2.3 Hydrology and Flood History

Introduction

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

Water flowing through West Kill into Schoharie Creek reflects the integrated net effect 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 streamflow, referred to as the stream's *hydrologic regime*. 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.

West Kill Statistics

West Kill watershed encompasses approximately 31.2 square miles of watershed area almost exclusively in the Town of Lexington. Streams in the West Kill valley are primarily perennial streams, that is, they flow year-round except in smaller headwater streams or in extreme drought conditions. West Kill watershed is typical of main headwaters tributaries to the Schoharie Creek in that it is a long, narrow watershed running east to west. This drainage pattern is controlled by the topography, formed in large part during the last period of glacial activity. Within the West Kill watershed, drainage pattern of small side tributaries is primarily dendritic (branching, tree-like form) , typical of Catskill Mountain sub-basins uncontrolled by geologic factors (see Section 2.4 Geology of the West Kill, for a discussion of how geology controls the shape of stream networks at larger scales.

Precipitation in the mountains that surround the West Kill watershed averages 45.2 inches (1149 mm) per year, high for the Catskills, and often comes in dramatic summer downbursts, remnants of autumn hurricanes, or late winter rain-on-snow events. Average slope of the watershed is the steepest of any sub-basin in the Schoharie Creek basin at 28.9% (watershed elevation drops 28.9 feet for every 100 feet horizontal distance). *Drainage density*, or how much stream length is available to carry water off the landscape is lower than average for the Catskills, at $0.0013 m/m^2$. Given the average drainage density, combined with steep side slopes, short tributaries and high precipitation, the West Kill stream system is relatively *flashy*, that is, stream levels rise and fall quickly in response to storm events. Northfacing slopes on the southern side of the valley, including of West Kill Mountain, North Dome and Sherrill, receive little solar radiation (sun exposure) compared to southfacing slopes, a in the Northern Hemisphere. As a result, half of the West Kill valley retains snowpack well into the spring when rain on snow events can cause dramatic spring flooding, compounding either snow melt or rain storms on their own. This flashiness is somewhat mitigated by heavy forest cover throughout much of the watershed, though northfacing slopes generally have less vegetative cover due to reduced sun exposure.

Streamflow

There are two general categories of streamflow of interest to stream managers: storm flow (also called 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) 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 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 West Kill 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, 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, 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 if the air temperature is above freezing, particularly in spring on northfacing slopes as discussed above.

Subsurface storm flow, or *interflow*, comes from rain or snow melt that infiltrates the soil and runs downslope 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 West Kill 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 to base flow conditions.

Base flow consists of water that drains from the land slowly over time 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. In this way treams can sustain flow for weeks or months between precipitation events and through the winter when the ground surface and all precipitation is otherwise frozen. This phenomenon is what enables fish and other aquatic life to survive in streams year-round.

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 definitively at storm flow or base flow. Some hydrologists analyze *hydrographs* to assign some statistical quantitative distinction to base flow by tracing the rate of rise and fall in stage, or water level. A hydrograph is a graphical representation of the magnitude of streamflow over some period of time. Drawing a line connecting "valleys" of the hydrograph (the low points between storms, especially if averaged over many years of a period of record) 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. 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 two continuously recording stream gages on the West Kill, one on the mainstem near Spruceton (established 1997, drainage area 4.97 mi^2, USGS ID# 01349711), and another on the mainstem near West Kill (established in 1953 with occasional measurements, continuous measurement started in 1997, drainage area 27.0 mi^2, USGS ID# 01349810). All gage information is available online at the USGS website at http://nwis.waterdata.usgs.gov/ny/nwis/rt

These gages measure the *stage*, or height, of the water surface at a specific location, typically 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 *rating curve*. Using this rating curve, the magnitude of flow in West Kill at the gage location can be determined at any time just by knowing 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.

Both West Kill gages have a long enough period of record to prepare a hydrograph for the stream (Figures 1 and 2). Each spike on the graph represents a 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 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.

We can analyze long time periods 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, with rain-on-snow events) compared to summer (drought conditions with vegetation using a lot of water). The highest flows of the year are generally associated with the hurricane season in the fall, followed by winter and spring snowmelt or rain-on-snow events.

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 West Kill at the gage location for particular storms or types of storms, and determine how the stream responds to storms both in timing as well as in magnitude of resulting floods.

