Batavia Kill Watershed
Stream Design and Monitoring Evaluation
Greene County, New York

Prepared for GCSWCD and NYCDEP

Design Report Prepared by Buck Engineering PC

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FINAL REPORT

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1.0 INTRODUCTION

The Greene County Soil and Water Conservation District (GCSWCD) and the New York City Department of Environmental Protection (NYCDEP) Stream Management Program have worked together during the past eight years to develop a comprehensive stream management plan for priority sub-basins of the New York City water supply watershed in an effort to improve water quality. This plan promotes the implementation of natural channel design concepts through the construction of demonstration restoration projects aimed at long-term stabilization of channel morphology and of the physical and biological functions of the selected streams. Stream stabilization reduces erosion, which in turn reduces turbidity and total suspended solids, ultimately improving water quality. Additionally, channel restoration and long-term stabilization reduces the loss of land to bank erosion, enriches aquatic and riparian habitat, and enhances aesthetics (Rosgen,1996).

The GCSWCD and NYCDEP have implemented several channel restoration projects in the Catskill Mountains. The design goals of these projects included water quality enhancement, reduction of bank erosion and fine sediment loading, improvement of sediment transport, testing of various methods used in natural channel design, and enrichment of aquatic habitat. Three of these demonstration projects were constructed between 1999 and 2002 along the Batavia Kill Stream in Greene County. The location of these demonstration projects is presented in Figure 1, identified as the Maier Farm project, the Brandywine project, and the Big Hollow project. To assess the effectiveness of these three projects in satisfying individual project goals, the GCSWCD and NYCDEP have performed pre- and post-construction monitoring of each of the projects. Monitoring activities for each of the project sites included the following:

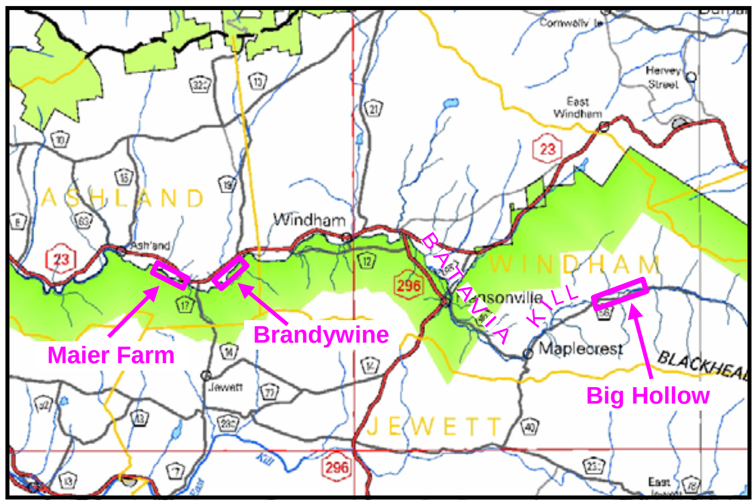

Figure 1. Location of project sites along Batavia Kill Stream.

- As-built survey of site topography, permanent cross sections, and channel bed profile along project reach
- Yearly post-construction survey of permanent cross sections along the project reach
- Pebble count – channel bed material at select locations
- Sieve analysis – bar material at select channel bars
- Measurements of surface area extent (length and height) of bank erosion problem areas (2003 only)
- Fish and benthic invertebrates sampling (Big Hollow project site only)
- Photographs
- Creation of GIS database of cross section locations, erosion point locations and descriptions (1997 and 2003 only), and photograph point locations

A comprehensive review of all the qualitative and quantitative monitoring data collected to date for each of the three project sites has been performed with the purpose of evaluating each project's effectiveness and success at meeting its original objectives. This report summarizes the findings obtained from the evaluation of the monitoring data collected to date for the Maier Farm, Brandywine, and Big Hollow stream restoration projects.

1.1 Analysis Objectives

The Maier Farm, Brandywine, and Big Hollow demonstration stream restoration projects constructed by the GCSWCD together with the NYCDEP had three principal objectives: (1) reduction of erosion and fine sediment inputs to the river from both stream bank and bed sources, (2) improvement of sediment transport, and (3) demonstration of the river process and natural channel design techniques in the Catskill Mountains area. On these objectives, the specific impact of each of these projects extend only on the reach scale; however each project set within the watershed scale is a piece of a larger management plan for the long term stability of the watershed system through improved stewardship approaches. Secondary goals for each project were enrichment of aquatic community and habitat integrity, and increase in aesthetics and property values.

The objective of the data analysis summarized in this report is to evaluate the performance of the Maier Farm, Brandywine, and Big Hollow stream restoration projects to assess their stability and determine their degree of success at achieving their design goals. Project stability was assessed by identifying shifts in several geomorphological characteristics of the stream such as channel cross sectional area and profile, bankfull width, bankfull depth, width to depth ratio, bank height ratio, and bed particle size. Channel pattern dimensions such as belt width, meander wavelength, radius of curvature, and sinuosity were also analyzed to observe how these parameters influence stream behavior and overall project performance. Trends in channel bank erosion over time were used to measure of the degree of success in achieving the main project objective of water quality enhancement. In addition, data collected on fish and benthic macroinvertebrate abundance over time was used to quantify enhancement in aquatic habitat conditions as an indicator of water quality improvement.

1.2 Report Overview

This report is organized as follows:

- Section 2 summarizes the various methodologies employed in the analysis of the monitoring data provided by the GCSWCD and the NYCDEP.
- Sections 3 provides site specific project details and assessment, based on the methodologies discussed in Section 2. For each project site, assessments on channel profile, dimension, pattern, bank erosion, and habitat are discussed, as well as a bed material analysis and sediment transport competency analysis. The extent of each assessment and analysis is dependent on the amount of relevant data available for each project site. Observations from the 2006 site visits and site specific recommendations are also included.
- Section 4 presents a summary of the conclusions reached from analysis of the monitoring data.
- Section 5 includes references and appendices that summarize computations performed in the data analysis.

2.0 ANALYSIS METHODOLOGY

2.1 Profile, Dimension, and Pattern Assessment

A naturally stable stream must be able to transport the sediment load supplied by its watershed while maintaining dimension, pattern, and profile over time so that it does not degrade or aggrade (Rosgen, 1994). A channel that is progressively incising (degrading) or that is experiencing excessive deposition causing the channel bed to rise (aggrading) is considered unstable. These physical adjustments develop as a stream tries to conform to a particular sediment load, sediment size, bed slope, and discharge, following disturbance. Using the monitoring data collected by the GCSWCD and the NYCDEP, profile, dimension, and pattern assessments were performed for each restoration project under study to determine its stability trend and ensure that each design conforms to the channel's sediment, slope, and discharge conditions.

As a first step in the analysis of the restoration projects, the dimension, pattern, and profile design values of each stream restoration project were compared to the reference design values obtained from three different sources: (1) evaluation of a variety of Buck Engineering past stream restoration projects performed along the Mountain and Piedmont area of North Carolina, with channel slopes varying from 0.5% to 1.0 %, (2) reference design values provided by Rosgen (1996), and (3) values summarized in the Army Corps of Engineers stream design manual (2003). These reference design numbers define the range of values for each stream parameter that have been observed in stable channels of each particular stream type The comparison to reference design values helps establish the initial conditions of stability for each project site. A summary of this comparison is provided in Table 1.

Table 1. Comparison of Stream Design Values.

	Rosgen Ratios		Past Project Evaluation		ACOE Manual NRCS ref c.1.		Maier Farm Project		Brandywine Project		Big Hollow Project (Phase I)	
Parameter	**MIN**	**MAX**	**MIN**	**MAX**	**MIN**	**MAX**	**MIN**	**MAX**	**MIN**	**MAX**	**MIN**	**MAX**
Stream Type (Rosgen)	C4		C4		C4		C4		C4		C4 (High bedload)	
Width to Depth Ratio, W/D (ft/ft)	12	18	8	12	N/A		16		N/A		20	
Riffle Max Depth @ bkf, Dmax (ft)	1.2	1.4	1.2	1.4	N/A		6.08		4.18	5.95	1.4	
Bank Height Ratio, Dtob/Dmax (ft/ft)	1.0	1.2	1	1.1	N/A		N/A		N/A		N/A	
Meander Length Ratio, Lm/Wbkf	11	12	7	12	11.3	12.5	12.6		N/A		12	
Radius of Curvature Ratio, Rc/Wbkf	3	4	1.8	3.5	1.5	4.5	240		N/A		4	
Meander Width Ratio, Wblt/Wbkf	N/A		3.5	8	N/A		4.24		N/A		3.6	
Sinuosity, K	1.2		1.2	1.6	1.2	5.3	1.25		N/A		1.5	
Riffle Slope Ratio, Srif/Schan	1.5	2	1.5	2	N/A		N/A		N/A		1.3	
Pool Slope Ratio, Spool/Schan	0.2	0.2	0	0.2	N/A		0.008		0.20		N/A	
Pool Max Depth Ratio, Dmaxpool/Dbkf	2.5	3.5	2.0	3.5	N/A		N/A		2.28		2.5	3.5
Pool Width Ratio, Wpool/Wbkf	1.3	1.7	1.3	1.7	N/A		N/A		1.15		1.3	
Pool-Pool Spacing Ratio, Lps/Wbkf	5	7	4	7	N/A		N/A		N/A		6.5	7.0

For each of these restoration projects, several of their design values were determined using dimension, pattern, and profile data from stable reference reaches within the Catskills Mountain area.

Permanent channel cross section locations were established during construction of each restoration project, and these were re-surveyed yearly during the post construction monitoring years. For each monitoring year, bankfull elevation was field determined at each cross section and incorporated into the survey data. However, analysis of the field-determined bankfull elevations revealed variations in bankfull elevation that fell outside the reasonable range, suggesting survey error and/or inconsistency in the methodology used to determine bankfull. To prevent this possible error from propagating through the monitoring analysis, riffle cross section maximum bankfull depths for each project were set equivalent to each project's original design maximum bankfull depth or to as-built depth to top of bank, whichever was lower, and this riffle bankfull depth was kept constant throughout all monitoring years. For each monitoring year, a bankfull line was defined along the entire reach of each project site using the bankfull depths determined for all riffle cross sections. The elevation of the bankfull line for each monitoring year was then used to define pool bankfull depths for each corresponding monitoring year.

Once bankfull elevations were defined for each project reach, the following parameters were determined for each reach cross section and for each monitoring year:

- Bankfull cross sectional area
- Bankfull width
- Bankfull maximum depth
- Width of flood prone area
- Maximum depth to top of bank
- Mean bankfull depth
- Width to depth ratio
- Entrenchment ratio
- Bank height ratio

Each cross section at each project site was examined individually, observing the variation over time of each of the parameters listed above. Trends identified from the time series analysis of each parameter were used to define channel behavior at each cross section location.

A survey of the longitudinal profile of each channel reach was not available for each monitoring year. However, a channel bed profile was developed for each site and for each monitoring year using cross section thalweg points from each year of monitoring data. A graphical overlay of all monitoring year profiles was prepared for each site, which was used to assess aggradation or degradation along the channel bed.

Channel plan form (pattern) was also examined to determine how it may influence any observed changes to channel dimension and profile.

The overall behavior and stability of each channel reach was established through a comprehensive review of the conditions at each channel reach cross section, changes to profile parameters, and channel plan form.

2.2 Bed Material Analysis

As part of the monitoring data collected to assess channel stability, the GCSWCD and the NYCDEP performed several pre- and post-construction pebble counts along each of the three project site. Data from these pebble count data were compared for each site to determine if there were observable trends in the bed material distribution of the site before and after restoration efforts. These trends were used to evaluate stability conditions throughout the site.

To compare data from different years, composite samples were created for each year by combining individual cross section pebble counts, to develop one cumulative sample for each project reach during each year. The cumulative sample was created by combining the counts within each size fraction for all sampled cross sections in a given year, as shown in the example below:

Particle Size Fraction (mm)	Pebble Count			Cumulative Sample
	XS 1	XS 2	XS 3	
< .062	2	2	7	11
.062 - .125	1	6	1	8
.125 - .25	14	5	2	21
.25 - .50	12	11	10	33
.50 - 1.0	10	11	7	28
1.0 - 2	1	9	3	13
2 - 4	4	7	3	14
4 - 6	2	1	0	3
6 - 8	2	1	1	4
8 - 12	4	5	6	15
12 - 16	3	6	3	12
16 - 24	7	10	4	21

The number and location of transects for which pebble count data were collected at each site differed during pre- and post-restoration monitoring. According to the pebble count data available, different numbers of pebble count samples were combined to develop the cumulative sample data for each year and for each site.

The variations in the number of pebble counts sampled for each year, the lack of long-term pre-restoration data, and the natural variability of pebble count data make detailed analysis of trends difficult. For these reasons, trends in the data are described more as qualitative observations than quantitative analyses.

2.3 Bank Erosion Assessment

Changes in rates of annual bank erosion relate directly to the main goal of these demonstration restoration projects. Quantification of pre- and post construction yearly erosion volumes were determined using the end-area method of soil volume calculation.

The end-area calculation method uses the erosion observed at cross sections along a channel to represent erosion conditions along discrete sections or lengths of the channel reach. For this calculation to be precise, the cross sections should be strategically placed at the beginning and end of lengths of the river with uniform erosion conditions, such that any cross section accurately represents the extent of erosion for the entire length of stream up to the next downstream cross section. In addition, cross sections at the upstream and downstream limits of the project area would be required.

Cross sections were surveyed at each project site during each post-construction year with the express intent of monitoring specific river bed features over time, not transitions in erosion conditions along the channel banks. The location of each cross section remained constant – a constraint necessary for the established objective of the cross section surveys, but which limits the application of the cross section data to estimation of erosion volumes using the standard end area method. Using the available cross section data, erosion observed at a particular cross section may not represent the erosion condition of the entire channel length up to its adjacent downstream cross section. With actual lengths of erosion along channel banks for each monitoring year unknown, the longitudinal extent of bank erosion observed at any cross section was assumed to be equivalent to the distance from the point halfway to the upstream cross section to the point halfway to the downstream cross section (See Figure 2).

The erosion occurring at a cross section during any given monitoring year was estimated by measuring the cut area revealed through an overlay of the geometry of that cross section for the year under study and that of the immediately preceding year, as shown in Figure 3. Erosion volume at each cross section was calculated by multiplying the erosion area of that cross section by its corresponding erosion length. Total site erosion volume for each monitoring year was computed as the sum of erosion volumes of all site cross sections for that same year.

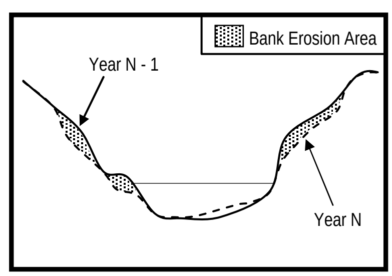

Figure 3. Determining bank erosion area for Year N.

