vulnerability of the communities to flooding and other related hazards.

The strategies included in this report are designed to generally reduce the risk of flooding by addressing the influence of individual properties. In addressing the range of issues within the Lower Moodna it is important to understand that this is the bottom of a large drainage area. Before Moodna Creek crosses Route 94 it has already drained 80,400 acres or 125 square miles. Some of the specific site mitigation projects that have been proposed show only a negligible impact to peak flows.

Strategies

Stormwater Management

The Moodna Watershed Flood Summit report highlighted the importance of stormwater management in any flood mitigation plan. Stormwater refers to rain that does not soak into the ground. This occurs across all land uses, but impervious surfaces prevent any water from penetrating and result in nearly 100 percent run-off. This run-off increases the volume of water in the streams and rivers throughout the storm event and increases the likelihood that water will spill out of the channel and into the floodplain.

Stormwater management is the practice of detaining or infiltrating this rainwater to prevent excessive run-off from entering the streams and rivers during a storm. Some approaches simply slow the flow of the run-off to streams and creeks, while other practices strive to infiltrate the water into the ground. The Summit report summarized the different management practices, advocating for low impact development approaches that mimic natural systems where possible. However, it did not necessarily advocate for regulating stormwater management for all development and redevelopment projects.

Parts of the watershed within the more densely developed areas fall under an MS4 permit from NYSDEC, which regulates activities that generate impervious surfaces and runoff at the local level. However, it does not cover the entire watershed. Stormwater management should be required for all projects and the regulations should strive to ensure development does not change the quantity, quality, or timing of run-off from any parcel within the watershed. It is also important to consider including stormwater management in any redevelopment projects. Even if any new development in the watershed succeeded in retaining or detaining stormwater on-site to match its pre-development state, flooding within the watershed would remain static. The Summit report identified stormwater management as a critical first step to reducing flood hazards. While true, often stormwater management ordinances focus on future flooding and do not address the existing flooding issues.

Land preservation

Land preservation, both within the floodplains and in upland areas, is the best way to minimize flood damage. Preserving land allows for natural stormwater management, as well as limits the exposure of development, and minimizes sources of erosion within the watershed. Preserved land also maintains the hydrologic and ecologic function of the land by allowing rainwater to be absorbed or retained where it falls and thus minimizing run-off. This is particularly true in upland areas where run-off can dramatically affect the timing and volume of water in streams and creeks.

At the bottom of the watershed, preservation within the floodplain is particularly important to minimize flood risk. Flooding is mainly a problem where there is development and infrastructure. Limiting this development in areas that are affected by high velocity flows, frequent flooding, and high water surface elevations reduces the exposure of property to damage. It also reduces the disruption to the community during and after a storm event. Within the Lower Moodna, approximately 21 percent of the floodplain, up to the 0.2 percent storm, is currently protected.

In addition to increasing exposure, development within the floodplain can reduce storage, restrict flows, and increase erosion along surrounding banks. The Project Team sought to evaluate how flooding may be affected as areas within the floodplain continue to be developed. Although any preserved land in a watershed will help maintain a healthy hydrologic system, the location of development does affect the creek's ability to hold its flows during a storm event. Some areas of the floodplain that remain undeveloped would be more likely to increase flooding issues if developed. Other sites may increase exposure. Through a desktop analysis, the Project Team identified sites to study based on size, location, and existing land use. The results varied between a small increase in flows if the site was developed to an increase of 45 percent at another site.

Although the analysis indicates variability in the land's influence on flooding, it is important to note that some parcels may offer critical ecological value beyond flood storage that warrants prioritization in a land preservation plan. This project looked only at the impact of these sites on flooding in a simple hydraulic model. There may be several other functions the land provides to the watershed. In addition to its benefits for flood damage, land preservation is also a critical tool for maintaining the historic landscapes and character of the region, as well as preserving water quality, air quality, and habitat within a watershed.

Where land preservation is not a financially viable option, but the land is undeveloped, prone to flooding, and offers ecological value that would be impacted by development it may be eligible for a Critical Environmental Area (CEA) designation. To be designated as a CEA, NYSDEC requires that an area must have an exceptional or unique character with respect to one or more of the following: 1) a benefit or threat to human health; 2) a natural setting (e.g., fish and wildlife habitat, forest and vegetation, open space and areas of important aesthetic or scenic quality); 3) agricultural, social, cultural, historic, archaeological, recreational, or educational values; or 4) an inherent ecological, geological or hydrological sensitivity to change that may be adversely affected by any change. Any local agency can designate an area as a CEA. CEA designation does not protect land in perpetuity from development, but would trigger environmental reviews for proposed development under the NY State Quality Environmental Review Act (SEQR). CEA designation provides an additional layer of scrutiny on projects to ensure they will not exacerbate flooding within the watershed or result in an unintentional increase in risk to existing properties and infrastructure.

Increase floodplain storage

One of the reasons there is flood damage within the Lower Moodna is the volume of water that moves through the channel during a rain event. Where stretches of the floodplain are preserved or undeveloped there is an opportunity to increase the storage or detention of floodwaters. When the channel swells, water spills over the banks and into the community. It is possible to increase the channel's ability to hold floodwaters by changing the grading and increasing the size and depth of the floodplain in certain areas or changing the landscape to store or redirect floodwaters before they reach the main channel. These projects seek to promote backflooding and overbanking into preserved areas. It is also possible to direct the water away from residential and commercial areas into undeveloped or underutilized parcels.

These sites do not have to be forested or wetlands, although these vegetation communities provide valuable ecological benefits within the floodplain; it is also possible to increase storage opportunities within parklands and golf courses. Increasing the storage can be an approach that mimics and enhances the natural functions of the system. Any site that does not have structures may be a viable option to retain redirected floodwaters. This approach may also be used in areas that were previously developed. In these areas expanding the storage includes restoring a historic floodplain that had filled in or was altered. The land cover, whether it's turf, forest, wetlands, or impervious cover affects the ecological benefits that are derived from its use as a floodplain, but does not change its storage potential. However, it can also be used to alter and distort the hydrology of the system in ways that have negative ecological impacts.

Increase Conveyance by Removing Constrictions

The WMP identified a need to inventory existing constrictions within the watershed and analyze their impact on flows. Stakeholders helped identify the locations of several areas where constrictions are known to force the floodwaters over roadways or other development. The floodplain mapping as part of this flood assessment was used to identify other constrictions that are causing flooding to affect homes and businesses. Between the two approaches, 5 stream crossings were identified as having constricted flows that result in backflooding upstream.

The two most common constrictions are bridges and culverts. The simplified solution is to remove these constrictions and improve flows, but these projects need to be carefully designed to not exacerbate flooding downstream. It is also possible to reduce the potential for constrictions to cause future flood issues by implementing culvert ordinances that regulate the size and passage of culverts to accommodate greater flows. For example, when the I-87 culvert is being replaced, if the ordinance is in place then the structure can be built to accommodate future flows and reduce future risk of flooding.

Building Regulations

According to the data available for this project, there are an estimated 79 buildings in the 0.2 percent flood zone that are not within the 1 percent flood zone. These structures are not required to carry flood insurance, even with a federally-backed mortgage, and are not subject to any special regulations to minimize their risk of flooding. However, these structures do carry a six percent chance of experiencing flooding over a 30-year period. This probability does not account for increases in high-precipitation events and higher flows associated with climate change and population growth.

All of the areas within the watershed are covered by the National Flood Insurance Program (NFIP) and therefore carry some building regulations in floodprone areas that are mapped by FEMA. All of the towns have adopted the NYSDEC Flood Damage Prevention Law which regulates construction in floodplains. This local law requires homes and non-residential structures within A-zones (1 percent flood zone) to be built at least two feet above anticipated flood levels; this requirement is often referred to as “freeboard”. Where the base flood elevation has not been delineated, the law requires freeboard of three feet. This requirement helps promote new construction to be built to standards that reduce probability of flood damage. The law also requires that all structures that experience substantial (greater than 50%) damage have to raise the structure to match current elevation standards. This is a minimum requirement for all communities in the NFIP, but the local law is more restrictive because it looks at cumulative damages. If a home is damaged 10 percent every year for five years it will have to elevate after the total cost of damages exceeds the 50 percent threshold defined by FEMA. This is an important mechanism to ensuring that homes and structures with minor repetitive loss are brought to code in order to reduce damages.

The law also prohibits the construction of critical facilities within the special flood hazard area (1 percent flood zone) or the floodplain for the 0.2 percent storm. The law defines these facilities to include those which have hazardous or combustible materials on-site; hospitals, nursing homes, and other facilities that house non-mobile populations; emergency response facilities; and public or private utilities whose operation is critical to restoring or maintaining normal services during and after a flood event. This is a fairly comprehensive definition of critical facilities that protects a municipality’s ability to respond and recover from flood events and appears to parallel the FEMA definition of a critical facility. However, this definition does not appear to cover schools, which can be extremely disruptive if they are flooded and often used as an emergency shelter. It also does not appear to cover prisons, which are difficult to evacuate in a flood. If possible, towns should consider additional uses that may not be covered by the state’s recommended definition.

For this watershed it is also critical to regulate construction on steep slopes and require buffers along riparian areas and wetlands in order to reduce erosion. This has already been recognized and codified through several ordinances within the municipalities. In a review of local ordinances, the WMP noted that the Towns of Blooming Grove and Cornwall include a 100-foot building setback as measured from the high-water mark of a flowing watercourse, in which no buildings may be constructed; both towns require the same set-back for lakes and ponds. The Town of Blooming Grove and the Village of Woodbury have protections for wetlands. The Village of Woodbury also regulates development in floodways.

It would be recommended that all towns consider ordinances that regulate development in areas with steep slopes. Given that several of the stretches of the Moodna and its tributaries have high valley walls, these ordinances should be written to address variability in the stability of these walls. The top of a steep slope can be undermined at various distances from the edge, which is correlated to the height of the valley wall. A slope that has a height of 200 feet would warrant a greater setback than a slope with a height of 50 feet. For municipalities that are concerned about over-regulation of private, developable land, the ordinance could allow for a variance if a stability analysis can demonstrate the buffer is unnecessary or overly restrictive.

In addition to steep slopes, ordinances that prohibit development in riparian areas, wetlands, and the filling of fluvial floodplains can also protect against future risk within the watershed. Protections for riparian areas, wetlands, and floodplains also have ecological benefits as these areas are critical habitats. It is recommended that each town consider including ordinances to address these protections in order to minimize future risk of flooding.

One additional method to protect against future flood risks in a fluvial area is expand the area affected by floodplain regulations. In several of the recent rainfall events in Louisiana, Texas, and South Carolina the damage was described to exceed the regulatory floodplain. Although the science is still in development, it is generally believed that there may be a shift towards larger more frequent rain events in the future. Adoption of local ordinances that expand elevation requirements, such as freeboard and prohibition of certain uses, beyond the existing 1 percent floodplain will increase the long-term resilience of the building stock.

There are a couple of approaches that can be used to expand the regulatory area. One option, which was explored through this project, is to add a freeboard requirement onto the base flood elevation, but not confine the limits of the regulation to the 1 percent floodplain. This project modeled what the extent would be if 2 feet of freeboard were automatically applied to the base flood elevation across the watershed. The extent of the regulatory area under this approach does extend beyond the effective 1 percent flood zone, which is the area to which the existing freeboard requirements apply.

The second option uses the existing FEMA mapping to regulate based on the 0.2 percent storm, not the 1 percent storm. This approach was just adopted by Harris County, TX in the wake of Hurricane Harvey. The new ordinance requires 2 feet of freeboard above the elevations for the 0.2 percent storm. The 0.2 percent storm is already mapped for all studied streams making it an accessible standard for all governments, regardless of data analysis capabilities.

Individual Property Mitigation

In some cases, there are properties at-risk of flooding where a large-scale engineering project is not financially or logistically possible. Where acquisition is not appropriate or supported, it may be possible for individual owners to address their own risk by elevating the structure, relocating, filling the property, or using floodproofing measures. The NFIP has specific requirements and guidance for each of these options. For owners that are mitigating their properties in response to NFIP regulations, there may be some financing available from FEMA to offset the Increased Cost of Compliance (ICC). ICC funds provide up to $30,000 for NFIP policyholders seeking to elevate, relocate, demolish, or floodproof their home or property to comply with standards that have been adopted since the structure was originally built. This program is an example of the programs offered by FEMA to help owners reduce risk in flood-prone areas.

Individual mitigation efforts can also be aimed to save homeowners money. A recent study by Pew Charitable Trusts found that in riverine communities, mitigation measures can save $4 to every $1 spent on projects to bring properties into compliance. For many homeowners, this is a required step after being substantially damaged after a storm. However, some homeowners also mitigate if they are trying to improve their home, reduce the flood insurance premiums, or increase the resale value. In many of these situations the appropriate mitigation approach is to elevate the home and use flood vents on the enclosure beneath the home to allow water to pass through during a flood event. This enclosure should not be used for any purposes other than parking, storage, or building access. Towns can encourage compliance with this regulation by having applicants sign an acknowledgement or a waiver demonstrating their understanding of this limitation.

There are other mitigation options available to individual property owners. Homes within the floodplain that were built with basements can fill the foundation and elevate the living space above the base flood elevation. This is particularly effective in places where flood insurance rates are high. Commercial property owners can also use dry-floodproofing measures. Dry-floodproofing refers to making a building water-tight to prevent floodwaters from entering. This may include removable barriers that prevent water from passing through doorways, windows, or other entrances into the structure. These options are only available to commercial properties and cannot be used to mitigate residential uses.

Another cost-saving measure for homeowners may be as simple as proving structures are not in the floodplain. In some watersheds, particularly those that have steep topographic changes, the mapping from FEMA can be limited in its accuracy. For this reason, FEMA relies on elevation certificates to provide an accurate understanding of risk to any structure within the floodplain. The NFIP requires that towns keep elevation certificates on file for properties within the floodplain, but many towns do not have these records for homes built before 1978. For property owners that have never experienced flooding, but are located in the floodzone, it is highly advised to get an elevation certificate. An elevation certificate, created by a professional surveyor or engineer, can exempt the property from flood insurance requirements, if the lowest-adjacent grade to the structure is found to be located above the base flood elevation.

If a property is found to be elevated above the mapped flood elevation the homeowner can file a request for a Letter of Map Amendment (LOMA). If the elevation certificate is filed after a mitigation project to fill the property, the owner would submit for a Letter of Map Revision based on fill (LOMR-F). Both processes result in the property being removed from the map and no longer being obligated to purchase flood insurance by the NFIP. However, it is important to note that lenders have the authority to require insurance even if the NFIP does not. If new mapping is adopted that increases elevations, it may result in the property being placed back into the floodzone.

Project Sites

In addition to the general strategies outline above, the Project Team identified 16 locations to analyze site-based solutions. Conversations with representatives from the Moodna Creek Watershed Council, NYSDEC, Orange County Planning, and the Towns of Cornwall, New Windsor, and Woodbury, and the Village of Cornwall-on-Hudson identified key facilities along the Moodna Creek and areas for the project team to focus on. Additionally, the Project Team compiled other sites based on existing studies, as well as a desktop analysis of the flood mapping, land use, hydrology, and future conditions.

Each site was evaluated to determine how it relates to flood issues in the watershed and if there are opportunities to mitigate. Where appropriate, the watershed model was used to analyze existing conditions and how the site may perform during future conditions. After the analysis was performed it was determined if the project would have significant impact and recommendations were generated minimizing future flood damage throughout the watershed. A general cost estimate where possible was also calculated. These estimates are included in the project descriptions and are further detailed in Appendix A. The sites are depicted on Figure 3 and detailed below. Some of the projects were determined to have minimal impact on flows, but are included in the report to document the analysis.

Site #1: Storm King Golf Club

Idlewild Creek travels adjacent to Continental Road south of Main Street in the Town of Cornwall. Under the Princeton Hydro model, the floodplain of Idlewild Creek for the 1 percent storm encompasses a number of homes on Continental Road, Hasbrouck Avenue, Robert Road, Sheldon Drive, and Halfmoon Drive. This differs from the FEMA model as a result of a variation in the topography on which the mapping is based. It is likely that if FEMA used the topography data incorporated into this study, these streets would be included in the regulatory floodplain.

Although this area was not noted as a repetitive loss area, it was selected as an opportunity to reduce exposure by redirecting and retaining floodwaters onto lands that do not have structures. In this case, expanding the floodplain within the property of the Storm King Golf Club. The Project Team looked at the topography on the golf course to see if directing flow onto the greens would alter the extent and reach of the floodplain that would reduce the potential for flooding along the roadways and properties in the adjacent neighborhoods. Based on LiDAR data, it was estimated that the alteration of 27 acres could increase floodplain storage by 130.5 acre-feet, which is equivalent to approximately 42.5 million gallons.

If the floodplain at this site were expanded per the analysis, there would be an estimated 32 percent reduction in the peak flows as Idlewild Creek enters Main Street in the Town of Cornwall. Unfortunately, it is difficult to know exactly how this decrease in flows will transform the floodplain in this area. Although the model indicates several homes are at risk from the 1 percent event, Hurricane Irene did not affect land outside of the channel. Since this was the storm used to model the reduction in flows, it cannot show any change in the floodplain.

The property owners of the golf club were not approached for this project, any alteration would obviously affect the experience for members and golfers. For the purposes of this analysis, the contours of the greens were not changed, but the elevations were lowered consistently across each impacted hole. Any final design would need to incorporate careful consideration of the impact on the golf course. It is estimated that this project would cost approximately $5.2 million.

Site #2: New Windsor Wastewater Treatment Plant

It was noted in conversations with stakeholders that the New Windsor Wastewater Treatment Plant experienced significant damage from the storms in 2011. Details of the damage from these events were not included in the HMP because the Town of New Windsor maintains its own plan. However, the Town’s plan was not accessible online at the time of this report. Therefore, there is limited information about the specific cause of damage. Prior to these storms the United State Army Corps of Engineers visited the watershed to assess flood risk and potential opportunities for federal interest. It was determined that the treatment plant warranted federal interest given its propensity for backflooding from the Moodna. The initial draft report acknowledged that backflooding at the plant resulted in untreated sewage discharging into the river as it joins the Hudson. In addition to this documented concern, the WMP highlighted that Infiltration and Inflow (I/I) is a problem within the service area. In systems with I/I problems, a heavy rainfall can overload the system and cause backflooding into basements and streets. The WMP also noted that the NYSDEC has imposed a moratorium on development within the Town of New Windsor due to limitations on the plant to receive additional flow. According to the WMP there are plans to expand the service capability of the plant. Any such project would be a great opportunity to improve flood protection onsite.

It appears based on imagery and field observations that after the 2011 flooding a small berm was created on the banks of the Moodna. However, this barrier does not appear to be designed to a particular elevation and will likely be insufficient to protect the facility during a major event. The H&H model indicates that the flood elevation during the 0.2 percent storm event exceeds the projected water surface elevations for the future 1 percent storm. Selecting the scenario with the highest anticipated flood elevation provides the greatest protection against major and minor flood events. A comprehensive flood wall would need to have an elevation of 22 feet NAVD88 to ensure that the facility was protected against floodwaters in a 0.2 percent storm.

However, given the surrounding topography it is important to note that any protection system could be overtopped given the right conditions. Without appropriate drainage the site could experience greater flooding as a result because a wall could hold the floodwaters in for an extended period of time. It is estimated that this project would cost approximately $2.9 million.

Site #3: Spring Rock Road and St. Anne Drive

This area was selected because the modeled floodplain and FEMA mapping indicates there may be a constriction at the St. Anne Drive culvert. According to the mapping, the stream floods approximately 2 acres upstream of the culvert. This includes 3 structures. This area was also interesting because upstream of the culvert a Letter of Map Revision (LOMR) was completed in the FEMA mapping for this tributary. Under Princeton Hydro's model, there is potential flooding that may affect the homes along Spring Rock Rd, Split Tree Drive, and Stone Ledge Lane. Within FEMA's mapping, the floodplain follows Spring Rock Road and Chimney Corner Road, but is largely contained within the right-of-way of the street and does not affect the adjacent properties. The inundation along Spring Rock Road is designated as a Zone AO, which means FEMA did not assign base flood elevations to this area.

By comparison, the Princeton Hydro mapping of this area is more conservative. The floodplain under the Princeton Hydro model encompasses 30 homes within the neighborhood. Unlike the FEMA LOMR, the results of this study are not for flood insurance purposes. Rather, it is to determine flood risk areas for both existing and future conditions. With homes and streets built alongside the tributary, it is clear that this area has the potential to experience extensive flooding. For planning purposes, the more conservative mapping is appropriate in order to understand the extent of potential flood risk within the neighborhood.

As part of this project, this area was selected to determine if altering the culvert under St. Anne Drive would improve conveyance and reduce the backflooding upstream. The Project Team also looked at the water surface elevations under future conditions for the floodplain around Spring Rock Rd. Under existing conditions, the culvert is 12 feet across and 5 feet high. It is limited in its ability to pass the floodwaters from even smaller events like the 10 percent storm. The larger storm events like the 0.2 percent event pool water behind the culvert.

This will be an increasing issue as storm frequency and intensity increase in the future. A comparison between the floodplain for the 0.2 percent storm in 2050 and the existing 0.2 percent storm shows that future precipitation may result in an increase of 1.2 acres of floodplain upstream of the culvert. The culvert is highly undersized for the area and could be expanded an additional four feet across and two feet high. Replacing the culvert with one that is more appropriate for this location will reduce flooding up to 1000 feet upstream of the culvert. Without replacing the culvert, 3.48 acres of land could be at risk for flooding from the 0.2 percent storm; after the culvert replacement the total acreage drops to 1.98 acres. In addition to a reduction in the extent of the floodplain, the culvert expansion would also drop the water surface elevation by 2 feet at the culvert. However, expanding the culvert is not anticipated to change the water surface elevations below St. Anne Drive and would thus not result in an increase in flooding downstream. It is estimated that this replacement would cost approximately $180,000 for the engineering, design, and permitting for the immediate in-stream work. There may be some additional costs for work upstream and downstream to stabilize the channel under the new flow regime. These costs would be per linear foot and could be estimated during the design phase of the project.

