V-B. Watershed Inventory and Assessment

The watershed level inventory and assessments performed for the Batavia Kill Pilot Project were initiated to assist the GCSWCD in evaluating and monitoring basin-wide physical characteristics, hydrology, and water quality. Initial assessments were conducted to characterize the physical attributes of the watershed, so as to document existing hydrologic characteristics and to refine their relationship to turbidity and total suspended sediment.

Watershed level assessments included valley morphology, stream order, and multiple hydrological assessments to include peak flow, historic flood trends, flood frequency, seasonal flow trends, and bankfull flow. Additionally an inventory of the hydraulic infrastructure to include bridges and culverts was performed as well as an inventory of the three flood retention structures located throughout the watershed.

1. VALLEY MORPHOLOGY

The classification of valley type and investigation of valley slopes can give an initial assessment of river morphology based on analysis of the broader landform characteristics. In general, headwater streams are steeper and less sinuous as the result of a narrower valley floor. As the stream progresses down its valley, slope typically decreases, the valley floor widens and streams exhibit greater sinuosity. Since stream channel types are closely related to valley morphology (Rosgen, 1996), an initial analysis was performed to delineate the Batavia Kill Valley into separate areas by slope class, Rosgen valley classification, and the Rosgen stream types found within each zones.

Rosgen (1996) identifies ten different valley types based on slope, confinement, sediment supply and whether the soils are colluvial, alluvial and/or glacial. While classification of the watershed based on valley types is somewhat broad, it can provide one variable by which stream managers can focus on typical stream form and function. An understanding of the valley form can assist stream managers in evaluating stream processes, as well as interpretation of channel resilience and recovery potential. To begin the analysis of valley morphology in the Batavia Kill basin, a digital terrain model of the watershed was created. A profile was then extracted from the model to illustrate the slope characteristics of the valley floor. In general, as shown on **Map IV-6**, the Batavia Kill Watershed is characterized by steep slopes and moderate to narrow valley widths. Approximately 80 percent of the land area in the watershed exceeds 10% slope. Seven general valley zones were identified from the valley profile on the basis of dominant slope characteristics **(Figure V-11)**. The seven zones, labeled "Valley Zone 1 - 7", starting with "Valley Zone 1" at the mouth, were then cross sectioned to illustrate the shape and grade of the valley slopes.

> **Valley Zone 1** extends from the mouth of the Batavia Kill at the Schoharie, to just over three miles up the valley. The overall land form slope of the zone was found to be approximately 1.2%. The slope and cross sectional characteristics of Valley Zone 1 suggest a type V valley. A type V valley is characterized by alluvial terraces, well-developed floodplains and a broad valley floor. Valley Zone 1 with a slope of 1.2% would typically support Rosgen stream types F, E, D and C.
>
> **Valley Zone 2** extends from the upper extent of Valley Zone 1 to about 8.25 miles up the valley from the mouth. The overall land form slope of this zone is approximately 0.3%. Valley Zone 2 is a type VIII valley, characterized by alluvial terraces, well-developed floodplains and a broad valley floor. The Rosgen stream types commonly found in valley type VIII with this slope are F, E, D, DA and C.
>
> **Valley Zone 3** extends from the upper extent of Valley Zone 2 to just under 12.75 miles up the watershed. The overall land form slope of the zone is approximately 0.7%. Valley Zone 3 is a type V valley, characterized by a wide, "u"-shaped valley trough, lateral and terminal moraines, floodplains, and alluvial terraces. The Rosgen stream types commonly found in this valley zone are G,D and C.
>
> **Valley Zone 4** extends from the upper extent of Valley Zone 3 to just over 17.25 miles up the valley. The overall land form slope of the zone is approximately 1.3%. Valley Zone 4 is a type V valley, characterized by a wide, "u"-shaped valley trough, lateral and terminal moraines, floodplains, and alluvial terraces. The Rosgen stream types commonly found in this valley zone are G, D and C.
>
> **Valley Zone 5** extends from the upper extent of Valley Zone 4 to just under 19 miles up the valley. The overall land form slope of the zone is approximately 2.7%. Valley Zone 5 is a type V valley, characterized by a wide, "u"-shaped valley trough, lateral and terminal moraines, floodplains, and alluvial terraces. The Rosgen stream types commonly found in this valley zone are G, D and C.
>
> **Valley Zone 6** extends from the upper extent of Valley Zone 5 to just over 19.75 miles up the valley. The overall landform slope of the zone is approximately 6.8%. Valley Zone 6 is a type I valley, characterized by "v"-shaped side slopes, high vertical relief, steep glacial scour lands. The Rosgen stream type most commonly found in this valley type, with such elevation relief, is the type A stream.
>
> **Valley Zone 7** extends from the upper extent of Valley Zone 6 to the upper most reaches of the valley. The overall land form slope of the zone is approximately 13.4%. Valley Zone 7 is a type I valley, characterized by "v"-shaped side slopes, high vertical relief, and steep glacial scour lands. The Rosgen stream type commonly found in valleys with slopes greater than 10% are the Aa+ streams.

The slopes present throughout a watershed is a constant physical parameter that influences many aspects of the watershed's stream network. By evaluating watershed slopes, stream managers can complete important analysis and interpretations of how water and sediment moves through the system. The magnitude and timing of both stream flow and sediment transport is strongly correlated to the watershed slope characteristics, and this influence on stream function in turn influences the stream's morphological form. The fluvial geomorphic approach applied to the management of the Batavia Kill requires an understanding of these constraints and their influence on the current form of the channel.

VALLEY PROFILE WITH REPRESENTATIVE CROSS SECTIONS

FOR EACH

VALLEY ZONE

VALLEY ZONE	VALLEY TYPE	VALLEY SLOPE	TYPICAL STREAM TYPES	STREAM TYPES FOUND
1	V	1.2%	G, D, C	F, B, C
2	VIII	.3%	F, E, DA, D, C	F, C
3	V	.7%	G, D, C	B, C
4	V	1.3%	G, D, C	B, C
5	V	2.7%	G, D, C	B, F
6	II	6.8%	A	A
7	II	13.4%	Aa+	Aa+ (NO ASSESSMENT)

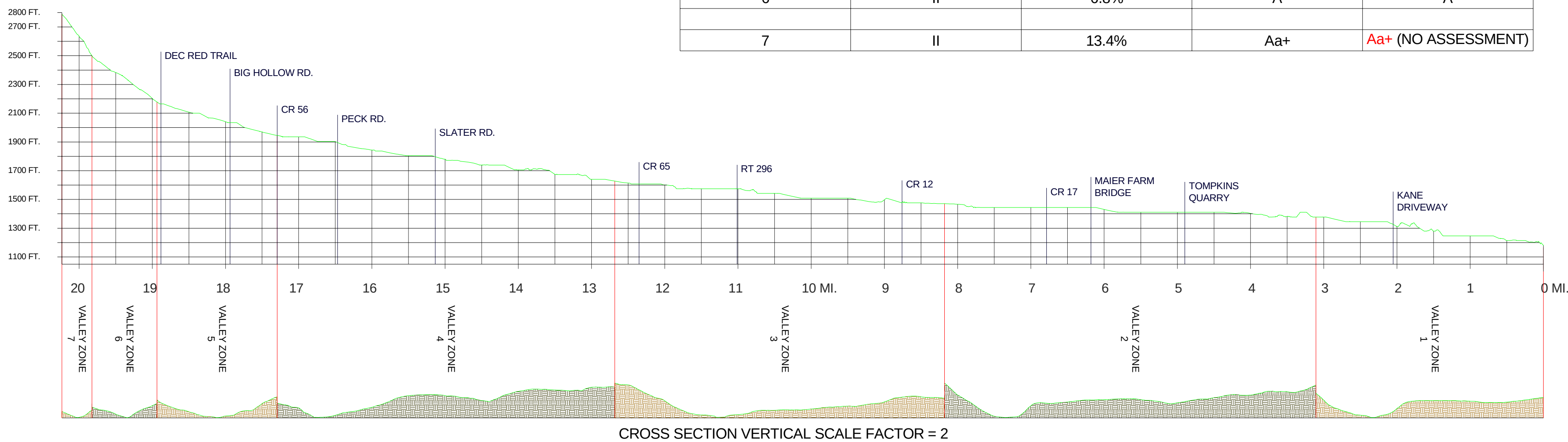


Figure V-11: Valley Zone delineation of the Batavia Kill watershed.

