Flood Predictive Model and Mitigation: Asher Dam

Village of Rhinebeck

May 2019

Marist College

Authors:
Members of Marist College's ENSC 477 Class:
Shea Bohan
Beatrix Bradford
Mia Colao
Hadeline Hanonik
Sara Hart
Anna Heard
Jessica Howe
Megan Nickel
Brooke Peterson
Jason Randall
Stephen Scalia
Jenna Vanadia

Acknowledgements:
The authors would like to thank Dr. Richard Feldman for his assistance, support, and technical-expertise in the field. The authors would also like to thank:

- Don Meltz, *Planning and GIS Specialist*
- Chris Algozzine, *Professional Lecturer of Computer Science*
- Zion Klos, *Professional Lecturer of Environmental Science*
- Dr. Melissa Gaeke, *Director: Center for Civic Engagement and Leadership*
- Joseph Eriole, *ESQ*
- Patricia Coon, *Village of Rhinebeck Clerk*
- Christopher Mitchell, *NYSDEC*
- Ethan Sullivan, *NYSDEC*

for their guidance and further assistance on this project.

Table of Contents:

1. Executive Summary:

Asher Dam, located on Crystal Lake, controls the natural flow of the Landsman Kill watershed through the operation of four valves. The Landsman Kill watershed extends from the Village of Rhinebeck into the Towns of Rhinebeck and Milan. Focusing upstream of Asher Dam, the watershed covers 27.2 kilometers of land that drains into Crystal Lake.

Regulations impacting the operation of the dam were assessed in order to determine if Rhinebeck is in compliance with New York Department of Environmental Conservation (DEC) guidelines. Some regulations were violated, making Rhinebeck vulnerable to lawsuits brought forward by flooding victims.

Regional precipitation rates and discharge values from Asher Dam were evaluated in order to create an instructional model for the operation of the dam valves. This model can be used to calculate differences in drainage depending on precipitation levels and the degree to which the valves are opened. However, this project highlights what further research needs to be monitored and recorded in the future to create a comprehensive predictive model.

Various monitoring and mitigation options were assessed in order to determine how the village should move forward in preventing flooding. Rain gauges, water level transducers, and stream gauges can all be used to produce accurate data on the watershed that can be used for a future predictive model. Research on riparian vegetation found fifteen species of shrubs and trees that are best suited for mitigation in Rhinebeck based on criteria such as growth rate, lifespan, root depth, and flood tolerance.

Grant opportunities were researched in order to provide the Village of Rhinebeck with funding options for mitigative projects and dam updates. The Climate Smart Communities Grant presents the most realistic opportunity for Rhinebeck based on the amount of money available and the number of annual recipients.

2. Introduction:

This document was prepared as a senior capping project for students within the major of environmental science and policy. More specifically, the project was part of a community based learning class run by Marist College. In this community based project, students worked with Mayor Gary Bassett and the Village of Rhinebeck to create a predictive plan for the operations of Asher Dam to prevent future flooding of future flood along the properties of Crystal Lake and the Landsman kill. This plan benefits both the residents and government officials of Rhinebeck in regard to flood education and planning.

As the climate continues to change within the Hudson Valley, precipitation events are occurring on a more severe scale (NYSDEC). For the Village of Rhinebeck specifically, this raises the concern of flooding around and upstream of Crystal Lake. This flooding has affected the people that reside in these flood regions, as their properties and homes have been damaged on an increasing scale within the past few decades. With the intention of preventing future flooding, the operation of Asher Dam was focused on in evaluating a mitigation plan for the Village of Rhinebeck. Natural mitigation measures such as vegetation and drainage alternatives were also considered for the village. Lastly, different grant opportunities were provided to give the Village of Rhinebeck the means necessary to fulfill some mitigative steps.

A predictive model was established after evaluating field data from Asher Dam, precipitation patterns within the Hudson Valley region and Crystal Lakes' surrounding soil content. Field visits to Asher Dam were conducted in February and March of 2019. Data was collected with the valves of Asher Dam opened to determine the spill rates of the valves. Residents residing on Crystal Lake were also contacted to determine the degree of flooding that has occurred in past years.

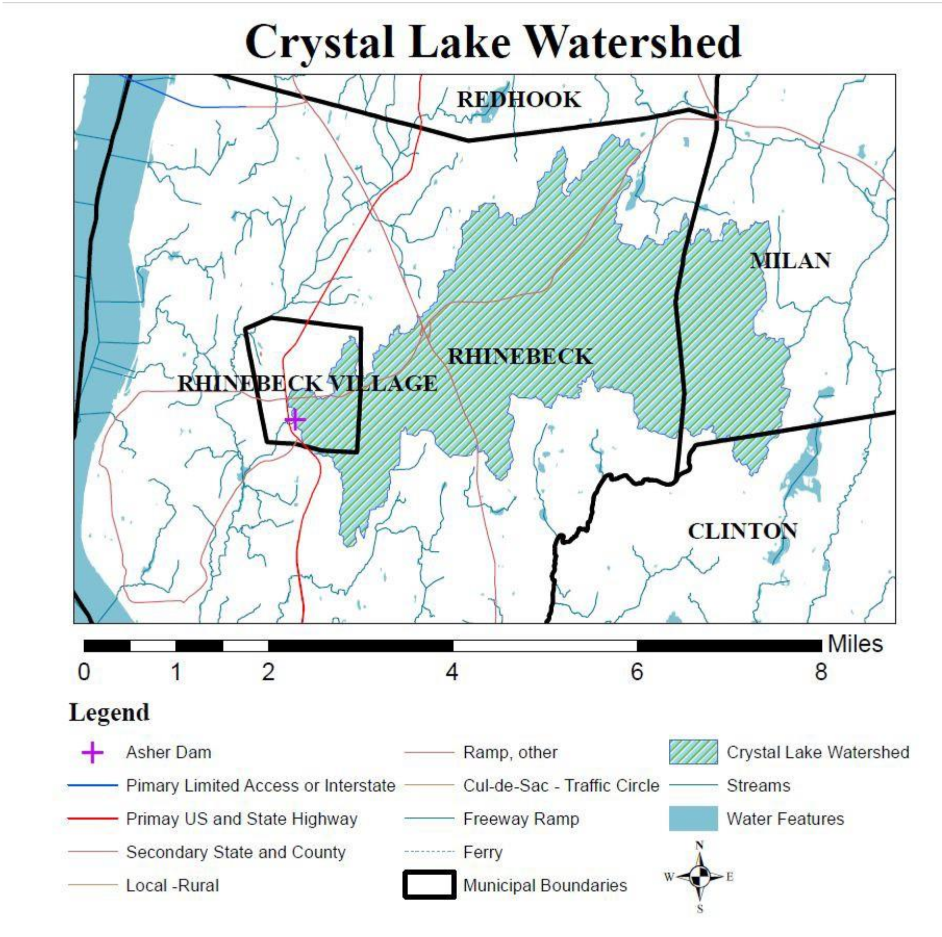
3. History of Flooding and Predictions:

The Mid Hudson region is characterized by a mix of suburban and rural land use patterns, interspersed with smaller and concentrated development. This includes the Village of Rhinebeck, located in Dutchess County, NY (Census, 2010). The village has a population greater than 2,657 and an abundance of important natural resources, making understanding the relationship between humans and water resources, as well as the effects each has on the other, vital. Floods occur within Dutchess County with an average of three events of varying degrees reported each year. The probability of flooding is greatest during December to April due to a combination of frozen ground and increased runoff from melting snow and ice (Environmental Management Council, 2012).

There are a number of major watersheds within the county, including the Landsman Kill, all of which have significant amounts of flood-prone areas surrounding them. These flood-prone areas are referred to as floodplains and include low-lying areas that become submerged during times of heavy rain or snow melts. Floodplains can act as shock absorbers or buffers, absorbing excess runoff as well as recharging groundwater supply. However, floodplains can only provide these benefits if they are left undisturbed. Increases in development and subsequent expansion of impervious surfaces can weaken the effectiveness of floodplains to absorb stormwater. Impervious surfaces lead to a greater amount of runoff, intensifying flood events and heightening the effects on downstream communities.

Floodplains can be further categorized by the percent change that a flood event will occur. The two most common categories are the 100-year floodplain and the 500-year floodplain. 100-year floodplains have a one percent annual chance of being submerged each year while 500-year floodplains have a 0.2 percent change (Findlay et al. 2010). However, environmental factors, such as human-induced climate change, have and will continue to alter the frequency of flooding within the categorized floodplains. The Village of Rhinebeck has an estimated 70 acres or 7.3 percent of land area within an identified floodplain (Findlay et al. 2010).

Climate change due to anthropogenic greenhouse gas emissions are predicted to raise the mean global temperature by a range of 2-3 °C within the next 30 to 50 years. (Intergovernmental Panel Climate Change (IPCC) 2007). The temperature increase will have effects on food production, plants, wildlife, invasive species, precipitation, and the economy. Specifically, its predicted that Poughkeepsie, NY will experience an increase in average annual precipitation up to 5 percent by 2020 or 10 percent by the 2050s. These changes in precipitation will likely lead to increases in flash food events throughout the area. A 67 percent increase in the number of 2-inch rainfall events occurring within a 48-hour period has been observed since the 1950s in New York State. Furthermore, the number and intensity of extreme weather events will increase as the effects of climate change continue. The Village of Rhinebeck will, therefore, experience more extreme flood events similar to the 2007 and 2011 floods (Findlay et al. 2010).



4. Regulations:

4.1. Municipally Owned Dam Regulations:

The Asher Dam, owned by the Village of Rhinebeck, is categorized as a municipality owned dam within New York State. It is classified as a Class B dam, as it poses an immediate hazard to the Village of Rhinebeck. According to the New York State Department of Environmental Conservation, dams that fall under this category threaten damage to homes, highways, minor railroads, and or important utilities such as water sewage treatment plants, fuel, power, or telephone infrastructure. Government-owned dams fall under Class B identification if they pose any threat of substantial economic loss and environmental damage to the surrounding community (NYSDEC, 2018b). However, dam classification is often in reference to the potential harm on areas located downstream from the dam. The Village of Rhinebeck is responsible for all operations of Asher Dam as the municipality sits as the sole owner of this given dam.

Miller Road Dam, located north of Crystal Lake, is identified as an “orphan dam,” as it has no current owner. Therefore, the Village of Rhinebeck cannot be held responsible for operating or regulating this dam. However, local officials from the village are responsible for contacting the

NYSDEC to identify any concerns about this dispossessed structure, as it may cause future complications in the flood mitigation efforts for the Landsman Kill and Crystal Lake.

Municipalities that directly own Class B dams are required to follow safety and regulatory policies set forth by the DEC (NYSDEC, 2009). The municipality owner of each Class B dam must draft an annual maintenance and preparation plan. The owner is required to accompany this plan with an Emergency Action Plan (EAP), which must be submitted to the DEC. State regulations also require that municipalities submit a contact chain of phone numbers to the DEC, which would be used in the event of a dam failure (NYSDEC,2009). Lastly, each municipality is responsible for hiring an engineer for their respective dam. These engineers perform yearly dam inspections in accordance with the maintenance and inspection plan. However, this inspection doesn't need to be submitted to the DEC unless it is specifically requested for (NYSDEC, 2018b).

4.2 Stormwater Regulations:

According to the New York Department of Environmental Conservation (DEC), stormwater is defined as water from rain or melting snow that runs off into waterways as opposed to soaking into the ground. It can flow from rooftops, over soil and paved areas, and open sloped lawns. While it flows, stormwater runoff collects a variety of pollutants that flow to surface waters, contaminating water, degrading drinking water quality, and damaging fisheries and plant habitat. Polluted stormwater can also affect swimming, boating, fishing and other recreational activities (NYSDEC, n.d.). Most state and federal regulations surrounding stormwater management stem from controlling pollutants that are being discharged from the source. For New York State, there are three State Pollutant Discharge Elimination System (SPDES) general permits that are required for activities associated with stormwater discharges.

One type of state permit arises from federal regulation by the Environmental Protection Agency. The 1990 National Pollution Discharge Elimination System (NPDES) Phase I Regulation requires medium and large cities or certain counties with a population of 100,000 or more to obtain NPDES permit coverage for their stormwater discharges associated with industrial activity. This includes municipal separate storm sewer systems (MS4) serving a population of 100,000 or more (EPA, 2012). An MS4 is a conveyance or system of conveyances that is owned by a state, city, town, village, or public entity that discharges to waters of the United States. It can be designed or used to collect or convey stormwater through storm drains, pipes, ditches and more. It is not a combined sewer and is not part of a sewage treatment plant or publicly owned treatment works (EPA, 2018a). In 1999, the NPDES revised the regulation as Phase II to include small MS4s located in urbanized areas with a density of 1,000 people per square mile (E. Sullivan, personal communication, April 19, 2019). Automatic designation under NYS MS4 regulations requires a population of 50,000 or greater and a population density greater than

1,000 people per square mile. The Village and Town of Rhinebeck are not covered by MS4 because they do not have a population of 50,000 residents or more. According to the 2010 Census, the village has a population of 2,657 while the town has a population of 7,548 (Data Access and Dissemination Systems (DADS), 2010). Automatic designation of SPDES requires MS4 communities to implement a Stormwater Pollution Prevention Plan (SWPPP). Some mitigation strategies suggested in SWPPPs to prevent polluted runoff coincide with mitigation strategies to help prevent flooding. These best management practices include building green infrastructure which will be discussed later on.

In Dutchess County, MS4 communities cooperate under the leadership of the Dutchess County Soil and Water Conservation District to meet the requirements of the MS4 permit. Unregulated communities such as Rhinebeck should consider participating in this group to implement stormwater controls. The Town and Village of Rhinebeck do, however, require land development activities to conform to the substantive requirements of the SPDES. Rhinebeck has adopted its own stormwater management plan to prevent runoff pollution and protect water quality for the health and safety of Rhinebeck's residents. Rhinebeck's stormwater program involves the regulation of stormwater runoff discharges from land development activities in order to control and minimize stormwater runoff rates and volumes, water quality, soil erosion, stream channel erosion, and nonpoint source pollution associated with stormwater runoff. Doing so should reduce flooding, siltation, temperature fluctuation, and streambank erosion while maintaining the integrity of stream channels and associated wildlife habitat (Town of Rhinebeck, 2019). In essence, the Town of Rhinebeck implements its own stormwater management program using the interpretation of laws and regulations set forth by the federal and state government such as those under the SPDES, the NPDES, and the SWPPP. The Village of Rhinebeck does not have a stormwater management plan regulated by New York State MS4 either and operates under the same town's stormwater management program under requirements set forth by the NYSDEC and overseen by the Village Engineer, Planning Board, and Village Highway Department (Village of Rhinebeck, 2018a).

