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Assessment of Stream Restoration Structures in Streams of North-Central Pennsylvania

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Report to the Cora Brooks Foundation

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ABSTRACT

Interest in stream restoration has increased over the last two decades, leading to a growth in the industry to the point that it has become a 1 billion dollar per year enterprise (Bernhart et al 2005, Thompson 2002). In northcentral Pennsylvania alone, over $9 million has been spent since 1999 on stream restoration projects, from the designing stage to actual construction and reconstruction of the sites. Even though a extensive amount of money is being spent on the construction of these projects, very little to no post-monitoring is taking place. Without post-monitoring of the projects, it is unknown if they actually work.

After a successful statewide stream restoration assessment was completed in North Carolina by the advisor of this project, it was discussed to undertake a similar one for the state of Pennsylvania starting with the northcentral region. This includes Bradford, Cambria, Cameron, Centre, Columbia, Lycoming, McKean, Montour, Northumberland, Potter, Sullivan, Tioga, and Union Counties. Within these 13 counties over 60 restoration projects have been implemented since the 1990s ranging in type from FGM structures to Fish and Boat Commission habitat structures. Twenty-two of the restoration sites comprising of 58,255 feet of restoration work were selected for individual site assessment during March 2008-May 2009. Over 300 structures were assessed during this period of time for structural integrity and the degree to which the adjacent bed and banks had been affected by unintended erosion or deposition.

Approximately 75% of the structures have sustained some structural damage (ranking >1) or erosion or deposition (ranking >1). Thirty-five percent of the structures have sustained significant damage (ranking >2) or significant erosion or deposition (ranking >3). Most of the damage (63% of all structures) is related to erosion or deposition which can impact the functionality of the structure. Many of the streams in northcentral Pennsylvania are experiencing pulses of aggradation of gravel-cobble size clasts throughout the stream system. This pulse of gravel is contributing to the partial burial of individual structures and may fill in the pool that was created by the structure. Out of the four highly used structure types (cross vanes, j-hooks, log vanes, and rock vanes), j-hooks and rock vanes sustained the highest percentage of damage compared to the other two structures. Much more work needs to be completed in this region before we can fully grasp an understanding for failure of the various structures.

INTRODUCTION

Background Information

Over the past two decades the number of stream "restoration" or more appropriately "rehabilitation" projects have increased dramatically. Many times a stable river is reconstructed because it is not aesthetically pleasing or is thought to be unstable as it adjusts itself to reach a stable state (Wohl 2004). Stable, single-thread, meandering channels are being constructed, which does not work in streams that were not originally meandering. As a result, many projects have failed; the stream either abandoned the reconstructed channel or obliterated it altogether (Kondolf 2006).

Stream restoration as defined by the Keystone Stream Team (2003) in their Guidelines for NSCD for PA waterways is "the process of converting an unstable, altered, or degraded stream corridor, including adjacent riparian zone and flood-prone areas to its natural or referenced, stable conditions considering recent and future watershed conditions. This process also includes restoring the geomorphic dimension, pattern, and profile as well as biological and chemical integrity, including transport of water and sediment produced by the stream's watershed in order to achieve dynamic equilibrium." The only issue with this definition is that in many cases it is unknown what the "natural" conditions of the stream are and the conditions might not fit the modern "stable" state of the stream due to changes in climate, land use, and system hydrology (Miller and Kochel 2008). Because it is difficult to determine if restoration practices are actually returning streams to their pre-disturbance state, using the term stream rehabilitation might be more appropriate. This refers to the intent to return the stream to a more natural state which may not necessarily be its pre-disturbance state (Miller and Kochel 2008). I have opted to use the term stream rehabilitation throughout this report in order to more accurately portray the ultimate goal.

Stream rehabilitation in the United States dates back more than 100 years ago to the Catskill region of New York. At this point in time, over-harvesting caused decreasing numbers in trout populations. In order to remedy this, structures were introduced to the stream. The mentality behind the construction of the structures changed over time from a desire to increase populations to a desire to eliminate the supposed inefficiencies of natural channels. During the Great Depression, the number of structures in the United States increased dramatically when the Civilian Conservation Corp (CCC) was tasked with the job of stream improvement. By 1936, 7,950 km of stream were "improved" by the CCC. This includes the installation of 31,084 structures on 406 mountainous streams between 1933 and 1935. The original designs neglected to consider the geomorphic characteristics of the channels to the degree that very little information is available on the channel type, width, slope, substrate size, or flood regime from the older publications. By the 1960s geomorphic principles were being applied to the design of channel-restoration projects. Many of the early structures failed within a few years of being built, yet minimal improvements were made to the structures. In fact, many of the instream structures used today are identical to those developed in the 1930s, fish habitat structures in particular (Thompson 2005).

Today, over 1 billion dollars is spent annually to fund stream rehabilitation projects (Bernhart et al. 2005). In Pennsylvania alone, $547.7 million will be spent between 1999 and 2012 on watershed restoration and protection, abandoned mine reclamation, and abandoned oil and gas well plugging projects through the state's Growing Greener Program. Growing Greener was established in 1999 to address Pennsylvania's critical environmental concerns of the 21st century (DEP nd). In northcentral Pennsylvania, over $9 million in Growing Greener Grants have been awarded for "restoration" projects since 1999. A breakdown of Growing Greener grants awarded by county for any type of "restoration" work including initial studies, FGM (fluvial geomorphology), fish habitat, and riprap is included in Table 1. Multiple funding sources exist for these restoration projects, such as EPA 319, Chesapeake Bay Watershed, and Caanan Valley Institute, but the Growing Greener grants remain the primary funding source.

With all the money being spent on stream "restoration" projects, there is remarkably very little post-monitoring data being collected. Most assessments are conducted on a site by site basis and do not address the successes and failures of the projects on a regional scale. Another issue is the lack of post-project monitoring and assessments of the success of individual projects. Bernhardt et al. (2005) conducted a general study of stream restoration projects in the United States and found that some form of assessment or monitoring only occurs in about 10% of all projects. Kondolf (1995) attributed this statistic to logistical challenges, the cost of conducting studies, and a tendency for agencies to avoid publicizing failures. In addition to the lack of post-monitoring data, many of the sites have been constructed with no as-builts drawn up afterwards. This can become a major problem when trying to assess individual sites. Without documention stating the location and type of structure an incomplete assessment will be made at the restoration sites. With the increasing amount of money, time, and energy spent on these projects, it is vital to understand how well the projects are going as a whole.

There are many objectives and goals behind stream rehabilitation projects. In the United States the most common goals of stream rehabilitation is to enhance water quality, to manage riparian zones, to improve in-stream habitat, for fish passage, for bank stabilization and to facilitate human uses (Bernhardt et al. 2005; Kondolf 2006). The common reasons why restoration efforts were undertaken in northcentral Pennsylvania include: to stabilize the banks, restore the proper sinuosity and width to depth ration, improve habitat for fish, and to alleviate flooding (Table 2). In many cases, it is unknown if these goals are actually reached because no post-monitoring exists for the site.

Types of Structures Evaluated

Eight types of restoration structures were used in the projects in this study. Below is a description of each type.

Cross Vanes (log and rock) – Cross vanes can either be constructed with boulders or logs. In appearance, it looks like a "U" that is pointed upstream (Figure 1a). It acts as a grade control structure by not allowing a change in slope. It is also supposed to reduce bank erosion, provide some plunge pool habitat, create a stable width/depth ratio, and maintain channel capacity while maintaining sediment transport capacity, and sediment competence (Lutz 2007, Rosgen 2001).

Table 1. Growing Greener grants awarded from 1999-2008 for streambank stabilization projects broken down by county.*

County	Grant money awarded
Bradford	$3,862,799
Cambria	$212,682
Cameron	$503,394
Centre	$391,991
Columbia	$798,529
Lycoming	$608,271
Montour	$101,800
Potter	$306,762
Sullivan	$961,381
Tioga	$1,047,601
Union	$243,029
Total	$9,038,239

*Amounts were totaled from the Department of Environmental Protections Growing Greener website (http://www.dep.state.pa.us/grants/growgreen.asp). It includes all grants used from streambank stabilization which includes FGM projects, log structures, or rip rap and excludes grants used for watershed group startups.

Table 2. Summary statistics for restoration projects in northcentral Pennsylvania

Parameter	Number/Percent
Total Number of Sites	22
• FGM	20
• Fish Habitat	2
Physiographic Location	
• Appalachian Plateau	16
• Ridge and Valley	6
Land Use	
• Agriculture	9
• Forested	12
• Urban	1
Type of Structures Used (n=299)	
• Cross Vane	35.8% (107)
• Rock Vanes	17.1% (51)
• J-Hook	14.4% (43)
• Log Vane	13.0% (39)
• Log Deflector	5.4% (16)
• Step Pool	4.3% (13)
• Mudsills	2.7% (8)
• Rootwad	1.0% (3)
• Log Cross Vane	0.7% (2)
• W-weir	0.3% (1)
• Unknown	5.4% (16)
Total Feet Restored (n=22)	58,255
Goals (Times cited as a goal) (n=8)	
• stabilize banks	75% (6)
• restore the proper sinuosity and W/D ratio	12.5% (1)
• improve habitat for fish	50% (4)
• alleviate flooding	12.5% (1)

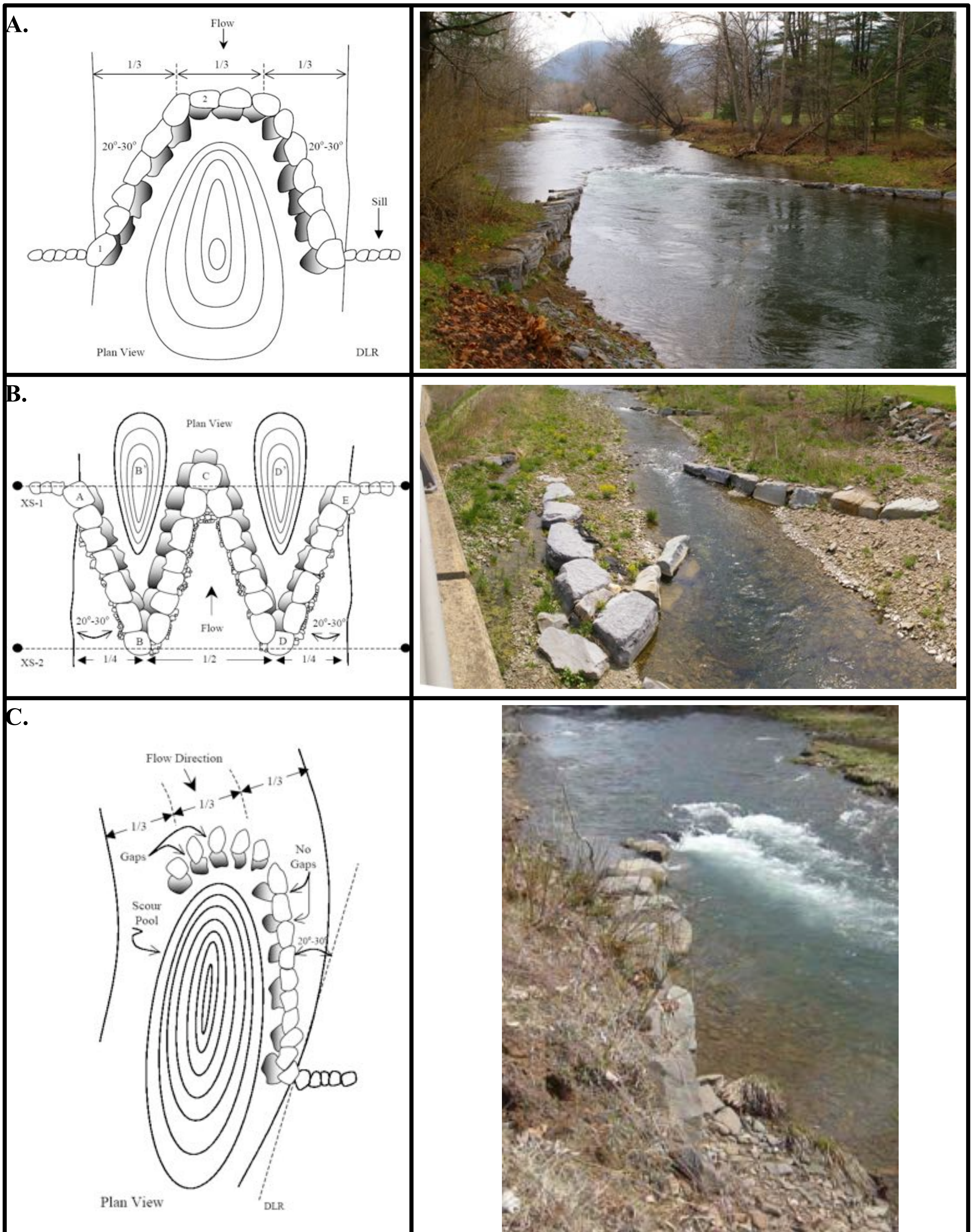

Figure 1. Sketches and photographs representing the types of structures used in stream restoration projects. A) Cross Vane. B) W-weir .C) J-hook. Sketches from Rosgen 2001. Photographs from C.Kassab and B. Hayes.