In addition to the direct influence on stream form and function, watershed slopes can impact overall stream health. As shown in the *Comprehensive Plan for the Town of Windham* (Chazen 2002), over half of the Town was characterized by slopes exceeding 25% and were considered unsuitable for development. Further investigations, which integrate slope with soil characteristics, indicate that nearly half the Town has severe limitations to support septic fields, road construction, foundations and other development features. The factors present conditions that can easily create non-point source impacts on the stream system.

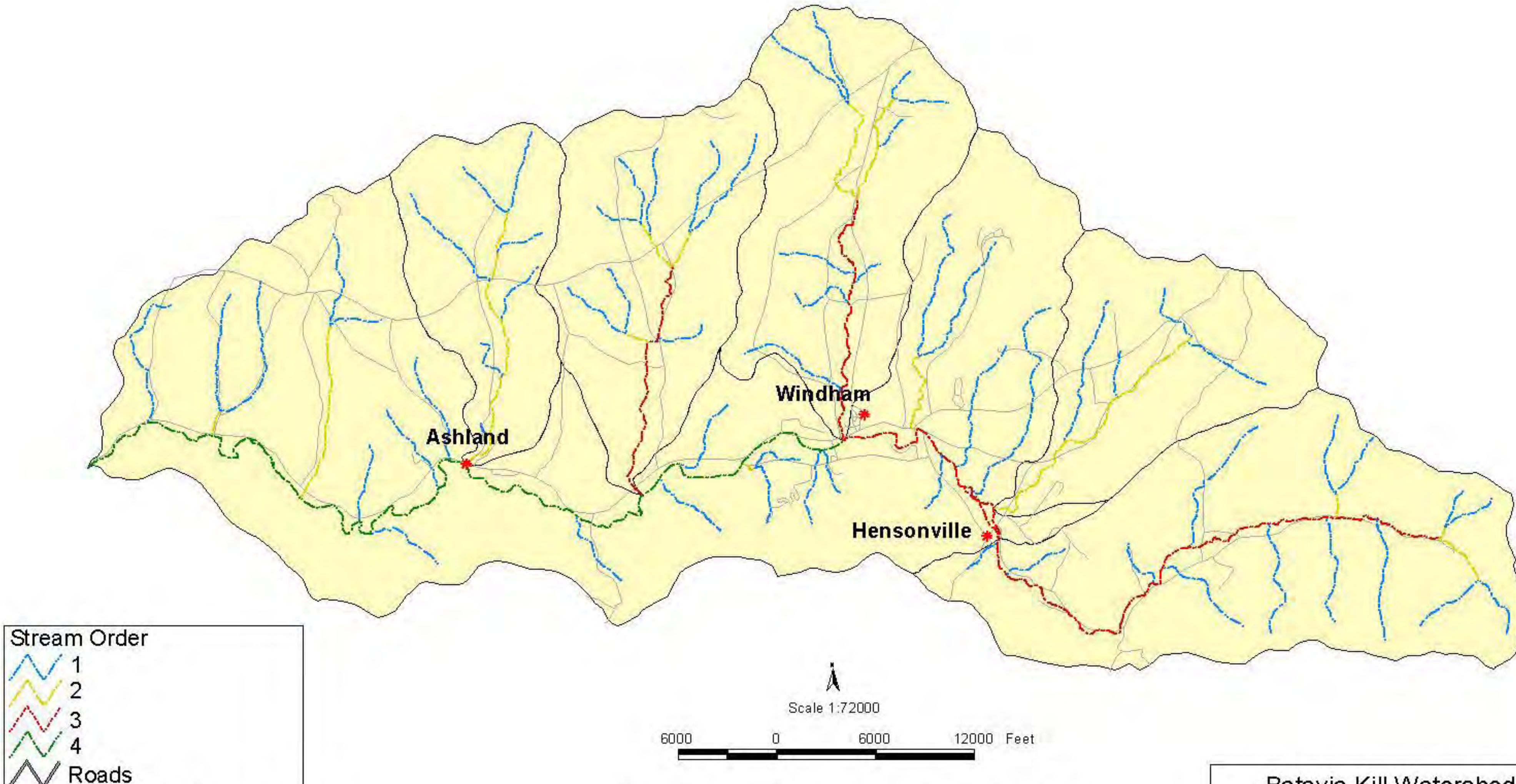
Although slope class ranges for the watershed were derived from low resolution data, the GCSWCD's evaluation of watershed slopes indicates that it is clearly evident that the watershed has areas where the valley walls impinge on the stream channel. These areas correspond with stream reaches that were experiencing severe erosion and mass wasting based on field inventories conducted after the 1996 flood. On the Batavia Kill, stream reaches subject to lateral constrictions are typically characterized by a reduction in floodplain area and increase in entrenched channel types. These reaches are subject to high stream energy within the channel, and are prone to degradation and vertical erosion. The formulation of these remotely sensed morphological 'nick-points' can assist in the development of a monitoring plan and assessment of reach limitations and constraints. The role of slope is discussed in further detail in Section V-C: Stream Corridor Assessment.

2. STREAM ORDER

In the Batavia Kill watershed, the GCSWCD examined the stream order classification using the methodology developed by A.H. Strahler in 1957 (Okanagan University, 2000). Using only those stream segments as identified on USGS (7.5 minute 1:24000) topographical maps for the watershed, the GCSWCD evaluated the stream ordering of the entire Batavia Kill watershed. The stream order characteristics of the Batavia Kill are presented in **Table V-1**, and **Map V-1**. Based on the application of the stream order classification system in various watersheds, researchers have observed a number of morphometric relationships that are commonly known as the Laws of Drainage Composition. (Stream order is a simple method of classifying stream segments based upon the number of tribuaries upstream. A stream with no tributaries is considered a first order stream. A segment downstream of the confluence of two first order is a second order stream. A n^{th} order stream is always located downstream of the confluence of two $(n-1)^{th}$ order stream.)

Table V-1 Summary of Stream Order in the Batavia Kill Watershed

Stream Order (J)	Number of Segments (N)	Length (mi) (L)	DA (mi^2) (A)
1	62	64.74	37.92
2	14	15.97	10.95
3	3	16.75	14.62
4	1	12.77	9.65



Data Sources:
Hydrography- digitized by NYCDEP from USGS Quad and SCS Maps 1993 edited by GCSWCD to show only streams found on USGS topo quads.
Watershed Boundary- NYCDEP derived from USGS topography 1965.
Stream Order-GCSWCD derived from USGS topo quads using Strahler stream ordering method
Roads-
Map produced by Greene County Soil & Water Conservation District, January 2001.
Note: GIS data are approximate according to their scale and resolution.
They may be subject to error and are not a substitute for on-site inspection or survey.

Stream Order	Length (m)	Length (ft)
1	104,194.96	341,846.28
2	25,694.76	84,300.20
3	26,958.89	88,447.62
4	20,556.45	67,442.26

Batavia Kill Watershed Stream Order

Map V-1
Greene County Soil & Water Conservation District
Batavia Kill Stream Corridor Management Plan

Researchers have proposed that these morphometric relationships indicate that some factor (or multiple factors) governs the structure of various stream attributes. Using these relationships, watershed managers can gain valuable information on the diversity of the drainage basin in relation to aquatic population, flow regimes and runoff characteristics (Pidwirny 2000).

Horton used the ratio of one stream order to the next higher order (Bifurcation Ratio, or BR) as an indicator of the Law of Stream Numbers. Work by Horton and others have shown BR value typically around 3, with values as high as 4.0 to 4.5 reported on other watersheds (Horton 1937). As shown n **Table V-2**, the Bifurcation Ratio in the Batavia Kill watershed is well within the limits of the typical values reported for other watersheds.

Table V-2 Bifurcation Ratio of the Batavia Kill

		2^{nd} to 1^{st}	3^{rd} to 2^{nd}	4^{th} to 3^{rd}
Bifurcation Ratio	$R_B = N_J/N_{J+1}$	4.4	4.7	3.0
Law of Stream Lengths	$R_L = L_{J+1}/L_J$	0.25	1.05	0.76
Law of Stream Areas	$R_A = A_{J+1}/A_J$	0.29	1.33	0.66

While the concepts of stream ordering have been used by researchers and stream managers for a number of years, the recent adoption of stormwater management guidelines, by NYSDEC, is expected to focus more attention on the role of specific stream segments within the overall drainage network. The recently published New York State Storm Water Design Manual (2001), provides sizing criteria for various levels of stormwater management. In addition to basic stormwater management criteria for water quality protection, the guidelines also address three additional levels of stormwater management. The Channel Protection (C_p) criteria are designed to protect stream channels from the impacts of the 1 year, 24 hr storm event, while Over-Bank Flood Protection (Q_P) addresses the 10 year, 24 hr storm event and Extreme Flood criteria (Q_f) address the 100 year, 24 hour storm event. Developed for NYSDEC by the Center for Watershed Protection, the design manual provides guidance on the requirements necessary to meet the conditions of the Phase II stormwater rules and regulations.