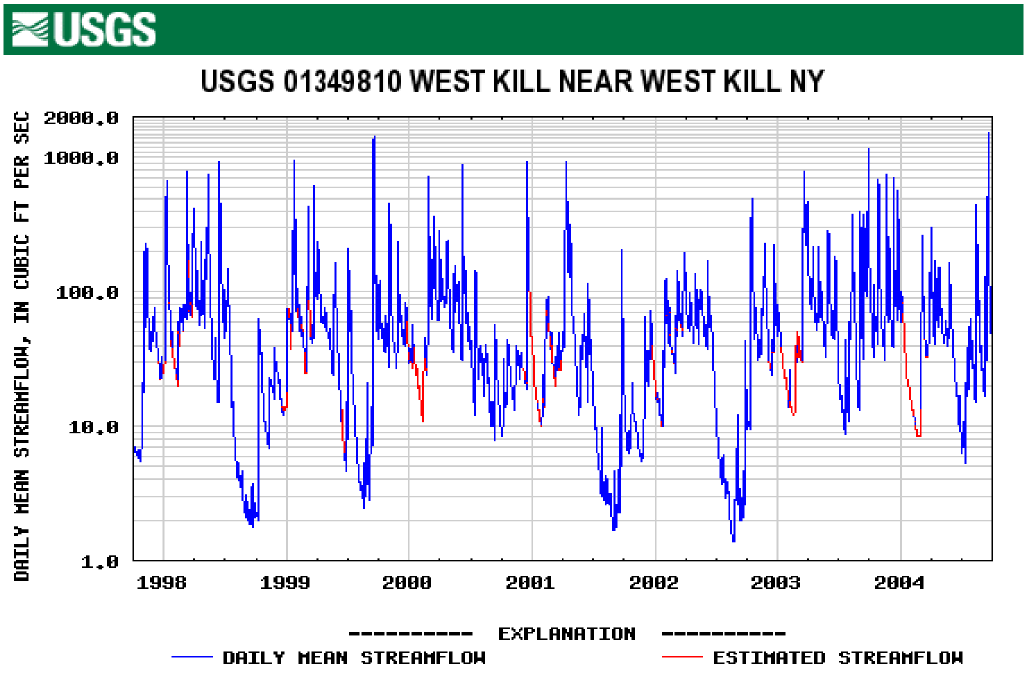

Figure 1. Hydrograph for the period of record WY98 through 04, USGS gage West Kill near West Kill.

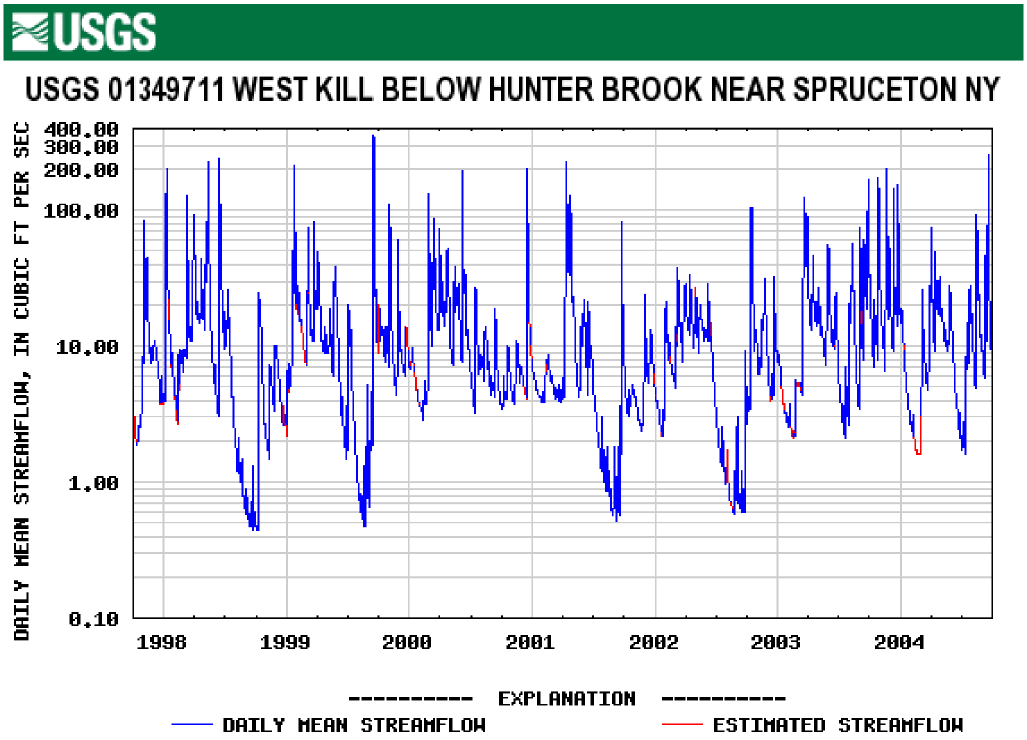

Figure 2. Hydrograph for the period of record WY98 through 04, USGS gage West Kill at Spruceton.