Site #4: Forge Hill Road

Upstream of the Forge Hill Road (Route 74) bridge, Moodna Creek has eroded into the valley wall on the river right bank. For approximately 1,000 linear feet, rising up to 100 feet in places, the entire valley wall slope has been exposed and destabilized. Aerial imagery from October 7th, 2011 captured the failure of the river right abutment and collapsed section of bridge, which has since been repaired. Immediately upstream of the Forge Hill Road bridge, a large gravel bar and boulder riffle have formed; much of this material may have originated from the valley wall itself. Some form of this riffle appears to have been present in 2007. This boulder riffle appears to be serving as a natural grade control, providing vertical stability to the channel – an important condition necessary for providing stability to the adjacent valley wall. The WMP noted the presence of steel I-Beams beneath the Forge Hill Road bridge and included a potential project to remove these beams as they pose a hazard to boaters. These beams were not observed in the site visit for this project.

If the channel appeared vertically unstable (i.e. actively downcutting) without a downstream grade control present, then continued erosion at the toe of that valley wall would be unchecked and expected to proceed more quickly. While no structures or developments exist at the top of the valley wall at its highest point, a former rail line and unimproved access road has eroded out. One structure near the Forge Hill Road Bridge is located close to the eroding slope – existing outbuildings lie on the precipice and are at significant risk of collapse. Other infrastructure at risk at this location include what appears to be a concrete-encased utility line crossing at the upstream extent of the failing valley wall. This structure is a noticeable hydraulic control in previous aerial images but appears to be more exposed since the 2011 flooding.

At the very least, the slope should be stabilized with armoring at the toe. Additional mitigation efforts could include installing structures such as bendway weirs or rock vanes (aka stream barbs or spur dikes) to redirect flow away from the bank; installing grade control structures to prevent further downcutting of the channel; realigning the channel away from the valley wall; and/or stabilizing the valley wall with an engineered retaining wall or bioengineered slope. For the purposes of this project, a cost estimation includes the bank stabilization, rock vanes, and armoring. The cost estimate does not include any modification of the channel because such a project would necessitate a detailed geomorphic and slope stability analysis that was outside of the scope and budget of this project and could vary drastically in its costs and design. The estimated cost for stabilization is $462,000.

Downstream of the Forge Hill Road bridge, the river left valley wall, approximately 60 feet in height, had also failed, a private residence had been removed, and the slope had been stabilized with five large boulder rock vanes (to direct flow away from the lower bank), riprap armoring on the lower half of the bank, and vegetative stabilization on the upper half of the slope. This appears to have been effective in stabilizing the wall.

Site #5: Butterhill Park

Downstream of the Forge Hill Road crossing, banks of Butterhill Park were identified as an area of concern because the Moodna is mapped to go out of bank and flood the road just north of Staples Lane during a 1 percent storm event. This reach of the Moodna is characterized by drastic geomorphic change, and heavy-handed channel and floodplain manipulation. The reach exhibits several boulder-dominated steep riffles, which appear to be constructed following a recent channel avulsion (i.e. a sudden and complete channel re-alignment occurring in a single event) during recent flooding in 2011. In addition, the banks on river right are now heavily armored with re-purposed concrete slabs, some of which are vertically oriented to form levee walls.

Past aerial images from Google Earth illustrate a timeline of events that help to explain the current conditions:

- **1995**: tight meandering around industrial property; channel appears to be entrenched and disconnected from its floodplain; pronounced grade drop, likely a weir or low-head dam, which formed a pool upstream of industrial property.
- **2001, 2004, 2006**: signs that weir / low-head dam is being bypassed by flows on river left (north side).
- **3/31/2007:** weir / low head dam fully bypassed and not visible (possibly buried or inundated); former pool now dewatered; all flow following river left alignment; effects of flood event of April 2007 not yet captured.
- **10/7/2011:** major channel avulsion; new central alignment; signs of river excavation and berming with river gravels.
- **9/19/2013**: gravel berms removed; riffle features apparent; channel narrowed.
- **4/16/2016**: floodplain regrading; river right bank now substantially armored with concrete slabs.

The recent flood events have eroded and reshaped the channel and floodplain, and in effect reconnected the channel to a portion of its floodplain. The recent flood events have also demonstrated the natural, inherent, dynamic nature of a river channel and floodplain and illustrate that a sensible management approach would be to accommodate space for fluvial erosion, to maintain adjacent low-lying floodplains, and to avoid and remove fill and development in and around river channels and floodplains. However, the typical post-flooding work to stabilize and armor the channel reflects the misperception that these processes are unnatural and require repair and resistance. Attempts to lock the channel in position and limit the connection to the adjacent floodplain will be undone again by similar flood events in the future.

The Project Team looked at the opportunity to expand the storage of the floodplain. The Project Team modeled the impact of removing the existing armoring and expanding the available storage within a 6.25 acre stretch downstream of the road crossing. It was assumed that an additional depth between 2 and 6 feet could be excavated from this area, which would allow nearly 37.5 acre-feet of additional flood storage. However, the results indicated this effort would only result in a 3 percent reduction of peak flow. Given the location of this site within the watershed and the volume of water in the channel at this site, it is not anticipated that a 3 percent reduction would impact the extent or depth of flooding upstream or downstream in any storm event. It is estimated that this mitigation effort would cost approximately $1.2 million.

Even without the additional storage project, depending upon landowner interest, another option would include removing the concrete armor on the channel banks and establishing a low-lying floodplain for more frequent inundation. This would allow for greater stability within this stretch, reduce the risk of the barriers becoming dislodged in a larger event, and restore greater ecological functionality to the stream.

Site #6: Blooming Grove Turnpike

As the Silver Stream passes under the Blooming Grove Turnpike in New Windsor it is constricted by the existing culvert, which is six feet high and eight feet wide. This causes water to pool behind the culvert and flood Old Forge Hill Road, the Olde Forge Apartments, and the Kingswood Gardens Condominium complex. The Project Team looked at how flooding would be mitigated by expanding the culvert to accommodate greater flows. By widening the culvert to 16 feet, without needing to raise it, the water surface elevation would drop by 1.5 feet and would shrink the 1 percent floodplain from 250 feet wide to 100 feet across. This larger structure would allow approximately 250 cubic yards of water to pass through in an event.

This approach would not remove any buildings from the floodplain, but it would improve emergency egress to the Kingswood Gardens Condominium and reduce the extent of flooding on Provost Drive and Old Forage Hill Road. This project also may improve critical passage for aquatic life and increase access to upstream habitat. The culvert was identified in an assessment by the North Atlantic Aquatic Connectivity Collaborative as a moderate barrier to passage. NYSDEC provides assistance and some funding to barrier mitigation projects. More information is available through the Hudson River Estuary Project office in Region 3. This project would cost approximately $850,000.

Site #7: Wetland area Silver Stream Watershed

In subwatershed 1, nestled between I-87 and Temple Hill Road, there are 254 acres of contiguous wetland. Part of this wetland is owned by the state as part of the Windsor Cantonment State Historic Site and part is owned by the Town of New Windsor, known as the New Windsor Historic Park Lands. The remaining area is vulnerable to development and according to aerial imagery there have been a number of encroachments on this wetland area since 1975, though the pace of development has slowed in the past 10 years.

For the purposes of this project it was assumed the entire wetland was developed, which resulted in the loss of 1,500 acre-feet of storage. Development of this wetland could cause a 42 percent increase in peak flows through this stretch.

Site #8: Wembly Road

Near Wembly Road, behind the Hudson River Inlay building, the Silver Stream narrows considerably into a confined channel. Based on the mapping it appears that the UPS Customer Center at 139 Wembly Road, the Airgas Store at 128 Wembly Road, and the Inlay Building at 207 Wembly Road may be impacted by flooding in large events in 2050. Under current conditions, the properties of the UPS and Hudson River Inlay may experience some minor flooding under large events. This is an area that has not been studied by FEMA so these buildings do not fall within a regulatory floodplain, even if they may face a low-chance of flooding. Under the Princeton Hydro model, this area may experience a nominal increase in risk under future conditions, but will remain a low-risk area if development remains static.

This site was selected for analysis as a potential opportunity to excavate the adjacent land, create storage, and reconnect the floodplain. Based on topography it was estimated that approximately 6.25 acres could be transformed into an active floodplain on the west side of the stream upland of the New Windsor Historic Parklands. The greatest depth that could be excavated was 6 feet to generate an additional 37.5 acre-feet of storage. This proposed project would result in a 14 percent reduction in peak flows. Although this is a moderate reduction in flows, the change in water surface elevation is only 2 tenths of a foot and would therefore not reduce flooding downstream. This project would cost approximately $1.2 million.

Site #9: Little Britain Road and Moores Hill Road

The headwaters for the Silver Stream are north of Square Hill Road just south of the airport. There is a confluence south of Square Hill Rd, just upstream of the Britain Road crossing, where the main stem of Silver Stream is joined by two tributaries, including flow from Brown’s Pond. This confluence has an expansive floodplain that includes some of the structures along Little Britain Road and Moores Hill Road. This site was selected based on desktop analysis because the modeled 1 percent floodplain includes several structures west of Interstate 87.

Under future conditions, this area is likely to see an expansion of the floodplain. Within the 0.2 percent floodplain in 2050, there are nine structures on Little Britain Road and Moore’s Hill road, and one building within Walter’s Mobile Home Village. The single trailer appears to be directly next to the stream, approximately 25 feet from the top of bank and only 2 feet above the stream. If the trailer is inhabited it may never have experienced flooding before because there are other low-lying areas within that reach that would flood first. However, it may experience flooding under major storm events in the future. Again, this area has not been studied by FEMA so these structures are not subject to NFIP requirements.

The Project Team was interested in analyzing if enough storage could be created upstream of the development to reduce the water surface elevation in the floodprone area. The proposed project would excavate 16 acres to increase storage of floodwaters upstream of this commercial intersection. The topography in this area limits the depth of excavation to only 1 foot, allowing for only 16 acre-feet of additional storage. This minimal increase in storage results in only an 8 percent reduction in flows. The project is estimated to cost $6.2 million. Given the expense and the nominal reduction in peak flows, it would likely be more cost effective to address each property individually, as needed.

Site #10: Paper Mill

The former paper mill on Mill Street in Cornwall has been decommissioned and demolished. The vacant site sits within the floodplain and presents a potential opportunity for floodplain restoration or reconnection. The site is inaccessible via public roads and therefore was not visited during this project; the following analysis is based on desktop study.

The site covers approximately 7 acres within the floodplain and restoring the historic floodplain would entail the removal of over 101,000 cubic yards of fill material. Additional floodplain storage would reduce peak flows by 5 percent and reduce instream erosion along river left where a residential development sits at the top of the steep slope. Ecological benefits could be realized with the restoration of this site. This project is estimated to cost $1,799,000, which includes the engineering and permitting, as well as excavating the historic fill and installation of riparian plantings, but does not account for any remediation of the site. It also does not include removing the dam, or any instream work to alleviate erosion.

Site #11: Route 32/Mill Street

Downstream of the Route 32 Bridge, along Mill Street, another major valley wall failure has occurred. For approximately 450 linear feet, rising up to 100 feet in height, the entire valley wall has been exposed and destabilized. The valley wall is comprised of highly erodible sandy soils. An existing private drive at the top of the slope has partially collapsed and remains undermined. Accumulated boulders and bedrock outcropping were observed at the base of the slope, both of which contribute to vertical stability of the channel and provide some stability to the valley wall.

The upstream Route 32 Bridge appears to span the valley and therefore is not likely contributing to valley wall erosion by constricting flows and causing localized increased channel velocities. The upstream dam is run-of-river, it has minimal active water controls despite a low-level outlet that was passing low flows at the time of the site visit. The impoundment is narrow and riverine and appeared mostly full of sediment including gravel, cobble, boulders and even shallow bedrock outcropping. Erosion on the banks indicate high flows have previously circumvented the dam abutments. With minimal water controls, it is unlikely that the dam has any effect on the condition of the downstream valley wall. Notching the dam could potentially create the ability to store peak flows within its impoundment; however, with a narrow impoundment at an estimated 900 feet in length, the limited storage would likely be overwhelmed during the larger flood events and thus provide little ability to reduce peak flows (and therefore shear stress) at the valley wall during the most critical erosive flood events.

At the very least, the slope should be stabilized with armoring at the toe. Additional mitigation efforts could include installing structures such as bendway weirs or rock vanes (aka stream barbs or spur dikes) to redirect flow away from the bank; installing grade control structures to prevent further downcutting of the channel; realigning the channel away from the valley wall; and/or stabilizing the valley wall with an engineered retaining wall or bioengineered slope. For the purposes of this project, a cost estimation includes the bank stabilization, rock vanes, and armoring. The cost estimate does not include any modification of the channel because such a project would necessitate a detailed geomorphic and slope stability analysis that was outside of the scope and budget of this project and could vary drastically in its costs and design. It is estimated that this project would cost $245,000.

Site #12: Pleasant Hill Road / Route 79 Bridge

The road approach to the Pleasant Hill Road / Route 79 Bridge crosses the Moodna just 300 feet downstream of the confluence with Woodbury Creek. The floodplain in this area, according to the Princeton Hydro model is broad although with limited impact on existing structures. There is a single house on the edge of the 1 percent floodplain. In reviewing the model, it is evident that the bridge crossing constricts the floodplain on the river right (south side). The bridge spans the width of the river and during the site visit, it was noted that two corrugated metal culverts (60" estimated diameter) were embedded into the road approach. This was likely a mitigation effort to convey floodplain flow. Deep riverbed scour was observed under the bridge, suggesting that constriction of flood flows is still occurring and these culverts are insufficient to pass the flow during a storm event. This site was selected out of concern that the volume of flows due to the confluence and the velocity of the creek may cause damage to the bridge during a future storm event.

The Project Team considered the impact of additional floodplain culverts or expansion of the bridge opening along with regrading of adjacent soils to further increase capacity and reduce bridge scour. Through the analysis, it was determined that expanding the bridge would be cost prohibitive since the current span reaches the entire width of the creek during base flow. The other option considered included the installation of two additional floodplain culverts. Both of these culverts would be installed at the same elevation (22.9 NAVD88) and width (5 feet) as the existing culverts. This would double the capacity of the floodplain culverts to convey flows in a storm event. The model showed that the addition of the culverts had minimal effect on the water surface elevations, but will decrease the shear stress at the bridge, which is a factor in the scour. Shear stress is the force of the water moving against the bed of the channel and it is an indicator for damage to instream structures. It is estimated that this project would cost $60,000. It would be recommended that this area be considered for a further analysis to evaluate the best design to reduce the risk of scour.

Site #13: Maranath Lane

Between Route 32 and I-87 there is a reach of the Woodbury Creek where most of the floodplain remains undeveloped and forested. At the end of Maranath Lane, the channel meanders through a stretch of low-lying land. Based on aerial imagery and the modeled floodplains, the Project Team selected this site as a good location to evaluate the impacts of development along the floodplain. The floodplain is about 100 feet wide and has an average depth of 1.5 feet along nearly one mile of the creek. The average depth was less than anticipated and therefore, the total storage provided by the site is only 18.1 acre-feet. If fully developed, this loss in storage would result in a 3 percent increase in peak flow. This increase is not sizable enough to have significant impacts on the water surface elevation or the downstream extent of the floodplain. This area may be an appropriate area to consider for CEA designation, which would allow review of the specific proposal to ensure its development would not increase flood risk downstream or to adjacent areas.

Site #14: Lakeside Drive

In Highland Mills, within the Town of Woodbury, there is a small mobile home complex adjacent to Woodbury Creek. The floodplain is broad at this stretch of the creek and encompasses 17 homes on Lakeside Drive and Lily Court, and an additional three homes off the cul-de-sac at the end of Rutledge Avenue. In looking at the topography, there is not a viable opportunity to create storage and retain flows to shift the floodplain in this area. The valley that contains Woodbury Creek along this stretch is too channelized. The mobile home park is located in a unique low-lying area that is subject to flooding. This area will likely see an expansion of the floodplain under future conditions. The future 1 percent includes a few more buildings along Lakeside Drive, but the future 0.2 percent storm would flood the complex to Lilac Drive.

In the absence of an opportunity to hold back flows, the next approach is to mitigate the individual properties. For new development or substantially improved structures, this would be addressed by a freeboard requirement. For existing residential buildings the mitigation option is to elevate the home. This site was not visited and the elevations of the individual properties were not determined. Based on a desktop analysis, application of the 2 feet of freeboard coincides with the future 0.2 percent floodplain in both elevation and extent. In this case either ordinance included in the general strategy recommendations would reduce risk and mitigate future flooding for these properties. Without knowing how many homes would actually need to be elevated, it is impossible to accurately assess the cost of an elevation project in this area. Elevation of homes can cost between $30,000 and $70,000 depending on size and foundation type.

There are two primary mechanisms that drive elevations in floodprone areas. First, through its floodplain management program, the Town has authority and responsibility to make sure all permit applications for substantial improvements and substantial damage repairs comply with elevation requirements. Secondly, under the NFIP, homes that secure a federally-backed mortgage or loan are required to carry flood insurance. This includes loans to individuals purchasing a mobile home and therefore new buyers may be obligated to elevate their homes. The policy encourages homeowners to consider mitigation strategies that may reduce their premiums, which often includes elevating the home.

Site #15: Pine Hill Road

Near the intersection of Pine Hill Road and Adams Street the 1 percent floodplain for Woodbury Creek expands dramatically. The floodplain is constrained on the eastern edge by the railroad tracks so it moves westward, nearly reaching a width of approximately 1,500 feet just north of the Woodbury Police Department. Under the projected 2050 scenario, the floodplain for the 0.2 percent touches the parking lot of the police department. Under existing conditions, the public works building and four homes with frontage along Pine Hill Road are within the 1 percent floodplain. The culvert under Pine Hill Road appears to constrict flows, based on the extent of the floodplain.

The Project Team looked at the impacts of both a culvert replacement project and a land preservation project. The culvert replacement was intended to reduce the backflooding south of Pine Hill Road that affects the residential area, the baseball field, and the public works facility. Enlarging the culvert from 37 feet to 49 feet wide would have no notable impact on water surface elevations or backflooding. The cost for the culvert replacement is $294,000.

The Project Team also looked upstream to see how flooding may be influenced by current land use. In this case, upstream of the culvert is a 40-acre wetland. According to the model, if this area were to be developed, peak flows could increase by 42%. This does not include any projections for how flows may increase over time. It is recommended that this area be considered for preservation. While land preservation would not eliminate the risk of the currently impacted structures, it could mitigate future risk for those structures and adjacent structures currently outside of the floodprone area. Individual property mitigation is recommended for the affected structures.

Site #16: Smith Clove Rd

In the headwaters area of the Woodbury Creek, where Smith Clove Road passes under I-87, near Falkirk Road, there is approximately 33 acres of undeveloped floodplain. This site was selected to analyze the impacts development would have on flows and the floodplain in an area that has already experienced encroachment into floodprone areas. According to the model, there are 14 buildings within the existing 1 percent floodplain. In July 2017 the Planning Board changed the zoning for Section 231, Block 3, Lot 6.2 from Industrial Business to Hamlet Business, which allows residential units that were not permitted under the Industrial Business zone. There is currently a development proposal to construct 9 townhomes on two lots that lie entirely within the 1 percent floodzone. The proposal, at the time of this report, is awaiting permit review. This single proposal would increase the percent of buildings at-risk by 64 percent. Although it is possible to build residential townhome units in a floodprone area while minimizing risk to the structure, it is important that such standards are incorporated into the review and design early in the process and account for how risk may change over the life of the building. Under future conditions it is anticipated that the floodplain would extend beyond its current bounds in a few locations. Specifically, the salvage yard would increase in risk, as would the homes on Estrada Road.

Developing this area, which has about five feet of storage on average, would result in a 42 percent increase in peak flows for this area. This loss of storage would increase the water surface elevation by 1.1 feet. This impact could be felt across the entire width of the floodplain between the railroad tracks and I-87.

Conclusion

The New York Climate Risk and Resiliency Act (CRRA) adopted in 2016 was a legislative effort in the state to increase resilience of communities as they adapt to climate change. Although this law was directed primarily at addressing sea level rise and coastal development, the principles and process is applicable to riverine communities. Adapting to climate change in a watershed requires an understanding of 1) the hydrology and topography; 2) how storm events and precipitation may change in the future; and 3) a thoughtful strategy that addresses existing development and future land use considerations. This project sought to bring these elements together and evaluate different projects that may be included in a final strategy for the watershed. It built upon existing studies and work that has been conducted in the Greater Moodna and provides datasets that can be used in the future to evaluate potential projects. The Lower Moodna will likely see an increase in flood risk due to a combination of increased development as well as changes in frequency and intensity of storms. This report outlines opportunities to minimize that increase by preserving undeveloped land, promoting green infrastructure, regulating future development, and mitigating existing structures.

The Lower Moodna is characterized by floodplains that are frequently constricted by topography, culverts, and bridge crossings. The streams and creeks in the Lower Moodna experience drastic drops in elevation, high velocities, and travel through narrow steep channels. The combination of these factors results in many stretches of the watercourses that narrow channelized floodplains with minimal variation in the extent of the floodplains of different storms. For example, less than 200 acres of land in the entire watershed, approximately 0.5 percent, is only affected in the 0.2 percent storm event, which is the largest storm modeled by FEMA. This area represents a 14 percent increase from the 1 percent storm. By comparison there is a 38 percent increase from the 10 percent floodplain to the 1 percent floodplain. This analysis indicates that while some areas may see unprecedented flooding from a large rain event, the majority of the floodplain faces exposure from smaller to moderate storms.