4.3. Compliance and Liability:

The Village of Rhinebeck's Flood Damage Prevention Codes were set, "to promote the public health, safety, and general welfare, and to minimize public and private losses due to flood conditions in specific areas" (Village of Rhinebeck, 2018b). These codes were updated in 2012 at the request of the Federal Emergency Management Agency to ensure that Rhinebeck qualified as a participating community in the National Flood Insurance Program. In doing so, Rhinebeck ensures that citizens are permitted to purchase insurance through the NFIP. Specifically, the village's Flood Damage Prevention codes prohibit the construction, extension, conversion, and alteration of structures in areas designated as special flood hazards (Village of Rhinebeck, 2018b). These areas, established by FEMA, are categorized as 100- year floodplains.

While some structures built upstream of Asher Dam are located within the special flood hazard area, they were all built before the passing of the National Flood Insurance Act of 1968. Therefore, the Village of Rhinebeck didn't violate FEMA regulations when it permitted citizens to build these structures (Dutchess County Real Property Tax Service Agency, n.d.). Some residents allowed students to conduct a site visit on their property in order to collect information regarding flood history. One resident's house was built in the special flood hazard area in 1950. This resident reported flooding of up to three feet in their backyard from Hurricane Irene in 2011. The soil content of the backyard was identified as predominantly clay, which impedes rainwater percolation. No riparian vegetation was present along the stream shoreline, allowing floodwaters to easily encroach on the property.

Within its Flood Damage Prevention Codes, the village attempts to exonerate itself from responsibility to prevent flooding by stating, "This chapter does not imply that land outside of the special flood hazards or uses permitted within such areas will be free from flooding or flood damage. This chapter shall not create liability on the part of the Village of Rhinebeck, any officer or employee thereof, or the Federal Emergency Management Agency, for any flood damages that result from reliance on this chapter or any administrative decision lawfully made thereunder" (Village of Rhinebeck, 2018b). However, there is no guarantee that this statement will absolve the village of liability in a court of law. Additional liability concerns surround the village's failure to follow New York State private dam regulations (J. Eriole, personal communication, April 17, 2019).

According to Part 673 of NYS Environmental Conservation Law and Dam Safety Regulations, private owners of Class B dams are required to, "maintain their dams in a safe condition at all times… this includes developing, maintaining, and following an Emergency Action Plan for use in the event of a developing dam failure or other uncontrolled releases of stored water" (NYSDEC, 2012). The Village of Rhinebeck's most recent Dam Safety Annual Certification Form, completed in 2011, states that the village doesn't have an Emergency Action Plan in compliance with part 673 of ECL Dam Safety Regulations. Furthermore, Asher Dam failed a 2013 visual inspection with the inspector citing maintenance and seepage violations (Reardon, 2011). Any floods that occur due to the village's neglect in maintaining the dam may place the village at risk of a lawsuit (J. Eriole, personal communication, April 17, 2019).

Previous lawsuits in New York State regarding dam maintenance should be considered when reviewing Rhinebeck's liability. In 2013, a court case reached the New York State Appellate level in which property owners surrounding a pond downstream of Lake Lucille sued the town for negligently designing and maintaining a stormwater drainage system that discharges runoff onto their properties. The plaintiffs also argued that the town failed to maintain the Lake Lucille dam, resulting in sediment deposition into the plaintiffs' pond. Ultimately, the court didn't hold the municipality liable because the plaintiffs failed to show proof of poor maintenance of the dam (*Zarlin v. Town of Clarkstown*, 2013). However, this implies that municipalities can be held liable if sufficient proof exists to show negligence. In the case of Rhinebeck, documentation exists showing the multiple violations that have yet to be remedied, potentially giving homeowners the necessary proof to show negligence (Reardon, 2011).

5. Predictive Modeling:

5.1. Precipitation Data:

Precipitation and discharge data were analyzed for trends and correlations, and to see if there was if they would be helpful for modeling. All precipitation was converted in the equivalent amount of water which would have fallen for comparison, thus snowfall was converted to the amount of rain which would have fallen instead of snow had it been raining not snowing. All precipitation data was obtained for Albany, NY as this was where the closest and complete precipitation data could be obtained for the time period which was examined. This data was obtained from the Local Climatological Data Publication: Albany, NY, from NOAA. The discharge data was obtained for Wappingers Creek as that was determined to be the closest stream for which historic discharge data was available. This data was obtained from National Water Information System: Web Interface: Wappinger Creek near Wappinger Falls NY Daily Data and Monthly Statistics from USGS and Advanced Hydrologic Prediction Service: Wappingers Creek at Wappinger Falls from NWS.

Precipitation totals and averages from 1970 to 2017 can provide useful information in predicting future totals, however, cannot be relied upon solely as a future indicator. Total precipitation trends from 1970 to 2017 in Albany, NY showed a slightly positive slope of 0.1405 inches per year, indicating an overall positive trend of increasing precipitation totals over these 47 years (Figure 1). While a trend of a slight overall increase in yearly precipitation was found, years with extreme low or high precipitation totals were often followed by the opposite extreme 1-2 years later (Figure 1). This may indicate that floods may be more likely a year or two after a year with abnormally low precipitation as many of the years with high precipitation contain one or more extreme precipitation events. An example of this is Hurricane Irene in 2011 with 4.81 inches of rain falling between August 27th to 28th which resulted in flooding (Appendix A). The year highest yearly total precipitation between 1970 to 2017 was in 2011 of 53.68 inches, and the total precipitation in 2010 and 2012 years was 37.84 inches and 36.99 inches, respectively which are years with lower precipitation (Figure 1, Appendix A).

Average total precipitation values per month in the same time period can be used to indicate which months a high precipitation total and potential flood would occur. June and July were found to have the greatest average total monthly precipitation, 4.04 inches and 4.06 inches respectively, in the 47 years examined (Figure 2, Appendix A). May through October are the months with the highest risk for highest total precipitation to occur, while it is less likely to occur between November and April (Figure 2). However, it is possible to have a high total precipitation in any month. Frequent precipitation events occurring or a high precipitation event occurring during a month can lead to the high monthly total precipitation. There is a chance of increased flood risk from the volume of precipitation received cumulatively during the month and from the high precipitation events.

The summer to early fall is suggested as the average monthly maximum precipitation in 24 hour events are compared for all 47 years by month the summer to early fall is when the highest amount of precipitation during these events is seen (Figure 3). The months with the highest precipitation during these events are July and August which have an average of 1.50 inches and 1.49 inches of precipitation during them respectively (Figure 3, Appendix A). From June through October there is an average of over 1.43 inches of precipitation during these event while other months have an average of 1.21 inches or less (Figure 3, Appendix A). When the months which had the maximum amount of precipitation for each year are analyzed over the 47 year period, the month with the most yearly maximum precipitation events is October with 11 events occurring during it (Figure 4). The summer to early fall period is where the most maximum precipitation events in 24 hours occur, which would suggest that this is part of the year where there is a higher risk of flooding as high precipitation events can lead to flooding (Figure 4).

Thus this suggests that precipitation events during the June through October period should be monitored carefully. These months show a higher frequency of maximum precipitation event and these events resulting in higher amounts of precipitation as well, along with having a higher total precipitation within the month. Flooding can result from both cumulative high level of precipitation as soils become saturated and can no longer retain more water and from sudden high precipitation events. Thus the June through October period can correlate to an increased risk of flooding due to the higher rate of volumes of water received cumulatively and suddenly. Thus in addition to normal monitoring of rain events, careful monitoring of rain events during this time is recommended as there could be an increased need to open the valves to mitigate this increase in precipitation which has been shown to occur during this time to prevent flooding.

From examining the maximum precipitation events within 24 hours between 1970 to 2017, an increase in both the average monthly maximum precipitation in 24 hours and the maximum amount of precipitation in 24 hours for each year is seen (Figure 5). An increase in the amount of sudden precipitation over time is seen which could be the result of climate change as climate change. This trend should be noted as higher amounts of precipitation during sudden precipitation events can lead to flooding. If the is a trend of an increasing amount of precipitation during these sudden events continues there could be a greater number of flood events which result. This would be due to the higher volumes sudden precipitation being seen which is at the level which leads to flooding. This should be taken into account when making mitigation and repair and maintenance decisions in addition to monitoring when to open the valves.

When examining the discharge data alongside the precipitation data a trend can be seen between total precipitation for the year and yearly average discharge. With the exception of 1986-1987 and 2013-2014, the change relative to the year before for both total precipitation and average yearly discharge was the same (Figure 6). If the following year had a higher yearly total precipitation it also had a higher yearly average discharge (Figure 6). However, when comparing the amount of precipitation received during single events to the discharge, a trend is not seen. A trend cannot be drawn about the amount of precipitation received and discharge occurring, a lower amount of precipitation could result in the same discharge as a higher amount of precipitation received (Table 1). Precipitation amount did not correspond to trend in crest height which could be used to predict flooding as lower amounts of precipitation resulted in higher crests than some higher amounts of precipitation received during high precipitation events (Table 1).

Additionally, a trend was not seen between the amount of precipitation received and days with elevated discharge with the same result occurring elevated discharge could occur for the same number of days with 2.11 inches of precipitation as 4.81 inches, both which resulted in four days of elevated discharge (Table 1 and Table 2). There was no difference in time to elevated discharge seen as well, as all precipitation in events leads to an elevated discharge within 24 hours of the precipitation event (Table 1 and 2). It is of note as well that there several yearly maximum precipitation events recorded in Albany which resulted in no change in Wappingers Creek discharge. Because of this precipitation could not be used as a predictor of discharge or crest height.

The lack of a trend seen between days of elevated discharge and time to the elevation of discharge prevented the incorporation of time into the model. This highlights as the need for a source of precipitation data which is located closer to the site of the discharge data. The failure for a trend to be seen between the amount of precipitation and changes in discharge and crest height could be accounted for by the fact that the precipitation data is from Albany while the discharge data is from Wappinger Falls. The possible reason why a trend is not seen, as there are likely different precipitation patterns between the two areas, which could mean there is a difference in precipitation received in Rhinebeck as well. As all data were obtained from the closest reliable sources of data rather than Rhinebeck itself for this time period, however, this analysis and data set do not necessarily represent the conditions which have occurred in the

Village of Rhinebeck. Thus the conditions cannot be said to correspond completely to those in Rhinebeck, all trends and conclusions should be interpreted with this consideration when applying them to the Landsman Kill.

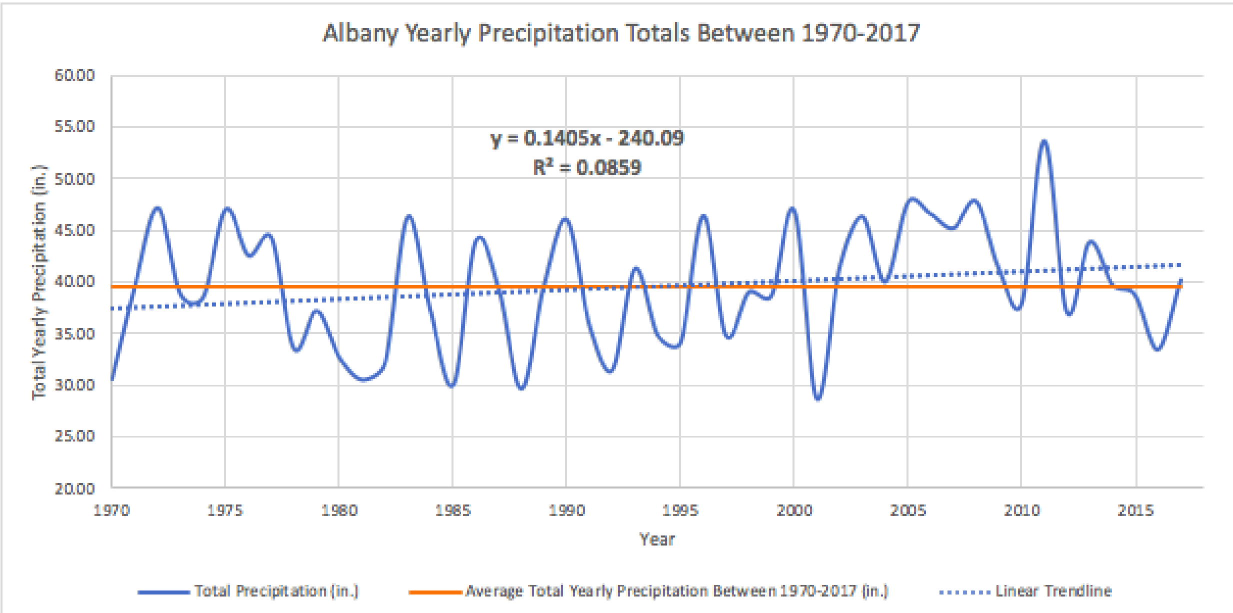


Figure 1. Yearly precipitation totals in Albany, NY using water equivalence (in.) from 1970-2017.

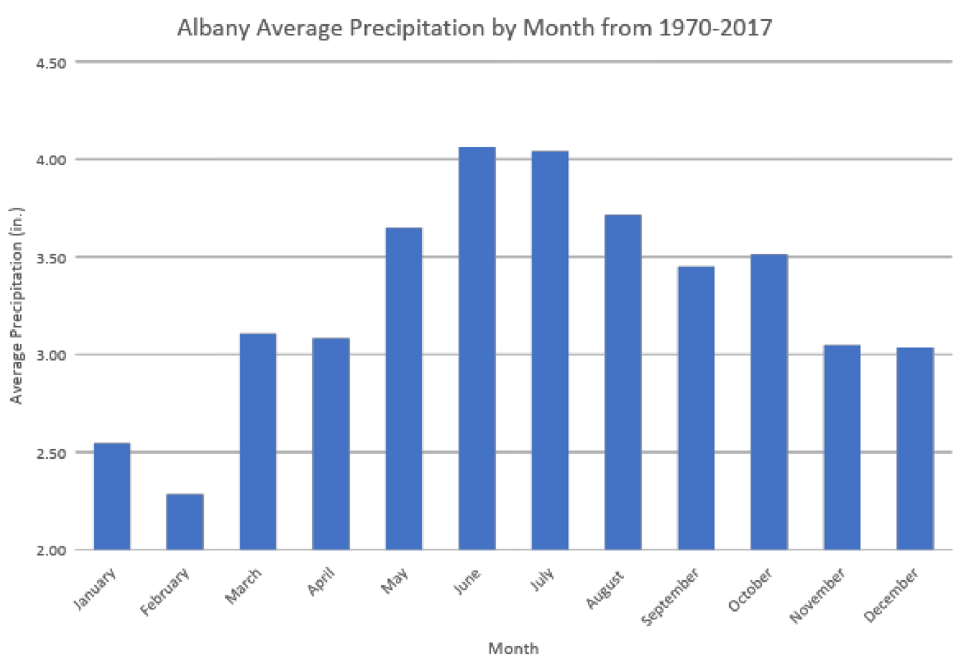


Figure 2. Average monthly precipitation using water equivalence (in.) for Albany, New York between 1970-2017.

