2.3 Hydrology and Flood History

Hydrology is the study of how water cycles through the landscape. By characterizing how the dynamic Stony Clove Creek watershed and stream system carry rain and snow over time as runoff and streamflow, we can gain some insight into how the landscape will likely react to future flood events. This can also help us predict changes in how the Stony Clove will behave during floods as a result of our management of the stream and its watershed.

Water flowing through Stony Clove Creek into Esopus Creek reflects the integrated net effect of all watershed characteristics that influence the *hydrologic cycle*. These 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 streamflow, referred to as the stream's *hydrologic regime.* Understanding the hydrology of a drainage basin is important to stream managers because stream flow patterns affect aquatic habitat, flood behavior, recreational use, and water supply and quality.

Stony Clove Creek Statistics

Stony Clove Creek watershed encompasses approximately 32.3 square miles of watershed area in the Towns of Hunter in the headwaters and Shandaken in the lower valley to the mouth of the Creek where it joins Esopus Creek. Streams in the Stony Clove valley are primarily perennial streams, that is, they flow year-round except in smaller headwater streams or in extreme drought conditions. Within the Stony Clove watershed, the drainage pattern is dendritic (branching, tree-like form), typical of Catskill Mountain sub-basins uncontrolled by geologic factors (see Section 2.4 Geology of the Stony Clove Creek, for a discussion of how geology controls the shape of stream networks at larger scales).

Precipitation in the mountains that surround the Stony Clove watershed ranges from 50-60" per year, high even for the Catskills, and often comes in dramatic summer downbursts or late winter rain-on-snow events. Average slope of the watershed is 36.4%, the highest of any sub-basin in the New York City water supply watershed. *Drainage density*, or how much stream length is available to carry water off the landscape is average for the Catskills at $0.0018 m/m^2$. Given the average drainage density, combined with steep slopes and high precipitation, the stream system is relatively *flashy*, that is, stream levels rise and fall quickly in response to storm events. This flashiness is somewhat mitigated by heavy forest cover throughout much of the watershed.