While the hydrology of the watershed is a critical factor in assessing flood risk, so is the land uses within the watershed and particularly, within the floodplain. Fortunately, approximately 21 percent of the 0.2 percent floodplain is already preserved within the Lower Moodna. Approximately 9,000 acres or 25 percent of the land outside of the floodplain are also protected. Both statistics are indicative of an active effort within the watershed to preserve the natural assets of the region. It is critical to the overall exposure within the watershed that there remains a commitment to preserving land. This will help maintain the same level of exposure for the communities in the watershed and minimize future damage, as well as provide other ecosystem service benefits. Where there is development pressure and land preservation is not possible, or pressure to intensify the density in existing development, communities should adopt and enforce building regulations, environmental ordinances, and stormwater management practices. These mechanisms help maintain exposure and limit the impacts of development on flood risk. Additionally, directing development away from sensitive ecological areas can preserve the watershed's ability to naturally attenuate its flows and reduce exposure to structures.

For existing infrastructure and development in the Lower Moodna, there are opportunities to mitigate through conveyance projects, floodplain restoration, and raising homes. This project evaluated 16 specific sites in terms of potential impacts to flooding within the watershed. Several of the projects detailed in this report would have local reductions in peak flows and water surface elevations, which would reduce the depth of floodwaters in any storm event. Additionally, the two projects designed to address the valley wall failures would provide critical stability to the system. Other projects focus on preventing flooding from being worsened by increased development.

As was discovered through this project, there is no silver bullet to solving flooding in the Lower Moodna. Many of the projects, when examined in isolation, appear to have minimal impact on flooding. However, the projects that only had minor impacts on flows and water surface elevations, especially the preservation projects, should still be considered by the stakeholder group for inclusion in the mitigation strategy. Although each individual project did not represent a dramatic impact on flooding within the watershed, the aggregate impact of developing these larger contiguous areas along the floodplain could be very significant. The participating communities should evaluate these projects in terms of feasibility, impact, funding availability, cost, and interest. These projects and data can be integrated into the County's HMP during the next annual review process as well as the communities comprehensive planning efforts.

Figures

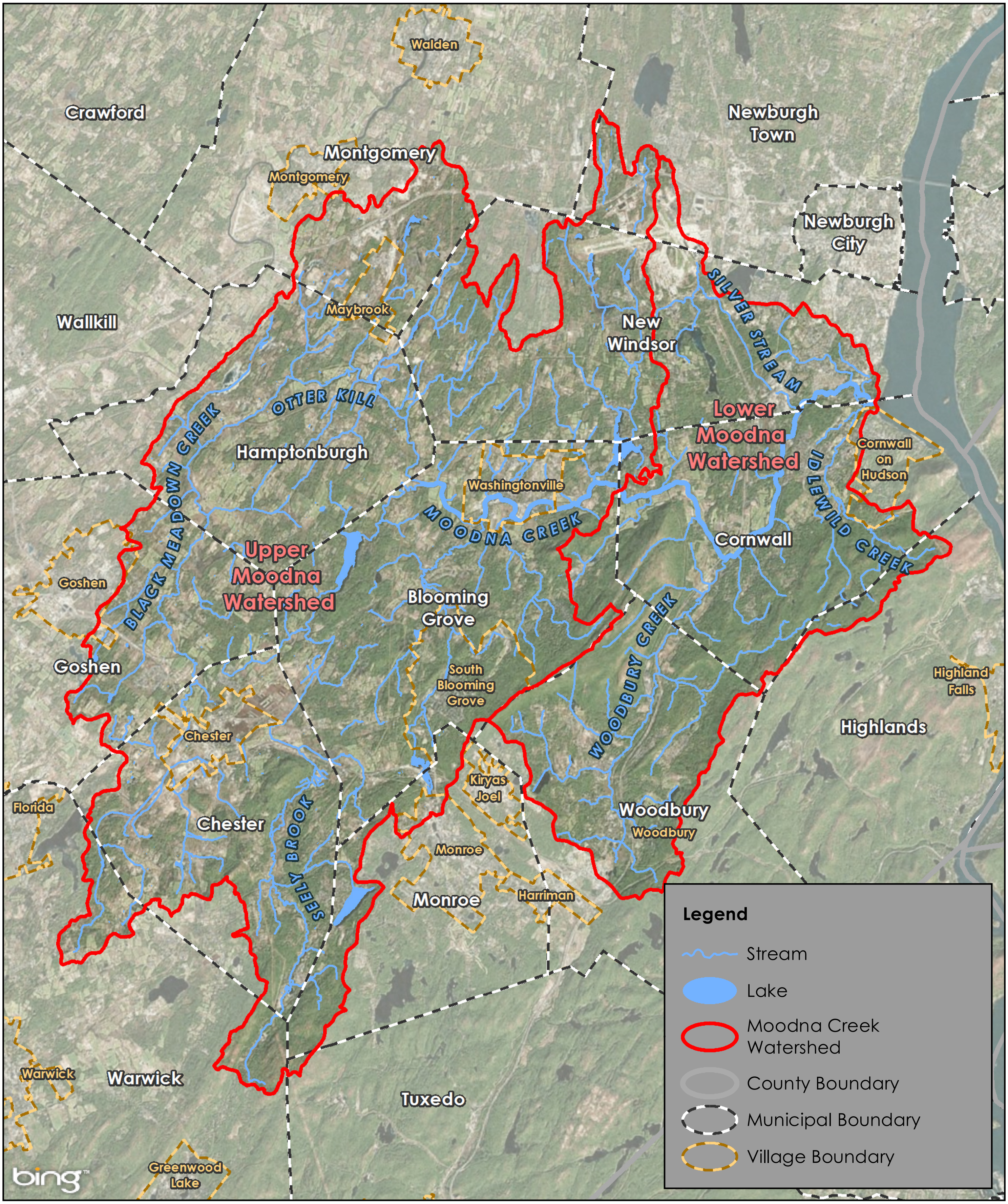

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FIGURE 1
WATERSHED MAP

MOODNA CREEK WATERSHED
AND FLOOD MITIGATION ASSESSMENT
ORANGE COUNTY, NEW YORK

pH

PRINCETON HYDRO, LLC.
1108 OLD YORK ROAD
P.O. BOX 720
RINGOES, NJ 08551
*with offices in NJ, PA and CT

NOTES:
1. Streams and lakes obtained from the United States Geological Survey's (USGS) National Hydrography Dataset (NHD).
2. County, municipal, and village boundaries obtained from the New York State GIS Clearinghouse: gis.ny.gov
3. 2001-2004 aerial imagery obtained through ArcGIS Online Bing Maps (C) 2017 Microsoft Corporation and its data suppliers.

0 7,000 14,000 Feet

Map Projection: NAD 1983 StatePlane New York East FIPS 3101 Feet

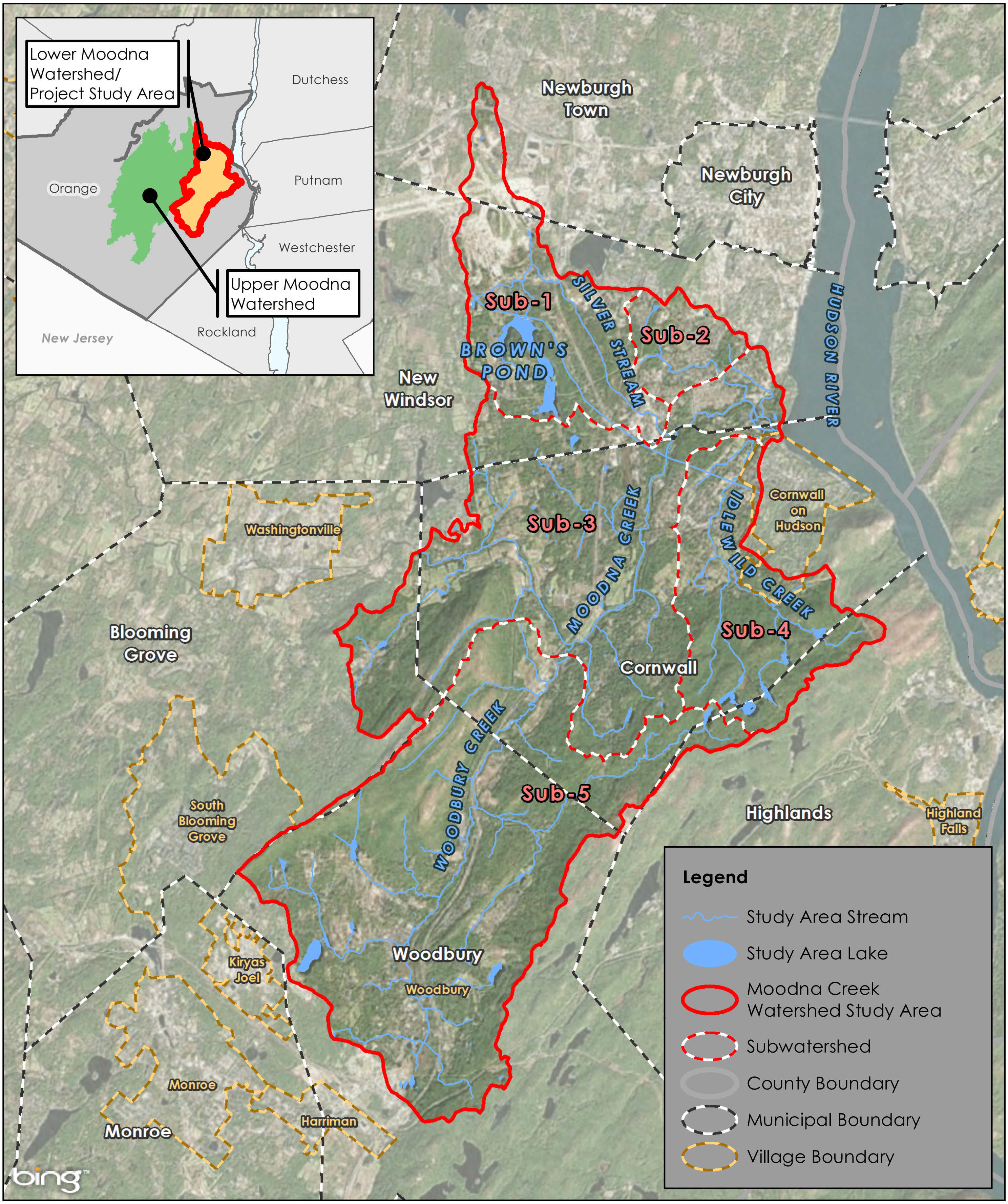


FIGURE 2
SUBWATERSHED MAP

MOODNA CREEK WATERSHED
AND FLOOD MITIGATION ASSESSMENT
ORANGE COUNTY, NEW YORK

PRINCETON HYDRO, LLC.
1108 OLD YORK ROAD
P.O. BOX 720
RINGOES, NJ 08551
*with offices in NJ, PA and CT

NOTES:
1. Streams and lakes obtained from the United States Geological Survey's (USGS) National Hydrography Dataset (NHD).
2. County, municipal, and village boundaries obtained from the New York State GIS Clearinghouse: gis.ny.gov
3. 2001-2004 aerial imagery obtained through ArcGIS Online Bing Maps (C) 2017 Microsoft Corporation and its data suppliers.

0 5,000 10,000 Feet

Map Projection: NAD 1983 StatePlane New York East FIPS 3101 Feet

File: P:\1449\Projects\1449003\GIS\MXD\Future_Flood_Assessment_Report_Maps\Moodna_Subwatershed.mxd, 1/30/2018, Drawn by thopper, Copyright Princeton Hydro, LLC.

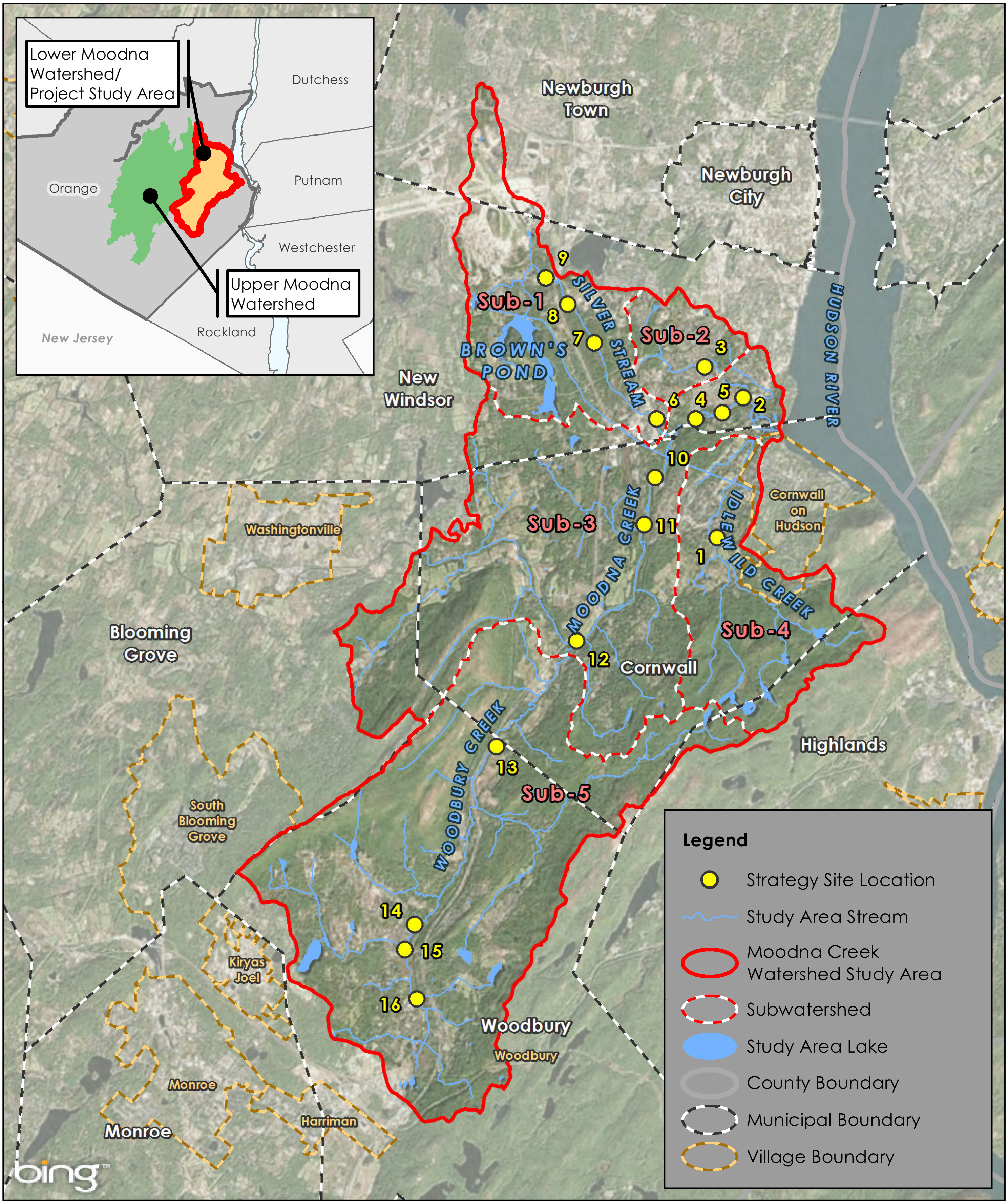


FIGURE 3
STRATEGY SITE LOCATION MAP

MOODNA CREEK WATERSHED
AND FLOOD MITIGATION ASSESSMENT
ORANGE COUNTY, NEW YORK

pH
PRINCETON HYDRO, LLC.
1108 OLD YORK ROAD
P.O. BOX 720
RINGOES, NJ 08551
*with offices in NJ, PA and CT

NOTES:
1. Strategy site locations are approximate.
1. Streams and lakes obtained from the United States Geological Survey's (USGS) National Hydrography Dataset (NHD).
2. County, municipal, and village boundaries obtained from the New York State GIS Clearinghouse: gis.ny.gov
3. 2001-2004 aerial imagery obtained through ArcGIS Online Bing Maps (C) 2017 Microsoft Corporation and its data suppliers.

0 5,000 10,000 Feet

Map Projection: NAD 1983 StatePlane New York East FIPS 3101 Feet

APPENDIX A

PROJECT SITE EVALUATION METHODS AND RESULTS

Project Site Evaluation Methods and Results

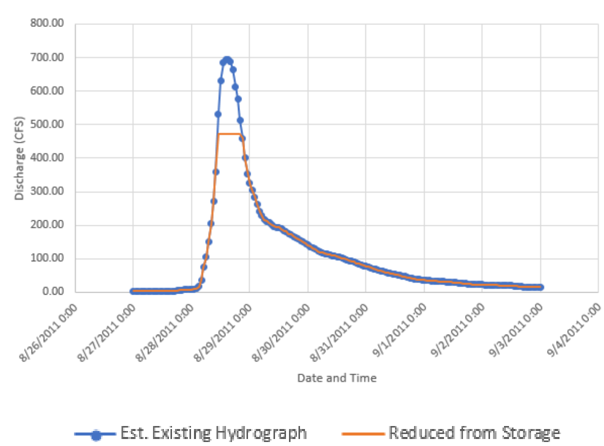
The Project Team identified 16 locations to analyze site-based solutions. Each site was evaluated for impacts resulting from the proposed strategy; increased floodplain storage, increased conveyance, or land preservation. The evaluation process analyzed either modifications to the hydrology – increase or loss in floodplain storage – or modifications to the hydraulics – increased conveyance. The assessment for land preservation analyzed the consequence of developing the land and losing the existing storage capacity, i.e. a loss in floodplain storage. Four of the sites, (2) New Windsor Wastewater Treatment Plant, (4) Forge Hill Road, (11) Route 32/Mill Street, and (14) Lakeside Drive, address site specific conditions, such as failing valley walls, and are thus not designed to directly impact upstream or downstream flood conditions.

Hydrologic Modifications

In order to assess the maximum beneficial impacts from the creation of storage and the maximum negative impact from the loss of storage, the Project Team analyzed the hydrograph from Hurricane Irene recorded along Moodna Creek (8-inches of total rainfall with 5.6-inches of runoff). A unit hydrograph (discharge per watershed acre) was created for the storm event. At each proposed storage location (increase or loss), the unit hydrograph was multiplied by the location's watershed area to create the estimated hydrograph for the same event that also produced 5.6-inches of runoff.

Beneficial Impacts from the Creation of Floodplain Storage

The maximum effect floodplain storage can have on peak flow is when the storage volume is removed directly from the peak of the hydrograph; effectively truncating the hydrograph down to a new peak flow. This is the assumption used by the Project Team for this analysis. Using this assumption, the area between the existing and proposed hydrographs equals the proposed storage volume. Through a series of iterative calculations, the reduced peak that produced the proposed storage volume (difference in hydrograph areas) was calculated.

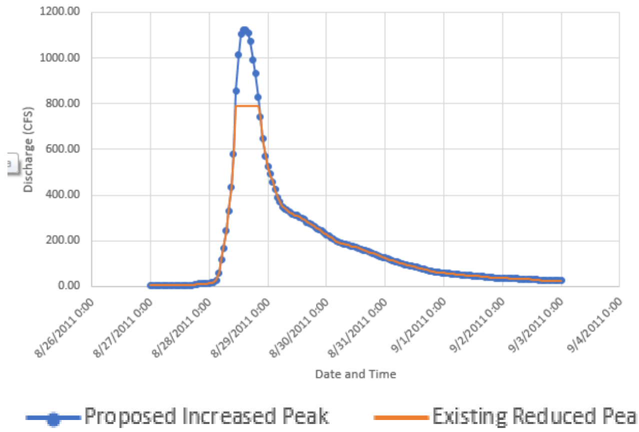


After the estimated existing peak flow and the reduced proposed peak flow had been calculated, both flows were modeled in the steady-state, 1-D HEC-RAS model created by the Project Team. These model results were used to estimate the maximum change in water surface elevation and flood extent that the proposed storage may provide.

Negative Impacts from the Loss of Floodplain Storage

The maximum effect the loss of storage can have on peak flow is when the storage volume is added directly to the peak of the hydrograph. Again, this is the assumption used by the Project Team for this analysis. Using this assumption, the area between the existing and proposed hydrographs equals the existing storage to be lost. Through a series of iterative calculations, the increased peak that produces the existing storage volume to be lost (difference in hydrograph areas) can be calculated. In several cases, the increased peak produced a total amount of runoff greater than the total number of inches of rainfall. In these cases, the peak was reduced such that the total runoff equaled the total rainfall. While this is an extreme case, it helps establish the maximum possible change.

As with the proposed storage locations, the estimated existing peak flow and the increased proposed peak flow were modeled in the steady-state, 1-D HEC-RAS model. These model results were used to estimate the maximum change in water surface elevation and flood extent that the loss of storage might create.



Hydraulic Modifications

Strategies that increase conveyance were evaluated based on the impact of enlarging the existing culvert or bridge, or increasing conveyance through the addition of floodplain culverts. The 1-D HEC-RAS model was modified to increase the bridge or culvert openings. Specifically, for bridge openings, the bridge width and low cord elevations were incrementally adjusted to provide increased conveyance. Culverts were similarly modeled by adjusting the culvert height, width, and diameter parameters, or adding additional floodplain culverts. The maximum proposed opening sizes were determined based on engineering judgement. There were no adjustments to the invert elevations or modifications to the terrain. Floodplain extents and water surface elevations were modeled with the proposed hydraulic modification and compared to existing conditions for both the existing 0.2 percent and future 1 percent storms.

