CONSIDERING CURRENT AND FUTURE INLAND FLOOD RISK

A consumers' guide to flooding tools for communities in New York State

2019

NEW YORK STATE OF OPPORTUNITY. | NYSERDA Supported

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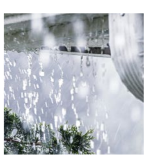
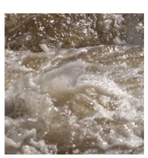
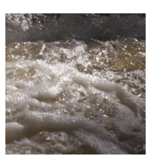

This toolkit provides different avenues for communities to assess their current and future inland flood risk based on the type of flooding they may experience. We do not necessarily intend it to be read cover-to-cover, instead we hope this toolkit will guide communities toward different resources and approaches. Start with the introduction and then follow the navigation prompts throughout the toolkit as appropriate.

Acknowledgments

This work was a collaborative effort. Amanda Stevens from NYSERDA provided technical guidance. Daniel Bader and Radley Horton were our climate leads. The Abt Associates team included Megan O'Grady, Andrew McFadden, Mark Lorie, Cameron Wobus, Matt Rissing, Christine Teter, Sarah Chadwick, Justin Stein, Beth Griffin, and Denise Young.

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Introduction

Climate change has the potential to affect inland flood risk in New York State communities. This toolkit will help communities better understand these potential changes by using existing inland flood assessment resources.[1] It aims to help local planners and decision makers, including floodplain and emergency managers, determine which resources to use for their communities and provides step-by-step guidance about how to use those resources.

What is in this toolkit?

This toolkit offers recommendations about how communities can estimate potential changes to inland flood frequency and magnitude. Consider this toolkit as a starting point to better understand potential changes to your flood risk. This toolkit:

- introduces existing flood risk resources
- provides guidance about which resource might be best for your community's needs (Step 1)
- offers step-by-step instructions about how to use each resource (Step 2)
- suggests how to estimate impacts (Step 3).

Step 1	Step 2	Step 3
Choose a resource The Resource Matrices provides an overview of the resources discussed in this toolkit. Step 1 also offers guidance about how to select resources to assess your current and potential future flood risk and an initial description of each resource.	**Understand potential changes to flood characteristics** This step details how to use the resource(s) you selected, including flow diagrams that visually depict using the resources to identify current or potential changes in flood magnitude or frequency.	**Assess changes to vulnerabilities and consider adaptations** This step will help you consider how changes to your flood magnitude or frequency might affect your community and how you might minimize those effects.

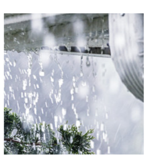
Climate Change in New York State

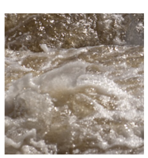
According to ClimAID: Responding to Climate Change in New York State, different types of extreme precipitation events can cause flooding in New York State. During warmer months, relatively brief but intense storms such as thunderstorms can bring heavy rainfall in short periods of time. These rainfall events are generally more localized. Extreme precipitation, which can affect larger areas, can also come from hurricanes in late summer and fall. During cooler months, longer duration storms occur such as extratropical cyclones (e.g., nor'easters) or, more rarely, tropical cyclones. These rainfall events can affect larger portions of the state. Flooding during any rainfall event can also be driven by existing conditions, which include saturated soils from prior rain events, rain-on-snow, and ice jams.

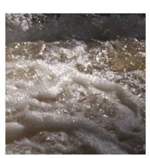
Over the past approximately 60 years, there have been more extreme precipitation events in the Northeast United States, including New York State. This is likely due, in part, to rising temperatures because a warmer atmosphere can hold more moisture. That moisture tends to fall out all at once in extreme events, rather than spread out across numerous lighter events.

Climate models project that both average annual and extreme precipitation across New York State will increase during the coming decades. Most of the increase is projected in the winter, with slightly reduced precipitation during the late summer and early fall. Larger increases are projected in the frequency, intensity, and duration of extreme precipitation events. Because climate models are not able to capture all key processes of precipitation events, scientists are still uncertain about future changes to lake-effect snow, coastal storms, and other precipitation extremes.

[1] We use the term "resource" to refer to existing sources of data or tools. While there are many available resources to support communities in their inland flood planning, this toolkit includes the five we found to be most useful in working with our partner communities. See the appendix for a list of additional resources. This toolkit does not offer explicit guidance for coastal flooding but focuses on riverine and nuisance flooding. However, some coastal tools such as the CIESIN Hudson River Flood Mapping tool might also be of interest to inland communities.







Nothing can give you a perfect forecast of how flood risks will change in your community, but the approaches in this toolkit can help you gain a better sense of potential changes. All of these resources contain a level of uncertainty so the outputs of this toolkit should not be used to justify significant investments without further detailed study. However, this toolkit will help you be better consumers of climate-related flood projections and provide you with screening-level information to identify:

- potential impacts
- information gaps
- target areas or assets that warrant further study
- opportunities to integrate future flood risks in existing planning frameworks.

We developed the approaches outlined in this toolkit in partnership with two communities in New York State: Broome County and the Town of Red Hook. Our team of climate, hydrology, and community risk planning experts conducted a study of potential changes to each community's inland flood risk and developed this toolkit based on our experience working in the communities. At the end of this toolkit, you will find community case studies—examples of how we followed the toolkit's three steps in work with our partner communities.

1% AEP or "1-in-100 year flood"?

Traditionally you hear floods referred to by their frequency, something like, "the 1-in-100 year flood". However, this language is misleading so flood managers are trying to move away from it. The 1-in-100 year flood does not mean a flood that will only happen once every one hundred years. It refers to a flood that has a 1% chance of happening in any year, or the Annual Exceedance Probability (AEP) (i.e., the probability each year that a flood will exceed a certain elevation). It is possible, therefore, that you could get two "1-in-100 year floods" two years in a row. To more accurately reflect this flood risk, flood plain managers are trying to refer to the "1-in-100" year flood as the 1% flood, or the "1-in-50" year flood as the 2% flood.

New York State Flood Risk Management Guidance

New York State has recognized the importance of preparing for changing flood risk, in part demonstrated by the New York State Community Risk and Resilience Act (CRRA). New York State recently released the New York State Flood Risk Management Guide (SFRMG), in-depth guidance about how to manage changing flood risk in accordance with CRRA. The SFRMG recommends the following general guidelines:

- The vertical flood elevation and corresponding horizontal floodplain that result from adding two feet (three feet for critical facilities[2]) of freeboard to the base flood elevation and extending this level to its intersection with the ground.
- The vertical flood elevation and corresponding horizontal floodplain associated with the 0.2-percent annual chance flood.
- The vertical flood elevation and corresponding horizontal floodplain determined by a climate-informed science approach (i.e., includes projected future stream or riverine flows) in which adequate, actionable science is available. (NYS DEC, 2018)

This toolkit can be used in conjunction with SFRMG to implement CRRA. The toolkit provides pathways to implement some aspects of the CRRA guidelines. These are pointed out throughout the toolkit including in the Resource Matrices, the Resource Flow Diagrams, and discussed in the text of relevant resources.

Refer to the SFRMG for more information and for specific guidance for certain infrastructure and circumstances.

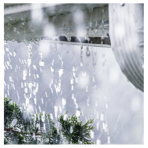
[2] Critical facilities are defined in the CRRA guidance (NYS DEC, 2018).

!

This toolkit is intended to be interactive. Users have the ability to click or hover over text and icons that will move you sequentially through the process of evaluating flood risk or take you to external sources of information or data. Internal links appear as *purple italicized text,* these take users to different locations throughout the document in a sequential order depending on the type of flood risks a community may face.

External links appear as blue underlined text, these take users to external web based locations that may house additional relevant information or data.

Clickable navigation arrows are represented by the following icons:



Step 1. Choose your resource

This step has two layers of information to help you select one or more resources that best fit your community's needs to assess current risks and how those risks may change in the future.

First, the "Resource Matrices" provides a high-level overview of all the resources included in this toolkit. It can help you compare each resource across a few common metrics. Second, you can find out more information about each resource by clicking on the resource title from within each matrix. This will take you to additional high-level information to help you decide if you want to use that resource.

! We recommend that you consider using more than one resource and compare the results. There are a range of uncertainties, advantages, and disadvantages to each resource. Using multiple resources will allow you to examine a wider range of potential flood risk changes and better understand how uncertainty may factor into potential future flood risk.

Resource Matrices

Each Resource Matrix provides high level information about:

- whether the resource provides information on current or future conditions
- what information or data you need to put into the resource (inputs)
- what type of information the resource will provide you (outputs)
- the general time commitment, level of technical knowledge, and computing requirements you will need to use that resource
- the type of flood characteristics the resource will help inform.

Hover over the category headings in the matrices for definitions of the terms.

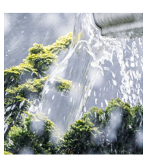
All of these resources are available at no cost. The classification values used in each matrix (e.g., "minimal") are only a relative comparison between the resources covered in this toolkit. As you use the Resource Matrices, consider that you can use each resource in different ways to yield different results. We attempt to capture these differences in the two columns of information for each resource.

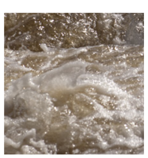
- For FEMA FIRMs and USGS Stream Gage Data, the left column represents what you need to identify current flood characteristics, and the right column corresponds with identifying an understanding of future projected characteristics.
- For the Future Peak Flow Application, Option 1 will provide you estimated changes to magnitude and frequency; Option 2 will provide you with estimated changes to magnitude, frequency, and stage.
- For the IDF curves resource, the left column represents an existing website that provides IDF curves for many areas in New York State, and the right column represents the effort to create your own IDF curves.
- The left column of ClimAID represent what you need to identify current and project regional changes where the right column illustrates what is needed to identify more local changes.

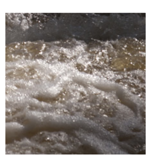
Step 1 Resource Descriptions

Clicking on a resource from the Resource Matrices will lead you to further decision-level details about that resource, including what outputs the resource will provide, general level of effort required to use the resource, necessary inputs, and limitations to using the information. This level of information will help you further assess if that resource might be appropriate for your community's needs.

From this Step 1 description of the resource, you can continue on to Step 2 with that resource which provides easy-to-follow instructions about how to use that resource to understand potential changes to your community's flood characteristics. You can also choose to go back to the Resource Matrices to select another resource.







Let's get started. Which type of flooding is of greater concern to your community?

River-related flooding »

Precipitation-related flooding »

Resource Matrix for River-Related Flooding

- Red = Significant
- Half yellow, half red = Moderate to significant
- Yellow = Moderate
- Green = Minimal

RESOURCE		FEMA FIRMs		Future Peak Flow Application		USGS Stream Gage Data	
				Option 1	Option 2		
		CURRENT	FUTURE**	CURRENT and FUTURE	CURRENT and FUTURE	CURRENT	FUTURE**
INPUTS	REQUIRED		GIS				GIS
INPUTS	OPTIONAL		Stage from USGS Stream Gages; Discharge from USGS Stream Gages; Future Peak Flow Application		Stage and/or discharge from USGS Stream Gages or FEMA FIRMs		Stage from USGS Stream Gages; Discharge from USGS Stream Gages; Future Peak Flow Application
OUTPUTS		1% & 0.2% AEP floodplains	1% & 0.2% AEP floodplains**; 1% AEP floodplain +2 or 3 feet**; Projected changes in flood characteristics	Observed and projected changes in flood characteristics	Observed and projected changes in flood characteristics	Observed flood characteristics	Projected changes in flood characteristics**
TIME		Minimal	Moderate to significant	Moderate	Moderate to significant	Moderate	Significant
TECHNICAL KNOWLEDGE		Minimal	Moderate	Moderate	Moderate to significant	Moderate	Significant
COMPUTING REQUIREMENTS		Minimal	Significant	Minimal	Moderate to significant	Minimal	Moderate to significant
FLOOD CHARACTERISTICS	MAGNITUDE	✓	✓	✓	✓	✓	✓
FLOOD CHARACTERISTICS	FREQUENCY	✓	✓	✓	✓	✓	✓
FLOOD CHARACTERISTICS	STAGE	✓	✓		✓	✓	✓

**Can be used to align with SFRMG recommendations

Resource Matrix for Precipitation-Related Flooding

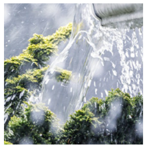
🔴 = Significant
🟡/🔴 = Moderate to significant
🟡 = Moderate
🟢 = Minimal

RESOURCE	ClimAID Regional	ClimAID Local	IDF Curves: NRCC IDF Curves for NYS	IDF Curves: Create your own IDF curves
	CURRENT and FUTURE	CURRENT and FUTURE	CURRENT and FUTURE	CURRENT and FUTURE
INPUTS – REQUIRED		Rain gage data		Local rain gage data Climate projections (e.g., ClimAID)
INPUTS – OPTIONAL				
OUTPUTS	Observed and projected changes in regional rainfall	Observed and projected changes in local rainfall	Observed and projected local rainfall	Observed and projected local rainfall
TIME	🟢	🟡	🟢	🔴
TECHNICAL KNOWLEDGE	🟢	🟡/🔴	🟡	🔴
COMPUTING REQUIREMENTS	🟢	🟡	🟢	🟡/🔴
PRECIPITATION CHARACTERISTICS – MAGNITUDE	✅	✅	✅	✅
PRECIPITATION CHARACTERISTICS – FREQUENCY	✅	✅	✅	✅

Step 1. Choose your resource: FEMA FIRMS

RESOURCE		FEMA FIRMs CURRENT	FEMA FIRMs FUTURE**
INPUTS	REQUIRED		GIS
INPUTS	OPTIONAL		Stage from USGS Stream Gages Discharge from USGS Stream Gages Future Peak Flow Application
OUTPUTS		1% & 0.2% AEP floodplains	1% & 0.2% AEP floodplains** 1% AEP floodplain +2 or 3 feet** Projected changes in flood characteristics
TIME		●	●
TECHNICAL KNOWLEDGE		●	●
COMPUTING REQUIREMENTS		●	●
FLOOD CHARACTERISTICS	MAGNITUDE	✓	✓
FLOOD CHARACTERISTICS	FREQUENCY	✓	✓
FLOOD CHARACTERISTICS	STAGE	✓	✓

**Can be used to align with SFRMG recommendations



step 1

Information
The Federal Emergency Management Agency (FEMA) issues Flood Insurance Rate Maps (FIRMs) to identify properties that are subject to the National Flood Insurance Program (NFIP). These maps are routinely used for regulatory flood hazard planning. FIRMs cover both coastal and inland areas, but this toolkit focuses on using them to support inland flood planning.

Output
FIRMs delineate special flood hazard areas (also referred to as flood zones or floodplains) for the 1% and 0.2% annual exceedance probability (AEP) events based on historic data. FIRMs may also provide other flood area characteristics such as floodwater depths, areas protected by levees, floodways, and other characteristics.

General level of effort
Regardless of when and how your community's FIRM was developed, it can be used to get a general sense of which parts of your community are most vulnerable to flooding. You can conduct a variety of analyses with FIRM information to assess current and future flood risk.

If spatially referenced (e.g., GIS) versions of FEMA FIRMs have been developed for your community, you can conduct more detailed analyses such as looking at specific properties or assessing the aggregate number or type of properties at risk. This approach, however, requires more investment in time, technical knowledge, and computing requirements.

When would your community use FEMA FIRMs?
FIRMs are used to designate regulatory flood zones. You can use FIRMs several ways to understand current estimates of flood risk from events of a specific return interval (typically 1% and or 0.2% AEP). This could include estimating flood inundation to understanding potential local vulnerabilities, or more detailed spatial analyses to estimate exposure, loss, and damages. FIRMs can be used to implement some of the methods described in the SFRMG.

What can FEMA FIRMs tell your community about estimating current and future flood risk?
FIRMs contain estimates of current (at the time of mapping) flood zones based on model outputs or other local historical information. Although FIRMs are only point-in-time estimates, you can use them in combination with other resources to better understand how flood risk may change in the future.

What are the limitations to FEMA FIRMs?
Like all of these resources, FEMA FIRMs contain a level of uncertainty, so the outputs should not be used to justify significant investments without further detailed study.

Many FIRMs were developed many years ago and have not been recently updated. Consider when and how your FIRMs were developed: *Are the FIRMs based on recent hydrologic modeling or more anecdotal evidence of flood depths? Have there been local changes to local hydrology that might affect the flooding regime, including urbanization or changes in land cover?* These factors may determine how reliable the FIRM is and what types of analyses you can conduct with your FIRM.

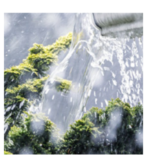
Additionally, FIRMs display only those areas prone to the 1% and 0.2% AEP floods. They do not show areas that are subject to smaller, more frequent floods, nor do they show areas that might be subject to storm water flooding.

« *If you would like to pick a different resource, go back to the Resource Matrices*

If this resource sounds right for your community move to Step 2 »

Step 1. Choose your resource: USGS Application of Flood Regressions and Climate Change Scenarios to Explore Estimates of Future Peak Flows

RESOURCE		Future Peak Flow Application Option 1 CURRENT and FUTURE	Future Peak Flow Application Option 2 CURRENT and FUTURE
INPUTS	REQUIRED		
INPUTS	OPTIONAL		Stage and/or discharge from USGS Stream Gages or FEMA FIRMs
OUTPUTS		Observed and projected changes in flood characteristics	Observed and projected changes in flood characteristics
TIME		●	●
TECHNICAL KNOWLEDGE		●	●
COMPUTING REQUIREMENTS		●	●
FLOOD CHARACTERISTICS	MAGNITUDE	✓	✓
FLOOD CHARACTERISTICS	FREQUENCY	✓	✓
FLOOD CHARACTERISTICS	STAGE		✓



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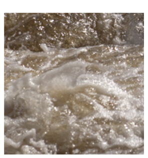
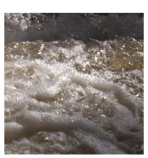




Introduction

The United States Geological Survey (USGS) Application of Flood Regressions and Climate Change Scenarios to Explore Estimates of Future Peak Flows (referred to in this toolkit as Future Peak Flow application), establishes a general rainfall-runoff relationship for watersheds in New York State, based on the relationship between observed precipitation and streamflow. The application then applies these relationships to a range of future precipitation projections to estimate potential future flood magnitude. The application contains inherent uncertainty so its outputs should always be used in conjunction with other resources such as those included in this toolkit. The SFRMG does not recommend using this application for implementation of its recommendations, but it can still provide additional context when used alongside other resources.

Output

This application provides estimated current and future stream flow (discharge), a measure of river or stream flow typically measured in cubic feet per second and percent change from current discharge. With additional analyses and inputs the application can also provide potential future flood inundation estimates.

General Level of Effort

The application has a user-friendly, map-based interface. Once you select a watershed it walks you through a set of easy-to-follow steps. You can only save outputs for one time period and one emissions scenario at a time; however, outputs are saved in a .csv table format which can easily transfer to a spreadsheet program such as Microsoft Excel.

When would your community use the Future Peak Flow Application?

You can use outputs from this tool as a screening level exercise to begin to understand current and potential future stream or riverine flood risk. As mentioned above, you should not use this resources alone to understand current and potential future flood risk, but it can provide additional context about these trends. The tool is most useful for locations with gaged streams so that observed data can be used to establish a baseline. You can use the application for ungaged watersheds, but the outputs will be more uncertain.

What can the application tell your community about estimating current and future flood risk?

The Future Peak Flow application provides information about potential changes to flood magnitude, including a percent change for a variety of flood return intervals for three future time periods (2030s, 2060s, and 2080s) under two different emissions scenarios (RCP 4.5 and RCP 8.5). You can also translate application outputs to flood stage by combining them with information from stream gage data and an understanding of the relationship between stream discharge and stage. You may also be able to estimate inundation area, although any additional analysis of output data from the application adds additional uncertainties, as discussed in Step 2.

What are the limitations to the Future Peak Flow application?

Future Peak Flow should not be seen as a standalone resource for understanding your flood risk. Due to the complexities and associated challenges of modeling future stream and river flows across different landscapes, use this resource in conjunction with at least one other resource to help inform future flood risk estimates. As with any modeling product, the results from this tool are best used as a measure of relative, rather than absolute, change in extreme flows.

« If you would like to pick a different resource, go back to the Resource Matrices

If this resource sounds right for your community move to Step 2 »

Step 1. Choose your resource: USGS Stream Gage Data

RESOURCE		USGS Stream Gage Data	
		CURRENT	FUTURE**
INPUTS	REQUIRED		GIS
	OPTIONAL		Stage from USGS Stream Gages Discharge from USGS Stream Gages Future Peak Flow Application
OUTPUTS		Observed flood characteristics	Projected changes in flood characteristics**
TIME		🟡	🔴
TECHNICAL KNOWLEDGE		🟡	🔴
COMPUTING REQUIREMENTS		🟢	🟡/🔴
FLOOD CHARACTERISTICS	MAGNITUDE	✓	✓
	FREQUENCY	✓	✓
	STAGE	✓	✓

**Can be used to align with SFRMG recommendations

Introduction

As part of the National Water Information System (NWIS) web interface, the United States Geological Survey (USGS) maintains a nationwide network of stream gages that provide discharge (or flow) and stage (or water depth) information. USGS stream gage data provides information on the historical characteristics of a given stream or river. Some gages have been recording information for over a century. USGS stream gage records, particularly those with long recording periods, can help you quantify flooding. These data can help you understand the magnitude and frequency of historical discharges, including those associated with flood events, and you can also use the data to better understand potential future changes.

Output

Each gaging site provides historical discharge (measured in cubic feet per second (cfs)) and stage (measured in feet) measurements. For some gages, USGS also provides rating curves which plot the relationship between discharge and stage.

General Level of Effort

You can use USGS stream gage data in different ways to assess current and potential future flood risk. Basic spreadsheet software like Microsoft Excel can be used to plot rating curves, rank annual maximum flows, and estimate return intervals of historical flows. More advanced statistical software such as R, SPSS, or Matlab may be necessary to generate more detailed statistics of historical flows, such as generalized extreme value (GEV) curves or other extreme value statistics, and when performing trend analyses over the period of record.

When would your community use USGS gage data?

You can use USGS stream gage data to understand historical flow characteristics including the magnitude and frequency of historical events.

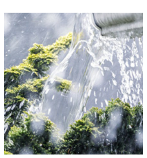
What can USGS gage data tell your community about estimating current and future flood risk?

Gage data can help you quantify historical extreme events. Gage data can put a particular observed flood event into context, i.e., “the floods of 2018 were a 1% AEP event”. The discharge and stage measurements from an adequately long and complete gage record (typically ≥ 30 years of continuous recorded data) can also help you quantify extreme flows and translate discharge into depth using a rating curve for the immediate vicinity of the gaging station. Gage data can also associate water depth with an event of historic significance.

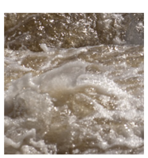
Communities with adequate gage records may also be able to estimate trends in flood characteristics over time and use that information to project trends in future flood characteristics.

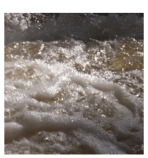
What are the limitations to USGS gage data?

The usefulness of your gage data depends on how long and complete gage records are in your area. Communities near streams with longer and more complete records will be able to estimate current and potential future flood magnitude and frequency with more confidence. Gages with upstream regulation (i.e., managed releases via dams and reservoirs) may require additional analysis to incorporate the effects of regulation on downstream flows, especially if regulation changed during the period of analysis.



step 1





« If you would like to pick a different resource, go back to the Resource Matrices

If this resource sounds right for your community move to Step 2 »

Step 1. Choose your resource: ClimAID

RESOURCE	ClimAID Regional	ClimAID Local
	CURRENT and FUTURE	CURRENT and FUTURE
INPUTS – REQUIRED		Rain gage data
INPUTS – OPTIONAL		
OUTPUTS	Observed and projected changes in regional rainfall	Observed and projected changes in local rainfall
TIME	●	●
TECHNICAL KNOWLEDGE	●	●
COMPUTING REQUIREMENTS	●	●
PRECIPITATION CHARACTERISTICS – MAGNITUDE	✓	✓
PRECIPITATION CHARACTERISTICS – FREQUENCY	✓	✓

Information
Responding to Climate Change in New York State (ClimAID) provides New York State climate projections and state-focused vulnerability and adaptation information, including for flood risk.

Output
ClimAID provides New York State-specific climate projections for temperature, precipitation, and sea level rise using the latest data, methods, and models available at the time of its publication. ClimAID includes projections for potential changes to average climate and for extreme events, including a discussion of flood-related vulnerability and adaptation. ClimAID provides specific projections for seven climatic regions (i.e., multi-county areas) in the state.

General Level of Effort
The ClimAID report is easily accessible and available to all communities and requires minimal effort to find the necessary data, especially at the regional scale. With a moderate level of effort, communities can use a basic spreadsheet application to apply the projected changes in precipitation for their region to their local rainfall records to obtain more local projections.

When would your community use ClimAID?
A community can use ClimAID as a high-level screening tool to understand the impacts of climate change on regional scale precipitation, including extreme events.

What can ClimAID tell your community about estimating current and/or future flood risk?
The ClimAID report can provide current and projected climate information, such as the frequency and intensity of heavy rainfall events.

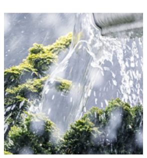
Historical precipitation data can provide some information about the links between local precipitation and flooding by looking at the rainfall patterns of past storms and associated flood hazards. Future climate projections can provide information about how your historic rainfall patterns might change in the future. Examples of flood impacts are also detailed in the report. While the report includes regional precipitation projections, it may not capture more localized climate variability.

What are the limitations to ClimAID?
Like all of these resources, ClimAID contains a level of uncertainty, so the outputs should not be used to justify significant investments without further detailed study.

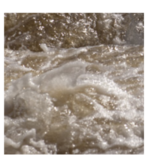
ClimAID has a state-wide focus so it does not include discussions of community-level precipitation changes. At its finest resolution, ClimAID only provides climate information for seven regions across the state. Communities may use the ClimAID data for their region, but if your community is not near the regional station be aware that the regional station may have different climate influences (e.g., distance from water, topography) than your local station, even if they are in the same region.[3]

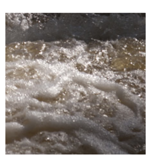
The projected changes to precipitation do not directly translate to changes in flood risk. Translating precipitation patterns into runoff and flood risk is a complicated process that involves simulating the different ways water can flow over a landscape. This more complex hydrologic modeling process is beyond the scope of this toolkit.