In the design manual, the section on uniform sizing criteria (chapter 4) states that local project reviewers may waive the requirements for addressing channel protection, over channel flow and extreme flood criteria if the stormwater discharge point is located in tidal waters or on a 4^{th} order or larger stream. On the Batavia Kill, the main stem of the stream is classified as 4^{th} order from the confluence of Mad Brook (Mitchell Hollow) to the Batavia Kill's confluence with the Schoharie Creek **(Map V-1)**. Subsequently, in this section of the valley, the NYSDEC guidelines allow for a waiver of all but stormwater management for water quality. The GCSWCD strongly recommends that local municipalities do not allow for exemptions to the NYSDEC guidelines in the Batavia Kill watershed based solely on the 4^{th} order stream waiver.

3. HYDROLOGICAL ASSESSMENT

Hydrology assessments in the Batavia Kill watershed were initiated to document and evaluate flood history, historical and seasonal trends in flow pattern, and to generate a basis for site specific monitoring. The initial step was to inventory the available data within the basin and to research existing analysis from regional studies or neighboring watersheds.

Figure V-12: USGS gage at Red Falls.

The USGS stream gaging stations located within the Batavia Kill watershed were inventoried, and historical flow data was assembled, in order to determine the magnitude and extent of historical flooding, and to evaluate the suitability of available data for development of seasonal trends in stream flow on the Batavia Kill. An additional gage station, located along the Schoharie Creek, was also evaluated to provide a longer historical record. This gage could be used in companion inventories with the Batavia Kill gages. The Batavia Kill is a sub-basin of the Schoharie Creek, and the gage is located downstream of the confluence with the Batavia Kill. The Schoharie gage has been used as a surrogate in other studies within the West of Hudson watershed due to the basin's similar physiography. The summary of the inventoried gage sites is provided in **Table V-3**.

Table V- 3: Batavia Kill USGS Gaging System Summary

USGS Gage #	Description	From	To	Drainage Area (mi^2)
01349840	Batavia Kill near Maplecrest	6/98	6/00	2.03
01349850	Batavia Kill at Hensonville	8/55	9/99	13.5
01349900	Batavia Kill near Ashland	4/87	6/00	51.2
01349920	Batavia Kill at Ashland	10/55	12/73	62.0
01349950	Batavia Kill at Red Falls	1/96	6/00	68.6
01349858	Silver Lake Outlet at Hensonville	5/76	9/77	6.70
01350000	Schoharie Creek at Prattsville	10/03	6/00	237.0

Primary assessments and examples were divided into three categories including, peak flow analysis, seasonal discharge trends, and bankfull discharge analysis. The GCSWCD has performed a number of additional analyses, but due to the nature of this plan only specific examples are presented.

Peak Flow Assessment

The assessment of peak stream flow in the Batavia Kill watershed can be used for numerous management interpretations. The analysis can identify peak flow history and frequency over time to assist in the understanding of the historic cycles of flooding. Additionally, peak flow assessment can assist in understanding the conditions that generate peak flows, provide a context for understanding the extent of channel disturbance, and confirm or dispel public perception about flood history.

Figure V-13: Monitoring site above Red Falls during bankfull event.

Specifically related to the Batavia Kill Pilot Project, the analysis of peak stream flows can be used to determine frequency and size of channel forming flows. Three categories of peak flow assessments are summarized below: historical flood trends, Batavia Kill flood frequency, and potential impacts from flood retention reservoirs.

Historic Flood Trends

Presently the USGS gage stations located within the Batavia Kill watershed do not provide a sufficient period of record for performing trends associated with climatic "wet and dry" cycles. The gage located on the Schoharie Creek at Prattsville has recorded 96 years of flow data, and is frequently used to study stream hydrology in the contributing sub-basins. Recent studies by the USGS have examined trends in extreme flows within the Catskill Mountains (Baldigo,1999). To analyze historic flooding trends, the USGS used the Schoharie Creek at Prattsville gage due to its long period of record, and its similarities to other basins in the area. In the analysis, the USGS also evaluated long term trends based on a 15-year weighted moving average of mean annual discharge. In 2001, the GCSWCD reproduced this analysis using additional data collected by the gage since the publication of the USGS study.

As shown in **Figure V-14**, the analysis completed by the GCSWCD was consistent with the findings of the USGS. The analysis indicated that the watershed was characterized by cycles of wetter and dryer periods. The axes represent the year of the storms occurrence and the peak discharge associated with them. Long-term discharge estimates for the frequencies of 10, 50 and 100 year storms are presented to show the magnitude of the flood events.

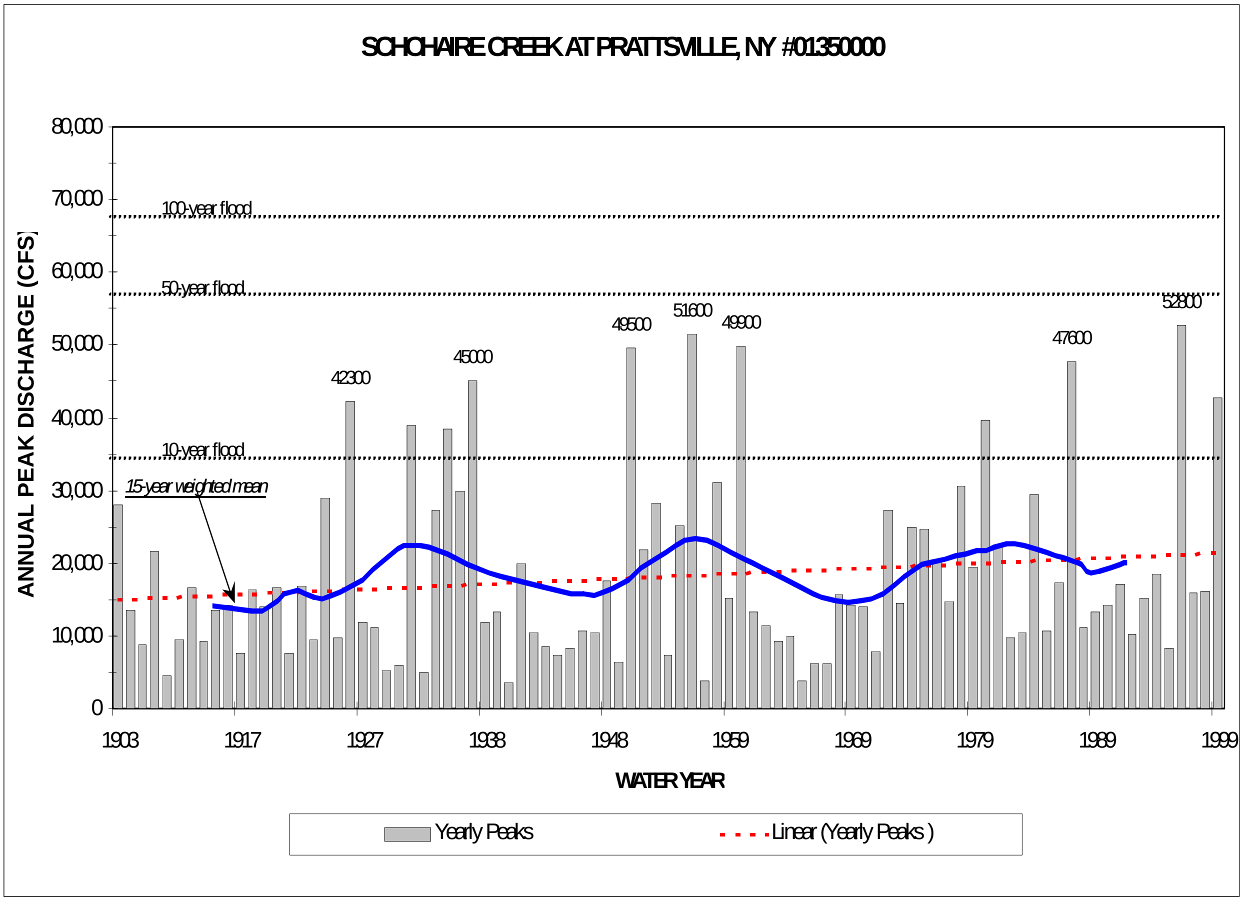


Figure V-14: Schoharie Creek historic yearly peak discharges.