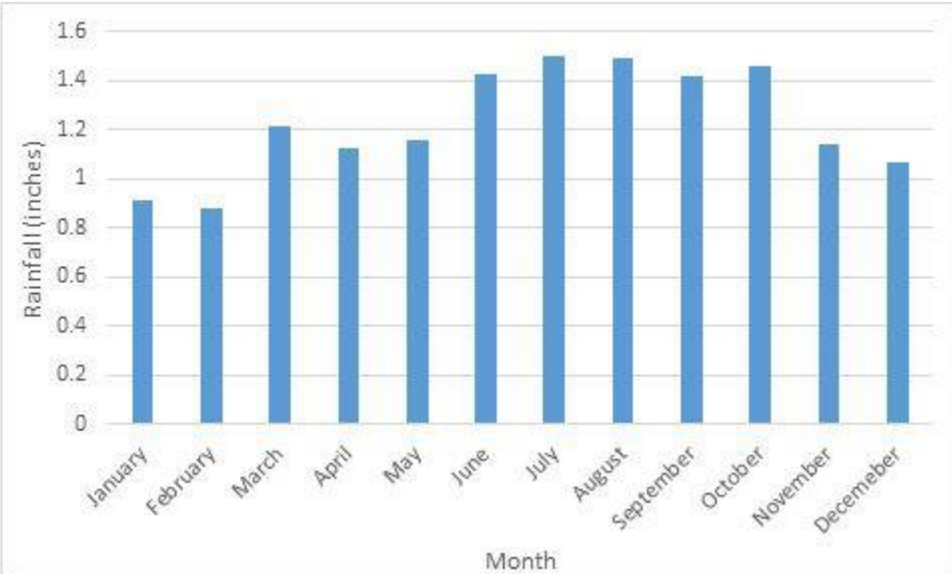


Figure 3. Average amount of precipitation received in water equivalent during maximum precipitation in 24 hours events between 1970-2017 per month.

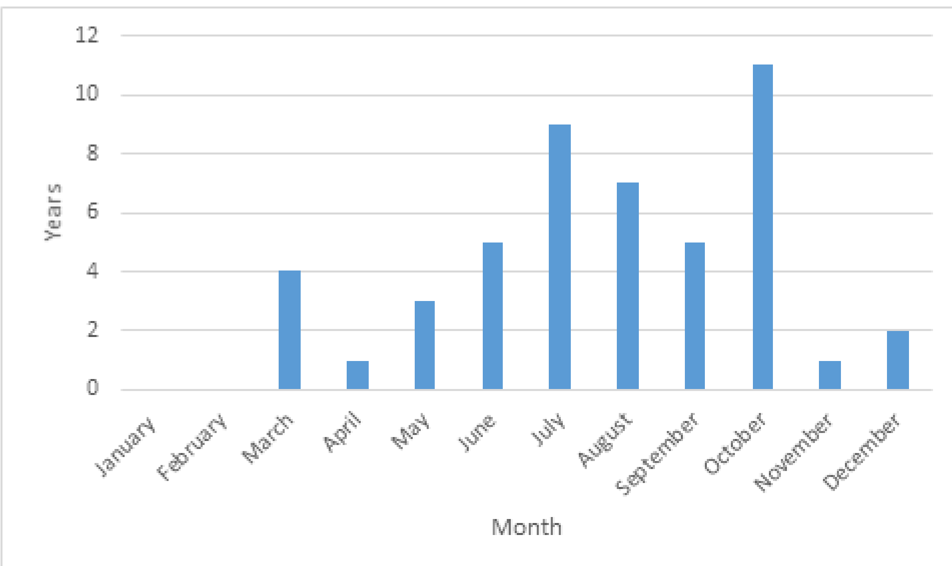


Figure 4. The total number of years for each month where the yearly maximum precipitation in 24 hours event of the year was within that month.

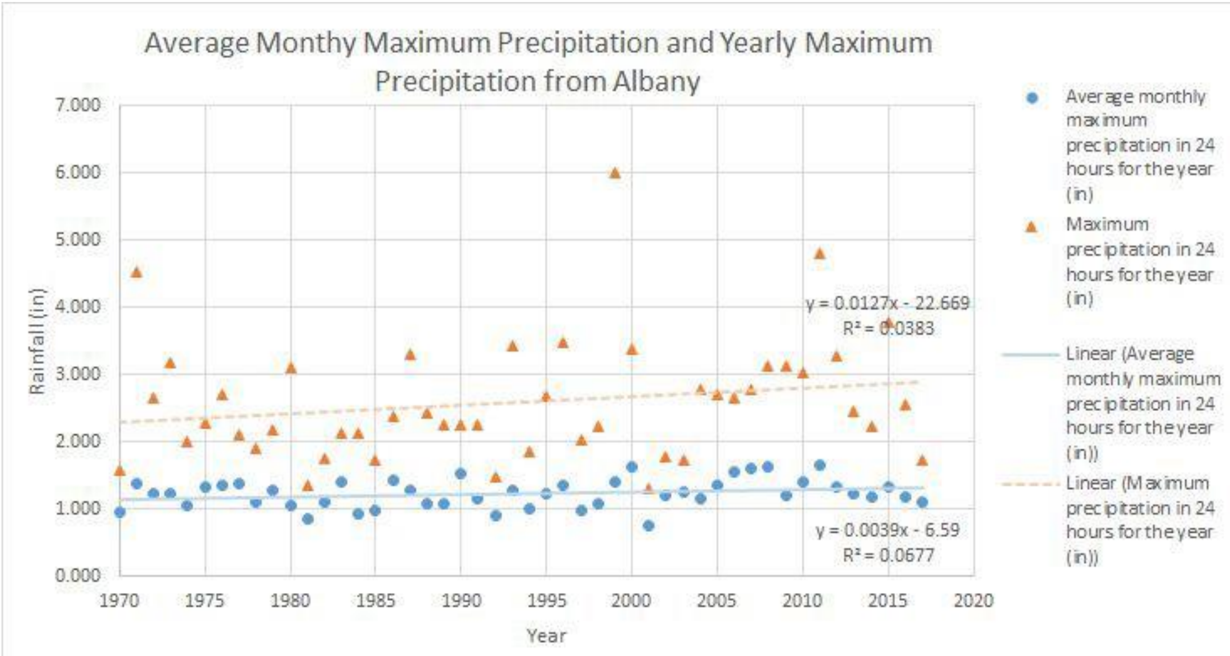


Figure 5. Maximum precipitation in water equivalent received in 24 hours from 1970-2017. The maximum precipitation in 24 hours for each year is indicated with orange triangles with a dashed orange trendline. Average monthly maximum precipitation within 24 hours for each year from 1970-2017 is indicated by the blue circles and the solid blue trendline.

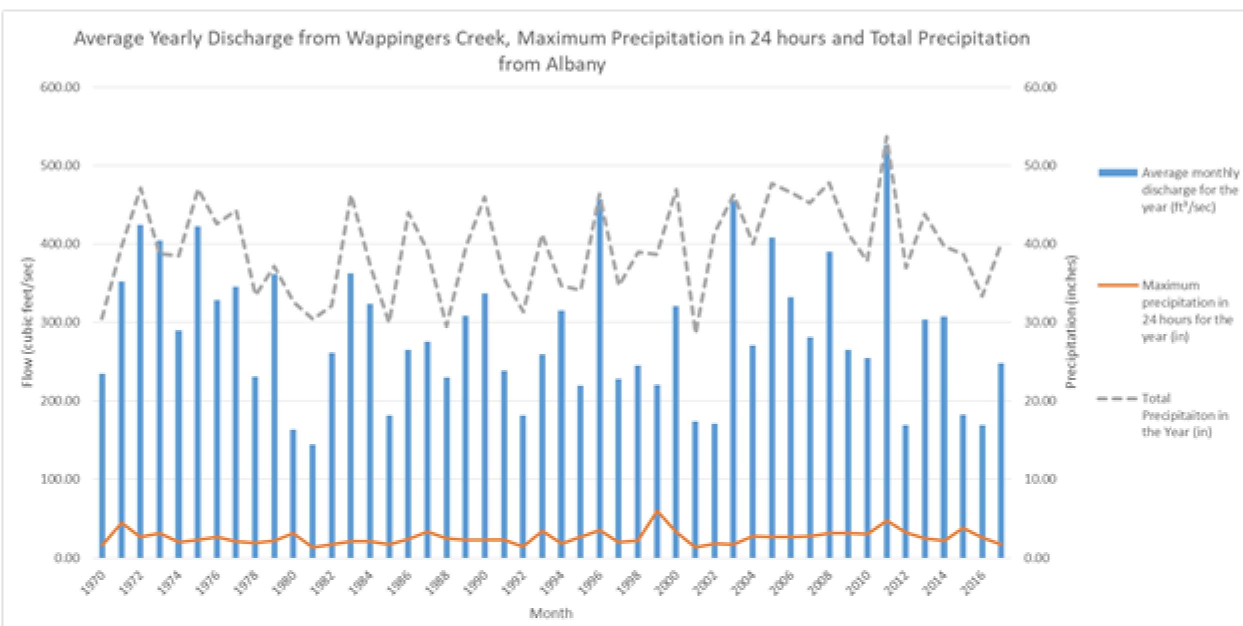


Figure 6. A graph showing Wappingers Creek discharge and precipitation in water equivalent from Albany from 1970-2017.

Table 1. Maximum crests at Wappingers Creek with corresponding maximum precipitation in 24 hours events from Albany. A listing of the number of days with a discharge of over 1000 cubic ft/sec, the discharge values for the first two days of elevated discharge and their corresponding dates, along with the first day the discharge drops below 1000 cubic ft/sec.

Year	**Crest height (ft)**	**Date**	**Maximum precipitation in 24 hours (in)**	**Date**	**Days with discharge over 1000 ft³/sec**	**Initial elevated discharge (ft³/sec)**	**Date of initial elevated discharge**	**Date of when discharge decreased to less than 1000 ft³/sec**
1973	14.12	30-Jun	3.19	jun 29-30	7	5530	30-Jun	7-Jul
1975	6.63	20-Oct	2.29	oct 17-18	4	1340	19-Oct	23-Oct
1977	7.51	14-Mar	2.11	mar 13-14	4	2230	14-Mar	18-Mar
1983	6.85	14-Dec	2.12	dec 12-13	5	1010	12-Dec	17-Dec
1984	12.18	30-May	2.14	may 28-29	7	1340	29-May	5-Jun
1986	8	15-Mar	2.38	mar 14-15	8	2600	15-Mar	19-Mar
1987	5.95	8-Oct	3.31	oct 3-4	4	1120	5-Oct	9-Oct
1989	7.38	21-Oct	2.26	oct 19-20	2	2310	21-Oct	23-Oct
1990	6.62	24-Oct	2.26	oct 23-24	2	1480	24-Oct	26-Oct

1991	5.8	23-Nov	2.26	nov 22-23	2	1150	23-Nov	25-Nov
1996	6.6	14-Jul	3.49	jul 13-13	3	1740	14-Jul	17-Jul
1997	6.22	1-Apr	2.02	mar 31-31	7	1690	1-Apr	8-Apr
2007	15.06	17-Apr	2.78	apr 15-16	7	1160	15-Apr	22-Apr
2011	15.29	29-Aug	4.81	aug 27-28	4	4620	28-Aug	1-Sep

Table 2: Maximum precipitation in 24 hours events for the year from Albany and corresponding discharge seen in Wappingers Creek. Discharge date was recorded if the discharge was over 1000 cubic feet/sec, if the discharge was less than this the discharge amount it was below was recorded. The number of days the discharge remained above 1000 cubic feet/sec was also recorded.

Year	**Maximum precipitation in 24 hours (in)**	**Date of maximum precipitation in 24 hours event**	**Start of over discharge over 1000 ft^3/sec**	**Days with discharge of over 1000 ft^3/sec**
1971	4.52	Aug 27-28	28-Aug	2
1973	3.19	Jun 29-30	30-Jun	7
1975	2.29	Oct 17-18	19-Oct	4
1976	2.70	Oct 8-9	10-Oct	1
1977	2.11	Mar 13-14	14-Mar	4
1982	1.75	Jun 5-6	6-Jun	3
1983	2.12	Dec 12-13	13-Dec	4

1984	2.14	May 28-29	29-May	7
1985	1.73	Sep 26-27	28-Sep	1
1986	2.38	Mar 14-15	15-Mar	6
1987	3.31	Oct 3-4	5-Oct	4
1989	2.26	Oct 19-20	21-Oct	2
1990	2.26	Oct 23-24	24-Oct	2
1991	2.26	Nov 22-23	22-Nov	2
1996	3.49	Jul 13-13	14-Jul	3
1997	2.02	Mar 31-31	1-Apr	7
1999	6.00	Sep 16-17	17-Sep	1
2000	3.37	Jun 5-6	7-Jun	2
2003	1.74	Oct 26-27	29-Oct	3
2005	2.70	Oct 8-9	9-Oct	2
2007	2.78	Apr 15-16	15-Apr	7
2010	3.04	Oct 1-1	1-Oct	2
2011	4.81	Aug 27-28	28-Aug	4

5.2. Model:

When considering predictive markers for valve opening at Asher Dam to reduce the risk of flooding upstream, a combination of empirical and anecdotal techniques were utilized. Limitations to these methods did not allow for the incorporation of time into a predictive model for when the valves should be opened. However, future comparisons made between drainage rates while valves are open and draining prior to events can provide a foundation for the creation of an optimized predictive model in the future.

Table 3. Impact of valve opening on maximum discharge and drainage rates at Asher Dam.

Valves Open	Maximum Discharge (m^3/s)	Relative Rate of Drainage
None	4.25	1
2 Large Valves	5.20	1.22
All 4 Valves	5.94	1.40

Table 3 highlights what would be seen during or directly following an extreme precipitation event where maximum discharge has been reached at the dam. The opening of the two larger valves increases the relative drainage rate by 1.22 fold at maximum discharge, whereas all four valves increase the rate by 1.4 fold compared to the spillway alone. These values act as indicators for the amount of time needed to return to base flow following an extreme precipitation event of known magnitude.