Streamflow

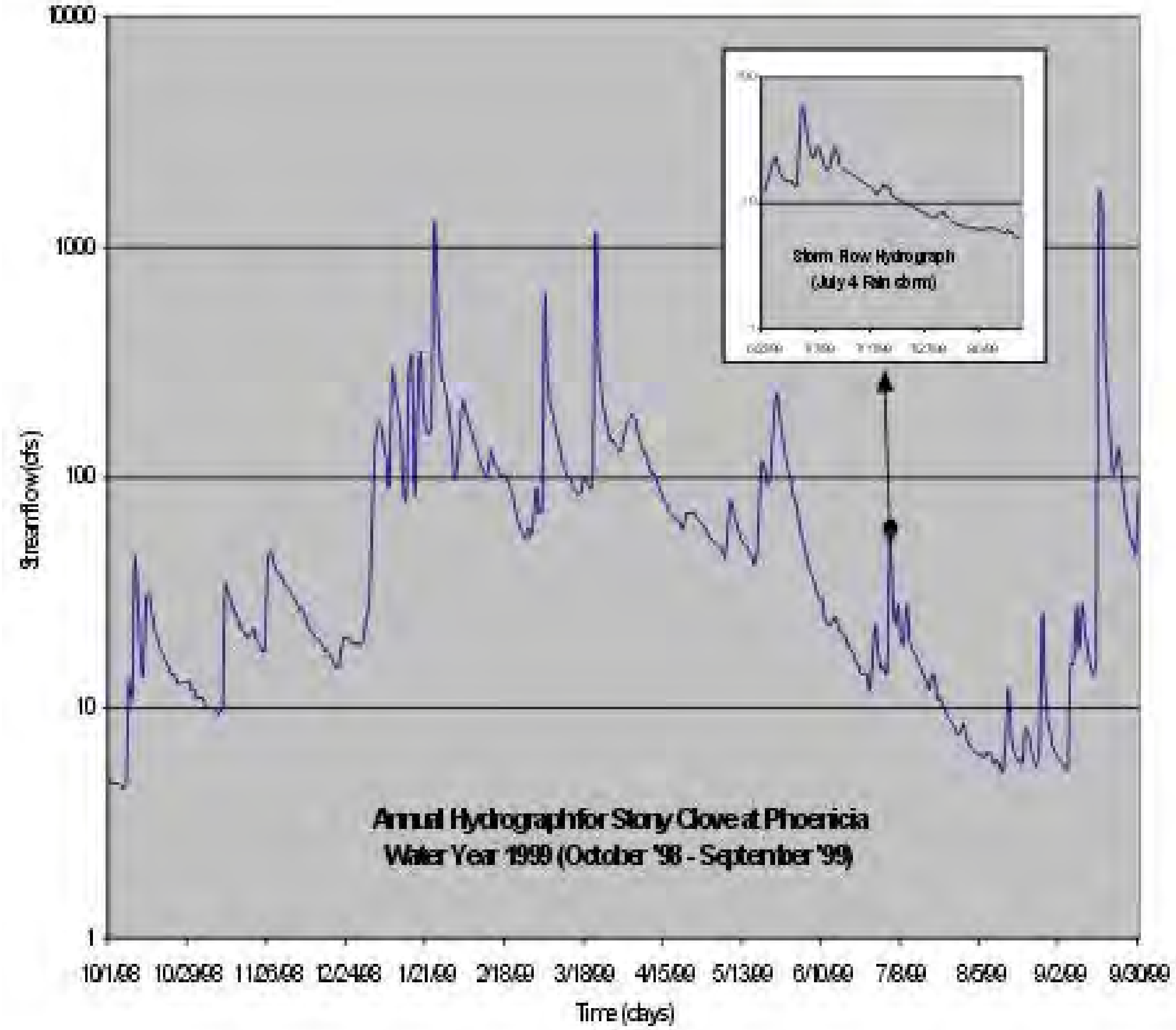
There are two general categories of streamflow of interest to stream managers: storm flow (also flood flow) and base flow, between which streams fluctuate over time. Storm flow appears in the channel in direct response to precipitation (rain or snow) and/or snowmelt, whereas base flow sustains streamflow between storms or during subfreezing or drought periods. A large portion of storm flow is made up of overland flow, runoff that occurs over and slightly 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 Stony Clove watershed is variable, depending upon time of year and severity of storms or snowmelt events. In general, higher streamflows are more common during spring due to rain and snowmelt 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, so precipitation events do not generally result in significant runoff to streams. However, frozen ground may increase the amount of overland flow resulting from a rain storm.

Subsurface storm flow, or interflow, comes from rain or snow melt that infiltrates the soil. Infiltrated water can flow rapidly through highly permeable portions of the soil or displace existing water into a channel by "pushing" it from behind. Subsurface storm flow shows up in the stream after overland flow, as stream flow declines back to base flow conditions. Base flow is water that drains from the land to sustain streamflow during dry periods and between storm flows. The source of baseflow is groundwater that flows through unsaturated and saturated soils and cracks or layers in bedrock adjacent to the stream.

The distinction between base flow and subsurface storm flow is transitional – that is, there is no specific time period or exact flow magnitude at which a stream is clearly at storm flow or base flow. Some hydrologists analyze hydrographs to assign some quantifiable distinction to base flow by tracing the rate of rise and fall of *stage*. Drawing a line connecting "valleys" of the hydrograph (the low points between storms) can serve as a divide for base flow and storm flow – amount of discharge above the line is storm flow, below the line is base flow. Another method involves calculating where the rate of rise and fall changes (identifying an "inflection point" on the graph) and connecting those points. These calculations can be useful in determining maximum sustainable rates of water withdrawals, or minimum releases from reservoirs, for preservation of wildlife and sustainable use of water supply.

Hydrologists use a *hydrograph* of a stream to characterize the relationship between flow and timing. A hydrograph is a graphical representation of the magnitude of streamflow over some period of time. A stream *gage* is necessary to monitor stream discharge and develop a hydrograph. The United States Geological Survey (USGS) maintains two continuously recording stream gages in Stony Clove Creek Watershed, one on the mainstem near Phoenicia (established 1996, drainage area 31.5 mi^2, USGS ID# 01362380), and another on Hollow Tree Brook tributary (established 1997, drainage area 1.95 mi^2, USGS ID# 01362342), in Lanesville.