The implications of the cyclic weighted average trend and the linear increase in average peak flow has tremendous importance in the management of the Batavia Kill. The cycle represented on the graph confirms trends in peak storm flow with approximately 20-25 years occurring between peaks. By forecasting the result forward, it can be determined that we are currently in a period of increased peak flow. Implications of this analysis can be applied to trends in erosion processes, floodplain function, and can be used to make management decisions regarding elements such as installation and construction of projects. The effects of land use and projected changes within the basin can also be used for planning the future use management of the Batavia Kill resource.

Batavia Kill Flood Frequency

Standard flood frequency determinations using guidelines outlined by the USGS (1981) requires a minimum period of record of ten years at each gage station used in the analysis. Presently, the majority of USGS gage stations located within the Batavia Kill watershed do not provide a sufficient period of record for performing flood frequency. The USGS gage near Ashland #01349900 has recently established 10 years of consecutive record for analysis, but caution must be used in its application due to effects of flow trends presented in **Figure V-14**, as well as implications of flood retention structures located in the watershed. Flood Frequency Curves for the Ashland and Hensonville gages are shown in **Figure V-15.**

Additional resources for discharge estimations and flood flow modeling include USGS regression equations (Lumia 1999) and a MOVE equation developed for the gage in Ashland (Heisig 1999). A summary of the flood frequency analysis for the Batavia Kill using these methods is summarized in **Table V-4**. Based on the flood frequency analysis shown in **Table V-4**, recent floods in 1996 (14,300 cfs) and 1999 (15,200 cfs) were slightly higher than the flood discharge calculated for a 10 year recurrence interval. Considering the level of damage from these two floods, and the observed scope of floodplain activity, the GCSWCD proposes that the watershed communities need to place a priority on preventing further development in the floodplain.

Table V-4 Batavia Kill Flood Flow Estimating

Batavia Kill Near Ashland, NY #01349900 (Flow values in cfs)			
Frequency	**Log Pearson III Ashland**	**Schoharie Regression for Batavia Kill (Heisig)**	**USGS Regional Regression Eq. (short)**
1.5	2954	4289	-------
2.0	4346	5655	*2493*
5	9293	10035	*4135*
10	13962	13870	*5507*
25	21717	19952	*7524*
50	28995	25497	*9216*

At the present time, improved Flood Insurance Rate Maps (FIRM) representing the 100 year floodplains are currently being developed by NYSDEC for the entire Schoharie basin (see Section IV-F). The new digital FIRMs are being developed with a much higher accuracy for modeling applications. Also, as the stream gage network within the Batavia Kill watershed matures, the data from a longer period of record will allow the development of flood frequency curves for these gages, thus increasing the accuracy of both flood frequency and flood surface estimation.

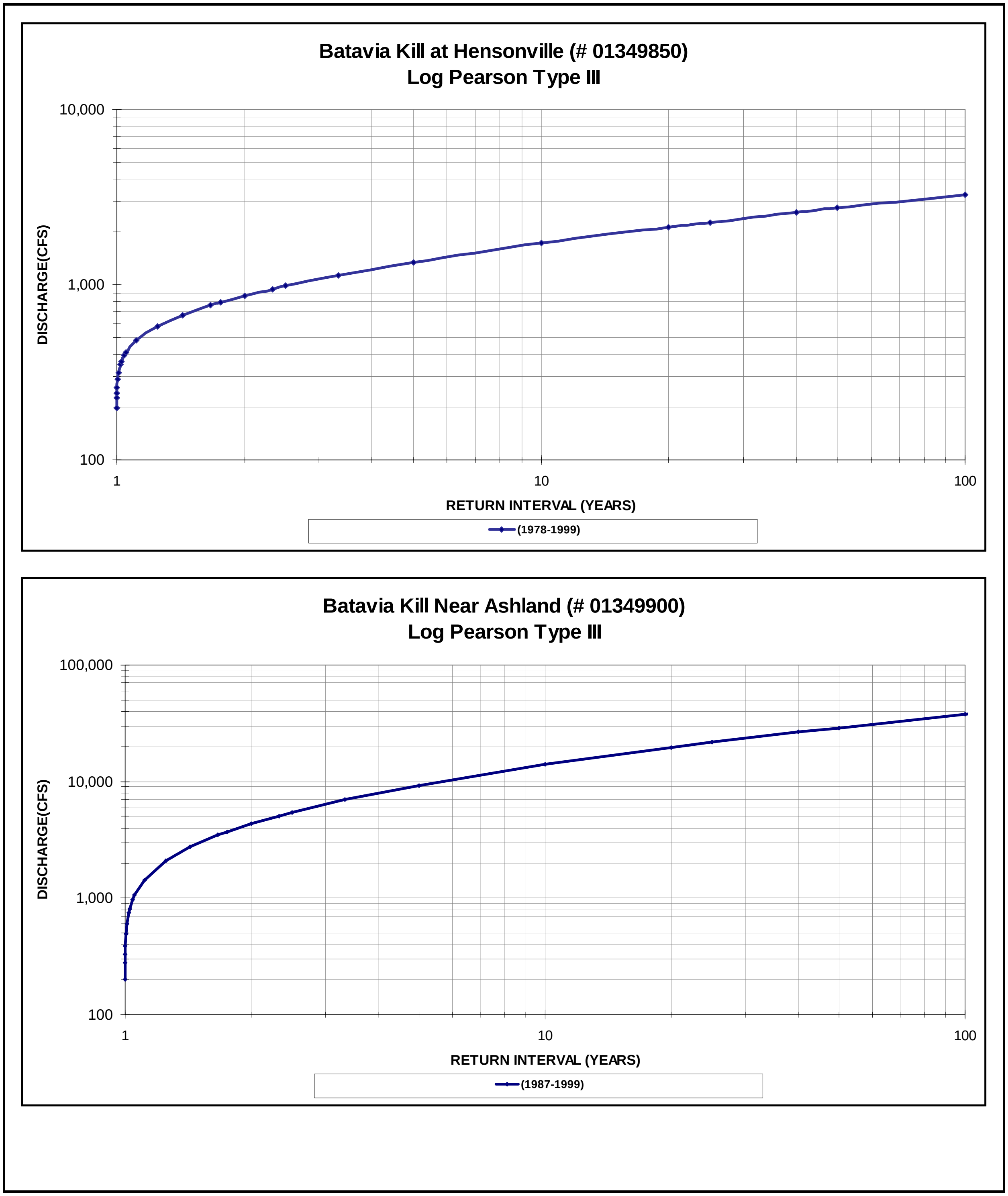


Figure V-15: Flood frequency curves for Hensonville and Ashland USGS stream gages.

Seasonal Flow Trends

Seasonal distributions of flow are also important for planning and management decisions. For example, knowledge of when a specific stream system experiences various levels of flow allows stream managers to schedule restoration efforts for intervals when the probability analysis indicates low flow conditions can be expected. Using the USGS gage near Ashland, the GCSWCD examined the seasonal flow variability on the Batavia Kill. As shown in **Figure V-16**, the Batavia Kill is characterized by a spike in the average discharge in the springtime, with runoff during April producing an average flow of over 155 cfs.

The months of July and August represent the summer low flows where the mean daily averages are only 4-8 cfs. The analysis also indicates smaller peaks in daily discharge in November and January. The November peak is likely associated with late fall storms, often related to the remnants of hurricanes. While the GCSWCD did not correlate the discharge data with either precipitation or daily watershed temperatures, it is thought that the January peak represents the "January Thaw".

