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 upper Rondout 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.

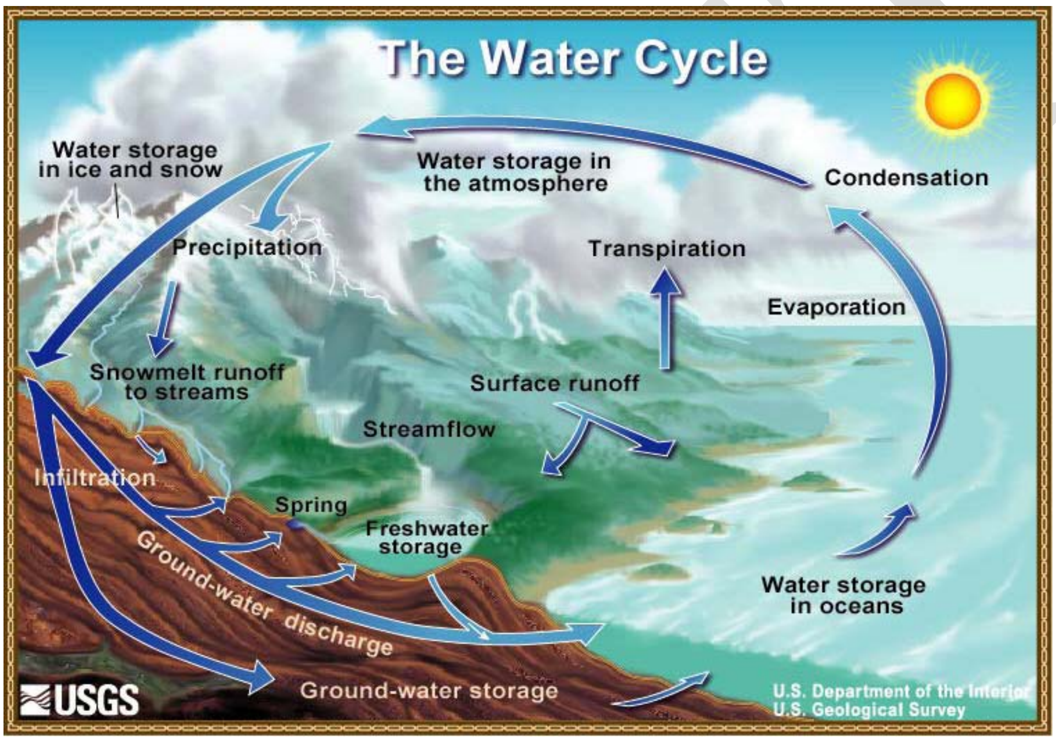

Figure 1 The Hydrologic (water) Cycle (http://ga.water.usgs.gov/edu/watercyclesummary.html)

Water flowing through the Rondout Creek 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 Rondout Creek, 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.

Rondout Statistics

The upper Rondout watershed encompasses over 40 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 upper Rondout runs northeast to southwest before entering the Rondout Reservoir in Neversink. The drainage pattern is controlled by the topography which was formed in large part during the last period of glacial activity. Within the upper Rondout 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 Upper Rondout*, for a discussion of how geology controls the shape of stream networks at larger scales).

Figure 2 High flows on Sundown Creek on January 25, 2010

Estimated mean annual precipitation at the USGS gage near Lowes Corners, NY is approximately 50-60 inches per year, and often comes as late winter rain-on-snow events (Photo 1), summer storms, or remnants of autumn hurricanes. 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 Rondout watershed is variable, depending upon time of year and severity of storms or snowmelt events. Higher streamflows 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 Rondout 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 two continuously recording stream gages on the upper Rondout, one above the confluence with Red Brook at Peekamoose (drainage area 5.36 square miles, USGS ID# 01364959), and another near Lowes Corners just upstream from the confluence with Sugarloaf Brook (drainage area 38.3 square miles, USGS ID# 01365000). 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 upper Rondout 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.

