Urban Stream Restoration Practices: An Initial Assessment

Final Report

Kenneth Brown
Center for Watershed Protection
8391 Main Street

Ellicott City, MD 21043

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Donna Boring
Ted Brown
Deb Caraco
Rich Claytor
Karen Cappiella
Hye Yeong Kwon
Tom Schueler
Paul Sturm
Laura Thomson
Rebecca Winer
Alex Yeboah
Jennifer Zielinski

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Executive Summary

This study examined more than 20 different types of stream restoration practices and included over 450 individual practice installations. The practice types were broadly classified into four practice groups, based on their intended restoration objective: bank protection, grade control, flow deflection/concentration and bank stabilization. Each practice was evaluated in the field according to four simple visual criteria: structural integrity, function, habitat enhancement, and vegetative stability.

Our assessment of urban stream restoration practices found that most practices, when sized, located, and installed correctly, worked reasonably well and are appropriate for use in urban streams. Of the 22 practices evaluated, only two appeared to have questionable value in urban stream restoration.

Overall, nearly 90% of the individual stream restoration practices assessed remained intact after an average of four years. This result suggests that most stream restoration practices have the potential for longevity. Yet, 20 to 30% experienced some degree of unintended scouring or sediment deposition. This may indicate that a greater percentage of practices may be subject to failure in the near future. While the vast majority of practices remained intact, only 78% fully achieved the practice objective. The greatest deficiency identified was the ability of the practices to enhance habitat. Less than 60% of the practices fully achieved even limited objectives for habitat enhancement. Table E-1 provides a summary of these findings based on five key assessment questions.

The basic design of most individual practices did not appear to cause practice failure. Rather, practice failure was primarily caused by inappropriate channel conditions for the practice, poor practice installation, and/or the improper overall project design. Most importantly, this study found that the key factors for practice success were a thorough understanding of stream processes and an accurate assessment of current and future stream channel conditions.

The majority of practice failures were observed at projects that attempted to create new channel plan form geometry. The creation of an entirely new channel plan form is a difficult task in a non-urbanized watershed and even more difficult in an altered/urbanized watershed where uncontrolled stormwater runoff and a history of watershed disturbance have greatly altered stream channel processes. Most of these projects attempted to create a natural (e.g., pre-disturbance) type channel morphology in an unnatural, disturbed watershed. While natural channel restoration has been successful in many rural and agricultural watersheds (Rosgen, 1994), this design approach needs to be further evaluated in urbanized watersheds.

In some older urbanized watersheds, where stream channels have adjusted to altered urban hydrology, many restoration projects utilized the existing channel geometry and the restoration practices had a higher rate of success. These types of watersheds may currently be the best candidates for urban stream restoration.

More research is needed into the relationships between channel geometry and flow regime for urban streams. This research should look at how the altered flow regime, sediment transport, and landscape processes in an urban watershed affect channel geometry, and how this information can be incorporated into stream restoration project planning. Along with this, further evaluation of urban stream restoration practices is necessary before the question of long term effectiveness can truly be answered. Repeating this study in three to five years on the same set of restoration practices would go a long way towards answering this question. Finally, the true measure of success in stream restoration is how the aquatic community responds. A detailed study of aquatic community response to stream restoration is necessary to truly evaluate the success of urban stream restoration projects.