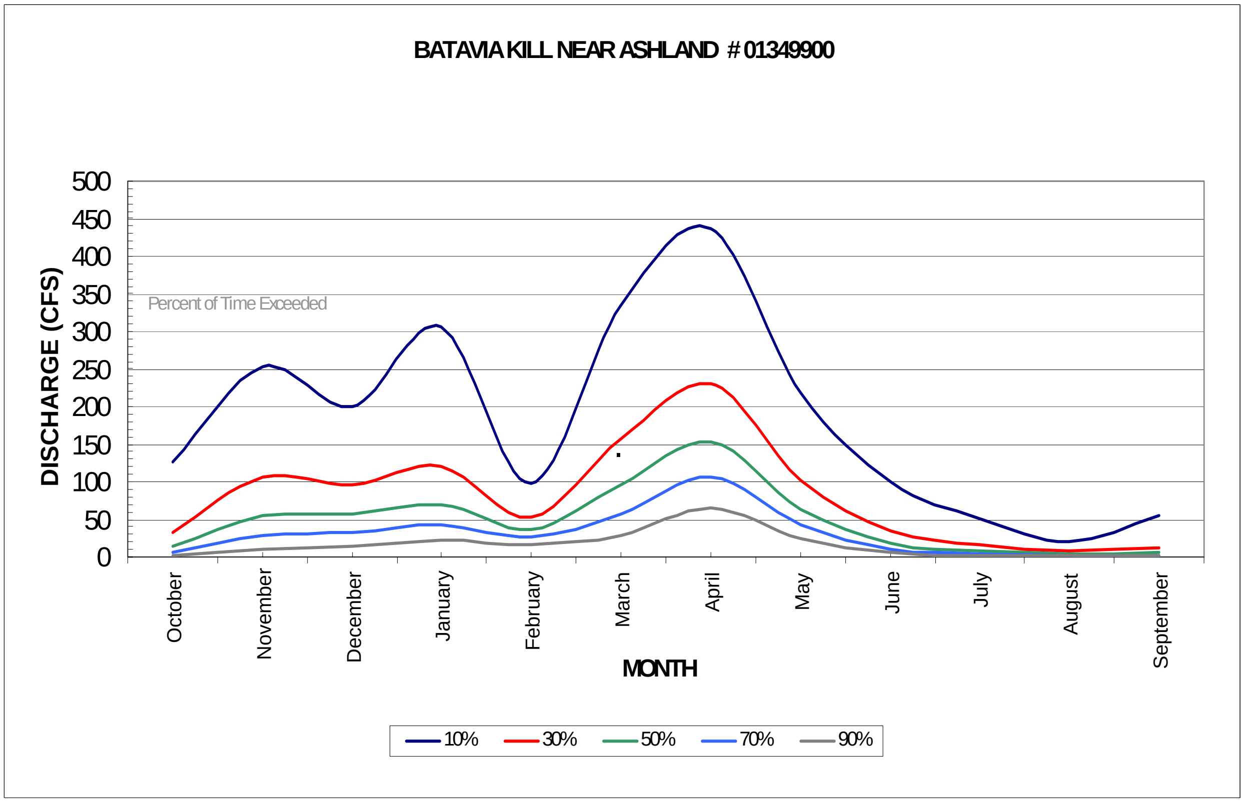


Figure V-16: Monthly probability curve for Near Ashland gage.

While the GCSWCD did not conduct detailed biological or fisheries habitat assessments in Phase I of the Batavia Kill Pilot Project, the impact of flow variability has long been a concern of stream managers. To sustain a healthy fish and macroinvertebrate community, a stream system must maintain adequate and stable stream flows throughout the entire year. Based on the GCSWCD's general observations of stream conditions on the Batavia Kill, seasonal low flows of 4-8 cfs in the lower watershed are often not adequate for maintaining suitable habitat conditions. Whether it is the complete loss of surface flow in highly aggraded areas, or the lack of adequate deep pools that provide thermal refugia for trout and macroinvertebrate communities, the Batavia Kill frequently experiences impacts from summer flows.

On the other hand, there has been a long running debate between stream regulators and the Catskill's ski industry regarding the impact of winter water withdrawals on in-stream habitat. The use of stream systems to supply water for snow making operations is central to the operation of the local ski industry. As important as summer low flows are on maintaining adequate temperatures, low winter flows can also have significant impacts on aquatic communities. Winter low flows can result in ice-over conditions which may reduce dissolved oxygen levels. A bigger impact is caused by the development of anchor ice when the flow is low and temperatures become very cold. Anchor ice destroys the insect and fish eggs deposited in the stream gravels which require a flow of water to provide the oxygen they need to survive the winter.

On the Batavia Kill, water withdrawals at Windham Ski Area are regulated and monitored by NYSDEC. Water withdrawals for snow making occurs between November and March. Ski Windham maintains a stream gage approximately ½ mile down stream from their water intake structure, and the ski slope's permit with NYSDEC allows for water withdrawals only when stream flows exceed 7 cfs. Again, while the GCSWCD did not correlate the data used to examine seasonal flow variability with the rate and amount of water withdrawals at Windham Ski Area, the reduction of flow during February as shown in **Figure V-16** may be impacted by these withdrawals.

The data analyzed by the GCSWCD appears to show that daily flows are typically much lower in the summer months than during the snow making season. The GCSWCD would recommend that additional studies be undertaken to determine if overall aquatic community sustainability would benefit more from mitigation of winter or summer low flow impacts. A resource for published duration curves for the specific gage at Ashland is the "Water Resources of the Batavia Kill Basin at Windham, Greene County , New York" (Heisig 1999), in which specific curves are given for the water consumption by Windham Mountain and the effects on stage and duration statistics.

Bankfull Flow

An evaluation of the stream discharge corresponding to the bankfull stage is central to the application of stream assessment and restoration methodologies based on geomorphology. The bankfull discharge provides a foundation for determination of hydraulic geometry and regime relationships that represent the morphological characteristics of the stream channel. There are several methods for determining bankfull discharge, including an evaluation of the specified recurrence interval, regional regression curves, and field identification of bankfull stage indicators. The calibration of bankfull discharge for the Batavia Kill corridor was assessed using a combination of these techniques.

Recurrence Interval

Figure V-17: Batavia Kill, at Maier Farm, at bankfull stage one day after tropical storm Floyd, Sept.1999.

The recurrence interval method for determining bankfull discharge assumes that the bankfull discharge exerts the primary influence on forming and maintaining the channel over time. Based on observations of researchers and stream managers across the country, the bankfull stage is typically associated with a discharge corresponding to a one to two year recurrence interval. This method involves calibrating field identified bankfull features with the stage-discharge relationships at a stream gaging station. As mentioned previously, the gage data through the Batavia Kill valley does not supply the period of record needed for a flood frequency estimation of the recurrence of the bankfull discharge. As a surrogate for this validation, regional relationships developed for similar basin conditions in the corresponding hydrophysiographic region can be used to estimate bankfull discharge in ungaged watersheds.

Regional Curves

The NYCDEP Stream Management Program is currently developing and testing a field protocol for bankfull discharge calibration at USGS stream gages. During Phase I of the project, the DEP conducted calibration surveys at 14 USGS gages located within the region. The provisional report by the NYCDEP Stream Management Program, *Identifying Bankfull Discharge and Hydraulic Geometry Relationships in the Catskill Mountains (2001)* has been used to assist the GCSWCD in the validation of bankfull discharge on restoration sites. When completed, the work by the NYCDEP and USGS will provide a full set of regional hydraulic geometry curves that will be useful to local stream managers. These curves will be used to assist in identifying and confirming bankfull stage during watershed-scale or site specific stream reconnaissance, to assist selection of bankfull discharge parameters at stable reference reaches used as templates in natural channel design, and to guide permit writers when issuing a NYSDEC or ACOE permit for stream disturbance (NYCDEP Five Year Plan, 2001).

Field Identification

Figure V-18: On stable stream reaches, the top elevation of depositional features such as this point bar are good bankfull indicators.

As discussed in Section III, there are a number of visual indicators which may be used to delineate the bankfull stage in the field. Some indicators are better than others, therefore this method must be used with caution, and bankfull determinations should be validated by other methods. Due to the limited period of record for stream gages on the Batavia Kill, and the lack of regional hydraulic geometry curves during the early years of the Batavia Kill Pilot Project, the GCSWCD initially developed limited hydraulic geometry curves based on field indicators. Riffle cross sections were surveyed at stream reaches that exhibited strong and consistent bankfull indicators, and the hydraulic geometry measurements of the cross sections were plotted against watershed area. The surveys also included water surface slope measurements and sediment particle size analysis to calculate the channel's relative roughness.