Both upper Rondout gages have a long enough period of record to prepare a hydrograph for the stream (see Fig. 3) for example from the gage near Lowes Corners). 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.

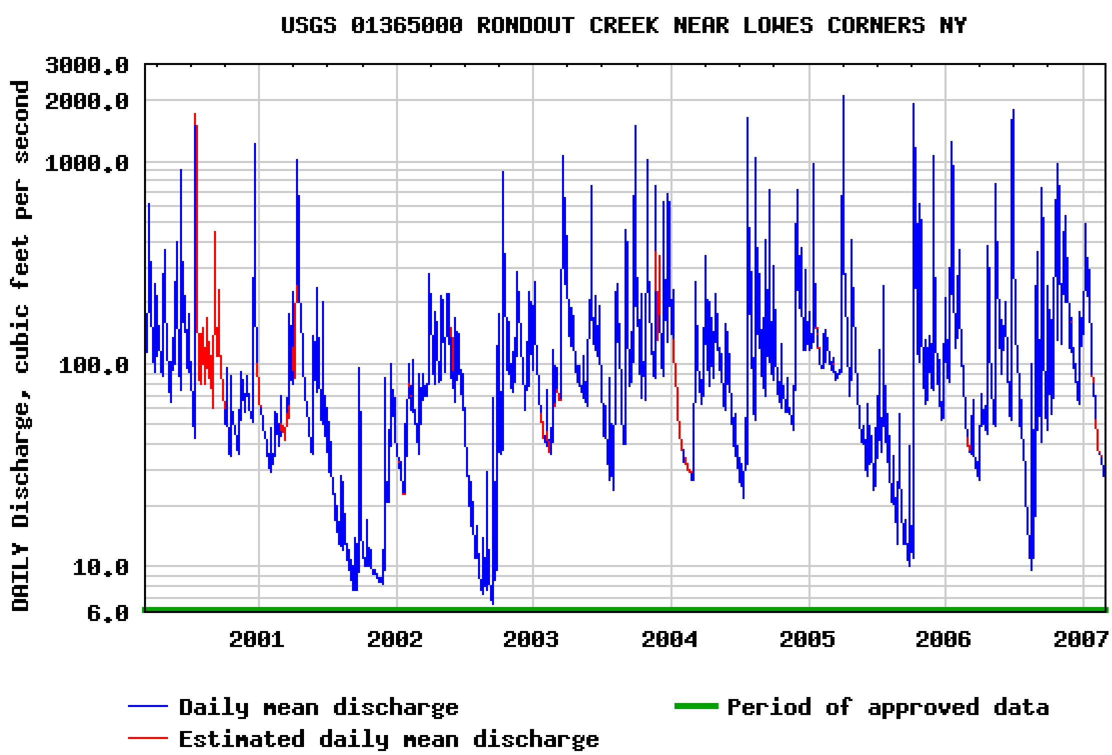

Figure 3 Hydrograph for the period of WY01 through 07, USGS gage Rondout near Lowes Corners