Table E.1: Summary of Urban Stream Restoration Practice Attributes

Practice Type	Attribute				
	% of Practice Remaining Intact	Achieved Design Objective	Caused Unintended Erosion /Scour	Caused Unintended Sedimentation /Deposition	Achieved Habitat Enhancement
Bank Protection					
Rootwad Revetment	Good	Fair	Fair	Fair	Fair
Imbricated Rip-rap	Excellent	Excellent	Excellent	Good	Fair
Boulder Revetment	Excellent	Good	Good	Excellent	Good
Lunker	Good	Good	Good	Fair	Good
A-jacks	Excellent	Fair	Fair	Good	Fair
Grade Control					
Rock Vortex Weir	Good	Fair	Fair	Good	Fair
Rock Cross Vane	Excellent	Excellent	Excellent	Excellent	Excellent
Rock Weir	Good	Poor	Poor	Poor	Poor
Step Pool	Excellent	Excellent	Excellent	Excellent	Excellent
Log Drop	Excellent	Fair	Poor	Fair	Fair
V-Log Drop	Excellent	Excellent	Good	Excellent	Excellent
Flow Deflection/ Concentration					
Single Wing Deflector	Excellent	Excellent	Excellent	Excellent	Excellent
Double Wing Deflector	Excellent	Fair	Good	Fair	Fair
Log Vane	Excellent	Excellent	Good	Excellent	Excellent
Rock Vane	Excellent	Excellent	Excellent	Excellent	Excellent
Cut-off Sill	Excellent	Excellent	Excellent	Excellent	Excellent
Linear Deflector	Excellent	Fair	Excellent	Excellent	Fair
Bank Stabilization					
Coir Fiber Log	Good	Fair	Fair	Fair	Poor
Live Fascine	Excellent	Good	Excellent	Excellent	Good

Excellent = ○ Good = ⦶ Fair = ◑ Poor = ●

1.0 Introduction

Urban stream restoration projects are being designed and constructed in increasing numbers across the country, employing techniques that vary from "hard" structural approaches to "soft" bioengineering approaches. These design approaches vary with the conditions, constraints, and goals of the individual projects, and no two stream restoration projects are exactly alike. The one factor that all stream restoration projects share, however, is the individual stream restoration practices that make up a restoration project.

The focus of this study is on the performance of these individual stream restoration practices. A stream restoration practice is defined in this study as one component of an overall restoration project, such as a single rootwad revetment or rock vortex weir. Most stream restoration projects include many different practice types as well as many applications of the same practice type. In general, few restoration projects have undergone any post-project monitoring to determine which practices perform best and under what conditions.

This study assessed the performance of more than 450 individual urban stream restoration practices installed at 20 restoration projects across a wide geographic area. It is important to note that our study was not intended to assess the overall success or failure of the restoration projects, since this is difficult to determine on most restoration projects for several reasons. First, measurable goals are seldom stated for most stream restoration projects. Second, when goals are stated, they are often ambiguous or difficult to define in measurable terms and are often unrealistic (i.e., the goals of a project often reflect long term watershed scale goals that are not attainable at a reach scale restoration project). Third, the success or failure of a stream restoration project is often subjective, and is defined by different people in different ways. The old adage that you can satisfy some of the people some of the time, but not all of the people all of the time, is very appropriate in the field of urban stream restoration. Fourth, urban stream restoration is an emerging field and often more art than science. Restoration designers continue to experiment with new techniques and practices, and older techniques are constantly modified to adapt to the significant challenges of the urban stream environment.

This study examined 22 different types of individual stream restoration practices, which were more broadly classified into four practice groups based on their intended restoration objective: bank protection, grade control, flow deflection/concentration, and bank stabilization. Each practice was evaluated in the field according to four simple visually-based criteria: structural integrity, function, habitat enhancement, and vegetative stability. The restoration practices were designed and implemented by numerous NGO's, local, state, and federal agencies, as well as by private consultants.

Combining the results from numerous projects can better illustrate the utility and applicability of individual practices. The primary goal of the assessment is to provide restoration designers, watershed managers, and interested persons with an objective assessment of how restoration practices function over time and to identify reasons why they fail in order to improve and refine specifications for future projects. The assessment is not intended to address the pros and cons of different design philosophies, which remains a matter of great debate among biologists, geomorphologists and restoration designers.

1.1 Limitations of the Assessment

The evaluation protocol was designed for rapid assessment of the integrity, function, and habitat value of a large number of individual stream restoration practices. As such, the conclusions must be tempered by the limitations of the methodology and the population of stream restoration practices sampled. Specific limitations include the following:

Age of Practice - Most of the stream restoration practices assessed were installed in the last three to four years. Consequently, a practice rated as successful in this study could conceivably fail in the future as it is subjected to a greater range of extreme flows. It is recommended that the same population of stream restoration practices be sampled in three to five years to provide a more definitive estimate of practice longevity.