Relative roughness was compared to a series of graphs published in The Reference Reach Field Book to determine Manning's roughness coefficient (DLR Wildland Hydrology 1998). The Manning's equation paired with the continuity equation (Discharge = Area x Velocity) can then be used to calculate an estimated discharge for the field verified bankfull stage. Each estimated bankfull discharge was plotted against its corresponding drainage area to produce a Batavia Kill specific relationship. This was performed on all stream reaches independent of stream type and apparent channel stability.

In order to have a basis for initial comparison of the discharge obtained during the field identification procedure, the regional regression equation for the 2-year return (Lumia and 1991) was compared with data at each site. Data was additionally compared to regional curves for the Eastern US (Rosgen1996) as well as provisional curves under development by NYCDEP Stream Management Program.

Storm Assessment of the Batavia Kill

During the course of the Batavia Kill Pilot Project, the GCSWCD conducted annual monitoring surveys on over 100 cross sections along the stream corridor. While the majority of these cross sections were located on reaches identified as having stability problems, some cross sections were also monitored on reaches that appeared to be stable. By conducting annual surveys of the cross sections, the GCSWCD could observe the ongoing changes in the active channel, and use this data to determine the process responsible for the instability.

Since the basic assumption of geomorphology based assessment techniques is that the bankfull discharge is the primary influence on stream form, the GCSWCD reviewed stream gage data from the monitoring period to determine how the number of events that reached (or exceeded) the bankfull stage correlated with the instability documented at the monitored cross sections. Knowing the timing, number of events, and magnitude of flows in relation to physical monitoring of the channel form during the pilot project was necessary. This was determined by investigating the real time gage data at the Ashland gage. Storm events were separated at baseflow discharge to reveal the storm hydrograph and the corresponding peak discharge. The peak discharge of the storms were then viewed in chronological order and separated at 1,000 cfs (bankfull discharge) and correlated to monitored transects to view the physical responses of the channel.

Figure V-19 summarizes the frequency of bankfull events during the period that the GCSWCD has been monitoring stream instability on the Batavia Kill. Using data from the Ashland stream gage, the GCSWCD wanted to determine how many times the stream discharge had met or exceeded the bankfull stage (1,000 cfs at Ashland gage). In January 1996, a mid-winter flood occurred in the basin with the flood peak exceeding 13,000 cfs. During that year, 4 additional flow events exceeded the bankfull discharge. When the period of stream monitoring conducted by the GCSWCD is evaluated (1997 - 2001), it can be seen that seven bankfull or greater events (dotted line) have occurred. This excludes tropical storm Floyd in September 1999 when the peak discharge was over 15,000 cfs.

The frequency of events exceeding bankfull is consistent with the cyclic pattern in long term peak discharges discussed earlier **(Figure V-14)**. The high number of bankfull events, and the magnitude of the flood associated with tropical storm Floyd, are both assumed to have been a primary factor in the excessive rates of stream instability observed during the project period.

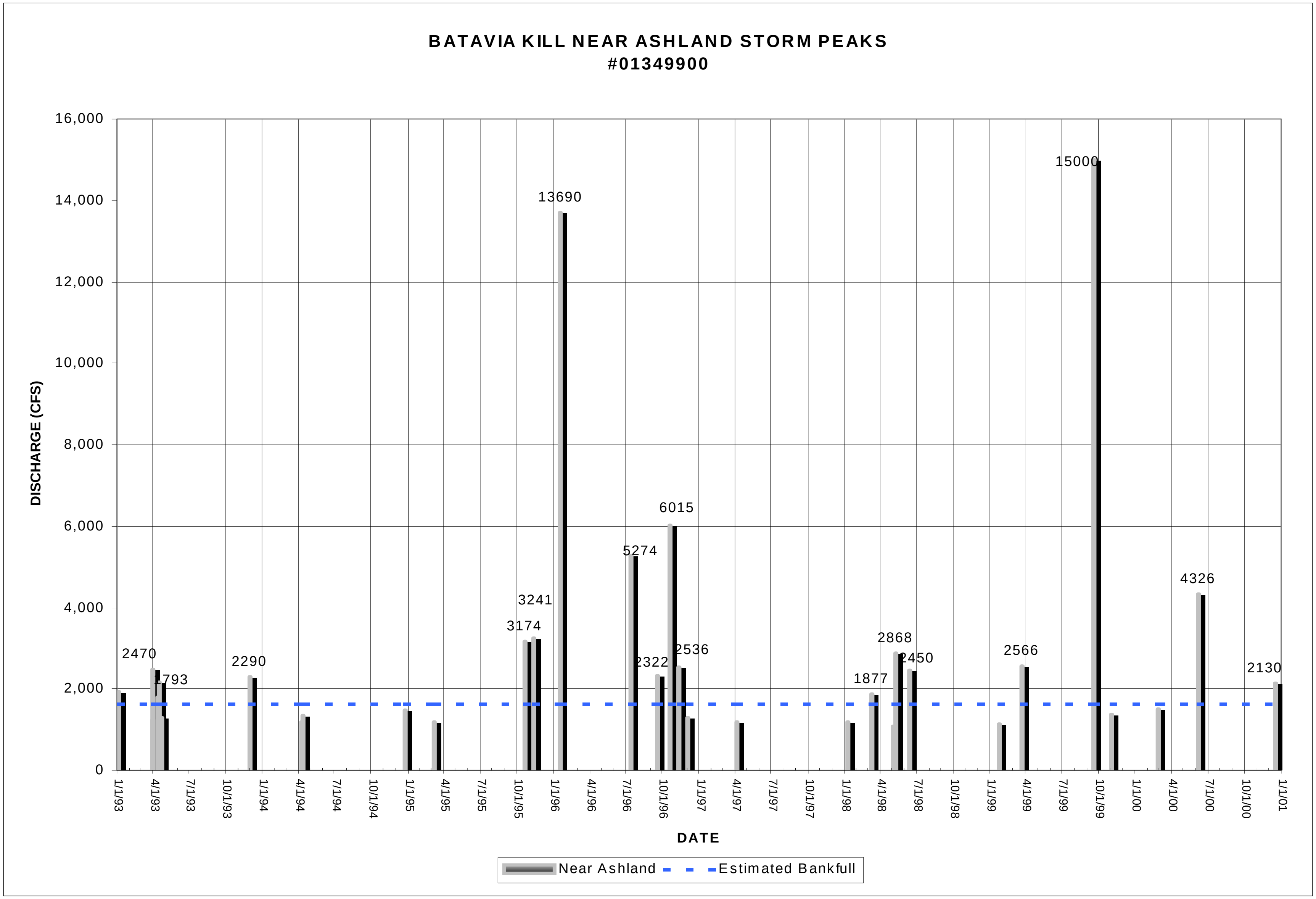


Figure V-19: Batavia Kill storm events over 1,000 cfs at Ashland, 1993-2001.