[3] If you want more local precipitation information, see the *IDF Curve Resource Description* for details about how to use data from local stations to understand current and future precipitation patterns.



step 1

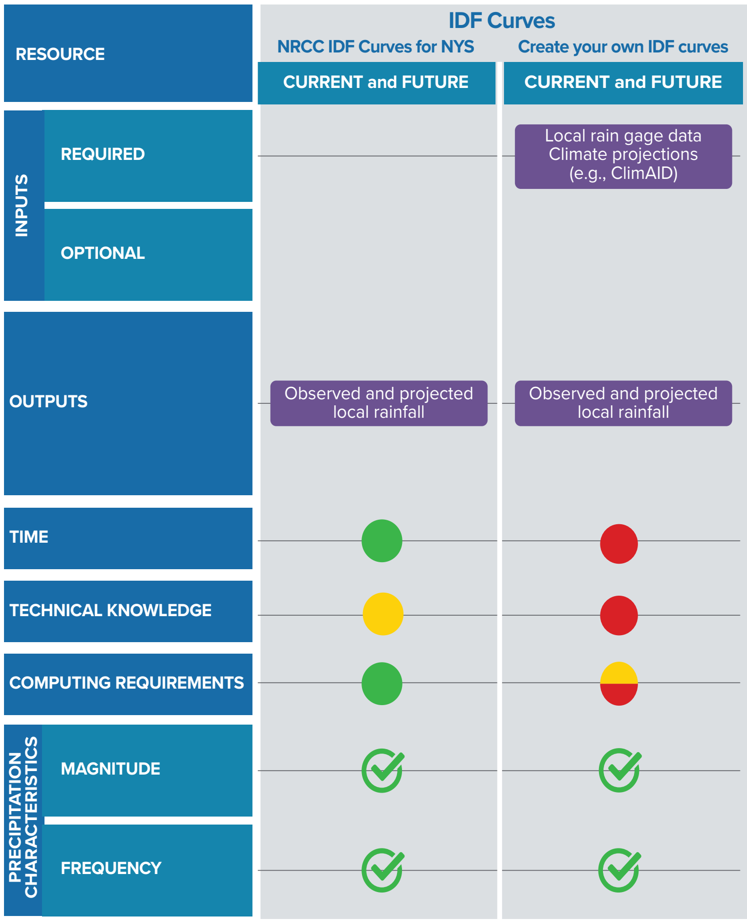




If you would like to pick a different resource, go back to the Resource Matrices

If this resource sounds right for your community move to Step 2

Step 1. Choose your resource: IDF Curves



Introduction

Intensity-duration-frequency (IDF) curves are graphs that relate rainfall intensity (typically measured in inches per hour or inches per minute), duration (measured in hours or days), and frequency. Frequency is typically measured in 2- to 100-year return intervals or the "Annual Exceedance Probability (AEP)" and should be thought of as the likelihood that the event will occur in any given year. As shown in Figure 1, these curves illustrate the relationship between intensity and frequency of precipitation; for example, a particular location might accumulate 1.25 inches of rainfall (intensity) in one hour (duration) every two years (frequency) and that same location might expect to see that same rainfall intensity (i.e., 1.25 inches per hour) last for four hours every 100 years. IDF curves are most commonly based on observed rainfall records from rain gages with a long (generally at least 30 years), unbroken record but can also be based on simulated rainfall models. These observed precipitation data provide information about the context of precipitation events that have resulted in flooding in the past and can be combined with climate projections to provide some insight into how those events may change in the future.

Output

Using an IDF curve, you can estimate the intensity and duration associated with a particular return interval or likelihood of a rainfall event. For example, an IDF curve can be used to answer:

- At what rate is rain expected to fall over the course of two hours for a "1-in-100 year rain event"?
- If rain is falling at a rate of two inches per hour, what is the duration (e.g., three hours) associated with a "1-in-100 year rain event"?
- How likely is a rainfall event where two inches of rain would fall per hour for three hours?

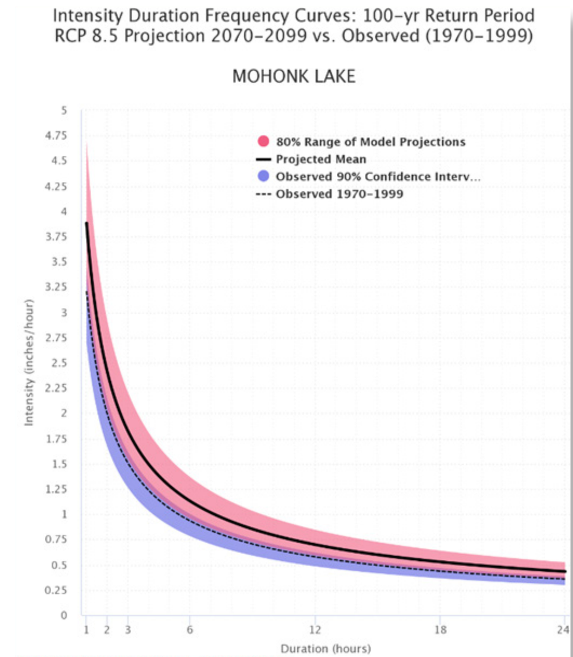


Figure 1. Shows an example IDF curve generated using observed data from the Mohonk Lake rain gage station near Poughkeepsie, NY. The graph displays intensity in inches/hour (Y-axis) and durations in hours (X-axis) for the 1-in-100 year return interval event (i.e., the event that has a 1% chance of occurring in any given year). This curve also shows lines for projected changes in to the curve and confidence intervals around both the observed and projected curves. (Source: Intensity Duration Frequency Curves for New York State http://ny-idf-projections.nrcc.cornell.edu/).

When combined with climate projections, you can also use IDF curves to project how historic rainfall events might change in the future.

General Level of Effort

The level of effort for generating IDF curves from precipitation data depends on if you use IDF curves that have already been developed for rain gage stations across the state or create new ones that are specific to your community. In Step 2 we consider both of these approaches to IDF curve generation.

Step 1. IDF Curves

The first is the "Intensity Duration Frequency Curves for New York State" web-based application that provides both current and projected future IDF curves for 157 stations across the state. Using this application is a relatively straightforward process that requires a lower level of effort.

The second approach involves manually creating your own IDF curves, including processing, analyzing, and generating curves from local rain gage station data. This is a more complex undertaking and typically requires more time and effort but you might consider it if you:

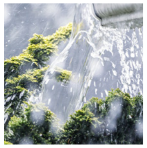
- have a local rain gage with adequate data (i.e., at least 30 years of uninterrupted data recorded at sub-daily intervals (e.g., hourly data)
- desire a more complete picture of your area's extreme precipitation patterns
- would like data from a closer weather station than the ones available through the web-based application.

You can also generate a different type of IDF curve, one for a single duration—a magnitude and frequency curve—if you only have daily rainfall totals. A magnitude and frequency curve conveys much of the same information as an IDF but is for a single event duration (i.e., 24 hours).

When would your community use IDF curves?
If your community experiences flooding particularly after heavy, localized rainfall events (e.g., where flooding is caused by small streams, storm sewer backups, or street flooding), you may want more information about local rainfall patterns and trends, which can be obtained from an IDF curve. You can use IDF curves generated from both observed and projected data to better understand extreme precipitation patterns.

What can IDF curves tell your community about estimating current or future flood risk?
Understanding the intensity, duration, and frequency of rainfall in the past, present, and future is important for estimating flood risk. However, although they are related, rainfall patterns are not the only contributor to a community's flood risk. Therefore, use caution when relating potential changes in rainfall to potential changes in flooding. Historical precipitation data can help provide some information about the links between local precipitation and flooding by looking at historical rainfall patterns and flood hazards, i.e., what types of rainfall events caused flooding in the past. Future climate projections can provide information about how your historic rainfall patterns might change in the future. Understanding historical rainfall patterns alongside future climate projections will help put the projections into context.

What are the limitations to IDF curves?
Limited or incomplete observed weather station data increase the uncertainty associated with IDF curves. For example, a weather station may have limited temporal data (e.g., it may only have daily rather than hourly data), the data may not capture a long enough record to provide reliable results (i.e., it may have less than 30 years of continual data), there may be gaps in the record (e.g., a gage was out of service for several years, or became inoperable during an extreme rainfall event). Also, for some communities, the nearest station with a quality record may be too far away to accurately reflect local extreme rainfall risks. While you can use the nearest station data to give an overview of your community's precipitation patterns, the data might not truly capture your local conditions. Finally, changes in precipitation do not directly translate to changes in flood risk. Translating precipitation patterns into runoff and flood risk is a complicated process that involves simulating the different ways water can flow over a landscape. This more complex hydrologic modeling process is beyond the scope of this toolkit.



step 1

« If you would like to pick a different resource, go back to the *Resource Matrices*

If this resource sounds right for your community move to *Step 2* »

Step 2. Identify how your floods might change: FEMA FIRMs

You have decided to use FEMA FIRMs to assess potential changes to your flood characteristics. This step will provide you with more information and easy-to-follow instructions about how to use FEMA FIRMs.

Resource Flow Diagrams
Use the *Resource Flow Diagram* alongside Step 2. This diagram will show you step by step how to use FEMA FIRMs to understand potential changes to flood risk. The diagram also visualizes how you can use information from one resource along with another to obtain a more holistic picture of your community's potential future flood risk.

The outputs from the flow diagrams will help you in Step 3: Identify vulnerabilities.

Where do you find FEMA FIRMs?
You can access FIRMs in numerous ways on the FEMA website. The most direct route for most users is through FEMA's interactive National Flood Hazard Layer (NFHL) web interface "NFHL Viewer." If your community has a FIRM, then you can zoom into your community on the map or enter your community in the search field. Clicking on a specific location on the map will open a pop-up window from which you can obtain more information regarding the type of available data for the FIRM.

You can also access your community's FIRMs and other FEMA flood risk products such as RiskMAP or a Flood Insurance Study report through the FEMA Flood Map Service Center search portal.

If you have GIS capabilities, you can obtain FEMA FIRMs by searching for "FEMA floodplains" and streaming in the full national flood hazard layer from ESRI here. These data require a GIS for display and analysis.

Additionally, the New York Climate Change Science Clearinghouse (NYCCSC) contains map viewers that display current FIRMs and other flood hazard areas for coastal communities including in some cases projected floodplain areas. Areas with location-specific map viewers include: New York City, Nassau and Suffolk Counties, counties along the lower Hudson River or its tributaries, and Long Island Sound.

How do you use FEMA FIRMs?
Your community's FIRM is a map of the 1% AEP and sometimes also the 0.2% AEP flood extent (also referred to as flood zones or floodplains). FIRMs estimate your community's current flood hazard based on historical data, but they can be used as a baseline to better understand how your flood hazard may change in the future.

*How to identify **current** flood risk*

The 1% and 0.2% AEP flood boundaries are represented by lines on the FIRMs with areas that may be shaded or pattern-filled. FEMA generally refers to the 1% AEP floodplain as the Special Flood Hazard Area (SFHA). The 1% AEP floodplain is typically labeled as Zone A but can have any of the following variations: A1-A30, Zone AE, Zone A99, Zone AR, Zone AR/AE, Zone AR/AO, Zone AR/A1-A30, Zone AR/A, Zone V, Zone VE, and Zones V1-V30.[4] FEMA uses these other zone designations to convey additional information on the type of flooding, the available map data, and proximity to the coast. The 0.2% AEP floodplain is depicted as Zone C or X. (See additional information on FEMA flood zones in the *Helpful Links* section for this resource.)

*How to identify **future** flood risk*

You can use FIRMs to estimate your future flood risk in a few different ways. All three of the following methods can be used to implement the SFRMG for some situations; refer to the SFRMG for more specific recommendations on when to use each method.

a. Use the 0.2% AEP floodplain as an approximate estimation of a potential future 1% AEP floodplain

b. Use GIS to add two to three feet of freeboard to the 1% AEP base flood elevation and project the increased elevation out to the adjacent topography (for a brief discussion of this process, see the *"2-3 ft addition to the 1% AEP FEMA floodplain layer" description* on the following page.)

c. Use stream gage data, FEMA FIRMs, and GIS to apply a percent change to stream discharge. To do this, add a change factor (the SFRMG recommends adding 10% in eastern New York, and 20% in western New York) to your current 1% AEP stream discharge values (you can get discharge values from either *USGS Stream Gage data* or a FEMA Flood Insurance Study (FIS). Then, use a *rating curve* to find the corresponding stage for the new discharge and then add 2 or 3 feet of freeboard to your new stage height. As discussed in method b. above, project this increased elevation from the 1% AEP floodplain out to the adjacent topography on your map using GIS.

While using one of these approaches will give you a preliminary understanding of how your flooding risk might change, using more than one approach will help you have a broader understanding of the range of potential future scenarios you might experience (using these approaches along with another resource is an even better way to improve your understanding).

[4] "V" zones are coastal

2-3 ft addition to 1% AEP FEMA floodplain layer

There is not one prescribed approach to conducing this type of analysis but here is one approach to consider:

1. Obtain a digital FEMA FIRM for the 1% AEP floodplain from FEMA.
2. Download the highest resolution DEM available for your community from the NYS Elevation Data Clearing House.
3. Rasterize the FEMA floodplain edge to the same grid size as the DEM.
4. Add 2 or 3 feet to the pixels representing the FEMA 1% AEP floodplain edge.
5. Assess adjacent elevations using a line of site allocation. All adjacent elevations that fall beneath the 2 or 3 feet floodplain elevation are considered to be within the new flood zone.

This is the approach our team took when we conducted this analysis for our two community partners, Broome County and the Town of Red Hook (for additional details, see the *community profiles*).

The USGS has also developed a GIS extension to facilitate this process for specific study reaches. The processing in this application is similar to the steps above but requires some additional inputs such as discharge and other parameters that can be gleaned from USGS gage records or from FEMA Flood Insurance Study documentation. The technical documentation for the application is available on the USGS website.

What additional information can contribute to the analysis?
You can also view FIRM data on a GIS platform in conjunction with other information such as critical facilities, census data, or emergency service routes to enhance the interpretation of FIRM inundation estimates. For example, you can combine FIRM data with digital elevation models (DEMs) to estimate depths within the 1% or 0.2% AEP floodplain, if depths are not provided with available FEMA flood map products for your community.

Using FIRMs in conjunction with outputs from other resources to assess future flood risk will provide a more nuanced understanding of your potential future flood risk. For example, you can combine FIRMs with the change in frequency results from the *Future Peak Flow* application to identify how much more often the current 1% might occur in the future. See the *Resource Flow Diagram* for additional information.

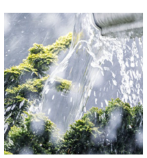
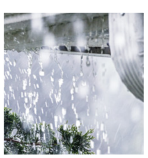
Are there any existing or planned changes to your local hydrology or infrastructure that might impact interpretation of these results or cause additional uncertainty?
Significant changes in land use and land cover including development can add to the uncertainties of the resources discussed in this toolkit because they influence rainfall-runoff relationships. Changes in land cover, such as paving a previously undeveloped area, can affect how precipitation runs through the landscape. Changes in land cover can also affect which areas are at risk of flooding due to extreme precipitation events or riverine flooding. Therefore, it is important to consider future land use and development plans when evaluating potential changes to flooding in your community.

What are the constraints of FEMA FIRMs?
As with all of these resources, there is inherent uncertainty in using FEMA FIRMs to estimate your community's flood risk. FIRM data alone can only be used as an estimate of a part of a community’s current flood risk and does not factor in potential changes to flood risks in the face of future climatic or local hydrologic changes. Outdated FIRMs do not always reflect the most accurate understanding of local hydrology, and this can be especially true of older FIRMs. Updating FIRMs can be a lengthy process that involves political and emergency management actors from federal, state, and local levels. Occasionally these updates are contentious as they may result in additional insurance requirements at the local level.

Helpful Links

Helpful links when using FEMA FIRMs:

- FEMA fact sheet on FIRMs. *Fact sheet discussing FEMA FIRMs and how to use them.*
- FEMA mapping center. *Centralized location for all FEMA flood related products including FIRMs and FISs.*
- General NFHL Information. *General information related to the National Flood Hazard Layer for GIS.*
- Interactive NFHL web interface. *Online interactive mapping tool for the National flood Hazard Layer.*
- FEMA flood zone descriptions. *Descriptions of all FEMA flood zone designations.*
- Glossary for FEMA FIRMs. *Appendix D: Glossary of FEMA terminology associated with FIRMs and other FEMA flood products.*

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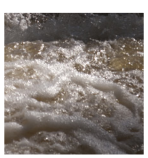
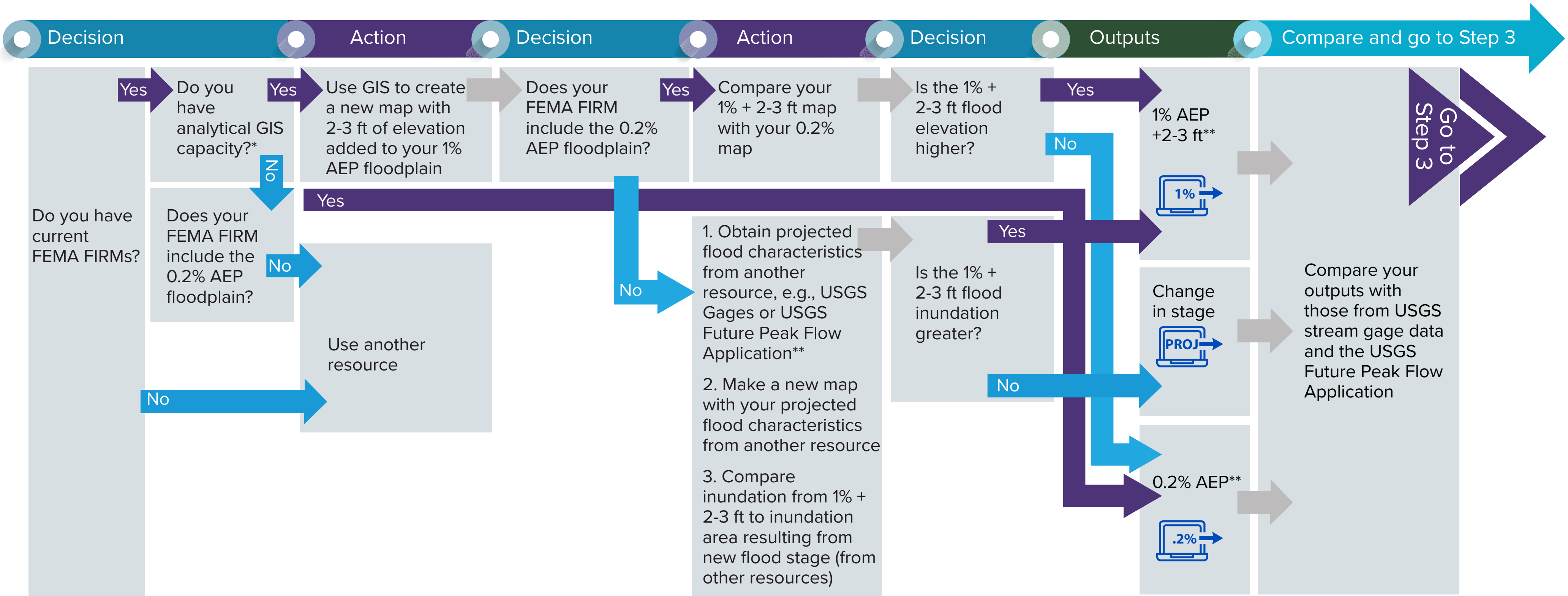


Resource Flow Diagram: FEMA FIRMs



*See description of GIS analysis in FEMA FIRMs resource description

**Can be used to align with SFRMG recommendations

If you would like more information on this resource, go back to Step 1

If this resource sounds right for your community move to Step 3

Step 2. Identify how your floods might change: USGS Future Peak Flow Application

You have decided to use the Future Peak Flow application to assess potential changes to your flood characteristics. This step will provide you with more information and easy-to-follow instructions about how to use this application.

Resource Flow Diagrams
Use the *Resource Flow Diagram* alongside Step 2. This diagram will show you step-by-step how to use the Future Peak Flow application to understand potential changes to flood risk. The diagram also visualizes how you can use information from one resource along with another to obtain a more holistic picture of your community's potential future flood risk.

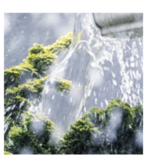
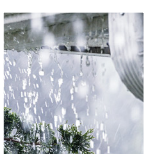
The outputs from the flow diagrams will help you in Step 3: Identify vulnerabilities.

Where do you find the Future Peak Flow application?
You can access the Future Peak Flow application online: https://ny.water.usgs.gov/maps/floodfreq-climate/.

How do you use the Future Peak Flow application?
Go to the application's homepage which presents a map of New York State.

1. *Select your location*. Zoom into a specific location on the map and then click on the green "Delineate" button at the top of screen (you will get an error message in the bottom right-hand corner of the screen if you are not zoomed in enough). Then click on the stream you wish to analyze to begin the analysis. Follow the on-screen prompts to calculate the watershed characteristics and stream flow estimates.

2. *View output*. The output from the application is a table of modeled estimates of current and future discharges for return intervals from 1.25 to 500 (e.g., 400% to 0.2% AEP) (see Table 1 as an example). The table includes mean, median, minimum, and maximum values for future projected discharge for three time periods (2030s, 2060s, and 2080s). The application uses projections of future annual precipitation from five climate models and two emissions scenarios (Burns et al., 2015).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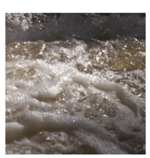


*How to identify **current** flood risk*

The Future Peak Flow application output provides estimates of the current magnitude of flood discharge for every recurrence interval. For example, in the Red Hook table on the next page, the current discharge estimates are displayed in column E.

*How to identify **future** flood risk*

The example output table also provides modeled estimates of future changes to the magnitude of discharge (columns F through I) and percent changes from the current flood discharge magnitudes (columns J through M). Here is more specific guidance about how to use the application's outputs to estimate changes in magnitude and frequency.

1. *Estimate your change in magnitude*. Magnitude is the discharge for an event of a particular frequency. You can use the application's output to estimate how discharge could change for an event of a given frequency (return interval). For example, how much more discharge will be associated with our 100-year return interval event in the 2080s? From the example table on the next page, the current discharge estimate for the 100-year return interval is 3,083 cfs. The future mean discharge estimate for the 100-year return interval for the 2075–2099 time period under the RCP 8.5 greenhouse gas scenario (column F) is 3,911 cfs. The projected future discharge is ~27% larger for a 100-year event. You could then translate this change in discharge to a change in stage with output from other resources such as USGS gage records (see the "*what additional information can contribute to the analysis*" section).

2. *Estimate your change in frequency*. You can also use the application's output to identify how much more often your current 100-year return interval flood is projected to occur in the future or a change in frequency. For example, from the table on the next page, the current discharge estimate for the 100-year return interval is 3,083 cfs. To identify how much more often the application models this same discharge will occur in the future, look in column F for the closest approximation for 3,083. In this case it is between the 25 year (2615) and 50 year (3,224) estimates. This means that, for this particular stream, according to this application, the current 100-year return interval flood is projected to become approximately twice as likely by the 2080s time period.

What additional information can contribute to the analysis?
When a stream has an adequate gaging record (typically ~30 years of recorded data), use the Future Peak Flow application percent change projections in conjunction with estimates of peak flows from the gage record to estimate the range of projected discharges at the gaged site. This analysis provides discharges that are based on measured flows, rather than the modeled outputs from the application. These values can be used in conjunction with a rating curve (a plot of the relationship between discharge and stage) from the gage to estimate water depths or stage for given discharges. You can translate the stage information into inundation estimates using a digital elevation model in GIS. Keep in mind that, particularly for the larger flood events, rating curves typically provide limited data so the curve fits at these boundaries are tenuous. This process will produce only screening-level estimates of potential inundation and should be used with other inundation information such as FEMA FIRMs where available.

Table 1. This table is an example output table from a small watershed near the town of Red Hook, NY for one emission scenario (RCP 8.5) and one time period (2080s). Each row presents the data from a different recurrence interval, from 1.25 to 500.

A	B	C	D	E	F	G	H	I	J	K	L	M
Location	Greenhouse gas scenario	Time Period	Recurrence Interval (yrs)	StreamStats Discharge (cfs)	Predicted Future Discharge (cfs) [Mean]	Predicted Future Discharge (cfs) [Median]	Predicted Future Discharge (cfs) [Max]	Predicted Future Discharge (cfs) [Min]	Predicted Future Discharge (% change) [Mean]	Predicted Future Discharge (% change) [Median]	Predicted Future Discharge (% change) [Max]	Predicted Future Discharge (% change) [Min]
Saw Kill at Bard College	rcp85_pr	2075 - 2099	1_25	488	554	552	581	534	13	13	19	9
Saw Kill at Bard College	rcp85_pr	2075 - 2099	1_5	590	682	679	720	653	16	15	22	11
Saw Kill at Bard College	rcp85_pr	2075 - 2099	2	735	865	862	921	824	18	17	25	12
Saw Kill at Bard College	rcp85_pr	2075 - 2099	5	1177	1429	1422	1539	1348	21	21	31	15
Saw Kill at Bard College	rcp85_pr	2075 - 2099	10	1548	1906	1895	2062	1790	23	22	33	16
Saw Kill at Bard College	rcp85_pr	2075 - 2099	25	2095	2615	2598	2843	2445	25	24	36	17
Saw Kill at Bard College	rcp85_pr	2075 - 2099	50	2562	3224	3203	3516	3007	26	25	37	17
Saw Kill at Bard College	rcp85_pr	2075 - 2099	100	3083	3911	3884	4277	3639	27	26	39	18
Saw Kill at Bard College	rcp85_pr	2075 - 2099	200	3666	4684	4650	5136	4348	28	27	40	19
Saw Kill at Bard College	rcp85_pr	2075 - 2099	500	4536	5853	5809	6441	5417	29	28	42	19

Are there any existing or planned changes to your local hydrology or infrastructure that might impact interpretation of these results or cause additional uncertainty?

Significant changes in land use and land cover including development can add to the uncertainties of the resources discussed in this toolkit because they influence rainfall-runoff relationships. Changes in land cover, such as paving a previously undeveloped area, can affect how precipitation runs through the landscape. Changes in land cover can also affect which areas are at risk of flooding due to extreme precipitation events or riverine flooding. Therefore, it is important to consider future land use and development plans when evaluating potential changes to flooding in your community.

What are the constraints of the Future Peak Flow application?

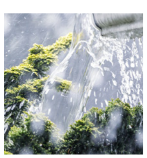
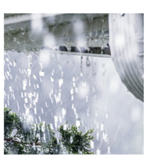
As with all of these resources, there is inherent uncertainty in using the Future Peak Flow application to estimate your communities flood risk. This application should only be used to understand general trends and always be used alongside other resources to estimate current and future flood risk. The application also has some technical constraints. To use this application, your stream reach has to be one that is mapped and “clickable” within the application’s interface.

What are known issues with this resource?

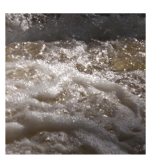
Occasionally, the model with require a refresh of the web browser to run successfully. Clearing your cache can help if the application seems not to be advancing in the modeling process.

Helpful Links

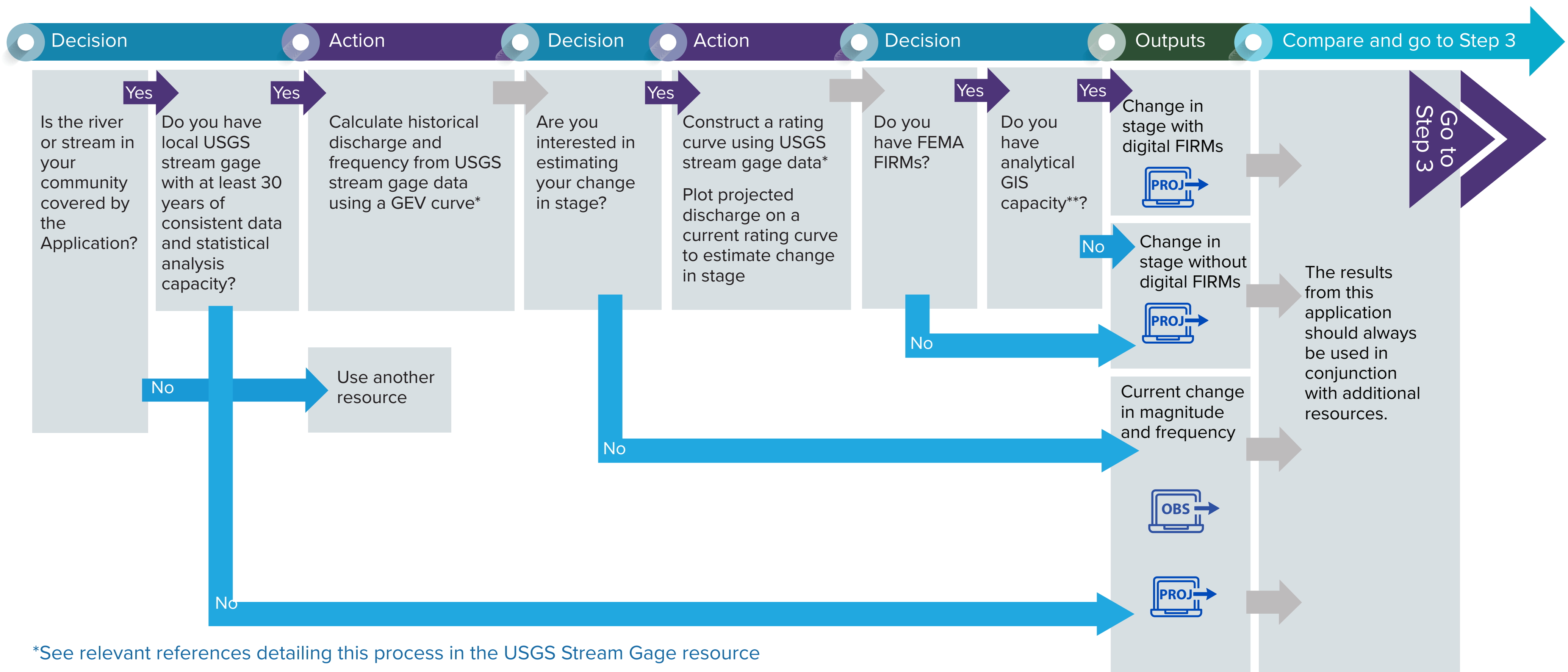
- Application of Flood Regressions and Climate Change Scenarios to Explore Estimates of Future Peak Flows. *Main User Interface for USGS Future Peak Flow application website.*
- Development of Flood Regressions and Climate Change Scenarios To Explore Estimates of Future Peak Flows (Burns et al., 2015). *Link for technical documentation for the application.*
- Magnitude and Frequency of Floods in New York (Lumia et al., 2006). *Discussion of uncertainty within the application.*

step 2



Resource Flow Diagram: USGS Future Peak Flow Application



*See relevant references detailing this process in the USGS Stream Gage resource

**See description of GIS analysis in FEMA FIRMs resource

If you would like more information on this resource, go back to Step 1

If this resource sounds right for your community move to Step 3

Step 2. Identify how your floods might change: USGS Stream Gage Data

You have decided to use USGS Stream Gage data to assess potential changes to your flood characteristics. This step will provide you with more information and easy-to-follow instructions about how to use the resource.