When assuming erosion lengths, the margin of error in the calculation of total erosion volume for each year may be substantial. For this reason, actual erosion volumes calculated by this modified methodology should be considered invalid, and should not be used as reference values of yearly erosion from each site. However, if the method in which erosion lengths are selected remains consistent for each monitoring year, the trends observed in bank erosion at each site over time are valid indications of whether an increase or reduction in bank erosion is occurring at each site, even if the total yearly erosion values do not accurately represent actual erosion rates. For this reason, the bank erosion assessment presented in this monitoring report is based on the trends observed in the calculations of erosion volume over time, and not on the magnitude of the calculated yearly erosion rates.

2.4 Competency Analysis

The ability of a stream to transport its total sediment load can be quantified through sediment transport competency analysis. A stream's competency is the ability of a stream to move particles of a given size, and is a measurement of force. Competency is an indicator of the ability of a stream to transport its sediment load, as a stream sediment load can only include particles sized up to that for which it has competency for. This analysis is used to determine if stream slope and dimension are sufficient to move particles of a given size at the bankfull flow.

Median substrate size (D50) has an important influence on the mobility of particles in stream beds. Critical dimensionless shear stress (τ^*_{ci}) is the measure of force required to initiate general movement of particles in a bed of a given composition. At shear stresses exceeding this critical value, essentially all grain sizes are transported at rates in proportion to their presence in the bed (Wohl, 2000). τ^*_{ci} can be calculated for gravel-bed stream reaches using surface and subsurface particle samples from a stable, representative riffle in the reach (Andrews, 1983). Critical dimensionless shear stress is calculated as follows to determine the critical dimensionless shear stress required to mobilize and transport the largest particle from the bar sample (or subpavement sample) (Rosgen, 2001a):

a) Calculate the ratio D50/D^50:

Where: D50 (mm) = median diameter of the riffle bed. For this analysis, the D50 was calculated for each site in each year by combining the pebble count data from sampled riffles.

D^50 (mm) = median diameter of the bar sample.

If the ratio D50/D^50 is between the values of 3.0 and 7.0, then calculate the critical dimensionless shear stress (τ^*_{ci}) using Equation 1.

$$\tau^*_{ci} = 0.0834\ (D50/D\hat{}50)^{-0.872} \qquad \textbf{(Equation 1)}$$

b) If the ratio D50/D^50 is not between the values of 3.0 and 7.0, then calculate the ratio of D_i/D50:

Where: D_i (mm) = largest particle from the bar sample.

D50 (mm) = median diameter of the riffle bed. For this analysis, the D50 was calculated for each site in each year by combining the pebble count data from sampled riffles.

If the ratio D_i/D50 is between the values of 1.3 and 3.0, then calculate the critical dimensionless shear stress using Equation 2.

$$\tau^*_{ci} = 0.0384\ (D_i/D50)^{-0.887} \qquad \textbf{(Equation 2)}$$

c) Aggradation analysis is based on calculations of the required depth and/or slope needed to transport large sediment particles, in this case defined as the largest particle of the bar sample. Required depth can be compared with the existing/design mean riffle depth to verify that the stream has sufficient competency to move large particles and thus prevent thalweg aggradation. The required depth is calculated by:

$$d_r = \underline{1.65\tau^*_{ci}D_i} \qquad \textbf{(Equation 4)}$$

S

Where: d_r (ft) = required bankfull mean depth

1.65 = sediment density (submerged specific weight) = density of sediment (2.65) – density of water (1.0)

t^*_{ci} = critical dimensionless shear stress

D_i (ft) = largest particle from the bar sample

S (ft/ft) = bankfull water surface slope, measured from as-built longitudinal profile data

d) Verify sediment competence by calculating bankfull shear stress using Equation 3.

$$\tau = \gamma RS \qquad \textbf{(Equation 3)}$$

Where: τ (lbs/ft^2) = bankfull shear stress

γ (lbs/ft^3) = specific weight of water = 62.4 lbs/ ft^3

R (ft) = average hydraulic radius of the as-built riffle cross sections for each reach

S (ft/ft) = bankfull water surface slope, measured from as-built longitudinal profile data

e) Use the calculated value of bankfull shear stress (τ) and the modified Shields Diagram to predict the moveable particle size at the bankfull shear stress and compare to the largest particles sampled from the bar.

2.5 Habitat Assessment

Monitoring of changes in habitat conditions and biological parameters was performed only for the Big Hollow reach, and focused on using abundance of fish and benthic macroinvertebrate species and individuals as indicators of habitat and water quality of the stream reach. Habitat monitoring data collected at the Big Hollow site included collection of pre-construction fish sampling data during 2000 and yearly collection of post-construction fish sampling data during 2001-2004; as well as of post-construction benthic macroinvertebrate sampling during 2002-2004. Species richness, as well as total fish numbers and biomass, were used to evaluate conditions of the fish community along the project reach. Metrics such as total and EPT taxa richness, biotic index (Hilsenhoff), and species diversity indices (Shannon-Weaver and Simpson) were used to evaluate the benthic macroinvertebrate community. Results of the evaluation of the fish and benthic macroinvertebrate communities were used to characterize the overall condition of the biological habitat provided by the project reach. Habitat conditions directly correlate to the water quality of the stream, and serve as indicators of project success.

3.0 SITE ASSESSMENT RESULTS

Over the years, the Buck Engineering team has conducted extensive research on stream design, studying and experimenting with contributions to this field of science from numerous different experts. In addition, this team counts with first-hand experience on design and construction of over 50 miles of stream restoration projects, which have served as an experimentation laboratory to test all the knowledge collected thorugh years of extensive research and determine which design values are practical for the various stream settings and configurations. This wealth of data is what the Buck Engineering team mainly uses as the range of reference values suitable for each particular stream type and setting, and to perform the channel dimension, pattern, and profile assessments summarized in this section.

3.1 Maier Farm

The Maier Farm stream restoration project was the first demonstration restoration project constructed along the Batavia Kill stream corridor as part of the Batavia Kill Stream Management Project. The design goals of this project included reduction of bank erosion and fine sediment loading, improvement of sediment transport, implementation of several natural channel design techniques, and enrichment of aquatic habitat. The project was completed in the fall of 1999. The site is located near the Town of Ashland, as shown in Figure 1. Discharge through this project reach is regulated by one flood control structure currently in place upstream of this site along the Batavia Kill. The project reach is approximately 1,690 feet in length and runs parallel to State Highway 23, at a location immediately downstream of the County Route 17 Bridge. The drainage area discharging into this project reach is approximately 52 mi^2.

Pre-restoration data was collected for this site from 1997 through 1999. This data included survey of two monumented cross sections, topography of the stream bed (1998), pebble counts, sieve analysis of bed material samples, annotation of field observed erosion problem areas, and photographs. Post-restoration data was collected for this site during from 1999 through 2005, including survey of six cross sections monumented at the time of construction, as-built topography of the stream bed, pebble counts, sieve analysis of bed material samples, and photographs. The monitoring assessments and calculations presented in this section are based on the pre- and post-restoration monitoring data collected.

3.1.1 Profile Assessment

Profile data was collected during the as-built survey in 1999 and in the subsequent monitoring years 2002, 2003, and 2005. Profile stationing for this project was surveyed from downstream limit of project (station 10+00) to upstream limit of project (station 26+92). The as-built thalweg surveyed in 1999 does not match well with the following years of data. It is assumed that this discrepancy is due to repairs done in 2000 after Hurricane Floyd. The 1999 thalweg is shown in the profile chart provided in Appendix A. However, this data was not used for comparison in this section of the assessment.

Overall, the thalweg followed similar trends from 2002 through 2005. There are several areas where profile data collected in 2003 were not as detailed as those collected in 2002 and 2005, particularly between stations 18+77 through 22+07 and 24+69 through 26+08. The changes seen in the 2003 profile in these areas are likely due to the difference in survey points chosen and should not necessarily be considered a change in profile.

An area of instability and erosion was noted between stations 18+77 and 22+07. This instability can be further documented in the profile starting just downstream of cross section 3. The profile data shows the upstream migration of the pool into the riffle area. One other significant change seen in the profile is the deepening of the pool at the downstream end of the project. The deepening of pools can be a natural occurrence in stream systems and not necessarily a sign of instability, especially after a large flow such as the one experienced in 2005. In general, a pool that gets deeper does not represent a problem; there is no threshold on pool depth. A problem may be occurring if bed slope began to increase across the pool as the depth increased. This could have the potential of initiating a headcut that could migrate upstream. Future monitoring efforts should seek to determine if this change in profile is a trend towards a more stable or unstable condition in the channel.

3.1.2 Dimension Assessment

As a general convention, descriptions of the left or right side of the channel refer to the corresponding side of the channel when viewed facing downstream. Cross sections were numbered in ascending order from the upstream end of the project (cross section 1) to the downstream limit of the project (cross section 6). The location and stationing of each cross section is shown in Appendix A.

Cross section 1 – Riffle

Cross section 1 is a riffle located near station 11+25. Dimension appears to be relatively stable in this cross section. Some aggradation can be seen in portions of the channel after the 2005 storms (~0.4 feet from 2004 survey to 2005 near the left side of the channel). Bankfull is at the top of bank in this cross section; therefore, the data shows a decrease in area, width, and depth from 2004 to 2005. The level of aggradation is not excessive and is likely part of a natural fluctuation or shifting in the stream bed (especially after a large flow event). The bankfull width to mean bankfull depth ratio (W/D) has increased yearly and is significantly higher at 31 in 2005 than the design value of 16. This high width to depth ratio, which often results in the formation of mid-channel bars, does not appear to be causing instability in this cross section. It is likely that as floodplain vegetation becomes more established sediment will deposit on the banks and floodplain resulting in a decreased W/D ratio.

Cross section 2 – Pool

Cross section 2 is a pool located within a series of rock vanes near station 14+45. Like cross section 1, this area seems to be relatively stable. Changes seen between 2002 and 2005 are possibly due to inconsistency in survey alignments and the location of survey points between years. This cross section shows signs of aggradation in the channel bed (~0.4 feet from 2004 to 2005). Cross sectional area increased from 225in 2004 to 250 in 2005 due to an increase in bed elevation and cross sectional width. Aggradation does not appear to be excessive and may be a product of surrounding rock vanes that, as seen in the profile, create a pool above and below this cross section. This cross section may be more accurately described as a glide area between two pools.

Downstream of cross section 2, in the lower third of the bend some erosion was observed around one of the rock vanes during a site visit in January 2006. This erosion is not captured by this cross section and is discussed further in the pattern assessment and field observation sections below.

Cross section 3 – Riffle

Cross section 3 is located in a riffle downstream of a cross vane near station 17+90. This cross section does not show any signs of bank erosion. However, after the 2005 storms some change in dimension can be seen in this cross section. Towards the center of the channel there has been some slight aggradation (~0.25 feet) while towards the edges of channel there has been some degradation (~ 0.6 – 0.7 feet). This indicates that the thalweg is shifting towards the edge of channel and a mid-channel bar may be forming. This could be the result of a bankfull width to mean bankfull depth ratio that is significantly larger then that seen in the design. Channels with high W/D ratios may not be able to transport sediment load, which can result in the formation of mid-channel bars. This depositional pattern may also be a result of the location of the cross section downstream of a cross vane. Often, especially during large flow events, the area directly downstream of the cross vane will scour; the scoured bed material will then be deposited in the riffle downstream of the structure. Future flows closer to bankfull should determine if this is a trend towards a more stable or unstable condition in the channel. The cross sectional area is within the design range at 230 ft^2. Area, width, and depth were consistent with those seen in 2004.

Cross section 4 – Pool

Cross section 4 shows the greatest amount of change on the project site. This cross section is located in the lower third of the bend and captures this area of erosion. There appears to have been steady erosion on the outside of the bend since the repairs conducted in 2000. Erosion from 2002 to 2004 was between 1.0 and 1.9 feet on the right bank. Erosion between 2004 and 2005 accounted for an additional 1.9 to 2.5 feet on the right bank. This is further demonstrated in the summary data in Appendix A. The cross sectional width at the top of bank remains consistent through the monitoring years due to the increase in depth resulting in a lower elevation at bankfull. The erosion on the right bank indicates a trend towards lateral migration where the bank may eventually become undercut, which could lead in bank failure. The depth has increased annually around the eroding section of bank, resulting in an increase in cross sectional area. Between 2004 and 2005 the depth increased from 8.6 to 9.4 and the cross sectional area increased from 570 ft^2 to 620 ft^2.

The possible causes of this erosion are further discussed in the pattern assessment and field observation sections below.

Cross section 5 – Riffle

Cross section 5 shows only minor changes in dimension since the 2000 repairs. There appears to be some possible erosion near the right side of the channel. However, erosion was not noted in this area during the site visit in January 2006. It also appears that some deposition has occurred on the stream banks after high flows in 2005. This could indicate a trend in the narrowing of the channel as woody vegetation becomes established on the streambanks. This should increase roughness and encourage deposition. Cross sectional area, width, and depth have remained relatively consistent throughout the monitoring years. The area and width are slightly higher than the design values and the width is slightly lower. The bankfull width to mean bankfull depth ratio, while larger than the design, is lower than those observed in the upper sections of this reach. It appears that this cross section is trending towards a more stable condition, though future monitoring efforts should seek to further evaluate any changes in dimension.

Cross section 6 - Pool

This cross section shows almost no change between 2002 and 2005 (even after a large flow event). Minor changes can be accounted for by variation in survey points between years and natural shifts in the stream bed. The cross section summary in Appendix A shows a decrease in width and cross sectional area. This decrease is a result of deposition on the top of bank (floodplain deposition). It can be assumed that this cross section is stable.

Dimension Assessment Summary

Several areas of this reach show signs of some erosion with associated increase in width to depth ratio (W/D). To avoid the increase in W/D ratio from reaching a point in which this may destabilize the reach, thicker vegetation should be established along the banks to provides stronger bank protection which will allow for minor erosion occurring along the reach to heal itself.

Some areas of the reach showed a decrease in width to depth ratio. Generally, a decrease in bankfull W/D ratio is a positive response as long as the bank height ratio does not increase due to incision. No significant increase in bank height ratio was observed for this project.

Further monitoring should continue to ensure changes observed along this reach are due to natural variability in the channel.

3.1.3 Pattern Assessment

The average channel slope at the Maier farm reach is 0.0026 ft/ft or 0.26%. Meandering channels with sinuosity ratios greater than 1.2 are typical for this type of valley. This project had a sinuosity of 1.3. Project sinuosity is controlled by the belt width, which is often limited due to land use constraints (in some instances, appropriate channel belt with for the stream's corresponding discharge, sediment supply, and valley slope may not be achieved when private property bordering the channel path limits the amount of space available for the project).

The design meander width ratio for the Maier farm reach was 4.2. This ratio is a conservative value that allows the designer to create a sinuosity greater than 1.2 with appropriate pool to pool spacing and riffles with 45 to 60 degree angles to the fall line of the valley. As-built and post as-built values ranged from 3.3 to 4.1, slightly lower than the design target. The meander width ratio of 3.3 occurred between the last two bends. This value is lower than the recommended minimum; however, it did not cause bank erosion problems for this site. Other areas where bank erosion did occur had meander width ratios greater than 3.7, within the recommended range. Bank erosion in these bends were likely caused by lack of vegetation, vertical banks, bank material, and poor performance of in-stream structures.

