Section 2.3
Hydrology & Flood History

Introduction

Hydrology is the study of the properties, distribution, and effects of water on the earth's surface, in the soil and underlying rocks (groundwater), and in the atmosphere. The *hydrologic cycle* includes all of the ways in which water cycles from the landscape (both underground and in streams and water bodies) to the atmosphere (as water vapor and clouds) and back (as snow, rain and other forms of precipitation) (Fig.1). Understanding the dynamics of how the Neversink watershed and stream system carry rain and snow over time as runoff and stream flow (discharge) helps us to predict flood frequency and magnitude, as well as appropriate ways to manage the stream and watershed.

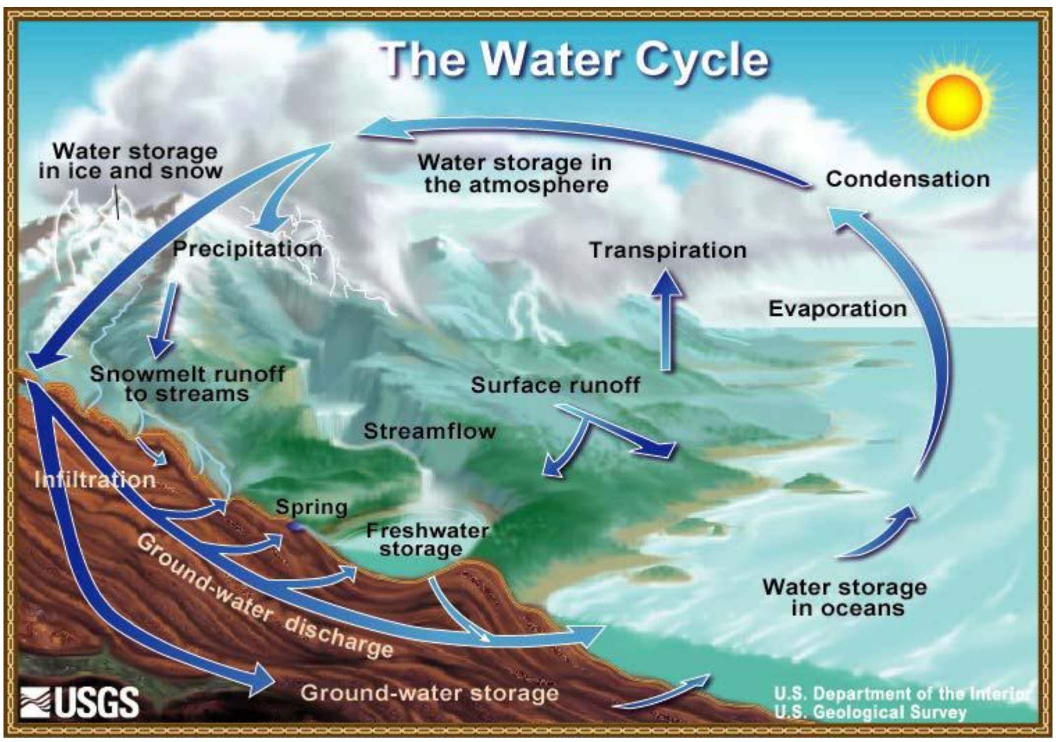

Figure 1 The Hydrologic (water) Cycle
(http://ga.water.usgs.gov/edu/watercyclesummary.html)

Water flowing through the Neversink River reflects the integrated effects of all watershed characteristics that influence the hydrologic cycle. Characteristics include climate of the drainage basin (type and distribution patterns of precipitation and temperature regime), geology and land use/cover (permeable or impermeable surfaces and materials affecting timing and amount of infiltration and runoff, and human-built drainage systems), and vegetation (uptake of water by plants, protection against erosion, and influence on infiltration rates). These factors affect timing and amount of stream flow, referred to as the stream's *hydrologic regime*. For example, a stream with an urbanized watershed where water will run off the hardened surfaces directly into the stream will have higher peak discharges following storms than a watershed, such as the Neversink River, which is predominantly forested and allows a higher percentage of rain water to infiltrate before it reaches the stream, releasing it more slowly over time. Understanding the hydrology of a drainage basin is important to the stream manager because stream flow patterns affect aquatic habitat, flood behavior, recreational use, and water supply and quality.