By looking at a shorter period of record, such as a single water year, we can see the seasonal pattern and specific storm events more clearly. The insert graph in Figure 3 is a close-up of the storm flow event associated with the remnants of Hurricane Ivan in September of 2004 at the West Kill near West Kill gage. Storm flow responded to precipitation very rapidly, with streamflow increasing from about 150 cfs to nearly 3,000 cfs within 24 hours. Within another two days, this flow nearly recovered to pre-storm flow. This storm was the highest recorded peak for this water year, and one of the highest for the entire period of record.

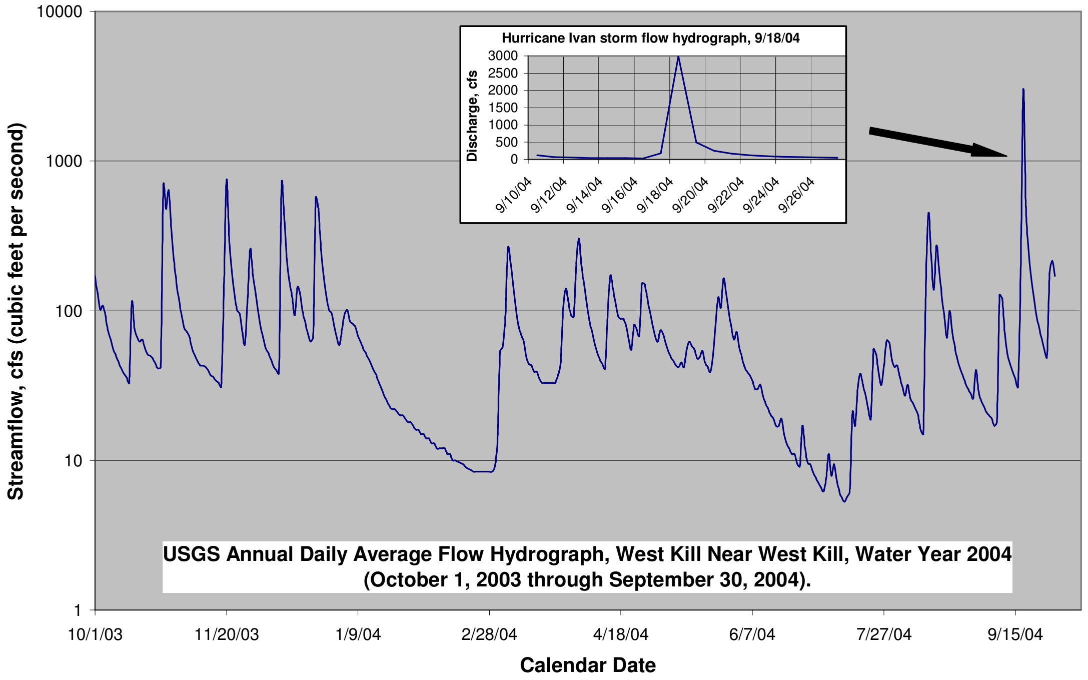

Figure 3. Daily Average Flow Hydrograph, USGS gage West Kill near West Kill, WY 2004.

West Kill 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 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 the dramatic range of peak flow magnitude that has been recorded on the West Kill, even in the relatively short period of record for each gage (Figures 4 and 5). The greatest flow in any single year is not always a significant event, such as that recorded for 2002, a drought year. A longer detailed flow record can assist stream managers in determining potential range of future flood behavior.