The as-built meander length ratio ranged from 9 to 11, which is well within the range of most design criteria guidance documents. The same is true for the radius of curvature values, which ranged from 2 to 3.

3.1.4 Bed Material Analysis

Pre- and post-construction pebble count data were compared for the site to determine if there were observable trends in the bed material distribution of the site before and after restoration efforts. Pre-restoration data were collected during 1998. Post-restoration data were collected during 2000, 2002, 2003, 2004 and 2005.

To compare data from different years, composite samples were created for each year by combining individual cross section pebble counts, as described more fully in section 2.2. The number of cross sections sampled in a given year varied depending on whether the sampling occurred pre- or post-restoration. During pre-restoration sampling year 1998, one cross section was sampled along the project reach. During post-restoration sampling years, five locations were sampled along the project reach. During post-restoration sampling, efforts were made to sample approximately representative distributions of riffles and pools. It should be noted that the primary purpose of the pebble count samples was to classify the restored system and not necessarily to document changes in bed material distributions from year to year. The differences between sampling methodologies for pre- and post-restoration data were considered when evaluating the data for apparent trends.

Cumulative pebble count data for the Maier Farm Site during 1998, 2000, and 2005 are compared in Figure 4. A graph showing data from all sampled years is provided in Appendix A. Pre-restoration data (1998) are colored black, while post-restoration data (2000 and 2005) are colored red, with different line styles and symbols for two different years. The data show that the pebble count distributions vary from year to year, but there are few observable trends in the data when comparing pre-restoration data to post-restoration data. Post-restoration data fall around the pre-restoration data, with year to year variability showing no apparent trends in the mid-regions of the distribution. In the lower and upper portions of the distribution (fine sediment and cobble size fractions, respectively), the data indicate that there is a larger percentage of fine sediment and cobble material in the post-restoration channel. This trend is most likely due to the lack of pre-restoration data. Data for pre-restoration conditions were collected from one cross section, most likely in a riffle location. Post-restoration data were collected from multiple cross sections, including riffles and pools. Therefore, the trend towards finer sediment in the post-restoration channel could be attributed to the difference in sampling one riffle versus a combination of riffles and pools. The trend towards larger cobble size material in the post-restoration channel could also be attributed to the sampling or more riffle locations along the reach following restoration.

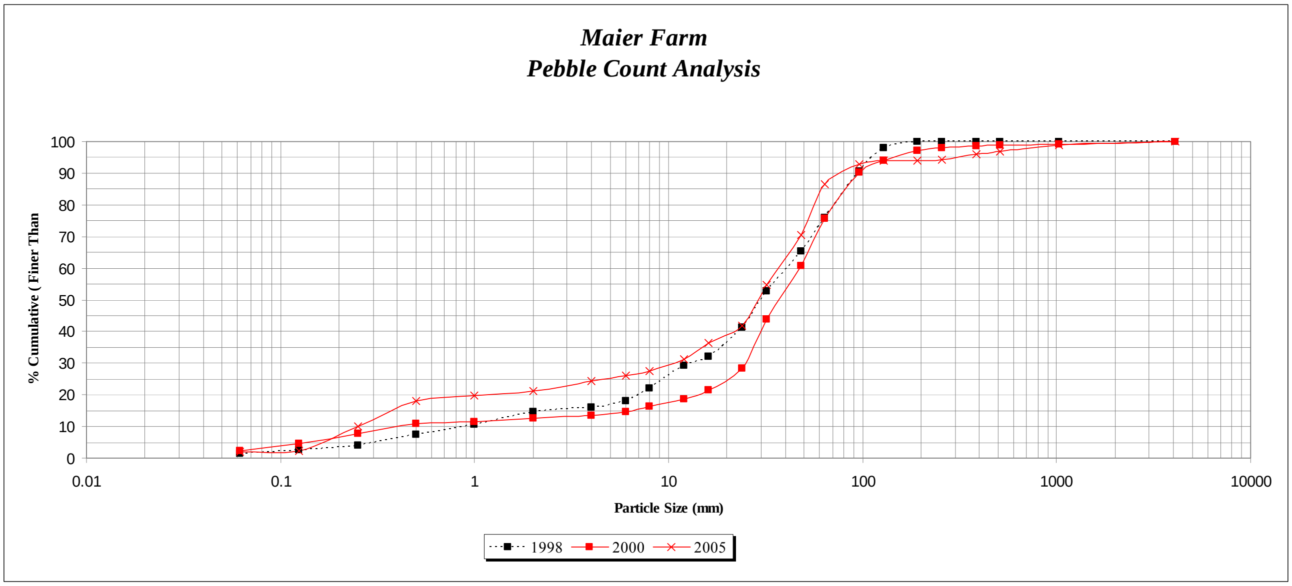

Figure 4. Cummulative pebble count data for the Maier Farm Site.

3.1.5 Bank Erosion Assessment

Pre-construction cross section survey data was available for the Maier Farm site for the years 1997 through 1999, and included survey of two cross sections across the site for each pre-restoration year. The location of these two sections was kept the same during each pre-construction year. An overlay of cross sections from year 1997 and year 1998 was used to calculate erosion volume for year 1998, while overlay of cross sections from year 1998 and year 1999 was used to calculate erosion volume for year 1999.

Post-construction cross section survey data was available for the Maier Farm site from 1999 through 2005, and included surveys of six cross sections across the site for each post-restoration year. In the same manner as under pre-restoration conditions, overlay of a cross section for a given year with the cross section for the previous year provided the erosion volume for that year.

The number and location of cross sections surveyed under pre- and post- restoration conditions varies, and accordingly, lengths of erosion represented by each cross section under pre- and post- construction conditions also varies. In addition, the total length of stream within project limits varies between pre- and post-construction conditions since stream alignments varies under each condition. The significant differences in data collection procedures between pre- and post-construction conditions does not allow for just comparison of erosion volume trends observed under pre- and post-construction conditions. However, it would still be valid to observe the variability and trends in erosion rates under post construction and use this as indicator of post-construction project behavior and success.

Following the methodology for computation of yearly erosion volume described in Section 2.3, yearly erosion volumes from the site were calculated as summarized below. These calculations were performed using an average soil density obtained for state of New York of 1.15 ton/yd^3.

Pre Restoration:

Total Erosion Rate Year 1998 (tons/yr)	1,719 tons/yr
Total Erosion Rate Year 1999 (tons/yr)	3,804 tons/yr

Post Restoration:

Total Erosion Rate Year 2000 (tons/yr)	2,314 tons/yr
Total Erosion Rate Year 2002 (tons/yr)	1,416 tons/yr
Total Erosion Rate Year 2003 (tons/yr)	458 tons/yr
Total Erosion Rate Year 2004 (tons/yr)	536 tons/yr
Total Erosion Rate Year 2005 (tons/yr)	679 tons/yr

As described in Section 2.3, the probable margin of error in these erosion volume calculations may be substantial enough to prevent the use of these numbers as approximations of the real erosion rates occurring at the Maier Farm site. However, the trends observed in these numbers are valid.

Only two years of erosion volume calculations are available for the pre-restoration condition. It is difficult to assess a trend in pre-construction erosion rates with only two data points. In addition, the locations of the two pre-construction cross sections used for this analysis were not selected to capture and represent erosion occurring along the reach, as cross section data was being collected at the time following a different objective. It is felt that the only cross section data available for the analysis of pre-construction erosion rates most likely underestimates the erosion rate from the site at the time, as these cross sections were located upstream of areas where most of the erosion was occurring.

For the post-restoration condition, the yearly erosion rate calculations demonstrate the erosion volume generally trends downward over time as compared to the as-built condition. This indicates construction of the project, coupled with the establishment of more mature vegetation along the project banks as post construction years progress, may be contributing towards a reduction of bank erosion from the site. This could be used as an indication of project success in reduction of bank erosion.

3.1.6 Competency Analysis

A) Required Depth Analysis

Riffle and bar sediment samples were collected at the Maier Farm site in 1998, 2003, 2004 and 2005. Riffle D50 samples ranged from 30 to 40 mm. The largest particles sampled from the bar had more variability, ranging from 60 to 115 mm. In neither case, however, did the sample variability show a positive or negative trend, i.e. there was no trend.

The design average bankfull depth for Maier Farm was 3.3 feet. The required depths were lower, ranging from 2.3 to 3.1 feet with the exception of 2003, which was 4.7 feet. The 2003 required depth was higher because of the much larger (115 mm) bar sample. The as-built and post as-built mean bankfull riffle depths ranged from 2.0 to 3.8 with most being within the required depth range. Based on this analysis, it appears that the mean depth variability associated with this site is within the normal range that can be expected in natural channels, especially during years with large floods. Results from the required depth analysis for the Maier Farm site are summarized in Table 2.

Table 2. Sediment Transport Analysis Results for the Maier Farm site.

Year Sampled	Sample Descriptor	D50 Riffle (mm)	D50 Bar Sample (mm)	Largest Particle on Bar (mm)	Critical Dimensionless Shear	Average Design Slope (ft/ft)	Average Design Mean Depth (ft)	Boundary Shear (lbs/sq ft)	Required Depth (ft)
1998	btw xs2-3	30	6	68	0.0205	0.0026	3.3	0.49	2.97
2003	sample	40	7.5	115	0.0194	0.0026	3.3	0.49	4.74
2004	XS4	35	5.9	60	0.0177	0.0026	3.3	0.49	2.25
2006.5	btw xs2-4	40	6.65	83.5	0.0174	0.0026	3.3	0.49	3.10

B) Boundary Shear Stress Analysis

The post construction data show that the stream has the appropriate amount of competency to support bed stability. The boundary shear stress for the design riffle was 0.49 lbs/ft^2, which is very similar to the Brandywine site discussed in Section 3.2 of this report. Since the Maier Farm and Brandywine sites have very similar valleys and slopes, noting similarity in boundary shear stress provides a converging line of evidence for the field work – obtaining similar response from different samples.

The largest particles sampled from the bar were plotted against the boundary shear stress and are shown in Figure 5. The largest particles sampled from the bar are smaller than those sampled from Brandywine. However, the particle size variability is within the range of the data used to develop the Colorado trendline. Furthermore, the lower as-built and post as-built mean bankfull riffle depths produce boundary shear stress values that are closer to 0.3 lbs/ ft^2. From the Colorado curve, this shear stress produces a particle size of 78 mm. The average of the largest bar samples was 82 mm. In other words, the as-built and post as-built mean depths represent the competency requirements better than the design.

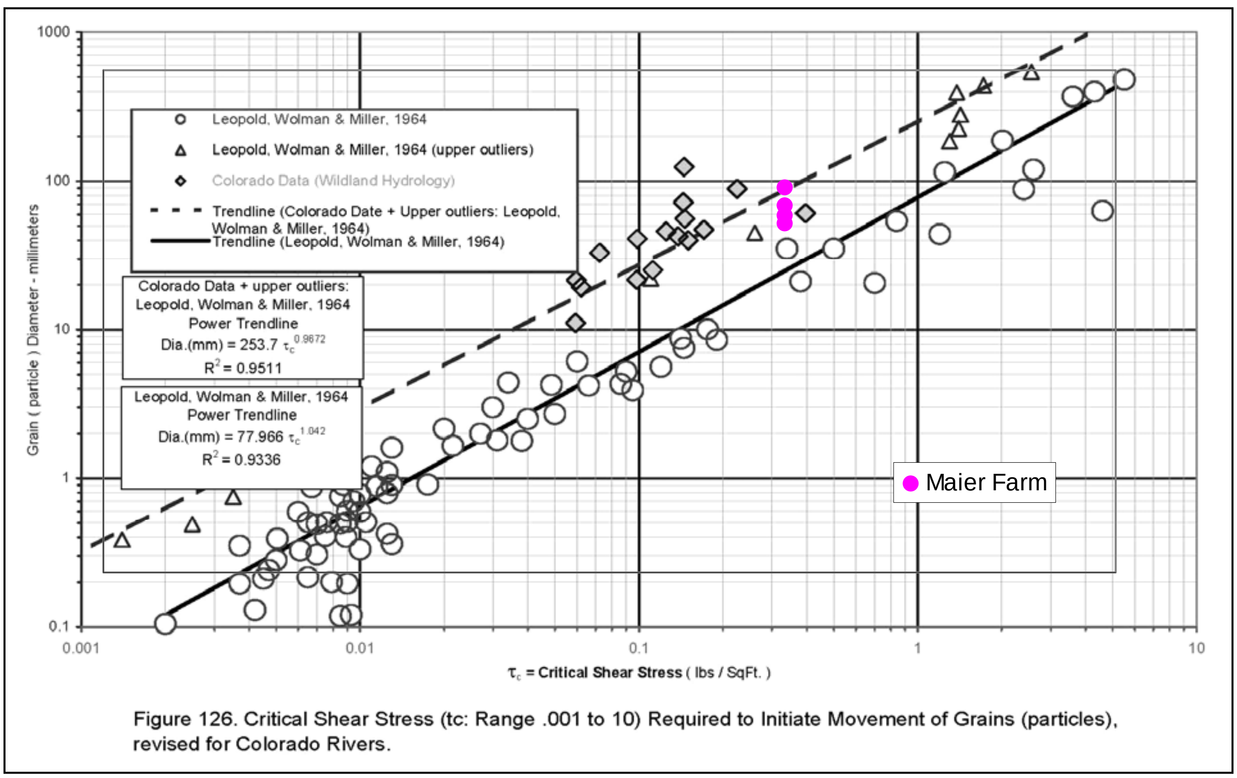

Figure 5. Shields Curve Diagram showing Maier Farm critical shear stress calculations for each monitoring year.

Overall, the sediment transport competency analysis suggests that the channel dimension and slope are sufficient to prevent long term aggradation or degradation. Observed fluctuations in the bed elevation are part of the natural variability associated with channels responding to large floods.

3.1.7 Habitat Assessment

Fish and benthic macroinvertebrates data was not collected on this site.

3.1.8 2006 Field Observations

A field visit was made on January 11, 2006. Overall, the site appeared to be functioning well. Streambank erosion was only observed in two bends, near station 16+00 and from 20+00 to 22+00. Erosion near station 16+00 was most prevalent upstream of a rock vane. The rock vane was shorter and steeper than current design guidance would suggest. If this had been a longer structure with a lower slope, it is likely that the apex of the bend would not have eroded, or eroded less severely. The bank is currently vertical and devoid of vegetation. Vegetation should be reinforced (see recommendations below).

The bend from station 20+00 to 22+00 had the most erosion. The banks are vertical and without any woody vegetation. The rock vanes have collapsed and are not providing bank protection.