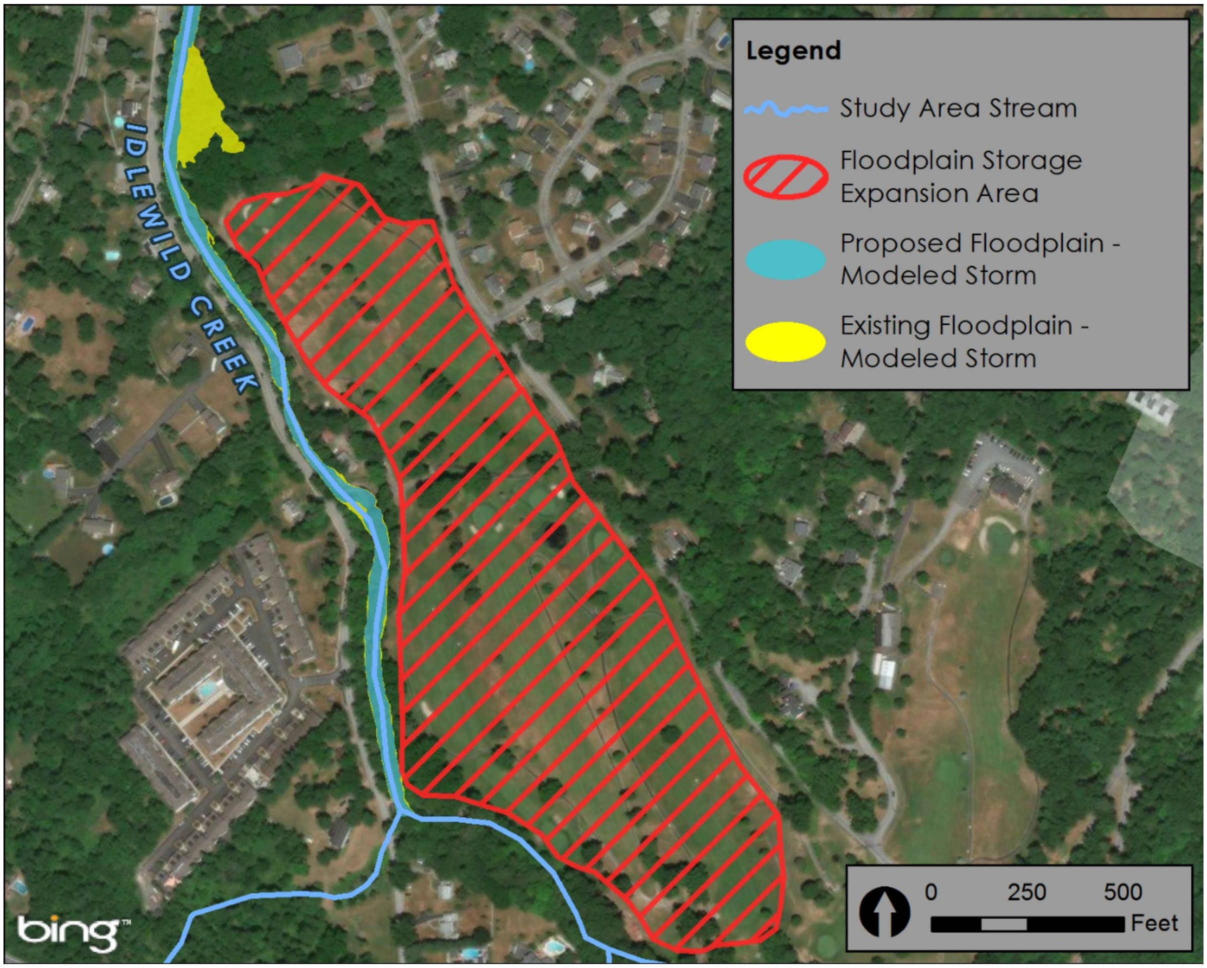
Project Site Results Summary

Results for each project site are displayed below. Flood extents and water surface elevation cross sections or stream profiles are shown, when appropriate. Cross sections are depicted from river left to river right looking downstream, and profiles are shown from downstream to upstream. General cost estimates are included based on construction costs obtained from RSMeans, engineering and permitting, and surveying estimates.

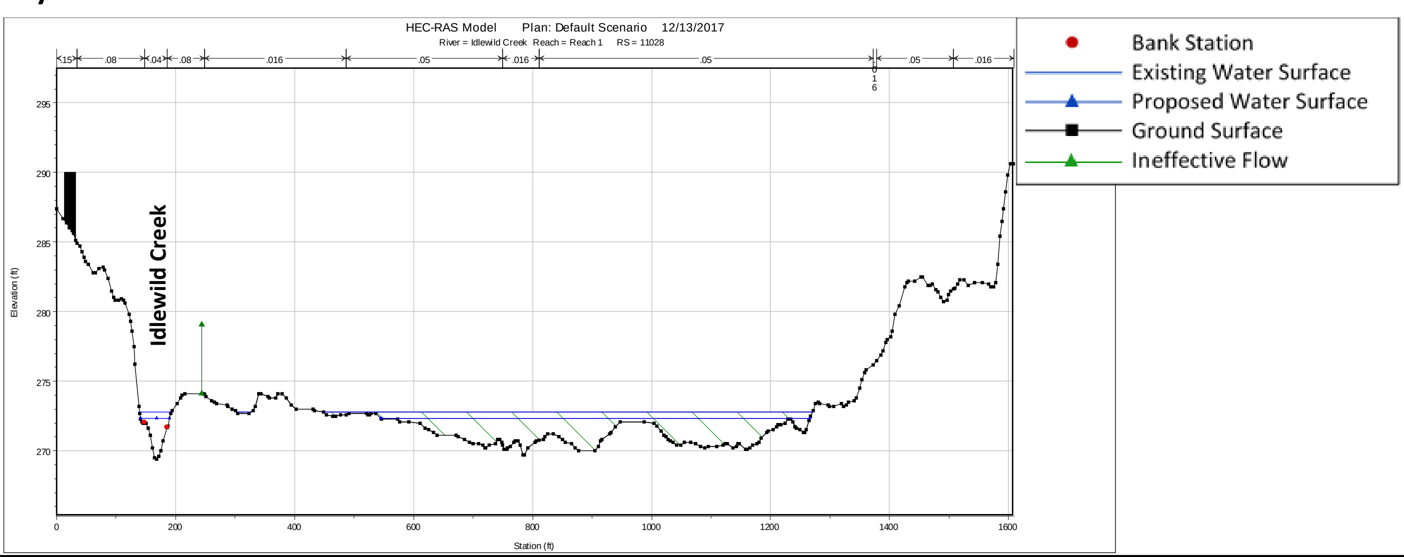
Strategy Site ID No.: 1
Strategy Site Name: Storm King Golf Club

Strategy Type: Increase Floodplain Storage
Site Location: 41.429, -74.033; Cornwall

Site Map



Hydraulic Model Cross Section



Cost Estimate

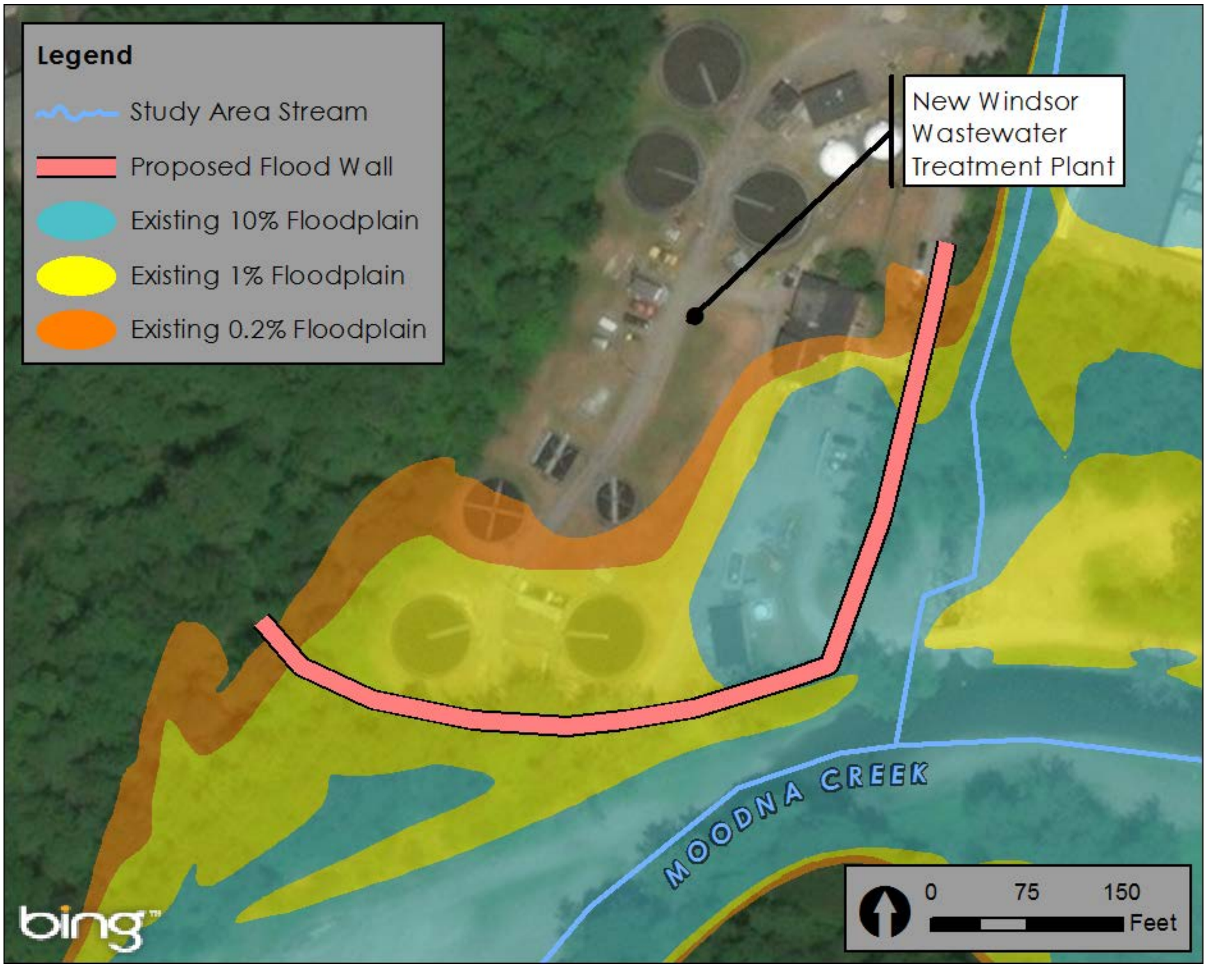
1. Continental Road				
Item	**Quantity**	**Unit**	**Unit Price**	**Extension**
1. Construction				
Mobilization and Demobilization (10%)	1	L.S.	$410,019	$410,019
Clearing	27	Acre	$7,179	$194,556
Excavation	210,540	C.Y.	$11	$2,419,105
Planting & Installation	1,180,476	SQ FT	$1.25	$1,475,595
Erosion Control	4,840	SQ YD	$2	$10,938
Subtotal (Construction):				$4,510,214
2. Engineering and Permitting (15%)				$676,532
3. Surveying				$15,000
Subtotal (Professional Services):				$691,532
			Total:	**$5,201,746**

Additional Facts & Figures

- Floodplain storage expansion area: 27 acres
- Floodplain storage expansion volume: 130.5 acre-feet (42.5 million gallons)
- Estimated peak flow reduction: 32% at Main Street in the Town of Cornwall

Strategy Site ID No.: 2
Strategy Site Name: New Windsor Wastewater Treatment Plant
Strategy Type: Onsite Mitigation
Site Location: 41.460, -74.026; New Windsor

Site Map



Cost Estimate

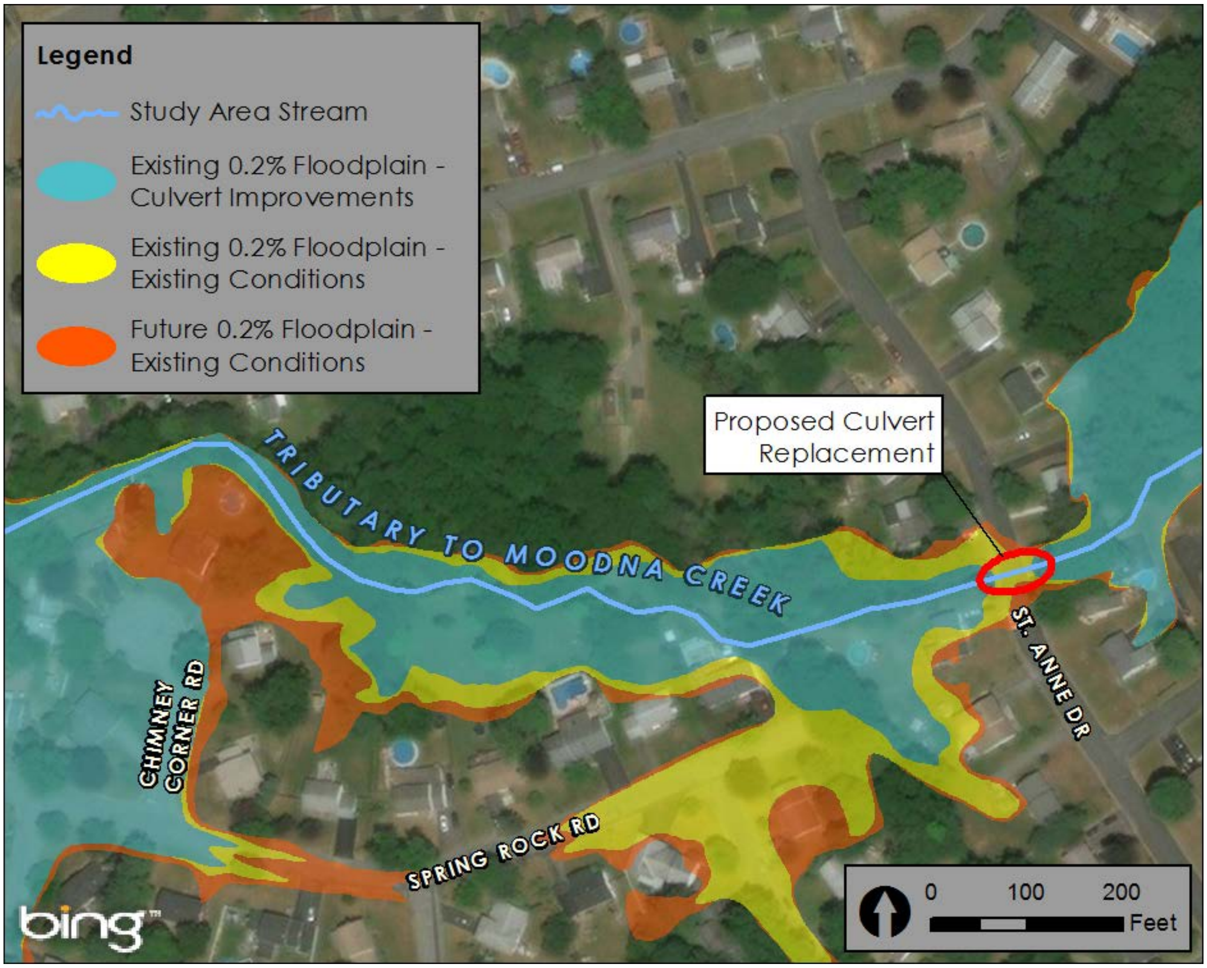
2. New Windsor WWTP Berm				
Item	**Quantity**	**Unit**	**Unit Price**	**Extension**
1. Construction				
Mobilization and Demobilization (10%)	1	L.S.	$230,087	$230,087
Clearing	0.20	Acre	$7,179	$1,436
Flood Log Flood Wall	9,840	SF	$232.50	$2,287,800
Planting & Installation	8,712	SQ FT	$0.08	$697
Erosion Control	4,840	SQ YD	$2	$10,938
Subtotal (Construction):				$2,530,958
2. Engineering and Permitting (15%)				$379,644
3. Surveying				$10,000
Subtotal (Professional Services):				$389,644
			Total:	**$2,920,602**

Additional Facts & Figures

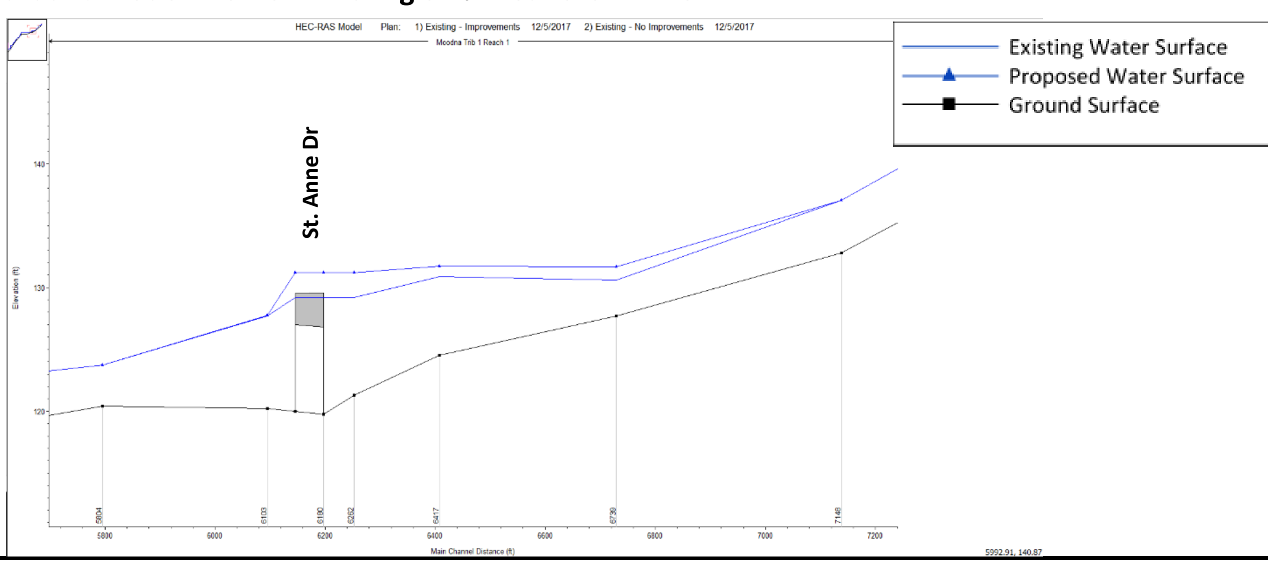
- Berm Elevation: 22 feet (NAVD88), provides protection up to the existing 0.2 percent storm

Strategy Site ID No.: 3
Strategy Site Name: Spring Rock Road and St. Anne Drive
Strategy Type: Increase Conveyance
Site Location: 41.467, -74.037; New Windsor

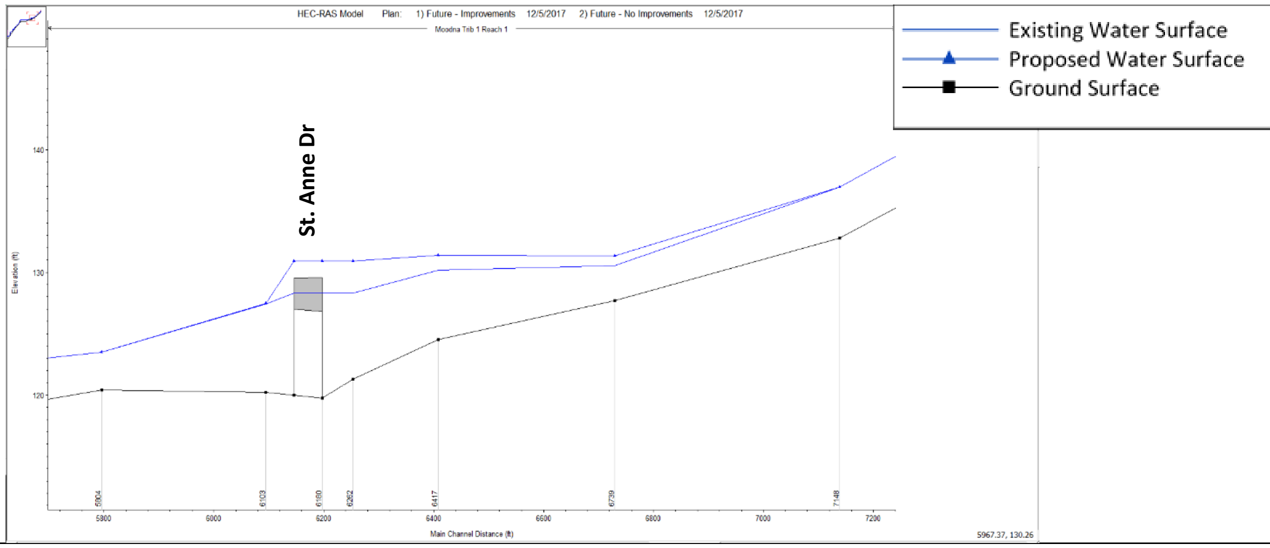
Site Map



Hydraulic Model Profile – Existing 0.2% Year Storm Event



Hydraulic Model Profile – Future 1% Year Storm Event



Cost Estimate

3. St. Anne Drive				
Item	**Quantity**	**Unit**	**Unit Price**	**Extension**
1. Construction				
Mobilization and Demobilization (10%)	1	L.S.	$11,540	$11,540
Clearing	0.1	Acre	$7,179	$718
Excavation	108	C.Y.	$11	$1,241
Planting & Installation	4,356	SQ FT	$0.08	$348
Erosion Control	484	SQ YD	$2	$1,094
Bridge Expansion	204	S.F.	549	$111,996
Subtotal (Construction):				$126,937
2. Engineering and Permitting (30%)				$38,081
3. Surveying				$15,000
Subtotal (Professional Services):				$53,081
			Total:	**$180,018**