Neversink Statistics

The Neversink River watershed encompasses over 70 square miles of watershed drainage area. Streams in this watershed are primarily perennial, meaning that they flow year-round except in smaller headwater streams or in extreme drought conditions. The Neversink runs predominantly southwest before entering the Neversink Reservoir in the town of Neversink. The drainage pattern is controlled by the topography which was formed in large part during the last period of glacial activity. Within the Neversink watershed, drainage pattern of small side tributaries is primarily dendritic (branching, tree-like form), typical of Catskill Mountain sub-basins (see Section 2.4 *Geology of the Neversink*, for a discussion of how geology controls the shape of stream networks at larger scales).

Estimated mean annual precipitation in the Neversink basin is approximately 47-50 inches per year, and often comes as late winter rain-on-snow events, summer storms, or remnants of autumn hurricanes[1]. Due to the steep side slopes of this watershed, stream levels can rise and fall relatively quickly during intense storm events. The watershed can also retain snowpack into the spring, often resulting in flash floods when rain melts existing snow. This flashiness can be mitigated by the heavy forest cover throughout much of the watershed, but is intensified in well developed areas which lack vegetated riparian zones and consist of impervious surfaces.

Stream Flow

There are two general categories of streamflow: storm flow (also called flood flow) and base flow, between which streams fluctuate over time. Storm flow fills the stream channel in direct response to precipitation (rain or snow) or snowmelt, whereas base flow is primarily groundwater fed and sustains streamflow between storms and during subfreezing or drought periods. A large portion of storm flow is made up of *overland flow*, runoff that occurs over and just below the soil surface during a rain or snowmelt event. This surface runoff appears in the stream relatively quickly and recedes soon after the event. The role of overland flow in the Neversink watershed is variable, depending upon time of year and severity of storms or snowmelt events.

Higher stream flows are common during spring due to rain, snowmelt and combination events, and during hurricane season in the fall. During summer months, actively growing vegetation on the landscape draws vast amounts of water from the soil through *evapotranspiration*. This demand for groundwater by vegetation can significantly delay and reduce the amount of runoff reaching streams during a rain storm. During winter months, precipitation is held in the landscape as snow and ice. However, frozen ground may increase the amount of overland flow resulting from a rain storm if the air temperature is above freezing, particularly in spring on north facing slopes.

Subsurface storm flow, or *interflow*, comes from rain or snow melt that infiltrates the soil and runs down slope through the ground. Infiltrated water can flow rapidly through highly permeable portions of the soil or displace existing water into a channel by "pushing" it from behind. In the Neversink valley, subsurface flow can occur fairly rapidly along layers of essentially impermeable glacial lake silt/clay deposits. Subsurface storm flow shows up in the stream following overland flow, as stream flow declines back toward base flow conditions.

Base flow consists of water that infiltrates into the ground during and after a rain storm, sustaining streamflow during dry periods and between storm flows. The source of base flow is groundwater that flows through unsaturated and saturated soils and cracks or layers in bedrock adjacent to the stream. In this way streams can sustain flow for weeks or months between precipitation events and through the winter when the ground surface and all precipitation is otherwise frozen. Stable-temperature groundwater inputs keep stream water warmer than the air in winter and cooler than the air in summer – this process is what enables fish and other aquatic life to survive in streams year-round.

Streams transition between subsurface flow and base flow based on weather conditions, and there is no specific time period or flow magnitude that defines which flow the stream is at. One method which is commonly used to trace the rate of rise and fall in stage, or water level, is the analysis of *hydrographs*. A hydrograph is a graphical representation of the magnitude of stream flow over some period of time, and often displays "peaks" and "valleys", which are high and low rates of discharge serving as a reflection of weather patterns. A distinction can be made between base flow and storm flow by drawing a line connecting the valleys of the hydrograph. Storm flows will be above this line, while base flows will fall below it. Hydrographs can also be useful in calculating an "inflection point", which is the point on the graph where the rate of rise and fall changes. The purpose of these calculations is to provide assistance in determining the sustainable use of water supply-water withdrawal, releases from reservoirs, and preservation of wildlife. These values are also critical for determining flow pumping rates for dewatering stream restoration projects, required by New York State law to preserve water quality during construction.