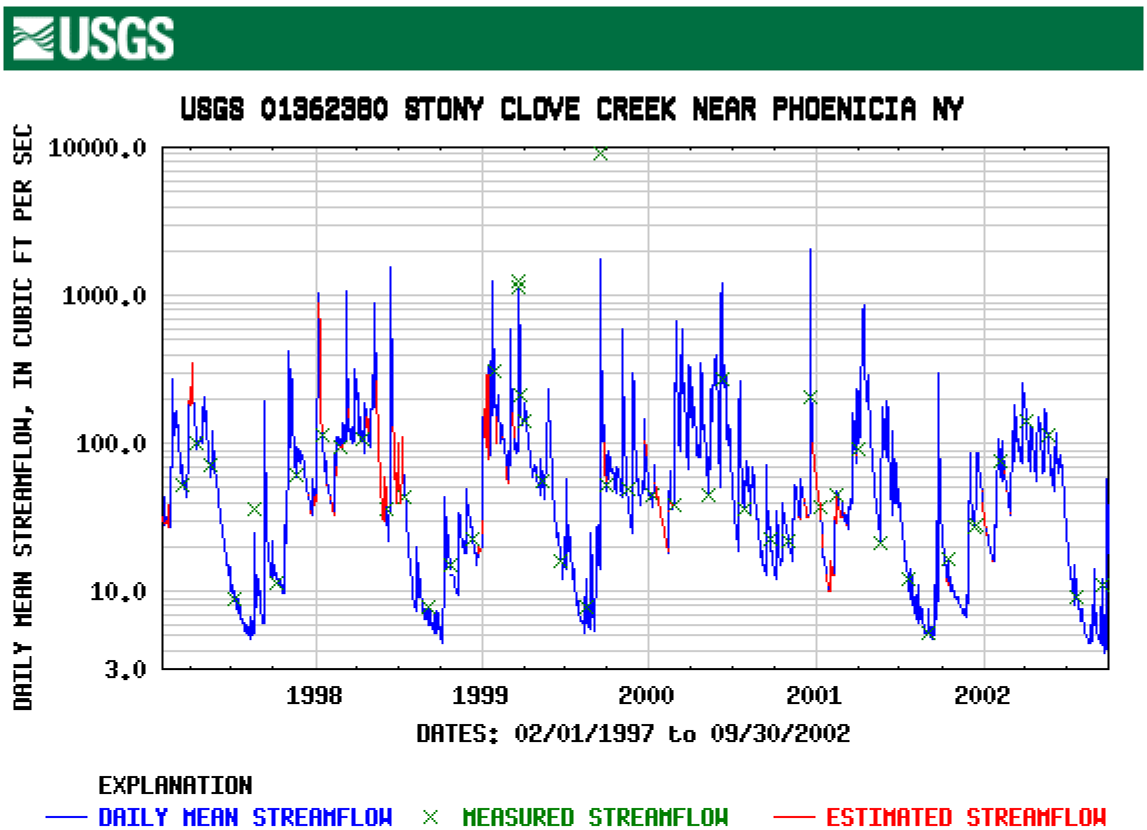
These gages measure the stage, or height, of the water surface at a specific location, updating the measurement every 15 minutes. By knowing the stage, we can calculate the magnitude of the *discharge*, or volume of water flowing by that point using a relationship developed by USGS called a stage-discharge or *rating curve.* Using this rating curve, the magnitude of flow in Stony Clove Creek at the gage location can be determined at any time just by knowing current stage, or predicted for any other stage of interest. Additionally, we can make use of 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.