Decreasing the volume of Crystal Lake prior to extreme precipitation events may decrease the probability of upstream flooding following the event. In order to determine the volume of water that should be removed from the lake prior to an event, the magnitude of the expected event must be investigated and then taking this into account the duration for opening the valves can be predicted. Although predictive rainfall totals from major weather sources carry a degree of unreliability, the following outlines the steps necessary to determine the volume of water that should be removed from the lake prior to an extreme event:

1. Determination of Expected Precipitation: Ɣcm

   Identify the total amount of precipitation expected from an event using a reliable weather source. Values will often either be supplied in total expected inches or inches/hour, which can be converted into total expected precipitation by adjusting for the expected duration of the event. Convert this value to centimeters by multiplying by 2.54.

2. Calculate Total Expected Precipitation Volume for Watershed: Ɣcm * 27.2km^2 * 1000= Ɣ'm^3

   Multiply the total expected precipitation in centimeters by the area of the watershed upstream of Crystal Lake (27.2 km^2) and then multiply this value by 1000 to account for unit changes to produce a volume in cubic meters (m^3) that should indicate the amount of water that will fall within the watershed for that event.

3. Safety Value Adjustment: Ӽ'm^3 * 0.7 = Ӽ''m^3

   As not all precipitation in the upper watershed will reach the lake in the following 24-48 hours, a safety value of 0.7 should be multiplied by the estimated total precipitation volume (m^3).

4. Determine the Number of Valves Opened:

   All four valves should only be opened prior to an extreme precipitation event if inadequate time was left to drain the necessary volume with just the two larger valves.

5. Calculate Duration of Valve Opening: Ӽ''m^3 / 3420m^3/hour = T hours

   The total expected precipitation volume with safety adjustment should then be divided by 3420 m^3/hour, which is the rate of water that is discharged from the two larger valves (Figure 8). This will provide the number of hours necessary to leave the two larger valves open prior to an extreme precipitation event.

6. Monitor:

   As many extreme events will produce a greater volume of precipitation than can be safely eliminated from the lake prior to the event, designate a minimum allowable water level on the dam. Upon first uses of this methodology, record the time necessary to drain the lake to this level and ensure that in the future valves are not left open longer than this timespan prior to the event.

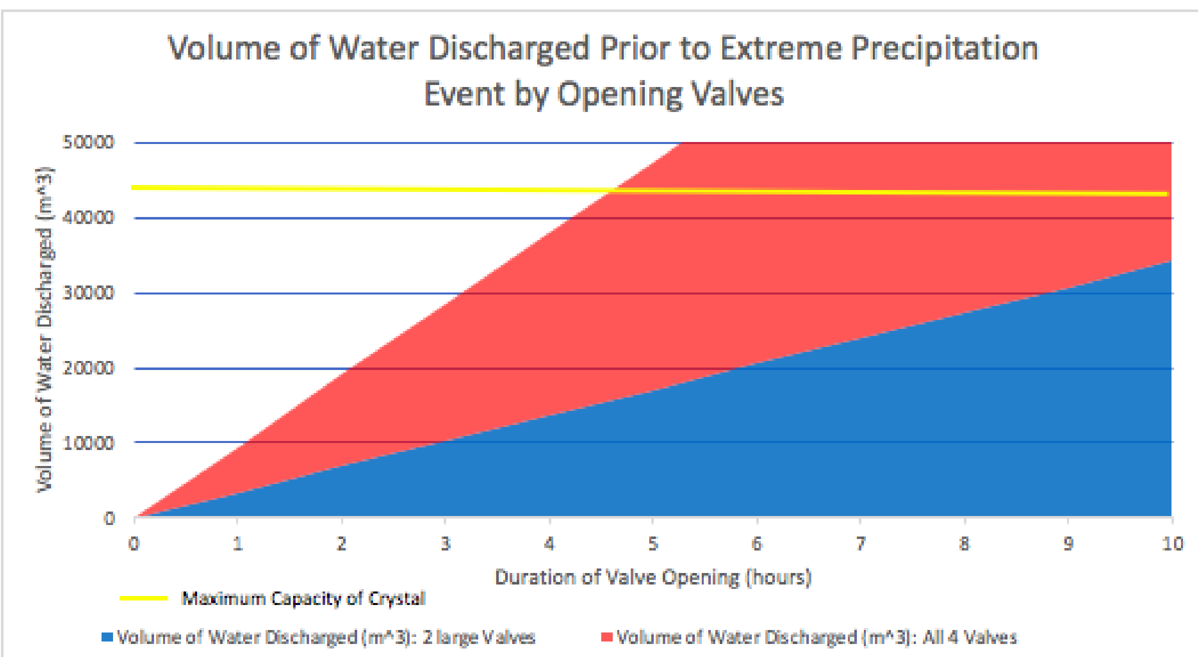


Figure 7. Duration valves are left open prior to an extreme precipitation event to drain a certain volume of water from Crystal Lake. Yellow line indicates the maximum capacity of Crystal Lake.

While Figure 7 relies on assumptions that may not apply to a natural system, the relative comparisons based number of valves open may be approximate to the natural setting. However, prior to the extrapolation or use of the data provided in Figure 7, discharge following extreme precipitation events should not be examined as a constant high velocity, but instead as a hyperbolic trend. Nonetheless, the general trend in discharge and flooding seen following high precipitation indicates the potential of opening the valves to decrease the duration of flooding.

5.3. Soils:

In addition to the consideration of the watershed that is feeding Crystal Lake, it is also important to determine soil types throughout the area, that will change how drainage occurs. Due to the extent of this task, and the lack of information available, modeling is conducted under the presumption of complete impervious soils, which allows for the construction of an upper limit.

The soils included in figure 9., are provided by The *Soil Survey of Dutchess County*, by the United States Department of Agriculture. The metadata was taken from *SSURGO soils, Dutchess County NY* by the Cornell University Geospatial Information Repository. The soil types were divided into four categories by the information provided by *The Soil Survey of Dutchess County*, indicated in the map by their respective symbology. The categories were Well Drained, Moderately Drained, Poorly Drained, and Impervious Surface.

Future GIS work for this map includes calculating the area of each soil types within the map using spatial analysis tools and then selecting for the soils that fall within the Crystal Lake Watershed. The areas of each soil category within the watershed should be then calculated using the calculated areas of each soil type. This will give an accurate ratio of Well Drained: Moderately Drained: Poorly Drained: Impervious Surface within the watershed feeding Crystal Lake.

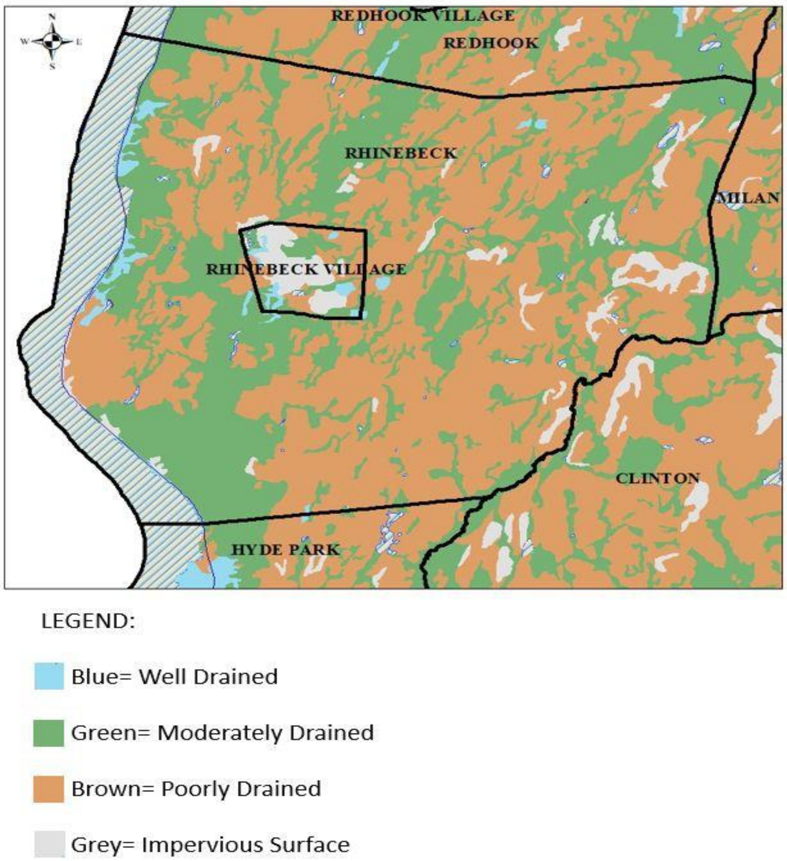


Figure 9: The soil survey of Dutchess County outlining the drainage types of soils within the area, from well drained, in blue, to poorly Watershed drained, in brown, and taking into consideration impervious soils, in grey.

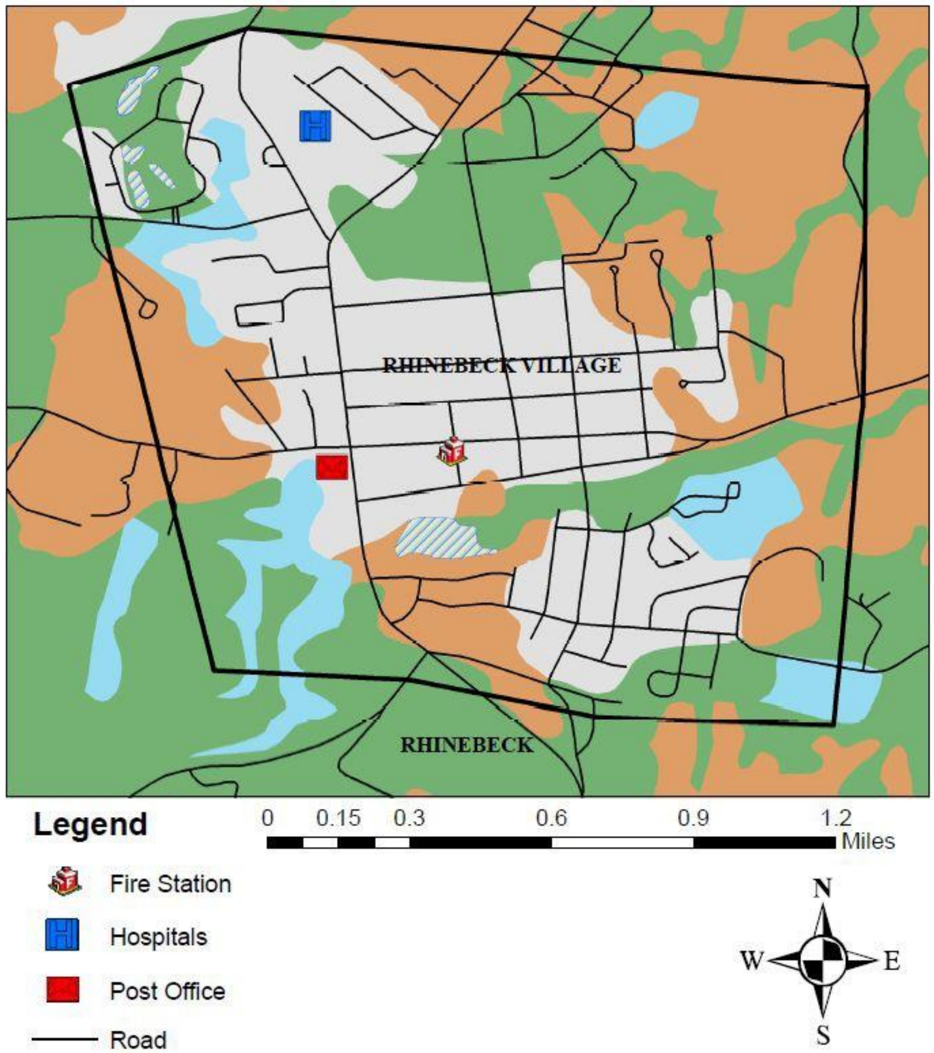


Figure 10; the soil survey map close up of Rhinebeck Village.

6. Mitigation Strategies:

6.1. Monitoring:

Although monitoring is not a direct form of mitigation it is the team's firm belief, supported by the personal correspondence of several professional individuals, that data collection can further help establish patterns for flooding and in such, act as an early warning system for the Village of Rhinebeck and its inhabitants. In creating a flood prediction model, the team found it challenging to find current data on the Landsman Kill, due to a lack of monitoring within the watershed. With active monitoring systems, the municipality of the Village of Rhinebeck will be able to establish a detection system to alert the proper officials of potential flood hazards occurring. These storm and precipitation events will likely increase water levels within the Landsman Kill, as well as increase and overfill the storage capacity of Crystal Lake, resulting in flooding and damages.

Suggested by personal correspondence with Christopher Mitchell, a research assistant with Hudson River National Estuarine Research Reserve (HRNRR), water level monitoring, achieved using a submersible water pressure transducer, may help aid in the further development of the prediction model proposed. (C. Mitchell, personal communication, April 4, 2019). Dr. Zion Klos, an assistant professor in the department of environmental science and policy at Marist College, also supports monitoring and suggests expanding to encompass precipitation measurements with rain gages. (Z. Klos, personal communication, February 2, 2019). Monitoring as a form of preemptive flood mitigation was also supported by retired president of Ecosystems Strategies, Inc, Paul Ciminello. (P. Ciminello, personal communication, April 4, 2019).

The lack of current available data for the area makes it difficult to accurately predict and find patterns in precipitation and flooding of the area. In the future, it is recommended to log precipitation events, and when it causes the need for the damn to be opened for drainage. How long the damn is opened for should be logged as well. Early warning and detection systems often cost roughly $2000-$3000, as described by a quote collected from Solinist Ltd., provided by Susan Loit. (S. Loit, personal communication, April 16, 2019). Preventing flooding from ever occurring will reduce overall costs to the Village of Rhinebeck, and allow for them to make necessary upgrades to the damn, surrounding land areas, and monitoring systems in the future.