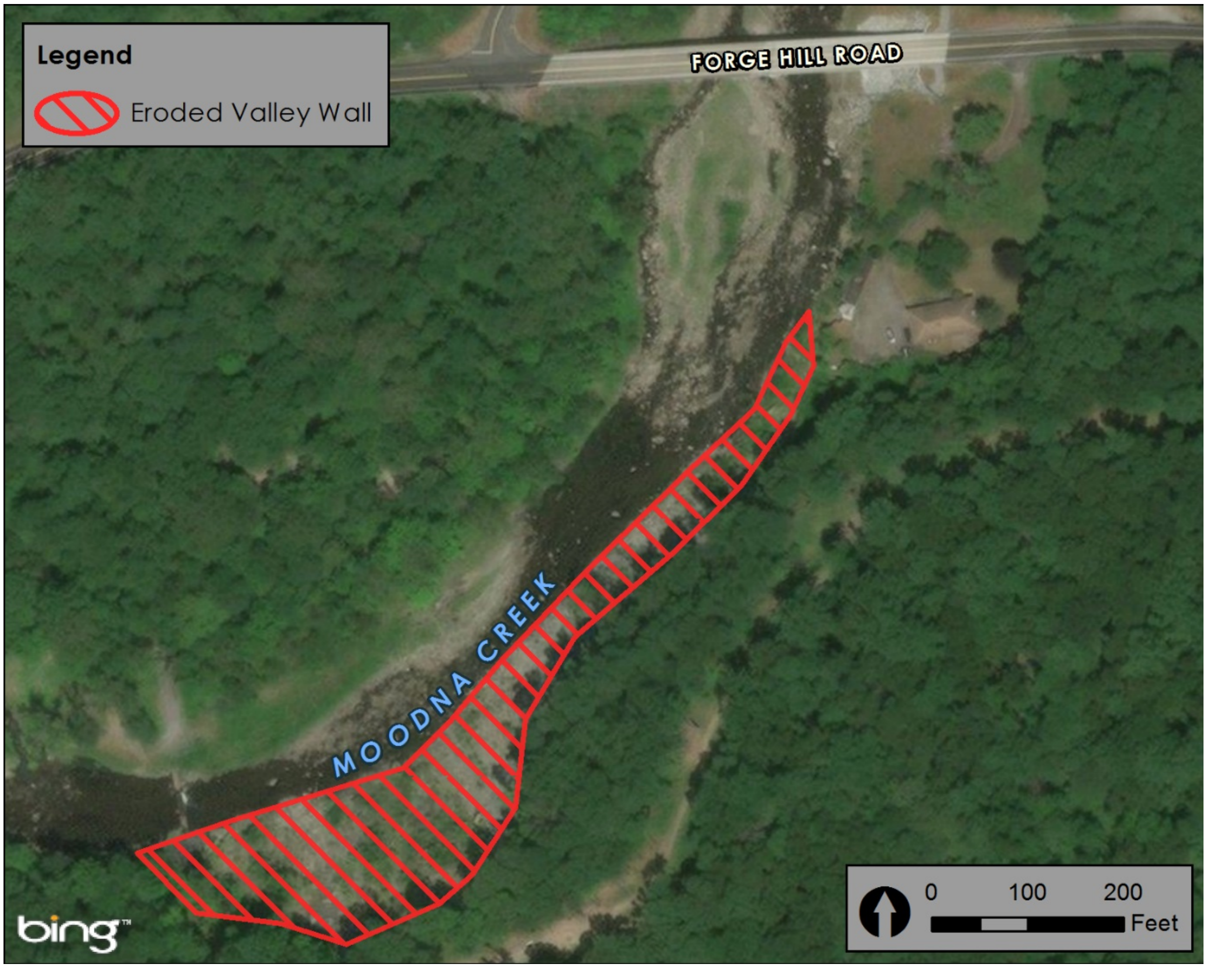
Additional Facts & Figures

- Existing culvert dimensions: 12 feet wide by 5 feet high
- Proposed culvert dimensions: 16 feet wide by 7 feet high

Strategy Site ID No.: 4
Strategy Site Name: Forge Hill Road

Strategy Type: Erosion Mitigation
Site Location: 41.456, -74.039; New Windsor, Cornwall

Site Map



Cost Estimate

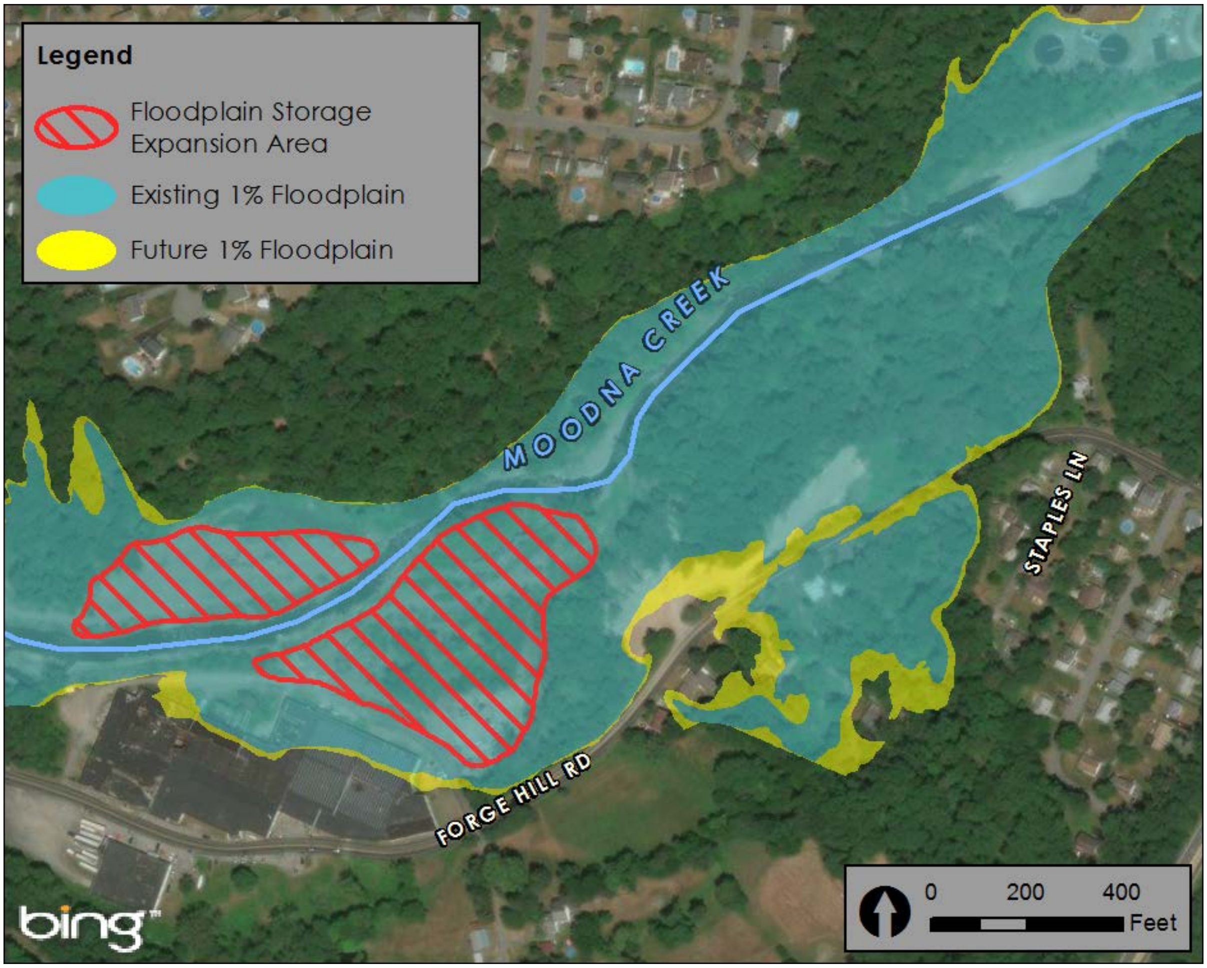
4. Forge Hill Road				
Item	**Quantity**	**Unit**	**Unit Price**	**Extension**
1. Construction				
Mobilization and Demobilization (10%)	1	L.S.	$35,316	$35,316
Bank Stabilization	1,000	L.F.	$300	$300,000
Rock Vanes	5	Per	$10,000	$50,000
Planting & Installation	5,000	SQ FT	$0.38	$1,900
Erosion Control	556	SQ YD	$2	$1,256
Subtotal (Construction):				$388,471
2. Engineering and Permitting (15%)				$58,271
3. Surveying				$15,000
Subtotal (Professional Services):				$73,271
			Total:	**$461,742**

Additional Facts & Figures

- Eroded valley wall area: 1.68 acres

Strategy Site ID No.: 5	**Strategy Type:** Increase Floodplain Storage
Strategy Site Name: Butterhill Park	**Site Location:** 41.457, -74.032; New Windsor

Site Map



Cost Estimate

5. Butterhill Park				
Item	**Quantity**	**Unit**	**Unit Price**	**Extension**
1. Construction				
Mobilization and Demobilization (10%)	1	L.S.	$91,183	$91,183
Clearing	6	Acre	$7,178	$44,864
Excavation	60,500	C.Y.	$11	$695,145
Planting & Installation	272,250	SQ FT	$0.38	$103,455
Erosion Control	30,250	SQ YD	$2	$68,365
Subtotal (Construction):				$1,003,012
2. Engineering and Permitting (15%)				$150,452
3. Surveying				$15,000
Subtotal (Professional Services):				$165,452
			Total:	**$1,168,463**

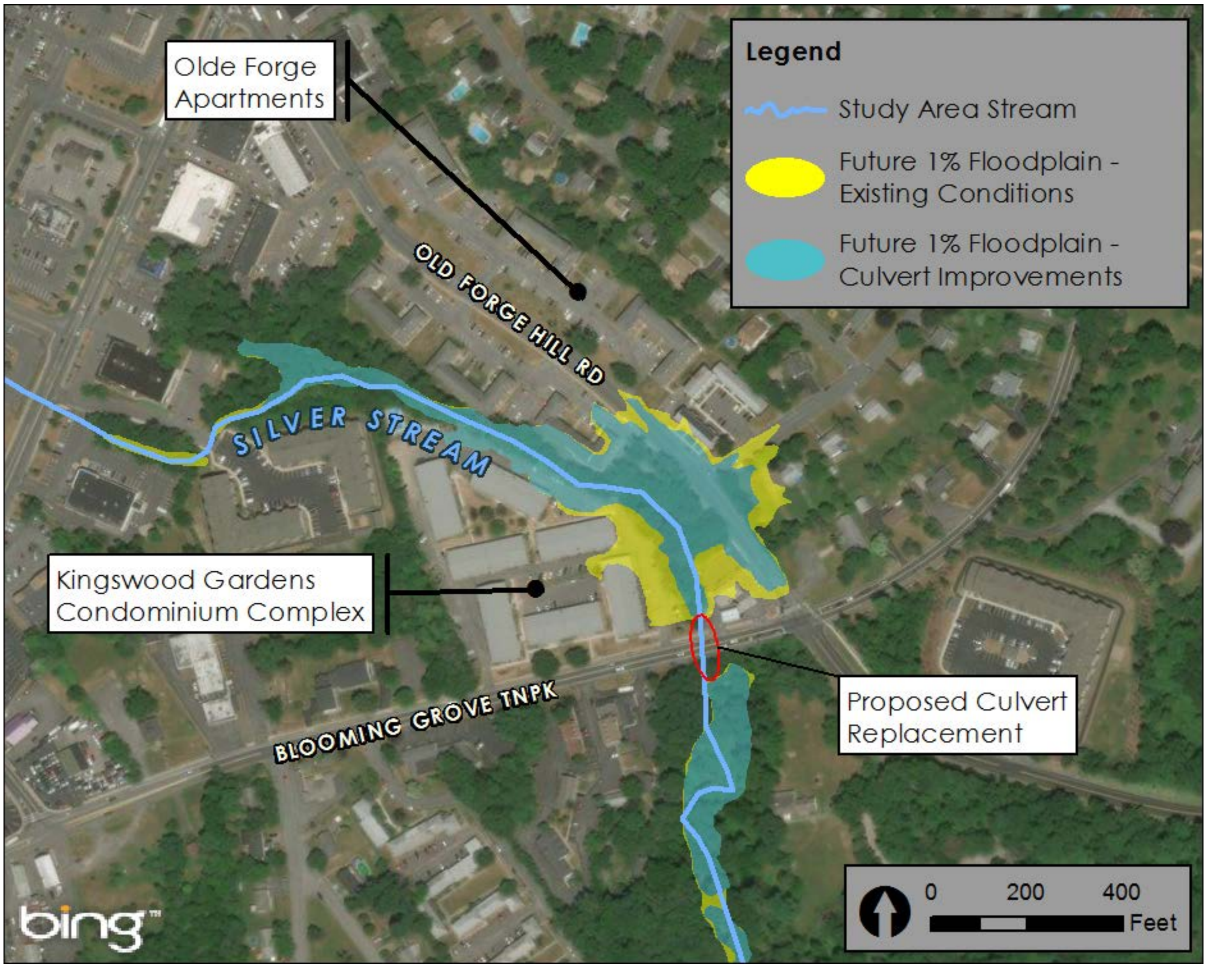
Additional Facts & Figures

- Floodplain storage expansion area: 6.30 acres
- Floodplain storage expansion volume: 37.5 acre-feet (12.2 million gallons)
- Estimated peak flow reduction: 3%
- Significant impacts to the extent or depth of flooding upstream or downstream in large storm events are not anticipated

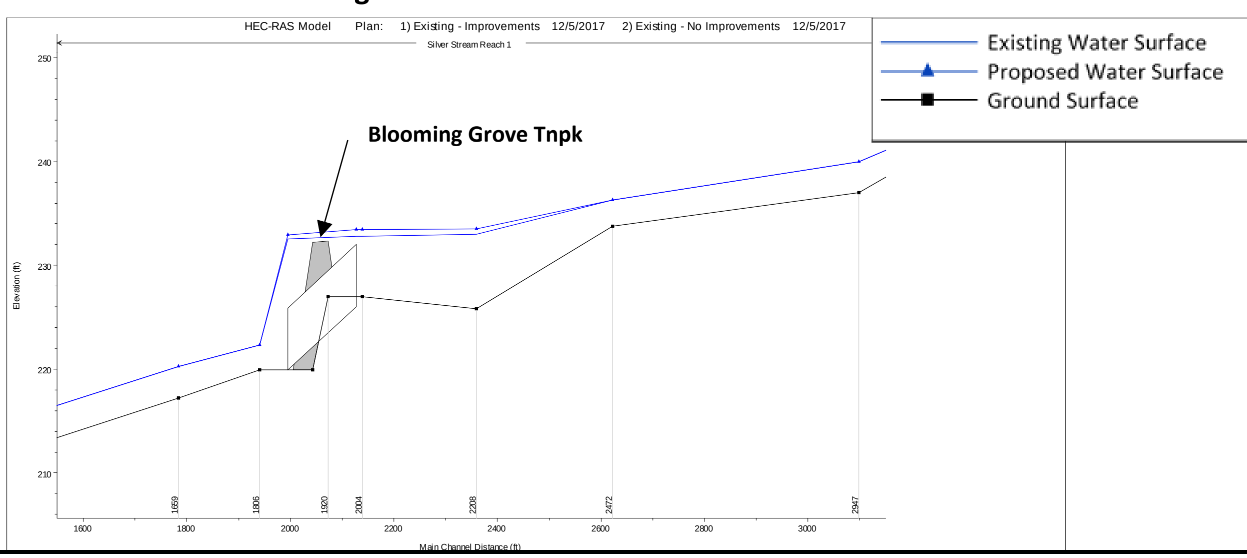
Strategy Site ID No.: 6
Strategy Site Name: Blooming Grove Turnpike

Strategy Type: Increase Conveyance
Site Location: 41.456, -74.050; New Windsor

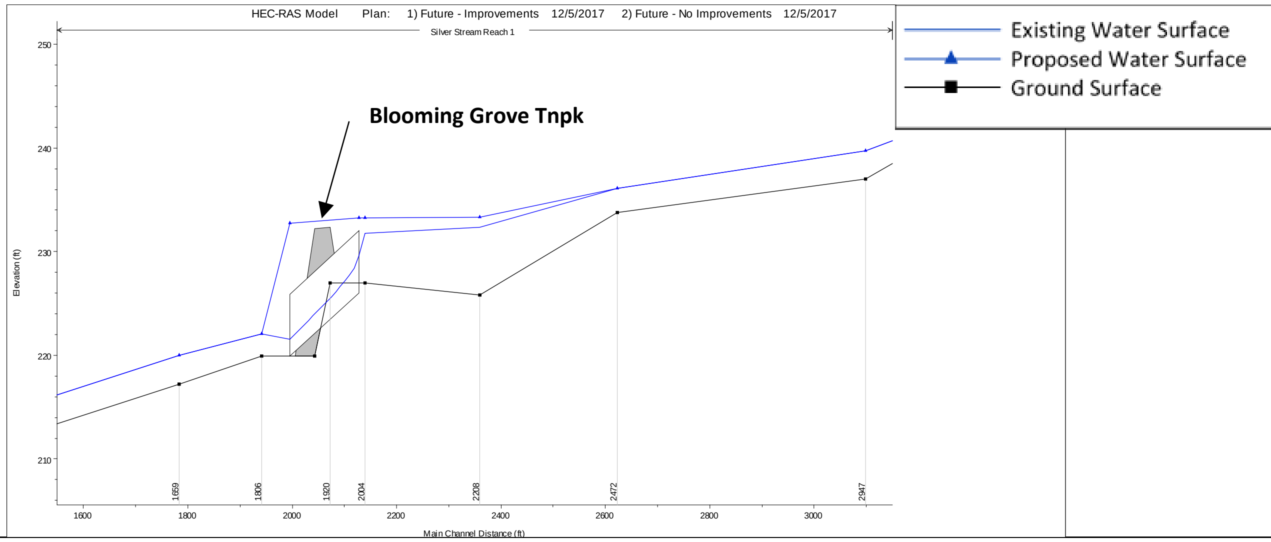
Site Map



Hydraulic Model Profile – Existing 0.2% Year Storm Event



Hydraulic Model Profile – Future 1% Year Storm Event



Cost Estimate

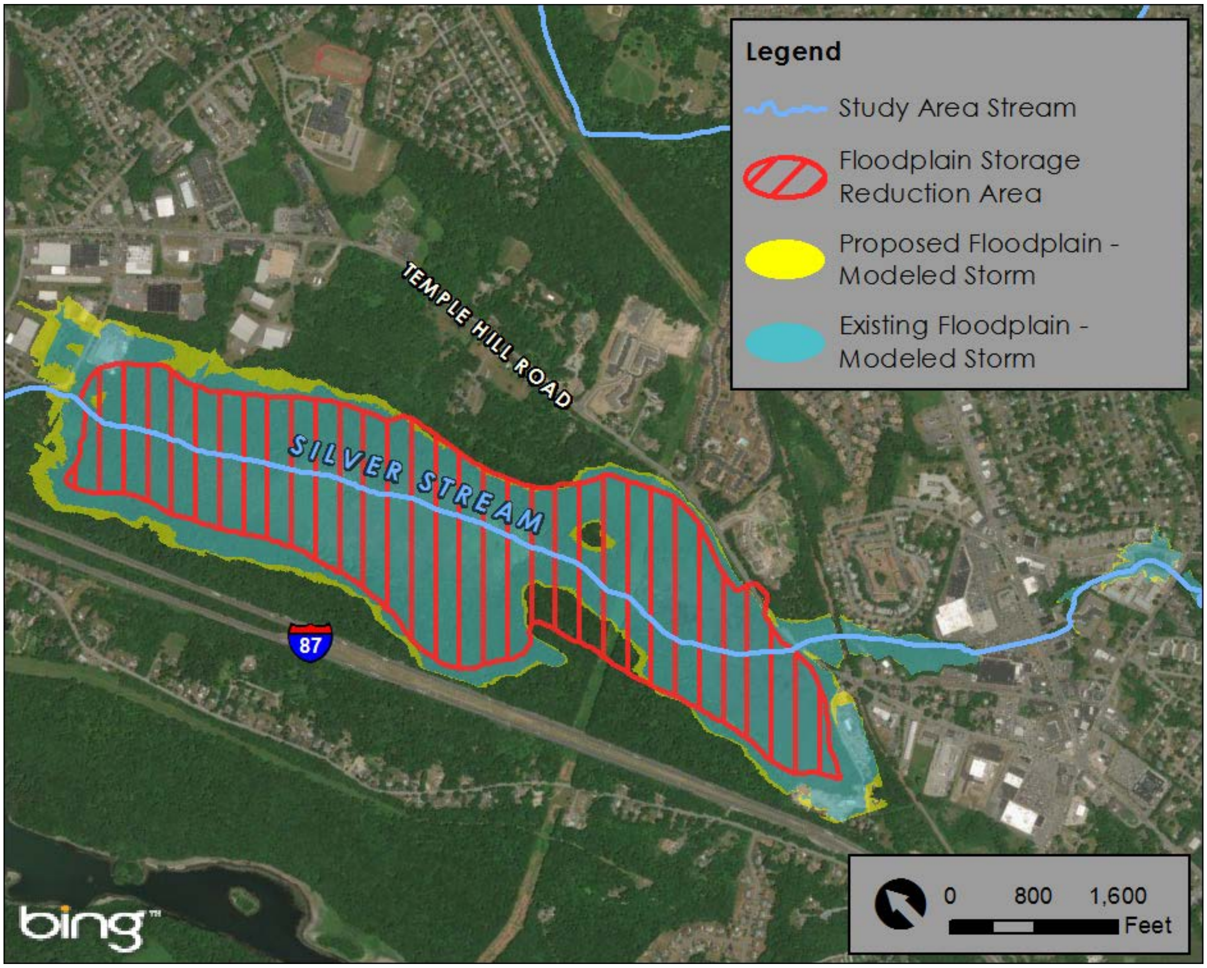
6. Blooming Grove Turnpike				
Item	**Quantity**	**Unit**	**Unit Price**	**Extension**
1. Construction				
Mobilization and Demobilization (10%)	1	L.S.	$58,487	$58,487
Clearing	0.1	Acre	$7,179	$718
Excavation	258	C.Y.	$11	$2,964
Planting & Installation	4,356	SQ FT	$0.08	$348
Erosion Control	484	SQ YD	$2	$1,094
Bridge Expansion	1056	S.F.	549	$579,744
Subtotal (Construction):				$643,356
2. Engineering and Permitting (30%)				$193,007
3. Surveying				$20,000
Subtotal (Professional Services):				$213,007
Total:				**$856,362**