Resource Flow Diagrams

Use the *Resource Flow Diagram* alongside Step 2. This diagram will show you step by step how to use USGS Stream Gage data to understand potential changes to flood risk. The diagram also visualizes how you can use information from one resource along with another to obtain a more holistic picture of your community's potential future flood risk.

The outputs from the flow diagrams will help you in Step 3: Identify vulnerabilities.

Where do you find USGS gage data?

Go to the state USGS stream gage website, "USGS Current Water Data for New York:" https://waterdata.usgs.gov/ny/nwis/rt.

How do you use USGS gage data?

1. *Find the nearest gage(s) to your community*. The map on the left-hand side of the gage website displays gage sites by colored dots. Click on the dot closest to your community. This map only ranks stations with at least 30 years of recorded data; dots that are not colored (unfilled grey circles) are unranked stations that may have records less than 30 years or record characteristics other than stream flow (e.g., stage). If available, select gages both upstream and downstream of your community which will provide you with more data.

2. *Select your discharge and stage data*. Once you have selected a station and are on the landing page for that station:

a. Scroll down through the gage description until you see the box that looks like the one in Figure 2:

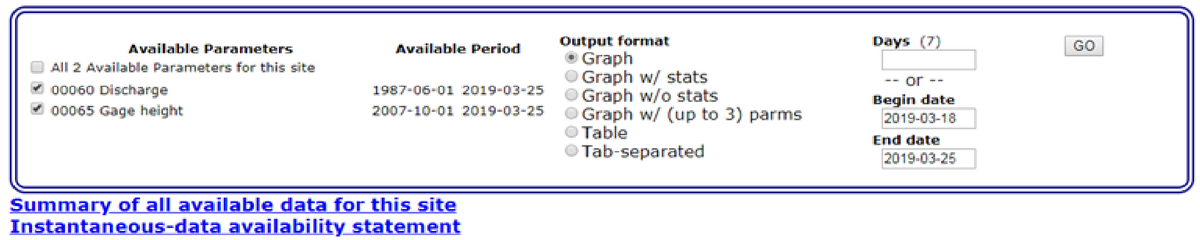


Figure 2. Shows the output selection box for available current and historical gage data for a given gage location.

b. Select the parameters. To generate a rating curve (as described in the *"Generating a rating curve"* section), you will need discharge and stage data. Stage data is also referred to as "gage height." If your gage only has discharge data available, you can still assess extreme event frequency and potential trends (see the *"How to identify current and future flood risk"* sections).

c. Choose your desired output format. The table or tab-separated formats are easiest to use.

d. Specify begin and end dates. Pulling the entire available record will give you the most thorough data for your analysis.

e. Click "GO" to start a download of the available file.

3. Check on the availability of peak stream flow data. Scroll back up to the drop-down menu at the top of the gage landing page, titled: "Available data for this site."

a. Use this drop down menu to select "SUMMARY OF ALL AVAILABLE DATA".

b. If it is available, "Peak stream flow" will appear under the Available Data list. Selecting it will bring you to a page that looks like Figure 3 below.

c. Choose your desired output format. The table or tab-separated files are the most suitable choices to estimate trends or understand peak flood magnitudes in your community.

The file type option "peakfq (watstore) format" runs the USGS PeakFQ application which can estimate the magnitude and frequency associated with extreme events in your community which can be used in concert with outputs from the NWIS site. To run this file, download the PeakFQ software. A tutorial on how to use the PeakFQ application is beyond the scope of this toolkit, but there are user tutorials available for this application at the USGS PeakFQ website. Prior to using the application, you should review the associated documentation for discussions of uncertainty, proper use, and known issues.

Figure 3. Shows an example of peak stream flow data that may be available for your local stream gage.

*How to identify **current** flood risk*

There are several ways you can use USGS gage data to identify your current flood risk. One approach involves the following steps:

1. Generate a rating curve
2. Plot annual maximum discharge
3. Generate a GEV curve
4. Estimate stage a for an event of a given frequency

1. Generate a rating curve.

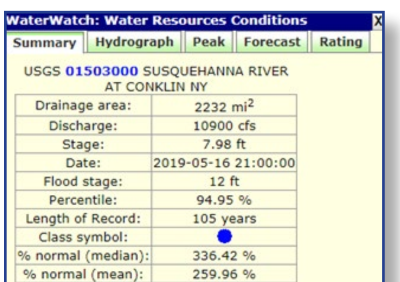
There are multiple methods available for generating rating curves from USGS gage data. We will cover two possible options below: using the USGS WaterWatch website and using your own USGS gage data.

Using the USGS WaterWatch website

The first and easiest method is to see if a gage close to your community is included in the USGS WaterWatch website that provides provisional rating curves for a large number of active gage locations throughout the United States. Access the [USGS WaterWatch].

a. Click on New York State to zoom into the [state-specific gage location map for New York.]

b. Click on the gage of interest to you. This will likely be the same gage (or gages) you identified in the *"How do you use USGS gage data?"* section on the previous page. This will bring up a box that looks like Figure 4.

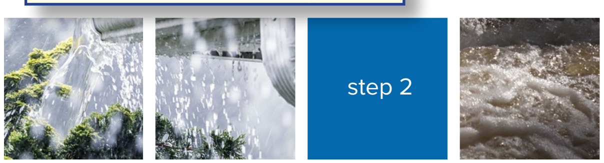

WaterWatch: Water Resources Conditions

Summary | Hydrograph | Peak | Forecast | Rating

USGS 01503000 SUSQUEHANNA RIVER AT CONKLIN NY

Drainage area:	2232 mi^2
Discharge:	10900 cfs
Stage:	7.98 ft
Date:	2019-05-16 21:00:00
Flood stage:	12 ft
Percentile:	94.95 %
Length of Record:	105 years
Class symbol:	
% normal (median):	336.42 %
% normal (mean):	259.96 %

Figure 4. A screenshot of WaterWatch showing water resources conditions of the Susquehanna River at Conklin, New York.



c. If a rating curve is available for the given gage location you will see the tab called "Rating" on the far right of the pop-up window. Click on the "Rating" tab, and then click on the small rating curve in the pop-up window to get to the "Customized Rating Curve Builder" page for your selected gage (if you know your gage number you can enter it directly into this [tool]). This page allows you to edit the inputs used to generate the rating curve (length of record used to generate the curve, and the inclusion of field collected stage data), and also allows for some customization of outputs (e.g., image size and labels). The curve regenerates automatically with your inputs.

Using your own USGS gage data

The second method is to generate the curve using downloaded gage data and fitting a curve to the data in a statistical software program. Using the discharge and stage data from your gage site (see *"how do you use USGS gage data"* section on the previous page), construct a rating curve by plotting discharge on the X-axis, stage on the Y-axis, and fitting a curve through these data (Figure 7 is an example of a rating curve). This provides an estimate of the water level associated with a given discharge. You can use a rating curve along with a magnitude and frequency curve to estimate the stage for a given recurrence interval (e.g., 1% AEP or 0.2% AEP) (see step 4). For more information on the analytical methods you can use to generate these types of curves see the "Rating Curve Information" portion of the *Helpful Links* section for this resource.

2. Plot your annual maximum discharge.

Gage data can also show you the largest discharge from each year, called the annual maximum discharge or annual peak flow, in the record. Plotting the annual maximum values would help you see if the data suggest an increase in annual maximum discharge over time. You may also be able use these data to understand potential future changes in annual maximum events (see *"How to identify future flood risk"* below for more information on this process).

Some gages have annual peak flow information available directly from the USGS gage site, as discussed in *"How do you use USGS gage data?"* section. If your gage does not, open your downloaded discharge data in a spreadsheet program (e.g., Excel or any other data processing or statistical software package). Using functions within your software programs (e.g., array functions or pivot tables in Excel) you can quickly obtain the maximum values for each year of your stream gage record and use these data to assess historical trends. For example, you can plot the maximum values for discharge on the Y-axis and year on the X-axis (see example plot in Figure 5).

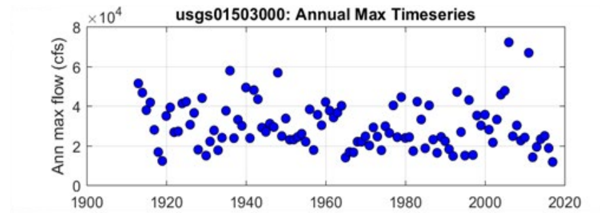


Figure 5. An example plot of annual maximum discharge.

3. Generate a generalized extreme value (GEV) magnitude and frequency curve.

Using the annual maximum flow data, you can also estimate the return intervals for a given flow magnitude. This information will help you better understand your historical flood risk. For more information about how to do this, the USGS has detailed guidelines for estimating flood frequency on its website, "Guidelines for Determining Flood Flow Frequency" ([England Jr. et al., 2017]).

4. Estimate the stage for a given return interval.

Stage estimates are useful metrics for discussions of potential flood inundation and estimated damages. You can estimate stage by first obtaining the discharge associated with a return interval using your magnitude and frequency curve, and then using your discharge information with a rating curve to estimate the stage.

a. A GEV magnitude and frequency curve (see *Step 3* on the previous page) can help you estimate the discharge for a particular event. For example, using the magnitude and frequency curve below (Figure 5), we can estimate that the discharge associated with the 1-in-100 year (1% AEP) event is about 70,000 cfs (highlighted by the red circle).

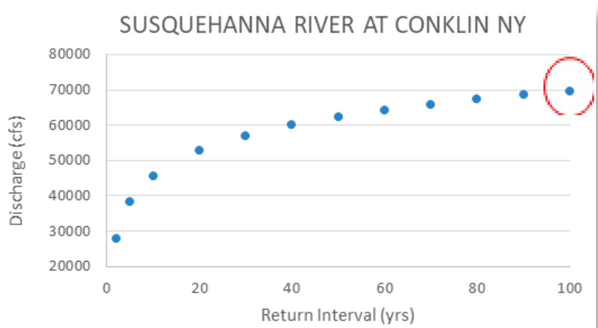


Figure 6. Figure shows a magnitude and frequency curve for the Susquehanna River at Conklin, NY. Discharge is show on the Y-axis and return interval (frequency) on X-axis. The red circle highlights that the discharge associated with the 1-in-100 year return interval (or 1% AEP) is approximately 70,000 cfs.

b. You can then use your rating curve from Step 1 (e.g., Figure 6) to estimate the stage associated with a particular discharge from your magnitude and frequency curve. To do this, find the discharge on the X-axis of the curve, and then find the corresponding point on the rating curve to determine stage (gage height). For example, the rating curve in Figure 6 is from the Susquehanna River at the Conklin gage and shows the data for all available reporting years (for this gage, the curve is available from the USGS website). Using this data, a discharge of 70,000 cfs (the 1% AEP discharge estimate for this location) corresponds with a gage height of ~24 feet (represented by the red dot).

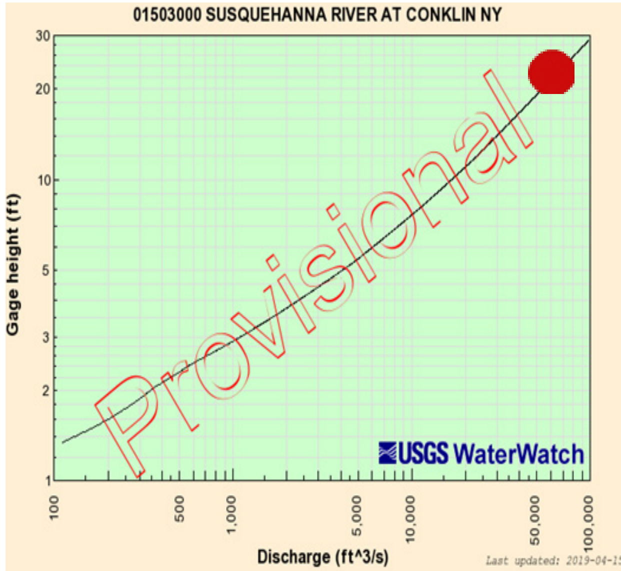


Figure 7. Figure shows a rating curve for the Susquehanna River at Conklin, NY. *Discharge is shown on the Y-axis and return interval (frequency) is on X-axis. The red dot represents the estimated stage for a discharge of 70,000 cfs (our estimate for the 1% AEP event).*

*How to Identify **Future** Flood Risk*

1. Plot annual maximum flood values.

Examine the annual maximum discharge data (the highest flow in each year of the gage record; see step 2 in the *"how to identify current flood risk"* section on the previous page) to see if you can identify trends in the maximum flows. This might suggest a shift in the higher flows over time.

2. Use a moving window analysis to plot changes in the 1% AEP flow.

One way to look at changes to a given return interval is to perform a "moving window analysis." The steps below illustrate how you would do this for a 1% AEP discharge.

- Identify the first 30-year window of your recorded data.
- Calculate the estimated discharge of the 1% AEP event for those 30 years by creating a GEV curve (see step 3 in the *"how to identify current flood risk"* section on the previous page)
- "Move" the window in five-year increments. For example if your first "window" covered the 30 years from 1900–1930, then your second "window" would cover 1905–1935.
- Recalculate the estimated discharge of the 1% AEP event for the second window.
- "Move" forward another five years for your next window and repeat the calculation.
- Continue this process over the entire span of your data (see Figure 7).

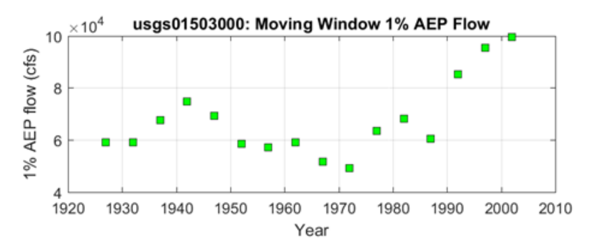


Figure 8. The plot above shows an example of a 30-year moving window analysis of the 1% AEP event flow from gage records taken from the USGS gage in the Susquehanna River at Conklin, NY. *Plots are for illustrative purposes only.*

!

Technical Knowledge and Computing Requirements

As indicated in the resource decision matrix, to obtain estimated future discharge amounts using USGS gage data alone requires a good understanding of statistical data analysis and processing, as well as knowledge of how to construct a generalized extreme value (GEV) curve (these are the curves used to estimate the frequency of a flow of a given magnitude). You may also need software that is capable of more advanced statistical operations such as R, SAS, or Matlab and a working knowledge of programming within the environments.

You can now assess how the 1% AEP discharge has changed over time. In Figure 7 the estimated 1% AEP discharge for each 30-year window suggests a potential increase in the magnitude of the 1% AEP event after about 1970. (This approach is also discussed in the Broome County community profile.)

3. Understand the influence of large historical flood events on projected trends.

You can also experiment with trends in the data by adding and subtracting significant flood events and then recalculating your 1% AEP discharge. This will help you understand the influence of specific events on the return interval estimates from your data. Remember that you should only use these approaches on records that have at least 30 years of continuous data.

What additional information can contribute to this analysis?
You can also combine stream gage data with other projected changes to give you additional estimates of your potential future flood risk. To do this, apply a projected percent change in discharge to your observed gage data. The SFRMG recommends adding a change in discharge of 10% in eastern New York and 20% in western New York. You could also use discharge projections from a local study that has been done in your community or from other resources (e.g., the *USGS Future Peak Flow application*).

Using a rating curve from your local gage and the projected change in discharge from other resources, you can also estimate the change in stage associated with future discharges of a given return interval. This information can help instruct discussions of potential future inundation extent and associated damage estimates. To do this multiply the discharge associated with a particular frequency (e.g., the discharge of the 1% AEP event) by the change factor from another discharge projection. Then plot the new discharge on your existing rating curve to estimate the change in stage associated with your new discharge value.

Are there existing or planned changes to your local hydrology or infrastructure that might impact interpretation of these results or cause additional uncertainty?
Significant changes in land use and land cover including development can add to the uncertainties of the resources discussed in this toolkit because they influence rainfall-runoff relationships. Changes in land cover, such as paving a previously undeveloped area, can affect how precipitation runs through the landscape. Changes in land cover can also affect which areas are at risk of flooding due to extreme precipitation events or riverine flooding. Therefore, it is important to consider future land use and development plans when evaluating potential changes to flooding in your community.

What are the constraints of USGS gage data?
Some gage records are shorter than 30 years or have coverage gaps which complicates the interpretation of their data. Gage data also do not capture potential future changes to discharge or stage from climate change, nor do they factor in impacts of future land use change. Like many of these resources, USGS gage data should be used in concert with other information available to provide a more complete picture of the inland flood hazard for a given community.

Helpful Links

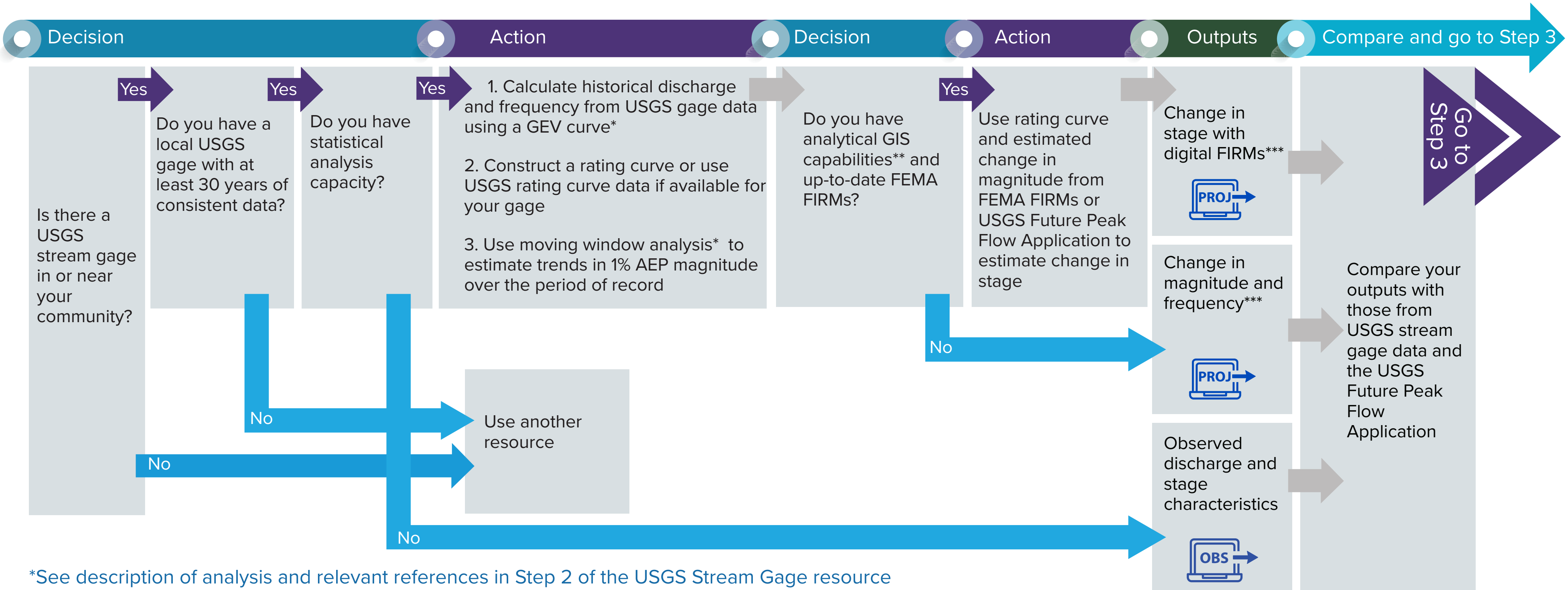
Helpful links when using the USGS stream gage data:

- USGS stream gage data website. *Website with interactive maps of stream gages throughout the US showing current flow, flood, and drought conditions as well as historical runoff and flows. Individual gages can also be reached through this site.*
- USGS WaterWatch website. *Map of gages experiencing high flow or flood conditions at a point in time, and link to Google Earth files for selecting flow gages by map.*
- USGS stream gage data for New York. *New York specific gage data*.
- USGS Guidelines for Determining Flood Flow Frequency Bulletin 17C. *Guidelines for estimating flood frequency*.

Helpful links for constructing rating curves:

- USGS What is a rating curve? Why does it change over time? *FAQs related to rating curves from the USGS; Includes online application to construct rating curves for USGS gage locations.*
- USGS. 2002. Standards for the Analysis and Processing of Surface-Water Data and Information Using Electronic Methods. *Discussion of standard methods for producing rating curves with electronic datasets.*

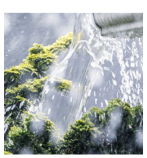
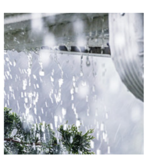
Resource Flow Diagram: USGS Stream Gage



*See description of analysis and relevant references in Step 2 of the USGS Stream Gage resource

**See description of GIS analysis in FEMA FIRMs resource

***Can be used to align with SFRMG recommendations

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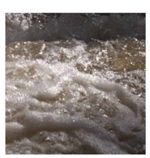


If you would like more information on this resource, go back to Step 1

If this resource sounds right for your community move to Step 3

Step 2. Identify how your floods might change: ClimAID

You have decided to use ClimAID to assess potential changes to your flood characteristics. This step will provide you with more information and easy-to-follow instructions about how to use ClimAID.

Resource Flow Diagrams
Use the *Resource Flow Diagram* alongside Step 2. This diagram will show you step by step how to use ClimAID to understand potential changes to flood risk. The diagram also visualizes how you can use information from one resource along with another to obtain a more holistic picture of your community's potential future flood risk.

The outputs from the flow diagrams will help you in Step 3: Identify vulnerabilities.

Where do you find ClimAID?
The ClimAID report can be found on the NYSERDA website at http://www.nyserda.ny.gov/climaid and is free to download. The most recent climate projection information is in the 2014 supplement update report; the other chapters have topic-specific material. For additional information related to flood risk, look at Chapter 4: Water Resources. If you need further follow-up on any of the topic-specific chapters, contact the chapter authors directly.

How do you use ClimAID?
From the website, download the 2014 Supplement—Updated Climate Projections Report.

*How to identify **current** precipitation patterns and extremes*

In Chapter 2: Observed Climate of the Climate Projections Report, you will find information on historic annual, seasonal, and extreme rainfall events. First, go to Figure 1 on page 1 which lists the ClimAID climate regions. Find the region that best aligns with your community. Next, review the data tables throughout Chapter 2 to see observed data in your region including trends in annual and seasonal precipitation and annual averages and extremes for days with rainfall exceeding certain thresholds. Contact NYSERDA at info@nyserda.ny.gov for the raw data behind any of the tables.

*How to identify **future** precipitation patterns and extremes*

Chapter 3 of the Climate Projections Report provides tables of future climate projections for precipitation, including projected changes to the number of extreme events and average annual precipitation changes.

To identify how the observed data in your region might change using ClimAID:

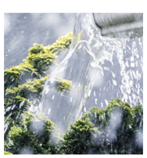
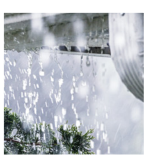
1. Go to Figure 1 on page 1 of the report and find the climate region that best aligns with your community.

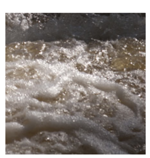
2. Locate the Extreme Precipitation Table that corresponds with your climate region (Table 5, page 10). The bottom two rows of these tables display the projected number of days with daily rainfall greater than one or two inches for the near-term (around the 2020s), mid-term (around the 2050s), and long-term (around the 2080s) for each region in New York. These projections are 30-year average values from models. The table includes the low (10th percentile), mid-range (25th to 75th percentile), and high (90th percentile) estimated projections. Table 2 below is an example from the ClimAID report of regional extreme precipitation projections for Region 5, the East Hudson and Mohawk River Valleys.

3. Use the information from these tables along with your local precipitation and flood records to estimate how much more frequently your observed events may occur in the future. See the *"what additional information can contribute to the analysis"* section on the next page for further details about how to do this.

	Low Estimate (10^{th} percentile)	Middle Range (25^{th} to 75^{th} percentile)	High Estimate (90^{th} Percentile)
2020s			
Days over 1" Rainfall (10 days)	10	10 to 11	12
Days over 2" Rainfall (1 day)	1	1 to 2	2
2050s			
Days over 1" Rainfall (10 days)	10	11 to 12	13
Days over 2" Rainfall (1 day)	1	1 to 2	2
2080s			
Days over 1" Rainfall (10 days)	10	11 to 13	14
Days over 2" Rainfall (1 day)	1	1 to 2	2

Table 2. Projection of Extreme Precipitation Events-Region 5 (Saratoga). Baseline data (shown in parenthesis) are for the 1971 to 2000 base period and are from the NOAA National Climatic Data Center (NCDC). Shown are the low-estimate (10^{th} percentile), middle range (25^{th} to 75^{th} percentile), and high-estimate (90^{th} percentile) 30-year mean values from model-based outcomes.



Additional projected climate change information in ClimAID

Projected average precipitation changes are also available from ClimAID. Although this information may be insightful, it will not help you characterize potential changes to your flood risk because changes in extreme events are not expected to correlate well with changes in average precipitation.

What additional information can contribute to the analysis?
You can use ClimAID along with your historical precipitation or flood data to get a rough estimate of potential future changes to your local precipitation patterns and related flooding.

1. Use the information from Table 5 on page 10 of the 2014 ClimAID supplement (as discussed in the *"how to identify future precipitation patterns and extremes"* section on the previous page).
2. Gather local historical precipitation records, especially information on precipitation events that caused flooding in your community. If you don't have this information readily available, you might find it through sources such as local newspaper records, emergency services call records, or by talking to local experts including emergency managers, flood plain managers, highway superintendents, soil and water districts, watershed groups, or local academics.
3. Compare the ClimAID projections to your local historical precipitation records to determine how much more often a particular event might occur in the future. For example:

    a. Consider a community in the Saratoga region. In 2008, a local bridge was overtopped during a heavy rainfall event. Looking at the local gage records, community officials see that more than two inches of rain fell over 24 hours when the bridge flooded.

    b. Look at the table from ClimAID for the Saratoga region (Table 2 on the previous page) and notice that an event of this magnitude currently occurs about once a year. By mid-century, this same type of event may be twice as likely to occur, e.g., occur approximately 2 days per year.

The ClimAID projections can also be used in a more complex analysis to create local IDF curves. See the *IDF curve resource description* for more information on this approach.