Hydrologists also use a hydrograph of a stream to characterize the relationship between flow and timing. A *stream gage* is necessary to monitor stream discharge and develop a hydrograph. The United States Geological Survey (USGS) maintains five continuously recording stream gages on the Neversink River upstream of the reservoir, which includes two on the east branch (USGS ID# 0143400680, drainage area 8.93 mi^2 & USGS ID# 01434017, drainage area 22.9 mi^2), two on the west branch (USGS ID# 01434021, drainage area 0.77 mi^2 & USGS ID# 01434498, drainage area 33.8 mi^2), and one on the main branch (USGS ID# 01435000, drainage area 66.6 mi^2). All gage information is available online at the USGS website at http://waterdata.usgs.gov/ny/nwis/rt.

Stream gages normally provide an update of the measurement of water *stage*, or height, every 15 minutes. From a given stage, it is possible to calculate the rate of *discharge*, or volume of water flowing by that point by using a relationship developed by the USGS called a *rating curve*. Using this rating curve, the magnitude of flow in the Neversink at the gage location can be determined at any time just by knowing the current stage, or flow can be predicted for any other stage of interest. Additionally, we can use the historic record of constantly changing stage values to construct a picture of stream response to rain storms, snow melt or extended periods of drought, to analyze seasonal patterns or flood characteristics.

All of the Neversink gages have a long enough period of record to prepare a hydrograph for the stream (see Fig. 3 for example from the gage on the main branch near Claryville). Each spike on the graph represents a peak in stream flow (and stage) in response to rain storms or snow melt. Stream level rises (called the "rising limb" of the hydrograph) and falls as the flood recedes (called the "falling (or receding) limb" of the hydrograph). In the examples below, overland flow accounts for most of the sharp peaks. These graphs represent the daily average flow calculated for each entire day, rather than the continuous 15-minute data.

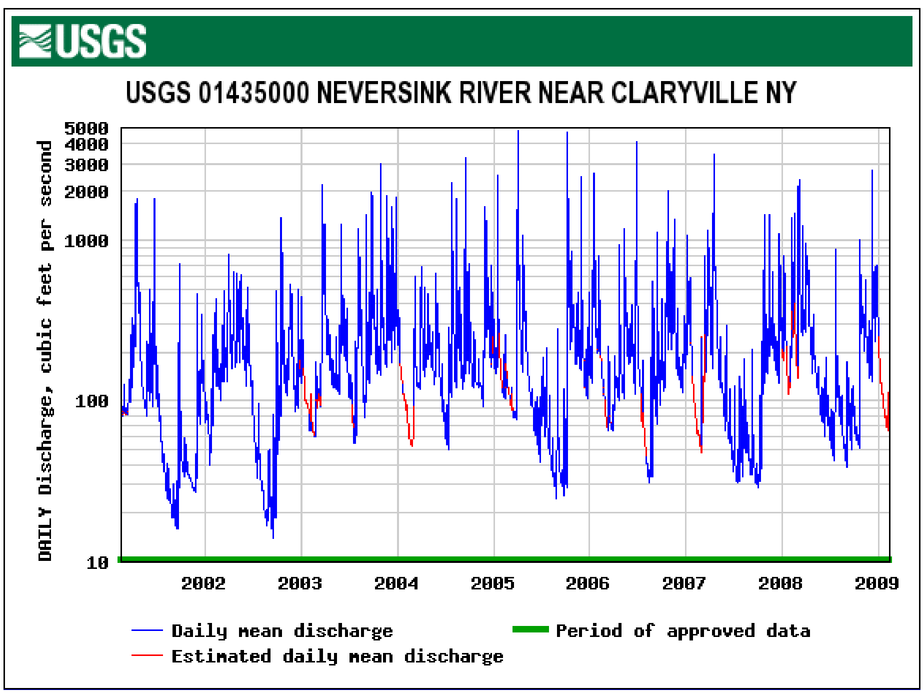

Figure 3 Hydrograph for the period of WY02 through 09, USGS gage Neversink River Near Claryville NY

Long time periods can be used to observe seasonal trends or long-term averages for the entire period of gage record. As is typical of the weather patterns in upstate NY, flows tend to be higher in the autumn (hurricane season) compared to winter (water held in ice and snow), and higher flows in spring (snow and ice melt, with rain-on-snow events) compared to summer (drought conditions with vegetation using a lot of water). However, changing climate patterns often make flows difficult to predict, and large events can happen during any season. For USGS gage near Claryville the average monthly mean daily flow during the period of record ranged from 252 to 419 cubic feet per second (cfs) during the spring, 83 to 155 cfs during the summer, 104 to 214 cfs during the autumn and 161 to 220 cfs during the winter.