Additional Facts & Figures

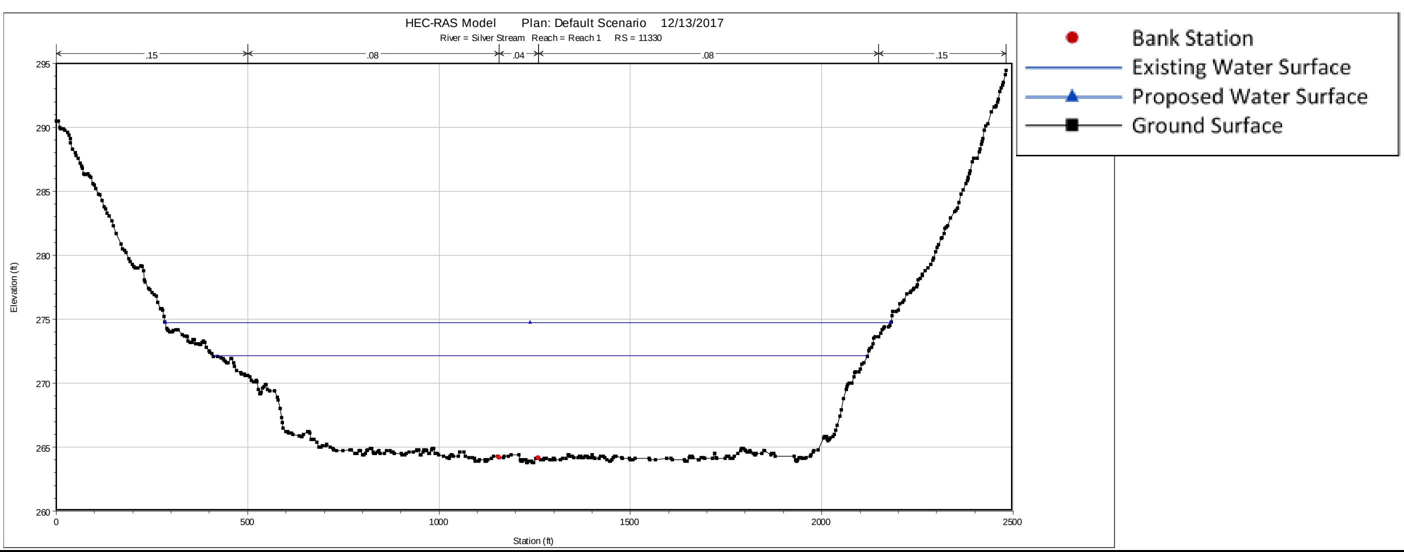
- Existing culvert dimensions: 8 feet wide by 6 feet high
- Proposed culvert dimensions: 16 feet wide by 6 feet high
- Estimated reduction in water surface elevation: 1.5 feet
- Estimated change in 1 percent floodplain width: 250 feet wide to 100 feet wide

Strategy Site ID No.: 7
Strategy Site Name: Wetland Area Silver Stream Watershed
Strategy Type: Land Preservation
Site Location: 41.472, -74.068; New Windsor

Site Map



Hydraulic Model Cross Section



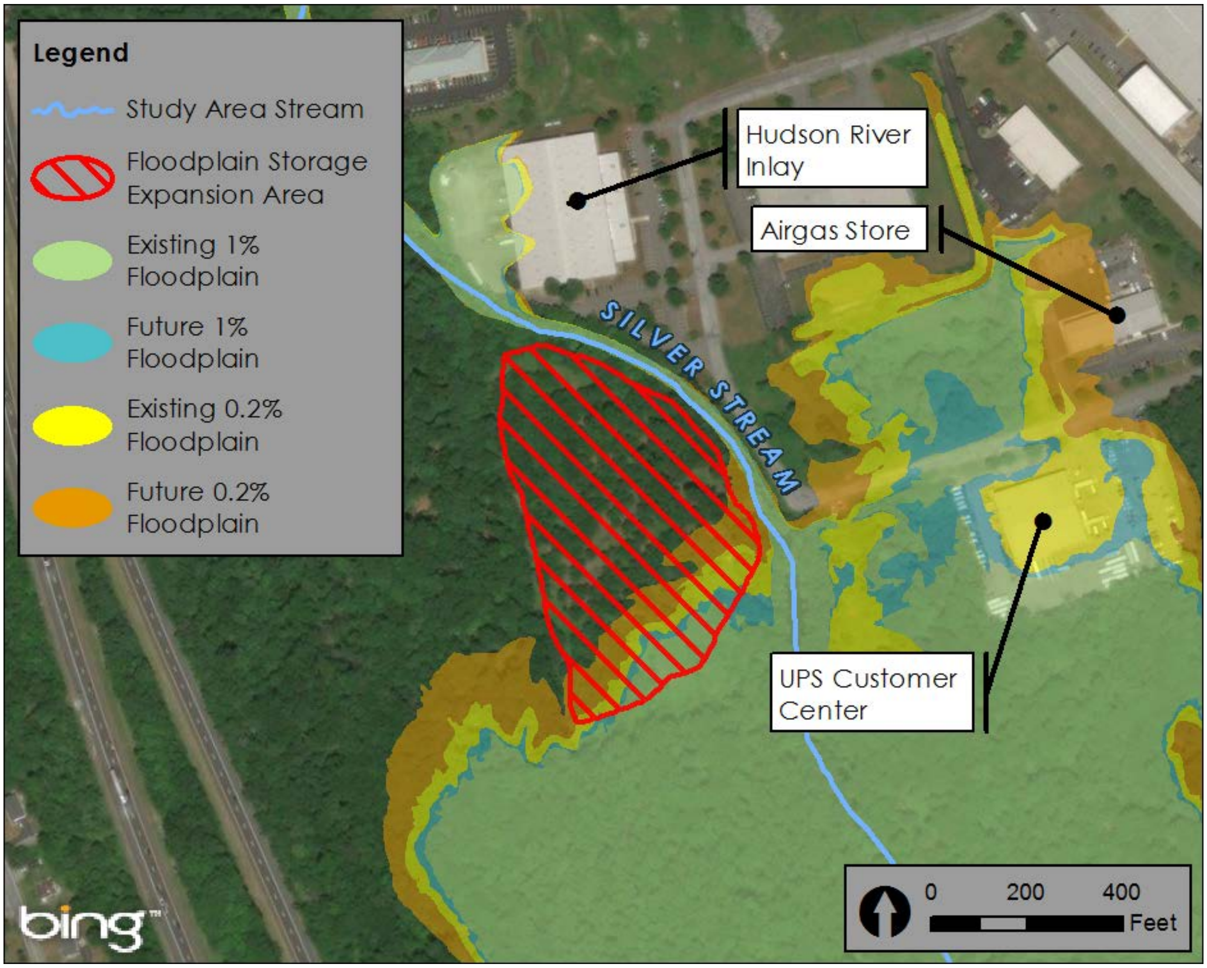
Additional Facts & Figures

- Floodplain storage reduction volume: 1,500 acre-feet (489 million gallons)
- Estimated peak flow increase: 42%

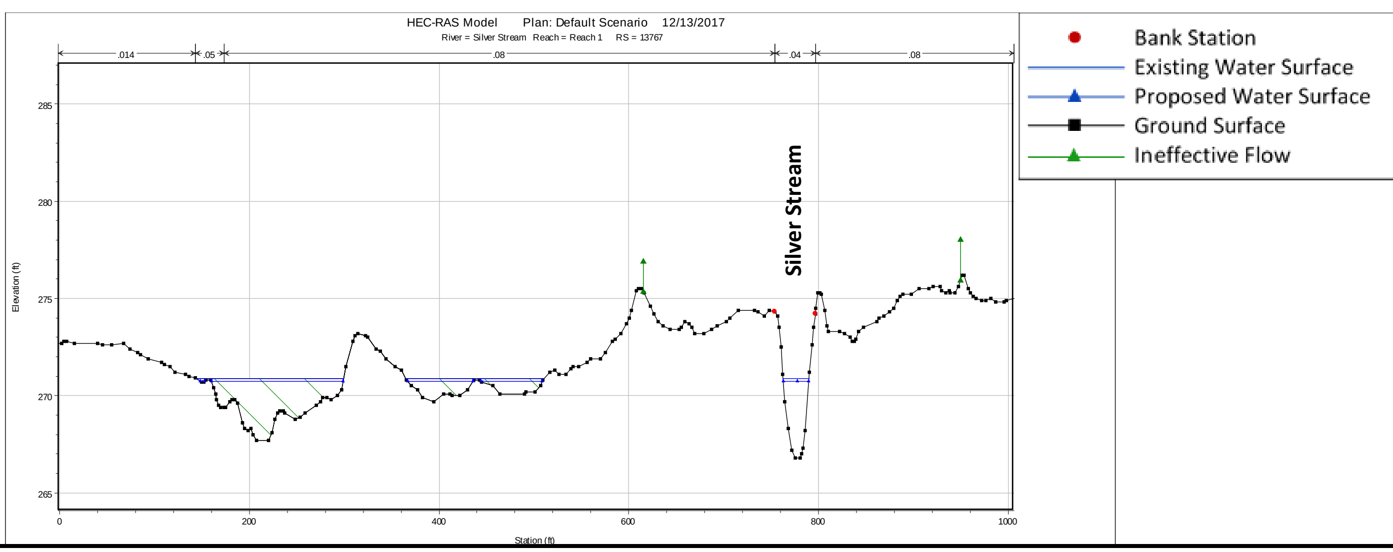
Strategy Site ID No.: 8
Strategy Site Name: Wembly Road

Strategy Type: Increase Floodplain Storage
Site Location: 41.480, -74.075; New Windsor

Site Map



Hydraulic Model Cross Section



Cost Estimate

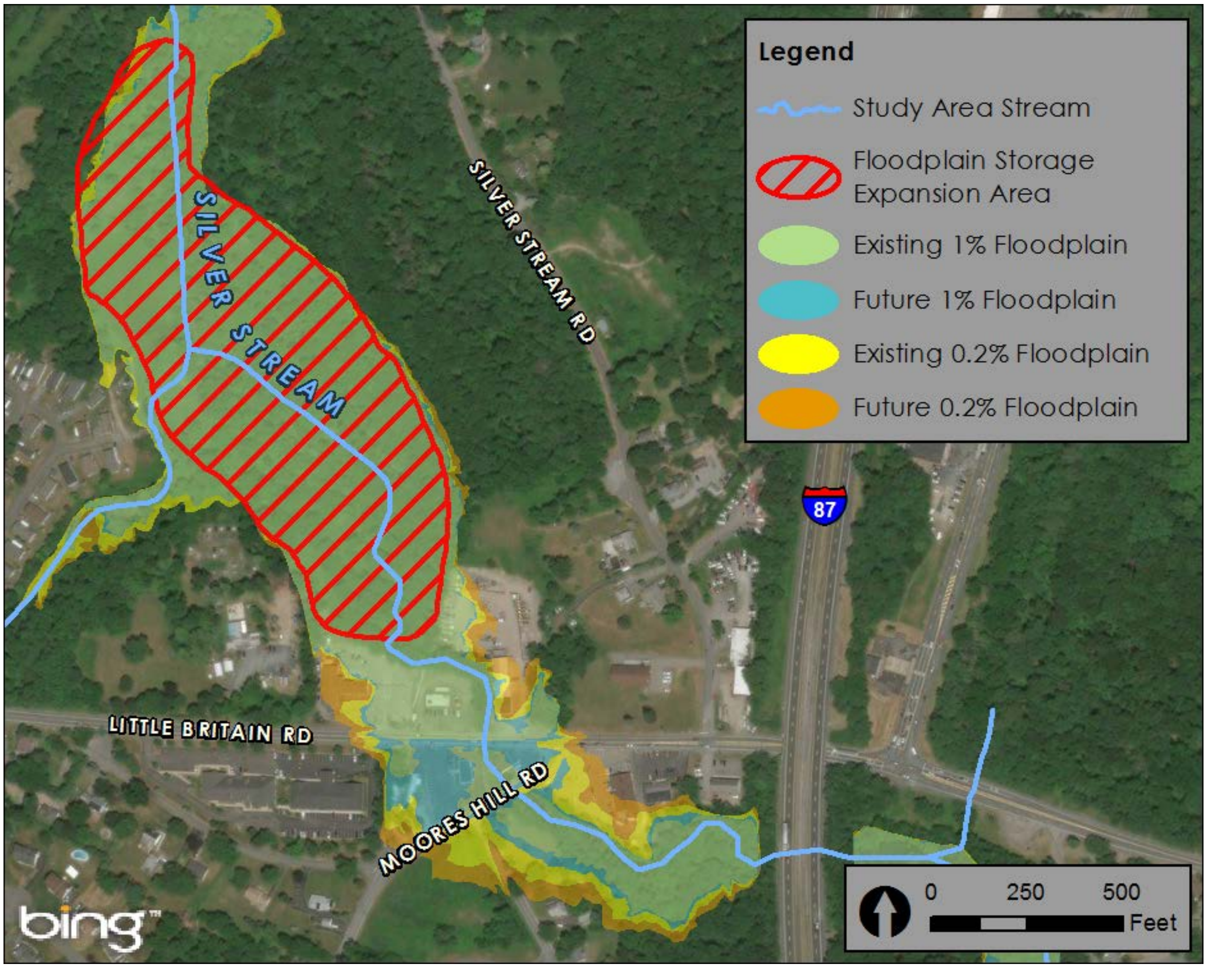
8. Wembly Road				
Item	**Quantity**	**Unit**	**Unit Price**	**Extension**
1. Construction				
Mobilization and Demobilization (10%)	1	L.S.	$91,037	$91,037
Clearing	6	Acre	$7,178	$44,792
Excavation	60,403	C.Y.	$11	$694,033
Planting & Installation	271,814	SQ FT	$0.38	$103,289
Erosion Control	30,202	SQ YD	$2	$68,256
Subtotal (Construction):				$1,001,407
2. Engineering and Permitting (15%)				$150,211
3. Surveying				$15,000
Subtotal (Professional Services):				$165,211
			Total:	**$1,166,618**

Additional Facts & Figures

- Floodplain storage expansion area: 6.25 acres
- Floodplain storage expansion volume: 37.5 acre-feet (12.2 million gallons)
- Estimated peak flow reduction: 14%
- Estimated reduction in water surface elevation: 0.2 feet

Strategy Site ID No.: 9
Strategy Site Name: Little Britain Road and Moores Hill Road
Strategy Type: Increase Floodplain Storage
Site Location: 41.486, -74.081; New Windsor

Site Map



Cost Estimate

9. Little Britain Road and Moores Hill Road				
Item	**Quantity**	**Unit**	**Unit Price**	**Extension**
1. Construction				
Mobilization and Demobilization (10%)	1	L.S.	$491,723	$491,723
Clearing	17	Acre	$7,178	$118,440
Excavation	26,620	C.Y.	$11	$305,864
Planting & Installation	718,740	SQ FT	$6	$4,312,440
Erosion Control	79,860	SQ YD	$2	$180,484
Subtotal (Construction):				$5,408,950
2. Engineering and Permitting (15%)				$811,343
3. Surveying				$15,000
Subtotal (Professional Services):				$826,343
			Total:	**$6,235,293**

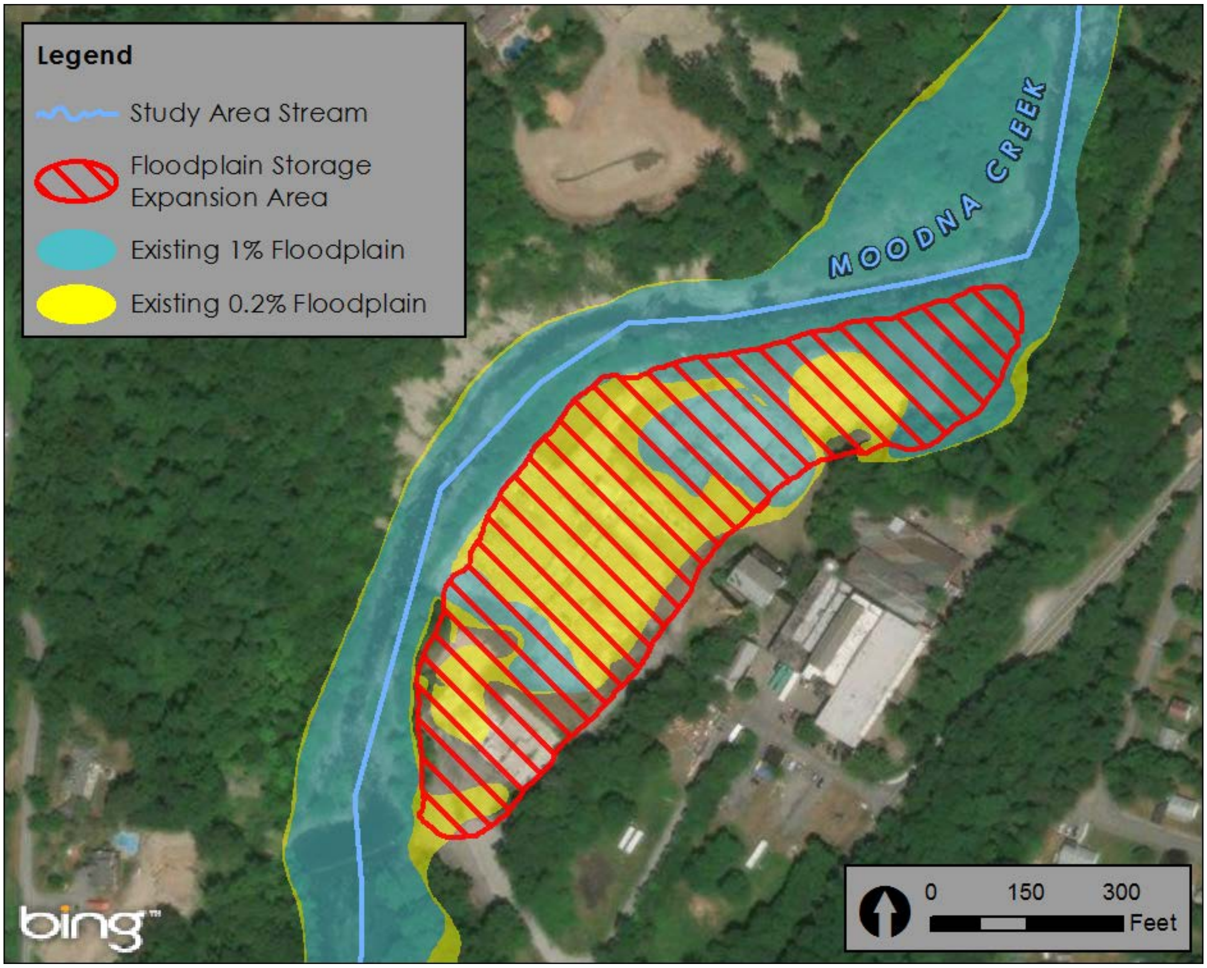
Additional Facts & Figures

- Floodplain storage expansion area: 16 acres
- Floodplain storage expansion volume: 16 acre-feet (5.2 million gallons)
- Estimated peak flow reduction: 8%
- Suggest individual property mitigation

Strategy Site ID No.: 10
Strategy Site Name: Paper Mill

Strategy Type: Increase Floodplain Storage
Site Location: 41.444, -74.051; Cornwall

Site Map



Cost Estimate

10. Paper Mill				
Item	**Quantity**	**Unit**	**Unit Price**	**Extension**
1. Construction				
Mobilization and Demobilization (10%)	1	L.S.	$141,053	$141,053
Clearing	7	Acre	$7,178	$50,247
Excavation	101,640	C.Y.	$11	$1,167,844
Planting & Installation	304,920	SQ FT	$0.38	$115,870
Erosion Control	33,880	SQ YD	$2	$76,569
Subtotal (Construction):				$1,551,582
2. Engineering and Permitting (15%)				$232,737
3. Surveying				$15,000
Subtotal (Professional Services):				$247,737
			Total:	**$1,799,320**

Additional Facts & Figures

- Floodplain storage expansion area: 7 acres
- Fill material removal volume: 101,000 cubic yards
- Estimated peak flow reduction: 5%