J-Hook – The J-hook is constructed to look like a "J" with the hook of the J pointed upstream and can be built using just boulders or boulders and logs (Figure 1c). It is typically located on the outside of stream bends to reduce bank erosion. It also provides fish habitat through the development of a pool in the hook of the structure and is supposed to be efficient at transporting sediment and maintaining width/depth ratios (Rosgen 2001).

W-weir – The w-weir appears exactly as the name suggests, a "W" with the two points at the upstream end of the structure (Figure 1b). The structure is supposed to provide grade control on larger rivers, enhance fish habitat, stabilize stream banks, reduce bridge center pier and foundation scour, and increase sediment transport at bridge locations (Rosgen 2001).

Vane (rock or log) – The vane is a linear deflector made of either boulders or logs that extends into the flow (Figure 2a). Log vanes are typically used in runs and pools to create and maintain small pockets of habitat and provide some streambank stabilization. Rock vanes are typically used in both straight stretches and along the outside of curves. They provide stream bank stabilization and some plunge-pool habitat (Lutz 2007).

Log Deflector – A deflector is a triangular shaped structure that points out into the stream channel (Figure 2b). It is used to narrow the existing stream channel, create habitat along the edge of the structure, and to provide some stream bank stability. Deflectors are often used on overly wide stream sections or to move the thalweg away from the stream bank (Lutz 2007).

Step pool – A step pool (also can be referred to as a vortex weir) consists of a line of boulders placed across the channel. It acts as a grade control structure and is supposed to maintain sediment transport through the reach. It also creates a more complex bed topography and enhances fish habitat (Miller and Kochel 2008).

Mudsill – A mudsill is either placed along the curve of a stream or a straight stretch to provide stream bank stability and create a stable undercut bank effect for fish cover (Figure 2c). It looks like a wall placed in the streambank constructed of logs stacked on top of each other (Lutz 2007).

Rootwad – A rootwad consists of a tree trunk, which is placed in the bank, with the root ball still attached and placed in the channel (Figure 2d). It provides habitat and acts to stabilize the stream bank as well. Rootwads are typically used along higher, eroding stream banks (Lutz 2007).

Objective

In 2008, J. Miller and R.C. Kochel completed an assessment of restoration projects for the state of North Carolina, one of the very few statewide assessments. Since then it had been discussed by R.C. Kochel and B. Hayes of the Bucknell University Environmental Center to complete a statewide assessment for the state of Pennsylvania. This study, focusing on projects in northcentral Pennsylvania, is the just beginning of a long-term statewide assessment of stream rehabilitation projects in Pennsylvania,. Northcentral Pennsylvania is defined as including

Bradford, Cambria, Cameron, Centre, Columbia, Lycoming, McKean, Montour, Northumberland, Potter, Sullivan, Tioga, and Union Counties. The main objectives of this project are to:

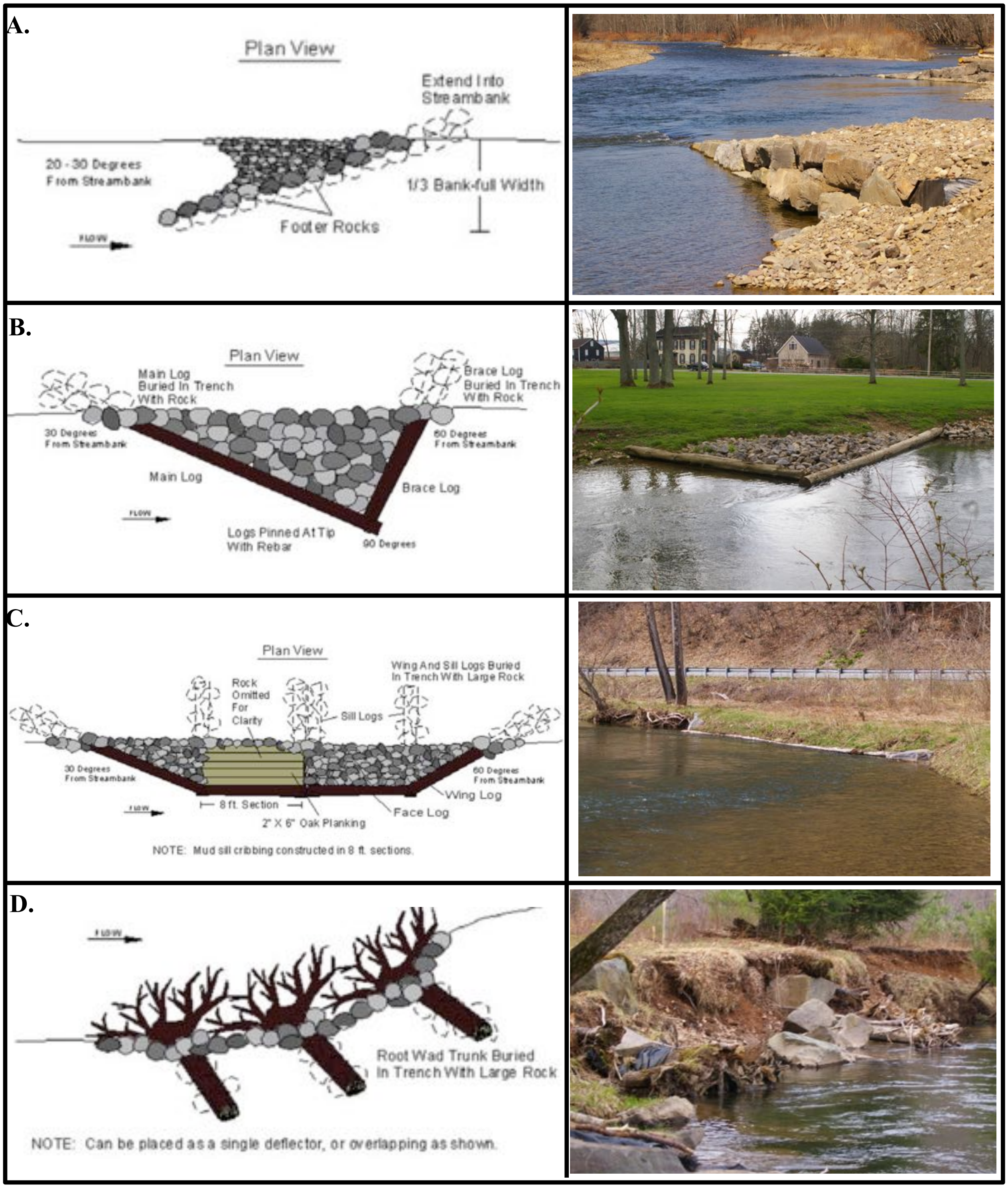

Figure 2. Sketches and photographs depicting the types of structures used in stream restoration projects. A) Rock Vane. B) Log deflector. C) Mudsill. D) Rootwads. Sketches are from Lutz 2007. Photographs by C. Kassab.

(1) create a database of stream rehabilitation projects in northcentral Pennsylvania, including information on project goals and objectives, design types, and other pertinent information
(2) assess stream rehabilitation projects for effectiveness and durability.

METHODOLOGY

Access Database

A relational database of stream rehabilitation projects constructed in northcentral Pennsylvania was developed using Microsoft Access. By developing this database, much of the information needed when comparing rehabilitation sites is contained in one place. Each rehabilitation project has its own page with pertinent information and the assessment of the structures at that site (Figure 3). The main parameters used in the database are listed in Table 3. Each project was assigned a specific number which it is referred by in text, so that certain projects are not labeled as successes or failures.

Data was gathered from numerous sources including the Department of Environmental Protection (Williamsport Regional Office), Keystone Stream Team NSCD/FGM Project Database, various County Conservation District Watershed Managers, and various internet sources (Clean Water Institute, PA Bulletin, and random articles). Sixty-six sites were identified through these sources and entered into the database. The majority of stream rehabilitation projects are on file at the DEP office because they were funded through the Growing Greener grant program which requires that they file a final report to the DEP. Many other rehabilitation sites were found by utilizing the KST database and PA Bulletin which announces permits for water obstructions. Finding data for some of the sites was extremely difficult. Sometimes all that was found was a permit stating that structures were to be constructed on a specific stream, but no geographic coordinates or description of the project exists. Some information is missing for many of the rehabilitation projects due to the lack of information in the source. Every effort was made to find out as much information possible by utilizing through the various sources.

At this point in time, the database is still a work in progress. The power of constructing a database is that multiple queries can be made to investigate similarities or differences between sites. For example, a query can be made for sites that are at least 3 years old. Or a queary can be made for individual structures that rank greater than two. As long as the parameter is in the database, a query can be made.

Individual site assessment

Out of the 66 sites entered into the database, 22 sites were chosen to go through the individual site assessment based upon the year they were constructed. Assl sites were constructed prior to the year 2007. These 22 sites are located in two physiographic regions: the Appalachian Plateau and the Ridge and Valley Region (Table 2). Over 300 structures were assessed.

The rapid assessment involved the evaluation of all remaining structures installed at a site in terms of their structural integrity and the degree to which the adjacent bed and banks had been affected by unintended erosion or deposition. It is based off of the methodology employed by

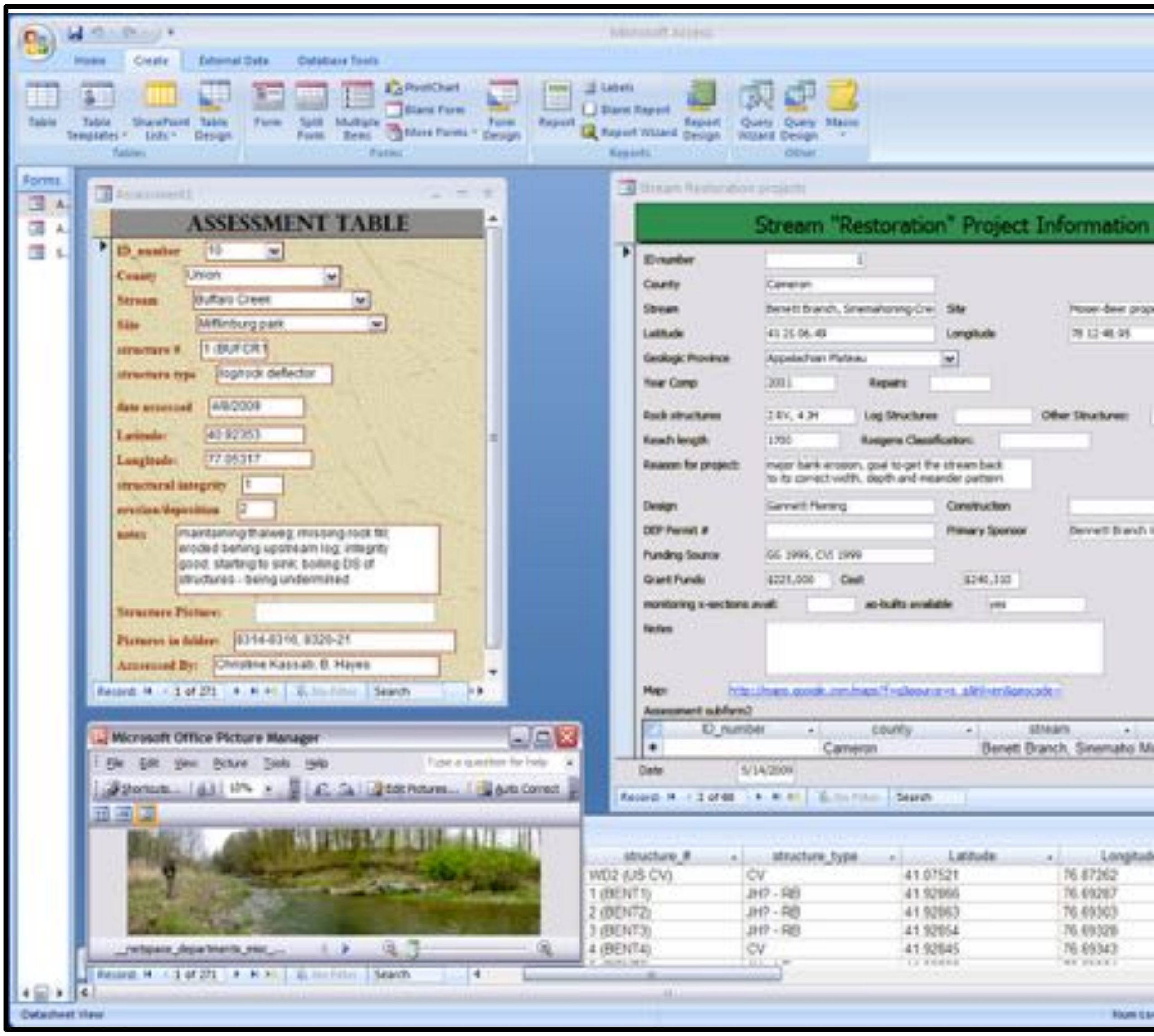

Figure 3. Screenclip showing the different parts of the Microsoft Access Database created for this project. N
"Restoration" Project Information form which contains all the known information about a project site plus in
structure assessments from that site.