The remaining sections of the channel appeared to be evolving in a positive direction. Willows and other early successional species are colonizing the point bars. The data suggest that over time, the width to depth ratio (W/D) of the reach could lower due to deposition on the banks and subsequent narrowing of channel width. If the decrease in W/D ratio of the channel does not occur together with an increase in bank height ratio (which would indicate incision), the narrowing of the channel represents a positive change for the channel in that it increases channel efficiency, and the channel may become more stable. Debris has accumulated on the downstream bridge; however, it is not causing a stability problem

3.1.9 Recommendations

These recommendations are based on the data analyses and field observations.

1. The rock vanes near station 16+00 and between stations 20+00 and 22+00 should be reconstructed with longer arms and lower slopes. The banks should be re-graded and planted with woody vegetation.
2. While equipment is on-site, the debris could be removed from the downstream bridge.
3. Overall, vegetation along the banks of the reach should be reinforced with woody vegetation to provide the ground cover required to protect from bank erosion.

3.2 Brandywine

The Brandywine stream restoration project was the second demonstration restoration project constructed along the Batavia Kill stream corridor as part of the Batavia Kill Stream Management Project, and was completed in the fall of 1999. The site is located near the Town of Ashland, as shown in Figure 1. Discharge through this project reach is regulated by one flood control structure currently in place upstream of this site along the Batavia Kill. The project reach is approximately 3,800 feet in length and runs parallel to State Highway 23. North Settlement Creek and another small unnamed tributary discharge into the Batavia Kill stream at the project site. The drainage area discharging into this project reach ranges from 43.1 mi^2 to 50.8 mi^2.

Pre-restoration data was collected for this site during 1997 through 1999. This data included survey of two monumented cross sections, topography of the stream bed (1998), pebble counts, sieve analysis of bed material samples, annotation of field observed erosion problem areas, and photographs. Post-restoration data was collected for this site during 1999 through 2005, including survey of seven cross sections monumented at the time of construction, as-built topography of the stream bed, pebble counts, sieve analysis of bed material samples, and photographs. The monitoring assessments and calculations presented in this section are based on the pre- and post-restoration monitoring data collected.

3.2.1 Profile Assessment

Detailed as-built profile data were collected for this site, and cross section thalweg points from subsequent years 2001 through 2005 were used to establish channel profile during monitoring years. To facilitate identification of variation in bed elevation, profiles for all years of data were overlaid graphically (see Appendix B). Profile stationing for this project was surveyed from downstream limit of project (station 10+00) to upstream limit of project (station 34+25). The profile graph demonstrates that both pools at stations 14+10 and 17+75 have aggraded. The riffles have mildly aggraded (approximately 9.5 inches) from station 10+00 to 20+75. The riffle at 20+75 (cross section 5) degraded from the as-built survey to 2004, but aggraded back to the as-built elevation in 2005. From 20+75 to 34+00, the bed has degraded approximately 2 feet from the as-built condition. This results in a 2005 bank height ratio of 1.5 (6ft/4ft) and is considered moderately unstable. When riffle bank height ratio increases above 1.2 and continues to display an increasing trend over time, aggradation and degradation occurring within the channel may indicate a tendency towards destabilization rather than natural variability throughout the channel bed. The observed changes in channel profile may be due only to the natural variability within a channel reach due to flood conditions. However, the reach should continue to be monitored to ensure bank height ratio does not continue to increase over time. Aggradation and degradation results are further discussed below in the dimension assessment.

3.2.2 Dimension Assessment

As a general convention, descriptions of the left or right side of the channel refer to the corresponding side of the channel when viewed facing downstream. Cross sections were numbered in ascending order from the upstream end of the project (cross section 1) to the downstream limit of the project (cross section 7). The location and stationing of each cross section is shown in Appendix B.

Cross section 1 – Riffle

Cross section 1 is located in a riffle near station 12+00. The cross section is downstream of a cross vane and between two rock vanes. Dimension appears to be relatively stable in this section of channel.

Minor fluctuations in bed elevation can be seen between monitoring years. Some aggradation can be seen in the channel after the 2005 storm (~0.8 feet from 2004 survey to 2005). The level of aggradation is not excessive and is likely part of a natural fluctuation or shifting in the stream bed (especially after a large flow event). It could also be caused by the downstream vane, which sets the grade and would flatten the slope at the cross section.

Cross section 2 – Pool

Cross section 2 is located in a pool near station 14+00. This pool aggraded approximately 3 feet from the as-built condition to the year 1 survey. However, aggradation has subsequently been less significant (~0.7 feet from 2004 to 2005). The bankfull pool width remained close to 100 feet from 2001 to 2004, but increased to 124 feet in 2005. This increase in width was caused by the 0.7 to 1.0 foot increase in bankfull stage, not bank erosion.

Downstream of cross section 2, in the lower third of the bend, some erosion was observed between a rock vane and cross vane during a site visit in January 2006. This erosion is not captured by the available survey data for cross section and is discussed further in the pattern assessment section below.

Cross section 3 – Riffle

Cross section 3 is located in a riffle near station 16+25. This cross section is located upstream of the confluence with North Settlement Creek and does not show any signs of bank erosion. Between 2001 to 2004, the bankfull cross sectional area varied from 205 ft^2 to 234 ft^2. This is range extends slightly below the design range of 225 ft^2 to 235 ft^2. Bankfull cross sectional area increased to 250 ft^2 in 2005 due to approximately 0.6 feet of bed aggradation and a corresponding increase in width. This cross section is also located in a riffle downstream of a cross vane. Often, especially during large flow events, the area directly downstream of the cross vane will scour; the scoured bed material will then be deposited in the riffle downstream of the structure. Since high flows occurred during 2005, the aggradation observed at this cross section is probably associated with inflow of sediment from the confluence of a tributary located just upstream of this cross section plus scour bed material from the upstream cross vane pool. This aggradation should be temporary. It is likely that future flows that are closer to bankfull will return the bankfull cross sectional area closer to the design range.

Cross section 4 – Pool

Cross section 4 is located in a pool near station 17+75. Like Cross section 1, this pool aggraded approximately 3 feet from the as-built condition to the year 1 survey. However, subsequent to this initial aggradation, this cross section shows very little change over the monitoring years. The bankfull pool widths have only varied from 66 to 69 feet and the maximum depths have remained relatively constant at 5.4 to 5.9 feet.

Cross section 5 – Riffle

Cross section 5 is located in a riffle near station 20+75. This cross section is located downstream of both the confluence with North Settlement Creek and a cross vane. Between 2001 and 2004, very few changes are were observed in the cross section. Cross sectional area varied from 147 to 159 ft^2. In 2005, the bankfull cross sectional area increased to 220 ft^2, due to an increase in bed elevation. After the high flow events in 2005 large amounts of sediment were deposited within the channel. It is interesting to note that this increase in bed elevation of almost 2 feet brought the bed back to the as-built elevation (see the profile graph in Appendix B). However, the 2005 bankfull W/D ratio of 24 remains higher than the design value of 18. In addition, the channel showed signs of a chute-cutoff on the right bank. As vegetation continues to establish on the floodplain and the channel experiences closer to normal flows, it is likely that this cross section will improve its ability to transport sediment.

Cross section 6 - Pool

Cross section 6 is located in a pool near station 23+00. This cross section is on the downstream side of a chute-cutoff that began upstream near cross section 5. Pool bankfull widths remained relatively constant from 2001 to 2004, only varying from 86 to 91 feet. The pool width decreased to 79 feet in 2005 due to deposition on its point bar. The bankfull pool depth increased to from 4.4 feet in 2004 to

5.9 feet in 2005. The profile shows the thalweg deepening during this time, even though the previous thalweg survey indicated aggradation. This is due to the lateral migration of the point bar that was present prior to the 2005 storm event. There is significant bank erosion downstream of cross section 6, starting in the lower third of the bend and extending into the riffle.

Cross section 7 - Riffle

Cross section 7 is located in a riffle near station 31+00. This cross section is located directly downstream of a cross vane. The cross section was surveyed as a riffle but may be more accurately described as a glide due to its location between the scour pool of the cross vane and the downstream riffle. Between 2001 and 2004, only minor shifts in dimension and bed elevation were observed. After the 2005 storm event the bed elevation degraded approximately 0.8 feet. This change in thalweg elevation is likely due to the location of the cross section downstream of a cross vane; during high flows the area below a cross vane scours and the scoured material is then deposited downstream in the riffle area. The cross section summary provided in Appendix B shows a decrease in area, width, and depth. However, the area has actually increased; the decrease shown is a product of the methodology used to determine bankfull elevation in riffles (fixed bankfull depth from channel thalweg to bankfull water surface was used, which may cause setting bankfull elevation at an elevation lower than actual bankfull, causing in turn for the bankfull cross sectional area measured below bankfull line to be lower than actual - see Section 2.1).

Dimension Assessment Summary

North Settlement Creek discharges into the Batavia Kill stream at station 17+00 of the Brandywine project (near the center of the project site). In general, the dimension assessment shows that the sediment regime in the downstream portion of the project reach is notably influenced by sediment supply brought in by the inflow from North Settlement Creek. The observed changes in channel dimension may be a result of natural variability which may mostly be due to inflow from North Settlement Creek. To prevent destabilization of the reach thicker woody vegetation cover that can act as a protective cover for the banks should be established and reinforced along the streambanks.

3.2.3 Pattern Assessment

Batavia Kill is located in a broad alluvial valley with an average channel slope of 0.002 ft/ft or 0.2%. Meandering channels with sinuosity ratios greater than 1.2 are typical for this type of valley. This project had a sinuosity of 1.25, which is characterized as a mildly meandering channel. Similar to Maier Farm, the project sinuosity was controlled by land use constraints.

The belt width or the meander width ratio (belt width divided by bankfull width) for this project is low. The as-built meander width ratio ranged from 2.8 to 3.7, while stable reaches of this stream type have been observed to have meander width ratios ranging from 3.5 to 8.0. These low meander width ratio values, along with recent disturbance to the stream (the in-stream structure construction) may have contributed to the bank erosion that occurred after construction. For example, the lowest meander width ratio occurred near station 23+00. A chute-cutoff occurred in this bend and it experienced the worst bank erosion, occurring from the downstream third of the pool through the next riffle. In addition, the upstream riffle near station 21+00 has a low angle off the fall line of the valley, which increases shear stress over the riffle and into the pool.

The as-built meander length ratio ranged from 9 to 12, which is well within the range of most design criteria guidance documents. The same is true for the radius of curvature values, which ranged from 2 to 3.

3.2.4 Bed Material Analysis

Pre- and post-construction pebble count data were compared for the site to determine if there were observable trends in the bed material distribution of the site before and after restoration efforts. Pre-restoration data were collected during 1998 and 1999. Post-restoration data were collected during 2000, 2002, 2003, 2004, and 2005.

To compare data from different years, composite samples were created for each year by combining individual cross section pebble counts, to develop one cumulative sample for the project reach during each year. The number of cross sections sampled in a given year varied depending on whether the sampling occurred pre- or post-restoration. During pre-restoration sampling years, one pebble count sample was collected for the project reach during each year. During post-restoration sampling year 2000, data from three samples were combined to develop the cumulative sample data. During post-restoration sampling in 2002 and 2003, data from six samples stratified evenly between riffles and pools were used. For post-restoration sampling in 2004 and 2005, data from seven samples (four riffles and three pools) were used.

Cumulative pebble count data for the Brandywine Site are compared in Figure 6. Pre-restoration data are colored black, while post-restoration data are colored red, with different line styles and symbols for different years. The data shown for 1997 and 1998 (pre-restoration sampling years) can be viewed as an indication of natural variability in bed material samples from year to year, since no modifications were made to the project reach during these years.

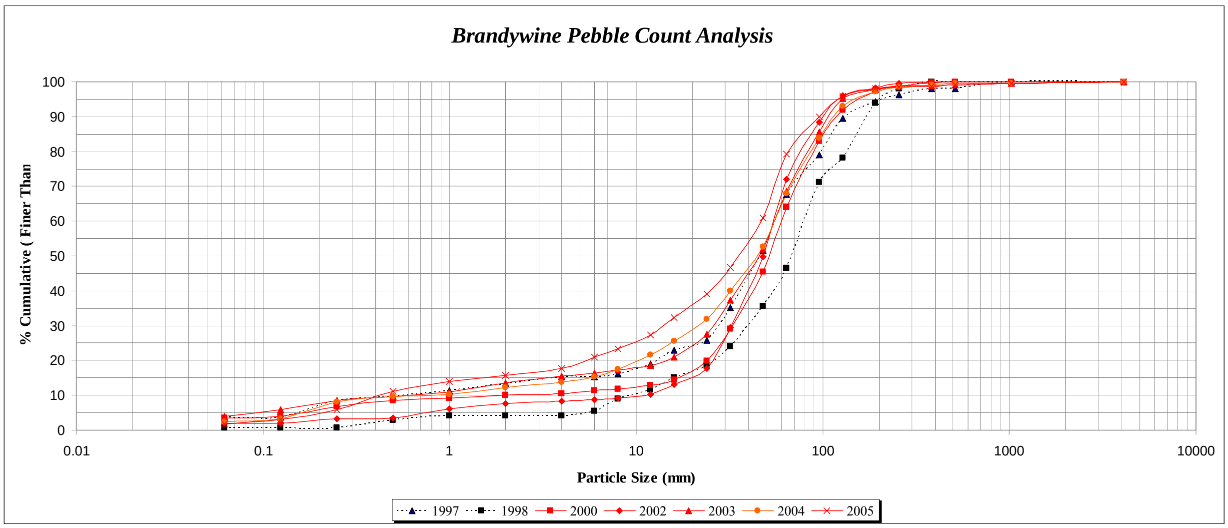

Figure 6. Cumulative pebble count data for the Brandywine Site.

The post-restoration data from 2002 through 2005 indicate a trend towards the bed material becoming finer. For these years, particles in the D20 to D50 range become smaller each year. For sampling year 2005, particle sizes in the D10 to D95 range are the smallest of any sampled years. To further investigate this trend, cumulative bed material samples were compiled for each post-construction year for only riffle features. This analysis was conducted to determine if fine material was collecting in pools and skewing the overall data. The data compiled for riffles are presented in Figure 7.