There is a delay between the time that the water hits the ground and when it runs off into the stream (known as lag time), which causes rises and peaks following the peak of a precipitation event. Knowledge of storm timing allows us to calculate lag time at Neversink gage locations for particular storms, which can be useful in predicting how a stream responds to storm events both in timing as well as in magnitude of resulting floods.

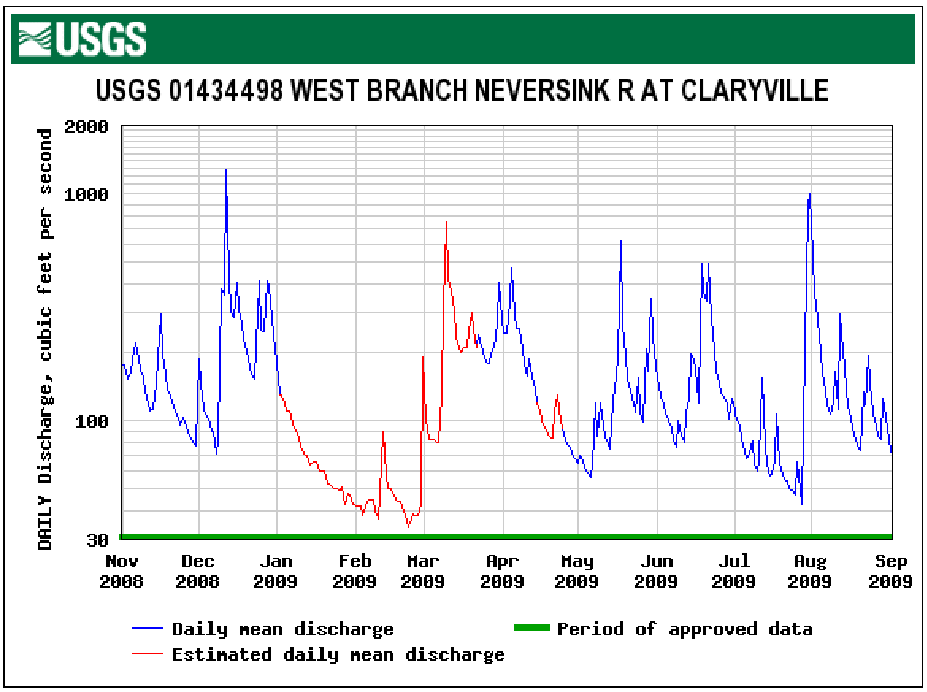

Figure 4 Daily Mean Flow Hydrograph, USGS Gage West Branch Neversink R at Claryville, WY 2009

The annual pattern of stream flow can be seen by looking at the flows from a single water year, such as the one displayed in Fig. 4. Fig. 5 displays the storm flow event associated with the remnants of Hurricane Tammy in October of 2005 at the West Branch of the Neversink River at Claryville. As of September 2005, the gage was experiencing low flows due to drought-like conditions. As weather events dumped rain across the area, storm flow responded to the precipitation very rapidly. This storm was one of the highest recorded peaks for this water year.