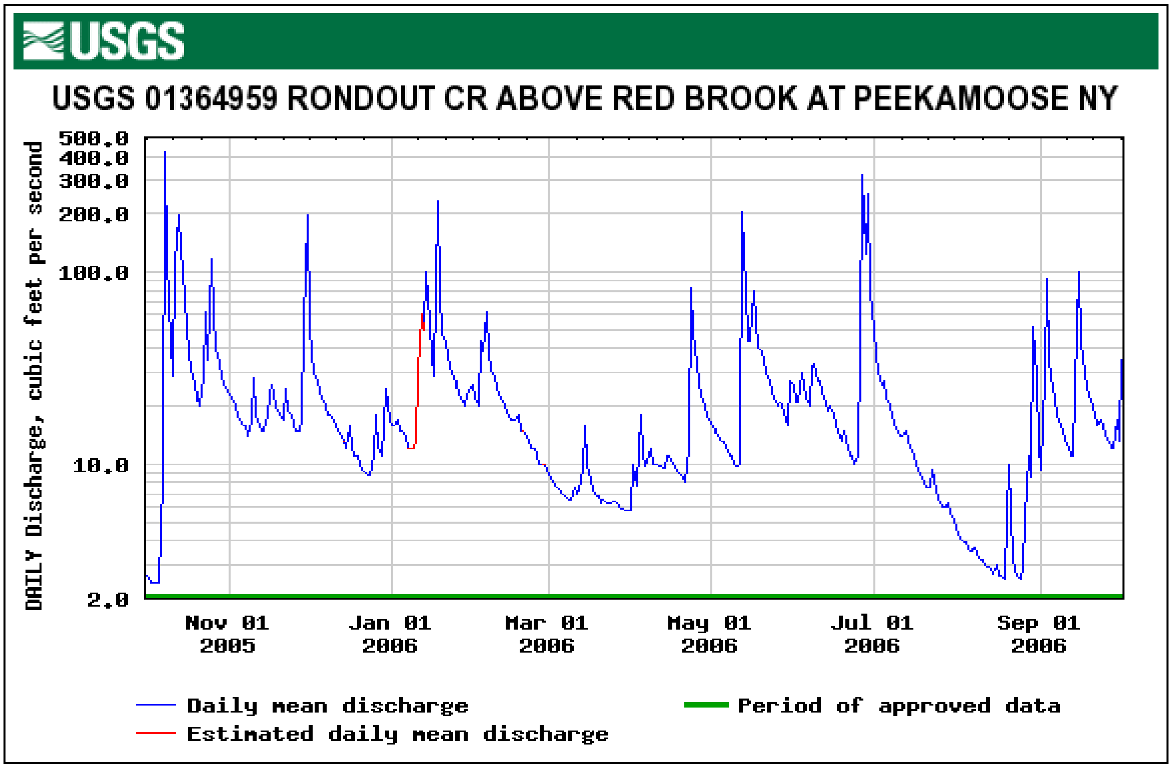

Figure 4 Daily Mean Flow Hydrograph, USGS gage Rondout at Peekamoose, WY 2006

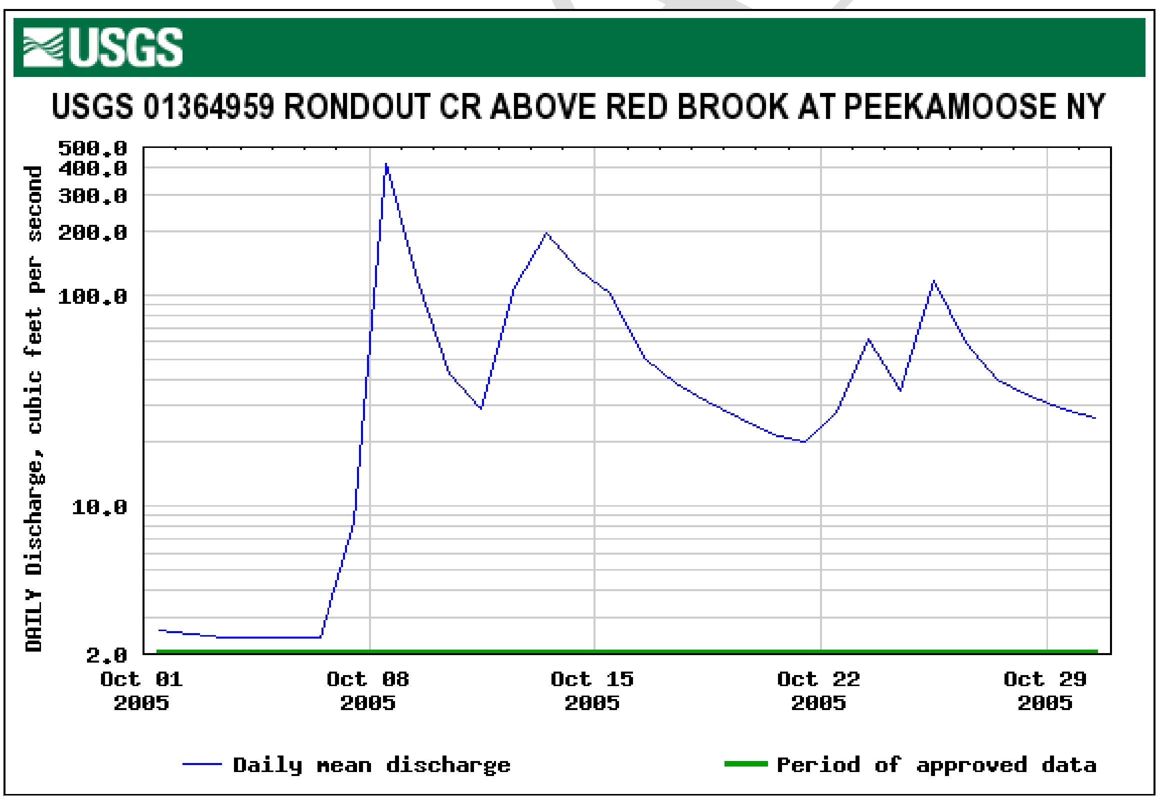

Figure 5 Hydrograph for October 2005 depicting remnants of Hurricane Tammy

The annual pattern of stream flow can be seen by looking at the flows from a single water year,