Table 3. Parameters included in the Access Database of stream restoration projects in Northcentral PA

Project Parameters	Individual Structure Parameters
• Site location (County, Geographic coordinates, physiographic provenance) • Project sponsor • Project funding and funding source • Project goal and objective • Project designer and contractor • Year completed, and if repaired – the year repaired • Rosgen Stream Classification • Type and number of in-stream structures utilized	• Site location (County, geographic coordinates) • Type of structure • Structural Integrity ranking • Unintended Erosion or Deposition ranking • Notes • Key Picture and a list of other photographs • Date Assessed • Name of the person completing the assessment

Miller and Kochel (2008) in North Carolina. Measures of integrity address such questions as the extent to which the original structure remained intact, and the degree to which structural elements (e.g., boulders) had been moved from their original position. Assessment of bed and bank erosion and deposition provided measures of the degree to which these processes had affected the functionality of the structure and the extent of unintended bed and bank erosion or deposition at as well as immediately up- and downstream of the structure (within ~5m). The assessment required the evaluation team to categorize the structures according to a classification system based on a pre-determined set of criteria. As is true for other similar assessment techniques, the rapid assessment method used here is semi-quantitative, and relies on the judgment of the evaluating team. The method's inherent subjectivity was minimized by using well-defined categorical answers, and by having all of the sites evaluated by the same individual (Miller and Kochel 2008).

The ranking tables established by Miller and Kochel (2008) were used to classify structures for structural integrity and for unintended erosion and deposition (Figure 4). The ranking table for rootwads established by Miller and Kochel (2008) was also used, but was modified due to the fact that some of the rootwads in this study did not fit into any of the established rankings (Figure 5a). A ranking system for mudsills was created for this study after assessing multiple mudsills in this study (Figure 5b).

DATA AND DISCUSSION

A total of 22 "restoration" sites on 11 streams were assessed from March 2008 through May 2009 (Figure 6). Over 58,000 ft of stream have been "restored" at these sites. The sites are located in two physiographic regions: the Appalachian Plateau and the Ridge and Valley region. Out of the 22 sites, 9 are located on primarily agriculturally impacted streams, 12 are forested streams, and 1 is an urban stream. Below is a discussion of how well the structures are functioning broken down by site/stream and type of structure.

Assessment of individual sites

Sites 2,3,4,6

Sites 2, 3, 4, and 6 were constructed along a 3 mile stretch of the same stream for flooding mitigation. These sites have a drainage area of 21.3-57.4 mi^2; the size is in the middle of all the streams in this study (Table 4). It is also one of the streams primarily located in agriculture. Funding was initially received in 1998 to complete a demonstration project that would apply the stream assessment methodologies and natural channel design approach by Dave Rosgen (Clear Creeks Consulting 2004). "Restoration" work began at site 6 in 1999 followed shortly by sites 2, 3, and 4. Additional funding was supplied by Growing Greener Grants awarded by the state of Pennsylvania. Over one hundred structures have been constructed and reconstructed at various times in these four reaches. Storm events in 2003 affected significant sections of the restoration work, forcing reconstruction of many structures (Clear Creeks Consulting 2004). No as-builts exist for any of these reaches so it is impossible to state the exact number and type of structures constructed at these sites.

A. *Ranking scheme used to classify structures for structural integrity*

Ranking	Description
Intact (1)	No visible damage; fully operational in terms of integrity
Damaged (2)	Structure functions as intended, but at least 10 % of structure visibly damaged; usually involved movement of one or more boulders
Impaired (3)	Structural components in general location of original structure, but feature does not longer functions as intended; 25-50 % of structure remaining
Failed (4)	Significant parts (> 75 %) have been removed from site; severely fragmented; incapable of achieving intended objective

B. *Ranking system used to categorize structures for unintended erosion or deposition*

Rating	Description	
	Erosion	Deposition
0	None visible	None visible
1	Minor localized erosion along margins of feature; structure maintains continuity with bank and bed; undermining of footings	Minor deposition over center of structure; pool remains well-defined
2	Localized, but erosion visible, which is likely to continue. Eroded area likely to influence flow	Deposition along 25-50 % of structure in channel; pool poorly developed and/or partially filled
3	Structure remains in contact with bank, but erosion has occurred along entire zone of contact with bank. Unintended erosion of channel bed must exceed 50 cm and be clearly related to the structure's influence on flow.	Deposition occurs long 50-75 % of structure's length in channel; pool very weakly defined or filled
4	Structure partially detached from bank; complete detachment eminent; feature no longer functions as intended	Sediments bury 75-90 % of structure in channel; no pool present
5	Structure completely detached from bank; no longer performs function intended	Sediments bury 90-100 % of structure in channel; no pool present

Figure 4. Ranking tables established by Miller and Kochel (2008) for ranking restoration structures. A) Ranking table used to classify structural integrity. B) Ranking table used to categorize for unintended erosion or deposition. Each structure received a separate ranking for structural integrity and unintended erosion or deposition.

Figure 5

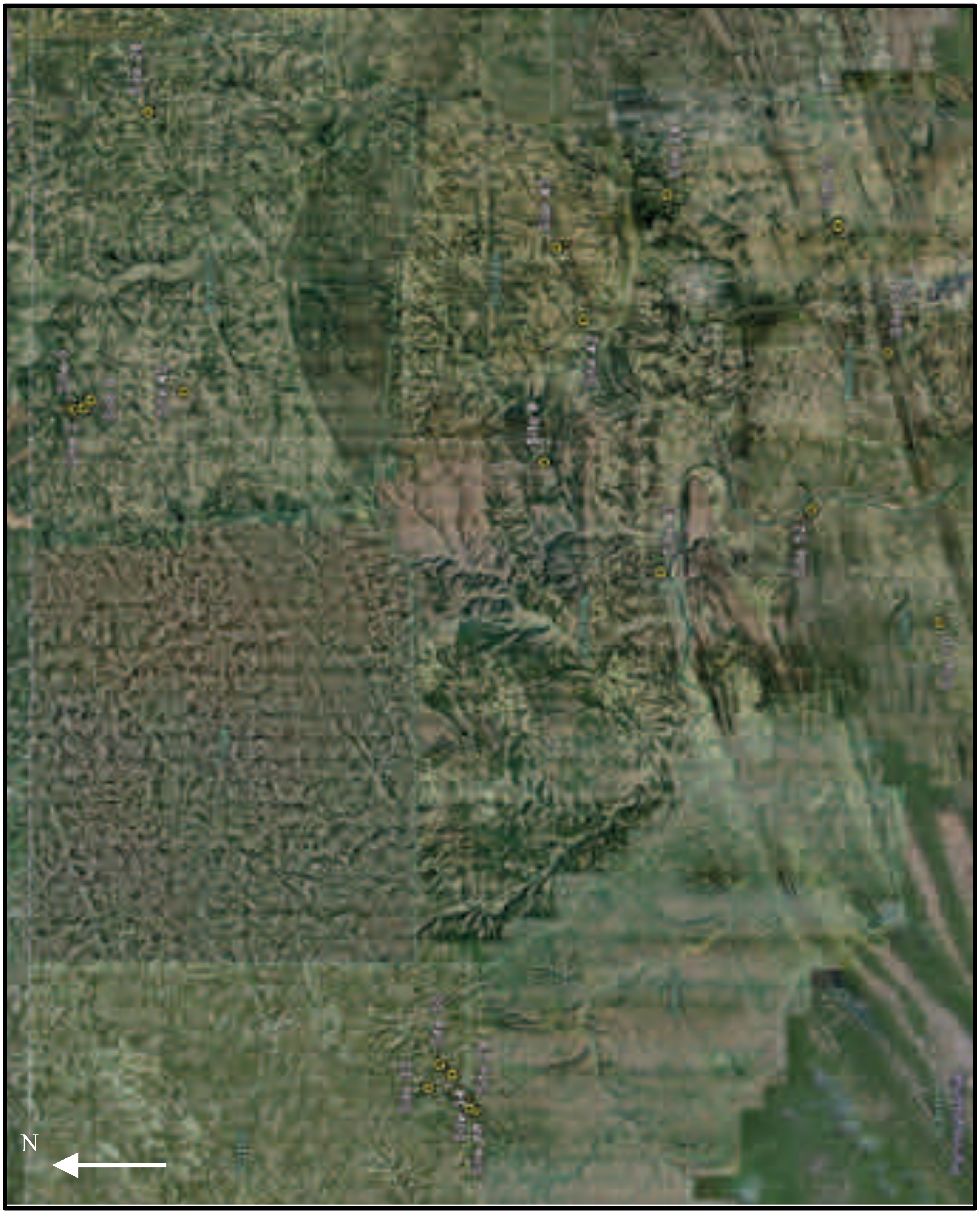

Figure 6. Aerial photograph taken from Google Earth illustrating the locations of the 22 sites that were assessed during this study. Note that the locations are from all over northcentral Pennsylvania and are located in two physiographic provenances: the Appalachian Plateau and the Ridge and Valley Region.

Table 4. Stream characteristics by site*

	Above restoration site		
Creek	**Total stream length**	**Drainage area (mi^2)**	**Adjusted basin slope (degrees)**
Site 23	468	284	8.49
Site 29	269	139	14.2
Site 68	266	137	14.2
Site 31	170	86.4	13.8
Site 32	165	83.7	13.6
Site 34	162	81.3	13.5
Site 30	154	76.8	13.3
Site 24	110	57	11.7
Site 4	75.3	51.4	7.56
Site 52	71.4	44.2	10.8
Site 42	71.5	40	11
Site 3	52.3	34.8	6.99
Site 33	65.2	33.3	14.1
Site 2	48.5	32.2	6.84
Site 38	68.5	30.2	7.97
Site 6	33.4	21.3	6.95
Site 10	33.8	20.9	4.88
Site 9	30.7	17.1	10.8
Site 41	15.7	7.85	10.1
Site 28	13.8	7.51	6.06
Site 40	8.98	7.41	6.39
Site 43	12.1	6.68	8.99

*Data calculated using the Stream Stats program provided by the USGS.

Over 70% of the structures on this stream have a ranking of 2 or greater, meaning that their structural integrity is damaged, impaired, or failed (See ranking table for description). Forty-three percent have a ranking of 3 or greater which means that they are not functioning all and are missing the majority of rocks used in building the structure (Figure 7a; Table 5). This percentage includes unknown structures which are remnants of structures in which the type of structure cannot be determined. No one structure is failing more than another type. Out of the known structures that are not functioning 16 are cross vanes, 9 are J-Hooks, 9 are rock vanes, and 1 is a W-weir.

Even though over half of the structures are still functioning, many of them are being impacted by the deposition of gravel bars over the wings and throats of the structures (Figure 7b). Out of the structures with an integrity ranking of one or two, meaning that they are still functioning, 75% of them are impacted by deposition or erosion (a ranking of 2 or higher). Over 80% of all the structures, including those that are impaired or failing, have a deposition/erosion ranking of 2 or higher. This means that deposition over at least 25% of the structure has occurred, along with deposition in the pool and/or erosion is visible which will likely influence flow. In this stream, the majority of structures are impacted by deposition of gravel over the wings of the structure or in the pool downstream of the structure. The amount of gravel moving through the system is seen in aerial photographs from Google Earth (Figure 8).