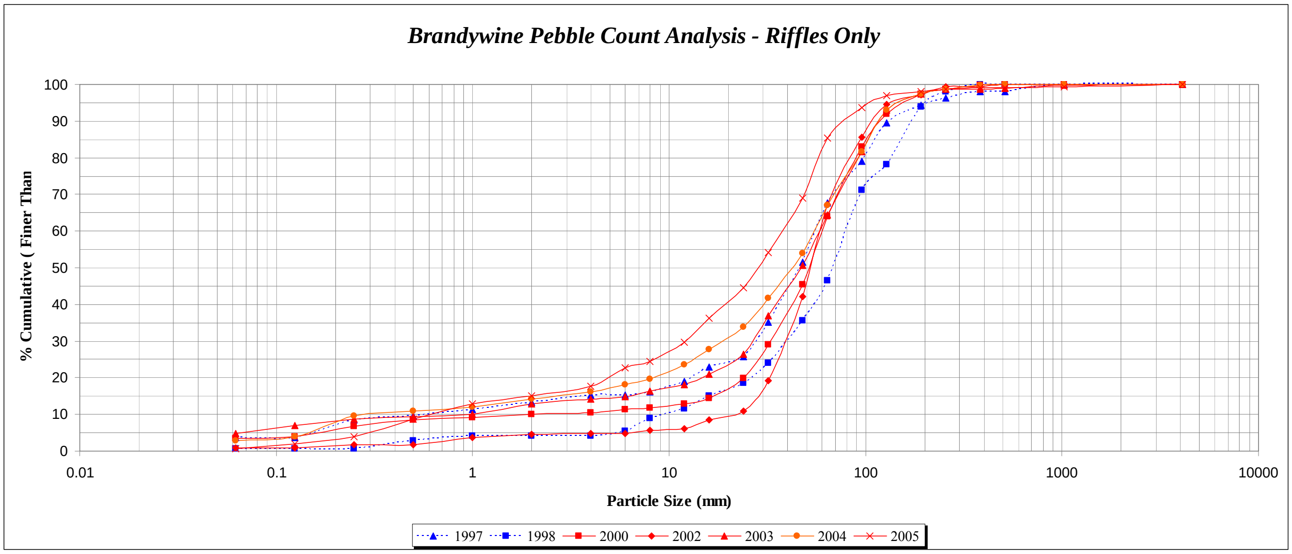

Figure 7. Cumulative pebble count data for the Brandywine Site, using riffles only.

The trend towards finer bed material is more apparent in the data compiled for riffles, indicating that overall particle distributions have become finer from 2002 through 2005, including riffle features.

While there is an apparent trend towards finer bed material over the past four years, the cause of this trend is more difficult to determine. Possible causes for the trend could be increased instability within the project reach, increased instability and fine sediment production in the upstream watershed above the project, or an influx of fine sediment produced during the extreme storm events during 2005. To accurately identify which of these possible causes is responsible for the observed trend, the sediment monitoring plan for the site will need to be modified in a way to allow assessment of causes. Future monitoring of sediment levels and bed material conditions in an upstream control reach could provide valuable information.

3.2.5 Bank Erosion Assessment

Pre-construction cross section survey data was available for the Brandywine site for 1997 through 1999, and included survey of two cross sections across the site for each pre-restoration year. The location of these two sections was kept the same during each pre-construction year. An overlay of cross sections from 1997 and 1998 was used to calculate erosion volume for 1998, while overlay of cross sections from 1998 and 1999 was used to calculate erosion volume for 1999.

Post-construction cross section survey data was available for the Brandywine site for 2001 through 2005, and included survey of seven cross sections across the site for each post-restoration year surveyed. In the same manner as under pre-restoration conditions, overlay of a cross section for a given year with the cross section for the previous year provided the erosion volume for that year.

The number and location of cross sections surveyed under pre- and post- restoration conditions varies, and accordingly, lengths of erosion represented by each cross section under pre- and post- construction conditions also vary. In addition, the total length of stream within project limits varies between pre- and post-construction conditions since stream alignments varies under each condition. The significant differences in data collection procedures between pre- and post-construction conditions does not allow for just comparison of erosion volume trends observed under pre- and post-construction conditions.

However, it would still be valid to observe the variability and trends in erosion trends under post construction and use this as indicator of post-construction project behavior and success.

Following the methodology for computation of yearly erosion volume described in Section 2.3, yearly erosion volumes from the site were calculated as summarized below. These calculations were performed using an average soil density obtained for state of New York of 1.15 ton/yd^3.

Pre Restoration:	
Total Erosion Rate Year 1998 (tons/yr)	12,114 tons/yr
Total Erosion Rate Year 1999 (tons/yr)	2,541 tons/yr
Post Restoration:	
Total Erosion Rate Year 2002 (tons/yr)	1,333 tons/yr
Total Erosion Rate Year 2003 (tons/yr)	846 tons/yr
Total Erosion Rate Year 2004 (tons/yr)	1,008 tons/yr
Total Erosion Rate Year 2005 (tons/yr)	3,734 tons/yr

As described in Section 2.3, the probable margin of error in these erosion volume calculations may be substantial enough to prevent the use of these numbers as approximations of the real erosion rates occurring at the Brandywine site. However, the trends observed in these numbers are valid.

Only two years of erosion volume calculations are available for the pre-restoration condition. It is difficult to assess a trend in pre-construction erosion rates with only two data points. In addition, the locations of the two pre-construction cross sections used for this analysis were not selected to capture and represent erosion occurring along the reach, as cross section data was being collected at the time following a different objective. It is felt that the only cross section data available for the analysis of pre-construction erosion rates most likely underestimates the erosion rate from the site at the time, as these cross sections were located upstream of areas where most of the erosion was occurring.

For the post-restoration condition, the yearly erosion rate calculations do not reveal a trend. The vegetation that has established along the banks in this site includes extensive areas of knotweed. This particular type of plant is invasive, and is very poor at providing bank protection during flood events. An important component of bank protection for restoration projects is establishment of vegetation whose root mass and land cover holds the bank stable. The type of vegetation along the banks of the Brandywine project may explain the trend towards increase in erosion rate is observed for the higher flow year (2005).

3.2.6 Competency Analysis

A) Required Depth Analysis

Results from the sediment transport analyses for the Brandywine site are shown in Table 3. Riffle and bar sediment samples were collected in 2000, 2003, and 2005. The largest particles sampled from the bar in 2000 and 2003 were 177 and 160 mm, respectively. The largest particle on the bar decreased to 102 mm in 2005, most likely due to excessive deposition from large floods. A similar reduction in size was observed in the D50 of the riffle, decreasing from 52 and 47 mm (2000 and 2003) to 28 mm in 2005. The required depths for initiation of particle movement for 2000 and 2003 were 4.7 and 4.3 feet respectively. The required depth in 2005, after the floods, increased to 5.2 feet rather than decreasing as did the bed material. This anomaly is likely a result of the floods moving different particle sizes than flows represented by the equation used for this analysis.

Table 3. Sediment Transport Analysis Results for Brandywine site.

Year Sampled	Sample Descriptor	D50 Riffle (mm)	D50 Bar Sample (mm)	Largest Particle on Bar (mm)	Critical Dimensionless Shear	Average Design Slope (ft/ft)	Average Design Mean Depth (ft)	Boundary Shear (lbs/sq ft)	Required Depth (ft)
2000	Bar #2, Sample 1	52	5.6	177	0.0130	0.0026	3.7	0.55	4.77
2003	Sample	47	24	160	0.0130	0.0026	3.7	0.55	4.31
2005	downstream XS5	28	6.9	102	0.0246	0.0026	3.7	0.55	5.22

From the 2000 and 2003 data, the required depth is greater than the design bankfull mean riffle depth as well as the as-built depth and post as-built depths. The as-built and post as-built mean riffle depths range from 1.9 feet to 3.3 feet. This indicates that there should have been aggradation of the bed since the required depth is greater than the actual depths. The profile and cross section data partially support this result. In the upper half of the project, the bed has aggraded; however, the lower part of the reach has degraded almost two feet.

B) Boundary Shear Stress Analysis. The boundary shear stress for the design riffle was 0.55 lbs/ft^2. The largest particles sampled from the bar were plotted against the boundary shear stress and are shown on Figure 8. The graph shows that these data bracket the dashed trendline within the range of the plotted data. For a shear stress of 0.55 lbs/ ft^2, the trendline predicts that a particle size of 142 mm should be mobile. It appears that the Colorado trendline is a reasonable predictor of the largest particle that would be deposited on a point bar during a bankfull discharge.

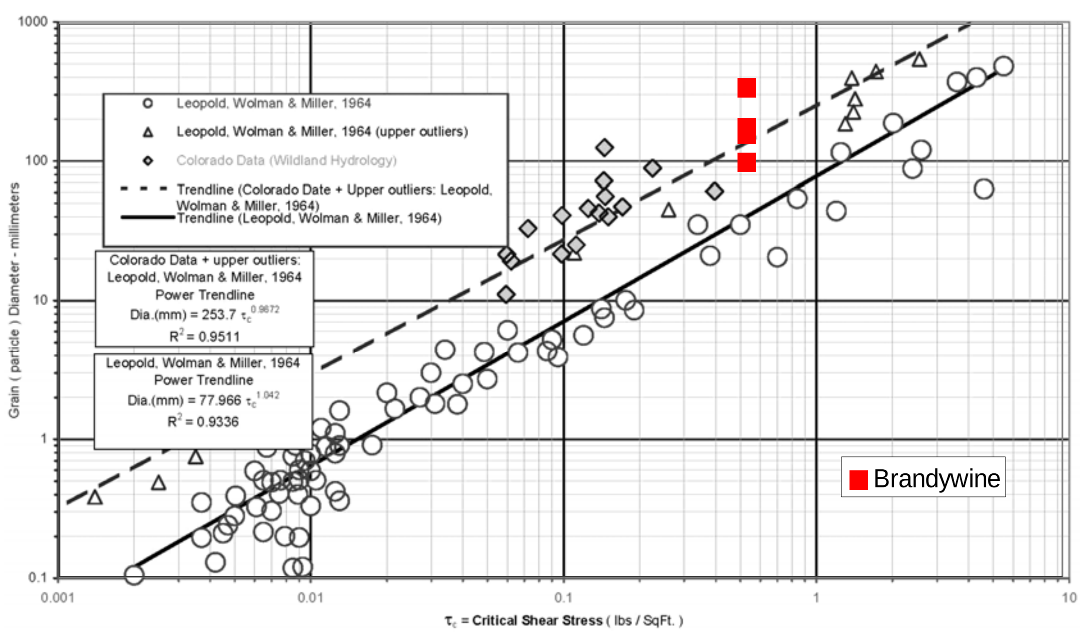

Figure 126. Critical Shear Stress (tc: Range .001 to 10) Required to Initiate Movement of Grains (particles), revised for Colorado Rivers.

Figure 8. Shields Curve Diagram showing Brandywine critical shear stress calculations for each monitoring year.

Overall, the sediment transport competency analysis shows that the bed material became finer after the large floods, both on the riffles and the point bars. The required depth analysis supports the cross section and profile observations (in the upper reach) that aggradation is more of a concern than degradation. The degradation in the lower reach cannot be explained by this analysis. Finally, the graphical results of the grain size versus boundary shear stress analysis presented in Figure 8 shows that the range of particle sizes being moved is within the range of data used to create the curve for Colorado Rivers shown in Figure 8. This in turn suggests the use of this curve for Colorado Rivers may be used in future assessments and designs for streams with geomorphological settings like the Brandywine site.

The results of this boundary shear stress analysis support the idea that as-built and post-as-built changes are minor and within the range of natural variability.

3.2.7 Habitat Assessment

Fish and benthic macroinvertebrates data was not collected on this site.

3.2.8 2006 Field Observations

A field visit was made on January 11, 2006. Overall, the site appeared to be functioning well. Vegetation was becoming established on the floodplain and erosion or instability appeared to be limited to isolated areas, e.g. the outside of meander bends. Bank erosion was most severe in the outside bends of stations 23+00 and 29+00. The rock vanes in these bends are no longer providing bank protection because of erosion behind the structure. In addition, the tributary that enters Batavia Kill near station 18+00 avulsed and now enters the stream several yards upstream of its as-built location. This avulsion was most likely caused by the downstream cross vane. This cross vane flattened the slope upstream which caused the tributary bedload to deposit along the right bank. The deposition caused the channel confluence to migrate upstream.

In addition, a chute cutoff has formed across the point bar of the station 23+00 pool. This chute cutoff was probably formed during the 2005 flood and should not cause long term stability problems. As woody vegetation continues to grow on the point bar, flood velocities should decreases and the chute cutoff may fill with sediment.

3.2.9 Recommendations

These recommendations are based on the data analyses and field observations.

1. The bank instability from 14+00 to 15+00 will likely become stable without intervention as woody vegetation continues to establish.
2. To allow establishment of vegetation that may provide better bank protection, the knotweed present throughout the site could be eliminated and replaced by woody vegetation.
3. The cross vane immediately downstream of the confluence with North Settlement Creek most probably flattened the slope at the location of confluence, encouraging deposition in this area. This deposition behind the cross vane arm then caused the confluence to shift upstream, where it settled at a new stable confluence point. For this reason, the tributary near station 18+00 should be stabilized in its existing location and not returned to its as-built location.
4. The rock vanes in bends 23+00 and 29+00 should be re-constructed. The new vanes should include boulders that provide a sill into the bank. In addition, the rock vanes should be constructed with lower arm slopes. The construction design of the vane arms should provide a means for which to prevent any bedload material from piping through the void space between the boulders. This could be achieved by backfilling behind the vane arms with a well graded mixture of sand, gravel, and cobble.

5. The left bank from station 24+00 to 28+00 should be heavily vegetated with live stakes and/or a brush mattress. This recommendation is made in lieu of changing the channel geometry to increase the belt width. However, it is recommended that future projects include a meander width ratio for each bend that exceeds 3.5.
6. The data show changes in the riffle bed elevations, i.e. some aggradation in the upstream reach and degradation in the lower reach. However, field observations suggest that the channel is vertically stable and just fluctuating due to large floods. There is no recommendation for changes in grade control.

3.3 Big Hollow

The Big Hollow stream restoration project was the third demonstration restoration project constructed along the Batavia Kill stream corridor as part of the Batavia Kill Stream Management Project, and was constructed in two phases. Phase I was completed in the fall of 2001, and Phase II was completed in the fall of 2002. The site is located in the upper reaches of the Batavia Kill headwaters near Maplecrest, as shown in Figure 1. This project reach is located 2,300 feet upstream of the 26 acre CD Lane Park Flood Control Structure, and Phase I and Phase II combined extend for approximately 5,160 feet. The drainage area discharging into this project reach ranges from 5.5 mi^2 to 7.2 mi^2.

Pre-restoration data was collected for entire Big Hollow site (Phase I and II) during 1997 through 2000. This data included survey of 14 monumented cross sections, pebble counts, sieve analysis of bed material samples, annotation of field observed erosion problem areas, and photographs. Post-restoration data was collected for the entire Big Hollow site during the years 2001 through 2005, including survey of thirty-five cross sections monumented at the time of construction, as-built topography of the stream bed, pebble counts, sieve analysis of bed material samples, and photographs. The monitoring assessments and calculations presented in this section are based on the pre- and post-restoration monitoring data collected.

3.3.1 Profile Assessment

Profile data was collected for the Big Hollow site during the Phase I as-built survey. Only cross section data was collected in subsequent monitoring years 2002 through 2005. Therefore, only cross section thalweg points from 2002 through 2005 used to create project profiles for these monitoring years. All cross sections within the Phase I reach of the project were consistently surveyed each monitoring year. For Phase II of the project, data on different cross sections is missing for different monitoring years. An overlay of project longitudinal profiles for all monitoring years is presented in Appendix C. Profile stationing for this project were surveyed from the upstream limit of project (station 0+00) to the downstream limit of the project (station 51+29).