There are numerous types of monitoring systems available, and separate components for implementation. Common monitoring systems will include; a deployment sleeve (in the case of water level monitoring); and a housing unit, which stores a Data Collection Platform or DCP, a cellular modem, used to transmit signals to a receiving device, and a battery. Solar panels can be outfitted to power devices, and rain gages, as well as other meteorological tools can be installed and connected to the DCP. It is with consideration of Dr. Klos, Mitchell, Ciminello, and in conjunction with systems designed by the Environmental Protection Agency, (EPA), (EPA ,2016), and the United States Geological Survey, (USGS), (Sauer, 2010), that water level and precipitation monitoring be utilized within the target area of the Landsman Kill and the Village of Rhinebeck. Additional monitoring systems, components and designs can be located in Appendix B: Monitoring Systems, which includes; images provided by Christopher Mitchell, (C. Mitchell, personal communication, April 14, 2019); figures sourced from a water level brochure, (Insitu, 2018); as well as from the USGS's *Staging Measurements and Gaging Stations* handbook. (Sauer,2010). Appendix B also compiles a few company websites that may be utilized to further grasp the design, and development of these systems, including AcuRite, (AcuRite, 2016), Baron, (Baron Services, Inc., 2019), and Davis, (Davis Instrument Corp., 2019).

Figure 10, was derived from the USGS handbook, in order to demonstrates a basic system design which incorporates a perforated polyvinyl chloride, PVC deployment tube, in which is a water level transducer, connected to a housing unit which holds the DCP, the cellular modem, and a battery. Whereas, Figure 11, shows the pathway data takes from point of collection to reporting to a device, presumably a cell phone or computer owned and operated by the municipality.

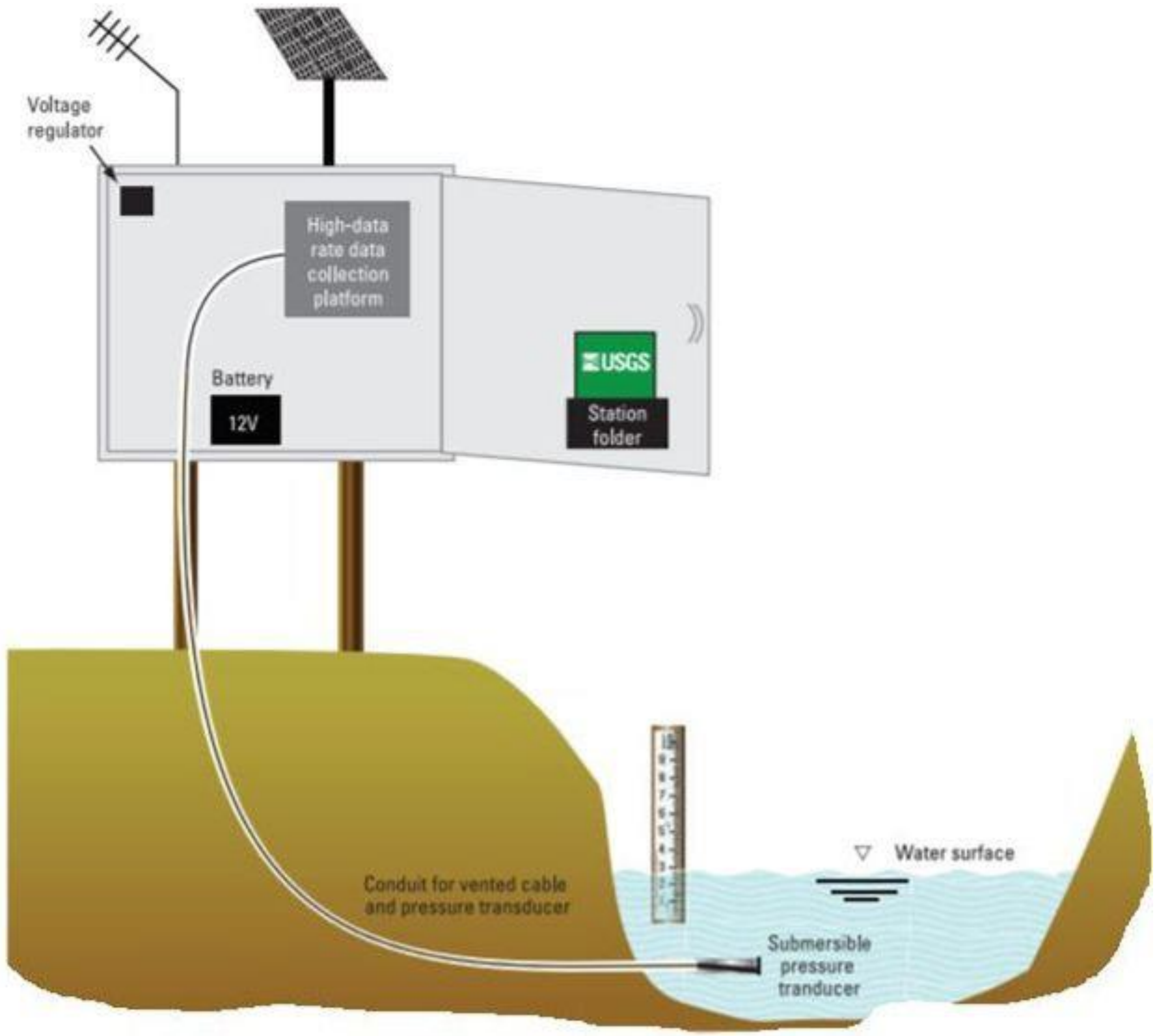


Figure 10: A diagram taken from the USGS Staging Measurements and Gaging Stations handbook which illustrates a simple telemetry station design that would utilize a housing unit on shore which will hold the data collection platform and modem (not shown), and the submersible water probe within the body of water. (Sauer, 2010).

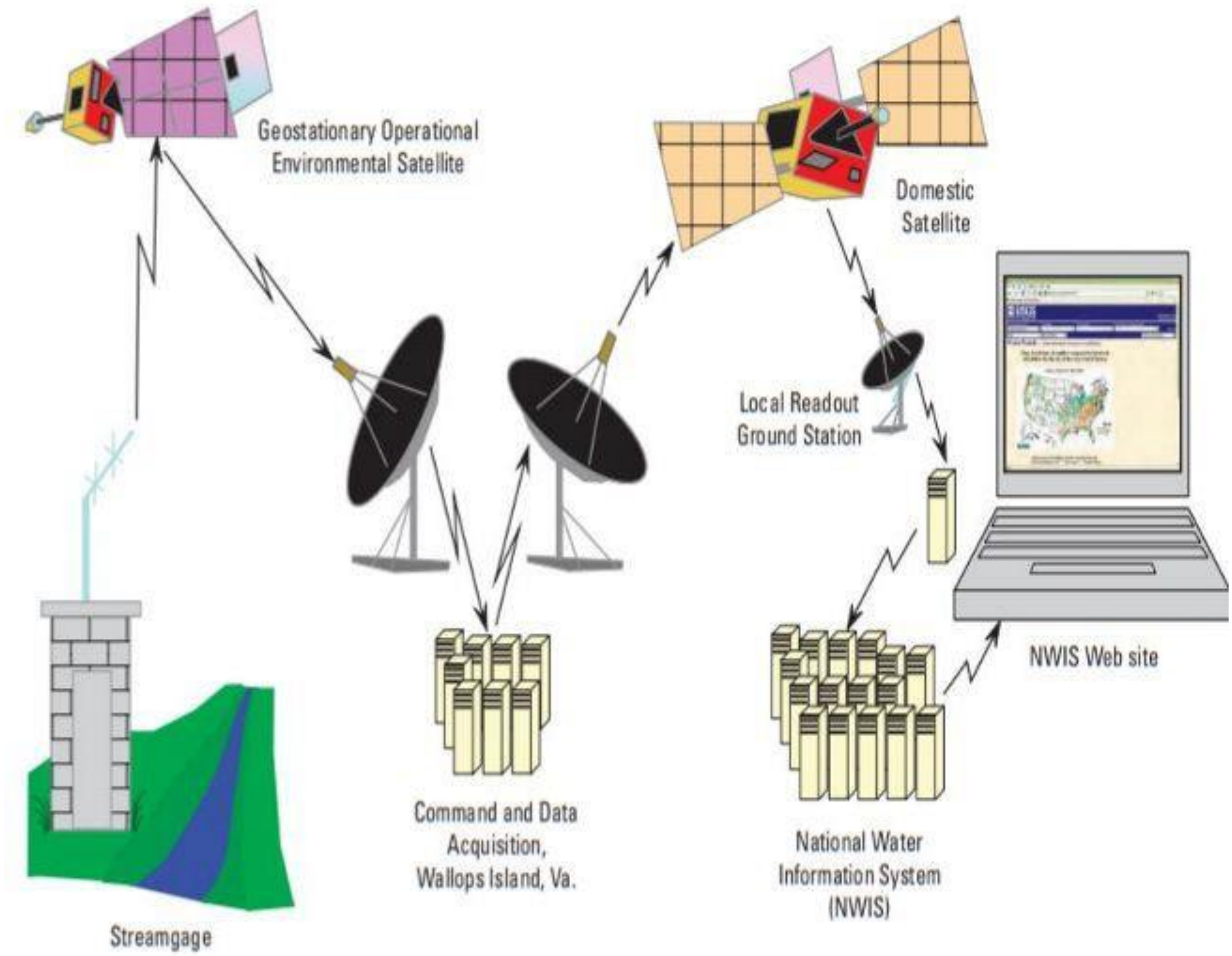


Figure 11: A representation of the monitoring station data pathway from collection at the stream gauge, to the processing on a local device. (In-Situ Inc., 2018).

1. Stream Gages:

Stream gages are a primary form of monitoring that has been evaluated and suggested for use in this specific project. Similar systems as the ones used by USGS and the National Oceanic and Atmospheric Agency (NOAA), may be a pertinent addition to a network of monitoring systems, to give real time data of the Landsman Kill creek itself. As advised, a water level transducer would work effectively at measuring real time water levels within the Landsman kill. With the Hobo transducer, the municipality can establish a small monitoring station that will record feedback and send alerts to another system, like a cell phone, if water levels exceed a specific threshold that may indicate flooding. A water level monitoring system would be greatly beneficial, indirectly alerting officials of instantaneous conditions that would prompt the opening of the damn to reduce the chance of flooding. Figure 12., is a NOAA telemetry station representing the type of stream gage station that would be recommended.

Figure 12. A NOAA telemetry station as depicted in the USGS handbook, (Sauer, 2010).

2. Rain Gages:

Rain gages directly measure precipitation totals and can even calculate rate of precipitation. These meteorological instruments can be established at their own stations, potentially on municipality buildings, or as an addition to established stream gages. It is recommended that rain gages have a clear, unobstructed view of the sky as to accurately collect falling precipitation. These gages may be implemented on municipality buildings such as the police station, firehouse, or even town hall. The use of rain gages with stream gages will allow the village to correspond the rate and accumulation of precipitation, to the rise in stream level. When these devices indicate threshold values for flooding, as determined by the model, the municipality can act accordingly and preemptively to mitigate flooding.

Locations have yet to be properly determined for the optimal location of monitoring systems, and require further evaluation. Stream gages should be localized to Crystal Lake and areas where flooding occurs upstream. (Z. Klos, personal communication, February 2, 2019), (C. Mitchell, personal communication, April 4, 2019). This monitoring system is best utilized within the body of water or at the head of the damn, to best indicate the current water levels. With a water level transducer in the water at the base of the dam, officials will have access to real time data and alerts pertaining to the water level of the lake, to allow for officials to act accordingly and with a much higher degree of response to events. Rain gages can be added to these stream gages, but would also be effective if implemented as an individual system, possibly on municipality buildings

6.2. Mitigation:

Mitigation is the best type of effective preventative measure to reduce chances of, and the degree of flooding, as well as the subsequent cost of repairs and clean up. Flooding almost entirely corresponds with stormwater management in urban areas. (Flynn & Davidson, 2016). The Village of Rhinebeck is a varying array of land use from urbanized streets, to rural forested lands, as well as agricultural fields. Primarily, before the development of the area, a high percentage of the land was a designated flood plain, and wetland. These types of ecosystems are pertinent to the ability of the land to control percolation, and retention rates of precipitation, through riparian vegetation zones, which in effect naturally mitigates flooding (Mondal & Patel, 2018). The challenge with urbanized development is the change in land use. Particularly in the case of the Village of Rhinebeck, the development of roadways has decreased the percentage of soil storage in those areas, and drastically increased the volume of storm runoff. Storm runoff contributes to flooding and damages, and as such is subject for modification for consideration. (Iarrapino & Attorney, 2014), (Lubick, 2006).

In order to increase flood mitigation, it is in the best interest of the village to invest in the repair and preservation of these riparian zones, and to incorporate mindful environmentally friendly strategies in future urbanization projects and developments. It is suggested that the most effective method of flood mitigation is the modification, establishment, repair, and/or protection of the riparian zones along the Landsman Kill, (Mondal & Patel, 2018). Besides the conservation of riparian zones, green engineering designs and methods should be implemented in any future developments. (Iarrapino & Attorney, 2014), (Flynn & Davidson, 2016). It is the professional suggestion of multiple individuals, and the conclusion of the conducted research, that these two factors be the major focus of the efforts of the Village of Rhinebeck to prevent and control flooding. Additional examples of local projects designed for stormwater management can be found on the New York Department of Environmental Conservation's website. (NYSDEC, 2018a).

1. Riparian Zones:

Supported by several experts and research conducted, riparian zones offer some of the best flood protection for waterways. (Mondal & Patel, 2018). Riparian zones are some 50 ft from the stream bank back of thick vegetation that helps to reinforce the bank soils of the stream from erosion, as well increase percolation of waters into the groundwater table. Riparian zones have notably been eroding from the Landsman Kill through the years as described by testimony from homeowners who wish to remain anonymous. Figure 13. shows an example of stream bank reinforcement. It is apparent that the change in land use has affected the ability of the existing vegetation to mitigate and control flooding, and it is, therefore, the suggestion to reinforce the vegetation along the stream banks of the Landsman Kill where applicable to do so. Targets species should be native to the lower Hudson Valley area as to decrease species competition and eliminate the probability of invasive species having adverse biological diversity effects on the ecosystems. Species under examination are referenced in Section 7: Vegetation and reinforced by the suggestions from Trees for Tribs and Buffer in a bag, state programs that allow for the funding of riparian zone replenishment in section 3 of the Hudson Valley, (NYSDEC, 2019a) (NYSDEC, 2019b). Funding from these sources is limited to the projections of the project, a minimal amount of stream bank available, and a timely submission to the corresponding agencies. These grant programs also include guides to help with planting and maintenance guides, (NYSDEC 2018c), (NYSDEC 2019d), of the trees and shrubs planted. As of this time, it is unlikely to meet deadlines for these sources, however, they run annually and there is no limit of submission by the same individual multiple times.