Aerial photographs provided by US Fish and Wildlife Service taken shortly after some of the reaches were finished show a completely different view of what the stream looks like today (Figure 9). Unfortunately it is unknown what the stream looked like originally, but after the first construction, a meandering pattern was created at site 6. Today the stream follows a more straightened pattern after it was reconstructed.

Overall this site does not receive a high ranking. Almost 50% of the structures are impaired beyond functioning and 80% experience deposition that impacts functionality of the structure. This restoration effort could be looked at as a misinterpretation of the geomorphic variables in a system. The fact that the stream is carrying large amounts of cobble- to boulder-size clasts during high water events suggests that it could be a braided channel. Many of the transportation bridges that cross the stream have two spans, one of which is filled with gravel. To illustrate the point about the amount of gravel moving through the system, this anecdote is offered. Later that night a high water event occurred that deposited approximately the same amount of gravel back underneath the bridge (Lovegreen 2009). This one night deposit is estimated to be five feet thick based upon the clearance underneath the other half of the bridge. With the amount of gravel moving through this stream system a hardened approach may not be the best approach because the channel cannot shirt in response to the deposition of clasts.

Site 9

Over 200 structures were constructed at Site 9 along a 3.8 mile stretch of stream in 1999. This stream has one of the smaller drainage areas, 17.1 mi^2 (Table 4) and is almost entirely forested.

Several bankfull events have occurred since construction that have damaged several of the structures, forcing them to be repaired (Zimmerman nd.). The objectives of this project were to stabilize the banks, restore the proper sinuosity and width to depth ratio, and to improve fish

Figure 7. A) Photograph from Site 2 showing an "impaired" structure. It is unknown if this is a rock vane and is just missing the boulders in the channel or if this was a j-hook or cross vane and is missing more boulders than could be seen. B) Photograph from Site 2 of a cross vane that is half buried by a major gravel bar along the left wing. The person in the white box is standing at the throat rocks of this structure. The left wing boulders were actually found buried in the gravel bar. Photographs by C. Kassab.

Table 5. Structural integrity of each stream*

		Percentage	
Site	Number Structures	Ranking > 1 (damaged-failed)	Ranking >2 (significant damage)
Sites 2, 3, 4, 6	123	73.98	43.09
Site 10	25	0.00	0.00
Sites 23, 24	10	30.00	10.00
Site 28	23	43.48	26.09
Sites 29, 30, 31, 32, 33, 34, 68	50	32.00	12.00
Site 38	2	0.00	0.00
Site 40	22	45.45	9.09
Site 41	6	33.33	0.00
Sites 42, 43	31	77.42	67.74
Site 52	2	0.00	0.00

Table showing the percentage of each type of structure that ranked > 1, meaning it ranked as damaged, impaired, or failed and the percentage of each type of structure that ranked > 2, meaning it ranked as impaired or failed. n=299.
* Does not include Site 9

Figure 8. Aerial photograph from Google Earth of part of site 4 prior to the current configuration of the channel and current set of structures. Note the large gravel bars (highlighted in yellow) illustrating the large amount of gravel that is moving through this reach of the system. This amount of gravel is not found further upstream in the "restored" reaches. Now that the channel has been reconfigured to a more straighter reach, the large gravel bars are not as prevalent.

Figure 9. Comparison aerial photographs of Site 6 showing the difference in channel configuration from the first construction to today. Note the change from a sinuous reach to a almost straight reach after a high water event destroyed the structures. Yellow arrows identify the same point in both photographs. A) Aerial photograph taken shortly after construction was finished at Site 6 in 1999/2000. Photograph courtesy of USFWS, State College. B) Aerial photograph from Google Earth.

habitat. When this site was assessed in the Spring 2008, no as-builts existed so many of the structures may have been incorrectly identified. The assessment was also completed differently then all of the other sites so individual assessments for each structure are not compatible with current assessments. And, this assessment of this site is incomplete due to the inability to gain access to the site. As a result, only a general overview of the site will be given.

Out of the structures assessed at this site, the majority are intact or slightly damaged. Because no as-builts exist for this site, it is difficult to determine structure type which may have impacted the assessment of the site. Both erosion and deposition is prevalent along much of the reach assessed. Most of the structures are experiencing aggradation of cobble-size material which limits pool growth and buries structures (Figure 10a). A few of the original pools have aggraded with so much cobble-size material that a new pool has formed further downstream. Yet some structures have not experienced significant amounts of aggradation, which may be due to the nature of the channel. Narrow stretches of channel encourage the movement of the bedload through the system instead of deposition. Even as this stream is experiencing aggradation of gravel in specific reaches, it is also experiencing downcutting (Figure 10b). This is a good indicator that the stream is trying to become "stable." Erosion is minor around most structures with the majority of erosion due to undercutting of the footer rocks downstream of the structure.

Unfortunately a full assessment could not be made at this site. It is one of the largest (in terms of number of structures) in the study area and there is much to learn from it.

Site 10

Twenty-three log structures (log/rock deflectors, log cross vane, log vanes) were constructed over ~1,100 feet at Site 10 at an unknown date. The drainage area of the stream above the restoration site is relatively small, 20.9 mi^2 (Table 4) and it is primarily an agricultural stream although the headwaters are forested. The usual goals for these structures is to increase fish habitat and it also seems to help protect the banks from eroding. The majority of structures at this site are PA Fish and Boat Commission structures. No as-builts exist for this site, which makes it extremely difficult to determine if all of the structures are still present.

All of the structures as identified are fully intact so structurally this site is working great. But, many of the log/rock deflectors are experiencing bank erosion either upstream and/or downstream that may eventually detach the structures from the bank. Three of the deflectors are completely detached from the bank and now the stream, during high water events, flows between the bank and the structure (Figure 11). Many of the deflectors are also being undermined which is causing the structures to sink into the stream (Figure 11). All of the log vanes are fully intact, but many do not extend far enough into the flow to control the thalweg (main current). At least two are also partially buried by a sandy bar that has developed. None of the log vanes have created a pool for fish habitat (Figure 11).

Overall this site is functioning well. None of the structures are damaged and less than half are experiencing any major erosion or deposition. These structures work well to provide fish habitat, but are not doing a great job at controlling the stream and reducing bank erosion. Most of the structures do not extend far enough into the channel to control the thalweg. Bank erosion is also

Figure 10. A) Photograph of a cross vane at Site 9. Note that the throat of this structure is buried by bedload to the point that a midchannel bar is beginning to form. There is no pool for fish habitat present at this structure, which is one of the goals of the structure design. B) Photograph of the left bank of the stream at Site 9. Note the exposed tree roots from the undercut bank and the deposition of the gravel bar at the same point in the stream. Photographs by R. C. Kochel.

Figure 11a. Photograph of log/rock deflector at Site 10. Note that it is completely detached from the bank. A deflectors objective is to keep the thalweg in the middle of the stream and off the bank which this structure can do at normal flow. At higher flows though, the current will flow between the structure and bank potentially causing more bank erosion.

Figure 11b. Photograph of log/rock deflector at Site 10. Note that it is being undermined and collapsing into the stream. This structure cannot be as effective at controlling the thalweg since it is currently below the water surface.

Figure 11c. Photograph of log vane at Site 10. Note that it is partially buried by a bar. This bar is made up of fine material. Also not that it has no control on the thalweg. All photographs by C. Kassab.

prevalent along the entire reach even though some of the banks have been rip-rapped to help control erosion. Unlike other streams, this stream is not transporting large amounts of gravel-cobble size clasts. It is a gravel bedded stream, but it seems to be mainly transporting fine material. As such, this reach was constructed how it should have been, a meandering channel, based upon the bedload and transported material.

Sites 23 and 24

Sites 23 and 24 are located along the same stream at two different locations. Site 23 is located towards the mouth of the stream (more agriculturally impacted) and Site 24 is located closer to the headwaters (forested). Site 23 was originally constructed in 2004 to stabilize bank erosion along the creek and provide a place for people to fish. In subsequent years, some of the structures have been damaged by the stream and are currently being reconstructed. Site 24 was constructed in August - September 2005 and heavily damaged during a high water event in November 2005 (Cinquina 2009). This reach was chosen for restoration based upon a recommendation from an engineering firm after conducting a watershed assessment in 2000. It was built to help speed up the streamflow to move the bedload through the system, protect a service road, and to increase fish habitat. Site 23 has the largest drainage area of any of the sites included in this study (284 mi^2; Table 4), which can impact the functionality of the site.

Overall, both of these sites are fairing well. An overview of site 23 is not included in this study because the assessment could not be completed due to the ongoing reconstruction efforts taking place. Also, some of the structures that were assessed were just installed this spring. At site 24 only one structure is ranked as having significant damage to the structure. All of the other structures have a ranking of two or less meaning that they are intact or slightly damaged. The erosion/deposition factor is the opposite. Of the six structures at site 24, all but one has significant deposition/erosion occurring that interferes with its functionality. Two structures are completely detached from the bank by at least 2 meters; they are sitting in the middle of the channel now (Figure 12a). All of the throats of the cross vanes are buried by bedload (Figure 12b).

As with many other streams, this stream is experiencing the downstream movement of large pulses of gravel. This has an impact on the course that a stream will ultimately take and can force it to move onto a landowners property. After talking with the current landowner, it seems like the structures at site 24 have created some stability to the channel. Prior to 2005 the channel was spread out and would destroy the landowners crop field whenever it flooded (Newhart 2009). Now the stream is in a controlled channel and the landowner has access to his land again. This can be ntoed as a success even though not all of the structures are still functioning properly. Maybe adding the structures to the stream allowed it to achieve enough stability that it can eventually be stable without hardened structures. Only time will tell.

Site 28

Twenty-three structures were completed at site 28 in 2005 for the purpose of alleviating flooding and educating students and the public about stream management and its effects. Site 28 has one of the smallest drainage areas, 7.51 mi^2 (Table 4), and is primarily forested. It appears that this