4. INFRASTRUCTURE INVENTORY

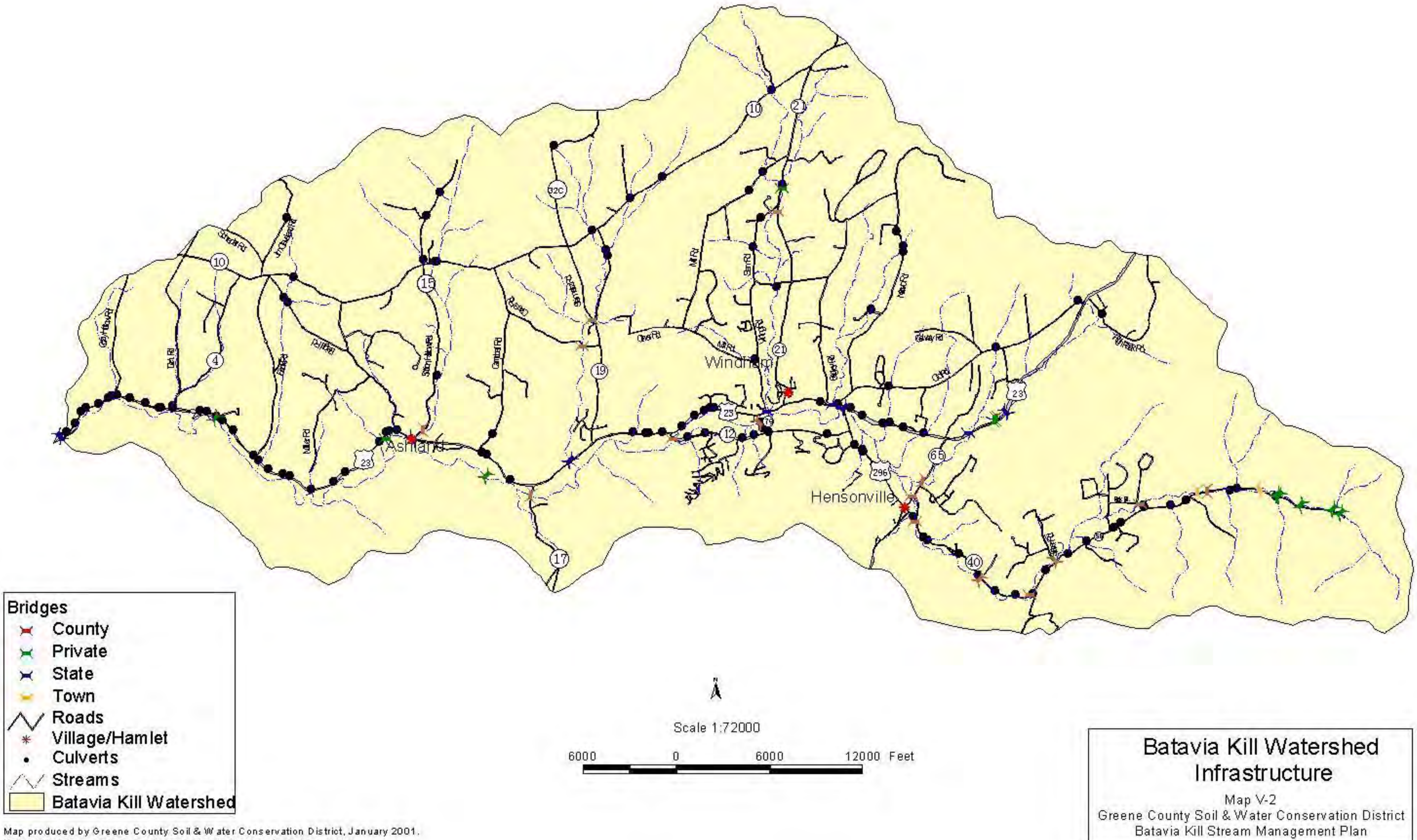
In any watershed, the location, size and other features associated with highway infrastructure components can have a significant impact on stream stability. In the Batavia Kill, the management of bridges and culverts, to minimize impacts on stream stability, is made difficult by the fact that these features fall under many different jurisdictions. Bridges may be the responsibility of NYSDOT, Greene County Highway Department, local municipalities and even private landowners. The larger bridges (over 24') are the responsibility of the Greene County Highway Department, the NYSDOT is primarily responsible for bridges on the state roads, and there are numerous bridges owned and maintained by private landowners.

In 2000, a cooperative effort between the GCSWCD and the Greene County Highway Department was initiated to create a GIS based inventory of bridges and culverts in the Batavia Kill watershed. The inventory was intended to provide a preliminary assessment of the impact of hydraulic controls in the watershed, and to develop an infrastructure maintenance and management tool for the Greene County Highway Department.

Figure V-20: Private bridge at Maier Farm demonstration project site.

The locations of all the structures were logged in the field using GPS technology, and information on the structure including structure ID number, road name, stream name, size, etc., was collected and associated with the location point. The one meter accuracy of the located structures is adequate for the purposes of this SMP. The data were imported into a database that can be used in multiple software applications and the bridges/culverts were mapped in ArcView **(Map V-2)**.

Using the GIS system, additional information will be incorporated into the attribute table for each of the bridge and culvert features as the Greene County Highway Department continues to develop its bridge/culvert maintenance program. Using data from the hydraulic geometry assessment, and stream channel characteristics such as drainage area, stream slope, and channel bank/bed materials, the GCSWCD will be able to effectively advise the Greene County Highway Department, as well as the highway departments in Windham, Ashland and Prattsville on the correct sizing of future bridges and culverts. The geomorphically derived design dimensions should be applied to bridge and culvert installations and replacements to promote proper conveyance of both flow and sediment through the structure. The impact of specific bridge/culvert structures on the Batavia Kill stream is discussed in later sections of this SMP.



Map produced by Greene County Soil & Water Conservation District, January 2001.
Note: GIS data are approximate according to their scale and resolution.
They may be subject to error and are not a substitute for on-site inspection or survey.
Data sources located in list of figures, tables, and maps.

5. FLOOD CONTROL STRUCTURES

As noted in **Section IV-L**, the Batavia Kill watershed contains two single purpose and one multi-purpose flood retention structures that were constructed as part of a watershed work plan to provide watershed protection, flood prevention and public recreational opportunities. The three dams are designated high hazard (class c) structures, and were constructed of compacted earth fill with concrete primary spillways and vegetated earthen emergency spillways. The last of the three structures was completed in 1976, and all three structures are presently under continual operation. To date, multiple storm events have been retained by the structures, with two events large enough to utilize the emergency spillway at dam site one (CD Lane). These flood flows were a result of tropical storm Floyd in September 1999 and a spring storm in April 1987. In the January 1996 flood, while the emergency spillways did not actually flow, the water level behind the dam was high enough to reach the elevation of the emergency spillway, with some flood waters creeping into the control section of the spillway.

While the Batavia Kill flood control structures (FCS) have clearly reduced flooding in the lower watershed, there is evidence suggesting that the regulation has resulted in adverse impacts. Flood control structures vary by their design and ability to modify the watershed's flow. Recent studies have begun to document the impacts caused by similar large impoundments on the physical, chemical, and ecological nature of the stream systems they regulate. These impacts have been well documented on many other stream systems and have shown implications throughout the entire system, sometimes taking many years to reveal themselves.

While the GCSWCD did not specifically assess the impacts of the Batavia Kill watershed flood control projects due to a lack of time and the overwhelming amount of both historic and current data that would be required to make conclusive judgements, the Batavia Kill Pilot Project did make some observations that are consistent with published research on dam impacts. A summary of these influences is provided below and correlated to the Batavia Kill system to the extent possible using observations and data collected along the stream system.

Discharge Modifications

The primary objective of the use of flood retention structures is to modify the stream flow during runoff events by providing storage for a portion of the watershed runoff above the structure. The stored runoff is then released at a slower, controlled rate in order to reduce the magnitude of the flood event by increasing the duration of the flow. The dams not only reduce the peak flow of any given storm, but the rising and recession limb of the downstream hydrograph are also impacted. The structures result in a slower rise in stream stage from pre-storm base flow levels to the storm peak, and more importantly the rate that the stream recedes to pre-storm levels is greatly extended. The increase in flood duration is a function of hydraulic design of the principle spillway of the structure and the size of the available flood pool behind the dam.

While the hydrograph for a storm event is influenced by many factors, unregulated streams in the Catskills typically recede quickly to base levels after even the largest flood events. This is due to watershed characteristics in the Catskill Mountains such as the steep valley relief and steep channel slopes. On the Batavia Kill, when a storm event is large enough to capture a significant volume of water behind the flood control dam, the stream takes a much longer period of time to return to pre-storm levels due to the slow release of this water.

Figure V-21: The Batavia Kill at just below bankfull stage two days after the tropical storm Floyd flood event.

After the flood associated with tropical storm Floyd in September 1999, the GCSWCD was able to observe the impact of the flood control structures on stream discharge. The peak discharge associated with the flood occurred on the Batavia Kill somewhere between 10:00 and 11:00 PM on Thursday, September 16th. Since the flood stage exceeded the staff plate elevations at key gages on the Batavia Kill, it is not possible to pin down the exact time. When the GCSWCD arrived in the watershed early the following morning, the stream had receded to the point where it was mostly within the channel, and at just over the bankfull stage. The GCSWCD continued to make daily observations of the stream, and by late in the day on Saturday, September 18th, the discharge was still running slightly below bankfull. By Tuesday September 21st, the discharge had dropped to approximately ½ of the bankfull discharge, and by one week after the flood, the stream stage was still higher than other streams in the watershed.

During this same period, the GCSWCD was also observing other local streams such as the East Kill, and it was noted that less than 24 hours after the flood peak, the stream discharge had dropped to significantly less than bankfull. As such, the flood control structures continued to release water for close to a week after the flood peak and bankfull or near bankfull discharge conditions were observed to have been extended to at least four days on the lower parts of the watershed.