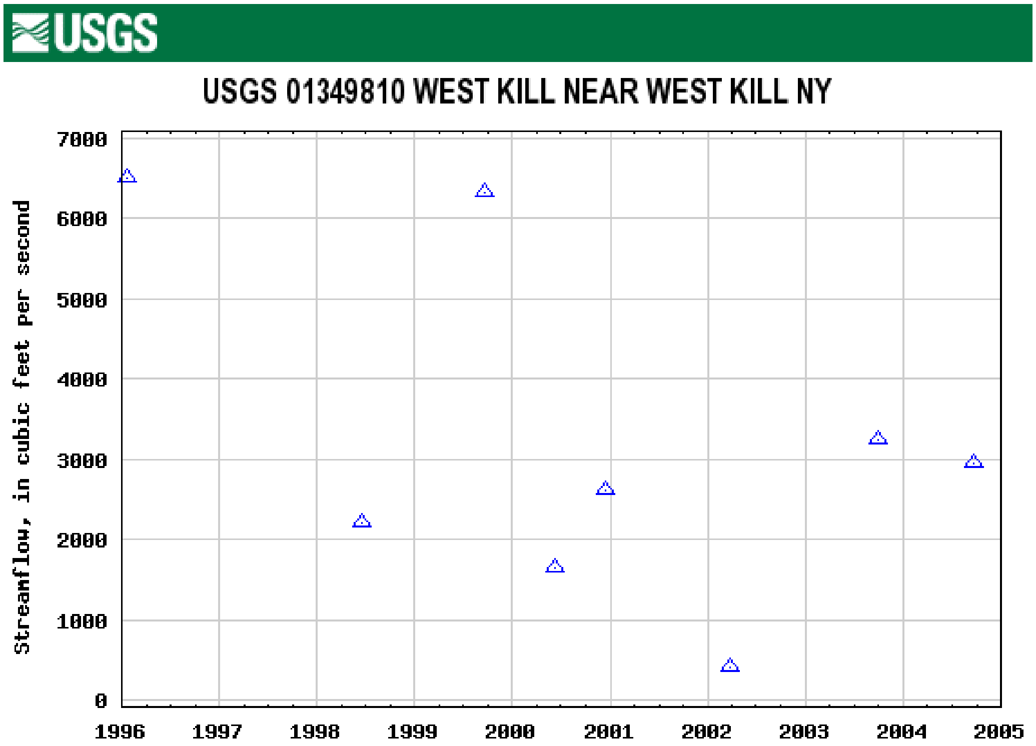

Figure 4. Annual peak flow for WY97 through 04, USGS gage West Kill near West Kill.

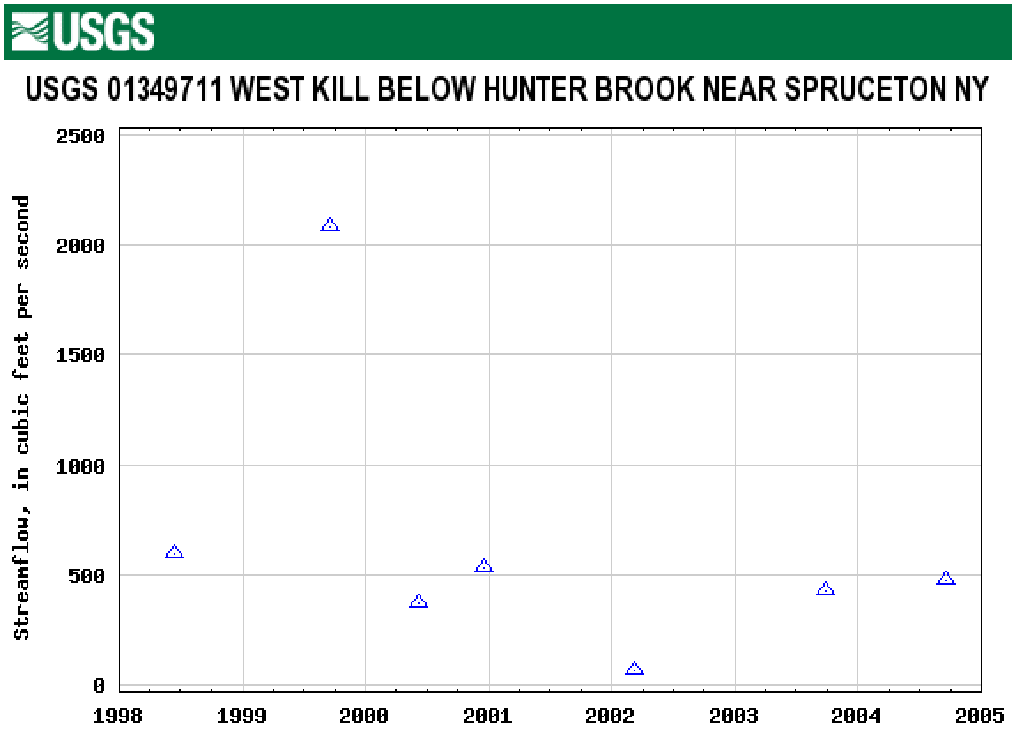

Figure 5. Annual peak flow for WY97 through 04, USGS gage West Kill at Spruceton.