Are there any existing or planned changed to your local hydrology or infrastructure that might affect interpretation of these results or cause additional uncertainty?
Significant changes in land use and land cover including development can add to the uncertainties of the resources discussed in this toolkit because they influence rainfall-runoff relationships. Changes in land cover, such as paving a previously undeveloped area, can affect how precipitation runs through the landscape. Changes in land cover can also affect which areas are at risk of flooding due to extreme precipitation events or riverine flooding. Therefore, it is important to consider future land use and development plans when evaluating potential changes to flooding in your community.

What are the constraints on ClimAID?
As with all of these resources, there is inherent uncertainty in using ClimAID to estimate your communities flood risk. It is useful to, keep in mind:

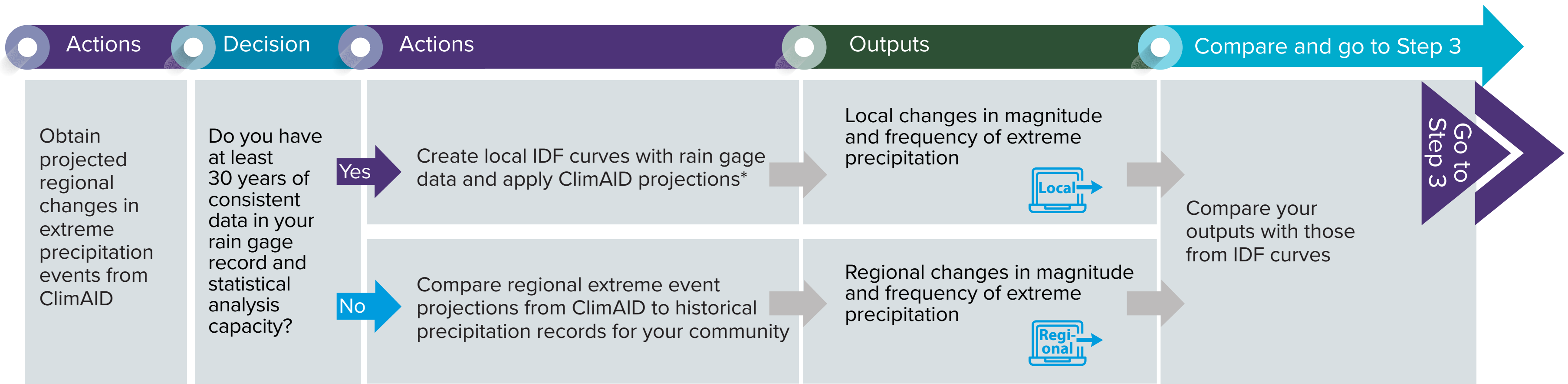
1. Most of the information in ClimAID is provided for broader regions of New York State and not specific communities. While the climate data in the report are broadly applicable, local features and elements of flood risk are not captured in the report. The ClimAID precipitation projections do not provide communities with local information on how changes in rainfall may translate to runoff or flood magnitude.
2. ClimAID's precipitation projections are based on daily rainfall totals, but local flooding is often caused by shorter duration events such as heavy summer thunderstorms that happen over short periods of time, even less than one hour in some cases.

Translating precipitation changes into local flood risk requires additional investments such as hydrologic modeling of runoff and streamflow. You can use the climate data from ClimAID in these models, but these types of modeling exercises typically require a substantial investment of resources. See the *IDF curve resource description* for more information on this approach.

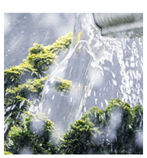
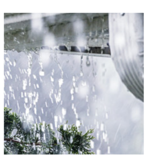
Helpful Links
Helpful links when using ClimAID:

- ClimAID Report. *Report on Responding to Climate Change in New York State.*

Resource Flow Diagram: ClimAID



*See discussions of Intensity Duration Frequency (IDF) Curves for New York State and using your rain gage data to generate IDF curves in the IDF Curve resource description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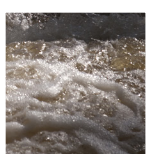


If you would like more information on this resource, go back to Step 1

If this resource sounds right for your community move to Step 3

Step 2. Identify how your floods might change: IDF Curves

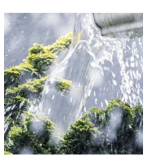
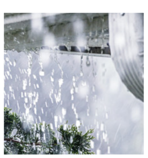
You have decided to use IDF curves to assess potential changes to your flood characteristics. This Step will provide you with more information and easy-to-follow instructions about how to use IDF curves.

Resource Flow Diagrams

Use the *Resource Flow Diagram* alongside Step 2. This diagram will show you step by step how to use IDF curves to understand potential changes to flood risk. The diagram also visualizes how you can use information from one resource along with another to obtain a more holistic picture of your community's potential future flood risk.

The outputs from the flow diagrams will help you in *Step 3: Identify vulnerabilities*.

The detailed information and instructions in this Step will help you use IDF curves to identify potential changes in the frequency or magnitude of extreme precipitation. We include two approaches for obtaining IDF curves. One approach uses the "Intensity Duration Frequency Curves for New York State" web-based application which is a pre-generated set of IDF curves created by researchers at the Northeast Regional Climate Center (NRCC) in partnership with NYSERDA. The other approach provides guidance on how to create your own IDF curves. The pre-generated IDF curves will provide sufficient information to meet the needs of most communities. If you have a longer rain gage record and would like more detailed information such as understanding multi-day precipitation events, you might consider manually generating your own IDF curves.

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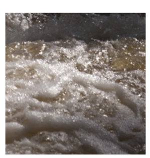


Which approach would you like to take to obtain an IDF curve?

Approach 1: Use NRCC IDF curves for New York State »

Approach 2: Create your own IDF curves »

APPROACH 1: USE NRCC IDF CURVES FOR NEW YORK STATE

About the NRCC IDF curves

The NRCC IDF curves website allows you to view observed and projected IDF curves for 157 locations in the state. The application uses observed daily rain gage data from 1970 to 1999 to create baseline IDF curves. To estimate future changes, the researchers incorporated data from climate models with the observed data.[5]

Where do you find IDF curves?

The website for the IDF curves for New York State is: http://ny-idf-projections.nrcc.cornell.edu/. (Note: This site works best in the Chrome or Firefox browser.)

How do you use IDF curves to determine changes in extreme precipitation patterns?

The actions below and example in the text box will walk you through how to use the NRCC IDF curves to determine current and projected rainfall characteristics.

*How to identify **current** extreme precipitation patterns*

1. *Choose your station*: Identify the station(s) closest to your community (you can zoom in if necessary). When you select that station on the map, that station's IDF curves are automatically displayed to the right.
2. *Choose your output*: In the blue box under the map, you can customize your output using the options on the right (note: Emission scenario and time period relate only to understanding your future precipitation patterns, but you need to enter a selection for each of these options to generate an IDF curve).

a. Return period—Select the rainfall event frequency you are interested in from a 1-in-2 year event (also called a 50% AEP event) to a 1-in-100 year event (or a 1% AEP event).

b. Emission scenario—This pertains to the future projections. Climate models are run under different emissions scenarios which represent different amounts of future GHG emissions. A high emissions scenario (RCP 8.5) represents a future where our trajectory of GHG emissions is not reduced. Selecting this option would provide you with higher estimates of future projections. A lower emissions scenario (RCP 4.5) represents a future where global GHG emissions gradually rise before stabilizing around mid-century.

c. Time period—You can select the time period you want to represent for future projections from early- (2010 to 2039), mid- (2040 to 2069), or later-century (2070 to 2099); late century projections generally show larger changes in magnitude and frequency but also have a higher uncertainty in terms of the model output.

d. Show NOAA Atlas 14 IDF—If you are interested in a deeper understanding of the technical basis of these results, this option allows you to compare projections generated by the NYS IDF curve interface with a set of curves generated by NOAA in the Atlas 14 Point Precipitation Frequency Estimates interface. NOAA uses a

[5] The climate model outputs were downscaled from global climate models (GCMs) for both high and medium-low emission scenarios. Downscaling refers to the process of taking coarse-scale global climate model (GCM) data and deriving finer-scale climate information for a more relevant picture of local climate. Generally GCM data is projected on grid cells that may be 100 km on each side, to understand more regional or local projections researchers use a variety of downscaling techniques to capture local impacts that may not be resolved at the global grid size (see DeGaetano and Castellano, 2015 for discussion of specific techniques used for NY State IDF curve generation).

slightly different methodology to generate the curves. More information on NOAA's IDF curves is available here.

3. *View relevant curves:* Once you have an IDF curve, you can select different return periods to understand the intensities associated with different durations. To consider current precipitation patterns, use the "Observed" curve (dotted line). See the example text box and "what additional information can contribute to the analysis" section below for suggestions about how to use the IDF information to characterize your flood hazard by comparing IDF data to historic events.

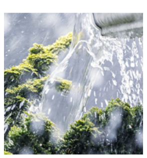
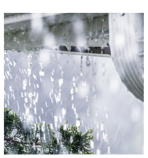
*How to identify **future** extreme precipitation patterns*

The NRCC IDF curves website can provide you with screening level estimates of changes in magnitude or frequency as a starting point for understanding how different types of precipitation events might change in the future.

To consider a change in magnitude, follow these actions:

1. *Select a station*: Identify the station (or stations) closest to your community and select that station on the map to display the corresponding IDF curve. The "Projected Mean" curve (solid line) and the surrounding pink area represent the model range of potential future intensities and durations.

2. *Select a time period*: From the blue shaded box under the map, select the time period you would like to consider, e.g., 2070–2099 which represents later-century projections.

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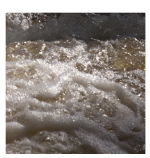


3. *Pick an emission scenario*: From the same menu specify the emission scenario that you are interested in viewing (RCP 8.5 which is high emissions scenario or RCP 4.5 a lower emissions scenario).

4. *Find the intensity estimates*: When you hover over any point along the curve, a pop-up box appears with projected and observed intensity estimates associated with the duration at that point. You can also look at the corresponding table under the graph to see the projected and observed intensity estimates for seven common durations (1, 2, 3, 6, 12, 18, and 24 hours).

To obtain a rough estimate of the changes of a particular event:

5. Toggle between different return periods while holding time period and emission scenario constant: These estimates can be a starting point for understanding how different types of precipitation events might change in the future.

What additional information can contribute to the analysis?

You can use data from IDF curves to better understand flood risk in your community by comparing the IDF outputs to data from local historical events. This will help characterize what types of rainfall events have caused flooding in the past. To do this, you will need other local data on historical rainfall events, including precipitation amounts and durations. Information about the impacts from those precipitation events, such as where and when flooding occurred, will give you even more context about precipitation events.

For example, if most people in your community are familiar with a particular flooding event, for example, "the floods in April of 2010," you can say that type of event might become twice as strong by mid-century. This type of messaging is likely to resonate with people in your community.

This approach should be used as a screening level exercise and a starting point for understanding the types of precipitation events that may be important when considering your community's flood risk.

In the text box on the following page, we provide an example of how you can use historical records to understand both current and potential future changes to extreme precipitation patterns and potentially associated flood risk.

Are there any existing or planned changes to your local hydrology or infrastructure that might affect interpretation of these results or cause additional uncertainty?

Land use and land cover can greatly determine how extreme rainfall may result in flooding. For example, an extreme rainfall event may not cause any flooding if it falls on a forested landscape, whereas the same event could cause significant flooding on a paved landscape with poor drainage. Using green infrastructure techniques such as pervious pavement or green medians can help to minimize flooding from extreme rainfall events. Changes in land cover, such as paving a previously undeveloped area, can affect how precipitation runs through the landscape. Along with changes in precipitation, changes in land cover will also affect which areas are at risk of flooding due to extreme precipitation events. Therefore, it is important to consider future land use and development plans when evaluating changes to future rainfall and flooding.

What are the constraints of the NRCC IDF curves for New York State website?

The NRCC IDF curves are based on 30 years of data. This may cause the curve for higher return interval events (e.g., 1-in-100 year event) to be less accurate than if the record was longer and contained more of these higher intensity, less frequent events. Also, as with any projection, keep in mind that there is uncertainty associated with the future climate projections used in the NRCC IDF curves. For more information, see the technical documentation available via the *Helpful Links* section.

Using IDF Curves: An Example Approach

This example from Ithaca, NY is one approach of how you can use IDF curves to assess your current precipitation patterns by comparing a historical event to the IDF model.

How to identify the frequency and intensity of a historic rainfall event

In this hypothetical example, Ithaca experienced a heavy rainfall event in the summer that produced five inches of rain in 24 hours (as recorded by a local rain gage) and caused significant nuisance flooding including flooding a local major highway. Ithaca is interested in learning more about the frequency and intensity of this event. To do so:

1. First, calculate the rainfall intensity in inches per hour, i.e., five inches of rain in 24 hours, or 5 divided by 24, which results in an intensity for this event of approximately 0.21 inches/hour.

2. Next, to determine how likely this event is to happen in any year under current conditions:

   a. Select Ithaca, NY on the NYS IDF curve website (this is the default location).

   b. Look at the table below the graph (See Figure 8) and find 24 hours in the first column, "Duration." Since we know our event occurred over a 24-hour period, this is the row we will want to use.

   c. Look at the right-hand three columns to find the "Observed" data and look at the last row, corresponding to the 24-hour duration.

   d. If necessary, select different return periods from the blue box under the map on the left side of the webpage (see the highlighted box in Figure 9 below) until you find a mean observed value close to the event's intensity, which is 0.21 in/hr for our example. In this instance, we find the closest match with the 50-year return period.

Take home: The hypothetical event Ithaca experienced with magnitude of five inches over 24 hours (with an intensity of approximately 0.21 in/hr) has a modeled estimated frequency of roughly 50 years (2% AEP) for Ithaca. In other words, this rain event has a 2% chance of occurring in any given year under current conditions.

How to identify future changes in frequency

1. To estimate what this change in intensity means to change in frequency, Ithaca selects the different return periods from the blue box under the map on the left side of the webpage (see Figure 9) until they find a mean observed precipitation intensity value close to 0.25 in/hr. Ithaca found that the current 100-year event has a mean intensity of 0.26 in/hr which is close to our projected intensity for a future 50-year event with the same duration (see Figure 12).

Take home: This suggests to Ithaca that the current 1% AEP (or 100-year) intensity event (with a fixed duration) may be twice as likely to occur in the future (the current 100-year event may be similar in intensity and duration to the future 50-year event).

	Projected 2040-2069 Intensity Ensemble Member			Observed 1970-1999 Intensity with Confidence Interval (CI) Bound		
Duration (hrs)	10th	Mean	90th	Low CI	Mean	High CI
1	2.04	2.24	2.59	1.72	1.96	2.11
2	1.27	1.39	1.60	1.07	1.21	1.31
3	0.96	1.05	1.21	0.81	0.92	0.99
6	0.59	0.65	0.75	0.50	0.57	0.61
12	0.37	0.40	0.47	0.31	0.35	0.38
18	0.28	0.30	0.35	0.23	0.27	0.29
24	0.23	0.25	0.29	0.19	0.22	0.24

Figure 9. Table from the NYS IDF Curve web interface. Values displayed are the projected and observed rainfall intensities for the 50-year return period at Ithaca, NY. The highlighted potion of the table shows the mean and range of intensities associated with a 24-hour rainfall event with a 50-year return interval.

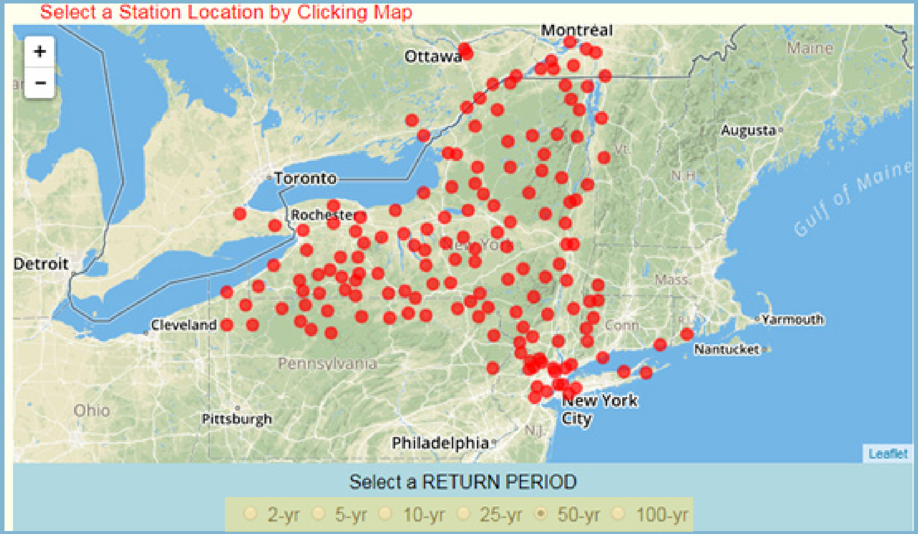


Figure 10. The radio buttons below the station map in the IDF webpage allow you to select return intervals ranging from 2–100 years. When you select a return period the intensity output table will update.

How to identify future changes in intensity

Now that Ithaca has an idea of its current precipitation patterns, the community wants to find the potential future change in magnitude.

1. First, consider our selection options from the blue box below the map (Figure 10).

   a. Ithaca wants to consider changes that might happen in 20 to 50 years or by mid-century, so we select the 2040–2069 time period.

   b. Ithaca decides to plan for the higher emissions scenario so we select the “high RCP 8.5.”

   c. We select the 50-year return period based on our work finding the observed frequency and intensity (from “How to identify the frequency and intensity of a historic rainfall event”).

2. Next, we find the location on the graph that corresponds with an observed intensity of approximately 0.21 in/hr, or 24-hour duration (the far right end of the graph). The pop-up box for this point (see the highlighted circle in Figure 10) indicates that the corresponding modeled projected intensity for a 50- year event will be approximately 0.25 in/hr.

3. You can also get this information by looking at the table beneath the graph. From the earlier actions in our Ithaca example, we found that an intensity of approximately 0.21 in/hr for the 50-year storm equated to a 24 hour duration, or the last row in the table. If you look across the entire 24-hour duration row (see Figure 11), the three columns under the “Projected” heading will provide you with an idea about how the intensity of the 50-year event might change by the mid-century compared to the “Observed,” with a mean estimate showing an increase to 0.25 inches per hour.

Take home: If Ithaca’s hypothetical event occurs in the mid-century, the rainfall intensity might be approximately 0.25 in/hr instead of the current intensity of approximately 0.21 in/hr.

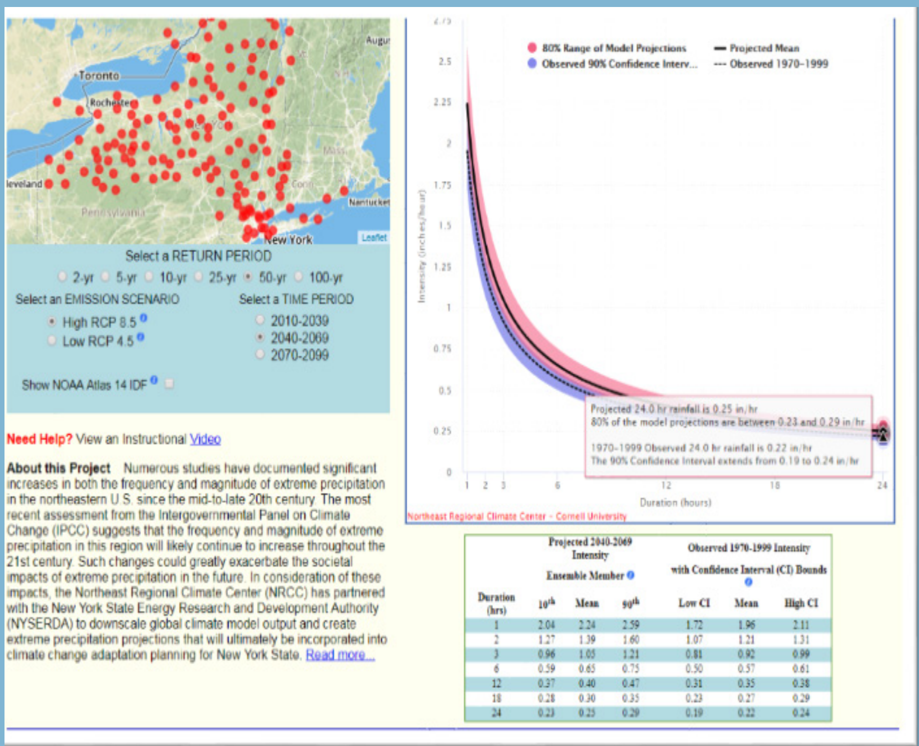


Figure 11. Snapshot illustrating actions 1 and 2. The pop-up box, which auto populates as you drag your mouse over the IDF curve, shows the observed and projected intensities for a given rainfall duration (24 hour duration in the example above).

Duration (hrs)	Projected 2040-2069 Intensity, Ensemble Member 10th	Mean	90th	Observed 1970-1999 Intensity with Confidence Interval (CI) Bounds, Low CI	Mean	High CI
1	2.04	2.24	2.59	1.72	1.96	2.11
2	1.27	1.39	1.60	1.07	1.21	1.31
3	0.96	1.05	1.21	0.81	0.92	0.99
6	0.59	0.65	0.75	0.50	0.57	0.61
12	0.37	0.40	0.47	0.31	0.35	0.38
18	0.28	0.30	0.35	0.23	0.27	0.29
24	0.23	0.25	0.29	0.19	0.22	0.24

Figure 12. Estimates for the 50-year event for Ithaca, NY. These correspond with an RCP 8.5 emission scenario for the mid-century time period (2040–2069). This estimate shows that the intensity of the 50-year event may increase from the current 0.21 in/hr to between 0.23-0.29 in/hr.

Duration (hrs)	Projected 2040-2069 Intensity, Ensemble Member 10th	Mean	90th	Observed 1970-1999 Intensity with Confidence Interval (CI) Bounds, Low CI	Mean	High CI
1	2.38	2.67	3.08	1.98	2.31	2.45
2	1.47	1.65	1.91	1.23	1.43	1.52
3	1.11	1.25	1.44	0.93	1.08	1.15
6	0.69	0.77	0.89	0.57	0.67	0.71
12	0.43	0.48	0.55	0.36	0.42	0.44
18	0.32	0.36	0.42	0.27	0.31	0.33
24	0.27	0.30	0.34	0.22	0.26	0.27

Figure 13. Estimates for the current 100-year event for Ithaca, NY. The mean intensity of 0.26 inches/hr is close to the projected 50-year event for this location, which suggests that the current 100-year event is close to the project future 50-year event. Stated differently, this indicates the current 100-year event may become twice as likely (your new 50-year event) by mid-century under the RCP 8.5 emission scenario.

APPROACH 2: CREATE YOUR OWN IDF CURVES

About manually generated IDF curves
You can create your own IDF curves if you want to conduct more complex analyses with your data. Although this is a more technical endeavor, creating your own IDF curves can allow you to more easily analyze your data such as assessing potential changes in frequency or analyzing rainfall event durations outside of those covered in the NRCC IDF curves, including events greater than 24 hours or shorter than one hour. To create your own curves, your local rain gage needs to have a complete record that is at least 30 years long. Below we provide details about how to create an IDF curve and combine it with climate projections.

Where do you find data to manually generate IDF curves?
To generate your own IDF curves, first download your local rain gage data.

*How to identify **current** extreme precipitation patterns*

1. Obtain rain gage data: Rain gage data, along with other historical weather and climate data, are available through both NOAA's National Centers for Environmental Information (https://www.ncei.noaa.gov/) and USGS's Water Data for the Nation (https://waterdata.usgs.gov/nwis).

   a. From either the NCEI or Water Data sources, select a particular station (typically the closest to your community) and then select specific variables (e.g., precipitation). For example, to obtain rain gage data from the USGS's Water Data's main page, first select "Surface Water," then "historical observations."

   b. In the Site Selection Criteria, check the applicable site location, identifier, and attributes.

   c. Next, select the precipitation parameters that you may need to generate your IDF curve or other parameters of interest (see Table 1). When you hit "submit," the site's host agency will process the information and send you the data in an email.

Table 3 below contains a list of possible parameter types and uses. Not all of these parameters are available for all gages. If your local station does not have some of these parameters available, it can limit the utility of your station data; at minimum, you will need a time series of precipitation to begin the process.

2. Sort the data: Using Excel or another basic spreadsheet software, sort historical precipitation data with the same duration from highest to lowest noting the corresponding date of each event. If available, aim to sort the daily or hourly information. This sorting is useful to understand the range of magnitudes in your area. Depending on the frequency of recorded precipitation observations it may be feasible to split or combine rainfall totals for durations ranging from less than one hour to more than three days. This approach can also help you better determine the seasonality of extreme precipitation events and associated flood risk because information on historical events of record can be helpful to determine when throughout the year flood risk may be higher. See the *Helpful Links* section for sources that offer more details about parsing and combining observed rainfall totals into discrete rainfall events.

Once you have sorted the data, these are two approaches you can use to analyze your community's precipitation patterns:

- IDF curve (if you have sub-daily precipitation data): To generate a traditional IDF curve, you will need access to sub-daily rainfall totals (e.g., hourly data). Continue to action 3.
- Single duration curve (if you have daily precipitation data): If your local station only records daily rainfall, you can generate a magnitude and frequency curve that provides the same information as an IDF but just for a single duration. Continue to action 4.

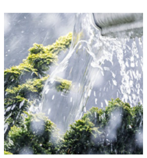
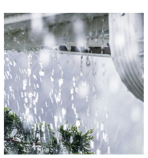
3. Generate IDF curves (for communities with sub-daily precipitation data): There are multiple approaches to creating an IDF curve. The actions a. to d. below are an overview of one possible approach:

   a. From your data table, find the highest rainfall amount for each duration from each year in your record (e.g. the event with the highest rainfall total for a 24-hour duration in the dataset).

   b. Next, for each duration, sort and rank all the rainfall amounts for that duration from largest to smallest so that the largest amount receives a #1 ranking.

Parameter	Description/Use
Precipitation, intensity at given time, inches per hour*	Rainfall intensity (in/hr); used to generate IDFs if intensities are available for a range of event durations (e.g., for events lasting 1–24 hrs)
Precipitation, intensity at given time, inches per minute*	Rainfall intensity (in/min); used to generate IDFs if intensities are available for a range of event durations (e.g., for events lasting between 15 mins and 24 hrs)
Precipitation, cumulative, inches*	Used to understand the cumulative amount of rainfall occurring over a given time period (e.g., over the period of record form the gage station)
Precipitation total for defined period, inches	Used to understand the rainfall totals from specific events of interest
Precipitation total for defined period, inches	Used in conjunction with event totals to estimate intensities associated with given rainfall events

Table 3. Examples of precipitation parameters and potential uses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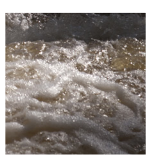


c. Find the return interval (frequency) for each rainfall amount using this formula:

$$\frac{\textit{(\# of years in your record +1)}}{\textit{rank of that rainfall amount}}$$

[Note that the exceedance probability is the inverse of this relationship, or: rank/(# of years in your record +1)].

d. Calculate intensities for each rainfall amount, or the number of inches of rainfall per hour, or per minute if you have sub-hourly data.

i. Create an IDF curve by plotting the intensity (from d.) on the Y axis and the return interval (frequency) (from c.) on the X axis. Note that each duration will have a distribution of observations associated with it, or a distribution curve. You may choose to show the whole range in your IDF curve or take the average from each duration.

There are other approaches to estimating the relationship between intensity, duration, and frequency, such as a Generalized Extreme Value (GEV) curve. To learn more about the IDF curve and these other approaches, see the *Helpful Links* section for links to additional technical documents.

4. Generate single duration, or magnitude and frequency, curves (for communities with daily rainfall data): A magnitude and frequency curve is another method for understanding observed (or projected, see next section) precipitation data. You can use this type of curve to estimate the range of precipitation magnitudes associated with different return intervals for a given rainfall duration.

For example, Figure 13 shows the magnitudes and frequencies for a 24-hour rainfall event.