The profile overlay graph shows that there has been either aggradation or degradation in most of the project reach, suggesting the project reach may still be adjusting to the disturbances caused by construction of the restoration project. From station 20+00 (upstream end of project) to station 42+30 (cross section 8), pools experienced mild to substantial aggradation. Pools from stations 44+35 (cross section 6) to 51+06 (downstream end of the project) were observed to have deepened over the monitoring period. In general, riffles were observed to have degraded over time from the as-built condition through 2004. This degradation in the riffles may be due to the vanes placed along the riffles, which may cause scour at their downstream side as flow drops across them during higher flows. A difference is seen during the 2005 flood, where riffles from station 3+24 to 13+89 and those through stations 31+86 through 35+17 experienced aggradation. During the 2005 flood, the channel made two avulsions and scoured extensive lengths of bank along the entire length of the channel. The large adjustments caused by the 2005 flood most likely surpassed the conveyance capacity through the riffles, causing some of the material moved from the 2005 avulsions and bank erosion to deposit along the riffles.

The continuous adjustments observed from the profile data for 2002 through 2005 may indicate some portions of the channel are adjusting to constraints in channel meander belt width (see Section 3.3.3).

3.3.2 Dimension Assessment

As a general convention, descriptions of the left or right side of the channel refer to the corresponding side of the channel when viewed facing downstream. Cross sections were numbered in ascending order from downstream end of project (cross section 1) to upstream limit of the project (cross section 35). The location and stationing of each cross section is shown in Appendix C.

Cross section 1 – Pool

Cross section 1 is located near station 51+00 in a scour pool located near the downstream end of a cross vane. This cross section showed a positive trend towards increasing pool depth from 2002 to 2004. During the 2005 storm event, high flows resulted in some erosion in the cross section and damage to the cross vane structure. The cross vane has since been repaired and the minor erosion problems in the cross section have been corrected. Overall, this cross section has been stable.

Cross section 4 – Pool

Cross section 4 is a pool located within a series of rock vanes near station 46+50. This cross section showed a positive trend towards increasing pool depth from 2002 to 2004. During the 2005 storm event, the channel thalweg shifted to the right through approximately 12 feet of erosion on the right bank and aggradation on the left bank. Bankfull width and area increased from 47 ft and 174 ft^2 to 53 ft and 216 ft^2, respectively. This channel shift appears to indicate the formation of a channel avulsion which led to split flow during the storm event and sediment deposition and aggradation on the left side of the channel. This cross section has since been repaired and the thalweg has been shifted back to the same location as prior to the storm event.

Cross section 6 – Pool

Cross section 6 is a pool located in the lower third of a meander bend within a series of rock vanes near station 44+25. There appears to have been steady erosion on the outside of the bend since construction. The right bank eroded approximately 2 feet from 2002 to 2004. During the 2005 storm event the channel eroded another 6 feet on the right bank. Bankfull area increased from 149 ft^2 to 187 ft^2. The erosion on the right bank indicates a trend towards lateral migration where the bank may eventually become undercut which could lead to bank failure. There are several possible causes of this erosion. It is common to see erosion problems in the lower third of meander bends in meandering channels. Also, the right bank in this area has very little vegetation to provide root density and soil cohesion. Finally, channel banks at this cross section seem to be higher than bankfull elevation. This prevents flows of depth between bankfull elevation and the elevation of top of banks from spreading over onto the floodplain to dissipate energy.

Cross section 7 – Riffle

Cross section 7 is located in a riffle near station 43+00 just downstream of a glide coming out of a scour pool below a cross vane. This cross section shows almost no change between 2002 and 2005 (even after a large flow event). Minor changes can be accounted for by variation in survey points between years and natural shifts in the stream bed. It can be assumed that this cross section is stable.

Cross section 9 – Riffle

Cross section 9 is located in a riffle near station 41+00. This bankfull cross section shows almost no change between 2002 and 2005. Minor changes, including the change in bankfull area in 2005, can be accounted for by variation in survey points between years and natural shifts in the stream bed. However, as seen in the cross section overlay in Appendix C, an avulsion is beginning to form along the right bank. Although this cross section appears to be stable, the section should be monitored to confirm if the change in cross section dimension observed from the cross section overlay represents a true potential for avulsion through this area.

Cross section 10 - Pool

Cross section 10 is a pool located in the middle of a meander bend with a rock vane on the right side near station 39+75. There appears to have been steady erosion on the outside of the bend since construction. Erosion from 2002 to 2004 was approximately 4.3 feet on the right bank. During the 2005 storm event, the channel eroded another 4 feet on the right bank. At the same time, the channel is aggrading on the left side and formed a significant mid-channel bar during the 2005 storm event (see May 2005 cross section in Appendix C). Since construction, the channel thalweg has shifted to the right approximately 13 feet. Bankfull width and area remained relatively constant due to the balance between erosion and aggradation. The erosion on the right bank indicates a trend towards lateral migration where the bank may eventually become undercut which could lead to bank failure. Additionally, this bank is higher than bankfull elevation, which limits the ability of the channel to dissipate energy during high flows by accessing its floodplain.

Cross section 11 – Riffle

Cross section 11 is located in a riffle near station 38+50 just downstream of the glide coming out of the scour pool below a cross vane. This cross section shows almost no change between 2002 and 2005. Minor changes can be accounted for by variation in survey points between years and natural shifts in the stream bed. It can be assumed that this cross section is stable.

Cross section 12 - Pool

Cross section 12 is located near station 36+50 in the center of a relatively low radius meander bend. This cross section was very stable and showed only minor changes from 2002 to 2004. During the 2005 storm event the channel avulsed and shifted 100 feet to the right. The constructed channel filled in completely with sediment. The channel avulsion formed with bankfull dimensions similar to the constructed channel. This reach has since been repaired and the channel shifted back to its design location. The current cross sectional area is 120 ft^2, similar to the as-built area.

Cross section 14 - Pool

Cross section 14 is located in the lower third of a meander bend within a series of rock vanes near station 34+25. This cross section was very stable and showed only minor changes from 2002 to 2004. During the 2005 storm event, the channel experienced significant widening and aggradation. Bankfull width increased from 50 ft^2 to 80 ft^2 and maximum bankfull depth decreased from 4.4 ft to 2.3 ft. This process resulted in an overly wide channel with a top of bank that is below the bankfull elevation. The slope in this meander bend is held flat by the cross vane at station 35+00. This area has since been repaired and the current cross sectional area is162 ft^2, similar to the as-built area.

Cross section 15 – Riffle

Cross section 15 is located near station 33+00 in a riffle section approximately 25 degrees offset to the right from the fall of the valley. This cross section was very stable and showed only minor changes from 2002 to 2004. During the 2005 storm event the channel thalweg shifted to the left by 30 feet through erosion of the left bank and aggradation on the right bank, searching for energy dissipation. Bankfull width and area increased significantly from 34 ft and 59 ft^2 to 59 ft and 108 ft^2, respectively. This process resulted in an overly wide channel with inadequate sediment transport competency and capacity to move its bedload. This unstable situation has since been repaired and the current cross sectional area is 49 ft^2, similar to the as-built area.

Cross section 17 – Riffle

Cross section 17 is located near station 31+00 in a riffle section approximately 20 degrees offset to the left from the fall of the valley. This cross section was very stable and showed only minor changes from 2002 to 2004. During the 2005 storm event the channel thalweg shifted to the right by 25 feet through erosion of the right bank and aggradation on the left bank. Bankfull width and area remained relatively constant due to the balance between erosion and aggradation. This process resulted in an overly wide channel with inadequate sediment transport competency and capacity to move bedload. This unstable situation has since been repaired and the current cross sectional area is 72 ft^2, similar to the as-built area.

Cross section 19 – Pool

Cross section 19 is a pool located within a series of rock vanes near station 29+00. This cross section has been stable both vertically and laterally with the exception of damage sustained during the 2005 flood event. A channel avulsion appears to have formed between stations 25+00 and 29+00. Erosion on the right bank was most likely a result of overland flow entering the stream at this point. Bankfull width increased from 59 feet to 88 feet during the storm event. This area was repaired following the storm event and now matches the pre-storm condition.

Cross section 20 – Pool

Cross section 20 is a pool located within a series of rock vanes near station 27+50. This cross section has been stable both vertically and laterally, with the exception of minor aggradation that occurred during the 2005 flood event. Some of this aggradation is likely the result of an avulsion in this area from station 18+50 to station 23+25. The avulsion would have resulted in a split flow during the storm event which led to sediment deposition and aggradation in the channel. Bankfull width remained constant during the storm event indicating that no erosion occurred. This area was repaired following the storm event to create a larger pool than was originally constructed.

Cross section 23 – Riffle

Cross section 23 is a riffle cross section that is located in the center of a meander bend between a series of rock vanes. This cross section has aggraded each year following construction from an as-built mean depth of 2.1 ft to a 2005 (post flood event) mean depth of 1.1 ft. Bankfull area also decreased each year in this cross section from an as-built area of 85 ft^2 to a 2005 post storm area of 44 ft^2. Some of this aggradation is likely the result of an avulsion upstream from station 18+50 to station 23+25. The avulsion would have resulted in a split flow during the storm event, which led to sediment deposition and aggradation in the channel. This cross section has since been repaired and the current cross sectional area is 70 ft^2, similar to the as-built area. A riffle has formed throughout this meander bend as a result of the aggradation. A consistent trend towards aggradation and riffle formation in the meander bends in addition to the avulsions forming between meander bends indicate this channel is migrating toward a non-meandering, step-pool channel morphology.

Cross section 24 – Pool

Cross section 24 is located in the center of a meander bend between a series of rock vanes. This cross section has aggraded each year following construction from an as-built maximum depth of 4.4 ft to a 2005 (post flood event) maximum depth of 1.8 ft. Some of this aggradation is likely the result of an avulsion in this area from station 18+50 to station 23+25. The avulsion would have resulted in a split flow during the storm event which led to sediment deposition and aggradation in the channel. Bankfull area also decreased each year in this cross section from an as-built area of 120 ft^2 to a 2005 post storm area of 44 ft^2. This cross section has since been repaired and the current cross sectional area is 65 ft^2, which is still significantly lower than the as-built area. A riffle has formed throughout this meander bend as a result of the aggradation. A consistent trend towards aggradation and riffle formation in the meander bends indicates this channel is migrating toward a step-pool channel morphology.

Cross section 26 - Pool

This cross section shows very little change between 2002 and 2005 (even after a large flow event). The only noticeable change is an increase in pool depth which is a positive trend. Some minor erosion at the toe of the streambank is evident visually; however, minor undercuts in the channel bank provide increased habitat diversity for fish and macroinvertebrates. It can be assumed that this cross section is stable.

Cross section 27 – Riffle

Cross section 27 is located in a riffle near station 13+75. This cross section shows almost no change between 2002 and 2005. Minor changes can be accounted for by variation in survey points between years and natural shifts in the stream bed. Mature trees along the top of bank have provided good rootmass leading to bank stability in this section of channel. It can be assumed that this cross section is stable.

Cross section 29 - Pool

Cross section 29 is located near station 10+25 in the lower third of a meander bend. This cross section has aggraded each year following construction from a 2002 (first year of record) maximum depth of 2.8 ft to a 2005 (post flood event) maximum depth of 1.2 ft. Bankfull area also decreased each year in this cross section from a 2002 area of 35 ft^2 to a 2005 post storm area of 13 ft^2. This cross section has been repaired, but has not been resurveyed since the repair. Similar to the other aggraded cross sections, current channel dimensions are likely similar to the 2002 dimensions. The outside bank through this meander bend is stable with good vegetation and no evident erosion indicating low near bank stress and erosion potential in this area. This meander bend appears similar to the bend at station 24+00 where a riffle has formed throughout the bend as a result of the aggradation. A consistent trend towards aggradation and riffle formation in the meander bends indicates that this portion of the channel is migrating toward a step-pool channel morphology.

Cross section 31 - Riffle

Cross section 31 is located in a riffle near station 6+00 in a high radius gradual bend to the left. This cross section was very stable and showed only minor changes from 2002 to 2004. During the 2005 storm event, the channel thalweg shifted to the left by 16 feet through erosion of the left bank and aggradation on the right bank. Bankfull area, depth, and width did not change significantly through this process. This cross section has since been repaired and the current cross sectional area is 79 ft^2, similar to the 2002 area (first year of record).

Cross section 33 – Riffle

Cross section 33 is located near station 3+25 in a riffle section approximately 25 degrees offset to the left from the fall of the valley. This cross section was very stable and showed only minor changes from 2002 to 2004. During the 2005 storm event the channel thalweg shifted to the right by 25 feet through erosion of the right bank and aggradation on the left bank. Bankfull width and area increased significantly from 38 ft and 67 ft^2 to 156 ft and 225 ft^2, respectively. This process resulted in an overly wide channel with inadequate sediment transport competency and capacity to move bedload. This unstable situation has since been repaired and the current cross sectional area is 78 ft^2, similar to the 2002 area (first year of record).

Dimension Assessment Summary

Overall, the Big Hollow reach seems to display satisfactory stability between years 2002 and 2004: pools generally . However, during a large flood event in 2005, substantial change was observed to cross section dimension along the reach, including three avulsions. The channel showed signs that it did not have the capacity to dissipate its energy efficiently under high flows. The as-built cross section data show that several portions of the channel reach were constructed with a high bank height ratio (over 1.3). This limits the ability for flows to spread onto the floodplain as soon as bankfull flow depth is surpassed, an action that would help dissipate flow energy. The high energy flow then has an increased capacity to erode banks and significantly alter channel morphology, as shown in the cross section survey of post-flood conditions. In addition, insufficient woody vegetation protecting streambanks along portions of the channel reach may also have contributed to the substantial erosion occurring during the 2005 flood event.

3.3.3 Pattern Assessment

The Big Hollow reach has the steepest valley of the three projects sites. The average channel slope is 0.014 or 1.4%. By comparison, the average channel slope for the Maier Farm and Brandywine sites are 0.22% and 0.26%, respectively. Most sections are still within an alluvial valley; however, there are short reaches that appear to have colluvial influences.

In the Catskills Mountain region, the commonly found stable stream reaches with average channel slopes similar to that of the Big Hollow project are observed to follow a meandering pattern, and this pattern proves to be an appropriate energy dissipation mechanism for this setting. It should be noted that for successful energy dissipation through a stable meandering channel, appropriate meander belt width ratio and sinuosity are key factors. When the sinuosity and meander belt width ratio of a meandering channel is too low, energy dissipation through the meandering process may not be as effective as required by the conveyed flow and this may force the channel to search for energy dissipation in alternate ways. The Buck Engineering team has learned from experience with other monitoring projects that this may lead to marked bank erosion and in some cases where meander width ratio and sinuosity are confined, evolution to energy dissipation through vertical meandering (step-pool channel morphology). Our team has observed this occur in valleys with slopes lower than the 2% (the 2% slope is described by Rosgen (1996) as the break slope between meandering and step-pool streams). In these cases, the channel confinement which reduces meander width ratio and sinuosity may be able to compensate for the lower than 2% slope in the formation of step-pool channel morphology, as vertical meandering is a function of both valley slope and confinement.