Figure 13. An image of Hudson Estuary Trees for Tribs volunteers planting trees and shrubs along the Casperkill Creek in Poughkeepsie Ny., taken from the NYSDEC website. (NYSDEC,2018a)

2. Green Urban Engineering:

Environmentally friendly engineering is essential for future development within the Village of Rhinebeck, and the surrounding lands of the Landsman Kill. Appendix C: Urban Engineering, encompasses multiple different designs taken from Urban Street Stormwater Guide, (National Association of City Transportation Officials, 2017). While there are many ways to implement green designs, it is most notable to mention the selection of semi-permeable pavements, (Keefe, 2011), (Murphy, 2018), bioretention/filtration designs (NACTO,2017), and even community-based efforts such as implementing rain gardens, (EPA, 2018b), (Kim, 2018), (Alyaseri et al., 2017). Most of the development of urbanized areas results in the removal of permeable sediments and soils or the paving over such surfaces with non-permeable pavements for roadways, foundations, parking lots, etc. This drastically increases the surface runoff waters that cannot percolate through the pavements, through the soils, and into the groundwater. The increased surface stormwater runoff is collected through storm drains in the streets, and this water is redirected to other areas that may not be suited to handle the increased fluctuation of the water. One notable location is the newly constructed storm drains in the village that drains directly into the site of concern, Crystal Lake. With the increased stormwater runoff, Crystal Lake is exposed to an increased flow of water that would otherwise disperse through the soils. With this in mind, future developments or modification should consider the needs of the space, and the changes the development will create. In order to decrease the issue these urbanized developments impose, semi-permeable pavements and other non-traditional resources can be utilized instead of traditional asphalt and concrete, as seen with the Taconic Regional Office (Keefe, 2011). In a cost benefit analysis, it is shown that the initial investments with permeable pavements outweigh the negative fiscal consequences that non-permeable pavements impose. (Murphy, 2018). Figure., 14 is an up-close shot of porous pavements, emphasizing the porousness, and therefor permeability of the alternative pavement.

Figure 14. Porous concrete parking lot, located at the Roeliff Jansen Community Library in Copake. (NYSDEC, 2018a).

Bioretention and filtration methods essential create surface space for water to safely accumulate during heavy precipitation events, throughout the municipality. These areas also offer a chance for aesthetic improvements throughout the municipality. Retention areas can be implemented at bus stops and parks, as well as through roadways. Strategic planting of certain species of trees, and flowering plants and bushes can help to increase rain absorption, water percolation, and add aesthetic value to the community. Figure 15., is an example of such a bioretention center, in the form of a vegetated swale. Illustrated by this figure is the conjunctive use of trees, shrubs and flowering plants to create a bioretention/filtration area along the road median.

Figure 15. A Vegetated swale in the median of a roadway in the Village of Greenwood Lake in Orange County. (NYSDEC, 2018a)

Rain gardens are described as, “A rain garden is a depressed area in the landscape that collects rain water from a roof, driveway or street and allows it to soak into the ground. Planted with grasses and flowering perennials, rain gardens can be a cost effective and beautiful way to reduce runoff from your property. Rain gardens can also help filter out pollutants in runoff and provide food and shelter for butterflies, song birds and other wildlife.” (EPA 2018b). Rain gardens are smaller bioretention/filtration systems designed to direct and retain precipitation that falls on homes and drains through gutters, into small flowering pools where the water can sustain native plant life and other species, as well as helping to decrease the surface runoff and increase percolation potential of the land. (Natural Resources Conservation Services, 2005). Rain garden designs can be found on the Three Rivers Rain Garden Alliance website. (Rain Garden Alliance, 2009). Additionally, the Natural Resources Conservation Services, (NRCS), provides an insightful look at the importance and implementation of rain gardens, from the designs to the native flowering species that should be utilized, (NRCS, 2005). Rain gardens are a perfect opportunity for the Village of Rhinebeck to lead by example, possibly implementing these types of bioretention centers at local parks, and village buildings, Figure 16 exemplifies the residential accent that a rain garden can have on a property.

Figure 16. A rain garden strategically placed at the end of a yard, in order to capture street and lawn runoff.

By adding an element of community support and responsibility to help with flood mitigation and control, the village can effectively recruit the help of the local residents, and business owners. The Saw Kill WaterShed Community, (SKWSC), was able to make headway on the protection of their watershed by invoking community involvement and support. (SKWSC, 2018). By helping to promote the knowledge to create rain gardens, the Village of Rhinebeck can benefit from community bonding and low-cost methods of flood mitigation. This idea highlights the importance of community effort and education. (Kim, 2018). If there are more resources for the residents of the Village of Rhinebeck to understand the risks of flooding, they can learn ways to effectively combat it. These services could be as simple as community DIY projects or blueprints, on such things as a rain garden, made available to the public through the town website. By cultivating a community response and knowledge, the bond of township grows, and tools available to protect it bloom.

7. Vegetation:

Riparian vegetation is vegetation that is found along bodies of water and is extremely valuable and important as it serves many functions along the tributaries of watersheds. Riparian trees and shrubs allow streambanks to be held in place while preventing erosion. They are also able to trap sediment and pollutants, which aids in keeping the water clean. Additionally, one of their most important features is that during high stream flows, riparian vegetation slows and dissipates floodwaters. They are essential for maintaining high water quality in streams, rivers, and lakes. Moreover, they are essential for use in mandatory channel depth as there reduce the risk of flooding. According to the New York State Conservation Reserve Enhancement Program, "…vegetated floodplain reduces the force, height and volume of floodwaters by allowing them to spread out horizontally and relatively harmlessly across the floodplain." (Cohen, 1999). Certain shrubs and trees function as "sponges" as they are able to soak up wetland soils and different pollutants. This vegetation retains runoff in upland areas that would otherwise flow into rivers and create flooding conditions downstream. These types of vegetation transpire large amounts of water and therefore transfers floodwaters into the atmosphere. This partially dries the soil and makes more room for precipitation in soils (floodwater). Ultimately, riparian vegetation helps prevent property damage and is a natural approach to reduce flood risks. (Cohen, 1999).

An important factor to consider when researching the appropriate vegetation for the Landsman Kill watershed in Rhinebeck is the type of soil in the area (National Cooperative Soil Survey, 2011). The soil series provided by the USDA on Rhinebeck indicates that there are poorly drained soils formed in clayey lacustrine sediments. The soils in Rhinebeck are on glacial lake plains and lacustrine mantled uplands. These soils that have been formed on the glacial lacustrine deposits have high clay and silt content. This is critical information as certain riparian vegetation require specific soil in order to properly grow (National Cooperative Soil Survey, 2011). The vegetation that would be most appropriate in this location would thrive on fine, clay soils.

In order to implement the most effective riparian vegetation along the Landsman Kill , native species were researched. Native species include plants, animals and other organisms that are naturally occurring and evolved in a specific part of the world. Non-native plants, animals, and other organisms did not naturally and historically occur in that specific part of the world. It is critical to plant and grow native species as non-native species can impact natural ecosystems, economies, and our relationship with the environment. Non-native invasive species can contribute to the decline of endangered or threatened species and compete with native species for moisture, sunlight, and nutrients. Native riparian vegetation along channels may help aquatic wildlife as well as stabilize stream banks and reduce flooding (USDA Forest Service, 2014).

Riparian vegetation is also crucial in slowing the flow of surface runoff, ultimately aiding in controlling the rate of soil erosion. The roots of riparian vegetation help absorb the water and pull it into the ground. Thus, pollutants and nutrients in the runoff become trapped in the soil and absorbed by the roots of these shrubs and trees. The longer their roots, the more capable they are to provide a high absorption of water as well as soil erosion control (Watershed Canada, 2015).

There are five native trees and shrubs that have been thoroughly researched based on moisture absorption, soil adaptability, flood tolerance, root depth, and growth rate. Additional characteristics and species can be found in Appendix D.

1) *Cephalanthus occidentalis*, button bush has a moderate growth rate, which is important to consider for initial implementation of this shrub. They also have a moderate moisture use meaning they are able to absorb copious amounts of water. Their adaptability to fine soils is ideal for the type of soil found in the village of Rhinebeck. It is also used for erosion control along shorelines and forms dense stands that stabilize the plant, this is done with their roots that reach 14 inches long. (USDA, NRCS, The PLANTS database, 2019). An additional that is relevant to one of the most important elements of riparian vegetation is that this species is flood tolerant. They are able to continue to flourish even through flooding. These multitudes of characteristics make button bush an appropriate candidate for riparian vegetation in the watershed (Wennerberg, 2004).

Figure 17. *Cephalanthus occiden*talis (Prairie Moon Nursery, (N.A.))

2) C*arya ovata,* Shagbark Hickory, is native to North America and has numerous riparian functions (USDA NRCS The PLANTS database, 2019). Although they have a slow growth rate, they are able to grow and flourish in the fine clay soils located in the Village of Rhinebeck. The species has medium moisture use and flood tolerance is one of their main features along with their incredibly long roots that can reach up to 48 inches This is a useful quality of this species as they are able to control erosion in an effective manner (USDA NRCS The PLANTS database, 2019).

Figure 18. C*arya ovata* (Chert Glades Chapter. (n.d.))

3) *Rhododendron viscosum*, swamp azalea, are tolerant of moist to wet soils, including the clay and silk found in Rhinebeck and tolerates periodic flooding. This shrub has a shallow root system of 14 inches that has a high retention of moisture (Missouri Botanical Garden, 2019). It is native to North America and has a slow growth rate, although, they are able to tolerant consistent flooding which is a crucial characteristic of riparian vegetation. Their high moisture and root system make them an important shrub to consider implementing in flood areas (USDA NRCS The PLANTS database, 2019).

Figure 19. *Rhododendron viscosum* (White Flower Farm. (n.d.).)

4) *Cornus amomum* is usually referred to as silky dogwood and is native to North America. They are a good shrub for moist and wet areas as they have a high moisture content and function well along streams/ponds for erosion control due to their roots that can reach 16 inches long (Missouri Botanical Garden, 2019). They are used for streambank protection as they are flood tolerant (USDA NRCS Northeast Plant Materials Program, 2002). It is able to adapt to fine soils, similar to those in Rhinebeck. Their moderate growth rate will allow them to be used in an appropriate amount of time in this area (USDA, NRCS, The PLANTS database, 2019).

Figure 20. *Cornus amomum* (NC State University. (n.d.).)

5) *Rose paulustris*, commonly known as swamp rose, is another important shrub to consider in riparian vegetation. They flourish in fine soils like those in the Village of Rhinebeck with a moderate growth rate. They tolerate some flooding but their roots of 18 inches allow them to control erosion as well as absorb a moderate amount of floodwater (USDA, NRCS, The PLANTS database, 2019).

Figure 21. *Rose paulustris* (Barrie Collins. (n.d.).)

The shrubs previously listed are very resilient and adaptive to wet conditions requiring absorption of water. They are ideal for implementation along the Landsman Kill Creek.

Phreatophytes are plants that depend on their water supply upon groundwater that lies within reach of their roots. The plants grow where they can send their roots down to the water table, or to the capillary fringe immediately overlying the water table, from which the plant pumps its supply of water. (Robinson, 1958). The USDA Plants Inventory recommends several species of trees based on their characteristics.

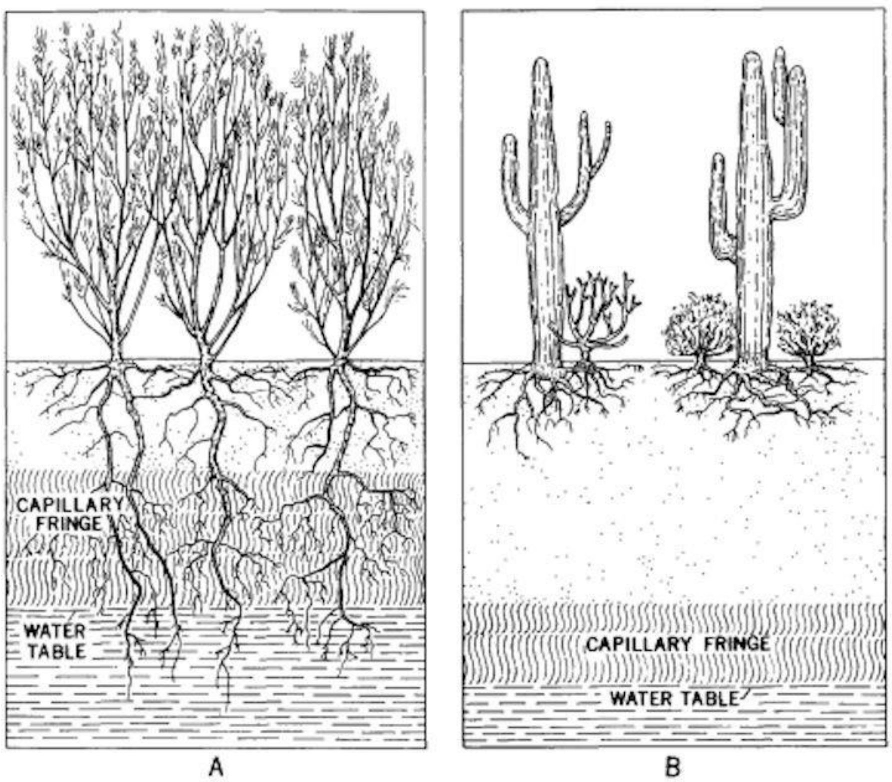


Figure 22. A depicts phreatophytes which have roots that extend long enough to reach the water table and pulls water up using capillary fringe. B, on the right, depicts the opposite, superficial roots with very limited capillary fringe being performed in places like deserts. (Robinson, 1958).

The following are potential trees that be implemented in the Landsman Kill.

1) *Betula nigra*, commonly known as river birch, grows rapidly in clay soils and is resistant to flooding. (USDA NRCS The PLANTS database, 2019) River birch has a high moisture use. (USDA NRCS The PLANTS database, 2019)

Figure 23. *Betula nigra* (Gardenia. (n.d.).)

2) *Alnus Serrulata*, the Hazel Alder/Speckled Alder is tolerant to various types of soils including clay and can tolerant seasonal flooding, while maintaining a rapid growth rate. (USDA NRCS The PLANTS database, 2019) Quercus bicolor, known by its common name, the white swamp oak, has a minimum root length of 40 inches which would aid in preventing erosion. Also, this species rapidly grows and is tolerant to flooding which is ideal.

Figure 24. *Alnus serrulata* (Cold Stream Farm. (n.d.).

3) *Salix bebbiana*, Bebb willow, is tolerant to flooding and has a high moisture use. Additionally, the species grows rapidly and is adaptable to fine soils which are found in the village of Rhinebeck (USDA NRCS The PLANTS database, 2019).