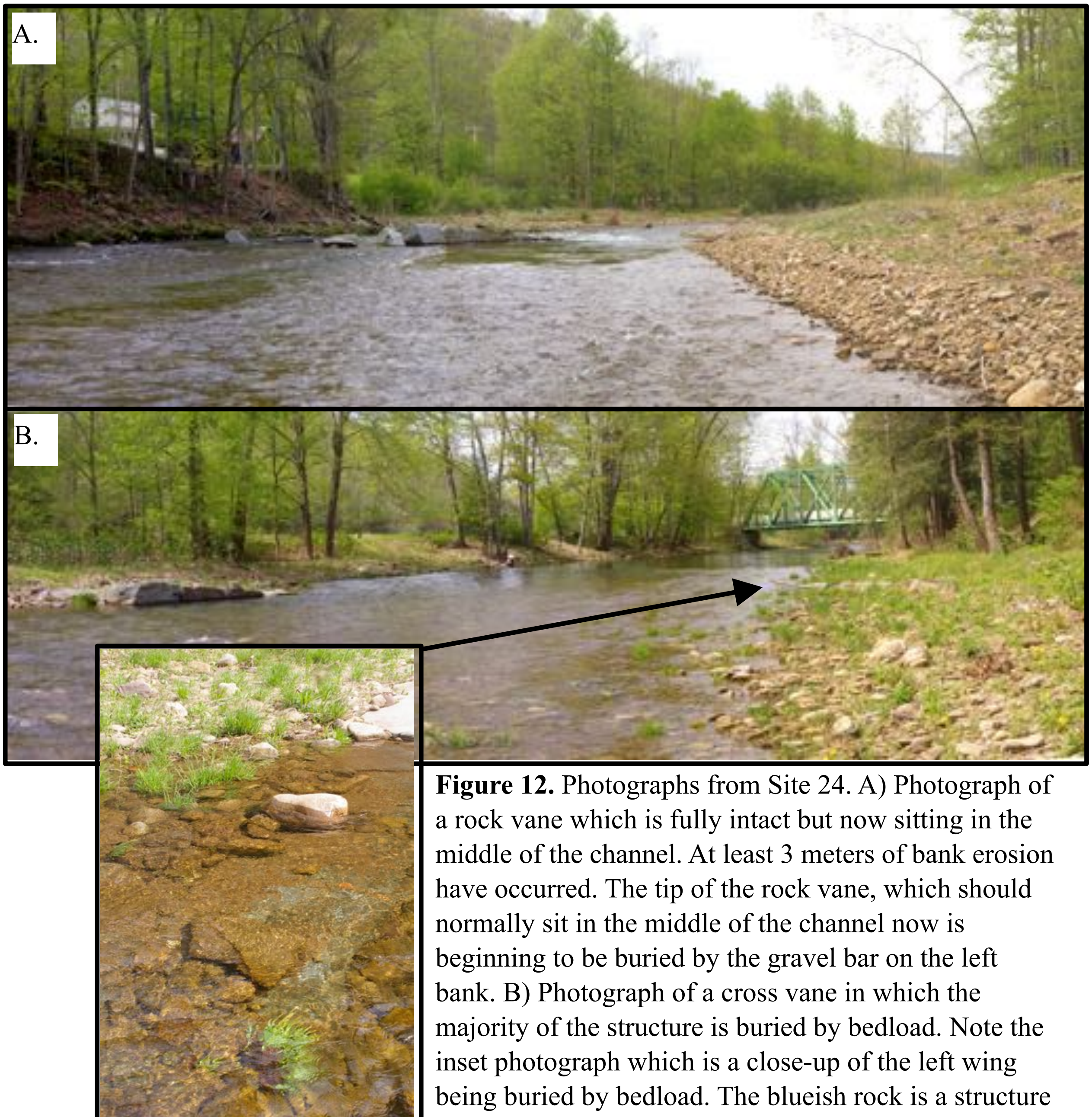

Figure 12. Photographs from Site 24. A) Photograph of a rock vane which is fully intact but now sitting in the middle of the channel. At least 3 meters of bank erosion have occurred. The tip of the rock vane, which should normally sit in the middle of the channel now is beginning to be buried by the gravel bar on the left bank. B) Photograph of a cross vane in which the majority of the structure is buried by bedload. Note the inset photograph which is a close-up of the left wing being buried by bedload. The blueish rock is a structure boulder and the small rocks are bedload burying the left wing. Photographs by C. Kassab.

stream is flowing off of an alluvial fan. Reconstruction efforts must have been completed at some point at this site because four structures have been replaced by a rip rapped back. This site occurs upstream and downstream of the junction of two streams.

Approximately 25% (6 structures) of the structures show significant damage (ranking >2) at this site (Table 5). Out of the 6 structures that do, 5 are completely missing; no traces can be found of them. And four of those five structures were replaced with a rip rapped bank (Figure 13a). So, only two current structures show significant damage at this site meaning that its overall integrity is good. But significant amounts of deposition are occurring at this site which decreases the functionality of the structures. Almost 70% of all the structures have significant erosion and/or deposition (ranking >2) occurring. Most of the deposition is burying the throat rocks of the structures and the pools that should be located downstream of the structure.

Overall, this site is doing well. The majority of structures are intact or have minor damage that does not affect their functionality. Most of the structures are being impacted by bedload deposition, but not to the same degree as some of the other sites in this study. One structure, a log vane, has been completely detached from the bank and currently sits on a gravel bar on the opposite bank than it originally sat (Figure 13b). Other than that, erosion is limited to minor outflanking at some of the structures.   This site has a much smaller drainage basin compared to many other sites, which may be a contributing factor in its success.

Sites 29, 30, 31, 32, 33, 34, and 68

All of these sites, except for site 34, were constructed along a 6.2 mile of the same stream. Each individual site ranges in reach length from 500 feet to 2,500 feet. The drainage areas for the six sites on the main stem range from 33.3-139 mi^2, some of which are the next largest drainage areas compared to site 23 (Table 4). Site 34 contains six small sites over a 2 mile reach and is located in major tributary to this stream with a drainage area of 87.3 mi^2. The oldest of these seven sites was constructed in 1999 and none of the sites have been reconstructed. All of the sites were constructed to decrease bank erosion and to increase fish habitat. This area is heavily forested with relatively few houses.

Considering the age of these sites, the majority of the structures are holding up very well. Over 70% of the structures are completely intact with no damage, which is unheard of at most sites in this study. Around 15% have significant damage (ranking > 2; Table 5). This is limited to the J-Hooks and log structures (mudsill and log vane) at four of the sites. Erosion and/or deposition is not major at any of these sites either. Less than 20% of all the structures are impacted by erosion and/or deposition. It is dependent upon the site whether the major contributing factor is erosion or deposition, but deposition of major gravel bars is not a prevalent here as in other streams.

Overall the structures at this stream are functioning very well compared to other streams. This stream has the second highest drainage area of the streams in this study. Some gravel is moving through the system, but not nearly at the scale of the streams at sites 2, 3, 4, 6, and 9. In the case of this stream, the gravel pulse could still be up in the headwaters and has not passed through this part of the system yet. In many places along the floodplain, multiple side channels can be identified suggesting that this may have been a braided or anastomosing stream at one point or

Figure 13. Photographs from Site 28. A) Photograph of the rip-rapped back that replaced four structures at some point after the original construction. B) Photograph of the log vane that is supposed to be along the left bank and is instead resting on a gravel bar on the right bank of the stream. The inset photograph is a side view of the log vane. It could be identified as a structure to the geotech fabric that was wrapped around the log. Photographs by C. Kassab.

they might be remnant logging channels. Further study is needed to determine this. Yet it is functioning well as a single channel meandering stream and it seems like the majority of the structures are working to keep it stabilized. Fish habitat definitely increased in this stream. Deep pools are located below almost all of the structures and some of the structures which are damaged and the mudsills are providing overhangs for the fish to hang out underneath. Bank erosion has been brought under control. Even though it is still occurring along some of the reaches with structures, it does not look like it is as bad as it was prior to the construction of the structures (Figure 14).

Site 38

Site 38 was constructed in 2006 along an 800 foot reach of channel to address major bank erosion issues and to create a better habitat for fish and other aquatic life. This site has a smaller drainage basin than most, 30.2 mi^2 (Table 4) and is primarily an agricultural stream. Two structures are located at this site and both are completely intact, but have limited impact on the flow. One of the structures is partially buried by a developing gravel bar that forces the flow against a bank they were trying to protect. The other does not extend far enough into the channel to help direct flow off of the bank. Overall the site is structurally fine, but deposition problems affect the functionality of the structures.

Site 40

Site 40 was constructed in 2003 in a cow pasture. Prior to the construction of structures, as the stream entered the pasture it would become a multi-channel, shallow, muddy stream (Lovegreen 2009). Following the construction, the stream is now a single channel meandering stream through historic mill pond sediments, which adds a complicating factor to this site. This site used to contribute to the sediment problems in the watershed, but since it has become “stable,” the sediment problems have been reduced (Lovegreen, 2009). This site has one fo the smallest drainage areas, 7.41 mi^2 (Table 4).

Less than 10% of the structures show significant damage, with only one structure being completely destroyed. Approximately 55% of the structures are fully intact with no damage which is good for a site that was constructed on fine-grained unconsolidated sediment and without anything to anchor the boulders into (Table 5). Partially because of the type of sediment this site was constructed in, erosion and deposition factors are high. Over half of the structures (~55%) have some significant erosion and/or deposition around the structure. A few of the structures are completely detached from the bank (Figure 15). None of these detachments are significant enough though to impact flow though (< 1 ft of detachment). Many of the structures are also experiencing deposition of gravel over part or even all of the structure. One structure is completely buried and the channel has shifted so that what used to be the left bank is now the right bank (Figure 15).

Building restoration structures on top of mill pond sediment is tough because there is nothing to anchor the structure rocks into. The fact that the majority of these structures are still functioning is testimony to the fact that it can be done. Even though this site was not entirely successful, many of the structures are experiencing erosion and deposition of bedload, 90% of the structures

Figure 14. Photographs from Site 31. A) Photograph of the bank erosion prior to the construction of rock vanes and j-hooks. The date of the picture is unknown. B) Photograph of the current state of the bank at the same site. Bank erosion has been reduced, but there is still some including the bank slump in this picture. Photograph by C. Kassab.

Figure 15. Photographs from Site 40. This site was constructed in mill pond sediments which as complexity to the overall integrity of the site. A) Photograph of a cross vane in which the right wing is completely detached from the bank, but a gravel bar has developed in the space between the bank and structure blocking the water from flowing there. B) Photograph of a cross vane that is no longer located in the active channel. The left wing is now along the right bank and a gravel bar has buried the structure. C) Note the vegetation in the channel. In many places along the stream this vegetation controls the flow during normal flow conditions impacting the functionality of the structures. Photographs by C. Kassab.

are still intact or only slightly damaged. Most of the structures, even though they aren't really damaged, are not controlling the thalweg as they should due to the burial of the structure and/or vegetation patches in the stream which influence the flow path (Figure 15).

Site 41

Site 41 is the only stream in this study that is an urban stream; all of the others are agricultural or forested streams. It also has one fo the smallest drainage areas, 7.85mi^2 (Table 4). This site was originally built in 2002 and rebuilt in 2005 along an 800 ft reach. It is unknown why this site was installed.

None of the structures at this site have significant damage. The majority are fully intact and a few have minor damage. No as-builts exist for this site which makes it difficult at points to determine an assessment when a structure could be one of two types. All of the structures are impacted by erosion and/or deposition. Only one structure is fully detached from the bank, but it does not have a significant impact on the flow. Most of the structures are being buried by the bedload and have no pool downstream of the structure.

Overall this site is doing okay. All of the structures are there but do not have a major influence on the flow. Deposition of bedload over the throat rocks and in the pool limits each structure's functionality. Because this site is located within a park, it is assumed that it was constructed to keep the stream from meandering into adjacent baseball fields.

Sites 42 and 43

Both of these sites are located along the same stream. Site 42 is located midway along the stream (drainage area, 40 mi^2) and site 43 is located in the headwaters (drainage area 6.68 mi^2, the smallest; Table 4). Site 42 was constructed in 2002 to protect a severely eroded stream bank. Most of the structures were damaged following a September 2004 high-water event generated by Hurricane Ivan. The creek ran around one of the vanes taking out a huge amount of bank. The site was rebuilt in June 2005 with the ruined vane built using larger rocks and extending deeper back into the bank, an additional vane constructed on the curve and rip-rap along the right bank. Site 43 was constructed in 2005 to stabilize bank erosion. A high-water event in mid-January 2006 caused damage to some of the structures prior to the completion of construction (Young, 2009). Many of the structures were modified or repaired to correct damage from this event.

Over 65% of the structures at these two sites have significant damage and many of the structures have been completely destroyed and the boulders have been transported downstream. Less than 25 % of the structures are fully intact with no damage (Figure 16; Table 5). With this many structures not functioning, the banks are not being protected as initially intended. Deposition of gravel-cobble size clasts also significantly impacts the functionality of the structures. Over 85% of the structures have significant (ranking > 2) erosion and/or deposition. In the case of these two sites, it is mainly deposition. One structure in particular is almost completely buried by a gravel bar and the channel has shifted away from it at least 10 feet (Figure 16). Many of the other structures are still located in the channel but the throat rocks are being buried by bedload or gravel bars are beginning to bury the wings.

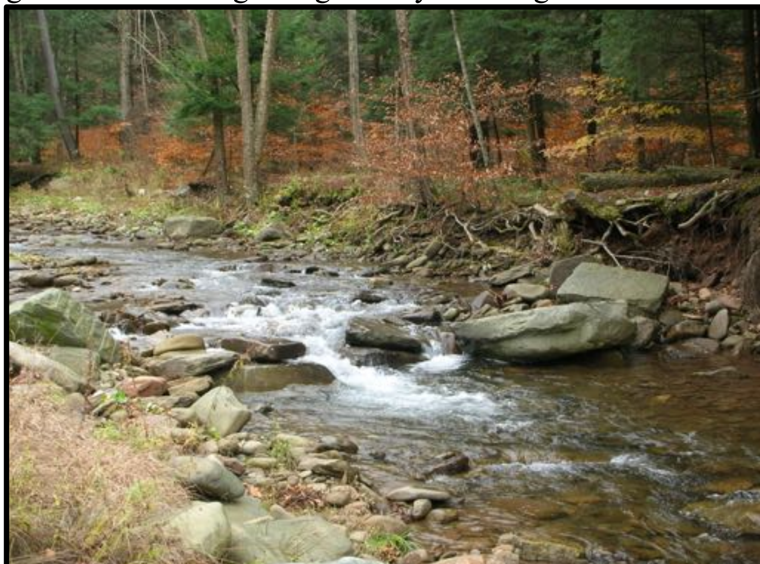

Figure 16a. Photograph of a failed step pool at Site 43. This was the only site to use step pools and all of them failed less than two months after they were installed. Photograph by C. Kassab.