The design sinuosity for the Big Hollow project is 1.5, however the as-built sinuosity was set lower at 1.2. A 1.2 sinuosity is on the border between meandering and step-pool channels. The design meander width ratio was 3.6, just above the recommended minimum value of 3.5 for meandering streams. The as-built meander width ratio values ranged from 3.1 to 5.0 along the entire project. This range, which includes portions of the reach with meander width ratio below 3.5, causes the channel to vary between a step-pool pattern (with meander width ratios less than 3.5 and sinuosities less than 1.2) and a meandering channel (meander width ratios greater than 3.5 and sinuosities greter than 1.2). This variability is part of the reason that the channel experienced large changes during the large floods.

For example, three large avulsions occurred after the 2005 flood, one near station 19+00 and the other at 34+00. In both cases, these avulsions occurred just downstream of a reach with meander width ratios less than 3.5 and sinuosities less than 1.2. Hence, the avulsions occurred at breakpoints where the channel transitioned from a step-pool to a meandering plan form. The problem was exacerbated two other conditions present at the location of the abandoned channel bed: (1) this area was devoid of vegetation, and (2) the area remained as the low point of the valley. Repair work placed the channel back into the meandering form. Sills were added to floodplain across the old channel. This additional structure may provide the armoring necessary to keep the channel in place; however, a more conservative approach may have been to keep the channel straighter and dissipate energy using step-pools.

In summary, some portions of the Big Hollow reach were constructed with slightly low meander width ratio and sinuosity. These parameters are constrained by land use and by the substantial number of rock structures within the channel (the closely spaced in-stream rock structures provide tight grade control). This in itself may not indicate the channel should be expected to evolve into a step-pool channel. Further monitoring of the Big Hollow site should continue to determine if the changes in this project's morphology, particularly those occurring during the 2005 flood, are due to lack of sufficient vegetation to protect the banks from erosion, unaccounted for disturbances to the upstream sediment supply, or if they indicate channel evolution to a step-pool channel.

3.3.4 Bed Material Analysis

Pre- and post-construction pebble count data were compared for the site to determine if there were observable trends in the bed material distribution before and after restoration efforts. Pre-restoration data were collected during 1998, 1999, and 2000. Post-restoration data were collected during 2004 and 2005.

To compare data from different years, composite samples were created for each year by combining individual cross section pebble counts, to develop on cumulative sample for the project reach during each year. The number of cross sections sampled in a given year varied depending on whether the sampling occurred pre- or post-restoration. During pre-restoration sampling years, 14 cross sections were sampled along the project reach. During post-restoration sampling years, 35 cross sections were sampled. During both pre- and post-restoration sampling, efforts were made to sample approximately even numbers of riffles and pools.

Cumulative pebble count data for the Big Hollow Site are compared in Figure 9. Pre-restoration data are colored black, while post-restoration data are colored red, with different line styles and symbols for different years. The data show that the pebble count distributions vary from year to year, but there are few observable trends in the data when comparing pre-restoration data to post-restoration data. The post-restoration distribution curves generally fall within the variability documented in year-to-year pre-restoration data.

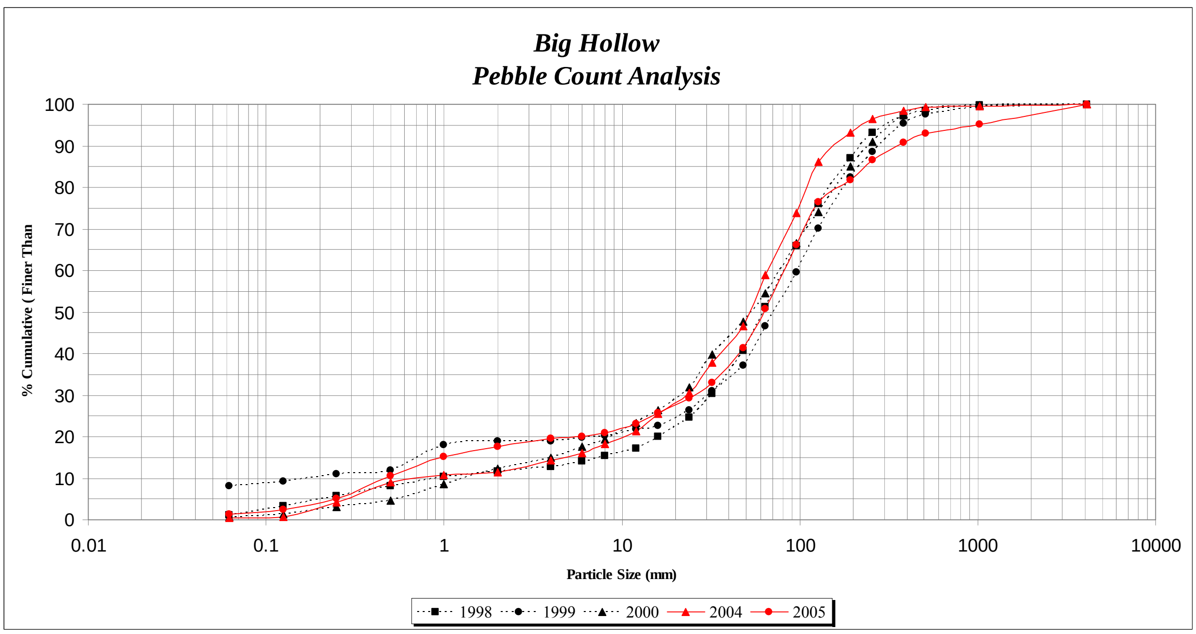

Figure 9. Cumulative pebble count data for the Big Hollow Site.

One notable variation is a measured increase in the D95 size particle for 2005, as compared to other sampled years. This apparent increase in the larger size fraction of the distribution is most likely due to the substantial amount of large bed material that was deposited through the system during the floods that occurred in 2005.

3.3.5 Bank Erosion Assessment

Pre-construction cross section survey data was available for the Big Hollow site for 1998 through 2000, and included survey of 14 cross sections across the site for each pre-restoration year. The location of these 14 cross sections was kept the same during each pre-construction year. An overlay of cross sections from 1998 and 1999 was used to calculate erosion volume for year 1999, while overlay of cross sections from year 1999 and year 2000 was used to calculate erosion volume for year 1999.

Post-construction cross section survey data was available for the Big Hollow site for the years 2001 through 2005, and included survey of 35 cross sections across the site for each post-restoration year. In the same manner as under pre-restoration conditions, overlay of a cross section for a given year with the cross section for the previous year provided the erosion volume for that year.

The number and location of cross sections surveyed under pre- and post- restoration conditions varies, and accordingly, lengths of erosion represented by each cross section under pre- and post- construction conditions also varies. In addition, the total length of stream within project limits varies between pre- and post-construction conditions since stream alignments varies under each condition. The significant differences in data collection procedures between pre- and post-construction conditions does not allow for just comparison of erosion volume trends observed under pre- and post-construction conditions. However, it would still be valid to observe the variability and trends in erosion trends under post construction and use this as indicator of post-construction project behavior and success.

Following the methodology for computation of yearly erosion volume described in Section 2.3, yearly erosion volumes from the site were calculated as summarized below. These calculations were performed using an average soil density obtained for state of New York of 1.15 ton/yd^3.

Pre Restoration:	
Total Erosion Rate Year 1998 (tons/yr)	4,369 tons/yr
Total Erosion Rate Year 1999 (tons/yr)	14,928 tons/yr
Post Restoration:	
Total Erosion Rate Year 2002 (tons/yr)	2,798 tons/yr
Total Erosion Rate Year 2003 (tons/yr)	2,579 tons/yr
Total Erosion Rate Year 2004 (tons/yr)	916 tons/yr
Total Erosion Rate Year 2005 (tons/yr)	9,038 tons/yr

As described in Section 2.3, the probable margin of error in these erosion volume calculations may be substantial enough to prevent the use of these numbers as approximations of the real erosion rates occurring at the Big Hollow site. However, the trends observed in these numbers are valid.

Only two years of erosion volume calculations are available for the pre-restoration condition. It is difficult to assess a trend in pre-construction erosion rates with only two data points.

For the post-restoration condition, the yearly erosion rate calculations demonstrate the erosion volume generally trends downward over time as compared to the as-built condition. This indicates construction of the project, coupled with the establishment of more mature vegetation along the project banks as post construction years progress, may be contributing towards a reduction of bank erosion from the site. This could be used as an indication of project success in reduction of bank erosion.

For the post-restoration condition, the yearly erosion rate calculations indicate the erosion volume generally trends downward over time, up to year 2004. A large flood event occurred during 2005, which was accompanied by an increase in erosion rate for this year. This may indicate that establishment of a more protective vegetation cover (thick, woody vegetation) is required along the banks of this reach to enhance project performance and further reduce erosion rates from this site during higher flows.

3.3.6 Competency Analysis

A) Required Depth Analysis

Results from the sediment transport analyses are shown in Table 4. Riffle and bar sediment samples were collected in 1998, 1999, 2000 and 2004. The largest particles sampled from the bar ranged from 126 to 300 mm with an average of 195 mm. The D50 of the riffle ranged from 31 to 78 mm with an average of 62 mm. The samples varied with each sampling year and did not show a trend.

Table 4. Sediment Transport Analysis Results for Big Hollow site.

Year Sampled	Sample Descriptor	D50 Riffle (mm)	D50 Bar Sample (mm)	Largest Particle on Bar (mm)	Critical Dimensionless Shear	Average Design Slope (ft/ft)	Average Design Mean Depth (ft)	Boundary Shear (lbs/sq ft)	Required Depth (ft)
1998	Sample 1	78	35	138	0.0231	0.0143	2.2	1.73	1.23
1998	Sample 2	60	19	138	0.0306	0.0143	2.2	1.73	1.62
1998	Sample 3	65	30	126	0.0213	0.0143	2.2	1.73	1.03
1999	Sample 3	77	45.5	248	0.0136	0.0143	2.2	1.73	1.30
2000	Sample 2	67	17	300	0.0252	0.0143	2.2	1.73	2.91
2000	Sample 1	53	16	280	0.0293	0.0143	2.2	1.73	3.16
2004	XS9-13	40	5.8	101	0.0155	0.0143	2.2	1.73	0.60

The design mean bankfull riffle depth was 2.2 feet. The as-built and post as-built mean depths ranged from 1.8 to 2.8. The required mean depths calculated for this site range from less than 1.0 to over 3.0 feet. This substantial variability in required depth along the same river reach is being driven by the variability in the largest particle sampled from the bar and their corresponding critical dimensionless shear stress. This site has experienced significant changes in bed material composition associated with large floods and corresponding channel avulsions. This together with the variability in the results suggests the largest particle samples may not be representative of stream competency, thus invalidating the required mean depth calculations. Because of these changes, along with pre-restoration instability, a comparison between the design, as-built, or post as-built depths and the required depths is not appropriate

B) Boundary Shear Stress Analysis. The boundary shear stress for the design channel is 1.7 lbs/sq ft, by far the highest of the three project sites. The largest particles sampled from the bar were plotted against the boundary shear stress and is shown on Figure 10. Three of the data points plot on the solid trendline and four plot below the dashed trendline but within the range of the data points used to create the trendline. This separation in data does not correlate with project construction or storm events. Again, this variability is likely due to the variability in bed material associated with the floods and channel avulsions. Overall, Big Hollow had the most problems with vertical stability of the three project reaches. However, these changes were not well represented by the sediment transport competency analysis.

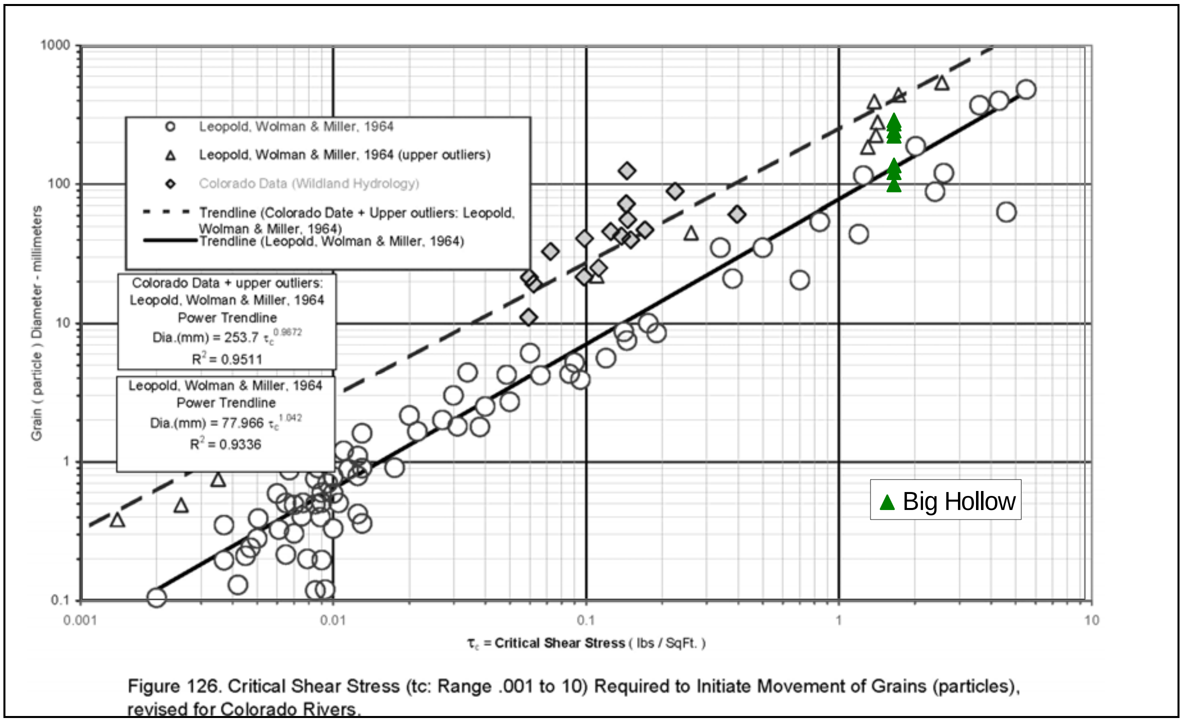

Figure 10. Shields Curve Diagram showing Big Hollow critical shear stress calculations for each monitoring year.

3.3.7 Habitat Assessment

A) Stream Benthic Macroinvertebrate Community

Benthic macroinvertebrate samples were collected from 2002 to 2004 at four sites in Big Hollow: one in an upstream section of the restoration project, one in a downstream section of the restored area, one in a stable reference reach upstream of the restored reach, and one in a disturbed control reach for the Big Hollow project that is comparable to the site prior to restoration. No pre-restoration samples were collected. A summary of the benthic macroinvertebrate sampling results at each location is presented in Table 5, with complete results presented in Appendix D.