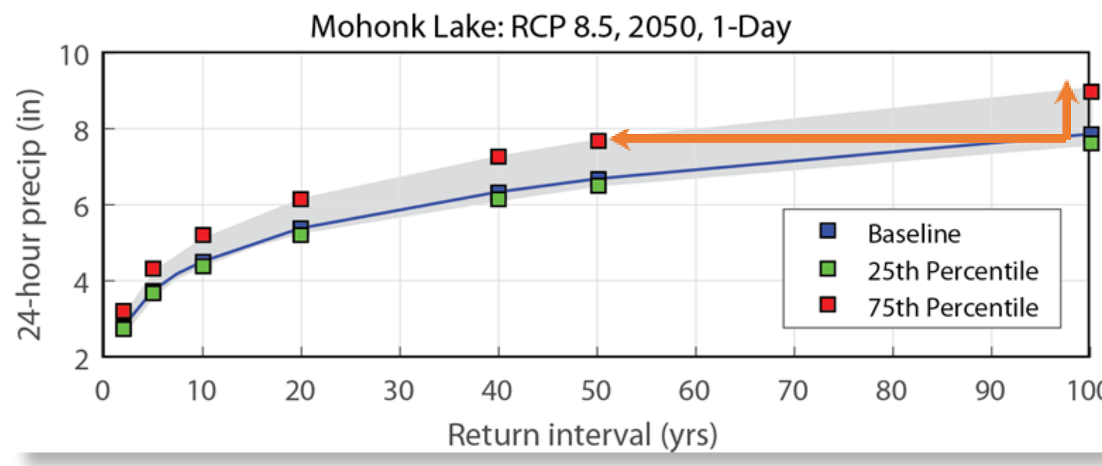


Figure 14. This plot shows estimated baseline (observed) and projected precipitation magnitudes and frequencies for the 24-hour rainfall event from the Mohonk Lake rain gage station. *One of the stations we used to estimate changes in extreme precipitation for our partner community, the Town of Red Hook, NY.*

a. To generate this curve, follow actions a. to d. from 3) starting on the previous page, but for a single event duration. In short,

i. Sort your data to find the highest rainfall amount for a given duration.

ii. Calculate the return interval for each event.

iii. Calculate the rainfall intensity for events using the gage frequency.

iv. Create magnitude a frequency curve with intensity (in/event duration) on the Y axis and return interval (frequency) on the X axis (see Figure 13 as an example).

(see *Helpful Links* section at the end of the section).

5. Use data to understand precipitation thresholds: You can also compute other metrics from the observed rain gage data including the number of days in a year that exceeded a certain rainfall threshold or estimates of the frequency and intensity of historical rainfall events. With a sufficient enough record, any of these metrics can be tracked through time to evaluate whether there have been discernible trends in historical rainfall.

*How to identify **future** extreme precipitation patterns*

To generate either curve from observed rain gage data, apply projected changes in precipitation to the observed record:

1. Project your current rain gage data (for IDF and single duration curves): You can use climate projections along with historical rain gage data to estimate potential future change. For example, the ClimAID report for New York State applied future modeled changes to the observed gage records for a set of stations across New York State. Communities with at least 30 years of rain gage data can apply the monthly projected percent change from ClimAID to their observed monthly average. For example, if ClimAID indicates a 10–20% increase in precipitation for your region by mid-century, then add 10–20% to your historical rain gage record to get an idea of what rainfall amounts might look like in approximately 30 years.

You can use your projected rainfall dataset to generate either an IDF or a single duration curve. To create an IDF curve with multiple durations go to action 2 below; to create a single duration curve go to action 3 below.

2. Generate a projected future IDF curve: You can generate a projected future IDF curve from a rain gage record with at least 30 complete years of data by multiplying your rain gage data by the ClimAID monthly projection factors, as discussed in action 1. Multiply each total rainfall amount by the percent change. Then recreate the IDF curve to estimate changes in extreme precipitation events under future change scenarios. To regenerate your IDF curves, use the same actions discussed in the "How to identify current extreme precipitation patterns" section of action 3 *Generate IDF curves (for communities with sub-daily precipitation data)*, with your projected rainfall data.

3. Generate a projected single duration magnitude and frequency curve: You can also use a single duration magnitude and frequency curve to understand potential changes events of a given duration. For example, using the curve in Figure 13, you can approximate a change in magnitude in your current 100-year 24-hour event (the blue square on the right-hand side of the graph) might increase in magnitude from approximately eight inches to approximately nine inches (the red square on the right-hand side of the graph) by mid-century (after applying projected changes from the ClimAID report). You can also approximate a change in frequency by seeing how the amount of precipitation associated with your current 100-year event (the blue square on the right-hand side of the graph) might correspond to a future 40- or 50-year event by mid-century (the red box in the middle of the graph).

To create this type of graph, multiply your rain gage data set by the monthly projection factors as discussed in action 1. Then recreate the single duration curve to estimate changes in extreme precipitation events under future change scenarios using the same steps discussed in action 4 *Generate single duration, or magnitude and frequency, curves (for communities with daily rainfall data)* on the previous page.

What additional information can contribute to the analysis?
As discussed earlier, you can use data from IDF curves to better understand flood risk in your community by comparing the IDF outputs to data from local historical events. This will help characterize what types of rainfall events have caused flooding in the past. To do this, you will need other local data on historic rainfall events, including precipitation amounts and durations. Information about the impacts from those precipitation events, such as where and when flooding occurred, will give you even more context about precipitation events.

For example, if most people in your community are familiar with a particular flooding event, for example, "the floods in April of 2010," you can say that type of event might become twice as likely by mid-century. This type of messaging is likely to resonate with people in your community more than just saying "our 100-year event might become twice as likely."

This approach should be used as a screening level exercise and a starting point for understanding the types of precipitation events that may be important when considering your community's flood risk.

Are there any existing or planned changes to your local hydrology or infrastructure that might affect interpretation of these results or cause additional uncertainty?
Significant changes in land use and land cover, including development, can add to the uncertainties of the resources discussed in this toolkit because they influence rainfall-runoff relationships. Changes in land cover, such as paving a previously undeveloped area, can affect how precipitation runs through the landscape. Changes in land cover can also affect which areas are at risk of flooding due to extreme precipitation events or riverine flooding. Therefore, it is important to consider future land use and development plans when evaluating potential changes to flooding in your community.

What are the constraints of IDF curves?
In addition to the limitations discussed in Step 1, each approach we discuss here has specific constraints.

Using rain gage data to create IDF curves

Much of the uncertainly associated with manually generating IDF curves is dependent on the quality of the station data (as discussed in Step 1). While you can use data from a nearby station, it might not truly capture your community's local environment. Applying projected precipitation change factors to observed data also comes with some of the same caveats as the future projections for the NYS IDF curves. For specific information about projection techniques and the associated limitations and uncertainty, see the projection uncertainty discussions from the ClimAID report.

Helpful Links

Helpful links for IDF Curves and precipitation projections in New York State:

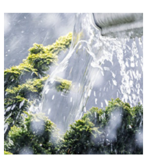
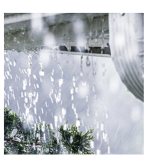
- Northeast Regional Climate Center IDF Curves for New York State. *Link to the IDF Curves for New York State website.*
- ClimAID Report. *Report on Responding to Climate Change in New York State.*

Links for nation-wide precipitation data:

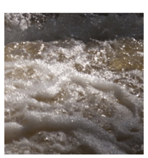
- NOAA precipitation data. *Nation-wide network of NOAA precipitation gages and associated data.*
- USGS precipitation data. *Nation-wide network of USGS precipitation gages and associated data*

Helpful links for creating and interpreting IDF curves:

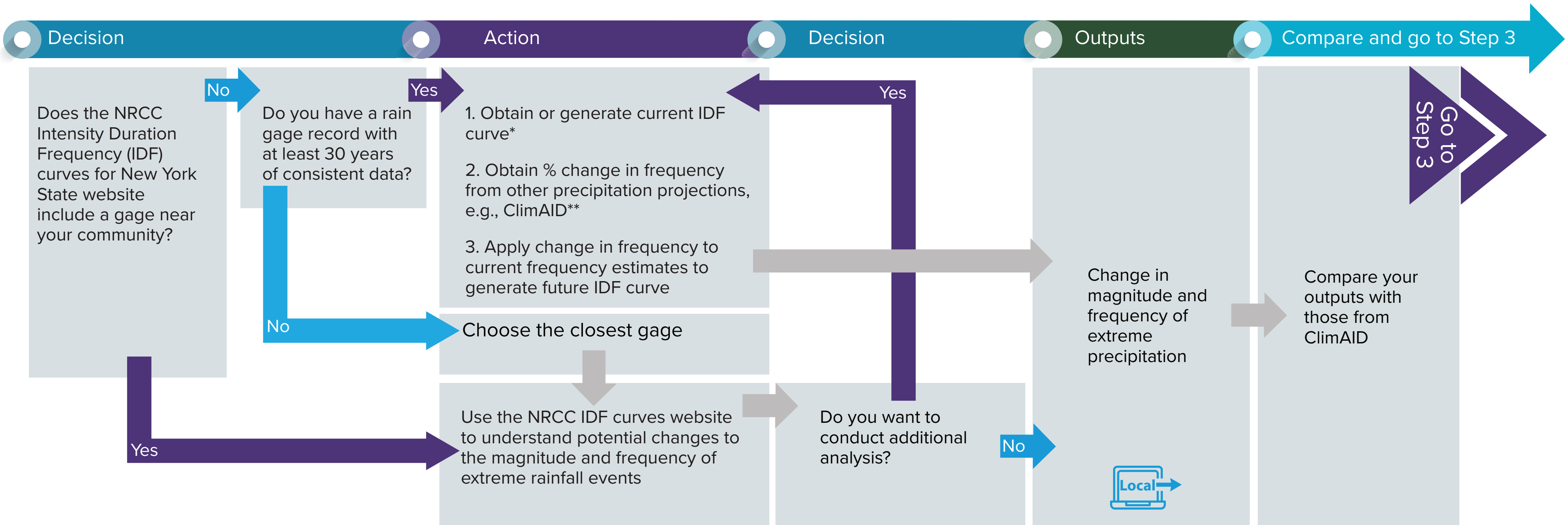
- DeGaetano and Castellano, 2015. *Technical reference for the New York State IDF projections from Cornell University.*
- Step-by-step overview of constructing IDF curves. *General step-by-step overview of constructing IDF curves from a Hydrology Class at Colorado State University.*
- McKay and Wilks, 1995. *Atlas of short duration extreme precipitation estimates for the northeastern US.*
- NOAA Atlas 14 Point Precipitation Frequency Estimates. Link to the NOAA Atlas for point precipitation frequency estimates for the United States.
- Additional documentation for the NOAA Atlas 14. *Documentation for the NOAA Atlas methodology for the northeastern US.*

step 2



Resource Flow Diagram: IDF Curves



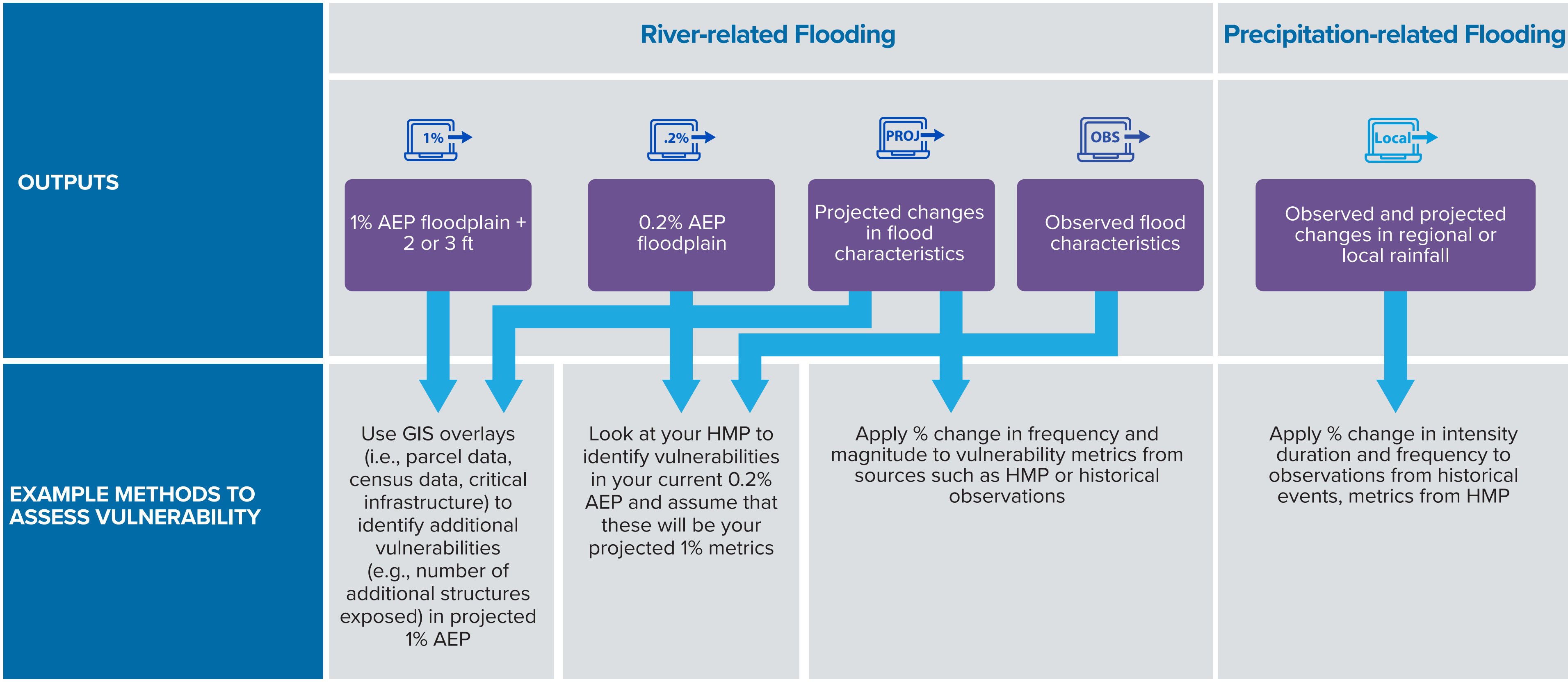
*See description of analysis and relevant references in the IDF Curve resource

**See description of analysis and relevant references in the ClimAID resource

If you would like more information on this resource, go back to Step 1

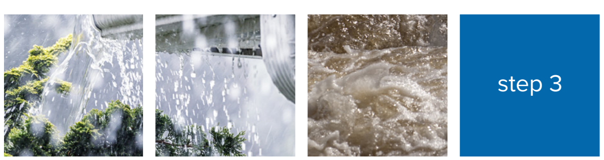
If this resource sounds right for your community move to Step 3

STEP 3. Identify vulnerabilities



Once you have identified potential changes to your inland flood magnitude, frequency, or stage from Step 2, Step 3 offers you guidance about how these changes might impact your community's vulnerability to increased flood risk.

The top of the flow diagram above illustrates the different outputs you can get from the resources. Follow the path from the outputs you obtained to see how you might assess changes to your community's vulnerabilities.



The bottom row of the flow diagram is a representative but not exhaustive list of how you could use the outputs from Step 2 to assess potential changes to your community's vulnerability. Here we offer additional detail about each of the methods listed in the bottom of the flow diagram above.

Although climate models can help us understand changes to magnitude and frequency of floods, it is harder to estimate when these changes might occur. Because changes will happen gradually over time, communities can focus on building resilience to systems generally. For example, consider requiring current 1% AEP construction standards for new construction within the 0.2% AEP zone, as feasible, as per the SFRMG guidance. Consider the expected lifespan of the infrastructure you are concerned about when reviewing options.

If you have a new projected 1% AEP

Use GIS to map the new projected floodplain and visually compare it to your current 1% on the map. You can also obtain GIS map overlays such as parcel data, census data, or maps of critical infrastructure to identify areas, specific assets, or population groups that fall inside your projected 1% AEP but are not within your current 1% AEP. These are areas that may warrant further specific analysis or special consideration in future plans.

If you are using the current 0.2% AEP as a proxy for your future potential 1% AEP

The simplest way to assess potential changes to vulnerability using this output is to see if your Hazard Mitigation Plan (HMP) has metrics for your current 0.2% AEP. If so, then use these metrics as a proxy to determine how costly your future 1% AEP or the impacts from it might be. For example, the HMP for the City of Binghamton in Broome County notes that 24% of its population lives within the current 1% AEP flood boundary, and 32% lives within the current 0.2% AEP flood boundary. This additional 8% of the population that lives within the current 0.2% boundary but outside the current 1% AEP boundary, or approximately 3,600 people, have the potential at some point in the future to be just as likely to experience a flood as those within the 1% AEP flood boundary do today. The 24% of the population within the current 1% AEP flood boundary also has the potential of an increasing likelihood of experiencing a flood in the future.

If you obtain a projected change in flood frequency

With a projected change in flood frequency, you can assess vulnerability by applying the same percent change to existing vulnerability metrics such as those from local HMPs or historical records. The example to the right illustrates one approach a community could take to conduct a screening level assessment of changes to future flood vulnerabilities. Projected percent changes in frequency are unlikely to be the same across different frequency events (i.e., if your current 1% AEP event is projected to become twice as likely, this does not necessarily mean your 0.2% AEP will, too; see Figure 14).

For example if your current 1% AEP is projected to become your new 2% AEP (the event becomes twice as likely), calculate the potential future estimated annualized damages for your new 1% AEP event (i.e., your current 2% AEP) by using historical data for the current 1% AEP event (e.g., estimated damages for the current 1% AEP flood from a hazard mitigation plan) and apply the change factor.

- Let's say your current 1% AEP event is estimated to result in $1,000,000 in damage. Calculate current estimated annualized damages by multiplying the damage estimate by the current event frequency ($1,000,000 x 0.01 = $10,000 per year).

- To calculate your estimated future annualized damages, apply the change in frequency factor for an event of this frequency (twice as likely, in this example) to the annualized estimated damages ($10,000 x 2 =$20,000 per year).

If you obtain a projected change in extreme rainfall

Similar to the approaches above, communities who focused their Step 2 work on changes to extreme precipitation can use the percent change in intensity, duration, or frequency to existing vulnerability metrics. As noted above, changes in frequency and magnitude may be different for each return interval; communities should not apply a particular percent change in magnitude or frequency across all return intervals.

Identify impacts

Many communities already have some estimates of the impacts from floods from sources such as records of historic storms or from HMPs. To consider how changes to flood risk might shift vulnerabilities for communities that do not have an HMP, consider the questions below:

How might changes to flood characteristics impact:

1. People: the number of residents affected, including their health, safety, livelihoods, and potential loss of life.

2. Community operations: the scope and duration of service interruptions, reputational risk, and the potential to encounter regulatory problems.

3. Property: the effect on all capital and operating costs and the loss of services. Property includes all buildings and infrastructure, especially critical infrastructure.

4. Additional factors: these include environmental effects, including the release of toxic materials, effects on biodiversity, changes to the area ecosystem, and impacts on historic sites.

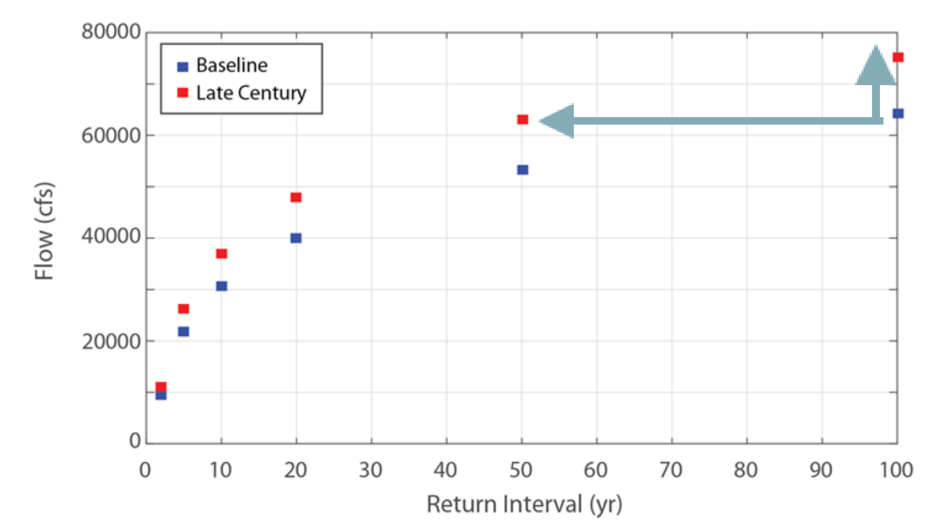
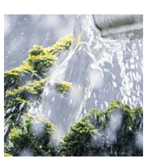
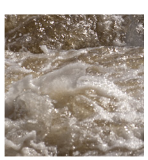


Figure 15. This generalized extreme value (GEV) curve shows the estimated flow (measured in cubic feet per second) associated with various return internals. The blue dots represent baseline conditions and the red dots represent projected changes. The arrows represent how you can use this type of figure to estimate the change in return interval for a given flow (the horizontal arrow) or figure the estimated increase in flow for a given return interval (the vertical arrow).





Community engagement

One way to assess vulnerability and impacts is to hold facilitated discussions with key stakeholders in your community. People who have lived through historic floods hold invaluable local knowledge that is often not captured in historical records. Engaging key stakeholders and community members for focused discussions and offering the general public the opportunity to contribute to the vulnerability discussion can draw on local institutional knowledge, create buy-in, identify feasible options, and might help generate innovative solutions. Generating community support for assessing future flood risk is helpful if you need to ask for tax payer support for adaptations such as upgrades to critical infrastructure.

On the right is an example of the questions we used with our community partners to help them consider potential changes to critical infrastructure. These types of questions may help stimulate community dialog.

Adaptations

Once your community has an understanding of potential changes to your flood vulnerability or impacts, you can start thinking about potential adaptations or things you can do to minimize the possible impacts from future floods. This toolkit does not cover the adaptation planning process, but communities may consider:

- Incorporating future projections of flood characteristics in planning documents such as Hazard Mitigation Plans, instead of relying on historical observations.
- Using projected values for flood characteristics hen building or renovating critical infrastructure or other types of development in areas identified as being at-risk from potential future changes to floods.
- Identifying best practices for building or renovating buildings in existing or potential future flood plains, such as the school building in Figure 15 from Binghamton, NY.

Will your current flood protection measures be adequate for future conditions?

In small groups, using the maps if they are helpful:

1. Review the current list of critical facilities from the HMP.
2. Identify the most critical assets from that list.
3. Identify assets missing from the list.

Then discuss:

4. How will changing flood characteristics impact these assets?
5. Where do you need more information to better understand how changing flood characteristics will affect impacts of these assets?
6. What planning efforts (current and future) can include consideration of changing flood risks?

When identifying the **most critical assets**, consider:

Which assets would have the highest impact if they failed?
- Impact to people? Community operations? Property? Other?
- Do you know what level of flooding would cause the asset to fail?
- Does the system have an adequate back-up?
- What would be the cost to the community if the asset failed, e.g., if the wastewater treatment plant flooded or if a critical sub-station for the electric grid flooded?

Are any scheduled for regular maintenance or rehabilitation?

Are there any **assets missing from the lists**?

Consider assets such as:
- Areas or facilities serving vulnerable populations
- Transportation infrastructure
- Future development
- Ecologically or historically significant areas

These questions will help you think about changes to your current flood risk:

- What does catastrophe look like for your community? What level of flood would be difficult for your community to recover from?
- Do you have planned new growth areas? Are they within a 0.2% floodplain?
- What are the assets in your community that fall between the 1% and 0.2% floodplains? Do these have emergency plans? What is their expected lifetime? Are there renovations planned?
- What current regulations do you have for your 1% floodplain that you might consider beginning to implement in your 0.2% floodplain?

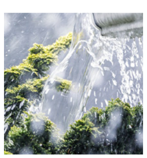
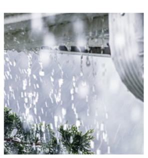
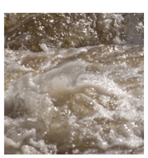
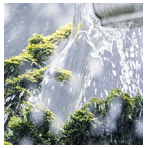
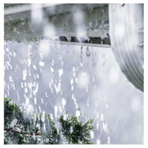




Figure 16. This school in Binghamton, NY was elevated after being damaged during severe flooding. *Infrastructure that can withstand floods or be easily replaced, such as the playground equipment, were located on the ground level. The classrooms and critical infrastructure such as cooling equipment are elevated to higher floors so they are less likely to flood.*

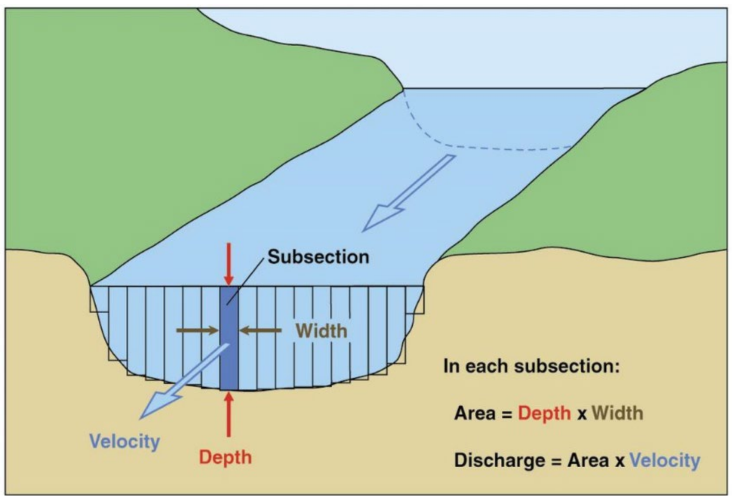

step 3

Appendix A. Definitions

Annual Exceedance Probability (AEP) – The chance that a particular type of flood will happen in any given year. For example, a 1% or AEP flood has a 1% chance of happening in any year. This is a more technically accurate way to describe floods and the "100-year flood" (a 1% AEP is often referred to as the "100-year" flood) *https://pubs.usgs.gov/gip/106/pdf/100-year-flood-handout-042610.pdf*

Asset – Any man-made or natural feature that has value, including people, buildings, infrastructure (such as bridges, roads, and sewer and water systems), and lifelines (such as electricity and communication resources or environmental, cultural, or recreational features like parks, dunes, wetlands, or landmarks).

Discharge – In a riverine flooding context, the discharge is the amount of flow in a waterway, typically measured in cubic feet per second (cfs). Discharge is calculated by multiplying the velocity the water by the cross-sectional area of the water body. The figure below shows an example of how a cross-sectional area may be estimated by dividing the water body into subsections and summing the discharge associated with each subsection. Also see *Flow* and *Magnitude*.



Source: https://www.usgs.gov/special-topic/water-science-school/science/how-streamflow-measured?qt-science_center_objects=0#qt-science_center_objects

Digital Elevation Models (DEMs) – A 3D representation of a terrain using gridded elevation data. DEMs are often used in a geographic information system (GIS) to produce digital relief maps. In a flooding context DEMs are typically used to estimate the extent of inundation.

Emission Scenario – Climate models are run under different emissions scenarios which represent different amounts of future GHG emissions. A high emissions scenario (high RCP 8.5) represents a future state where current levels of GHG emissions are not curtailed. Selecting this option would provide you with higher estimates of future projections. A low emissions scenario represents a future where global GHG emissions decline.

FEMA FIRMs – Federal Emergency Management Agency (FEMA) Flood Insurance Rate Maps (FIRMs) – "the official map of a community on which FEMA has delineated both the special hazard areas and the risk premium zones applicable to the community" *https://www.fema.gov/flood-insurance-rate-map-firm*

Flow - In a riverine context, flow is the amount of water in a waterway passing a fixed point over a given unit of time. For US waterways flow is typically measured in cubic feet per second (cfs). Also see *Discharge* or *Magnitude*.

Frequency – The frequency of an event represents how likely it is that a flood or precipitation event of a given magnitude will happen in any year. In many instances frequency is also referred to as the return interval (e.g. 1 in 100 year event). This terminology can be misleading because there is the same probability of that event happening every year. This event is more accurately stated as the "1% *annual exceedance probability (AEP)* event".