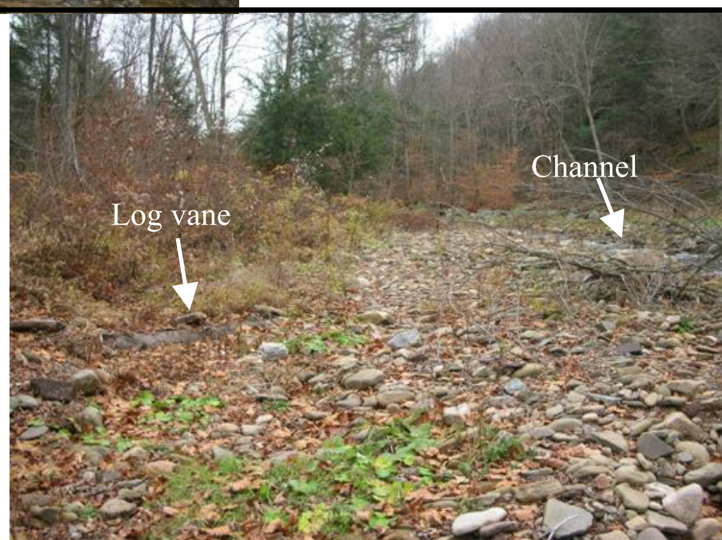

Figure 16b. Photograph of a log vane that is no longer in the active channel at Site 43. In fact the channel has shifted at least 10 feet from the constructed channel. Photograph by C. Kassab.

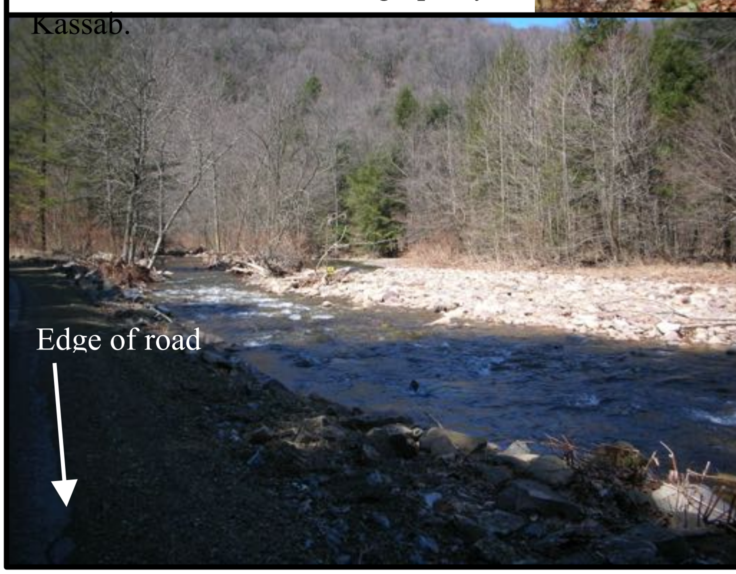

Figure 16c. Photograph showing the amount of aggradation that is common in the reach of stream between Sites 42 and 43. The gravel bar along the right bank has aggraded to the floodplain level and is forcing the stream to flow along the road. During high water events, the road is probably flooded. Photograph by C. Kassab.

Overall these sites are not functioning well. With well over half of the structures significantly damaged and almost 90% of the structures impacted by deposition of gravel, the structures cannot and are not functioning as intended. This stream has a major pulse of gravel moving through the system with the downstream extent just below site 42. In many places along this stream, aggradation above the floodplain level is occurring, forcing the flow through a smaller channel and during high water events, over the floodplain and onto landowners property or the road (Figure 16).

Site 52

In 2006, site 52 was constructed to alleviate the heavy gravel-cobble deposition that is commonly seen in many of the streams in this area and to reduce streambank erosion. Both of the structures at this site are fully intact except that they are limited by the bedload moving through the system. The one structure is completely buried by the bedload and is no longer functioning. The other structure is partially buried by a gravel bar but is still functioning keeping the thalweg off the bank. A double terrace rip-rap system was also installed at this site to help decrease bank erosion.

Assessment based on structure type

Cross Vanes

Cross vanes compromise about 35% of all the structures in this study and were utilized at 17 of the sites. Out of the 107 cross vanes assessed less than 20% had significant damage and the majority of those were located on one stream. Many of the cross vanes with significant damage were missing the throat rocks and usually one of the wings. Over 50% of the cross vanes were completely intact (Table 6). This may be due in part to the fact that cross vanes are tied into both banks. Even though the majority of the structures were still structurally functioning well, over 70% of the cross vanes experienced significant erosion and/or deposition. This ranges anywhere from complete detachment of the bank to partial burial of the structure to the lack of a pool downstream of the structure. Erosion or deposition of gravel impacts the functionality of the structure. In many cases the functionality of the cross vane is impacted by the deposition of gravel on part of the structure, forcing the thalweg out of the center of the stream and along one of the banks.

Overall cross vanes are holding up very well in northcentral Pennsylvania. The majority of them are still intact with some deposition and erosion problems. Based upon the data available on other types of structures, the cross vane may be one type of structure to use if longevity of structural integrity is part of the goal.

Rock Vanes

Rock Vanes comprise about 17% of all the structures in this study and were utilized at 14 of the sites. Out of the 51 rock vanes assessed ~30% had significant damage and the majority of those are located on one stream (Table 6). Almost all of the rock vanes with significant damage were missing most or all of the structure rocks located in the channel with just the rocks tied into the

Table 6. Structural integrity of each type of structure*

		Percentage	
Type of Structures Used	**Number In Study**	**Ranking > 1 (damaged-failed)**	**Ranking >2 (significant damage)**
Cross Vanes	107	48.60	18.69
Rock Vanes	51	60.78	29.41
J-Hooks	43	58.14	37.21
Log Vanes	39	17.95	17.95
Log Deflector	16	0.00	0.00
Unknown	16	100.00	100.00
Step Pool	13	100.00	100.00
Mudsills	8	87.50	12.50
Rootwad	3	100.00	100.00
Log Cross Vane	2	0.00	0.00
W-weir	1	100.00	100.00

Table showing the percentage of each type of structure that ranked > 1, meaning it ranked as damaged, impaired, or failed and the percentage of each type of structure that ranked > 2, meaning it ranked as impaired or failed. n=299.

* Does not include structures from Site 9

bank still present. Approximately 40% of the rock vanes were completely intact and these were located among a variety of streams including the stream that had the majority of damaged structures. That goes to show that it may not necessarily be the type of structure used, but the placement of the structure in the whole system. Even though the majority of the structures are structurally intact, 70% of the rock vanes experienced significant erosion and/or deposition. In many cases this ranking is due to the lack of a pool located downstream of the structure, but also detachment from the bank and deposition of bedload or a gravel bar over part of the structure.

J-hooks

J-Hooks comprise about 14% of all the structures in this study and were utilized at 11 of the sites. Out of the 43 J-hooks assessed, almost 40% had significant damage (Table 6) and the majority of those are located on one stream. Most of those with significant damage are missing the center rocks (the hook) and the wing is still present. A few of the J-hooks are completely missing. Only 40% of the J-hooks are completely intact and are located among a variety of streams. Approximately 65% of all the J-hooks experienced significant erosion and/or deposition. Most of the structures are being buried by bedload or a gravel bar over part of the structure, which partially fills in the pool as well. Overall, J-hooks do not seem to be doing as well as some of the other structures in northcentral Pennsylvania.

Log Vanes

Log vanes comprise about 13% of all the structures in this study and were utilized at 7 of the sites. Out of the 39 log vanes assessed, less than 20% had significant damage (Table 6). This is partially due to the fact that a log vane is either there or not, so the structure is assessed based upon whether or not it is present. Over 80% of the log vanes are completely intact and 13% of the logs vanes are completely missing in this study. Compared to other structure types, log vanes seem to be holding up well structurally. Less than 30% have significant erosion and/or deposition. Most of the log vanes with significant erosion and/or deposition are mainly impacted by gravel deposition. One log vane in particular has been completely buried by a gravel bar and the channel has shifted over 10 feet in the opposite direction. Overall log vanes seem to be functioning very well in northcentral Pennsylvania as long as they have not been washed away.

Other structures

Six other types of structures comprise less than 15% of all the structures in this study and were utilized at 9 of the sites. These structures include log deflectors, log cross vanes, step pools, a w-weir, mudsill, and rootwads. Approximately 40% of these structures have significant damage; the actual number is dependent upon the exact type of structure (Table 6). Log cross vanes have help up well, along with mudsills and log deflectors. The other three types of structures have experienced significant damage. Approximately 75% of the structures have significant erosion and/or deposition. Again, which is greater is dependent upon the type of structure. The log deflectors have greater erosion problems than deposition. Most of the other structures are being impacted by the deposition of bedload in pools and gravel bars over part of the structure.

Comparison to North Carolina Study by Miller and Kochel

In 2008 Miller and Kochel, completed a statewide assessment of stream restoration projects for the state of North Carolina. During their assessment they examined a larger number of structures (558 compared to ~300 in this study) at a similar number of sites (26 sites compared to 22 in this study). Similar to their study, the majority of structures used were cross vanes. Out of all the structures assessed in North Carolina, 24% experienced some loss of structural integrity (ranking >1) and 15% no longer functioning as intended (ranking > 2). Out of the 299 structures assessed in northcentral Pennsylvania, 52% experienced some loss of structural integrity and 31% are no longer functioning as intended. In most cases, those structures that are no longer functioning in Pennsylvania are missing significant portions numbers of the boulders used to build the structures. Many times the pool has undercut the boulders and as a result they have fallen in or the boulders have been transported downstream. Twenty seven percent of the structures in North Carolina have experienced significant erosion and/or deposition (ranking > 2) compared to 35% of the structures in northcentral Pennsylvania. In Pennsylvania most the structures are experiencing more significant deposition than erosion as large pulses of gravel are moving through the system. When both structural integrity and erosion and deposition are taken into account, 32% of the structures in North Carolina experienced either significant loss of functionality or significant erosion and/or deposition. This is compared to 67% of the structures in northcentral Pennsylvania. Overall, in comparison to the structures in North Carolina, it seems like the structures in Pennsylvania show significantly (~30%) more damage. Presumably this is related to a number of factors including flood magnitude and frequency, sediment yields, boulder size, quality of design and construction and other factors. With over two-thirds of the structures showing some sort of significant damage (either structurally or erosion/depositionally), the longevity of structures in Pennsylvania is slim.

Cross vanes, which were the most common structure used in both studies, had the highest percentage of damage in North Carolina (30% with some impairment and 20% with severe impairment) and one of the lowest percentages of damage in Pennsylvania (82% with some impairment and 23% with severe impairment). Severe impairment in this case is being defined as given an integrity ranking of 3 or 4 or an erosional/depositional ranking of 4 or 5 and some impairment is being defined as given an integrity rating of 2 or an erosional/depositioning ranking of 1-3. In both states of those that were damaged, most were impacted by losses of structural integrity, although aggradational and erosional processes were also important. Cross vanes usually function best during low flow conditions and cannot control flow during high flow conditions. This can lead to decreased control of bank erosion during the times when it is most important.

In North Carolina both rock vanes and J-hooks each account for 10% of the evaluated structures. Approximately 15% of both types of structures show significant (ranking > 2) damage with respect to erosion or deposition or exhibit some structural loss. In Pennsylvania the percentage of rock vanes and J-hooks experiencing significant damage is 84% and 79%, respectively. The primary mechanism of failure for both types of structures in North Carolina was erosion or burial along aggrading channels. There is no primary mechanism for failure in Pennsylvania as both the loss of boulders and erosion and deposition played similar role to cause both types of structures to sustain significant damage.

There is a significant difference in the success of structures in North Carolina and Pennsylvania. A much greater percentage of structures sustained significant damage (integrity or erosion/ deposition) in Pennsylvania compared to North Carolina (67% to 37%). This is probably in part to numerous factors. Most of the streams in the Pennsylvania study are experiencing pulses of gravel-cobble size clasts being transported through the system. The aggradation of the clasts is burying the structures or creates gravel bars which impede the functionality of the structure.