Strategy Site ID No.: 11
Strategy Site Name: Route 32/Mill Street

Strategy Type: Erosion Mitigation
Site Location: 41.434, -74.054; Cornwall

Site Map

Cost Estimate

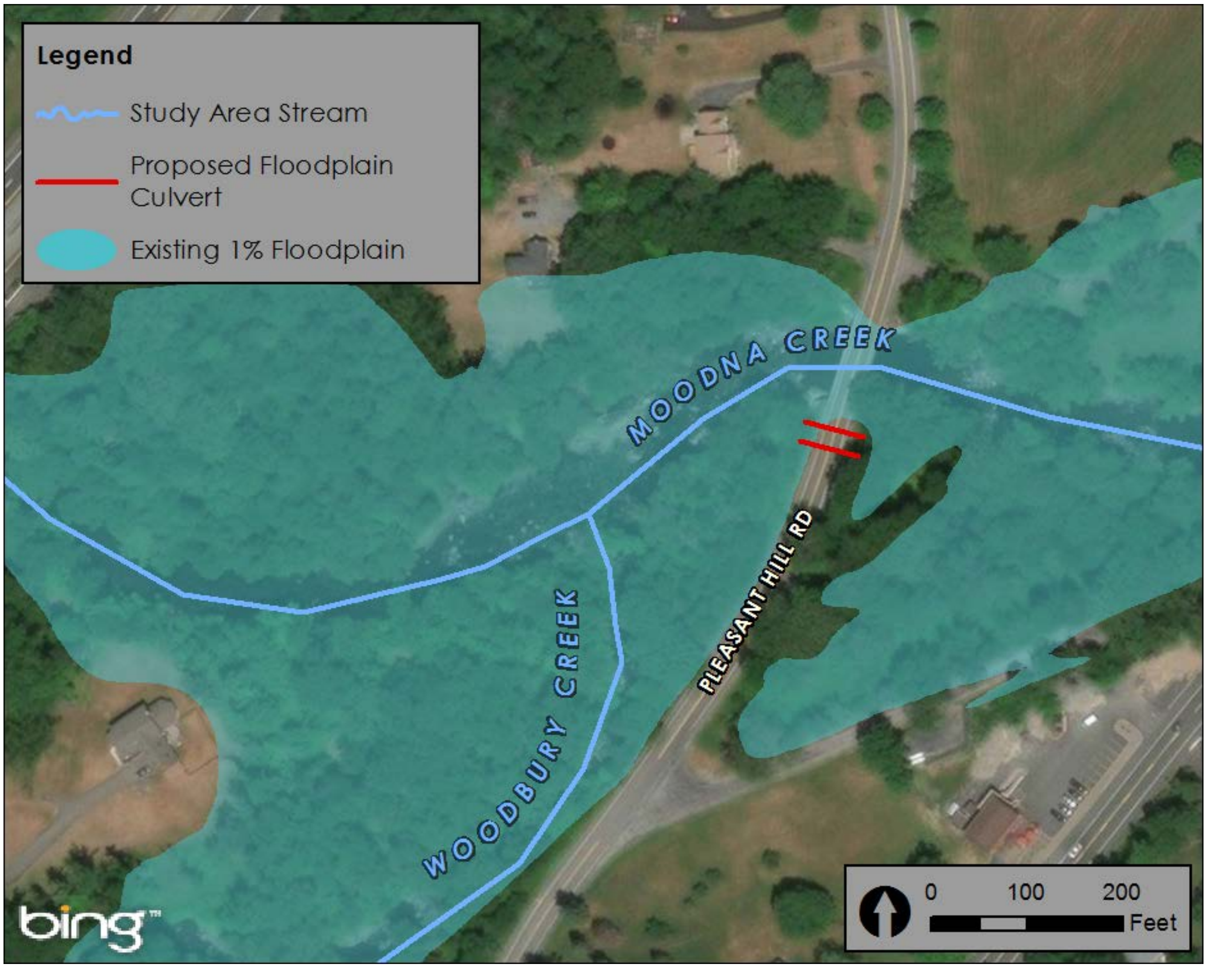
11. Failing Valley Wall #2				
Item	**Quantity**	**Unit**	**Unit Price**	**Extension**
1. Construction				
Mobilization and Demobilization (10%)	1	L.S.	$18,158	$18,158
Bank Stabilization	500	L.F.	$300	$150,000
Rock Vanes	3	Per	$10,000	$30,000
Planting & Installation	2,500	SQ FT	$0.38	$950
Erosion Control	278	SQ YD	$2	$628
Subtotal (Construction):				$199,736
2. Engineering and Permitting (15%)				$29,960
3. Surveying				$15,000
Subtotal (Professional Services):				$44,960
			Total:	**$244,696**

Additional Facts & Figures

- Eroded valley wall area: 0.86 acres

Strategy Site ID No.: 12	**Strategy Type:** Increase Conveyance
Strategy Site Name: Pleasant Hill Road / Route 79 Bridge	**Site Location:** 41.409, -74.073; Cornwall

Site Map



Cost Estimate

12. Pleasant Hill				
Item	**Quantity**	**Unit**	**Unit Price**	**Extension**
1. Construction				
Mobilization and Demobilization (10%)	1	L.S.	$3,074	$3,074
Clearing	0.1	Acre	$7,179	$718
Excavation	63	C.Y.	$11	$724
Planting & Installation	4,356	SQ FT	$0.08	$348
Erosion Control	484	SQ YD	$2	$1,094
Floodplain Culverts	86	L.F.	323.95	$27,860
Subtotal (Construction):				$33,818
2. Engineering and Permitting (30%)				$10,145
3. Surveying				$15,000
Subtotal (Professional Services):				$25,145
			Total:	**$58,964**

Additional Facts & Figures

- 2 floodplain culverts proposed
- Proposed culvert elevation: 22.9 feet (NAVD88)
- Proposed culvert width: 5 feet each
- Strategy reduces shear stress

Strategy Site ID No.: 13

Strategy Site Name: Maranath Lane

Strategy Type: Land Preservation

Site Location: 41.387, -74.096; Cornwall, Woodbury

Site Map

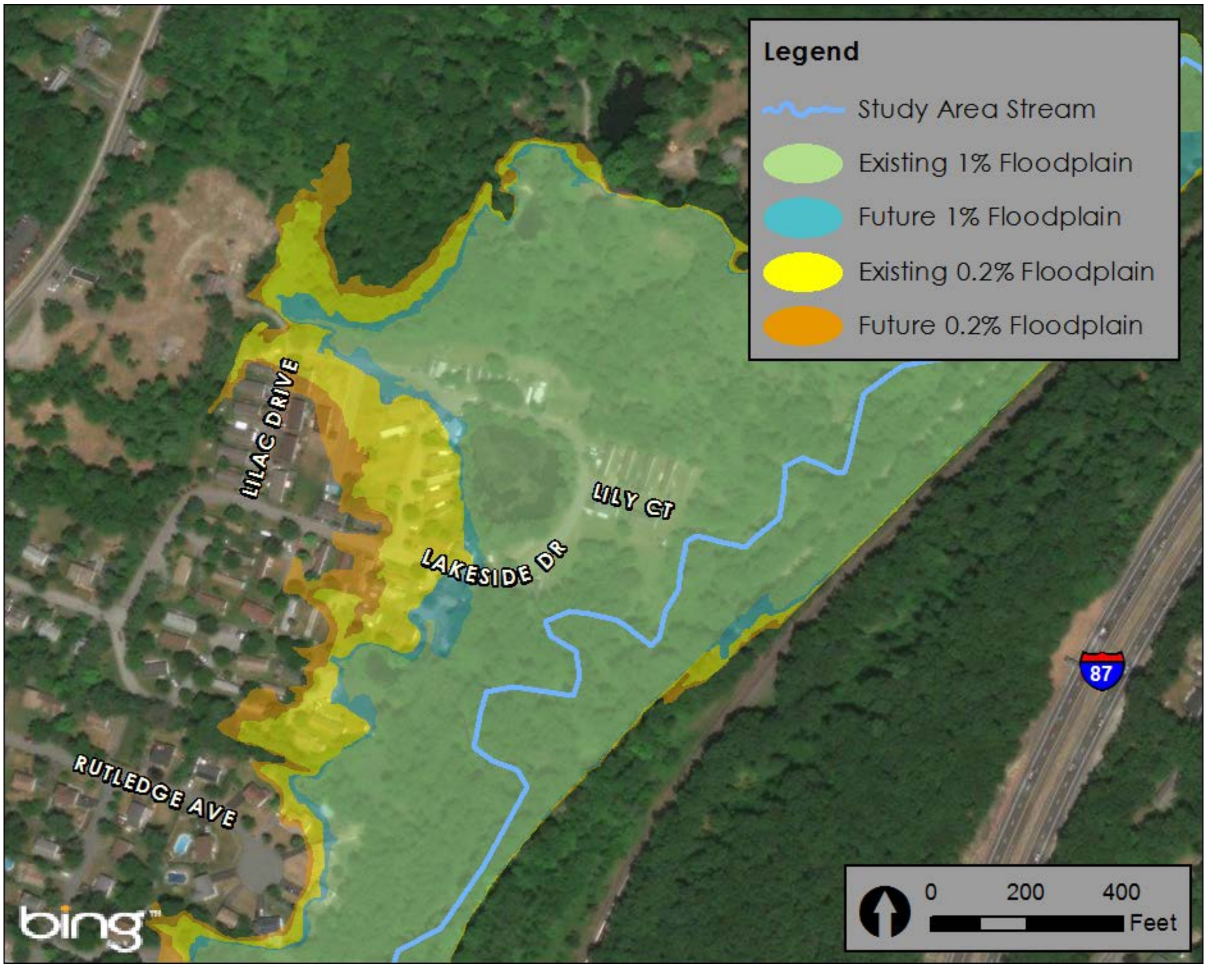
Additional Facts & Figures

- Floodplain storage reduction volume: 18.1 acre-feet (5.9 million gallons)
- Estimated peak flow increase: 3%

Strategy Site ID No.: 14
Strategy Site Name: Lakeside Drive

Strategy Type: Onsite Mitigation
Site Location: 41.350, -74.119; Woodbury

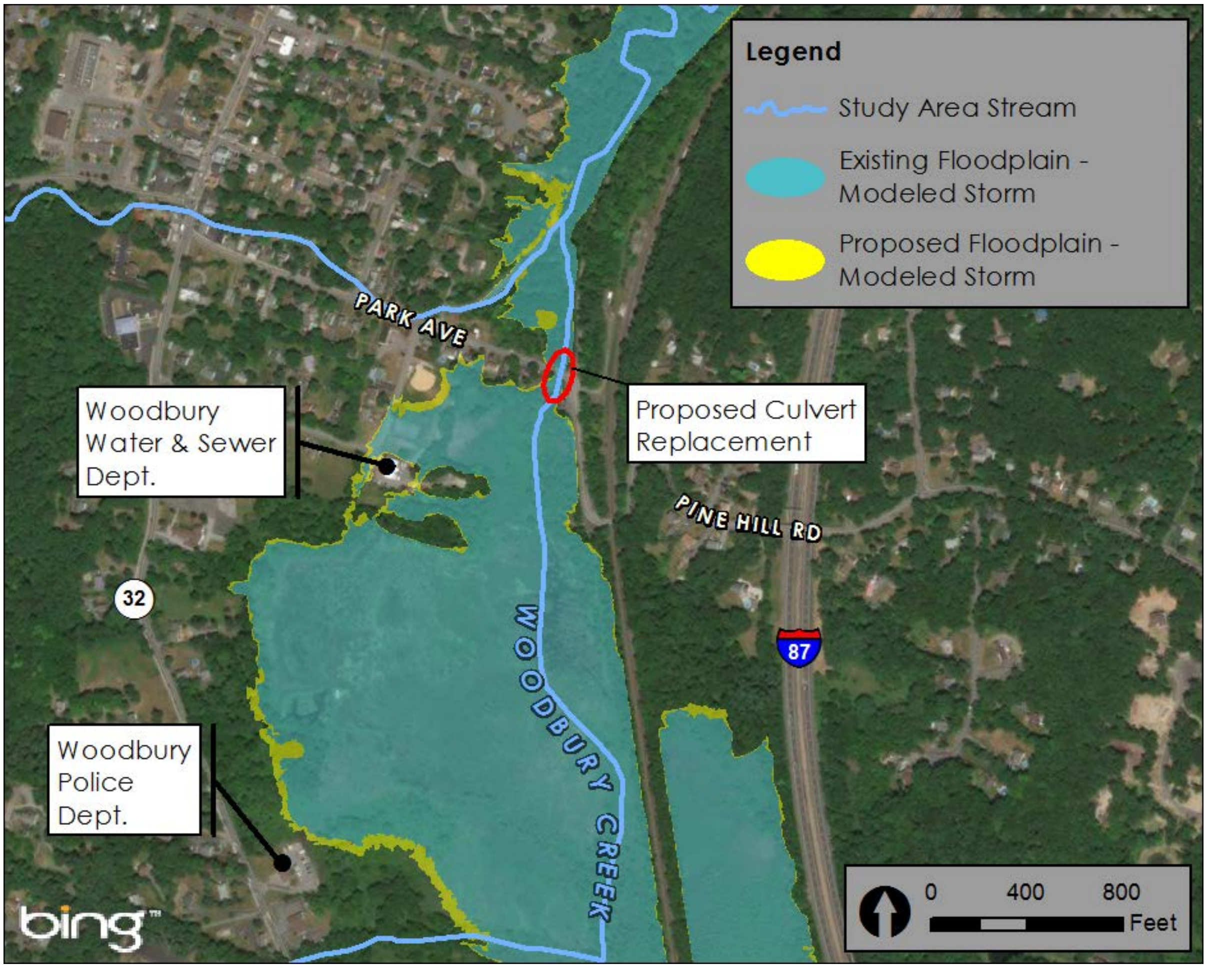
Site Map



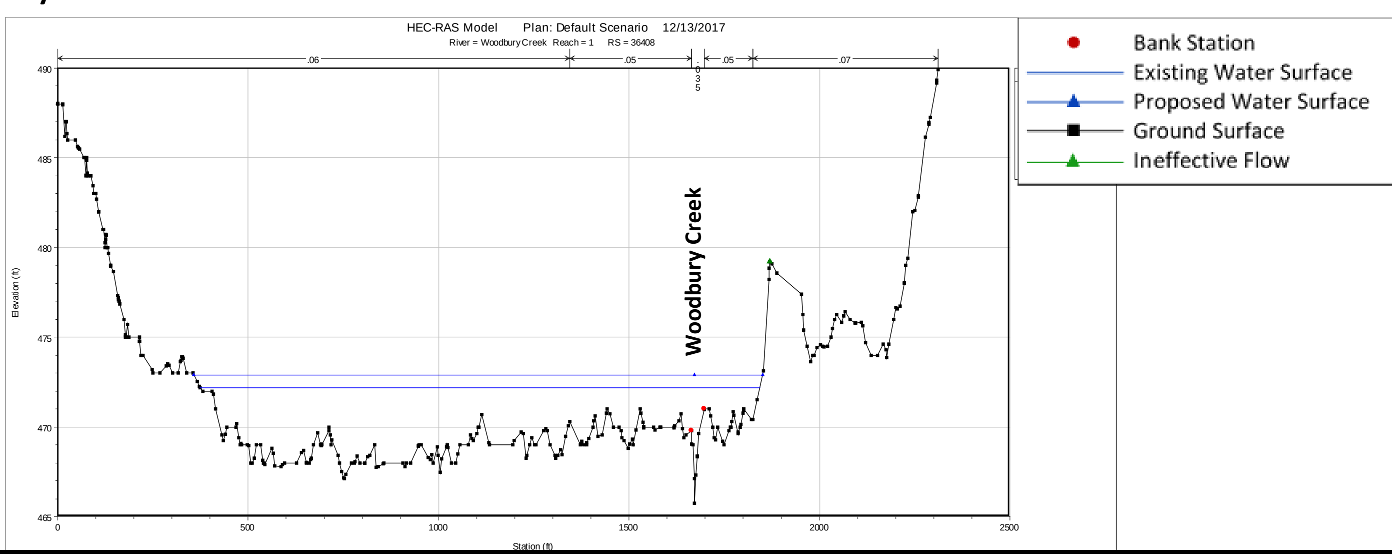
Strategy Site ID No.: 15
Strategy Site Name: Pine Hill Road

Strategy Type: Increase Conveyance/Land Preservation
Site Location: 41.344, -74.122; Woodbury

Site Map



Hydraulic Model Cross Section



Cost Estimate

15. Pine Hill Road				
Item	**Quantity**	**Unit**	**Unit Price**	**Extension**
1. Construction				
Mobilization and Demobilization (10%)	1	L.S.	$19,117	$19,117
Clearing	0.1	Acre	$7,179	$718
Excavation	109	C.Y.	$11	$1,252
Planting & Installation	4,356	SQ FT	$0.08	$348
Erosion Control	484	SQ YD	$2	$1,094
Bridge Expansion	342	S.F.	549	$187,758
Subtotal (Construction):				$210,288
2. Engineering and Permitting (30%)				$63,086
3. Surveying				$20,000
Subtotal (Professional Services):				$83,086
			Total:	**$293,374**

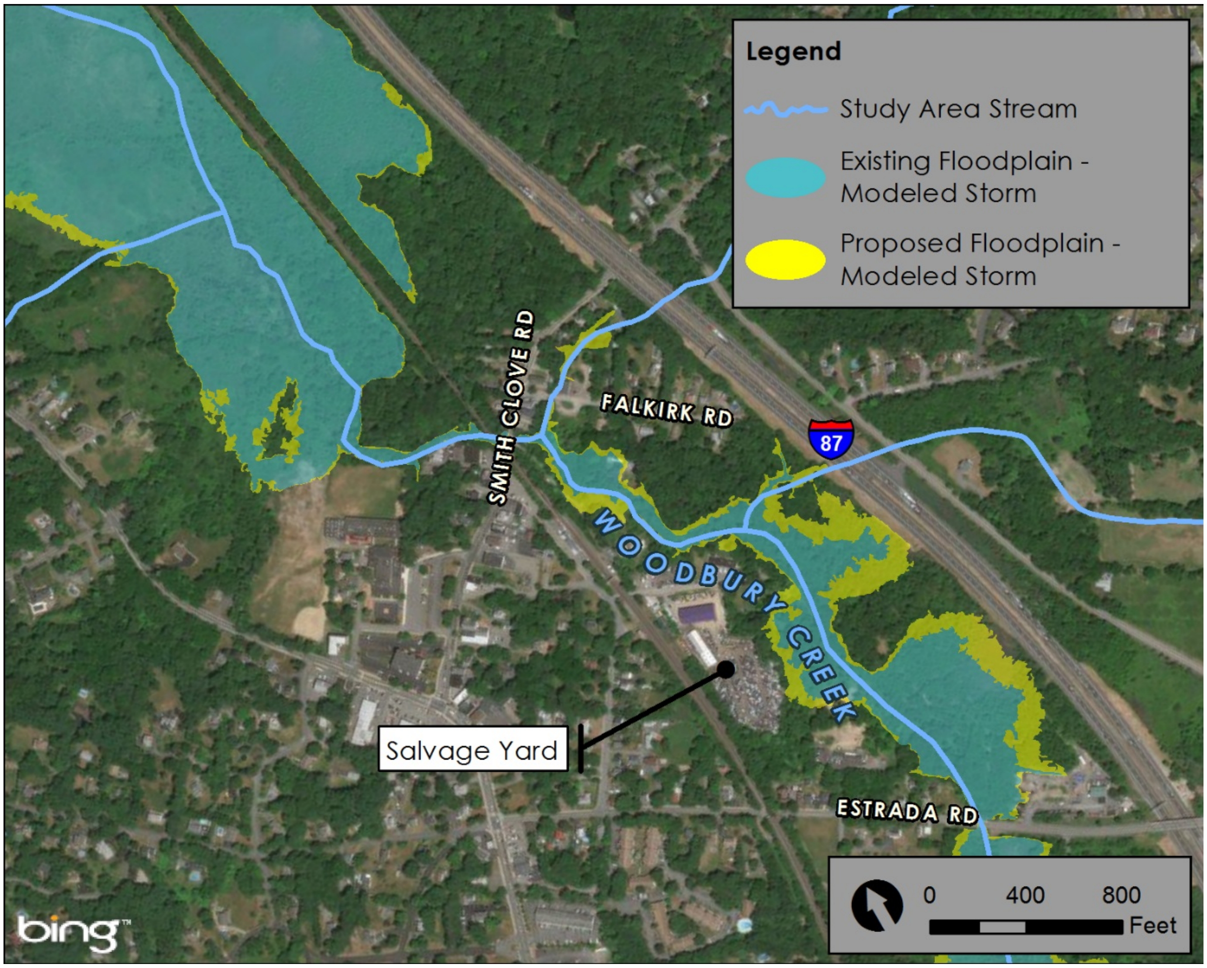
Additional Facts & Figures

- 2 strategies were evaluated, culvert expansion and land preservation. Culvert expansion was found to have minimal effects on flooding while development of the floodplain would lead to large increases in peak flow. Therefore, land preservation would be the more effective strategy at this site.
- Culvert expansion
  - Existing culvert width: 37 feet
  - Proposed culvert width 49 feet
- Preservation (effects of land development)
  - Floodplain storage reduction Area: 40 acres
  - Estimated peak flow increase: 42%

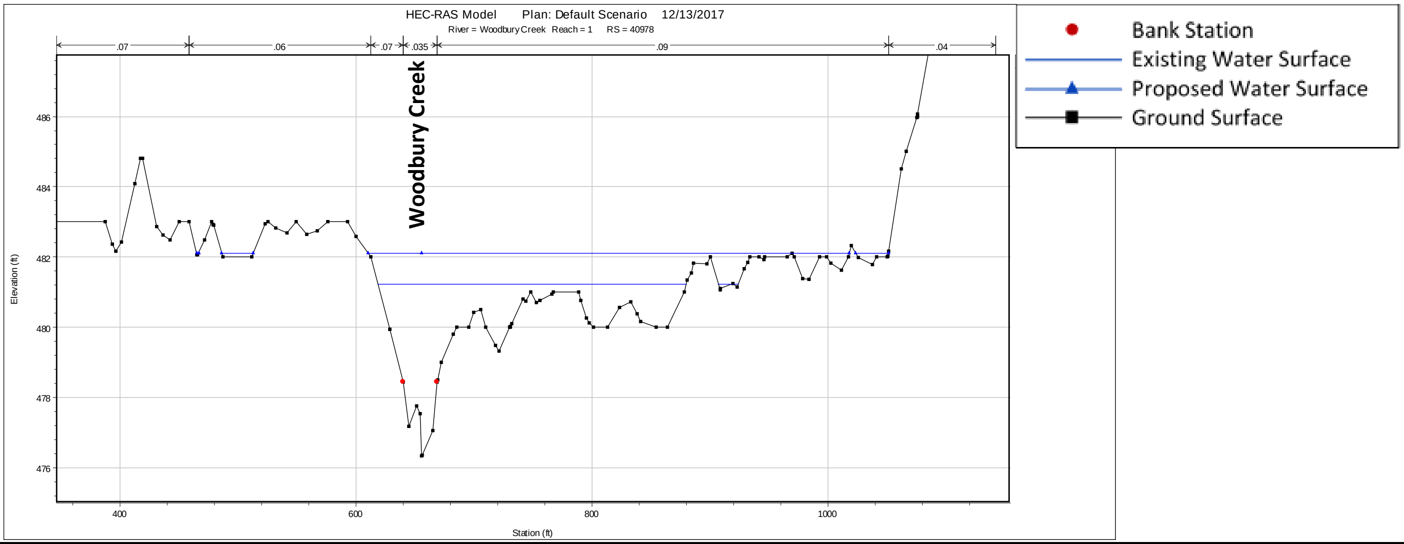
Strategy Site ID No.: 16
Strategy Site Name: Smith Clove Road

Strategy Type: Land Preservation
Site Location: 41.334, -74.119; Woodbury

Site Map



Hydraulic Model Cross Section



Additional Facts & Figures

- Floodplain storage reduction area: 33 acres
- Estimated peak flow increase: 42%
- Increase in water surface elevation: 1.1 feet

APPENDIX B

HYDROLOGIC AND HYDRAULIC MODELING REPORT

Moodna Creek Watershed and Flood Mitigation Assessment Hydrologic and Hydraulic Modeling Report

Orange County, NY

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November 2017

Contents

1.0 Introduction

Princeton Hydro was tasked with developing a flood risk assessment of the Lower Moodna Creek Watershed. This included the development of a hydraulic model and delineation of floodplains. Many of the watershed's rivers, streams, and tributaries have been previously analyzed as part of FEMA's Flood Insurance Program. However, some of the studies are decades old and have not been updated since. A primary goal was to update the hydraulic computations and generate new floodplains using current data and modeling techniques.