Figure 25. *Salix bebbiana* (University of Wisconsin Green Bay. (n.d.).)

4) *Salix discolor*, may be better known as pussywillow, is another species that is recommended for the area. Like the other species mentioned, Salix discolor grows rapidly and is adaptable to the fine soils found near the Landsman kill. The deep roots of the species prevents soil erosion and the species has high moisture use (USDA NRCS The PLANTS database, 2019).

Figure 26. *Salix discolor* (Long Island Natives. (n.d.).)

Table 1 has additional characteristics listed for the previous nine vegetation species mentioned. They are related to the most important elements that these species offer. This may be linked to their ability to retain water or the physical properties the species display. Appendix D has this table as well as another table that contain more specie options as well as the qualities found in Table 1.

Species	Common Name	Type	Growth Rate	Lifespan	Adaptable to Fine Soils	Fertility Requirement	Moisture Use	Propogated by Bare Root	Propogated by Cuttings	Palatable Browse Animal	Berry/Nut/Seed Product	Flood Tolerance	Root Depth Min
Alnus serrulata	Speckled alder	Tree/Shrub	Rapid	Moderate	Yes	Medium	High	Yes	No	Medium	No	Yes	24in
Betula nigra	River birch	Tree	Rapid	Short	Yes	Medium	High	Yes	Yes	Medium	No	Yes	20 in
Carya ovata	Shagbark hickory	Tree	Slow	Long	Yes	Medium	Medium	Yes	No	Low	Yes	Tolerant	48in
Cephalanthus occidentalis	Common buttonbush	Tree/Shrub	Moderate	Short	Yes	Low	High	Yes	Yes	Low	No	Yes	14in
Cornus amomum	Silky dogwood	Shrub	Moderate	Moderate	Yes	Medium	High	Yes	Yes	Low	No	Yes	16in
Rhododendron viscosum	Swamp azalea	Shrub	Slow	Moderate	Yes	Low	High	Yes	No	Low	No	Yes	14in
Rose palustris	Swamp rose	Shrub	Moderate	Long	Yes	Medium	Medium	Yes	No	Low	No	Tolerates some	18in
Salix bebbiana	Bebb willow	Tree	Moderate	Moderate	Yes	Medium	High	Yes	Yes	Medium	No	Yes	16in
Salix discolor	Pussy willow	Tree	Rapid	Long	Yes	Low	High	Yes	Yes	Medium	No	Tolerant	20in

Table 1. List of species in report with their respective characteristics and features.

7.1. Trees for Tribs Program:

A possible source to help riparian vegetation is the Trees for Tribs program, funded by the New York State Department of Environmental Conservation (DEC) and offers free native trees and shrubs for eligible projects. Based on the location of the Landsman Kill, applications and potential projects must go through the Hudson River Estuary Trees for Tribs Program.

In order to be eligible for the services of Trees for Tribs, applicant projects must be within a riparian area that is adjacent to a waterbody where plants can be used to extend or enhance existing vegetation, but will not be separated from the waterbody by a road or other structure. Priority is given to projects that are adjacent to streams over lakes, ponds, and wetlands and therefore the Landsman Kill is a great potential project. However, the organization has a few stipulations, including that plantings are not available for stormwater ponds, drainage ditches, or other man-made structure, which unfortunately makes Crystal Lake ineligible. The deadlines for project applications for spring plantings is March 1 and August 1 for fall plantings. If a project is accepted, the Hudson River Estuary Program may be able to assist in plant selection, creating a planting plan, site preparation, advice on installation and other various technical information.

8. Grants for Upgrades to the Dam and Other Options:

A variety of options should be pursued and evaluated regarding Asher Dam and flooding. Crystal Lake provides a sense of place and natural beauty for those who live nearby. The impacts of climate change and extreme weather events may necessitate the consideration of mitigation strategies. The current infrastructure of the dam may not be able to withstand stronger and more frequent weather events. Further, a future storm with the same destructive strength of Hurricane Irene is not only possible, but very likely.

8.1. Option A: The Climate Smart Communities Grant:

The Climate Smart Communities Grant (CSCG) is the prime option for a source of funding to address the flood risk near Crystal Lake and Asher Dam. The program began in 2016 and runs through the New York State Department of Environmental Conservation's (NYSDEC) Office of Climate Change. It provides a fifty-fifty grant to municipalities undertaking either adaptation or mitigation projects. This matching grant can be used for a wide variety of climate change focused projects, such as the construction of natural resiliency measures, greenhouse gas reductions, and, relevant to the Village of Rhinebeck, flood mitigation (NYSDEC, 2019d).

Of the thirty recipients of grants in 2018, six were projects that dealt exclusively with flood mitigation and reduction (Table 1). Many others were generalized, multi-step projects that included flood mitigation as well. They illustrate the large amount of funds available through the CSCG. These projects can be used as case studies, highlighting the solutions that are currently being utilized to reduce the increased risk of flooding associated with climate change.

Municipality	Amount	Project
Town of Dewitt	$100,435	Stormwater management: implementation of best management practices for neighborhood with chronic flooding, ie culverts, porous pavement, infiltration basins, street trees, and water storage areas.
Town of Batavia	$255,172	Stormwater management: check dams, creek bed enhancements, native vegetation, and a stormwater treatment pond in Bigelow Creek watershed to prevent flood, erosion, and sedimentation.
Town of Southampton	$410,000	Alewife creek culvert resizing: right-size a culvert under Noyac Road at North Sea Road to restore proper water flow through Alewife Creek; allows for excess water flow.
Town of Fallsburg	$168,713	Culvert resizing: to reduce flood risk along a tributary to the East Mongaup River in Hurleyville.
Sullivan County	$934,084	Hamlet of Kohlertown flood risk reduction: constructing on overflow pipeline to divert excess water from the East Branch of the Callicoon Creek, which regularly floods businesses and homes.
Town of Kirkwood	$91,000	Stormwater management: replacing underground drainage system beneath the highway garage.

Table 2: Climate Smart Communities 2018 Grant Recipients with a focus on flood reduction or mitigation. Source: NYSDEC 2019,

In order to apply for this grant, as with most other grants in New York State, the Village of Rhinebeck must be registered through the NYS Grants Gateway. The Village must be able to enter into a contract, provide a work plan and a budget for the project, and be able to provide a matching amount of funding. Furthermore, the Village must provide documents related to insurance, workers compensation coverage, proof of disability or exemption from disability, commercial green liability insurance, professional liability insurance, and marine protection and indemnity (NYSDEC, 2019e).

8.2. Option B: Green Innovation Grant Program:

The second most promising option for funding is the Green Innovation Grant Program (GIGP), which is distributed through the Governor's Consolidated Funding Application and administered by the New York State Environmental Facilities Corporation (NYSEFC). The two goals of the GIGP are to improve water quality and create green stormwater infrastructure. It is meant to support innovative solutions that treat flooding as not just a problem, but an opportunity. This grant poses a greater creative challenge than the CSCG, as it requires more than simply a band-aid solution. Examples of past projects include daylighting streams and creating rain gardens. In this grant program, 40 to 90 percent of the costs of a project can be met with these funds, meaning that municipalities are required to provide no less than 10 percent but no more than 60 percent of the project funding if awarded a grant (NYSEFC, 2019a).

It appears that this grant program, compared to the Climate Smart Communities Grant Program, awards fewer albeit larger grants; in 2018, there were fifteen grants awarded. The smallest grant awarded was $220,000 to the University of Albany to fund a green roof, while the largest was an impressive $2,500,000 to the Village of Ilion to restore Steele Creek to its natural stream channel and floodplain (NYSEFC, 2019b). Close to home, the City of Poughkeepsie was awarded $1,200,000 in 2018 for a stormwater management initiative in two parking lots located on Liberty and Academy Streets. The projected plan is to retrofit these two lots with porous pavement, which will mitigate flooding and improve water quality (Howland, 2019).

The website for the GIGP is a valuable resource that contains information about turning the problem of flooding into an opportunity to restore natural habitats and improve water quality. There are eight eligible practices (Table 2).

Project	**Description**
Permeable Pavement	Reduces runoff by allowing water to infiltrate and collect underground. Dependent on appropriate soil type, but can be used for parking lots, roads, plazas, and sport courts.
Bioretention (rain gardens)	Collects excess water and allows it to infiltrate, reduces runoff, natural pollutant control.
Green Roofs & Green Walls	Vertical and horizontal structures with plant material to collect and filter rainwater.
Stormwater Street Trees/Urban Forestry Programs	Engineered tree pits, tree boxes, and trenches that capture stormwater from roads and manage it through evapotranspiration and infiltration. Provides additional benefit in the forms of air and water pollution control, reduced energy use from tree shade, CO2 sequestering, and providing wildlife habitat.
Establishment or Restoration of Floodplains, Riparian Buffers, Streams, or Wetlands	Floodplains: areas of water flow, have been built upon over time. Provide filtration of sediment, storage of water, and allows for infiltration and evaporation. Riparian buffers: vegetated areas surrounding streams that reduce erosion, pollution, and slow water flow. Streams: restoring streambanks to reduce erosion and destructive flows. Wetlands: shallow marshes excellent for water filtration, reduction of run off, and animal habitat.

Stream Daylighting	Restoring a stream to its natural flow from man-made pipes or culverts.
Downspout Disconnection	Disconnecting runoff from draining directly into sewage systems or stormwater systems
Stormwater Harvesting and Reuse	Mainly for residential areas, basins to collect water to be used for other activities, like watering lawns.

Table 3: Green Innovation Grant Program Eligible Practices for Stormwater Management. Source: NYS Environmental Facilities Corporation, 2019b.

The application for this grant is run through the Consolidated Funding Application, found on the Regional Economic Development Council's website. There are many requirements for applying to this grant; a detailed feasibility study is required from a licensed professional to assure the feasibility of proposed green infrastructure at the site. The study must include the following elements: cover page, executive summary, project objectives, existing conditions, project description, proposed schedule, anticipated regulatory approval and permits, project cost estimate, and water quality/water monitoring. Additional requirements include an existing conditions graphic, as well as a conceptual site plan and photographs of the site (NYS Environmental Facilities Corporation, 2019c).

8.3. Matching Funding:

While grants offer a great opportunity for funding, there is a significant financial burden on the municipality which necessitates planning and foresight. The Town of Poughkeepsie, for example, is a recipient for the Climate Smart Communities Grant in the 2018 cycle. Michael Welti, the Director for Municipal Development in the Town, outlined the planning and requirements that went into the Town's grant. In the budget, $65,000 was set aside in advance for planning and consultation beforehand, which was used to match the $45,000 from the Climate Smart Communities Grant and an additional $20,000 from the Hudson River Greenway Grant (M. Welti, personal communication, April 15, 2019).

The matching portion of the grant does not necessarily need to be money. Depending on the nature and requirement of the grant, municipalities can also offer what are known as "in-kind contributions." Essentially, if a small municipality does not have sufficient funds to provide a monetary match for a grant, they can provide other services towards the project that would equate to the value of the match. For instance, the municipality could offer volunteers and their labor to match a grant, as well as the services of the public works department. This is another option for smaller municipalities, but it requires a very close attentiveness to the precise amount of time and labor paid to ensure that it is equal to the necessary match. (NYSDEC 2019d). Finally, the Village of Rhinebeck must consider that these grants are reimbursement grants, meaning the village will have to provide the money upfront before receiving the grant.

This will likely determine the size and scope that is possible for the Village to undertake (M. Welti, personal communication, 4/15/2019).

9. Conclusion:

Policy research on municipally owned dam regulations found that Rhinebeck is in violation of some DEC regulations. It's recommended that village officials take the necessary steps in order to comply with regulations to protect the village from liability issues.

A model was developed based on historic precipitation records and current discharge values from Asher Dam. Rhinebeck precipitation records and historical discharge rates were unavailable. Therefore, the predictive model only identifies how precipitation levels and valve operations impact drainage rates. The findings emphasize what data will need to be collected and analyzed in future projects to produce a more accurate model.

This project provides the Village of Rhinebeck with various grant opportunities which could be used for mitigative efforts or dam updates. These mitigation efforts include planting various species of riparian vegetation, which have been identified based on characteristics such as flood tolerance, root depth, and growth rate. These grants could also go towards monitoring systems such as water level transducers, and stream and rain gauges. It is recommended that these monitoring systems be installed to provide future students with the necessary data required to develop a comprehensive model. The most feasible grant that will cover these expenses comes from comes from the Climate Smart Communities program, which gives out comparatively smaller reimbursement grants to numerous communities throughout New York.

References

AcuRite. (2016). Retrieved from https://www.acurite.com/

Alyaseri, I., Zhou, J., Morgan, S.M. et al. (2017). Initial impacts of rain gardens' application on water quality and quantity in combined sewer: field-scale experiment. Front. Environ. Sci. Eng. (2017) 11: 19. Retrieved from https://doi.org/10.1007/s11783-017-0988-5

Baron Services, Inc. (2019). Baron Critical Weather Intelligence. Retrieved from https://www.baronweather.com/industries/insurance/claims/weather-monitoring/

Barrie Collins. (n.d.). Rosa palustris - Swamp Rose. https://landscapeofus.com/garden/rosa-palustris-swamp-rose/ Chert Glades Chapter. (n.d.). Our Charming Hickory Trees. http://www.chertglades.org/blog/2016/10/5/1symm43bpsdo851nkunuawdta3ejn8

Cohen, R. (n.d.). Fact Sheet # 2 Functions of Riparian Areas for Flood Control, 1–3. https://soilseries.sc.egov.usda.gov/OSD_Docs/R/RHINEBECK.html

Cold Stream Farm. (n.d.). Speckled Alder. https://www.coldstreamfarm.net/product/speckled-alder-alnus-rugosa/

Data Access and Dissemination Systems (DADS). (2010). American FactFinder. https://factfinder.census.gov/faces/nav/jsf/pages/community_facts.xhtml

Davis Instruments Corp. (2018). Davis Instruments. https://www.davisinstruments.com/weather-monitoring//

Dutchess County Real Property Tax Service Agency [Map]. (n.d.). Parcel Access. https://gis.dutchessny.gov/parcelaccess/parcelaccess_map.htm

Environmental Management Council (EMC). 2012. *State Of The Environment Report: Dutchess County.* https://dutchessemc.files.wordpress.com/2012/04/dcsoereport2012.pdf

Environmental Protection Agency. Stormwater Phase II Final Rule. (2012). https://www3.epa.gov/npdes/pubs/fact2-1.pdf

Environmental Protection Agency. (2016). Watershed Academy Web https://cfpub.epa.gov/watertrain/pdf/modules/monitoring.pdf

Environmental Protection Agency. Stormwater Discharges from Municipal Sources. (2018a). https://www.epa.gov/npdes/stormwater-discharges-municipal-sources

Environmental Protection Agency. (2018b). Soak Up the Rain: Rain Gardens. https://www.epa.gov/soakuptherain/soak-rain-rain-gardens

Faber, M *et al*. (2019). *Soil Survey of Dutchess County, New York*. United States Department of Agriculture. https://www.nrcs.usda.gov/Internet/FSE_MANUSCRIPTS/new_york/NY027/0/Dutchess.pdf

Flynn, C. D., and C. I. Davidson. (2016). Adapting the social-ecological system framework for urban stormwater management: the case of green infrastructure adoption. *Ecology and Society* 21(4):19. Retrieved from http://dx.doi.org/10.5751/ES-08756-210419

Findlay, Stuart et al. Water Resources Of Dutchess County, NY. 2010. Accessed 28 Mar 2019.