Both Stony Clove gages have a long enough period of record to prepare a hydrograph for the stream (Figs. 1 & 2). Each spike on the graph represents increase and peak in stream flow (and stage) in response to rain storms. 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 hydrographs below, overland flow accounts for most of the sharp peaks. The insert graph in Figure 1 is a close-up of one of the storm flow events in the Stony Clove watershed at the Stony Clove at Phoenicia gage. At the end of June 1999 there was a small rainfall event that brought streamflow up from summer baseflow conditions. Storm flow receded back toward base flow conditions prior to the July 4, 1999 rain storm. Streamflow response to the July 4, 1999 rainstorm is rapid, presumably due to antecedent conditions from the previous rainfall, rising to approximately 80 cubic feet per second (cfs). Minor rains followed but eventually the landscape drained and streamflow returned to summer base flow conditions, approximately 8 cfs.

Streamflow always rises and peaks following the peak of a precipitation event because it takes time for water to hit the ground and run off to the stream (this is known as *lag time*). Knowing storm timing, we could also calculate lag time for Stony Clove Creek at the gage location, and determine how the stream responds to storms both in timing as well as in magnitude of resulting floods.

We can analyze a longer time period to see seasonal trends or long-term averages for the entire length (period) of gage record. We can see the record for both gages show higher flows in fall (hurricane season) compared to winter (water held in ice and snow), and higher flows in spring (snow and ice melt) compared to summer (drought conditions with vegetation using a lot of water). The highest flows of the year are generally associated with spring snowmelt.



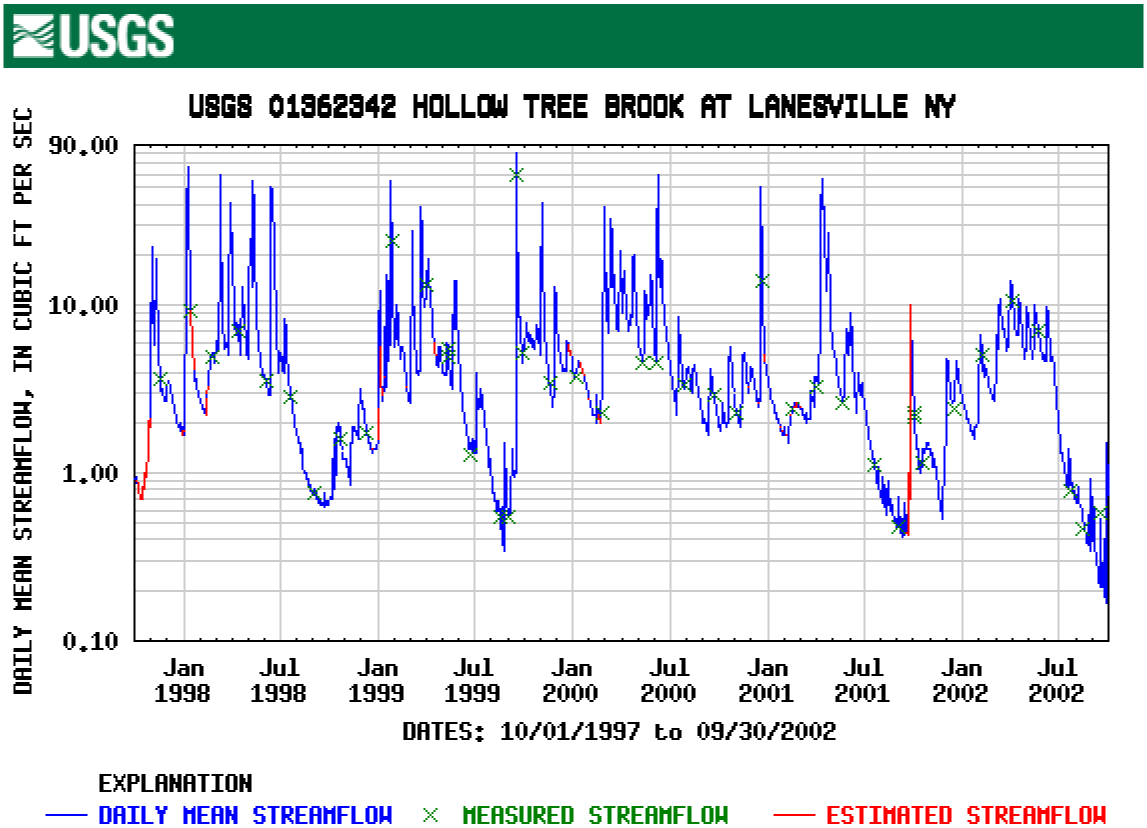
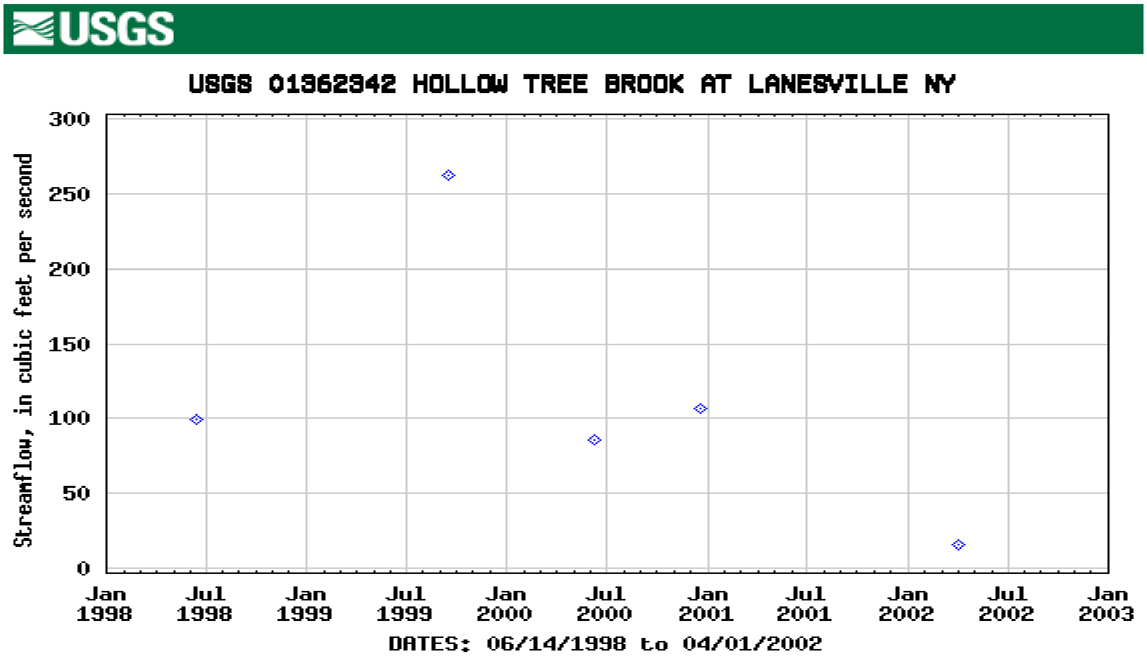