While the flood control structure functioned as designed by releasing runoff at a rate which allowed for the stream stage to be maintained within the streambanks below the structure, dam designers in the 1960's did not have the knowledge and data that is available today on the impact of these extended flows on stream channel stability. As noted in **Section III** of this document, the bankfull flow plays an important role in maintaining the geomorphic form of the river, and it appears that the design discharge rate for the flood control structures closely corresponds to the bankfull discharge. If indeed the flood control structures are releasing storm flow at or near the bankfull discharge, then the channel forming flow is being sustained for longer durations. By sustaining the duration of the stream at bankfull stage, the active process which form and maintain the channel are also extended.

Sediment Modification

The three flood control structures in the Batavia Kill watershed are designed to provide storage for 100 years of sediment. In effect the structures capture all of the transported bedload sediment from the supplying area, with only a portion of the finer particles in the suspended load capable of passing the dam structure. Downstream, water released from the dam possesses the energy to move sediment, but has little or no sediment load.

Figure V-22: Section of Batavia Kill stream just below the C.D.Lane dam, note the absence of any sediment supply in the channel.

This clear water released from the dam is often referred to as hungry water, because the excess energy is typically expended on erosion of the channel bed and banks for some years following dam construction, resulting in incision (downcutting of the bed) and coarsening of the bed material until equilibrium is reached and the material cannot be moved by the flows *(Matt Koldolf - Profile Hungry Water: Effects of Dam and Gravel Mining on River Channels...).* The armor layer may continue to coarsen until the material is no longer capable of being moved by the reservoir releases or spills, thereby limiting the ultimate depth of incision *(Williams and Wolman 1984, Dietrich and others 1989).*

The three flood control structures on the Batavia Kill were analyzed in the planning stage for the adverse effects of sedimentation, and the cost for historical maintenance (USDA 1965). This included sediment derived from streambank erosion, gullying and bedload sediment. It was determined that 30 percent of the major sediment sources on the Batavia Kill in 1965 were located behind the structure sites. The designed system anticipated a 95 percent reduction in bedload sedimentation in reaches to Windham and a 90 percent reduction in damage reaches from Windham to Ashland (Batavia Kill Watershed Work Plan, 1965). This approach looked at sedimentation and its effects on the flood storage capacity of the structure, focusing on channel efficiency rather than the natural system potential and natural fluvial processes. A limited management approach focused on increasing channel efficiency can have negative secondary effects such as channel degradation, accelerated bank erosion throughout the system and problems such as localized abutment scour.

As shown in **Figure V-22**, on the Batavia Kill it appears that the stream channel immediately below the flood control structures has established an equilibrium based on the modified flows. For some distance below the structure in Maplecrest, the stream is characterized as being extremely stable, though the channel has essentially no depositional features associated with in-stream sediment storage. The GCSWCD does not have conclusive information regarding the impact of the loss of sediment from the upper watershed on stream reaches further down the valley.

Suspended Sediment

As stated previously, the Batavia Kill flood retention structures capture all of the transported bedload sediment from the supplying area but only settle a portion of the suspended load. The majority of the suspended sediment load is transported through the flood retention pool without having sufficient detention time to settle the particles from the water column.

Figure V-23: Discharge from the C.D.Lane dam spillway two days after tropical Storm Floyd.

Figure V-23 shows water release downstream of the C.D. Lane Park structure outlet during the recession of flow following the tropical storm Floyd event in September of 1999. It is clear from this image that the release is laden with suspended load. It is this suspended sediment that is currently the primary limiting factor of the value of the Batavia Kill resource and the focus of the pilot project.

Batavia Kill stream channel responses to flow regulation:

Downstream

A sediment analysis was performed above and below the CD Lane Park Flood Control Structure using pebble counting data obtained during the summer 2000 survey. Four sites were selected upstream of the structure, outside the effects from the flood retention pool, and four sites downstream of the structure, before the introduction of any major tributary. The results of the analysis confirm a change in dominant channel materials from gravel above the structure to cobble below the structure. The average D_{50} (mean point of a particle size distribution) changes from 53mm (coarse gravel) to 82mm (small cobble) with the average D_{84} (the particle size for which 84% of the distribution is finer, 84^{th} percentile) changing from 150mm to 256mm.

Observations and monumented cross sections through the stream channel above and below the structure also reveal a moderately entrenched stream channel below the structure with a slightly entrenched channel upstream of the structure. Riparian conditions and overall channel stability are good below the CD Lane Park structure which would lead to the conclusion that the stream channel has incised, coarsened its bed material and has reached a form of equilibrium in the area extending to Hensonville. Lower in the valley, the stream is experiencing fairly severe instability associated with adjustments in its plan form. It is speculated that the increased duration of the bankfull flow paired with bedload sediment from unregulated tributaries is compounding the problem.

Upstream

Sedimentation issues are rarely confined to the flood retention reservoir and downstream reaches. The backwater reach upstream of the reservoir can extend many miles upstream. The depositional impacts immediately following construction of the impoundments is typically confined to the delta region at the head of the reservoir. As this delta builds up, additional sediment is deposited in the upstream reach of the stream, resulting in channel aggradation. The aggradation of the stream channel at the confluence with the flood pool, coupled with the impact of the water level in the flood control structure during a flood event, in turn raises water surface elevations, creating additional backwater and deposition even further upstream. This mechanism allows the depositional environment to propagate much further upstream then the initial hydraulic backwater assessment might suggest *(World Commission on Dams, Contributing Paper, Managing for Unforseen Consequences of Large dam Operations)*.

These results are shown in the Batavia Kill's response upstream of the CD Lane Park reservoir. The area located immediately upstream of the recreation lake is an aggradational zone forming a braided stream channel for several hundred feet through the delta zone at the lakes entrance. This has lead to the over-widening of the stream channel and lateral migration causing stream bank failure. A second area upstream of the Peck Road bridge has shown similar signs of channel aggradation and over-widening, which is attributed to the backwater caused when the flood reservoir is at flood capacity.

Secondary Effects on Watershed

It has been shown in multiple studies that fish populations in rivers have declined drastically from historic levels due in large part to dams and water diversion projects. The largest common impact is the blocking of fish passage to upstream and downstream reaches. The flood control structures on the Batavia Kill are located along three of the largest contributing headwater drainage networks and inhibit migratory fish passage. The combination of structures account for approximately 45 miles of stream channel disconnected with the lower watershed, most of which is located in typical trout rearing areas in the upper headwaters. In 1978, the USDA Soil Conservation Service evaluated the need for construction of the 4th and final dam planned for the Batavia Kill watershed (USDA 1978), and the conclusion was that the structure could not expect to achieve a positive cost benefit, and that the impact to fisheries due to loss of additional tributary areas was not acceptable to NYSDEC. The final structure was not constructed.

Less obvious effects of impoundments include the development of mature vegetation throughout the channel that lacks diversity in age and species (Florsheim et al., 1993;

Wirth, 1997; Schmidt et al., 1998;USBR, 1994). This uniform habitat may be detrimental to the overall ecosystem because different species may use plants at different stages of growth. When the vegetation is finally scoured in a major event, the extensive loss may leave a scarred system more susceptible to the invasion of non-indigenous species *(World Commission on Dams, Contributing Paper, Managing for Unforseen Consequences of Large dam Operations..).* These effects are noted along the Batavia Kill, and this may account for the widespread density of the invasive plant Japanese Knotweed *(Polygumun cuspidatum).*

6. RECOMMENDATIONS FOR ADDITIONAL STUDIES

As noted earlier, the study of watershed hydraulics is often complicated, and requires the collection of years of data on stream flow. During the Batavia Kill Pilot Project, the GCSWCD did not have the time or manpower resources to study these issues in greater detail, and the lack of adequate historical data was also a significant limiting factor. As time and funds allow, the GCSWCD recommends that additional studies of the watershed hydrology be completed. These studies may include, but are not necessarily limited to:

> Further studies of the flood structures and their impact on stream stability. Additional studies could examine the impact of the structures on the duration of the bankfull discharge, and the spacial scale of disturbance created by the flood control structures, and the impact of the backwater effect on upstream stream reaches. While there is limited opportunity to modify either the structures, or their operation to benefit stream system stability, a better understanding of the structures on stream stability would still be helpful.
>
> Further study is also required to fine tune regional hydraulic geometry curves and flood frequency curves. USGS stream gage data in the watershed should be rigorously maintained, and additional analysis completed as the period of record allows.