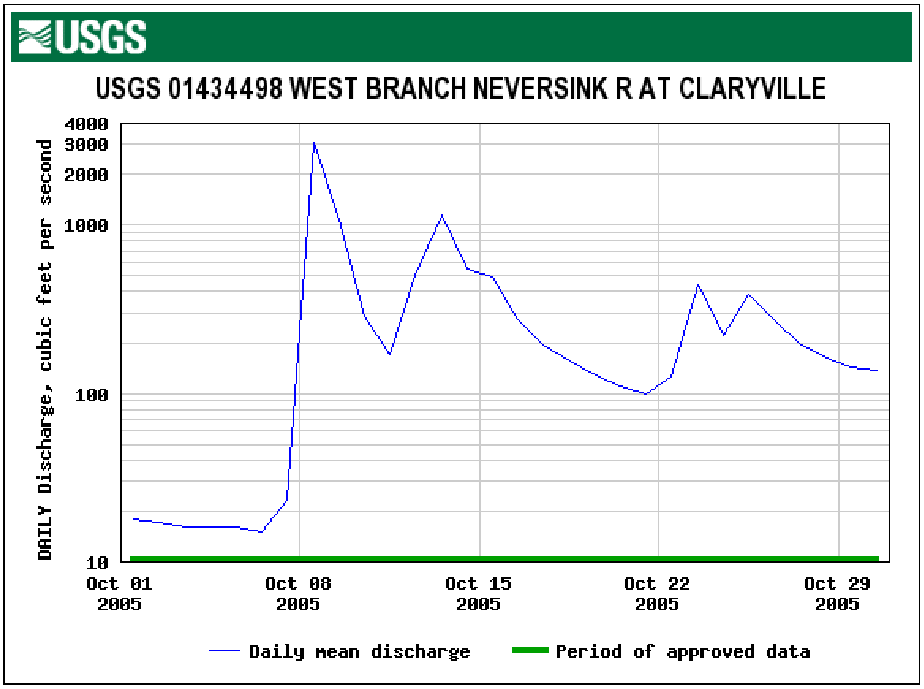

Figure 5 Hydrograph for October 2005 depicting remnants of Hurricane Tammy at the gage along the West Branch of the Neversink at Claryville

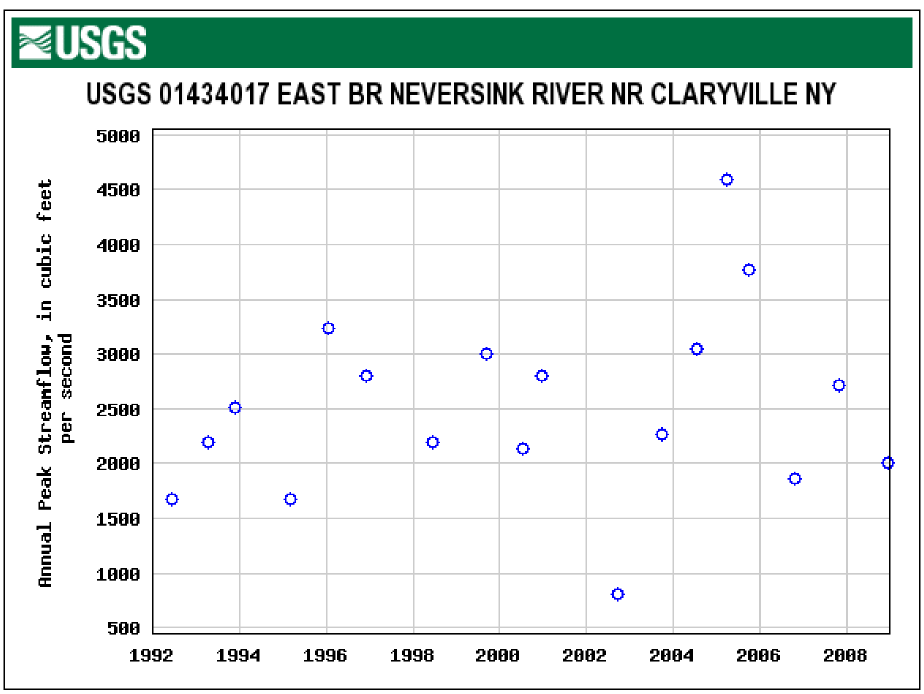

Figure 6 Peak annual flows for the entire record of the gage along the East Branch of the Neversink near Claryville