Figure 2 Hydrographs for selected periods, from USGS gages on Stony Clove at Phoenicia, and Hollow Tree Brook at Lanesville

Stony Clove Creek Flood History

Annual peak streamflow is the highest stream flow recorded for a particular 12-month period (usually from October 1 through September 30, or the "hydrologic Water Year"). The range of annual peak flows shows the dramatic range of peak flood magnitude that has been recorded on Stony Clove Creek, even in the relatively short period of record for each gage (Fig. 3). The greatest flood in any single year is not always a significant event, such as that recorded for 2002, a drought year. A longer detailed flood record can assist stream managers in determining potential range of future flood behavior.

Storm flows that exceed stream channel capacity or a certain stage are called floods. 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 raging torrents that wipe out bridges and carve new channels. Many agencies rely on evaluation of the likelihood of stream flooding in order to effectively manage the resource, plan developments or anticipate infrastructure or property damages and reconstruction needs.



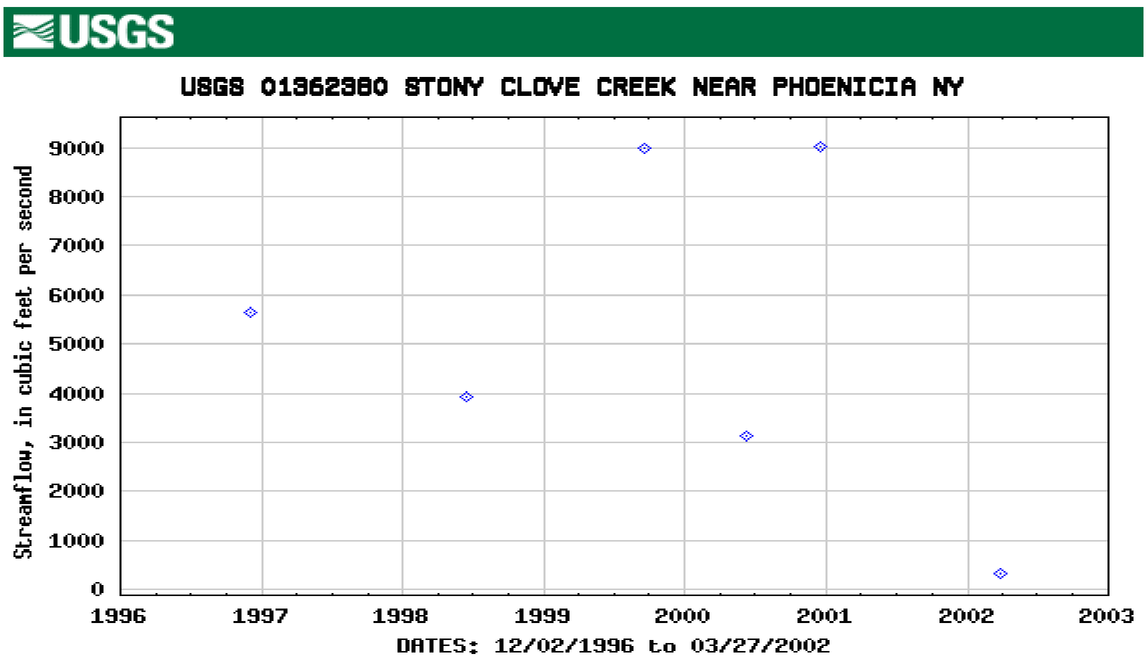


Figure 3 Flood peaks for selected periods, from USGS gages on Stony Clove Creek at Phoenicia, and Hollow Tree Brook at Lanesville

The most common way to analyze flood risk is to take the long-term peak flow record and assign a probability to each magnitude of flood event. USGS has a standard method for creating a flood frequency distribution from flood peak data for a gage, and provides peak flow data for public use (though generally provide flood frequency tables or graphs only on request).

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 the "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; probability remains the same year to year over time for a particular size flood to occur, 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.

As another interesting characteristic of flood frequency distributions, the 5-year flood may not even occur the "right" number of times in a certain period of record – for example, we might expect to see about 2 for every 10 years of record. 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 in 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. Because the length of gaging records is typically short compared to long-term history (on the order of 10-30 years, whereas 200-300 years might give a better long-term record), 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.

Since there have been no long-term historic stream discharge gages installed in Stony Clove Creek watershed, we can only report the specifics of major flood events of recent history in the basin (since 1996 or 1997). However, we can also evaluate gage records at two nearby gages, and interview knowledgeable individuals from the area to describe some major historical flood events and draw conclusions about the nature of flooding in the valley. Two nearby gages that have a sufficiently long record (10 years or more) to evaluate flood frequency and occurrence are Esopus Creek at Allaben and Bushnellsville Creek at Shandaken. Floods recorded at these gages that exceed a 5-year recurrence interval provide an example of distribution of floods over time. Recurrence interval can be misleading if a flood of a certain size is expected to occur at regular intervals. For example, during the 1980s four floods exceeding the "5-year event" occurred within a seven-year span on the Esopus, while there were no such events during the entire decade of the 1970s.