Generalized Extreme Value (GEV) Curve – This curve is used to estimate the relationship between extreme events (stream or river discharges or rainfall events) and the frequency, or return interval, of an event. There are a number of other methods for estimating this relationship (e.g., Wiebull, Gumbel, or Log-Pearson type III distributions). The most applicable methodology for estimating this relationship will vary by location. See USGS Gage resource description for helpful references and additional information on this process.

Impacts (sometimes called consequences or outcomes) – Effects of extreme weather and climate events on natural and human systems, if a potential vulnerability were to occur. Impacts can include effects on population (e.g., lives, livelihoods, health), property (general building stock including critical facilities), infrastructure, services, ecosystems, and the economy.

Inundation – A measure of the spatial extent and depth of flooding for a given location. Flood inundation maps are available from FEMA (FIRMs), the USGS, and potentially from other federal, regional, or local entities.

Intensity Duration Frequency (IDF) Curve – This curve estimates the relationship between the intensity, duration, and frequency of precipitation events. IDF curves can be generated for a range of event durations from sub hourly to multi-day precipitation events.

Magnitude – In a flooding context, the magnitude of an event is the amount of flow (or discharge) in a waterway, typically measured in cubic feet per second (cfs). Also see *Discharge* and *Flow*. In the case of extreme precipitation magnitude is a measure of the intensity of the event over a given unit of time (e.g., in/hr).

National Flood Insurance Program (NFIP) – “The National Flood Insurance Program aims to reduce the impact of flooding on private and public structures. It does so by providing affordable insurance to property owners, renters and businesses and by encouraging communities to adopt and enforce floodplain management regulations. These efforts help mitigate the effects of flooding on new and improved structures. Overall, the program reduces the socio-economic impact of disasters by promoting the purchase and retention of general risk insurance, but also of flood insurance, specifically.” See *https://www.fema.gov/national-flood-insurance-program* for additional information.

Nuisance flooding – Also called surface flooding. Localized flooding caused by intense precipitation (e.g., street flooding, storm drain overflows). Not confined to stream channels.

Precipitation-related flooding – flooding that occurs as a result of excess precipitation. Flooding during a rainfall event can also be driven by existing conditions, which include saturated soils from prior rain events, rain-on-snow, and ice jams.

Rain gage – Rain gages are the standard measurement device for recording precipitation throughout the United States. Depending on the gage location, recorded precipitation amounts are available at hourly, daily, monthly, or annual timescales. For analytical purposes and estimating trends in climate variables, including precipitation, a 30 year record of climatic data is generally thought to adequately capture the regional climate variability (Guttman, 1989).

Rating Curve – This curve is used to estimate the relationship between stream or river discharge and stage (water depth).

Risk – The combined consideration of the probability that a hazard will occur and the impacts or consequences, should that hazard occur. Risk is often expressed in relative terms such as a high, moderate or low likelihood of sustaining damage above a particular threshold due to occurrence of a specific type of hazard. Risk also can be expressed in terms of potential monetary losses associated with the intensity of the hazard.

Return interval/recurrence interval – the probability that a flood of a certain magnitude will occur in any given year. This is often expressed as a return internal (e.g., the “1-in-100 year flood”) or as an annual exceedance probability (i.e., 1% AEP). Also see *AEP*. See *https://water.usgs.gov/edu/100yearflood.html* for additional information.

River-related (riverine) flooding – Flooding that occurs along established river channels.

Special Flood Hazard Area – “The land area covered by the floodwaters of the base flood is the Special Flood Hazard Area (SFHA) on NFIP maps. The SFHA is the area where the National Flood Insurance Program's (NFIP's) floodplain management regulations must be enforced and the area where the mandatory purchase of flood insurance applies. The SFHA includes Zones A, AO, AH, A1-30, AE, A99, AR, AR/A1-30, AR/AE, AR/AO, AR/AH, AR/A, VO, V1-30, VE, and V.” See *https://www.fema.gov/special-flood-hazard-area* for additional information.

Stage – Is a measure of the water level from some arbitrary point. Typically stage is measured from the bottom of a stream bed (as the zero value) and is generally reported in feet. See https://water.usgs.gov/edu/qa-measure-streamstage.html for additional information.

Stream gage – Discharge (flow) and stage data (see above) derived from stream gage records are the foundation of most flood risk analyses. The USGS maintains a network of stream gages throughout the US that record stream flow, stage, and in some locations, water quality information. For analytical purposes and estimating trends in climate variables, including flow regimes, a 30 year record of climatic data is generally thought to adequately capture the regional climate variability (Guttman, 1989).

Uncertainty – An expression of the degree to which future climate is unknown. Uncertainty about the future climate arises from the complexity of the climate system and the ability of models to represent it, as well as the inability to predict the decisions that society will make. There is also uncertainty about how climate change, in combination with other stressors, will affect people and natural systems (U.S. Global Change Research Program, 2016).

Vulnerability – the degree to which an asset faces risk from climate. It considers whether the unit is exposed to a climate driver, i.e., is it in the floodplain, and the extent to which the driver can affect the unit (called sensitivity). A key factor in determining vulnerability is the resilience of the unit. The vulnerability of one element of the community is often related to the vulnerability of another. For example, many businesses depend on uninterrupted electrical power. If an electric substation is flooded, it will affect not only the substation itself, but a number of businesses as well. Often, indirect effects can be much more widespread and damaging than direct effects.

Appendix B. Additional Resources

Resource	Link
General Information on flood risk	
FEMA FLOODSMART webpage	https://www.floodsmart.gov/
NOAA Flood Safety webpage: http://www.floodsafety.noaa.gov/; NY specific: http://www.floodsafety.noaa.gov/states/ny-flood.shtml	http://www.floodsafety.noaa.gov/
New York State Hazard Mitigation Plan	http://www.dhses.ny.gov/recovery/mitigation/plan.cfm
Local GIS clearinghouses	Not applicable, community specific
Non-profits, universities, local stakeholder groups	Not applicable, community specific
General information/data on climate change and risk	
U.S. Climate Resilience Toolkit	https://toolkit.climate.gov/climate-explorer2/topic.php?param=water
CREAT Risk Assessment Application for Water Utilities	https://www.epa.gov/crwu/creat-risk-assessment-application-water-utilities
Partnership for Resilience and Preparedness (PREP)	https://www.prepdata.org/
New York Climate Change Science Clearinghouse (NYCCSC)	https://www.nyclimatescience.org/
Flood plain and flood hazard information	
FEMA NFIP data	https://www.fema.gov/policy-claim-statistics-flood-insurance
FEMA HAZUS	https://www.fema.gov/hazus
Other FEMA Products (eg. Risk MAP, historic, preliminary, and pending, FIS Reports, NFHL, LOMCs)	https://msc.fema.gov/portal
NYU Furman Center FloodZoneData.US	http://furmancenter.org/floodzonedata
USGS PeakFQ Flood Frequency Analysis	https://water.usgs.gov/software/PeakFQ/
Columbia University Center for International Earth Science Information Network (CIESIN) Hudson River Flood Mapping Tool	http://www.ciesin.columbia.edu/hudson-river-flood-map/
New York State Flood Risk Management Guidance (SFRMG)	https://www.dec.ny.gov/energy/102559.html
Data on past flood events	
NOAA Storm Events Database	https://www.ncdc.noaa.gov/stormevents/
NWS New York Significant Weather Event Archive	https://www.weather.gov/okx/stormevents
USEIA Energy disruptions and real-time storm monitoring	https://www.eia.gov/special/disruptions/
Hydrologic and Climate change projections	
NOAA NWS USGS AHPS	https://water.weather.gov/ahps/
NOAA Office of Water Prediction	http://water.noaa.gov/
USACE HEC-RAS	http://www.hec.usace.army.mil/software/hec-ras/

Appendix C. References

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Appendix D. Community Partner: Broome County

Introduction

The toolkit is a direct result of work the project team[1] did in partnership with two communities in New York State—Broome County and the Town of Red Hook. Figure A.1 is a schematic of the process we used to work with the communities. We identified the resources that best fit each community's situation, as represented by the inputs on the left-hand side of the figure. We used as many resources as feasible within our project constraints and analyzed and modeled potential changes to flooding for the community. The outputs from these efforts included maps, tables, and graphs that we presented to the communities during a stakeholder engagement workshop where the community could begin to think about how to plan for future flooding.

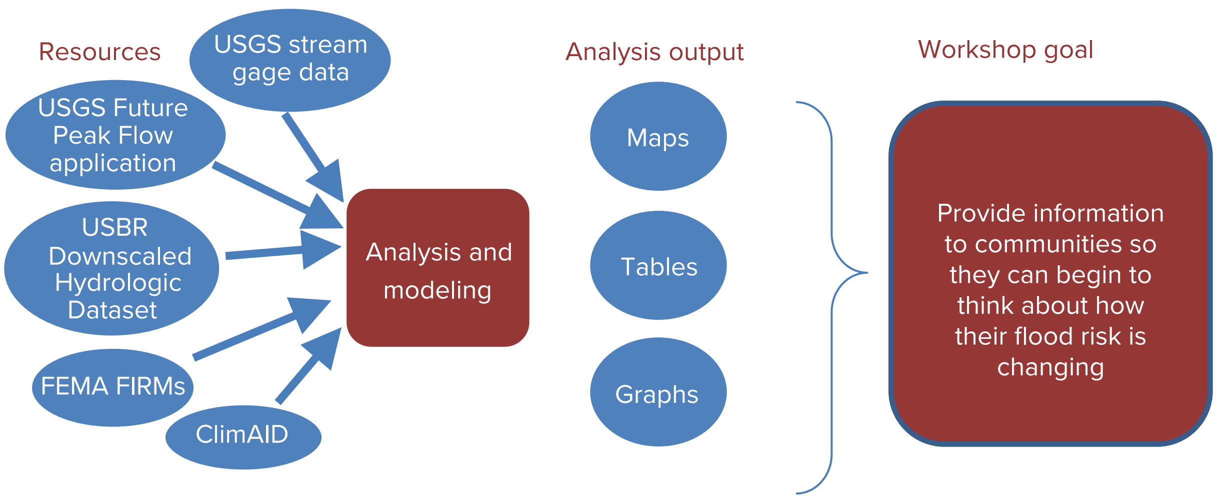

Figure A.1. Schematic of our community partnership process[2]

1 Throughout the remainder of the profile we refer to the "project team," which represents the team of individuals who conducted the analysis and management of this project and included climate, hydrology, and community risk planning experts from Abt Associates and two local NY State climate experts.

2 We used the Bureau of Reclamation Downscaled Hydrology Dataset to understand projected changes to flood magnitudes in Broome County. Unfortunately, these data are not publically available at this time so this is not included as one of the resources in this toolkit (see the [USBR Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections website]).

This community profile introduces Broome County and its flooding history. We then discuss the resources we used in Broome County, including our methods and results, mirroring Steps 1 and 2 from the toolkit. Next, we explain how we engaged key stakeholders in a discussion about using the results to begin to think about changing flood risk in the County, mirroring the toolkit's Step 3.

Background

Located in the Southern Tier of New York State, Broome County is approximately 715 square miles and has approximately 200,600 residents (U.S. Census Bureau, QuickFacts). The county includes 16 towns, seven villages, and one city, Binghamton, the county seat. The City of Binghamton sits at the confluence of the Susquehanna and Chenango rivers and is one of the "tri-cities" along with the Villages of Endicott and Johnson City.

The two major drainage basins in Broome County are the Susquehanna River and the Delaware River. Close to 90% of runoff in the county drains into the Susquehanna, the largest river basin on the Atlantic Coast, with the remaining 10% flowing into the Delaware. The drainage area of the Susquehanna River upstream of Broome County is more than 3,800 $mi.^2$ As a result, regional precipitation and snowmelt events drive flooding along the Susquehanna River and its tributary network before reaching Broome County. The Susquehanna flows into Broome County from the north, briefly crossing into Pennsylvania before heading back north and meeting the Chenango River in Binghamton. The river proceeds to head west into Chemung County after passing through the tri-cities.

Heavy rainfall events, where intense precipitation falls over a short duration, and snowmelt during the winter and spring contribute to flooding of the Susquehanna and Chenango Rivers. The Southern Tier averages approximately 35 inches of precipitation per year. Precipitation during the warm season from April to September is generally driven by convective storms associated with frontal systems or tropical cyclones that can bring moisture well inland into New York State. Both of these events can produce heavy rainfall that can lead to flooding. In the cool season, from October to March, areas of low pressure moving along the East Coast, typically known as nor'easters, bring longer duration periods of rainfall, which can also lead to flooding, especially if they follow snowfall events (Horton, et al., 2014).

The structure of the drainage basins across this part of New York and recent changes in land use are additional factors that can influence flood events. Residential land use is increasing while agricultural and wild/forested use is decreasing, causing a net reduction in pervious land surface (Land Use Chapter of the Broome County Comprehensive Plan: http://gobroomecounty.com/comprehensiveplan). Increases in impervious surfaces can alter runoff patterns and impact stream and river flows, causing the system to become more "flashy" or respond rapidly in the event of extreme rainfall (as discussed in papers including Hollis, 1975).

Flood history

A 2016 vulnerability assessment conducted by the New York State Department of Environmental Conservation (NYSDEC) ranked Broome County as the sixth most vulnerable county in the state for flood hazards (Broome County, 2016). This ranking is based on information from National Flood Insurance Policy (NFIP) claims, damages, losses, and the number of flood events (New York State, 2011). Additionally, Broome is either the highest or tied for the highest of all counties in the state across several metrics that illustrate flood risk, such as presidential disaster declarations for flood events and flood property damage by county (New York State, 2014).

Broome County has experienced numerous and significant flood events over the past century. A flood event in 1936 caused widespread damage in the Susquehanna River valley, including locations within New York State. In 1972, moisture from Hurricane Agnes extended into upstate New York and caused flooding along the river. More recently, heavy rainfall caused record breaking floods in 2006 and again in 2011. The rainfall in 2011, caused by the remnants of Tropical Storm Lee, overtopped levees in Broome County with certification for a 100-year flood magnitude (NWS, 2012). Reports show damage estimates of $503 million for the County from that storm (Broome County, 2013). Most recently periods of heavy rainfall led to flooding in August, 2018.

Given the historical occurrence of flooding in Broome County, the County operates and maintains many publically-owned flood control structures (Broome County, 2013). In addition, the U.S. Army Corps of Engineers have built several flood control structures that are maintained by NYSDEC (Broome County, 2013).

Changes to flood risk in Broome County

Each of the factors that contribute to flood risk in Broome County is likely to change and therefore increase Broome County's flood risk in the future.

Climate change has the potential to influence the climate-related factors that contribute to flooding in the County such as changes to precipitation. New York State's climate change report, ClimAID, projects that mean annual precipitation for the southern tier of New York State will increase by 5 to 15% by the 2080s. The report projects most of the precipitation increase will occur in the winter, with slightly reduced precipitation projected for the late summer and early fall. Looking at the factors that contribute to flooding in Broome County, increased winter precipitation could enhance the likelihood of events caused by snowmelt and runoff.

Across the Northeast United States, heavy rainfall events (defined as the heaviest 1% of all daily events) have increased by more than 70% between 1958 and 2010 (National Climate Assessment, 2014). Climate models project this trend will continue and perhaps even increase into the future. ClimAID also projects increases in the frequency, intensity, and duration of heavy rainfall events that can cause flooding. It's uncertain how the individual events that can cause these rainfall extremes, such as coastal and tropical storms and lake event snows, may change in the future.

Land use changes are in part influenced by flood zone designation and regulation. Following the floods in 2006, FEMA updated the Special Flood Hazard Area (SFHA) maps for Broome County, which increased the number of properties in the flood zone. Most of these properties fall within the “urban core” of Broome County. The combination of stricter building regulations, requirement for properties with a federally-backed mortgage to have flood insurance, and a FEMA-backed buyout program, has reduced the population in the floodplain, which may reduce vulnerability to flooding. However, the movement of people from the urban core to the surrounding areas creates additional pressures in the suburbs (Broome County, 2013).

Methods for helping Broome County identify changes to its flood risk

Our project team worked with Broome County to help the county better understand how changes in mean annual precipitation and changes in heavy rainfall events might affect its future flood risk. Following the approach defined in the toolkit, we used existing tools to identify a range of potential changes for Steps 1 and 2 and the implication these changes may have had on community-specific vulnerabilities for Step 3. Our intention was to conduct a screening level analysis as there are limitations to the data and uncertainties associated with each of these resources.

Step 1: Choose a resource

The project team chose to look at five resources to give Broome County a more robust picture of potential future changes — the United States Geological Survey (USGS) rain gages, USGS Future Peak Flow application, the United States Bureau of Reclamation (USBR) Downscaled Hydrologic Dataset,[3] FEMA Flood Insurance Rate Maps (FIRMs), and the ClimAID report. There are advantages and disadvantages to each resource. Using multiple resources allowed us to assess the potential range of flood risk changes and better understand how uncertainty factors into potential future flood risk.

Step 2: Understand potential changes to flood characteristic

Below we detail how we used each of these resources, following the processes from Step 2 of the toolkit.

USGS Stream Gage Data

Data from historical stream gaging records form the foundation of any present-day flood risk analysis in the United States (USGS, 1982). There are three USGS gages along the Susquehanna River and its tributaries that can provide information on current and future flood risks for Broome County. One of these gages is upstream of Binghamton along the Susquehanna River (USGS 01503000, Susquehanna River at Conklin); the second is upstream of Binghamton on the Chenango River (USGS 01512500, Chenango River at Chenango Forks); and the third is downstream of Binghamton on the Susquehanna

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3. The USBR Downscaled Hydrologic Dataset is not included as a resource in this toolkit. See the Step 2 discussion of this resource below for further details.

River (USGS 01513500, Susquehanna River at Vestal). These three gages have different periods of record, and only the gages at Chenango Forks and Conklin recorded both the 2006 and 2011 historic flooding events. Figure A.2 shows the full hydrograph and the annual maximum flow timeseries for the Susquehanna gage at Conklin, which has the longest and most complete record of the three sites.

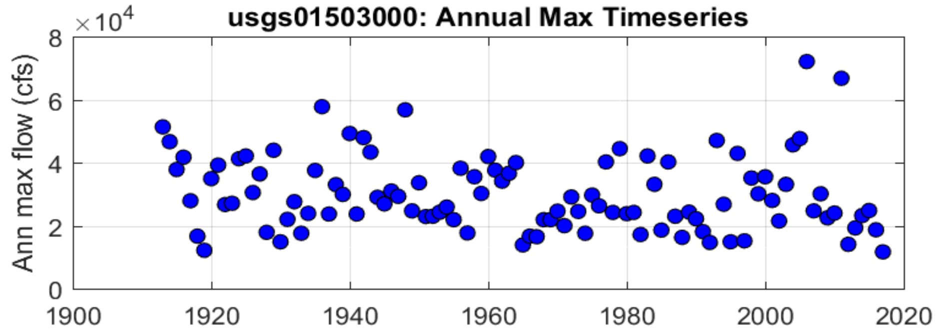

Figure A.2 The annual maximum flow record for the Susquehanna at Conklin.

Our project team used these gaging records to estimate the frequency and magnitude distribution of historical flooding events, using standard methods recommended by the USGS. We extracted the annual maximum flow for each year from the full discharge record at each gage. We then used that data to construct an annual maximum flow timeseries. Then, we fit Log Pearson Type III (LP3) and generalized extreme value (GEV) distributions to the annual maxima over the complete period of record (Figure A.3). Using both of these model fits, we selected the flow magnitude for a range of probability events, including the 1% AEP or "100-year" event. In all cases, the GEV and LP3 fits were very similar which justified our use of the simpler GEV fit for many of the other analyses described here.

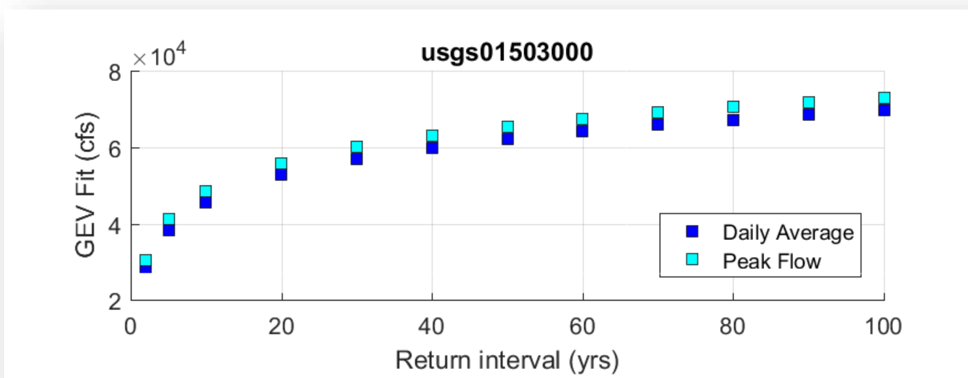

Figure A.3. This GEV curve displays the discharge (Y axis) for each return interval using observed daily average data and daily peak flow from the USGS gage site on the Susquehanna River at Conklin.

Using these data we then developed a moving window analysis to extract 30-year subsets from the annual maximum timeseries output from the gages on the Susquehanna at Conklin and on the Chenango River at Chenango Forks. We broke the full record into 30 year segments and fit a new GEV curve to the 30 annual maxima to calculate the 1% AEP event for each time slice. We then moved this "window" by five-year intervals to calculate the trend in the 1% AEP event for each window (Figures A.4 and A.5 bottom graphs). The plots in each of these cases suggest a potential upward trajectory in the magnitude of the 1% AEP event particularly when looking over the last 30 to 40 years of record. We will discuss more of these results in the *Comparing Results Section* below.

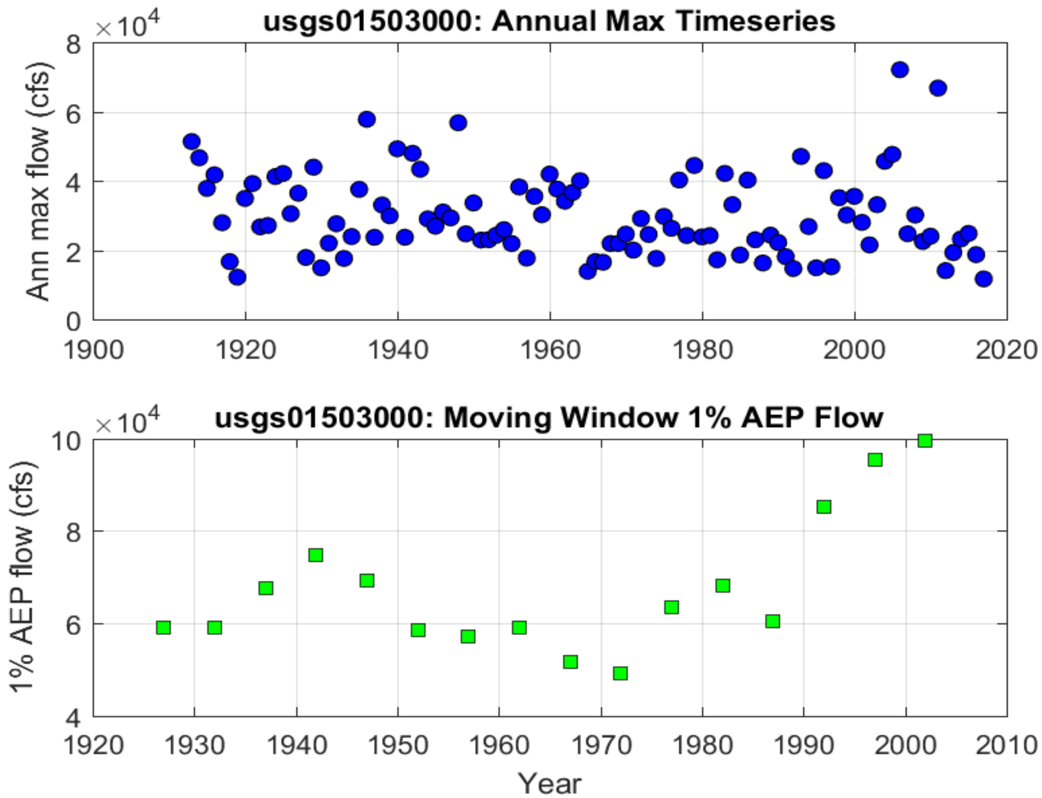

Figure A.4 The annual maximum flow record for the Susquehanna at Conklin (top graph), and extracted 1% AEP flows over time from the 30-year moving window analysis. (bottom graph)

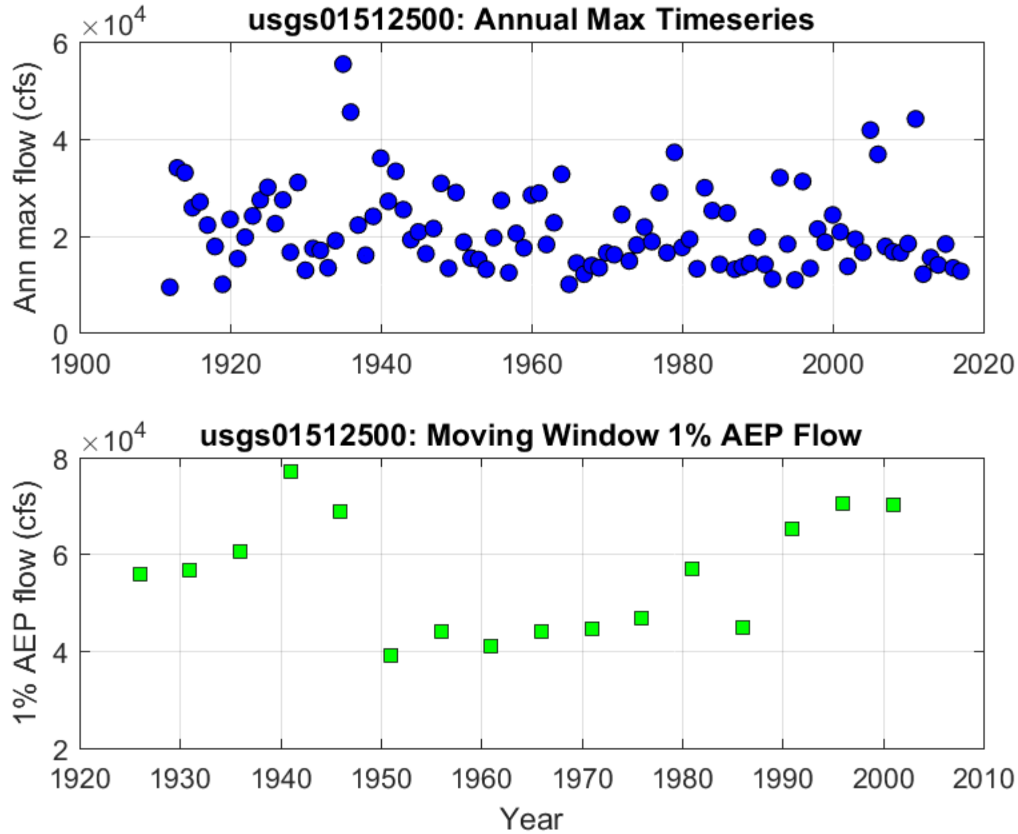

Figure A.5 The annual maximum flow for the Chenango River at Chenango Forks (top graph), and extracted 1% AEP flows over time from the 30-year moving window analysis. (bottom graph).

For more information about USGS Gages, including limitations and uncertainties associated with this resource, see the *USGS Stream Gage Data resource description* in this Toolkit.

USGS Future Peak Flow application

For our work with Broome County, we ran USGS's Future Peak Flow application for the same three gage locations: the Susquehanna River at Conklin and at Vestal, and the Chenango River at Chenango Forks. Selecting these locations allowed us to compare results between the Future Peak Flow application and output from other resources (e.g., USGS gages and USBR downscaled hydrology).