The components of the benthic macroinvertebrate community that are commonly used to evaluate habitat and water quality are the EPT taxa. The EPT taxa include specimens belonging to the insect orders Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies). These groups are generally the least tolerant to water pollution and therefore are very useful indicators of water quality. The presence of substantial numbers of EPT taxa and individuals is considered indicative of relatively undisturbed "higher quality" streams. Common metrics used to evaluate the benthic macroinvertebrate community include total and EPT taxa richness, biotic index (Hilsenhoff), and species diversity indices (Shannon-Weaver and Simpson), as shown in Table 5.

A healthy community is characterized by high species richness (both total and EPT), high species diversity indices (both Shannon-Weaver and Simpson), and a low Hilsenhoff biotic index. Based on this, year 2003 appeared to be the most favorable for the benthic macroinvertebrate community for all sites. This was most likely in response to the higher stream flow level experienced in 2003.

EPT taxa richness for the downstream reach of the restoration project during 2002 was the lowest measured during the monitoring period, while EPT taxa richness increased to meet or exceed the reference reach numbers in 2003 and 2004. Total and EPT taxa richness and species diversity indices were similar between all sampling sites during 2003 and 2004, while the Hilsenhoff biotic index was consistently lower in the reference reach as compared to the restored and control reaches for all sampling years. This indicates that the benthic community for the restoration and control reaches was dominated by more pollution tolerant organisms than the reference reach community through 2004. The reference reach was dominated by more intolerant EPT organisms such as *Sweltsa* sp. (a stonefly) and *Lepidostoma* sp. (a caddisfly), while more tolerant EPT organisms such as *Hydropsyche* spp. and *Cheumatopsyche* sp. (both caddisflies) and midges were prevalent at the restoration and control reaches (Appendix D).

Overall, it appears the benthic macroinvertebrate community is responding positively to the project restoration. However, no pre-restoration surveys were conducted and the control site was not sampled in 2004. Therefore, it is difficult to assess the relative improvement made from pre-restoration conditions through 2004. While the restored reach has supported more EPT species since 2002 and, therefore, appears to be improving, the community was still dominated by more tolerant organisms than the reference reach through 2004.

Table 5. Summary of Benthic Macroinvertebrate Data for Big Hollow.

Sites	Total Taxa Richness	EPT Taxa Richness	Hilsenhoff Biotic Index	Shannon-Weaver Index	Simpson's Index
2002					
Restored Reach-Downstream end	45	16	4.47	1.25	0.89
Control Reach	45	25	4.75	1.34	0.93
Reference Reach	45	24	4.40	1.31	0.90
2003					
Restored Reach-Upstream end	62	29	4.15	1.56	0.96
Restored Reach-Downstream end	53	25	4.46	1.45	0.95
Control Reach	54	24	4.48	1.48	0.95
Reference Reach	53	24	3.72	1.47	0.95
2004					
Restored Reach-Upstream end	47	22	4.17	1.36	0.93
Restored Reach-Downstream end	44	22	4.55	1.37	0.94
Reference Reach	51	19	3.99	1.38	0.94

B) Stream Fish Community

The fish community of Big Hollow project reach was sampled annually from 2000 to 2004 in order to document changes resulting from restoration activities. Three areas were sampled: the project site (at both the upstream and downstream end), a stable reference reach upstream of the project area, and a disturbed control site similar in characteristics to the project area prior to restoration. The fish data collected from these sampling practices are listed in Appendix D.

Sampling was conducted in July and August, generally months of low flow, although stream flows in 2000 were considerably higher than those measured in subsequent years, as shown in Table 6. Metrics taken were extent of area surveyed, stream flow in, number of species or species richness, total fish number observed, and total fish biomass (in grams).

Prior to restoration (2000-2001), four species were recorded at the downstream section of the project area, six species were recorded at the reference site, and five species were recorded in the control site. Both the proposed site and control site were dominated in number and biomass by blacknose dace (*Rhinichthys atratulus*) and slimy sculpin (*Cottus cognatus*), while the reference site was dominated by brook trout (*Salvelinus fontinalis*) and slimy sculpin.

After restoration, the diversity of fishes increased significantly in the restored area while remaining relatively constant at the control and reference sites. In 2002, seven fish species were recorded at the downstream section of the project area and five were noted in the upstream end. Notable records from the restored area are three species of trout: brown (*Salmo trutta*), brook, and rainbow (*Oncorhychus mykiss*). In 2003 and 2004, eight and six species, respectively, were recorded from the downstream section of the restored area. Blacknose dace, brown trout, and white sucker (*Catostomus commersoni*) were dominant in numbers and biomass. The upstream restored section had brown trout, brook trout, blacknose dace, and slimy sculpin dominating. The reference site had predominantly brown trout, brook trout, and slimy sculpin.

Prior to restoration, only two fish species were common in Big Hollow reach: blacknose dace and slimy sculpin. Only two other species, creek chub (*Semotilus atromaculatus*; 6 in 2001) and rock bass (*Ambloplites rupestris*; 1 in 2002) were collected in the two years of pre-restoration sampling. After restoration, seven species were collected from the downstream section of the project and five were collected in the upstream section. While blacknose dace and slimy sculpin were still the most common, significant numbers of the other species, in particular brown trout (54) and creek chub (23), were also taken. Creek chub, white sucker, brown trout, and brook trout were also commonly seen. This trend of increased number of species and number of specimens continued from 2002 to 2004 (Table 6). The significant positive changes noted subsequent to restoration are presumably a result of increased habitat complexity.

Table 6. Summary of Fish Sampling Data.

Sampling Year and Location	Index					
	Reach Area (m^2)	Stream Flow (cfs)	Sample Date	Species Richness	Total Fish Number	Total Fish Biomass
Year 2000						
Restored Reach-downstream	588	6	7/27/2000	3	754	2339
Reference Reach	532	4.3	7/28/2000	5	461	2962
Control Reach	389	3.1	8/11/2000	4	426	1760
Year 2001						
Restored Reach-downstream	343	0.3	8/7/2001	3	1461	4266
Reference Reach	330	0.9	8/14/2001	6	1127	5543
Control Reach	259	0.5	8/8/2001	5	1250	6427
Year 2002						
Restored Reach-downstream	526	0.9	7/15/2002	7	250	1576
Restored Reach-upstream	315	0.7	7/16/2002	5	1124	3224
Reference Reach	521	2	7/11/2002	5	659	3925
Control Reach	295	1.1	7/16/2002	5	1355	4831
Year 2003						
Restored Reach-downstream	435	1.9	7/15/2003	8	1066	2310
Restored Reach-upstream	455	2.4	7/16/2003	4	773	2459
Reference Reach	549	1.8	7/14/2003	5	959	4151
Control Reach	311	3.1	7/7/2003	5	1207	4590
Year 2004						
Restored Reach-downstream	416	0.9	7/14/2004	6	1422	4560
Reference Reach	534	1.1	7/15/2004	5	1036	6486
Control Reach	596	0.7	7/13/2004	7	2636	8005

3.3.8 2006 Field Observations

A field visit was made on January 11, 2006. Big Hollow had more stability problems than the other two sites. The upper section from station 3+00 to 14+00 appeared to be functioning well. This section of channel was fairly straight and the cross vanes formed deep pools. There was mild aggradation upstream of the bridge, which was likely caused from backwater effects. The small mid channel bar should diminish with bankfull flows. Overall, the bedform through this section varied from steep riffles to pools characteristic of a step/cascade – pool sequence. This reach is functioning well.

The structures at station 14+00 and 15+50 had large drops, greater than 2 feet. It appeared that a headcut had migrated upstream from the cross vane at station 19+00 to the structure at station 15+50. Evidence for the headcut included the large drop over the 15+50 structure and a plane bed from station 19+00 to 15+50.

A repaired avulsion was observed from station 19+00 to 23+50. During the 2005 flood, the material filling the old channel was washed out and enough material deposited in the new channel downstream of station 23+50 to almost completely fill it. The bend at station 23+50 was severely aggraded with top of bank pool depths less than the bankfull mean depth.

The remaining part of the channel showed similar trends. The straighter sections seemed to perform better. They were more stable and the pools, formed by cross vanes and grade control j-hooks, were deeper. There were very few pools in the outside of the meander bends. In fact, riffles were forming in many of the bends. It also appeared that the pools were too wide. Most of the pools had aggraded and baseflow was running over the point bar. There was mild erosion on most of the bends. Given the land use constraints and heavy sediment load, it appears that a step-pool design may have been a more conservative approach.

3.3.9 Recommendations

These recommendations are based on the data analyses and field observations.

1. Continue monitoring. It is important to gather sufficient data on this site, including assessment of the relation between the floodplain and channel geometry at the areas of the 2005 avulsions, to determine the cause of the changes in this project's morphology, particularly those occurring during the 2005 flood. Possible causes may be lack of sufficient vegetation to protect the banks from erosion, unaccounted for disturbances to the upstream sediment supply, or constriction of the channel floodplain. It is very possible that Big Hollow will begin to respond in a healthy direction as vegetation becomes established and bankfull flows transport some of the aggraded material downstream.
2. If further monitoring indicates that the stream is not evolving in a stable direction, one of two options should be considered for this project: (1) create a step-pool channel with vertical meandering and meander width ratio less than 3.5 or, (2) negotiate with landowners to use more of the natural valley width and achieve a meander width ratio greater than 3.5. The approach selected should improve sediment transport and channel efficiency throughout the reach.

4.0 CONCLUSIONS

4.1 Maier Farm

Overall, the site appeared to be functioning well. The only two locations where streambank erosion was observed were at a location where rock vanes were constructed shorter and steeper than current design guidance would suggest and where banks were vertical and without any woody vegetation to provide protection (station 16+00 and stations 20+00 to 22+00). At these locations, the banks should be re-graded and planted with woody vegetation. Overall, vegetation along the reach should be reinforced with woody vegetation and other species providing good bank protection, this way providing better guarantee against bank erosion.

The remaining sections of the channel appeared to be evolving in a positive direction. Willows and other early successional species are colonizing the point bars. Over time, the channel should narrow and become more stable. Debris has accumulated on the downstream bridge; however, it is not causing a stability problem. While equipment is on-site, the debris could be removed from the downstream bridge.

Pebble count data and the bed material analysis could not reveal an observable trend in the adjustment of bed particle size towards stability or instability. The sediment transport competency analysis showed that the mean depth variability associated with this site appears to be within the normal range that can be expected in natural channels, especially during years with large floods. The analysis also suggested channel dimension and slope are sufficient to prevent long term aggradation or degradation. The observed fluctuations in the bed elevation are part of the natural variability associated with natural channels responding to large floods.

The bank erosion assessment showed a trend towards reduction in total bank erosion rate from this site throughout the monitoring years.

4.2 Brandywine

Overall, the site appeared to be functioning well. Erosion or instability appeared to be limited to isolated areas on the outside of meander bends. Bank instability present as of January 2006 in areas not invaded by knotweed will likely become stable without intervention as woody vegetation continues to establish. The invasion of knotweed should be controlled to allow more protective, woody vegetation to establish, as knotweed does not provide adequate bank protection and further erosion problem areas may develop where knotweed exists along the banks. Overall, vegetation along the reach should be reinforced with woody vegetation and other species providing good bank protection, this way providing better guarantee against bank erosion.

During the monitoring period, the tributary that enters Batavia Kill near station 19+00 avulsed and now enters the stream several yards upstream of its as-built location, a transition most likely caused by the cross vane immediately downstream. This cross vane flattened the slope upstream, which caused the tributary bedload to deposit along the right bank, forcing the channel confluence to migrate upstream. This tributary should be stabilized in its existing location and not returned to its as-built location.

Reconstruction of rock vanes in bends at project stations 23+00 and 29+00 and re-vegetation of the left bank from station 24+00 to 28+00 are recommended as described in Section 3.2.9 of this report.

The data show changes in the riffle bed elevations, mainly some aggradation in the upstream reach and degradation in the lower reach. However, field observations suggest that the channel is vertically stable and just fluctuating due to large floods. There is no recommendation for changes in grade control.

Pebble count data and the bed material analysis show an apparent trend towards finer bed material over the past four years. This may indicate the reach has yet to reach its stable condition subsequent to the construction disturbance; however the cause of this trend in bed material is difficult to determine with the monitoring data available.

The upstream portion of the channel experienced aggradation over the monitoring period. The sediment transport competency analysis results show the required flow depth for initiation of bed particle movement is greater than the actual flow depths, which may explain why the aggradation occurred. This analysis also shows that the range of particle sizes being moved is within the range of natural variability for the particular project conditions.

The bank erosion assessment did not reveal a trend in changes to total bank erosion rate over time. This may be due to poor vegetation cover along the banks, which leaves the banks exposed and without scour protection.

4.3 Big Hollow

Analysis of monitoring data and field observations revealed the Big Hollow site had more stability problems than the other two sites. The upper section of the project reach appeared to be functioning well. The bedform through this section varied from meandering riffle-pool sequences to steep riffles and pools characteristic of a step/cascade – pool sequence. However, the portions of the channel constructed to dissipate energy through a meandering riffle-pool sequence evidenced continuous adjustment of varying degree in channel dimension, pattern and profile. There were very few deep pools in the outside of the meander bends; many bends showed a development of riffles within.

The straighter sections of the restoration project seemed to perform better. Stability in the meandering channel configuration may require more belt width than is available due to the land use constraints. Dissipation of energy may be too limited horizontally, and the monitoring data suggests the channel may be attempting to dissipate its energy vertically, searching for stability through a step-pool configuration, as explained in Section 3.3.3 of this report. In addition, the heavy sediment load through the channel may contribute towards potential re-configuration of the channel.

It is possible that Big Hollow may begin to respond in a healthy direction as vegetation becomes established. Overall, vegetation along the reach should be reinforced with woody vegetation and other species providing good bank protection, this way providing better guarantee against bank erosion. Monitoring of this site should continue. If further monitoring shows that the stream is not evolving in a stable direction, consideration should be given to converting the channel into a step-pool morphology.

Pebble count data and the bed material analysis failed to reveal an observable trend in the bed material size when comparing pre-restoration data to post-restoration data. Any apparent increase in the larger size fraction of the bed particle distribution is most likely due to the tremendous amount of large bed material that was deposited through the system during the floods that occurred in 2005.

The sediment transport competency analysis showed more variability in required mean depths of flow for particle movement than is usually expected from this analysis. This variability is likely due to the variability in bed material associated with the floods and channel avulsions experienced by the site. Overall, Big Hollow had the most problems with vertical stability. However, these changes were not well represented by the sediment transport competency analysis.

The bank erosion assessment for the Big Hollow site showed a general trend towards reduction in total bank erosion rate from this site subsequent to construction of the project.

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Appendix A

Cross Section and Profile Data Analysis for Maier Farm Site

Appendix B

Cross Section and Profile Data Analysis for Brandywine Site

Appendix C

Cross Section and Profile Data Analysis for Big Hollow Site

Appendix D

Summary of Benthic Macroinvertebrates and Fish Sampling Data