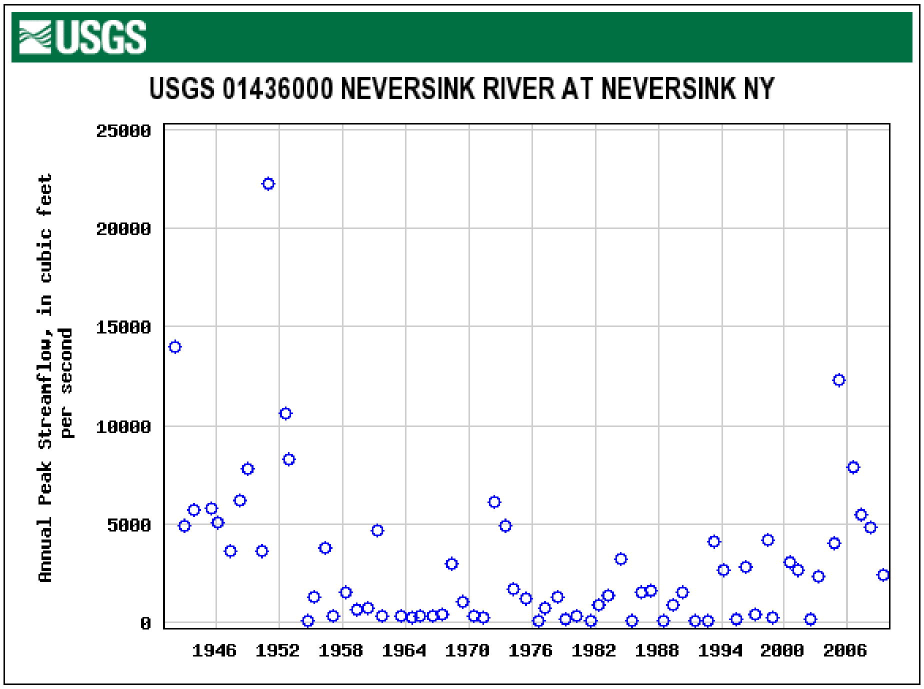

Figure 7 Peak annual flows for the entire record of the gage along the Main Branch of the Neversink at Neversink

Neversink Flood History

The highest stream flow recorded over a 12-month period (usually from October 1 through September 30, or the "Hydrologic Water Year") is called *annual peak stream flow*. The beginning of the Water Year is chosen to represent the average "beginning" of the high flow season following summer low flow period. The range of annual peak flows shows an example of the dramatic range of peak flow magnitude that has been recorded on the Neversink (Figs. 6 and 7). The greatest flow in any single year is not always a significant event, such as that recorded for 2003, a drought year that began in 2002.

Storm flows can exceed stream channel capacity and cover previously dry areas, which is referred to as flooding. Flooding can occur in response to runoff associated with spring snowmelt, summer thunderstorms, fall hurricanes, and winter rain-on-snow events, and can range from minor events to significant discharges that extend far beyond channel boundaries, damage infrastructure and carve new channels.

The prediction and evaluation of the likelihood of flooding is a useful tool to resource and land managers, as it allows for the appropriate planning of development and infrastructure, as well as anticipate potential property damage and safety issues. The USGS has developed a standard method for calculating flood frequency from peak flow data at stream gages, which is provided for public use upon request. This is accomplished by taking the long-term peak flow record and assigning a probability to each magnitude of flood event. Generally, the longer the period of record the more accurate the statistical probability assigned to each flow magnitude.

Flood frequency distributions show flood magnitude for various degrees of probability (or percent likelihood). This value is most often converted to a number of years, called "recurrence interval" (RI) or "return period". For example, the flood with 20% chance of occurring or being exceeded in any single year corresponds to what is commonly referred to as a "5 –year flood" (each of these values is the inverse of the other – just divide 1 by % probability to get RI in years, or divide 1 by RI in years to get % probability). This simply means that on average, for the period of record (the very long term), this magnitude flood will occur about once every 5 years. This probability is purely statistical; in a stable climate, the probability for a particular size flood to occur remains the same year to year over time, though the actual distribution of flood events in time is not regular. Many years may go by without a certain magnitude flood, or it may occur several times in a single year.

The length of gaging records is relatively short compared to the history of flows for any particular stream. Gage records typically range 10-30 years, whereas a record of several hundred years might give a better ideas of how often the range of floods may occur. For example, in a given 10 year record, the largest flood may not necessarily be a 10-year flood, despite the fact that the flood only occurred once in that 10 year record. Therefore, we need to fit some other probability to the floods we do see, based on their magnitude in relation to the other floods in the record, and the average shape of distributions for very long-term records – so individual floods can be plotted where they belong in a more accurate risk of occurrence.

Plotting the frequency of floods against their magnitude produces a flood frequency curve. Because the flood frequency curve is not linear, that is, the shape of the curve doesn't progress along a steady line; we can't simply divide up the floods in a record and rank them in order. For example, in a 10 year record, the largest flood is not necessarily a 10-year flood, even though that flood only occurred once in that ten year record.