Lack of Standardization -The stream restoration practices assessed were installed by a wide range of public and private entities often with differing design objectives, construction methods, and practice specifications. Thus, it is possible that a practice rated as a failure in this assessment might have been successful had it been constructed or designed using different methods or specifications.

Influence of Adjacent Practices - Many of the individual restoration practices are located within the context of other similar or different restoration practices. The influence of practices on each other was not directly assessed, but was sometimes found to contribute to the success/failure of individual practices. In some instances, upstream practices provided a measure of protection to downstream practices while in other cases, they had an adverse impact. This can be an important factor when practices are closely spaced, which is often the case in urban stream restoration projects.

Sample Size - The study design attempted to assess as many different types of stream restoration practices as possible. Consequently, the sample size of some individual practices is small and, in some cases, all of an assessed practice type occurred on a single project. For instance, only two log drop structures were assessed, with both occurring on a single project. In contrast, more than 200 rock vortex weirs were evaluated at eight stream restoration projects. Any conclusions drawn regarding the effectiveness of practices with small sample populations is considered preliminary.

Defining Success - Our definition of a successful or unsuccessful restoration practice related only to the physical attributes of the practice and its impact on the channel stability and stream habitat. The true measure of success in stream restoration is how the aquatic community responds, which can only be assessed through biological monitoring. This level of effort was beyond the scope of this assessment.

1.2 Report Organization

This assessment report is comprised of five sections. Section 1 provides an introduction to the assessment and outlines the limitations under which the results should be interpreted. Section 2 provides a brief background on the alterations to stream processes that can occur in urban watersheds and how these alterations have been addressed in the past. Section 3 presents the criteria used to select the urban stream restoration projects for inclusion in the assessment and the methodology utilized to assess the individual stream restoration practices. The results of the assessment are presented in Section 4. Recommendations for improving the design and application of restoration practices, based upon the results of the assessment, are presented along with a summary of conclusions and suggestions for future research in Section 5. References and a glossary are provided in sections 6 and 7, respectively.

The report includes four appendices. Appendix A provides brief descriptions of the 20 urban stream restoration projects included in the assessment. Appendix B provides detailed descriptions and illustrations of the individual stream restoration practices. Appendix C includes an example of a completed field data sheet. Appendix D details the results of the assessment for each stream restoration practice in a tabular format.

2.0 Background

In order to assess stream restoration practices, it is important to understand the dynamics of urban streams as well as the terminology used to describe the processes. This section provides a brief overview of urban stream processes; the reader may wish to consult Leopold (1994), Thorne *et al.* (1997), Caraco (2000), and the other references cited in this section for a more detailed review.

Stream channels are dynamic systems that are constantly adjusting in an attempt to maintain an equilibrium with their flow regime and surroundings. Stream channels attempt to reach or maintain this equilibrium by changing their physical dimensions of width, depth, sinuosity, and slope. Stream equilibrium and hence stability are controlled by two dominant factors: sediment load (L) and hydrology (Q), as shown in Figure 2.1.

A change in either one of these factors will lead to the formation of new channel dimensions (Bovee, 1982; Harvey and Watson, 1986; Booth, 1990). The direction of these dimensional changes is, for the most part, predictable.

2.1 The Effects of Urbanization on Stream Channels

Urbanization can cause significant changes in both stream hydrology (Q) and sediment load (L) within stream channels, especially when land development occurs with inadequate stormwater management and/or sediment controls. When a watershed undergoes urbanization, a series of events is set in motion that can greatly alter the receiving stream's physical characteristics (Morisawa and Laflure, 1979; Booth, 1990).

Initially, construction activities such as clearing and grading can contribute large volumes of sediment to stream channels during storm events, particularly when inadequate sediment and erosion control measures are utilized. A stream at a given flow has a finite capacity to transport sediment. When this sediment transport capacity is exceeded, deposition occurs. The sediment begins to accumulate in the channel (aggradation), at first filling pools and then depositing in run and riffle areas. Channel aggradation is usually accompanied by channel widening, which in turn leads to the following:

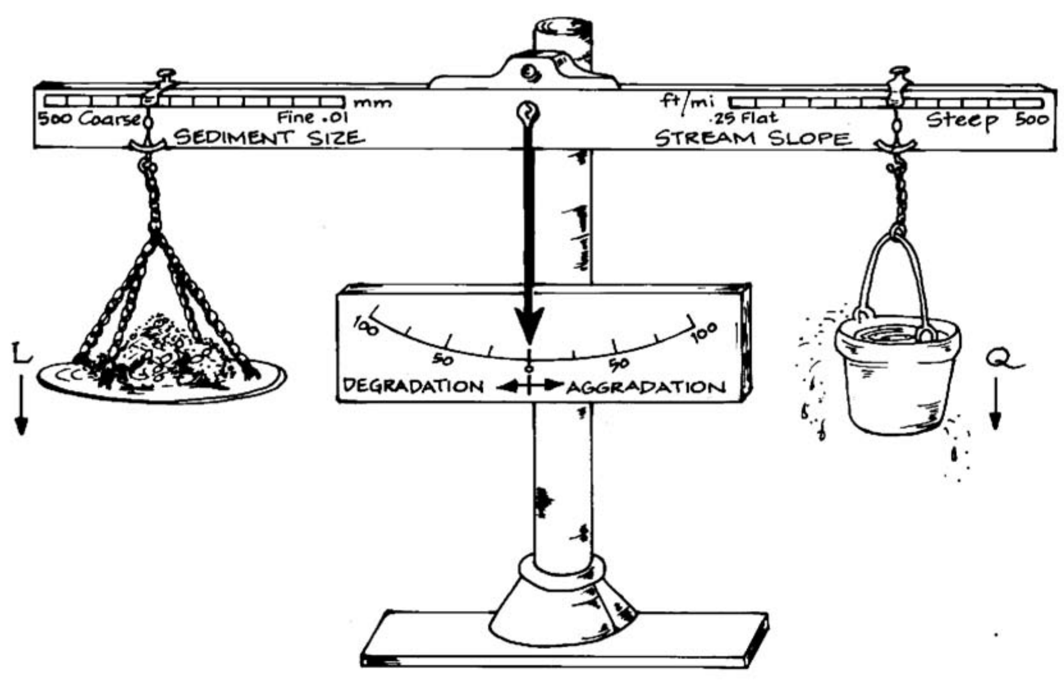

Figure 2.1: The Balance of Stream Dynamic Equilibrium (Adapted from Lane, 1955)

- An increase in the meander wavelength (the channel becomes straighter)
- An increase in the width to depth ratio (the channel becomes shallower)
- An increase in the stream gradient (the channel slope becomes steeper)

The result is a stream channel that is shallower, wider, and straighter (Bovee, 1982). The hydraulically smoother, steeper, and straighter channel results in higher stream velocities as the channel adjusts to transport the increased sediment load. In extreme cases, where sediment load far outpaces the sediment transport capability of the stream, the channel may become braided, forming several flow paths that meander within the channel.

Sedimentation and the subsequent changes in the physical characteristics of the channel have a significant detrimental effect on the ability of the stream to support aquatic life. Finer sediments (silt and sand) fill the voids between larger substrate particles (gravels, cobbles), which in turn eliminates habitat niches for aquatic macroinvertebrates, smothers fish spawning areas, and covers submerged and emergent aquatic vegetation beds (Gordon *et al*., 1992; Schueler, 1997).

As urbanization progresses, other substantial changes occur. The amount of impervious cover increases as roads, parking areas, and driveways are paved and buildings are constructed. The higher impervious cover produces a greater volume of runoff over a wide range of storm events. In addition, increased stormwater volumes are transmitted to the stream channels in less time by storm drain systems that efficiently collect stormwater and convey it directly to stream channels. The impervious cover and storm drain system together produce an increase in both the frequency and magnitude of storm flows within the stream channels, compared to undeveloped streams.

The greater storm flows have the ability to transport large volumes of sediment. Impervious surfaces generate relatively small amounts of sediment in relation to the volume of stormwater runoff. Thus, the greater storm flows have excess sediment transport capacity and can begin to remove sediments previously deposited within the stream channels. When this sediment supply is exhausted, the stream bed and banks become sediment sources. Thus, the combination of reduced sediment input (L) and increased hydrology (Q) triggers a phase of accelerated channel erosion, known as channel enlargement. Figure 2.2 shows the enlargement response of stream channels in relation to increasing impervious cover.