In addition, the project area is expected to experience increased flooding due to changes in land use and climate. As urbanization continues within Orange County, undeveloped land will be replaced with impervious cover, resulting in increased runoff. Climate change is also expected to bring more frequent, higher intensity rainfall events. The combination of these factors will produce higher water elevations and increase floodprone areas. Therefore, it is vital to consider the increased flood risk when planning new development and designing infrastructure. Utilizing climate change models and predicting future development, Princeton Hydro completed a flood risk assessment for conditions in 2050. This methodology for the existing and future conditions hydraulic and hydrologic computations are outlined in this report.

2.0 Existing Conditions

Hydraulic computations of the Lower Moodna Creek Watershed were completed using the United States Army Corps of Engineers (USACE) HEC-RAS computer program, Version 5.0. Princeton Hydro developed an updated watershed model using existing flood studies and new data specific to the project. Existing hydraulic and hydrologic data and models were obtained from FEMA flood studies including Moodna Creek, Moodna Creek Tributary 1, Moodna Creek Tributary 2, Idlewild Creek, and Woodbury Creek. Silver Stream, a tributary to Moodna Creek, was previously unstudied by FEMA, however its vicinity to development and prominence necessitated its inclusion. The final hydraulics model for the Lower Moodna Creek Watershed is a combination of previous flood studies and new data.

2.1 Summary of Effective Models

Princeton Hydro received FEMA HEC-RAS models for Woodbury Creek, and HEC-2 models, the precursor to HEC-RAS, for Moodna Creek, Moodna Creek Tributary 2, and Idlewild Creek. Since the Woodbury Creek models were georeferenced and used more recent data, the model inputs including cross sections, discharges, roughness, coefficients, etc. were imported into Princeton Hydro's model with minimal changes. However, unlike HEC-RAS, the HEC-2 program does not have a graphical interface and it is entirely text based. HEC-2 also does not have the ability to georeference cross sections and is limited in bridge computations compared to HEC-RAS. Due to these limitations, it was decided to re-study these steams using HEC-RAS, which meant developing new cross sections and river reaches. This method enabled Princeton Hydro to take advantage of HEC-RAS' modern capabilities and to use more up-to-date data. The HEC-2 models delivered by FEMA did provide valuable information about the discharges and bridges along these streams which were used in creating the HEC-RAS models.

A Letter of Map Revision (LOMR) was completed by FEMA for Moodna Creek Tributary 1 in 2014, and the associated HEC-RAS models were provided to Princeton Hydro. The LOMR covers the upstream portion of the tributary from Blooming Grove Turnpike to Willow Lane. The purpose of the revision was to study the flood mapping along Spring Rock Road, as it was observed that water from the tributary spills out of the main channel and onto the road. As part of the LOMR, a HEC-RAS model was developed that described two scenarios: one to calculate water elevations in the tributary and one to define the overland flow along Spring Rock Road. Upon completion of the revision, the flooding along Spring Rock Road was designated as a Zone AO. The model designated for the main channel was incorporated into Princeton Hydro's model of the Moodna Creek Watershed. Since the LOMR model only covered the upper portion of Moodna Creek Tributary 1, the reach was extended and additional cross sections added to connect with Moodna Creek. For the unstudied portions, the new cross sections were generated using updated terrain.

2.2 Terrain

Station-elevation points for all new cross sections were generated using 2014 1-meter resolution LiDAR data. As previously noted, the cross sections for Woodbury Creek and Moodna Creek Tributary 1 were imported from existing HEC-RAS models. Stream channel and floodplain geometry were previously surveyed by FEMA for these models and, as such, provided greater detail than the 1-meter LiDAR.

2.3 Roughness Coefficients

Manning's roughness coefficients were based on the 2011 National Land Cover Database developed by the USGS. Each land cover type was assigned a Manning's n value and then overlaid with the cross sections.

2.4 Conveyance Obstructions

Blocked obstructions were assigned by intersecting the cross sections with building outlines in ArcGIS. The building outlines were provided by Orange County and updated manually using Bing Aerial Imagery.

2.5 Bridges and Culverts

Many of the bridge and culvert structures were coded based on information obtained from the HEC-2 models provided by FEMA. The bridge modeling capabilities of HEC-2 are very limited compared to HEC-RAS as there are fewer bridge methodology options and all bridge openings are assumed to be rectangular in shape. Regardless, important data such as opening width, bridge deck thickness, and invert elevations were obtained using the HEC-2 data. In combination with the 2014 LiDAR data and orthoimagery observations, the HEC-2 data were used to develop bridge geometry for structures within Princeton Hydro's HEC-RAS model.

Bridge data for Woodbury Creek were imported from the FEMA HEC-RAS model. For Silver Stream, which had no existing hydraulics model, bridges were coded based on measurements and observations made from orthoimagery and field measurements.

2.6 Peak Discharges

Peak discharges used for the hydraulic modeling were a combination of the effective FEMA data, and regression-based computations. In order to develop a baseline condition, Princeton Hydro believed that flood mapping of the existing conditions should be consistent with existing FEMA flood studies. As a result, many of the discharges from streams came directly from the FEMA Flood Insurance Study and hydraulic models for Orange County. Other stream discharges were computed using the USGS StreamStats computer program. The discharges for each stream are summarized below:

Moodna Creek – Discharges for Moodna Creek were recomputed in a 2009 flood study revision using rural regression equations from USGS WRI 90-4197. These discharges were reported in the 2009 FEMA FIRM and utilized in the existing conditions model.

In the original proposal for the project, Princeton Hydro sought to coordinate with the 2017 Upper Moodna Creek Drainage Master Plan, in order to tie in the two flood studies. Most importantly, Princeton Hydro would use the discharges and water surface elevations for Moodna Creek at the tie-in located immediately downstream of the Beaverdam Lake tributary. This was to ensure that floodplain delineation would be more consistent for the entire scope of the Moodna Creek watershed.

Discharge and water surface elevation data for the 2-, 5-, 10-, 25-, 50-, and 100-year events were provided to Princeton Hydro in June, 2017. It was observed that the discharges calculated for the Upper Moodna Creek existing conditions were significantly greater than the discharges used in the FEMA effective flood study. Table 2.1 displays a comparison of the discharges at the tie in location reported for the FEMA effective, StreamStats, and Upper Moodna Creek models. While differences in discharges, even significant ones, are to be expected due to differences in methodology, computational tools, and land cover changes, the 69-86% increases of the Upper Moodna Creek discharges over the FEMA effective discharges warranted additional investigation.

Table 2.1. Discharges at Lower/Upper Moodna Creek Boundary

Return Period	Discharge (cfs)		
	FEMA Effective	StreamStats	Upper Moodna Creek
10-year	5289	4460	9853
50-year	9188	7020	16433
100-year	11384	8310	19271
500-year	18140	11900	N/A

Discharges for the Upper Moodna Creek were developed in a HEC-HMS model that was calibrated using stream gage data collected by the Orange County Water Authority (OCWA). OCWA installed five stream gages along Moodna Creek in December, 2010 and collected continuous gage levels until June, 2014. The gage levels were accompanied by discharge estimates. According to OCWA, discharges were computed using rating tables developed from the FEMA effective hydraulics model and not measured directly in the field.

The estimated stream gage discharges have a high degree of uncertainty. The FEMA hydraulics model used was developed in HEC-2, which has fewer capabilities in comparison to HEC-RAS. Also, cross sections in the HEC-2 model were less detailed compared to modern, LiDAR-derived standards. In order to more accurately develop a rating curve for each gage, detailed surveys would be required at each gage location. There was no indication that field surveys were conducted after the gages were installed. Gages were also not installed along tributaries in the Lower Moodna Creek Watershed, which meant there was limited data to calibrate flows in these streams. With this high uncertainty, Princeton Hydro felt that using the FEMA effective flows and StreamStats was the best alternative.

Moodna Creek Tributary 1 – The most recent study of Moodna Creek Tributary 1 was completed in 2013 as part of a Letter of Map Revision (LOMR). Hydrologic computations were updated as part of this revision. The effective model provided by FEMA, along with the associated discharges, were incorporated into the HEC-RAS existing conditions model.

Moodna Creek Tributary 2 – Peak discharges were calculated using the USDA NRCS TR-55 method and have not been updated since the original study in 1977. Due to the computations being 40 years old, Princeton Hydro investigated if StreamStats discharge values were more reflective of modern hydrologic conditions. However, the StreamStats discharges were significantly less compared to the FEMA effective. Using smaller discharges would result in smaller floodplains compared to the effective, which would be problematic because it would remove already identified risk areas from the flood zone and may result in underestimating risk during the future conditions analysis. Therefore, it was decided that using the higher FEMA effective discharges for the existing conditions model was the best approach.

Idlewild Creek – Peak discharges for Idlewild Creek have not been updated since the stream was studied in 1981. Unfortunately, the FEMA Flood Insurance Study did not provide details on the methodology used for the hydrologic computations. As with the Moodna Creek Tributary 2, Princeton Hydro compared the effective discharges with those computed from StreamStats.

Table 2. Idlewild Creek Discharges

Return Period	Upstream Discharges (cfs)		Downstream Discharges (cfs)	
	FIS	Stream Stats	FIS	Stream Stats
10-year	522	590	593	817
50-year	1014	1041	1185	1432
100-year	1312	1552	1551	1757
500-year	2298	1971	1782	2684

In general, the SteamStats discharges were higher than the effective FEMA discharges, with the exception of the 500-year return period at the upstream discharge location. Due to the age of the effective discharges and uncertainty with the methodology, it was decided to use the SteamStats discharges for Idlewild Creek. Since SteamStats utilizes more modern watershed characteristics data, it likely computes a more accurate estimation of the peak discharges.

Silver Stream – Peak discharges for Silver Stream were computed in SteamStats. Silver Stream has not been studied before and, as such, there are no previous discharge calculations.

Woodbury Creek – Woodbury Creek peak discharges were provided in the hydraulics model obtained from FEMA and incorporated into the Princeton Hydro model. The FEMA model was completed as part of a June, 2007 re-study of the steam and discharges for the study were computed using USGS WRI 90-4191.

3.0 Future Conditions

Upon the completion of the existing conditions hydraulic model, the second phase of this project assessed the flood risks in 2050 due to changes in land cover and climate change. Urbanization of Orange County is expected to continue as population increases, leading to an increase in impervious area. In addition, warmer temperatures in the coming decades are likely to lead to the increased frequency and intensity of rainfall events. Both factors will contribute to increase in flood risk areas.

3.1 Land Cover Changes

In order to predict future changes in land cover, Princeton Hydro sought to establish a relationship between population and impervious area. Census data from 1980 to 2010 for Orange County were obtained from the United States Census. 2001 to 2011 National Land Cover Database (NLCD) data were downloaded from the USGS's National Map website for Orange County. Land cover data before 2001 were not available. Census data were collected every 10 years and land cover data were collected every 5 years. For periods where the two datasets were collected within a year apart, it was assumed that the population and land cover did not significantly change year to year and therefore, directly correlated with one another. A summary of the data between 2000 and 2011 are shown below:

Table 3.1. Population and NLCD Percent Impervious Cover

Time Period	Population	Percent Impervious
2000 - 2001	341,367	14.85
2005 - 2006	N/A[1]	15.63
2010 – 2011	372,813	16.36

[1] Census data not collected for 2005 to 2006. Assumed a linear interpolation between 2000 and 2010, with an estimated 2006 population of 357,090 people.

Based on the historic population trends and projected growth rate as reported by the Cornell Program on Applied Demographics, the projected population for Orange County in 2040 is 444,322 people. The Cornell projections did not project beyond 2040, therefore 2040 was used as an analog for 2050. For the purposes of this study, it was assumed that population was evenly distributed across Orange County.

Several methods for correlating land cover and population were examined for this study. The first and simplest approach assumes a linear trendline between population and impervious area. Data available for this study were between 2000 and 2011, therefore, using this method is statistically bias since only three data points are available to establish the trendline.

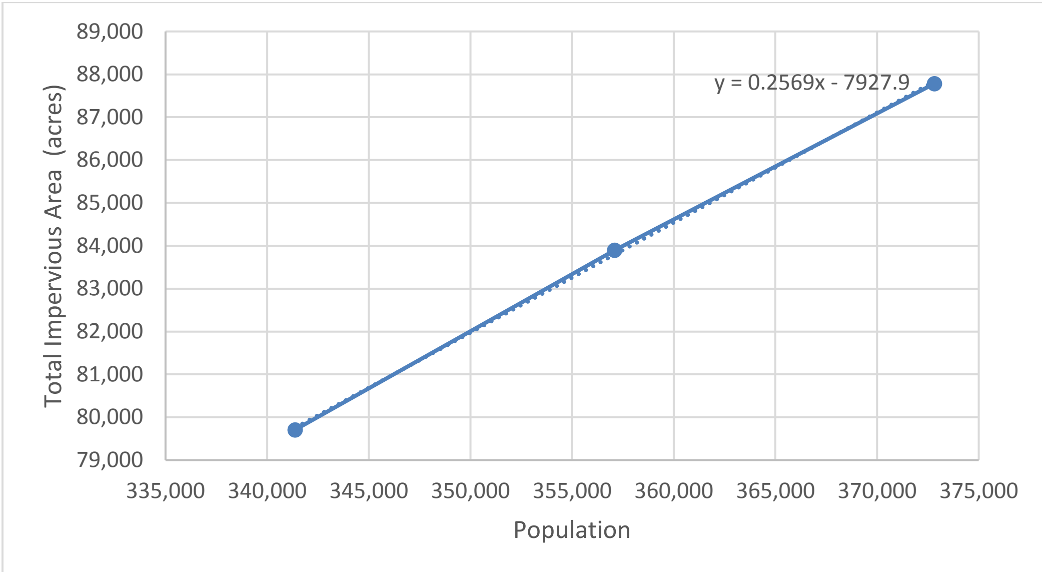

Figure 3.1. Total Impervious Area vs. Population from 2000 to 2011

Hicks and Woods (2000) derived an empirical relationship between population density and impervious area. This relationship is often cited in other studies such as “Estimating and Project Impervious Cover in the Southeastern United States” (Exum, et. Al 2005) and “The Impact of Climate Change and Population Growth of the National Flood Insurance Program through 2100” (AECOM 2013). The equation is shown below:

$$IA = 95 - 94\exp(-0.0001094PD)$$

Where IA is percent impervious cover and PD is population density per square mile. Again, Princeton Hydro assumed that population density and impervious cover were evenly distributed across Orange County, and thus the Moodna Creek Watershed.

A study by the University of Connecticut (Chabaeva, Civco, and Prisloe 2004) developed a relationship between population density and impervious cover for the Northeastern United States. Based on the NLCD and population data from several different representative areas in Connecticut, Massachusetts, and New York, the study developed the formula shown below:

$$IA = 0.0019(PD) + 16.732$$

Where IA is percent impervious cover and PD is people per square miles.

To evaluate the validity of both the Hicks and University of Connecticut equations, the percent impervious cover for 2001, 2006, and 2011 were compared to the NLCD data for those years (Table 3.2).

Table 3.2 Percent Impervious Area

Year	Population	Percent Impervious		
		NLCD	Hicks	UConn
2001	341,367	14.86	5.10	17.51
2006	357,090	15.64	5.28	17.54
2011	372,813	16.36	5.46	17.58

As shown, the Hicks equation severely underestimated the percent impervious cover for the watershed; while the University of Connecticut equation slightly overestimated impervious cover, although the data do align more closely to the NLCD data. However, between 2001 and 2006 there was a 1.5% increase in impervious cover according to the NLCD. For that same time period, the University of Connecticut equation only computed a 0.07% increase. In projecting out to 2050, the equations predict a 6.30% and 17.74% impervious cover for Hicks and University of Connecticut, respectively.

Due to these factors, Princeton Hydro determined that using a linear relationship between the population and impervious area would be the best approach to predicting future conditions. Using the linear trendline developed from the 2001 to the 2011 data, the estimated impervious cover for 2050 is 20.64%. As stated earlier, this method is likely over-conservative. However, the other two methods mentioned above likely underestimate impervious cover increase and were not derived from data specific to Orange County.

Hydrologic models of the existing and future conditions were developed in HydroCAD to quantify the increase in discharge resulting from an increase in impervious area. The model included a single drainage area with an outlet location at the confluence of Moodna Creek and the Hudson River. The 2011 NLCD data and NRCS SSURGO soil hydrologic soil groups were used to compute a composite curve number (CN) of 79 for existing conditions. 24-hour precipitation for 10-, 50-, 100-, and 500-year events were obtained from NOAA Atlas 14. The time of concentration was calibrated so that the discharges from the hydrologic model matched well with the existing condition discharges calculated by HEC-RAS at the Moodna – Hudson confluence.

For future conditions, Princeton Hydro assumed that the estimated increase in impervious area would replace currently forested area. This is a conservative assumption that would generate more runoff, and thus result in increased discharges. A predicted 20.64% impervious cover for 2050, increases the impervious area by 18,436 acres. In the composite curve number computations, 18,436 acres of impervious (CN = 98) were added while an equivalent acreage of deciduous forest with a hydrologic soil group of D (CN = 79) were removed. The result was a future conditions curve number of 82. This future condition CN was input into the hydrologic model to determine percent increases in discharges, which are reported in Table 3.3.

Table 3.3. Percent Increase in Runoff Due to Projected Changes in Impervious Cover from 2017 to 2050

Return Period	Percent Increase
10-year	9.8
50-year	7.0
100-year	6.3
500-year	4.5

Preliminary discharges for the future conditions model were the product of the percent increase in runoff and the existing conditions HEC-RAS discharges. The method outlined above is conservative as it assumed that only forest area will be converted to impervious cover and it assumed that the percent increase would be the same for all tributaries. In reality, impervious cover will increase throughout a range of different land covers, and the various tributaries in the watershed will have different responses to those land cover changes. However, it is difficult to accurately predict where future development will occur. Utilizing a more conservative approach ensures that potential at-risk areas are identified.

3.2 Climate Change

It is anticipated that the Moodna Creek Watershed will experience greater precipitation amounts by 2050 due to climate change, which will increase the flood risk for areas both within and outside the existing floodplains. When planning new development and designing mitigation projects, it is vital that increased risks due to climate change are taken into account.

The USGS of New York has developed a web-based tool to predict future discharges in the State of New York, outlined in "Development of Flood Regressions and Climate Change Scenarios to Explore Future Estimate of Future Peak Flows" (Burns et al. 2015). In summary, the tool uses the USGS StreamStats program as the base. Using five different climate change models, the USGS tool computes a mean future annual precipitation. The predicted mean annual precipitation is then input into the SteamStats program to calculate to future peak discharge and a percent increase compared to existing conditions. The tool does not account for changes in land cover or storage.

The Princeton Hydro model did not use StreamStats outputs for all the discharges and as such, did not input the predicted peak discharges from the USGS tool directly into the model. However, the reported percent increases were incorporated to calculate future peak discharges. At each flow change location, the USGS climate change tool was used to calculate a percent increase for each return period at the mid-range-emissions scenario (RCP 4.5) and time period 2050 – 2074. These percent increases due to climate change were then applied to the discharges in the Princeton Hydro model to produce predicted discharges for 2050.

The final future conditions discharges are the product of the existing discharges, the percent increase due to land cover change, and the percent increase due to climate change. Given the goal of the project to identify future risk, a conservative method was appropriate for delineating future floodplains and identifying at-risk areas. The discharges were input into the Princeton Hydro HEC-RAS model to compute future conditions water surface elevations. Other inputs such as terrain, blocked obstructions, and roughness coefficients were not altered, although this data will likely change as development continues in the Moodna Creek Watershed.

4.0 Floodplain Delineation

Upon completion of the existing and future conditions HEC-RAS models, floodplains were generated using the calculated water surface elevations and the 2014 1-meter LiDAR. Minor mapping issues were encountered, particularly for the 10-yr floodplains, due the resolution of the LiDAR. For these cases, the floodplains were manually adjusted.

As noted earlier, a LOMR was completed in the FEMA effective mapping area for Moodna Creek Tributary 1, and the inundation along Spring Rock Road was designated as a Zone AO. The Princeton Hydro mapping of this area is more conservative, with the existing 100-year floodplain extending to Split Tree Drive to the southeast. Unlike the FEMA effective LOMR, the results of this study are not for flood insurance purposes. Rather, it is to determine flood risk areas for both existing and future conditions. With homes and streets built alongside the tributary, it is clear that this area has the potential to experience extensive flooding. Therefore, the more conservative mapping was appropriate.

5.0 Conclusion

Princeton Hydro completed a hydraulic study for the Lower Moodna Creek Watershed. The model was developed using current data and information from previous studies. Utilizing climate change models and analyzing future land cover based on population, discharges for 2050 were estimated and input into the model to compute future conditions water surface elevations. The results of the existing and future conditions models were used to generate floodplains to identify flood risk areas and assess potential flood mitigation solutions.

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