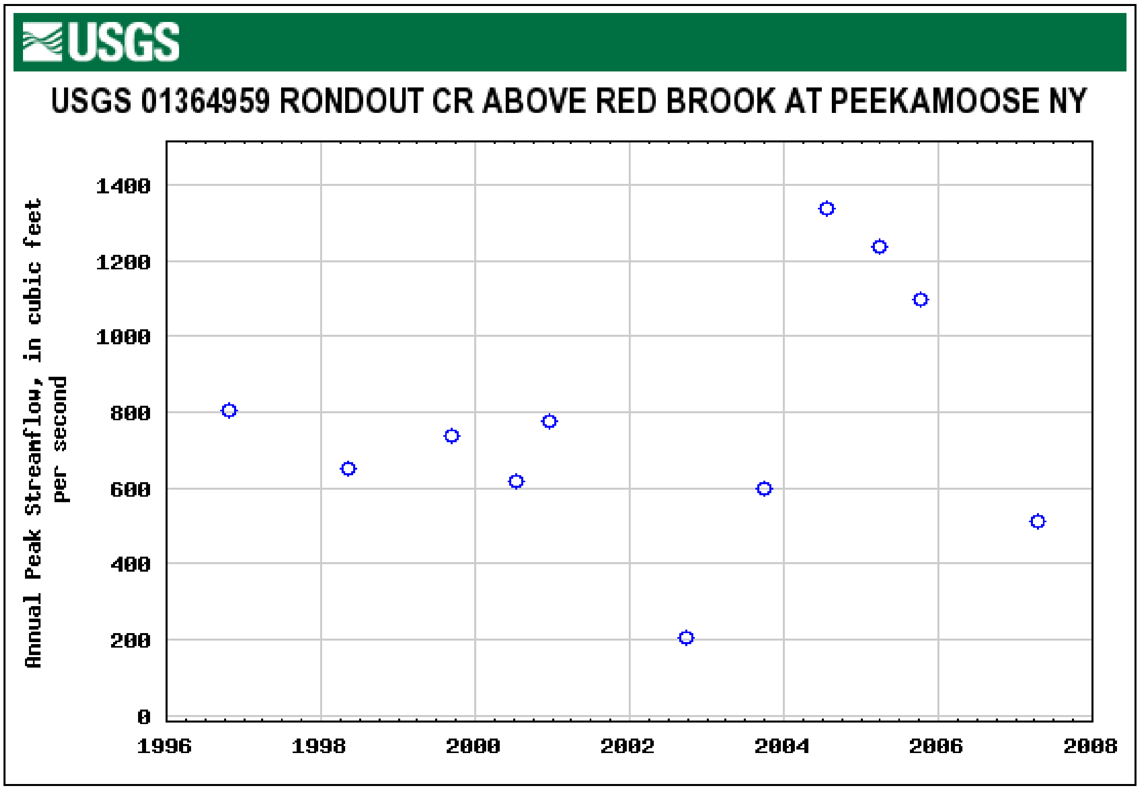

Figure 6 Annual peak flow for WY97 through 07, USGS gage Rondout at Peekamoose

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 Rondout gage at Peekamoose. 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. Stream flow increased from approximately 3-4 cubic feet per second (cfs) to nearly 400 cfs within 24 hours. Within another three days, this flow had dropped over 300 cfs and