If the streambed is not sufficiently armored with relatively immobile substrate material such as bedrock, large cobbles, or boulders, the channel may begin to downcut, a process referred to as stream incision (Booth, 1990). Stream incision is one of the most destructive alterations that can occur to a stream channel. Stream incision oc-

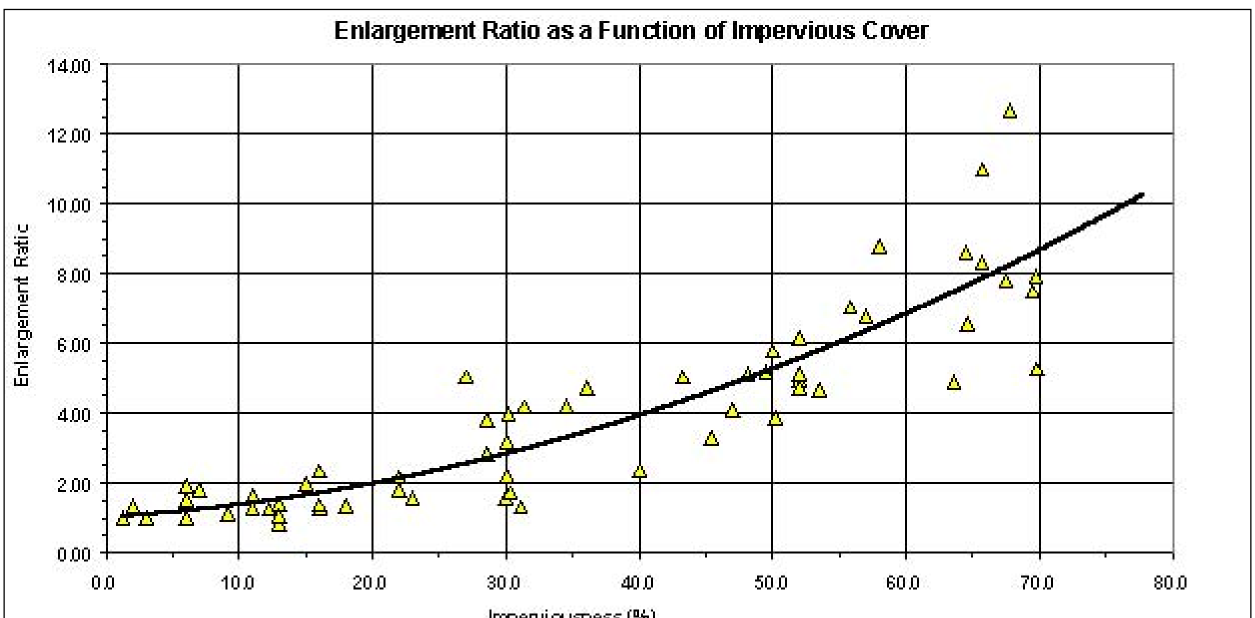

Figure 2.2: Channel Enlargement as a Function of Impervious Cover in Alluvial Streams in Maryland, Vermont and Texas (MacRae and DeAndrea, 1999; Brown and Claytor, 2000)

Table 2.1: Physical Limitations on Fisheries of Perennial Streams in the United States
Source: NRC, 1992

Limitation	Miles	Percent impacted
Siltation	265,000	39.8
Bank erosion	152,000	22.8
Channel modification	143,500	21.5
migratory blockages	39,700	6.0
Bank encroachment	9,000	1.4

curs as a point of active downcutting that migrates in an upstream direction. The point at which the downcutting occurs is referred to as a nick point. This nick point migrates in an upstream direction until a new stable channel slope is achieved or it reaches a grade control such as bedrock or a structure such as a dam or road culvert. The formation and upstream migration of a nick point allows the stream to reduce its slope and thus reduce flow velocities and the ability to transport sediments.