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.

Photo courtesy Paul VanValkenburg

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. 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). Generally, the longer the period of record the more accurate the statistical probability assigned to each flow magnitude. Both gages on West Kill have too short a period of record to yield accurate flood frequency statistics at this time.

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 occur the "right" number of times in a certain period of record. For example, we might expect to see about 2 "5-year floods" for every 10 years of record, but any particular 10 year period may contain greater or fewer of this size flood.

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. 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 picture of how often the range of floods may occur. 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.

Since there have been no long-term historic stream discharge gages installed on the West Kill , we can only report the specifics of major flood events of recent history in the basin (since 1996 or 1997). However, we can evaluate gage records at nearby gages (Table 1), 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. Three nearby gages that have a sufficiently long record (30 years or more) are the mainstem Schoharie Creek at Prattsville, Esopus Creek at Allaben and Bushnellsville Creek at Shandaken. The Esopus and Bushnellsville are useful because they share a watershed divide (the mountains that border each watershed) and represent very similar hydrology and topography. The Schoharie Creek is useful because it represents the total accumulation of floods for the West Kill and its sister tributaries, but this large river can "damp" the flashy nature of floods in West Kill if other tributaries had lesser flooding for a particular storm.

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

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*
9/18/04	*6,700*
4/02/05	*20,400*
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*
9/18/04	*No data available*
4/02/05	*No data available*
Schoharie Creek at Prattsville, NY	
Date	***Flood Discharge (cfs)***
Sep. 30, 1924	*29,000*
Nov. 16, 1926	*42,300*
Aug. 24, 1933	*39,000*
Mar. 03, 1934	*50,002*
Jul. 08, 1935	*27,400*
Mar. 18, 1936	*38,500*
Feb. 22, 1937	*29,800*
Sep. 21, 1938	*45,000*
Nov. 25, 1950	*49,500*
Dec. 11, 1952	*28,200*
Aug. 13, 1955	*25,100*
Oct. 16, 1955	*51,600*
Dec. 21, 1957	*31,000*
Sep. 12, 1960	*49,900*
Jun. 22, 1972	*27,400*
Dec. 21, 1973	*24,900*
Dec. 08, 1974	*24,800*
Jan. 09, 1978	*30,600*
Mar. 21, 1980	*39,600*
Apr. 05, 1984	*29,500*
Apr. 04, 1987	*47,600*
Jan. 19, 1996	*52,800*
Sep. 16, 1999	*42,800*
Sep. 18, 2004	*26,500*
Apr. 2, 2005	*42,500*

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[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
Schoharie Creek at Prattsville, NY: 5 yr RI flood: ~24,000 cfs 10 yr RI flood: ~33,000 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, 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. On the Schoharie Creek in the 1930s, there were significant floods six years in a row, with two greater than the 25-year event – the size flood for which most NYS and county bridges are designed. By contrast, there were no such events during the entire decade of the 1940s.

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, weather in the Catskills can produce localized historically significant flood events such that a peak event may not be recorded at each gage for the same time period or storm event. Significantly, we can see that 10 of 25 events at Schoharie Creek occurred during hurricane season (late summer to late fall), 13 occurred during winter and spring, and only 2 occurred during summer. The January 1996 flood was approximately a 10-year RI flood on the Bushnellsville Creek, less than a 40 year event at Esopus Creek, and the "flood of record" at the Schoharie Creek. This shows that between-stream comparisons are not always perfect. This is especially so with summer thunderstorms, where highly localized storm cells can produce 10 or more inches of rain in one watershed, and only a few inches in an adjacent watershed for the same storm. Summer peaks shown in Table 1 do not overlap between any of the three sites.

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 ground is still frozen (or partially so), and minimal evapotranspiration from vegetation, which would otherwise route moisture back into the atmosphere. Other major floods can be expected during hurricane and tropical storm season in the late summer and fall, particularly as vegetation enters the dormant season and demand for water in the landscape drops off.

The 1990s were generally a time of moderate flood events in the vicinity of West Kill, 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.

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 West Kill 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, and seasonal patterns are generally reliable. The last really large flood was in April, 2005, but the probability is high that, when the next flood occurs, late winter/early spring during snowmelt/rainy season will be prime time.

Implications of West Kill Flooding

The unique hydrology of the West Kill has consequences for 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 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, and 6.2.5 Flood Mitigation & Protection.