began to approach normal flow conditions. This storm was the highest recorded peak for this water year.

Rondout 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 the dramatic range of peak flow magnitude that has been recorded on the Rondout (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

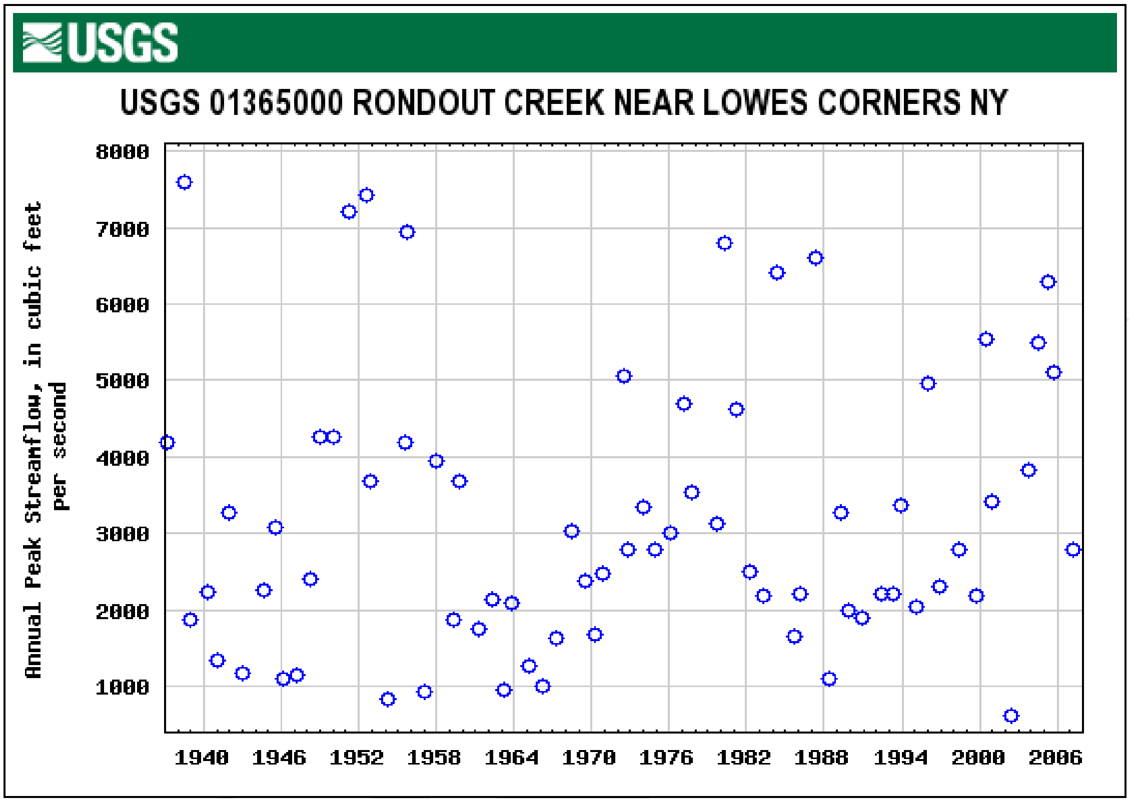

Figure 7 Annual peak flow for WY41 through 07, USGS gage Rondout near Lowes Corners