Esopus Creek at Allaben, NY	
Date	**Flood Discharge (cfs)**
3/30/51	20,000
7/28/69	7,870
3/21/80	15,900
2/20/81	6,540
4/5/84	8,470
4/4/87	16,100
1/19/96	15,000
Bushnellsville Creek at Shandaken, NY	
Date	**Flood Discharge (cfs)**
11/25/50	1,350
10/15/55	1,830
3/21/80	845
4/5/84	896
4/4/87	1,000
1/19/96	996

Table 1. Flood Flows at Nearby Gages that Exceed Five Year Recurrence Intervals[1]

Flooding occurs in response to excessive runoff associated with spring snowmelt, summer thunderstorms, fall hurricanes, and winter rain-on-snow events. Five of the seven major floods recorded at the Esopus Creek at Allaben station occurred in late winter/early spring and are presumably associated with major snowmelt events from either spring thaw or rain-on-snow events. The largest recorded flood is a spring runoff event. A summer flood in 1969 and the flood of January 1996 are the two other large floods recorded at the gage. Three of the six major floods recorded at the Bushnellsville gage occurred during the spring and are coincident with three of the Esopus events, showing some comparison can be made between nearby streams. Conversely, the figure also shows that weather in the Catskills is such that storms can produce very localized historically significant flood events.

Two of the events (the two largest) are late fall events in the 1950s and are associated with large tropical storms/hurricanes. The January 1996 flood was approximately a 10-year RI flood on the Bushnellsville Creek (whereas this event produced much larger recurrence floods in other areas, demonstrating that between-stream comparisons are not always perfect). There have been many other floods that exceed the bankfull discharge event but are less than the 5-year RI flood. A little less than half of all recorded flood events occur in spring. Approximately 10% of flood events occur in summer. The remainder of floods are evenly split between winter and fall flood events.

From review of available data we can generalize that most bankfull and greater events will occur in late winter/spring as the result of thaws and major rain-on-snow events. This is in large part due to landscape storage of available water as snow and ice, reduced infiltration capacity if the

[1] Flood frequency statistics based on recorded peak flows through 1997.
Esopus Creek at Allaben, NY: 5 yr RI flood:~6,500 cfs 10 yr RI flood: ~9,500 cfs
Bushnellsville Creek at Shandaken, NY 5 yr RI flood:~800 cfs 10 yr RI flood: ~1,000 cfs

ground is still frozen (or partially so), and minimal evapotranspiration from vegetation, which would otherwise route moisture back into the atmosphere. Major floods of the 1980s all occurred in late February – early April, the largest on April 4, 1987 – most likely associated with considerable snow pack and melting conditions.

The 1990s were generally a time of moderate flood events in the vicinity of Stony Clove, with the exception of the winter flood of January 19, 1996, which was similar in scale to April 1987. Tropical Storm Floyd flood (September 1999) was typical of tropical storm events and sometimes uneven distribution of precipitation associated with those storms. While flooding in Esopus drainages was typically less than a 5-year event, several drainages in bordering Schoharie system had over a foot of precipitation in 24 hours with flooding that exceeded the 10-year event discharge. Summer thunderstorms are even more unevenly distributed across the Catskill Mountain landscape. The July 4, 1999 storm (Inset fig. 1*)* only affected sub-regions of the Catskills. Flash flooding may be occurring in response to a sustained storm cell in some of the drainages that feed Esopus Creek (e.g. Stony Clove), while only steady, lighter rainfall along the storm boundary results in a moderate, gradual increase in stream flow elsewhere in the Esopus system.

The years 2000 – 2002 were characterized by droughty conditions with intervening wet conditions. High water events were typically limited to bankfull (or smaller) events. 2003 was an unusually wet year, with several larger than bankfull events occurring during the summer. Predicting precisely when the next 5-year (or greater) flood will occur in Stony Clove is impossible – the probability for a large flood is the same each year – though weather and storm patterns can be used to anticipate conditions for a few months out, and general seasonal patterns are generally reliable. The last large flood was in winter 1996, and the probability is high the next flood will likely occur in late winter/early spring when snowpacs melt under heavy rains.

Implications of Stony Clove Flooding

The unique hydrology of the Stony Clove affects how the stream corridor should be managed. 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 stream banks and in the floodplain. For example, applications for NYS DEC stream disturbance permits typically peak following floods, as landowners and municipalities attempt to repair damage caused by floods. If we want to minimize flooding impacts 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 usually 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, and 6.1 Flood Protection General Recommendations.