Land Use Impacts

As mentioned previously, the majority of streams assessed in this study are experiencing major aggradation as a result of pulses of gravel-cobble size clasts moving through the system. At this point in time, there is limited understanding as to the origination of the clasts. One unpublished theory is that the clasts are a result of logging practices that took place in the late 1800s to early 1900s in northcentral Pennsylvania. Almost all of the streams in the study were clear cut at one point or another during the logging boom (Kline 1970, 1971; Taber 1970, 1971, 1972a, 1972b, 1995.)

It is hypothesized that prior to logging, most of the streams in the area were gravel bed streams. When clear-cutting occurred, erosion of the hillsides followed shortly because there was no vegetation to keep the soil in place. This finer grained material was deposited in the streams. Once logging stopped and reforestation of the hillslopes took hold, the water flowing off of the hillsides was clear which has a higher energy potential. As a result, the clear water eroded away the finer material previously deposited during the logging era. Once the finer material had been eroded away, the gravel from earlier stream beds became exposed and is now being transported through the system. This is based off of a model developed by Tully (2006) for streams in the northeastern United States and an unpublished hypothesis of B. Hayes.

Each of the streams in the study is at a different stage in the transportation of the gravel. Some of the streams are experiencing major pulses of gravel moving through the headwaters while others are moving minimal amounts of gravel. This may be due to the fact that the gravel has not been disturbed enough to begin moving through the system. Most of the streams experiencing pulses of gravel have also experienced some development. This aggradation of gravel is what is impacting the majority of structures in the study. Many of the structures were designed to help transport the gravel through the system faster, but instead the gravel is being deposited over parts of the structure impacting its functionality.

CONCLUSION

1) Stream rehabilitation structures in northcentral Pennsylvania are not fairing very well. Approximately 75% of the structures have sustained some structural damage (ranking >1) or erosion or deposition (ranking >1). Thirty-five percent of the structures have sustained significant damage (ranking >2) or significant erosion or deposition (ranking >3). This is a much greater number than what was discovered in the North Carolina study.

2) Most of the damage (63% of all structures) is related to erosion or deposition which impacts the functionality of the structure. Many of the streams are experiencing pulses of aggradation of gravel-cobble size clasts within the stream system. This pulse of gravel buries parts of individual structures and may fill in the pool that was created by the structure. The loss of structural integrity (52% of all structures experienced it) also plays a role in the decreas in functionality. Some structures can still function with one boulder missing depending upon the location of the missing boulder, but for many, the boulder that is missing was one that helped control the thalweg.

3) Out of the four highly used structures (cross vanes, J-hooks, rock vanes, and log vanes), log vanes by far had the least amount of damage. This is in part due to the fact that under normal circumstances the log vane will either be in place or completely missing. J-hooks and rock vanes sustained the highest percentage of damage compared to the other two structures. One explanation for this may be due to the fact that cross vanes are tied into both banks of a stream, which may limit the amount of outflanking and lateral movement of the channel that may occur. Rock vanes and J-hooks only extend partially out into the channel which may make the end rocks more susceptible to downstream transport.

4) Many of the streams that are experiencing aggradation problems were extensively logged during the logging era of the late 1800s and early 1900s. It is hypothesized that the pulse of gravel-cobble size clasts being transported through the system are a result of clear-cutting and then reforestation.

There is a balance between the need for stream restoration structures and the need to let a system in disequilibria naturally re-equate itself. In many cases, people see a stream in disequilibria as a need to construct structures to stabilize it when it just needs to be let go. In the case of the majority of sites, stream restoration structures were constructed for bank stabilization. Part of the reason that the banks are unstable is that the stream is trying to adjust its hydraulic variables in order to transport the large bedload that is now moving through the system. This bedload has been attributed to the remobilization of pre-logging gravel. As found in one study (Kassab 2008) much of the bedload can be transported downstream in lower than bankfull events, signifying that is moving during many high water events. Many of the structures have been impacted significantly by the increase in bedload burying the structures and rendering them ineffective.

Watershed groups that attempt to do good for the stream may not always understand the complexities of the fluvial system. It is pertinent that assessments like this one continue in order to provide watershed groups and governmental agencies who fund and design projects with increased knowledge before installing restoration structures in streams where they might not function as intended. This is especially important for streams in the Appalachian Plateau and Ridge and Valley region that may be currently experiencing the flux of cobble-sized clasts moving through the fluvial system. These clasts significantly affect the functionality of many restoration structures, mainly burying them and rendering them ineffective. Through continued monitoring of existing sites and expansion of the assessment, a greater understanding can be reached.

REFERENCES

Bernhardt, E.S., Palmer, M.A., Allan, J.D., Alexander, G., Barnas, K., Brooks, S., Carr, J., Clayton, S., Dahm, C., Follstad-Shah, J., Galat, D., Gloss, S., Goodwin, P., Hart, D., Hassett, B., Jenkinson, R., Katz, S., Kondolf, G.M., Lake, P.S., Lave, R., Meyer, J.L., O'Donnell, T.K., Pagano, L., Powell, B., Sudduth, E., 2005. Synthesizing U.S. river restoration efforts: Science, vol. 308, no. 5722, p. 636-637.

Cinquina, M.L., 2009. Personal communication: Scout Executive Columbia-Montour Council.

Clear Creeks Consulting, 2004. xxx Creek Restoration Projects: An Evaluation: Jarrettsville, MD, 50 p.

Department of Environmental Protection, nd. What is Growing Greener? http://www.depweb.state.pa.us/growinggreener/cwp/view.asp?a=3&q=481281 (accessed 10 May 2009).

Kassab, C., 2008. Assessment of stream restoration structures and geomorphic analysis of Muncy Creek, Sullivan County, Pennsylvania: Independent Research, Bucknell University, 60 p.

Keystone Stream Team, 2003. Guidelines for Natural Stream Channel Design for Pennsylvania Waterways: Alliance for the Chesapeake Bay, 90 p.

Kline, B.F.G., Jr., 1971. Pitch pine and prop timber *in* The logging railroad era of lumbering in Pennsylvania : a history of the lumber, chemical wood, and tanning companies which used railroads in Pennsylvania.

Kondolf, G.M., 1995. Five elements for effective evaluation of stream restoration: Restoration Ecology, vol. 3, no. 2, p. 133-136.

Kondolf, G.M., 2006. River restoration and meanders: Ecology and Society, v. 11, no. 2. http://www.ecologyandsociety.org/vol11/iss2/art42/ (accessed 6 May 2008).

Lovegreen, M., 2009. Personal Communication: District Manager, Bradford County Conservation District.

Lutz, K.J., 2007. Habitat Improvement for Trout Streams: Pennsylvania Fish & Boat Commission, Harrisburg, 35 p.

Miller, J.R. and Kochel, R.C., 2008. Characterization and evaluation of stream restoration projects in North Carolina: Final Report to The North Carolina Clean Water Management Trust Fund.

Newhart, F., 2009. Personal communication: landowner.

Rosgen, D.L., 2001. The cross-vane, w-weir, and j-hook vane structures...Their description, design and application for stream stabilization and river restoration: Proceedings of ASCE Conference on Wetlands Engineering and River Restoration, Reno, NV, p. 1-22.

Taber, T.T., III, 1970. Ghost Lumber Towns of Central PA, 76p. *in* The logging railroad era of lumbering in Pennsylvania : a history of the lumber, chemical wood, and tanning companies which used railroads in Pennsylvania.

Taber, T.T., III, 1971. The Goodyears, An empire in the hemlocks, 84p. *in* The logging railroad era of lumbering in Pennsylvania : a history of the lumber, chemical wood, and tanning companies which used railroads in Pennsylvania.

Taber, T.T., III, 1972a. Sunset along the Susquehanna Waters, 94p. *in* The logging railroad era of lumbering in Pennsylvania : a history of the lumber, chemical wood, and tanning companies which used railroads in Pennsylvania.

Taber, T.T., III, 1972b. Whining Saws and Squealing Flanges, 96p. *in* The logging railroad era of lumbering in Pennsylvania : a history of the lumber, chemical wood, and tanning companies which used railroads in Pennsylvania.

Taber, T.T., III, 1995. Williamsport-Lumber Capital: PaulhamusLitho, Inc, Mountoursville, PA, 87p.

Thompson, D., 2005. The history of the use and effectiveness of instream structures in the United States: Geological Society of America Reviews in Engineering Geology, vol 16, p. 35-50.

Tully, C.D., 2006. Regional changes in channel behavior due to historical deforestation and reforestation in the northeastern United States: Undergraduate Thesis, Bucknell University.

Young, A., 2009. Personal communication: member xxx Creek Watershed Association.

Wohl, E., 2004. Disconnected rivers: linking rivers to landscapes: Yale UP, New Haven, 301 p.

Zimmerman, M. nd. Restoration of xxx Creek (Lycoming County, PA): Clean Water Institute. http://www.lycoming.edu/biologydept/cwi/reports/bbcarticle.htm (accessed 10 May 2009).

Appendix A
Site assessment tables

Site Number 2 Rapid Assessment (Assessed 5/5-5/6/2009)			
Structure #	**Structure Type**	**Structural Integrity**	**Erosion/Deposition**
BENT34	Cross Vane	2	1
BENT35	Rock Vane?	3	0
BENT36	Cross Vane	3	2
BENT37	J-Hook	2	2
BENT38	Cross Vane	1	2
BENT39	Rock Vane	1	3
BENT40	Rock Vane	1	1
BENT41	Cross Vane	2	1
BENT42	Cross Vane	2	1
BENT43	Rock Vane?	3	0
BENT44	Cross Vane	1	2
BENT45	Cross Vane	3	2/3
BENT46	Cross Vane	1	2
BENT47	Cross Vane	2/3	2
BENT48	J-Hook?	2	1
BENT49	Unknown	4	3
BENT50	J-Hook?	3	4/3
BENT51	Cross Vane	2	2
BENT52	Cross Vane	1	2
BENT53	Cross Vane	3	2
BENT54	Unknown	4	2/1
BENT55	Cross Vane	4	2
BENT56	Cross Vane	1	2
BENT57	J-Hook?	3	2
BENT58	Cross Vane?	2	2
BENT59	Cross Vane	1	1
BENT60	Cross Vane	1	2
BENT61	Cross Vane	2	3
BENT62	Cross Vane	2	2
BENT63	Cross Vane	2	2
BENT64	Cross Vane	1	1
BENT65	Cross Vane?	4	3
BENT66	Cross Vane	2	3
BENT67	Cross Vane	1	2
BENT68	Cross Vane	2	2
BENT69	Cross Vane	3	2
BENT70	Cross Vane	3/4	2
BENT71	Cross Vane	2	2
BENT72	Cross Vane	3	2
BENT73	Cross Vane	2	2
BENT74	Cross Vane	3	2
BENT75	Rock Vane?	2	3
BENT76	Rock Vane?	1	2
BENT77	Rock Vane?	2	2
BENT78	Rock Vane?	1	3

Site Number 3 Rapid Assessment (Assessed 5/6, 5/12/2009)			
Structure #	**Structure Type**	**Structural Integrity**	**Erosion/Deposition**
BENT79	Rock Vane?	2	2
BENT80	Rock Vane	2	2
BENT81	Rock Vane	3	2
BENT82	Rock Vane	2	3
BENT83	Rock Vane	2	3
BENT84	Cross Vane	1	2
BENT85	Cross Vane	1	2
BENT86	Rock Vane?	2	2
BENT87	Rock Vane?	3	2
BENT88	Rock Vane?	3	2
BENT89	Rock Vane	3	2
BENT90	Cross Vane?	4	4
BENT91	Cross Vane?	3	2/3
BENT92	J-Hook?	2	3
BENT93	Unknown	4	3
BENT94	J-Hook?	3	3
BENT95	J-Hook?	4	3
BENT96	Unknown	4	3
BENT97	Rock Vane	3	2
BENT98	Unknown	4	3
BENT99	Unknown	4	3
BENT100	Unknown	4	3
BENT101	Unknown	4	3
BENT102	Unknown	4	3
BENT103	Rock Vane?	1	2
BENT104	Rock Vane	1	1
BENT105	W weir	3	3

Site Number 4 Rapid Assessment (Assessed 5/12/2009)