Since some of the stream gages along the Neversink have been established for several decades, we can study historic records, interview knowledgeable individuals from the area, and look at photographic records from the watershed to help describe some major historical flood events and draw conclusions about the nature of flooding in the valley.

Table 1 Peak Annual Flows on the Neversink River through water year 2009 that Exceed Five Year Recurrence Intervals[1]

East Branch Neversink River Northeast of Denning, NY **Period of Record: 1991-Present**	
Date	**Flood Discharge (cfs)**
9/16/1999	3,070
12/17/2001	2,700
7/23/2004	2,480
4/2/2005	2,920

East Branch Neversink River near Claryville, NY **Period of Record: 1992-Present**	
Date	**Flood Discharge (cfs)**
4/2/2005	4,590
10/8/2005	3,770

West Branch Neversink River at Winnisook Lake near Frost Valley, NY **Period of Record: 1992-Present**	
Date	**Flood Discharge (cfs)**
4/16/1993	226
9/16/1999	212
4/2/2005	218

West Branch Neversink River at Claryville, NY Period of Record: 1992-Present	
Date	**Flood Discharge (cfs)**
1/19/1996	8,020
11/9/1996	7,920
12/17/2000	9,500
4/2/2005	9,570
6/28/2006	8,310

Neversink River near Claryville, NY Period of Record: 1938-Present	
Date	**Flood Discharge (cfs)**
7/22/1938	12,400
12/24/1941	10,000
11/25/1950	23,400
7/10/1952	10,200
10/15/1955	9,950
7/28/1969	9,880
3/13/1977	10,000
9/6/1979	11,700
3/21/1980	15,600
2/20/1981	14,400
4/5/1984	10,700

4/4/1987	19,300
1/19/1996	12,700
11/9/1996	10,400
12/17/2000	11,800
4/2/2005	17,200
6/28/2006	11,5000

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[1] Flood frequency statistics based on recorded peak flows through 2009.

East Branch Neversink River Northeast of Denning, NY: 5 yr RI flood: ~2,412 10 yr RI flood: ~2,800 cfs

East Branch Neversink River near Claryville, NY: 5 yr RI flood: ~3,324 10 yr RI flood: ~3,670 cfs

West Branch Neversink River at Winnisook Lake near Frost Valley, NY: 5 yr RI flood: ~190 cfs 10 yr RI flood: ~212 cfs

West Branch Neversink River at Claryville, NY: 5 yr RI flood: ~7,302 cfs 10 yr RI flood: ~9,120 cfs

Neversink River near Claryville, NY: 5 yr RI flood: ~9,836 cfs 10 yr RI flood: ~12,454 cfs

Floods recorded at these gages that exceed a 5 year recurrence interval provide an example of distribution of medium to large floods over time. However, it is important not to be misled by recurrence intervals by expecting a flood of a certain magnitude to occur on regular intervals. For example, from 2000-2006 three floods exceeding the "5-year event" occurred on the main branch of the Neversink.

Flooding occurs in response to excessive runoff associated with spring snowmelt, summer thunderstorms, remnants of fall hurricanes, and winter rain-on-snow events. Ten of the thirty-one major floods recorded at the Neverink River gages above the reservoir occurred in spring and are presumably associated with major snowmelt events from either spring thaw or rain-on-snow events (see Fig. 8). Some dates of flood occurrences are consistent between multiple Neversink gages, showing some comparison can be made between the separate branches.