We used the projections for each of the three time periods provided by the Future Peak Flow application (2025–2049, 2050–2074, and 2075–2099) and greenhouse gas scenarios (RCP 4.5 and 8.5) to synthesize potential changes in flow for a range of recurrence intervals. The results suggest an increase in the potential magnitude for flood events in Broome County at all return intervals. Projected changes are largest in the most frequent events, but there is a larger potential for variability in flow for shorter return intervals. Figure A.6. shows the Future Peak Flow application results for the Susquehanna River at Conklin for late in the century for a high emission scenario, RCP 8.5. These results show an increase in the percent change in peak flow for all recurrence intervals. For example, the flow associated with the circled 1% AEP or 100-year event might experience a 10 to 30% increase in the future. Currently, the flow associated with the 1% event at this location is estimated to be around 70,000 cfs (FEMA FIS, 2010). This means that the flow associated with the 1% event could increase to between 76,000 to 90,000 cfs by the end of the century.

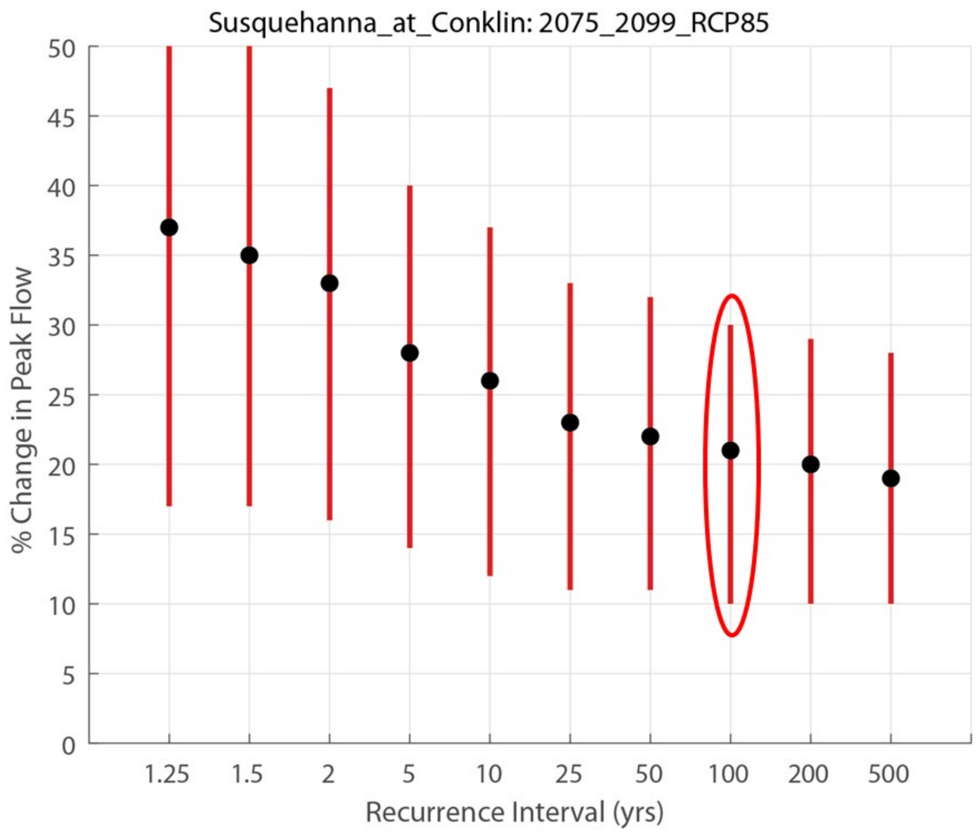

Figure A.6. USGS Future Peak Flow application output for the Susquehanna River at Conklin under RCP8.5 for the late century, 2075–2099. The range in projected %change in peak flow for 1% AEP (or 100-year return interval) event is circled in red.

In general, the Future Peak Flow application projections suggest that 1) increases in the magnitude of more frequent flows (e.g., 1.5-year and 2-year events) are larger than increases in magnitude of the more rare events (e.g., 100 to 500-year events), but have larger variability and 2) changes in peak flows are larger later at the end of century and for higher greenhouse gas emissions scenarios than they are for the earlier century and more aggressive greenhouse gas mitigation scenarios.

For more information about the Future Peak Flow application, including limitations and uncertainties associated with this resource, see the *USGS Future Peak Flow resource description* in this toolkit.

USBR Downscaled Hydrologic Dataset

The USBR downscaled hydrologic dataset uses a set of recent hydrologic modeling outputs developed by the USBR, National Centers for Atmospheric Research (NCAR), and the U.S. Army Corps of Engineers (USACE) to characterize projected changes in the magnitude of future flood events. The dataset is a simplified hydrologic model that simulates infiltration, runoff, and snow accumulation on a nationwide routing scheme that simulates the travel time of flood waves through the channel network (Reclamation, 2014). USBR developed its dataset using statistically downscaled climate inputs.

For this analysis, we extracted the data for flow projections from 29 different climate models and two different greenhouse gas emissions scenarios
(RCP4.5 and RCP8.5) at the modeled Susquehanna River channel that reaches closest to Binghamton. Using these simulated flows for each of the climate models and emissions pathways, we calculated the magnitude of flows with return intervals ranging from two to 100 years (50% to 1% AEPs). Similar to the USGS gage analyses above, we extracted the annual maximum time series from each model run and fit a GEV distribution to this timeseries. Using the resulting GEV parameters, we calculated each of the specified return intervals for each location. We repeated this process using projected flows from 2000–2050 ("early century") and 2050-2100 ("late century") to characterize the frequency-magnitude distribution of floods in both time periods. For each GCM, we compared the magnitude of early century and late century events for each return interval to characterize how expected flooding might change over the course of the 21st century.

The USBR dataset analysis produced a wide range of future projections, including results that modeled decreased flows, as well as increased flows. Figure A.7. below shows an example result for the Susquehanna River at Conklin, for the RCP8.5 scenario. In this example, for the circled 100-year event, the USBR dataset projected a range of changes in flow from a 25% decrease to a 40% increase.

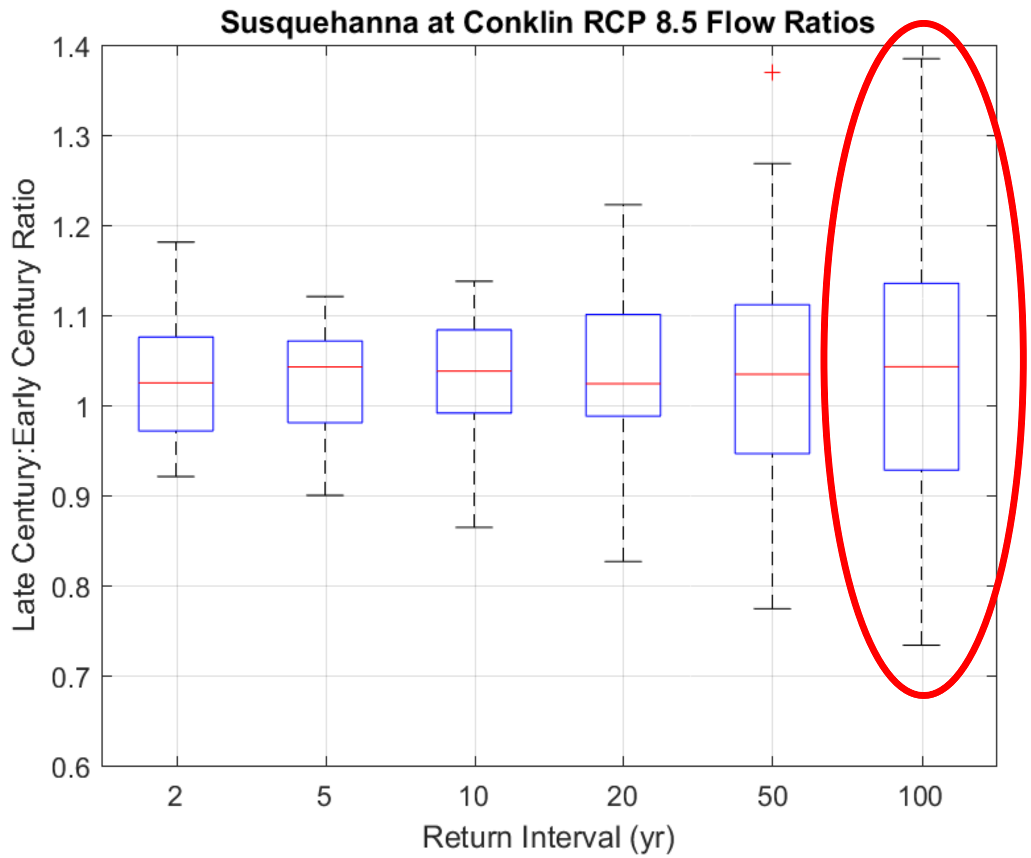

Figure A.7. Ratio of late century to early century modeled stream flow from the USBR downscaled hydrology dataset for the Susquehanna River at Conklin for the RCP8.5 scenario. Modeled end of century flow projections for the 100-year event (circled in red) range from a 25% decrease to a 40% increase.

Unfortunately these data are not publically available at this time, so the USBR downscaled hydrologic dataset is not included as a resource in this toolkit. We wanted to compare the results from this approach with our other resources and had the developers' permission to use these data for this project. See the USBR Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections website for more information.

FEMA FIRMs

We downloaded Broome County's FIRMs from the county's GIS webpage and then using GIS software we projected a 2 to 3 foot increase onto the edge of 1% AEP FIRM layer and using a line of sight analysis. Next, we mapped the area above the current 1% AEP that would be inundated under the 2 to 3 foot increase in flood elevations.

We then compared the new flood elevation layers to the inundation extents for the current 1% and 0.2% AEP events. As shown in Figure A.8. the inundation extents from the 1% AEP + 2 and 3 feet track fairly well with the 0.2% AEP floodplain in and around Binghamton within Broome County, with some clear exceptions. This suggests that, for most locations in Broome County, the 0.2% AEP may be a reasonable proxy for a 2 to 3 foot rise in the 1% AEP flood level. See the Comparison of Results section below for more discussion on this.

These results are meant to demonstrate low-lying areas that may be at increased risk of flooding in the future. Any community should undertake additional detailed hydraulic and climate modeling of areas of concern before making investment or legal decisions.

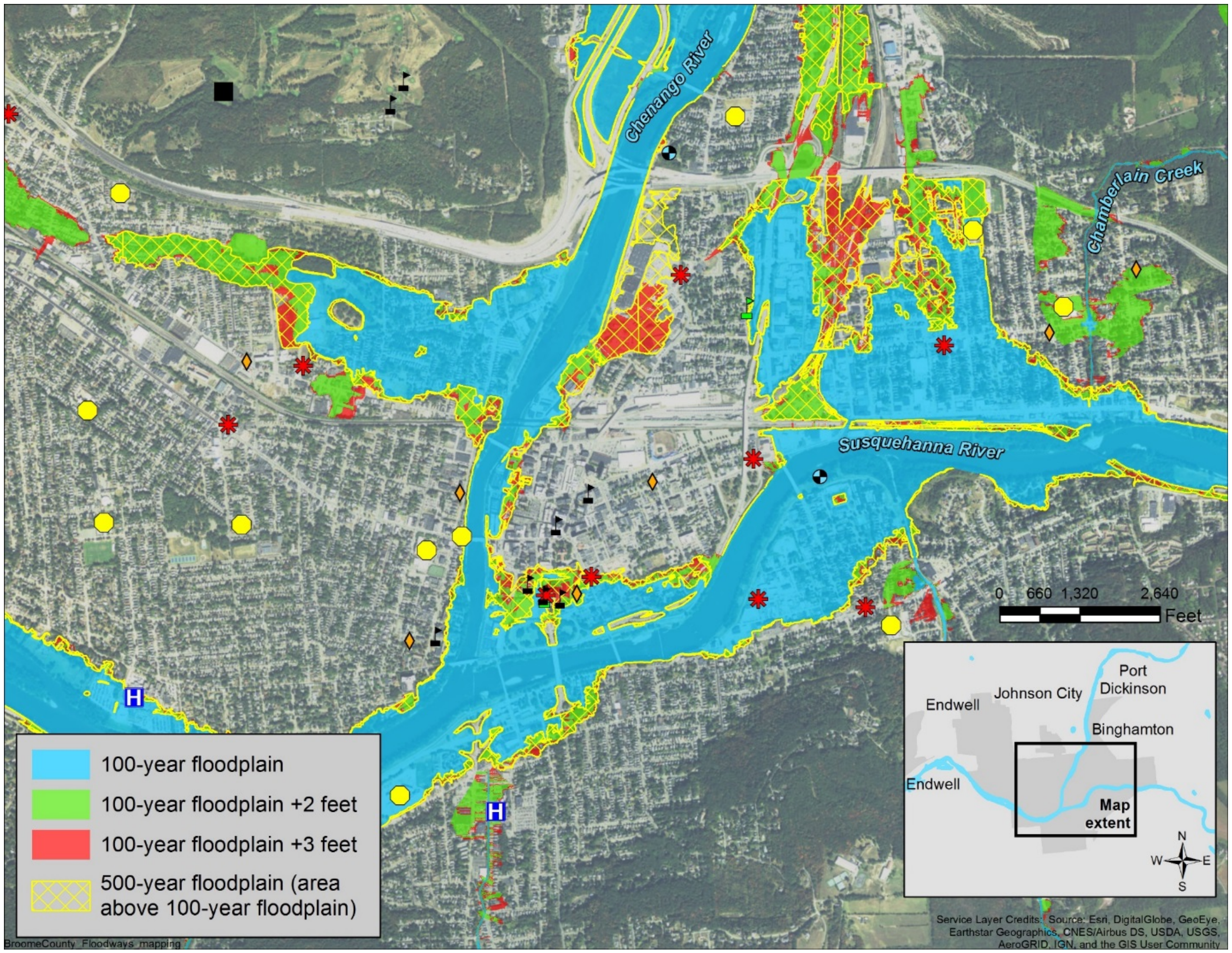

Figure A.8. Results from the 1% AEP FEMA FIRM plus 2 to 3 feet analysis for a section of Broome County including Binghamton.

Comparing Results

Once we had completed the analysis for each resource, we compared the results and placed them in the context of existing flood vulnerabilities within Broome Country. Looking across all the different methods, the projected late century changes in the 1% flow roughly correspond to an increase in flood depth of 2 to 4 feet. The modeled changes in flow are very close to the current 0.2% flood magnitude of 83,000 cfs (based on 2010 FEMA Study). Table A.1 presents the results from each resource and how they compare to the current flood discharge amounts.

Table A.1. Summary of results from Future Peak Flow application, USBR downscaled hydrology, and USGS gage historical trend analysis, for USGS Susquehanna Gage at Conklin.

Input	Current 1% AEP Discharge (elevation)	Discharge % change	Projected 1% AEP Discharge (cfs)
Historical Trends	~70,000 cfs (~865 ft NGVD1929)	~15-30%	~80,000-90,000 cfs
USGS Future Peak Flow application		~10-30%	~76,000-90,000 cfs
USBR hydrology		~-25-40%	~52,000-97,000 cfs

STEP 3. Assess changes to vulnerabilities

Once we had the outcomes from our analysis, we presented this information to a group of decision makers and stakeholders from Broome County and began to help them identify how the results might translate to potential changes to their vulnerability. We reminded the stakeholders that our results should only be used as screening level tools, but that they could help Broome County consider potential impacts from climate-related flood risks, including identifying:

- information gaps
- areas or critical assets that warrant further study
- opportunities to integrate future flood risks in existing planning and decision making.

Using the Hazard Mitigation Plan

One approach we used with Broome County was to consider the results of our analysis against the County's HMP, which offers an in-depth assessment of the county's current flood vulnerability based on historical flooding data. We first selected a set of metrics from the HMP including population exposed, building stock loss, and the number of critical facilities exposed to help us understand Broome County's current flood vulnerabilities. We then applied the results from our analysis to the current vulnerabilities to assess how those same vulnerabilities might change in the future. For an example see Figure A.9., which demonstrates an estimate of how many additional critical facilities might be exposed in a future 1% AEP boundary versus how many are within the current 1% AEP boundary.[d] This type of analysis is useful because it points to areas within the county that will experience greater vulnerabilities from projected future flood risk estimates. Rather than narrowing in on the exact change to the number of facilities, this helps the county identify the areas within the county that might warrant a more focused mapping analysis versus those that might not experience a change. For example, Binghamton might warrant a more focused analysis than Colesville. Broome County can, therefore, better target its resources for future flood analysis.

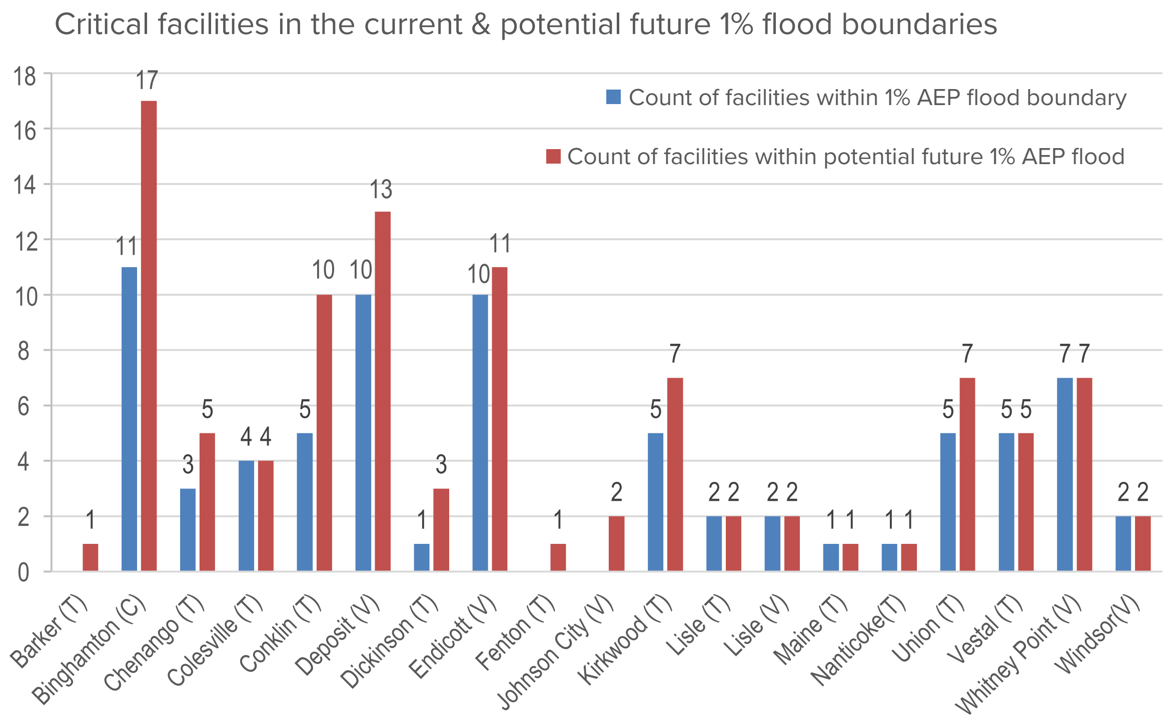

Figure A.9. An example of our results, comparing the number of critical facilities exposed to flooding in the current 1% AEP flood boundary and those in the potential future 1% AEP boundary (which is approximated from Broome County by the current 0.2% AEP boundary). Towns or cities not included in this plot did not have critical facilities listed in the 1% or 0.2% AEP flood boundary in the most recent version of the Broome County Hazard Mitigation Plan.

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d. In Broome County, our results suggested a potential future 1% AEP that closely aligned with the current 0.2% AEP, which allowed us to use existing information from the HMP. This may not be the case in all communities. For communities where the future projections do not align with the 0.2%, additional GIS analysis would be necessary to understand potential vulnerabilities.

Using the maps

We also presented each community with the revised maps (See Figure A.8) and had a conversation about low-lying areas that were just outside the 1% or 0.2% AEP boundaries and also areas where the 1% AEP + 2 and 3 foot exercise didn't correspond well with the current 0.2% AEP boundary. We identified these areas as the type that might warrant further study, especially those that have critical infrastructure, housing, or were marked for future development. We emphasized the caveats associated with the maps and reinforced that stakeholders should only use them for preliminary inquiries about potential changes.

Stakeholder engagement

We shared the results from our analysis during a workshop with key stakeholders and decision makers in the County. We used our results as a starting point for discussions about potential changes to flood risk. We presented our results, including a series of maps, and followed the protocol presented in *Step 3* of the toolkit to facilitate a discussion which helped the stakeholders interact with the results. This approach allowed the County stakeholders to convene and discuss potential areas of concern to monitor or perhaps conduct a further, more detailed analysis.

Appendix E. Community Partner: Red Hook

Introduction

The toolkit is a direct result of work our project team[1] did in partnership with two communities in New York State—Broome County and the Town of Red Hook. Figure B.1 is a schematic of the process we used to work with the communities. We identified the resources that best fit each community's situation, as represented by the inputs on the left-hand side of the figure. We used as many resources as feasible within our project constraints and analyzed and modeled potential changes to flooding for the community. The outputs from these efforts included maps, tables, and graphs that we presented to the communities during a stakeholder engagement workshop where the community could begin to think about how to plan for future flooding.

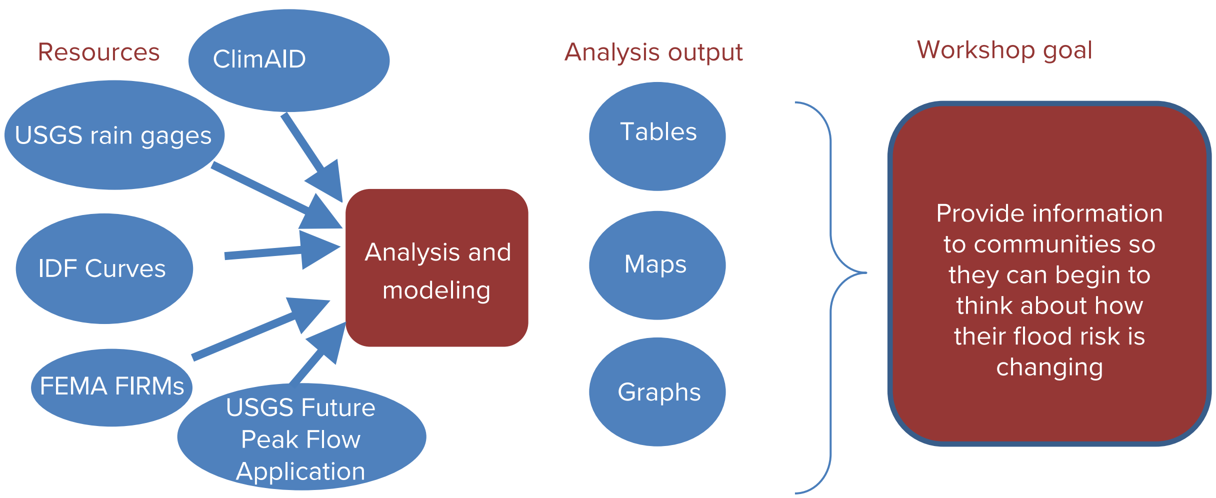

Figure B.1. Schematic of our community partnership process[2]

This community profile introduces the Town of Red Hook and its flooding history. We then discuss the resources we used in partnership with the Town, including our methods and results, mirroring Steps 1 and 2 from the toolkit. Next, we explain how we engaged key stakeholders in a discussion about using the results to begin to think about changing flood risk in the Town, mirroring the toolkit's Step 3.

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1 Throughout the remainder of the profile we refer to the "project team," which represents the team of individuals who conducted the analysis and management of this project and included climate, hydrology, and community risk planning experts from Abt Associates, two NY State climate experts, and Amanda Stevens from NYSERDA.

Background

Red Hook is a town in the Hudson River Valley in New York with approximately 11,181 residents. The town has a total area of 40 square miles and is located in Northwest Dutchess County, approximately three miles to the east of the Hudson River. The Town of Red Hook includes the Villages of Red Hook and Tivoli, along with a several other communities and neighborhoods. The town has two small tributary streams that flow into the Hudson River; the main stem of the Saw Kill river flows just north of the Village of Red Hook, and Stoney Creek passes through the Village of Tivoli.

Climate patterns in Red Hook

Observed climate patterns

The climate in Red Hook has been historically similar to most of New York State with warm summers and cold winters. Rainfall is generally evenly distributed throughout the year, with the heaviest events typically coming from coastal storms (e.g., nor'easters and tropical cyclones) or convective precipitation events (e.g., thunderstorms). Rainfall on top of melting snow can also cause flooding in the late winter and early spring. According to rainfall data from the Mohonk Lake rain gauge station,[2] the top five heaviest rainfall events to impact the Red Hook area were from tropical cyclones and their remnants, the greatest being the precipitation from Hurricane Irene in August, 2011 (see Table B.1).

Date of event	Rainfall	Impact
8/18/2012	1.58 inches	Road closures due to flooding
10/3/2011	4.12 inches in preceding week	Numerous roads flooded in the town. Bridge closure.
8/28/2011	8.21 inches	Significant damage. Road closures, bridge damage.
3/11 to 3/13/2011	2.82 inches from 3/10-11	Road washouts in the town.

Date of event	Daily Rainfall	Impact
8/28/2011	8.21 inches	Hurricane Irene
10/8/2005	6.16 inches	Tropical remnants/frontal system
7/13/1996	5.06 inches	Hurricane Bertha
8/28/1971	5.04 inches	Tropical Storm Doria
9/12/1960	4.83 inches	Hurricane Donna

Table B.1. On the left, recent flooding events that caused impacts in Red Hook and the accumulated rainfall associated with these events. On the right, the heaviest days at Mohonk Lake, New York.

Across the Northeast United States, heavy rainfall events (defined as the heaviest 1% of all daily events) have increased by over 70% between 1958 and 2010 (Walsh et al., 2014). One specific trend for the region surrounding Red Hook is that the number of days with rainfall exceeding one inch, one metric of "heavy rainfall events," has increased over the past several decades (Figure B.2). This trend is representative of the broader trend in the Northeast.

2. For Red Hook, the nearest weather station with the most complete and longest observed record is Mohonk Lake, New York. At this location, there are 95 years of data for daily rainfall.

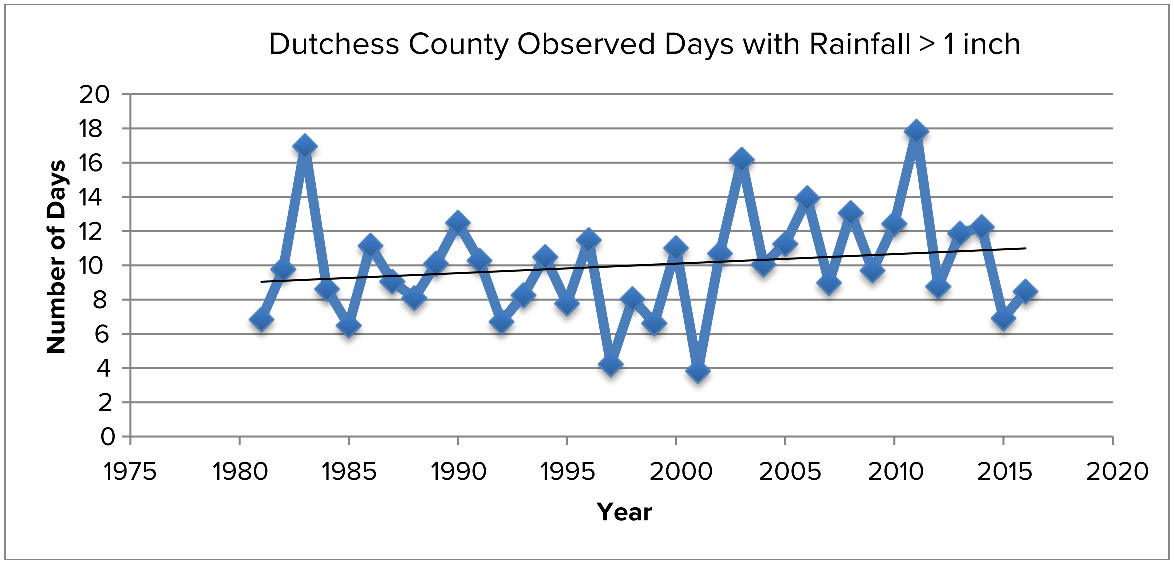

Figure B.2.Observed days per year with rainfall greater than 1 inch in Dutchess County (NYSCCSC, 2017).