Gardenia. (n.d.). Betula nigra 'Heritage' (River Birch). https://www.gardenia.net/plant/Betula-nigra-Heritage-River-Birch

Howland, Jack. Dutchess Environmental Initiatives Get Boost for 2019. *The Poughkeepsie Journal*. January 14, 2019. https://www.poughkeepsiejournal.com/story/news/local/2019/01/14/dutchess-environmental-initiatives-get-boost-2019/2447511002/

Iarrapino, A., & Attorney, S. (2014). A natural solution green infrastructure is transforming stormwater management for the 21st century. *Conservation Matters*, *20*(3), 2+. http://link.galegroup.com.online.library.marist.edu/apps/doc/A372694021/AONE?u=nysl_se_marist&sid=AONE&xid=d431aff4

In-Situ Inc. (2018). Water Level Brochure. *Your Eyes in the Field.* For Collings, Colorado, USA. http://in-situ.com/wp-content/uploads/2016/02/WaterLevelBrochure.pdf

Keefe, D. (2011, March 3). State Parks Taconic Region Headquarters Awarded Highest-Level LEED Green Building Certification. Staatsburg, NY, USA. https://parks.ny.gov/newsroom/press-releases/release.aspx?r=842

Kim, Jinki. (2018). Exploring green infrastructure benefits at house and neighborhood scale: Case study of illinois, USA. Landscape and Ecological Engineering, 14(1), 165-174. doi: http://dx.doi.org.online.library.marist.edu/10.1007/s11355-017-0331-0

KUNZ v. UTAH POWER LIGHT CO | 9th Cir. | Judgment | Law. (n.d.). https://www.casemine.com/judgement/us/5914959cadd7b049345d1dc9

Long Island Natives. (n.d.). Salix discolor - Pussy Willow. https://longislandnatives.com/products/salix-discolor-pussy-willow

Lubick, Naomi (2006). Using nature's design to stem urban storm-water problems. Environmental Science & Technology., 40(19), 5832–5833. https://doi.org/10.1021/es062782n

Missouri Botanical Garden. (2019). Missouri Botanical Garden. http://www.missouribotanicalgarden.org/PlantFinder/PlantFinderDetails.aspx?taxonid=280018

Mondal, S., & Patel, P. P. (2018). Examining the utility of river restoration approaches for flood mitigation and channel stability enhancement: A recent review. *Environmental Earth Sciences, 77*:195, 1-25. doi:10.1007/s12665-018-7381-y

Murphy, L. (2014, October 15). Managing Stormwater in the Hudson Valley: A Cost-Benefit Analysis of Permeable Pavement. NY, USA. https://www.lhccd.net/uploads/7/7/6/5/7765286/libby_murphy_seny_10-15-14.pdf

National Cooperative Soil Survey. (2011). *Rhinebeck Series.* USDA. Retrieved from https://soilseries.sc.egov.usda.gov/OSD_Docs/R/RHINEBECK.html

National Association of City Transportation Officials, (NACTO). (2017). *Urban Street Stormwater Guide.* Washington: Island Press.

National Oceanic and Atmospheric Administration. (2019 March). Local climatological data publication: Albany NY. https://www.ncdc.noaa.gov/IPS/lcd/lcd.html?_page=1&state=NY&stationID=14735&_target2=Next+%3

National Resource Conservation Service. NRCS. (2005). *Rain Gardens: absorb water, reduce runoff, prevent flooding.* https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_011366.pdf

National Weather Service. (2019 April 15). Advanced Hydrologic Prediction Service: Wappingers Creek at Wappinger Falls: Historic and Recent Crest. https://water.weather.gov/ahps2/hydrograph.php?wfo=aly&gage=wapn6

NC State University. (n.d.). Cornus amomum. Retrieved from: https://plants.ces.ncsu.edu/plants/all/cornus-amomum/

New York City Bar. (2016). Duty of Care. https://www.nycbar.org/get-legal-help/article/personal-injury-and-accidents/duty-care/

New York State Department of Environmental Conservation. (n.d.). Stormwater.

https://www.dec.ny.gov/chemical/8468.html

New York State Department of Environmental Conservation. (2009). December 2009 Letter to Class C and Class B Dam Owners. https://www.dec.ny.gov/lands/61381.html

New York State Department of Environmental Conservation. (2012). *Emergency Action Plans for Dams*. http://www.dec.ny.gov/docs/water_pdf/dow313eaps.pdf

New York State Department of Environmental Conservation. (2018a). Green Infrastructure Examples for Stormwater Management in the Hudson Valley. https://www.dec.ny.gov/lands/58930.html#Rain

New York State Department of Environmental Conservation. (2018b). Dam Safety. https://www.dec.ny.gov/lands/4991.html

New York State Department of Environmental Conservation. (2018c). *Trees for Tribs: Guide to Planting Your Trees and Shrubs*. NY, USA. https://www.dec.ny.gov/docs/lands_forests_pdf/tftpguide.pdf

New York State Department of Environmental Conservation. (2018d). *Trees for Tribs: Site Maintenance Guide for Streamside Plantings*. NY, USA. https://www.dec.ny.gov/docs/lands_forests_pdf/tftmguide2.pdf

New York State Department of Environmental Conservation. (2019a). Buffer in a Bag. https://www.dec.ny.gov/animals/115903.html

New York State Department of Environmental Conservation. (2019b). Trees for Tribs. https://www.dec.ny.gov/animals/77710.html

New York State Department of Environmental Conservation. (2019c). Grant Funding for Municipalities. https://www.dec.ny.gov/energy/109181.html

New York State Department of Environmental Conservation. (2019d). *Climate Smart Communities Grant Program Request for Applications*. https://www.dec.ny.gov/docs/administration_pdf/cscrfa19.pdf

New York State Department of Environmental Conservation. (2019e). *Climate Smart Communities 2018 Grant Awards*. https://www.dec.ny.gov/docs/administration_pdf/18cscawardswlogo.pdf

New York State Environmental Facilities Corporation. (2019a). Green Innovation Grant Program. https://www.efc.ny.gov/GIGP

New York State Environmental Facilities Corporation. (2019b) *2018 Green Innovation Grant Program (GIGP) Recipients*. https://www.efc.ny.gov/sites/default/files/uploads/Green%20Innovation%20Grant%20Program/Previous%20Awards/GIGP10_Project%20List.pdf

New York State Environmental Facilities Corporation. (2019c) *Required Documentation Guidance*. https://www.efc.ny.gov/sites/default/files/uploads/Green%20Innovation%20Grant%20Program/Required%20Documentation%20Guidance-GIGP%2011.pdf

NY CREP. (2017). Fact Sheet #2: Functions of Riparian Areas for Flood Control. NY, https://www.nys-soilandwater.org/crep/forms/FactSheet2.pdf

Prairie Moon Nursery. (n.d). Cephalanthus occidentalis - Buttonbush. https://www.prairiemoon.com/cephalanthus-occidentalis-buttonbush-prairie-moon-nursery.html

Rain Garden Alliance. (2009). *Three Rivers Rain Garden Alliance*. http://raingardenalliance.org/

Reardon, J. (2011). New York State Department of Environmental Conservation Bureau of Flood Protection and Dam Safety [Dam Safety Annual Certification Form]. https://ilearn.marist.edu

Robinson T. W. (1958). Phreatophytes. Pubs.usgs.gov. https://pubs.usgs.gov/wsp/1423/report.pdf

Saw Kill WaterShed Community. SKWSC. (2018). *About SKWC*. https://sawkillwatershed.wordpress.com/

Town of Rhinebeck, N.Y., : Stormwater Management. Ch. A125, Art. A § A125-60 (2019). https://ecode360.com/14084678?highlight=stormwater#14084678

University of Wisconsin Green Bay. (n.d.). Trees of Wisconsin: Salix bebbiana, Bebb's willow. https://www.uwgb.edu/biodiversity/herbarium/trees/salbeb01.htm

U.S. Census Bureau. (2017, December 05). 2010 Urban Area FAQs. https://www.census.gov/programs-surveys/geography/about/faq/2010-urban-area-faq.html

U.S. Department of Agriculture, Forest Service. (2019). *Forest Service*. https://www.fs.fed.us/wildflowers/invasives/index.shtml

U.S. Department of Agriculture, NRCS. (2004). *Plant Guide.*

https://plants.usda.gov/plantguide/pdf/pg_ceoc2.pdf

U.S. Department of Agriculture, NRCS. (2018)[1]. Soil Survey of Dutchess County, New York. NY, https://www.nrcs.usda.gov/Internet/FSE_MANUSCRIPTS/new_york/NY027/0/Dutchess.pdf

U.S. Department of Agriculture, National Resource Conservation Service. (2018)[2].*Carpinus caroliniana American hornbeam* https://plants.sc.egov.usda.gov/java/charProfile?symbol=CACA18

U.S. Department of Agriculture, NRCS. (2018)[3]. *Larix laricina tamarack* https://plants.sc.egov.usda.gov/java/charProfile?symbol=LALA

U.S. Department of Agriculture, NRCS. (2018)[4]. *Cephalanthus occidentalis Common button bush* https://plants.sc.egov.usda.gov/java/charProfile?symbol=BENI

U.S. Department of Agriculture, NRCS. (2018)[5]. Natural Resources Conservation Service. Retrieved from https://plants.usda.gov/java/charProfile?symbol=CEOC2

U.S. Department of Agriculture, NRCS. (2018)[6] Salix bebbiana Webb willow https://plants.usda.gov/core/profile?symbol=sabe2

U.S. Department of Agriculture, NRCS. (2018)[7] Salix discolor Pussy willow https://plants.usda.gov/core/profile?symbol=SADI

U.S. Department of Agriculture, NRCS. (April 2019)[1]. National Cooperative Soil Survey. United States Department of Agriculture. https://soilseries.sc.egov.usda.gov/

U.S. Department of Agriculture, NRCS. (April 2019)[2]. SSURGO Soils, Dutchess County NY. Cornell University Geospatial Information Repository. https://cugir.library.cornell.edu/catalog/cugir-002722

U.S. Department of Agriculture, NRCS.(n.d.). Conservation Plant Characteristics, The PLANTS database. https://plants.usda.gov/plantguide/pdf/pg_ceoc2.pdf

U.S. Geological Survey. (2019 April)[1]. National Water Information System: Web Interface: Wappinger Creek Near Wappinger Falls NY Daily Data: Discharge. https://waterdata.usgs.gov/nwis/dv?cb_00060=on&format=html&site_no=01372500&referred_module=sw&period=&begin_date=1969-04-01&end_date=2019-04-14

U.S. Geological Survey. (2019 April)[2]. National Water Information System: Web Interface: Wappinger Creek Near Wappinger Falls NY Monthly Statistics: Discharge. https://waterdata.usgs.gov/nwis/monthly/?referred_module=sw&site_no=01372500&por_01372500_105182=1049141,00060,105182,1928-08,2017-11&format=html_table&date_format=YYYY-MM-DD&rdb_compression=file&submitted_form=parameter

_selection_list

Village of Rhinebeck, N.Y., : Storm Drainage Facilities. Ch. A126, Art. V § A126-31 (2018a). https://ecode360.com/6611516?highlight=stormwater#6611516

Village of Rhinebeck, N.Y., : Flood Damage Prevention. Ch. 59, § 59-1-21 (2018b). https://ecode360.com/6609324

Watershed Canada, (n.d). The Riparian Zone. (2015). https://watersheds.ca/wp-content/uploads/2016/02/The-Riparian-Zone-Final.pdf

Wennerberg, S. (n.d.). Plant Guide Common Buttonbush, U.S DA NRCS. https://plants.usda.gov/plantguide/pdf/pg_ceoc2.pdf

White Flower Farm. (n.d.). Rhododendron viscosum, Swamp Azalea.
Retrieved from: https://www.whiteflowerfarm.com/rhododendron-viscosum

Vernon B. Sauer, D. P. (2010). Stage Measurement at Gaging Stations. In D. P. Vernon B. Sauer, *Techniques and Methods 3-A7.* Reston: USGS.

Zarlin v Town of Clarkstown, 102 A.D.3d 865, 958 N.Y.S.2d 464, 2013 N.Y. App. Div. LEXIS 305, 2013 NY Slip Op 329, 2013 WL 239072 (Supreme Court of New York, Appellate Division, Second Department January 23, 2013, Decided). https://advance-lexis-com.online.library.marist.edu/api/document?collection=cases&id=urn:contentItem:57K0-8KJ1-F04J-7539-00000-00&context=1516831.

Contacts:

Christopher Mitchell

Research Assistant, New England Water Interstate Pollution Control Commission/Hudson River National Estuarine Research Reserve
Division of Marine Resources
(845) 889-4745 x119
christopher.mitchell@dec.ny.gov

Dr. Zion Klos

Assistant Professor Department of Environmental Science and Policy
Marist College
zion.klos@marist.edu

Donald Meltz

Adjunct Professor Department of Environmental Science and Policy
Marist College
donald.meltzjr@marist.edu

Paul Ciminello

President (retired)
Ecosystems Strategies, Inc.
paul.ciminello@marist.edu

Susan Loit

Sales & Technical Representative
Solinst Canada Ltd.
(905) 873-2255 x234
susan.loit@solinst.com

Ethan Sullivan

Assistant Engineer, MS4 Permit Coordinator
New York State Department of Environmental Conservation, Division of Water
(518) 402-1382
Ethan.Sullivan@dec.ny.gov

Joe Barbagallo

Professional Engineer Woodard Curran
jbarbagallo@woodardcurran.com

Michael Welti, AICP

Director of Municipal Development
Town of Poughkeepsie
mwelti@townofpoughkeepsie-ny.gov