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 the Rondout gage near Lowes Corners has been established for 71 years, 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. In addition, we can evaluate gage records at nearby gages that have a sufficiently long record (30 years or more) (Table 1). Three examples are the Chestnut Creek at Grahamsville, Neversink River near Claryville, and Esopus Creek at Coldbrook. These gages are particularly useful because they surround the upper Rondout near Lowes Corners, and represent similar hydrography and topography.

Table 1 Flood Flows on the Rondout and Nearby Gages that Exceed Five Year Recurrence Intervals[1]

Rondout near Lowes Corners, NY	
Date	**Flood Discharge (cfs)**
7/22/1938	7600
3/30/1951	7200
7/10/1952	7430
10/15/1955	6940
6/22/1972	5050
3/13/1977	4690
3/21/1980	6800
2/20/1981	4630
4/5/1984	6410
4/4/1987	6610
1/19/1996	4950
7/14/2000	5550
7/23/2004	5500
4/2/2005	6300
10/8/2005	5100
Esopus Creek at Cold Brook, NY	
Date	**Flood Discharge (cfs)**
8/24/1933	59,600
3/12/1936	65,300
2/22/1937	55,200

3/30/1951	38,500
12/11/1952	51,700
10/15/1955	34,700
12/21/1957	30,000
12/21/1973	29,200
11/8/1977	53,600
3/21/1980	55,000
4/5/1984	37,400
4/4/1987	27,400
1/19/1996	46,900
9/16/1999	26,800
12/17/2000	26,800
4/3/2005	27,000
Neversink River near Claryville, NY	
Date	**Flood Discharge (cfs)**
7/22/1938	12400
12/24/1941	10000
11/25/1950	23400
7/10/1952	10200
10/15/1955	9950
7/28/1969	9880
3/13/1977	10000
9/6/1979	11700
3/21/1980	15600
2/20/1981	14400
4/5/1984	10700
4/4/1987	19300
1/19/1996	12700
11/9/1996	10400
12/17/2000	11800
4/2/2005	17200
6/28/2006	11500
Chestnut Creek at Grahamsville, NY	
Date	**Flood Discharge (cfs)**
7/19/1945	2200
11/25/1950	3900
7/10/1952	3320
8/18/1955	3800
10/15/1955	4640
12/20/1957	2190
7/28/1969	3630
6/29/1973	3560
7/20/1975	4310
4/4/1987	2200
4/2/2005	2950
6/28/2006	2820

[1] Flood frequency statistics based on recorded peak flows through 2008.
Rondout Creek near Lowes Corners, NY: 5 yr RI flood: ~4,395 10 yr RI flood: ~5,585 cfs
Esopus Creek at Cold Brook, NY: 5 yr RI flood: ~26,485 cfs 10 yr RI flood: ~37,411 cfs
Neversink River near Claryville, NY: 5 yr RI flood: ~9,840 cfs 10 yr RI flood: ~12,445 cfs
Chestnut Creek at Grahamsville, NY: 5 yr RI flood: ~2,148 cfs 10 yr RI flood: ~2,884 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 2000-2005 four floods exceeding the “5-year event” occurred on the Rondout, while there were no such events during the entire decade of the 1960s.

Flooding occurs in response to excessive runoff associated with spring snowmelt, summer thunderstorms, remnants of fall hurricanes, and winter rain-on-snow events. Six of the fifteen major floods recorded at the Rondout Creek near Lowes Corners station occurred in early spring and are presumably associated with major snowmelt events from either spring thaw or rain-on-snow events (see Fig. 8). The largest recorded flood at this gage was a summer event. Seven of the sixteen major recorded floods at the Esopus gage occurred during the late winter/early spring, five of which are coincident with the Rondout events, showing some comparison can be made between nearby streams.