Projected climate patterns
Regional climate change projections for the Hudson River Valley suggest that the area will continue to see an upward trend in precipitation. New York State's climate change report, ClimAID, projects that mean annual precipitation in this area will increase from between 5 to 15% by the 2080s (Horton, et al., 2014). ClimAID projects that most of the increase in precipitation will come in the winter, and the late summer and early fall might see a slight reduction in precipitation. In addition to changes in mean precipitation, ClimAID also projects the area will experience an increase in the frequency, intensity, and duration of heavy rainfall events that can cause flooding. Climate scientists are uncertain how the individual events that can cause these rainfall extremes, such as coastal and tropical storms, may change in the future.

Flooding impacts

In recent years, flooding from rainfall in Red Hook has closed roads, led to road washouts, and caused significant damage. In some cases, flooding occurs on the day of a precipitation event, and other times days of rainfall can build up to cause impacts.

Within the town, several locations are vulnerable to flooding from intense rainfall events as identified in the Dutchess County Hazard Mitigation Plan (Tetra Tech, 2000). One of the most critical is a pumping station that provides water for the town's municipal water supply. Other points include several privately owned dams and ponds and also roadways and bridges, which already experience flooding impacts. For example, during rainfall events debris blocks a culvert along State Route 199, a main road for the town, which caused the route to flood.

Red Hook is far enough away from the Hudson River and high enough above the river's water level that major flooding from the river is not a concern. However, the Saw Kill River and Stoney Creek are small basins (approximately 20 square miles each) that drain into the Hudson River and bisect the north and central portions of the Town of Red Hook boundaries. Because these watersheds are so small, highly localized precipitation events drive flooding in both systems.

Methods for helping Red Hook identify changes to their flood risk

Our project team worked with the Town of Red Hook to help communities better understand how changes in mean annual precipitation and changes in heavy rainfall events might affect their future flood risk. The Town of Red Hook is largely outside of the 1% AEP floodplain as shown in the map below, so the team focused largely on nuisance flooding due to extreme precipitation events in assessing flood risk.

Following the approach defined in the toolkit, we used existing tools to identify how nuisance flooding risk might change. However, to ensure we generated a more complete picture of Red Hook's potential future flood risk, we also conducted some analysis of potential changes to river flooding on the Saw Kill and Stoney Creek. During Steps 1 and 2 we identified tools to help us provide a range of potential changes for nuisance and riverine flooding, and then during Step 3 we discussed the implications of these changes on community specific vulnerabilities. Our intention was to conduct a screening level analysis as there are limitations to the data and uncertainties associated with each of these resources.

Step 1: Choose a resource

To conduct the analysis for Red Hook, the project team used data from the ClimAID report, USGS rain gages, Intensity-Duration-Frequency (IDF) curves, FEMA Flood Insurance Rate Maps (FIRMs), and the USGS Future Peak Flow application. There are advantages and disadvantages to each resource so using multiple resources allowed us to assess the potential range of flood risk changes and better understand how uncertainty factors into potential future flood risk.

We used local rain gauge records along with ClimAID projections as a primary method for understanding potential changes to Red Hook's nuisance flood risk. We used USGS Future Peak Flow application and FEMA FIRMs to assess changes in river flood characteristics.

Step 2: Understand potential changes to flood characteristic

Below we profile details on how we used each of these resources, following the processes from Step 2 of the toolkit.

ClimAID and IDF Curves

1) ClimAID with rain gage data

The project team obtained observed rainfall data for the area around Red Hook through NOAA's National Centers for Environmental Information. We used data from the Mohonk Lake station, the nearest weather station to Red Hook with the most complete and longest observed record. The record at Mohonk Lake contains 95 years of daily rainfall data. We decided to create our own IDF curves in addition to looking at the Northeast Regional Climate Center's (NRCC) *Intensity Duration Frequency Curves for New York State: Future Projections for Changing Climate* web-based application to account for the full station record (the NRCC IDF curves use the last 30 years of recorded data).

We conducted statistical analyses of the Mohonk Lake station data. First, we sorted and ranked historical daily rainfall and then identified the most extreme events for the full record. Next, we calculated the number of days per year when rainfall exceeded a threshold (e.g., 1 inch, 2 inches, 4 inches) and calculated a trend analysis to see how these rainfall events have changed over time. We calculated rainfall return intervals using multiple methods. Finally, we also used the observed data to create a magnitude and frequency curve using the Gumbel Distribution approach, fit to both the rainfall observations and projected daily time series of rainfall.

To gain an understanding of how the observed trends in Red Hook might change over time, we then applied climate projections to the observed data. We obtained climate projections for Red Hook and the surrounding regions from the 2014 update of the New York State ClimAID assessment report[3]. ClimAID includes data and projections that can be used to identify several storm events (e.g., 1-in-50 year, 1-in-25 year, 1-in-10 year) and information on how the frequency and intensity of these events may change in the future. The ClimAID data is projected for two timeslices, the 2050s and 2080s, and two representative concentrations pathways (RCPs), 4.5 and 8.5. The report presents results for the low-estimate (10th), middle range (25th to 75th), and high-estimate (90th) percentile of the projected values of 35 climate model runs for each RCP. The timeslices, RCPs, and the distribution points are consistent with the ClimAID report update from 2014.

We applied the mean monthly percentage changes in precipitation from ClimAID to the observed climate data from Mohonk Lake using a delta-method approach. Briefly, we applied the modeled monthly projection data for each of the four percentile points (10th, 25th to 75th, and 90th) to the observed daily rainfall from Mohonk Lake. We took the model projection for each distribution point and applied the projected change to the observed daily rainfall series. We pair the change factors with the historical data based on what month they occur in (e.g., a heavy rainfall in October is multiplied by the mean change in annual precipitation for that month at the four percentile points).

The plots below (Figure B.3 and B.4) show the projected changes in precipitation frequency and intensity we derived from the Mohonk Lake precipitation gauge records. The top plot contains frequency estimates of 24-hour rainfall totals for the 25th and 75th percentiles under RCP 8.5 for the 2050s. The arrow on the plot illustrates the potential for a shift in frequency of the baseline 1% annual exceedance probability (AEP) event to a 2% AEP event under the 75th percentile projections by mid-century. The bottom plot shows the same information but for projections into the 2080s.

3 The data used in this analysis are the raw information used to develop the published ClimAID projections in the 2014 report. These data are available upon request to the ClimAID project team.

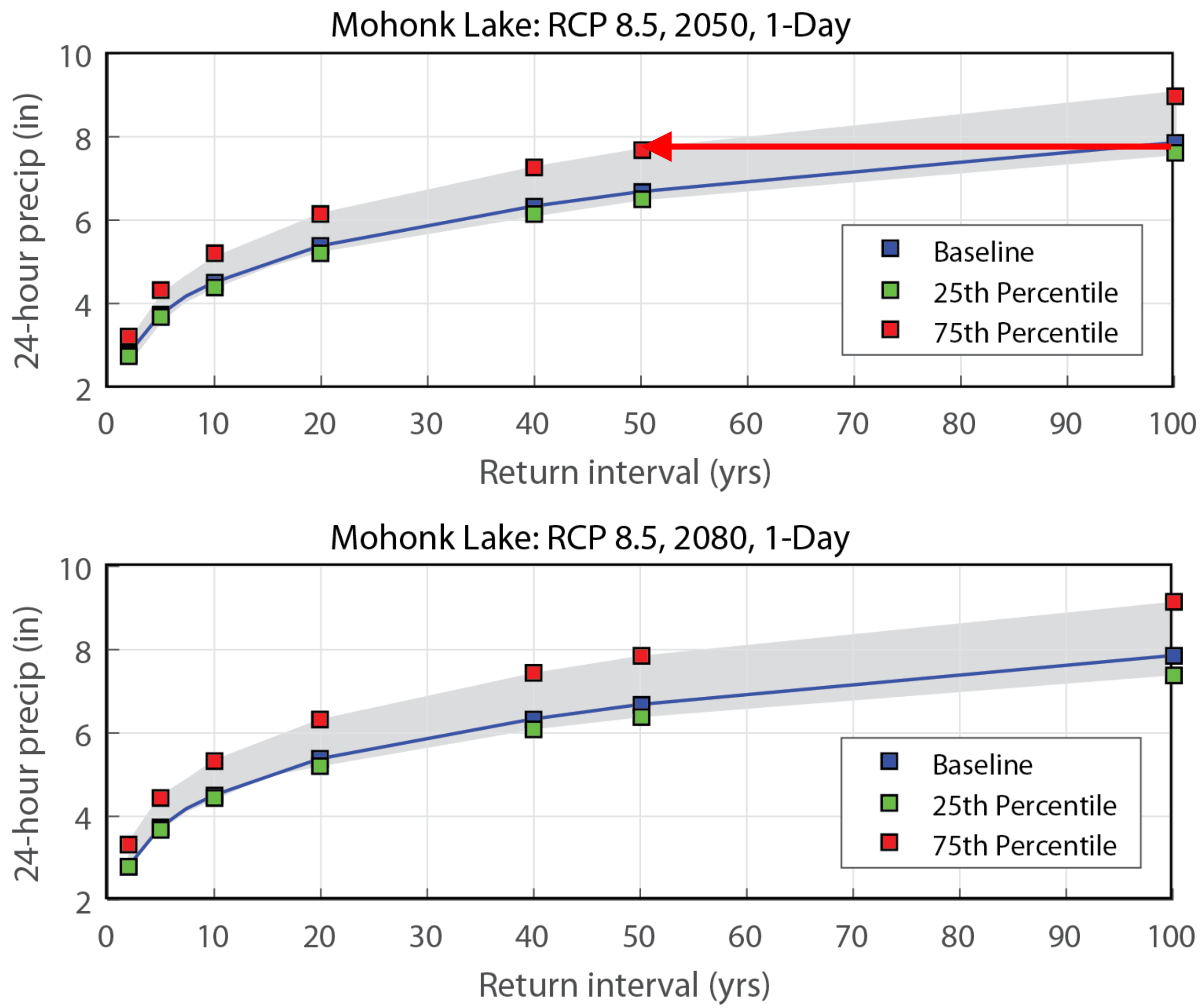

Figure B.3 (top) and B.4 (bottom) Magnitude and frequency curves for Mohonk Lake. The blue line represents the current curve, based on observed data. The green and red squares represent the 25th and 75th percentile projections from the delta change method, respectively. The top plot shows the projections for the mid-century or 2050s, and the bottom shows projections for late-century or 2080s.

Table B.2 below presents the frequency data for a set of daily rainfall return periods for the observed record and for projected future timeslices across both RCPs. These projections show how the current 24-hour rainfall totals for each frequency event may change in the future (e.g., the majority of models project that the 24-hour rainfall amount associated with the 1-in-50 year event could increase from 6.45 inches to between 6.4 and 8.4 inches by mid-century).

The high and low projections are the 10th and 90th percentile values from the ensemble of projections used to produce the projected estimates. The values in parenthesis are the 25th and 75th percentile values. For each frequency, the majority of models project an increase in the rainfall (see the ClimAID report for additional discussion about projected changes to rainfall in New York State).

Current and Future Projected combined RCPs (Mohonk Lake Gauge)

Frequency	24 hour rainfall (in)	2050s (RCP 4.5 and 8.5)	2080s (RCP 4.5 and 8.5)
1 in 50 year	6.45	6.4 (6.8-7.8) 8.4	6.4 (7-7.9) 8.2
1 in 25 year	6.15	5.3 (5.8-7.1) 7.6	5.2 (5.7-6.8) 7.6
1 in 10 year	5.07	4.7 (5-5.9) 6.3	4.5 (5-5.9) 6.5
1 in 5 year	4.55	4.1 (4.5-5.3) 5.7	4.1 (4.5-5.3) 5.7
1 in 2 year	3.79	3.4 (3.6-4.2) 4.6	3.4 (3.7-4.4) 4.8

Projected values are: 10th (25th–75th) 90th percentiles

Table B.2. Observed and projected values for the 24-hour rainfall event for a set of return periods. Projections are based on 35 GCMs and 2 RCPs.

2) NRCC IDF Curves

We compared these results with the Mohonk Lake outputs on the NRCC IDF Curves application. Using this additional resource gave us another line of evidence that supports a general increase in precipitation events under the RCP 4.5 and 8.5 climate change scenarios by mid-century.

Table B.3 shows output from the NRCC IDF Curve application for the Mohonk Lake Station. The values in the table are the mean 24-hour rainfall totals (intensity in inches/hour multiplied by 24 hours). The values in parentheses for the observed rainfall totals are the high and low confidence intervals. For the projected values the parentheses contain the 10th and 90th percentile values from the ensemble of projections used to produce the projected estimates (see the IDF Curve resource description for more information and links to the application and technical documentation).

Frequency	Observed 24-hour rainfall (in)	2040-2069 (RCP 8.5)	2040-2069 (RCP 4.5)
1 in 50 year	7.44 (6.48-7.68)	8.4 (7.44-9.12)	7.92 (6.96-8.88)
1 in 25 year	6.24 (5.76-6.72)	7.2 (6.48-7.68)	6.72 (6.24-7.2)
1 in 10 year	5.28 (4.8-5.52)	5.76 (5.52-6.24)	5.52 (5.28-5.76)
1 in 5 year	4.56 (4.08-4.8)	5.04 (4.8-5.28)	4.8 (4.56-5.04)
1 in 2 year	3.6 (3.36-4.08)	4.08 (3.84-4.32)	4.08 (3.84-4.32)

Table B.3. Observed and projected values for the 24-hour rainfall event for a set of return periods from the NRCC IDF Curve application. Observed values are the mean and 90% low and high confidence intervals, and the projected values are the mean and 10th and 90th percentile values from the ensemble of projections (application used a total of 49 global downscaling technique combinations to generate future intensities).

In general, the IDF curve output suggests increasing intensity at this station, similar to the values shown in Table B.2. The observed and projected values from the NRCC IDF Curve application do indicate slightly larger 24-hour rainfall totals than the results presented in Table B2. This difference may stem from the difference in the number of years used to estimate the observed magnitude and frequency (we used the full gage record and the NRCC IDF Curve application uses observed data between 1970 and 1999). There are also differences in the projection techniques between those used in the NRCC IDF Curve application and the ClimAID report.

While the nearest station data may be a good proxy for local climate, if it is too far away it may not capture the nuances in the local environment that are most useful for adaptation planning. This was the case in Red Hook, as the nearest gage, Mohonk Lake, is approximately 20 miles away from the town. When searching for the closest station, we pulled data from a USGS gauge from a site located along the Saw Kill, however, this record only included data for six years and was not complete enough for use in any further analyses.

Additionally, the delta method approach described above assumes the historical variability does not change in the future. Yet, climate scientists are still uncertain about how the climate system, including extreme precipitation, will respond to future levels of greenhouse gas emissions and what path the emissions will take.

For more information about rain gages and ClimAID, including limitations and uncertainties associated with these resources, see the *IDF resource description* in this toolkit.

FEMA FIRMs

Both the main stem of the Saw Kill and Stoney Creek have FEMA FIRMS available for the 1% AEP and 0.2% AEP floodways. Using a geographic information system (GIS), we projected a 2 to 3 foot increase onto the edge of 1% AEP FEMA FIRM layer using a line of sight analysis, and then mapped the area above the current 1% AEP that would be inundated under the 2 to 3 foot increase in flood elevations. Figure B.5 displays the results of this analysis.

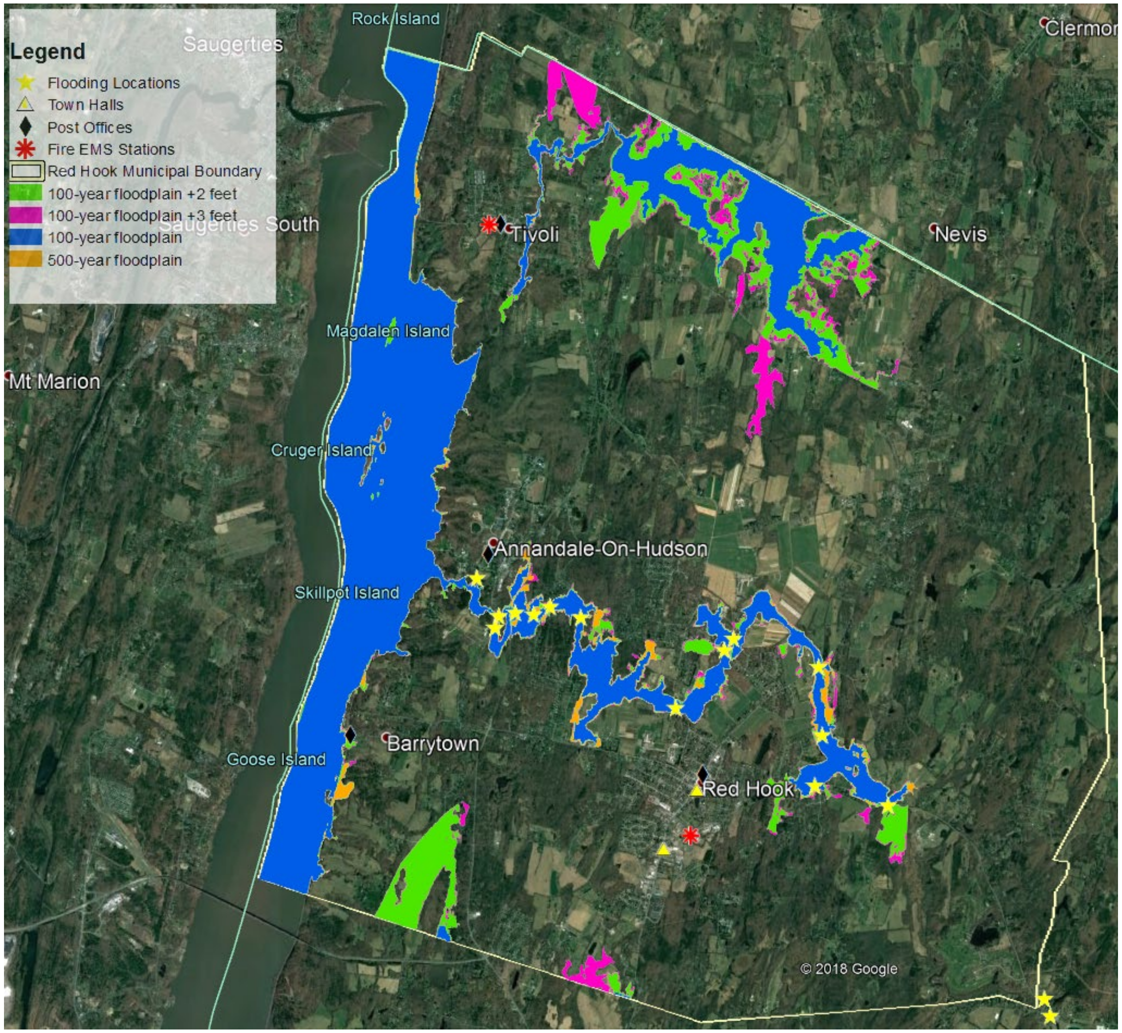

Figure B.5 Showing inundation polygons within the Town of Red Hook Municipal boundary for the 1% and 0.2% AEP floodplains using FEMA FIRMs, and the 1% AEP floodplain +2 to 3 ft (screenshot of kml file in Google Earth).

Table B.4 presents the percent change in inundation areas along the main stem of the Saw Kill, a smaller area within the municipal boundary of Red Hook (using a location of interest polygon in GIS). We focused on this portion of the river because local FEMA FIRMs indicate the potential for riverine flood impacts to town infrastructure along this reach. Results from this analysis indicate that in some cases along the main stem of the Saw Kill the 1% AEP + 2 to 3 foot flood inundation extent is larger than the inundation area associated with the 0.2% AEP. The table shows changes in inundation area relative to the 1% AEP for the main stem of the Saw Kill, both for the current 0.2% AEP floodplain and the 1% AEP +2 or 3 foot inundation areas.

Floodplain along the main stem of the Saw Kill	Floodplain Area (acres)	Percent change from 1% AEP
1% AEP	569.89	N/A
0.2% AEP	683.43	+~20%
1% AEP +2 ft	806.82	+~42%
1% AEP +3 ft	882.18	+~55%

Table B.4 Percent change in inundation from the 1% AEP flood plain along the main stem of the Saw Kill in comparison to the 0.2% AEP flood plain. The results in the table suggest that the inundation area resulting from the 1% AEP +2 to 3 ft is larger in many cases than the 0.2% AEP floodplain. We limited the result to the main stem of the Saw Kill because this reach has a mapped 0.2% AEP FEMA FIRM.

Because the Saw Kill only has six years of recorded stream flow, we used regression equations and stream surveys to develop the FEMA flood plain maps and associated discharge and return interval estimates. These methods, though viable for screening level exercises, likely do not capture local variability in stream flow and do not produce the same accuracy as we would expect from a gaged basin with long-term flow records.

For more information about FEMA FIRMs, including limitations and uncertainties associated with this resource, see the *FEMA FIRMs resource description* in this toolkit.

USGS Future Peak Flow

The project team ran the United States Geological Survey (USGS) Application of Flood Regressions and Climate Change Scenarios to Explore Estimates of Future Peak Flows or the “Future Peak Flow application” for six locations within the Saw Kill and Stony Creek basins. The analysis focused on locations that the town highway supervisor indicated experienced road closures due to overtopping of bridges at flood stage.

Figure B.6 contains estimated current and future discharge values from the Future Peak Flow application for one of the Saw Kill locations at Linden Avenue in the Town of Red Hook. This is a site that has experienced previous road closures do to bridge overtopping. These results suggest that the application projects that the discharge amount currently associated with the 1% AEP (or 100-year return interval) will be associated with a 2% AEP (or 50-year return interval) by mid-to-late century. At a screening level, this information might indicate to Red Hook that this bridge will be closed much more often in the future and might be a location to consider for a more in-depth engineering analysis.

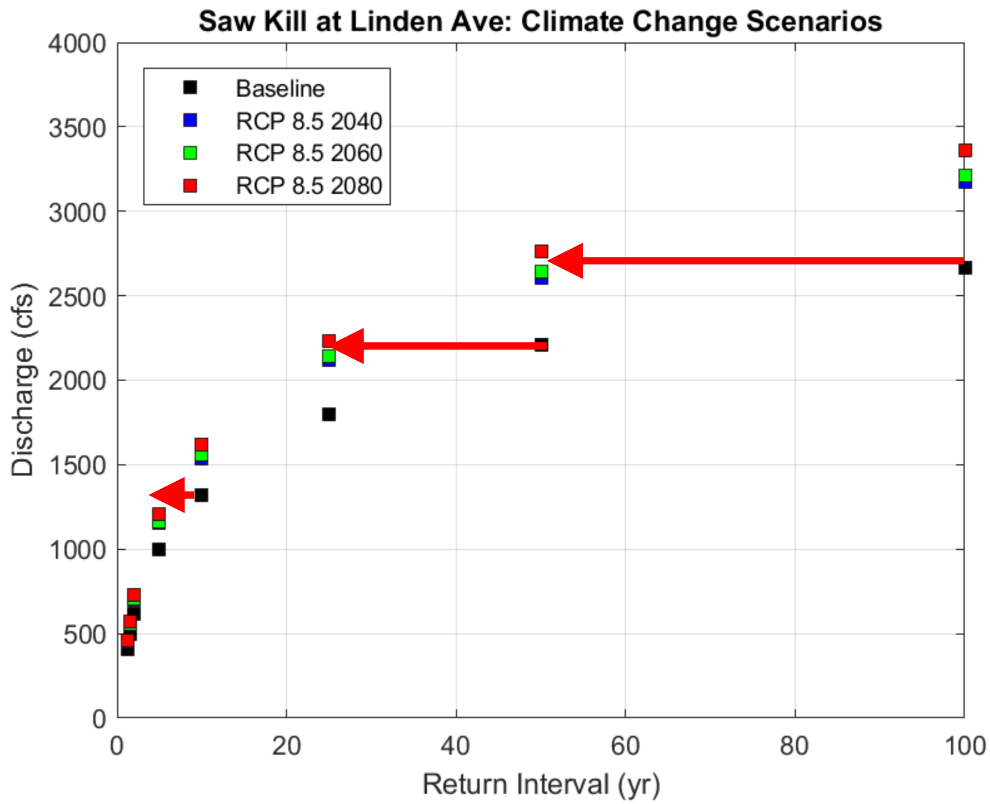

Figure B.6 Baseline and projected discharge (cfs) for the Saw Kill at Linden Avenue just north of the village of Red Hook for return intervals between 2-100 years (50%-1% AEP events) from the USGS Future Peak Flow application.

For more information about the Future Peak Flow application, including limitations and uncertainties associated with this resource, see the *Future Peak Flow Application resource description* in this toolkit.

STEP 3. Assess changes to vulnerabilities

Once we had the outcomes from our analysis, we presented this information in a workshop with a group of decision makers and stakeholders from the Town of Red Hook to help them begin to consider how these results might translate to potential changes to their vulnerability. We reminded the stakeholders that our results should only be used as screening level tools, but that they could help Red Hook consider potential impacts from climate-related flood risks, including identifying:

- information gaps
- areas or critical assets that warrant further study
- opportunities to integrate future flood risks in existing planning and decision making.

Using historical data

The help provide some context to the results, we identified the rainfall characteristics of past extreme precipitation events. Via conversations with area key stakeholders, (e.g., highway supervisor) and reviewing review of historic information, we identified examples of impacts from specific past storms. For example, we heard that a certain bridge flooded during a storm that occurred in a particular month and year. Then we compiled that information with the storm record and identified precipitation amounts and return intervals associated with past storms that caused impacts around the town. We then used our projections from Step 2 to identify the future return interval for that same type of storm event (see Table B.5). For example, in 2011 Hurricane Irene caused significant damage throughout the village. This type of event, currently calculated as a “1-in-100 year event,” or an event that has a 1% likelihood of occurring in any year, could be twice as likely to occur in any given year by 2080s.

Table B.5.. Example of results presented to stakeholders in Red Hook. This table depicts observed events and their impacts, observed rainfall amounts, and calculated return interval. We also identified how the return interval of a similar event might change in the future. The symbol “<<” represents an even greater reduction in the two-year event than the current estimate.

Date of event	Impact	Observed Rainfall (in inches)	Return interval*	Future return interval 75% 2050s	Future return interval 75% 2080s
8/18/2012	Road closures due to flooding.	1.58 for the day	<2 year event	<<2 year event	<<2 year event
10/3/2011	Numerous roads flooded in the town. Bridge closure.	4.12 in week preceding	<2 year event	<<2 year event	<<2 year event
8/28/2011 (Irene)	Significant damage. Road closures, bridge damage.	8.21 for the day	~100 year event	~60 year event	~ 50 year event
3/11-13/2011	Road washouts in the town	2.82 on 3/10 and 3/11.	<2 year event	<<2 year event	<<2 year event

Using the maps

We also presented each community with the revised maps (See Figure B.5 above) and discussed low-lying areas that were just outside the 1% or 0.2% AEP boundaries. We identified these areas as the type that might warrant further study, especially if they have critical infrastructure, housing, or are marked for future development. However, we also emphasized the caveats associated with the maps and reinforced that stakeholders should only use them for preliminary inquiries about potential changes.

Stakeholder engagement

During the workshop in Red Hook we followed the protocol presented in *Step 3* of the toolkit to facilitate a discussion which helped the stakeholders interact with the results. This approach allowed the stakeholders to convene and discuss potential areas of concern to monitor or perhaps conduct a further, more detailed analysis.

Our partners in Red Hook indicated that the visual presentation of changes in flood risk, specifically with the maps, was an effective way to convey the changing risk potential with the community. The planning officials also indicated that the discussion of broader spatial and temporal scale projections was helpful in framing their understanding of changing risk. They were able to use that information to discuss how changes in climate and precipitation may impact flooding more generally.

We found it difficult to estimate changing risk from nuisance flooding in this community in part due to a lack of a consistent records about nuisance flooding occurrences. Planning officials stated that they had a hard time relating changing precipitation regimes to shifts in nuisance flood risk. They indicated that it would be useful to present additional examples of areas at risk of nuisance flooding.