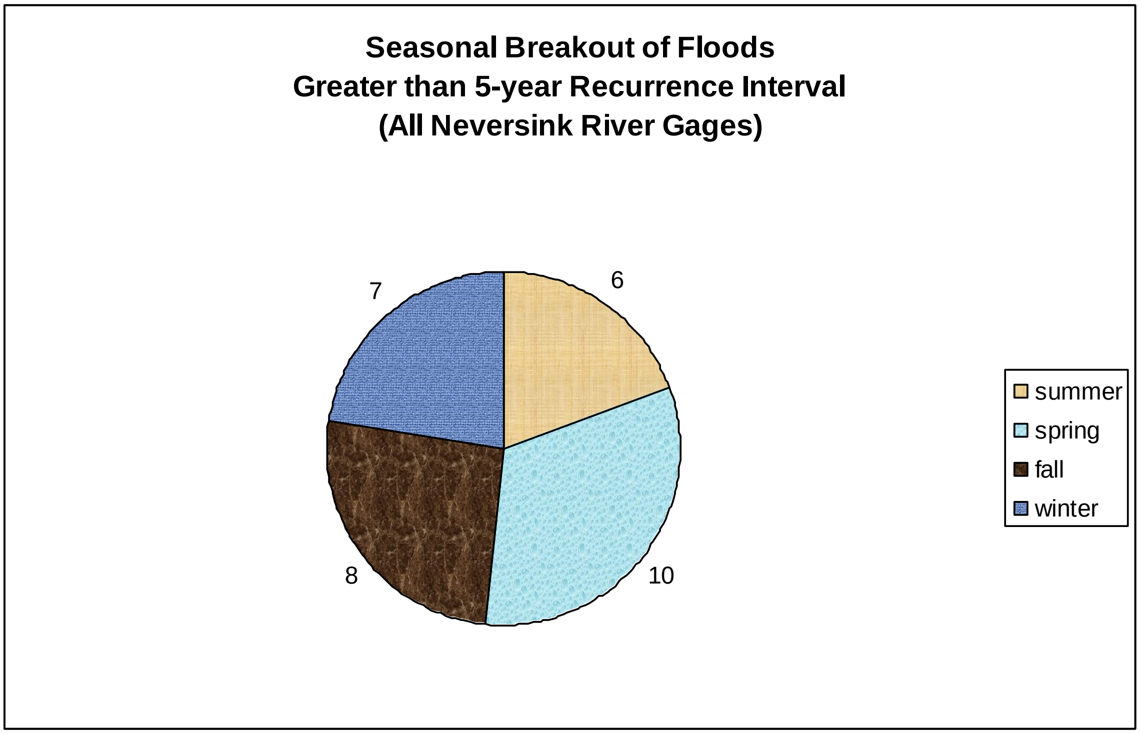

Figure 8 Seasonal distribution of floods of greater than 5-yr return frequency

Conversely, weather in the Catskills can produce localized historically significant flood events such that a peak may not be recorded at each gage for the same time period or storm event. An event in January of 1996 resulted in a greater than five year RI floods at the Neversink near Claryville and West Branch Neversink at Claryville gages; yet did not cause a significant event at any of the other Neversink gages. This shows that comparisons between various sections of the same stream are not always perfect. This is especially so with summer thunderstorms, where highly localized storm cells can produce ten or more inches of rain in one portion of the watershed, and only a few inches in an adjacent portion of the watershed watershed for the same storm.

Implications of Neversink River Flooding

Predicting precisely when the next five year (or greater) flood will occur on the Neversink is impossible – the probability for a large flood, or a flood of any particular size, is the same each year - though weather and storm patterns can be used to anticipate conditions for a few months out.

The risk of flood damage to public and private properties increases as development encroaches further into floodplains. Observed trends in stream gaging records suggest that damaging floods may be occurring at a higher frequency than they have in the past. As large floods occur more frequently, morphological changes to the stream channel happen at a more rapid pace, resulting in increased erosion rates and instances of channel migration into developed floodplains. An increasing trend in flood frequency makes it difficult to predict the probability of recurrence for large flows. As a result, bridges and other forms of infrastructure that are designed based on flood recurrence intervals are at risk of being inadequately constructed.

Unique hydrology should be taken into consideration for the management of any stream, as flood history and dynamics play a large role in determining the shape, or morphology, of stream channels and the hazards associated with land uses on the banks and in the floodplain. For example, applications for stream disturbance permits (from NYS DEC) typically increase following floods, as landowners and municipalities attempt to repair damage caused by floods. If we want to minimize their impact on property, infrastructure and other damages or inconvenience, it is critical that we understand and plan for flooding behavior. Historically, this "planning" has emphasized attempts to constrain and control stream channels, rather than working with processes we can measure and, to some extent, predict. The results are often costly, and sometimes catastrophic, such as when berms or levees fail, or bridges wash out. These "control" approaches typically result in ongoing maintenance costs that can draw valuable community resources away from other projects. With a better understanding of stream and floodplain processes, we can reduce these costs. For more information, see Section 3.2, Introduction to Stream Processes.