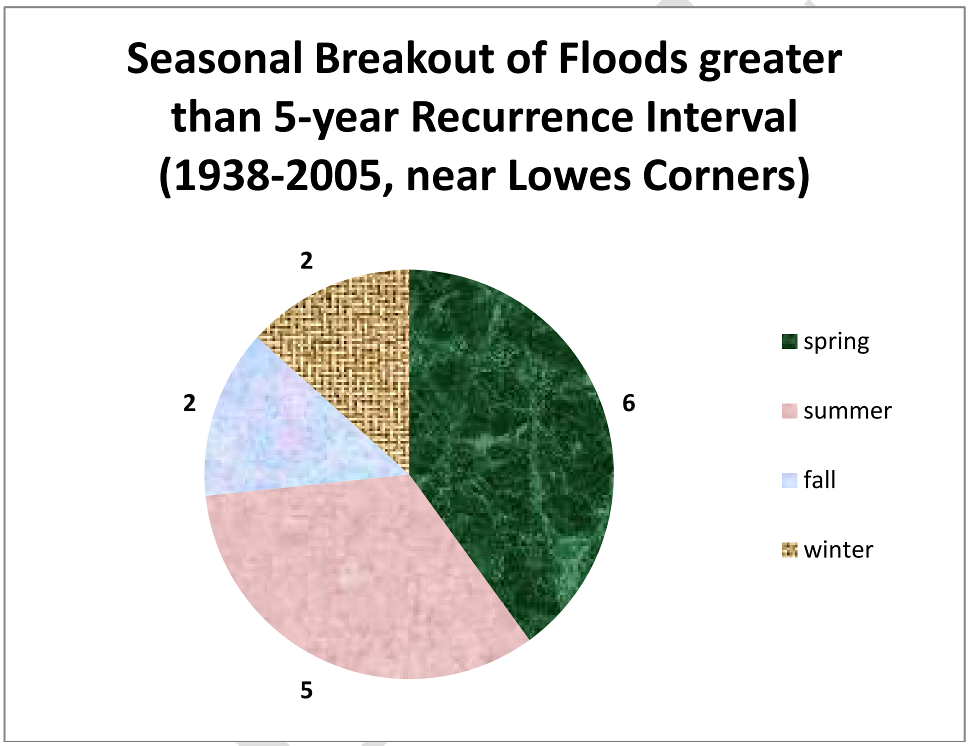

Figure 8 Seasonal distribution of floods of greater than 5-yr return frequency

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 ten year RI flood on the Esopus and Neversink, as well as strong five year events on the Rondout; yet did not cause a significant event on Chestnut Creek. In the table above, 29 floods happened between 1945-2006, the common timeframe among all four gages. Of these 29 floods only 4 floods were documented at all four gages, while 14 high flows were documented at single gages. This shows that between-stream comparisons 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 watershed, and only a few inches in an adjacent watershed for the same storm.

The 1990s were generally a time without significant flooding events on the Rondout, as well as nearby Chestnut Creek. The years 2000-2006 were characterized by drought-like conditions with

Figure 9 (a-d) Flood on Rondout Creek, April 4, 2005; gage near Lowes Corners registered 6300 cfs as the peak discharge (Photos by Linda Comando)

intervening wet conditions. High water events were typically limited to bankfull (or smaller) events. 2005 was a particularly eventful year for the Rondout, producing an above bankfull event in both the spring (Fig. 9, a through d) and autumn.

Implications of Upper Rondout Flooding

Predicting precisely when the next five year (or greater) flood will occur on the Rondout 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.

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. Understanding and planning for flooding behavior is critical to minimizing their impact on property, infrastructure and other damages or inconvenience. 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. 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.