Structure #	Structure Type	Structural Integrity	Erosion/Deposition
BENT106	Cross Vane	1	2
BENT107	Unknown	4	3
BENT108	Cross Vane	4	2
BENT109	Cross Vane?	4	2
BENT110	Unknown	4	3
BENT111	Cross Vane?	4	3
BENT112	Rock Vane?	1	2
BENT113	Rock Vane?	3	3
BENT114	Rock Vane	2	3
BENT115	Unknown	4	3
BENT116	Rock Vane?	2	1
BENT117	Rock Vane	2	3
BENT118	Rock Vane	2	1
BENT119	Unknown	4	3
BENT120	Rock Vane	1	3
BENT121	Rock Vane	1	1
BENT122	Rock Vane	1	3
BENT123	Rock Vane	2	2

Site Number 6 Rapid Assessment (Assessed 5/5/2009)			
Structure #	**Structure Type**	**Structural Integrity**	**Erosion/Deposition**
BENT01	J-Hook?	3/4	4
BENT02	J-Hook?	3/4	4
BENT03	J-Hook?	4	2
BENT04	Cross Vane	2	2
BENT05	J-Hook	2	2
BENT06	Cross Vane	1	3
BENT07	J-Hook	1	4
BENT08	Cross Vane	2	3
BENT09	J-Hook	1	1
BENT10	J-Hook?	4	5
BENT11	Rootwad	6	N/A
BENT12	Rootwad	6	N/A
BENT13	J-Hook?	3	0
BENT14	Cross Vane	1	2
BENT15	Cross Vane	1	3
BENT16	J-Hook?	2	2/1
BENT17	Cross Vane	2	1
BENT18	J-Hook?	2	2
BENT19	Cross Vane	1	2
BENT20	Cross Vane	1	1/2
BENT21	Rock Vane?	1	2
BENT22	Rock Vane?	1	2/3
BENT23	Unknown	4	5
BENT24	Unknown	4	1/5
BENT25	Rock Vane?	2	1
BENT26	Cross Vane	3	1/1
BENT27	J-Hook?	2	1
BENT28	Cross Vane	2	1
BENT29	Cross Vane?	3	2
BENT30	Unknown	3	1
BENT31	Cross Vane	1	2
BENT32	Cross Vane	2	2
BENT33	Rock Vane?	3	2

Site Number 10 Rapid Assessment (Assessed 4/8, 4/30/2009)			
Structure #	**Structure Type**	**Structural Integrity**	**Erosion/Deposition**
BUFCR1	Log/Rock Deflector	1	2
BUFCR2	Log/Rock Deflector	1	2
BUFCR3	Log/Rock Deflector	1	2
BUFCR4	Log/Rock Deflector	1	2
BUFCR5	Log/Rock Deflector	1	2
BUFCR6	Log/Rock Deflector	1	1
BUFCR7	Log/Rock Deflector	1	0
BUFCR8	Log/Rock Deflector	1	1
BUFCR9	Log/Rock Deflector	1	5
BUFCR10	Log/Rock Deflector	1	1
BUFCR11	Log/Rock Deflector	1	0
BUFCR12	Log/Rock Deflector	1	1
BUFCR13	Log/Rock Deflector	1	1
BUFCR14	Log/Rock Deflector	1	3/4
BUFCR15	Log/Rock Deflector	1	4
BUFCR16	Log/Rock Deflector	1	3/4
BUFCR17	Log Cross Vane	1	1
BUFCR18	Log Vane	1	0
BUFCR19	Log Vane	1	0
BUFCR20	Log Vane	1	1
BUFCR21	Log Vane	1	2
BUFCR22	Log Vane	1	2
BUFCR23	Log Vane	1	1
BUFCR24	Log Vane	1	2
BUFCR25	Log Vane	1	1

Site Number 24 Rapid Assessment (Assessed 5/7/2009)			
Structure #	**Structure Type**	**Structural Integrity**	**Erosion/Deposition**
FCCLAV2	Cross Vane?	4	3
FCCLAV3	Rock Vane	1	5
FCCLAV4	Cross Vane	2	1
FCCLAV5	Cross Vane	1	3
FCCLAV6	Cross Vane	1	4
FCCLAV7	Rock Vane	2	5

Site Number 23 Rapid Assessment (Assessed 3/17/2009)*			
Structure #	**Structure Type**	**Structural Integrity**	**Erosion/Deposition**
FCS3	Cross Vane	1	1/2
FC4	Rock Vane	1	0
FC5	Rock Vane	1	0
FCS2	Rock Vane	1	1

* Could not complete assessment because repairing some structures at the site

Site Number 28 Rapid Assessment (Assessed 4/9/2009)			
Structure #	**Structure Type**	**Structural Integrity**	**Erosion/Deposition**
JOHCR1	Cross Vane	2	2
JOHCR2	Cross Vane	1	2
JOHCR3	Cross Vane	1	1
JOHCR4	Cross Vane	1	3
JOHCR5	Cross Vane	4	5
JOHCR6	Cross Vane	1	3
JOHCR7	Cross Vane	1	1
JOHCR8	J-Hook	2	2
JOHCR9	Log Vane	1	1

JOHCR10	Cross Vane	1	1/2
JOHCR11	J-Hook?	4	5
JOHCR12	Rock Vane	4	5
JOHCR13	Rock Vane	4	5
JOHCR14	Rock Vane	4	5
JOHCR15	J-Hook	1	3
JOHCR16	Log Vane	1	1
JOHCR7A	Cross Vane	2/1	1
JOHCR6A	Rock Vane	1	2
JOHCR5A	J-Hook	1	2/3
JOHCR4A	Log Vane	4	?
JOHCR3A	J-Hook	1	2/3
JOHCR2A	J-Hook	2	2
JOHCR1A	J-Hook	1/2	1/2

Site Number 29 Rapid Assessment (Assessed 4/21/2009)			
Structure #	**Structure Type**	**Structural Integrity**	**Erosion/Deposition**
KCDEB1	Cross Vane	1	1
KCDEB2	Cross Vane	1	1
KCDEB3	J-Hook	2	1

Site Number 30 Rapid Assessment (Assessed 4/21/2009)			
Structure #	**Structure Type**	**Structural Integrity**	**Erosion/Deposition**
KCFBC1	Cross Vane	1	1/2
KCFBC2	J-Hook	3	2
KCFBC3	J-Hook	3	1
KCFBC4	Rootwads	3	N/A

Site Number 31 Rapid Assessment (Assessed 4/21/2009)			
Structure #	**Structure Type**	**Structural Integrity**	**Erosion/Deposition**
KCKER1	J-Hook?	3	1
KCKER2	J-Hook	1	1
KCKER3	J-Hook	1	1
KCKER4	J-Hook	1	1
KCKER5	Rock Vane	1	1

Site Number 32 Rapid Assessment (Assessed 4/21/2009)			
Structure #	**Structure Type**	**Structural Integrity**	**Erosion/Deposition**
KCH1	Cross Vane	1	0/1

KCH2	Cross Vane	1	1
KCH3	Cross Vane	1	2
KCH4	Cross Vane	1	2/1
KCH5	J-Hook	1	1
KCH6	Cross Vane	1	2
KCH7	mudsill	2	N/A
KCH8	J-Hook?	4	5
KCH9	J-Hook?	4	5
KCH10	J-Hook	1	0/1
KCH11	Cross Vane	1	1
KCH12	J-Hook	1	1
KCH13	Cross Vane	1	1

Site Number 33 Rapid Assessment (Assessed 5/8/2009)			
Structure #	**Structure Type**	**Structural Integrity**	**Erosion/Deposition**
KCCRF6.1	Mudsill	2	N/A
KCCRF6.2	Log Vane	3	3
KCCRF6.3	Log Vane	3	3
KCCRF5.1	Mudsill	1	N/A
KCCRF5.2	Mudsill	2	N/A
KCCRF3.1	Mudsill?	4	N/A
KCCRF3.2	Mudsill	2	N/A
KCCRF3.3	Log Vane	1	1
KCCRF3.4	Log Vane	1	0
KCCRF3.5	Log Vane	1	1
KCCRF2.1	Log Vane	1	1

KCCRF2.2	Log Vane	1	1
KCCRF1.1	Log Vane	1	1
KCCRF1.2	Log Vane	1	1
KCCRF1.3	Log Vane	1	1
KCCRF1.4	Log Vane	1	0
KCCRF1.5	Log Vane	1	1
KCCRF1.6	Log Vane	1	1
KCCRF1.7	Log Vane	1	1
KCCRF1.8	Log Vane	1	1
KCCRF1.9	Log Vane	1	1

Site Number 34 Rapid Assessment (Assessed 4/21/2009)

Structure #	Structure Type	Structural Integrity	Erosion/Deposition
KCBB1	Log Vane	1	0
KCBB2	Mudsill	2	N/A
KCBB3	Log Vane	1	0
KCBB4	Log Vane	1	0

Site Number 68 Rapid Assessment (Assessed 4/21/2009)

Structure #	Structure Type	Structural Integrity	Erosion/Deposition
KCKIS1	Mudsill	2	N/A
KCKIS2	Log Vane	1	0
KCKIS3	Log Vane	1	0
KCKIS4	Log Vane	1	0
KCKIS5	Log Vane	1	0

Site Number 38 Rapid Assessment (Assessed 4/7/2009)

Structure #	Structure Type	Structural Integrity	Erosion/Deposition
MAHCR1	Rock Vane	1	2
MAHCR2	Cross Vane	1	2

Site Number 40 Rapid Assessment (Assessed 4/27/2009)

Structure #	Structure Type	Structural Integrity	Erosion/Deposition
MILC1	Cross Vane	1	2/3
MILC2	Cross Vane	2	1
MILC3	Cross Vane	2	2
MILC4	Rock Vane	4	5
MILC5	Cross Vane	1	5
MILC6	Cross Vane	2	4/3

MILC7	Cross Vane	2	1
MILC8	Cross Vane	2	1
MILC9	Cross Vane	1	3
MILC10	Cross Vane	2	1
MILC11	Cross Vane	1	1/2
MILC12	Cross Vane	1	1
MILC13	Cross Vane	1	1
MILC14	Cross Vane	2	3
MILC15	Cross Vane	3	5
MILC16	Cross Vane	1	2
MILC17	Cross Vane	1	2
MILC18	Cross Vane	2	1/2
MILC19	Cross Vane	1	5/4
MILC20	Cross Vane	1	1
MILC21	Cross Vane	1	1
MILC22	Cross Vane	1	2

Site Number 41 Rapid Assessment (Assessed 3/18/2009)

Structure #	Structure Type	Structural Integrity	Erosion/Deposition
MR1	Cross Vane	1	2
MR2	J-Hook	1	2/3
MR3	J-Hook?	1	2/1
MR4	Rock Vane?	2	1
MR5	J-Hook	1	3
MR6	Cross Vane?	2	3/4

Site Number 42 Rapid Assessment (Assessed 11/13/2008)

Structure #	Structure Type	Structural Integrity	Erosion/Deposition
CV1	Cross Vane	3	3
RV1	Rock Vane	1	1/2
RV2	Rock Vane	3	1
RV3	Rock Vane	2	1
RV4	Rock Vane	4	3
CV2	Cross Vane	2	2/1

Site Number 43 Rapid Assessment (Assessed 11/2, 11/5/2008)

Structure #	Structure Type	Structural Integrity	Erosion/Deposition
144+78	Step Pool	3	4
145+24	Step Pool	3	4
145+65	Step Pool	4	5/4

146+02	Step Pool	4	5/4
146+42	Step Pool	4	5/4
148+09	Cross Vane	1	2
150+86	J-Hook	1	1/2
152+10	Log Vane	4	5
153+80	Cross Vane	1	3/2
154+39	Log Vane	4	5
155+85	J-Hook	4	5
157+20	Log Vane	1	5
158+70	Log Vane	4	5
159+03	Step Pool	4	5
159+54	Step Pool	3	2
159+89	Step Pool	4	5
160+16	Step Pool	4	5
161+34	Cross Vane	2	2/3
163+35	J-Hook	1	4
165+61	Log Cross Vane	1	2/1
171+00	Step Pool	4	5
171+40	Step Pool	4	5
171+80	Step Pool	4	5
172+40	Step Pool	4	5
175+00	Log Vane	4	5

Site Number 52 Rapid Assessment (Assessed 4/22/2008)			
Structure #	**Structure Type**	**Structural Integrity**	**Erosion/Deposition**
WD1	Cross Vane	1	2
WD2	Cross Vane	1	4