As the nick point migrates upstream, streambanks become taller and more exposed. Over time, the lower stream invert can result in the drying of the upper streambanks. Often, this process causes densely rooted riparian vegetation to be replaced by weakly rooted upland species, further weakening the streambanks. At this point, overbank flood flows that formerly left the channel to flow across the floodplain are now confined to the incised channel. These confined flows are extremely erosive. Over time, the streambanks erode and the channel begins to widen. This process of channel enlargement can occur rapidly or over a period of decades and can lead to channels that are much larger than that needed to convey storm flows (Booth, 1990). Cross-sectional increases on the order of 400% to 1,000% percent have been reported (Harvey and Watson, 1986; Caraco, 2000).

The process of stream incision is most evident in low order (e.g., headwater) streams. The stream invert may be only slightly lowered in elevation at the location where the nick point initially forms. However, as the nick point moves upstream toward the headwaters, the height of the nick point grows in order to achieve a new stable channel slope. Thus, a reduction of stream gradient of only 0.1% carried upstream one mile above the nick point results in a drop in the stream invert of more than five feet at the head of the stream.

Stream incision does not occur in all streams subject to increases in stormwater runoff or decreases in sediment loads. When streams have immobile or resistant bed materials, they must erode their banks to expand their cross sectional area in response to increased flows. These streams are referred to as having natural grade controls. Urban stream channels often have artificial grade control in the form of road culverts and utility crossings. These artificial controls can also reduce the extent of incision. But in extreme cases, these structures can be overwhelmed by the incision process, becoming exposed and subject to failure.

The process of channel enlargement in headwater streams often has further, far-reaching impacts to downstream receiving waters. Poor land use practices resulting in stream incision and widening can generate massive volumes of sediment (Trimble, 1997). While headwater streams are very effective at transporting these sediments, downstream low gradient rivers, tidal areas, and embayments often act as sediment traps. These areas can be subject to severe sediment deposition. Sedimentation in these waters may reduce their capacity to accommodate high flows and can lead to an increase in flood frequency and magnitude.

2.2 Past Management of Urban Streams

Historically, the way engineers typically managed the impacts of urbanization on streams was to remove large woody debris (LWD) from the channel, straighten the channel, confine the stream in a concrete channel, armor the banks with rip-rap, or enclose the stream in a pipe. The intention was to protect stream side property and move stormwater downstream as quickly as possible to prevent local urban flooding. Not only did these practices pass the flooding problem downstream, but they greatly altered the urban stream environment.

The extent of headwater stream loss due to these past management strategies is illustrated in Figure 2.3. This figure presents the Rock Creek watershed located in the suburbs of Washington, D.C., before and after widespread urbanization.

The extent of stream channel alteration is not confined to a few older urban watersheds. In 1984, the U.S. Fish and Wildlife Service reported that, of 660,000 miles of perennial streams surveyed for physical limitations, channel modification was cited as a limiting factor in 21.5% of the stream miles. While the study did not differentiate between urban and non-urban streams, urban streams undoubtedly accounted for a large portion (National Research Council, 1992). Table 2.1 depicts the physical limitations revealed in the study.

While much of the 20th century was devoted to stream management strategies that channelized and enclosed urban streams, the conservation movement was slowly awakening the public to the need to improve the recreational quality of the nation streams. As far back as the 1930s, the U.S. Bureau of Sport Fisheries began a program of trout stream improvement projects. Over the period of a decade, more than 30,000 stream habitat improvement structures were installed in trout streams across the country (Hunter, 1991). By the 1960s, trout stream improvement had developed into a discipline unto itself, even as more and more urban streams were enclosed in pipes, channelized and degraded.

More recently, the same techniques and practices that had been used for decades in trout streams were applied to urban streams. Unfortunately, urban streams possess few of the characteristics of naturally flowing trout streams such as steady flows, stable streambanks and unimpaired water quality. Many of the stream improvement techniques had little effect or were short lived in urban streams. The realization that urban streams did not simply lack habitat, but were hydrologically and structurally different from naturally flowing streams, forced restoration designers to adapt new practices and techniques to address the changes that had occurred due to urbanization.

As these practices and techniques have been implemented, questions have arisen as to their ability to function in the urban stream environment, and the extent to which they are able to improve urban stream habitats. This assessment provides initial answers to some of these questions and offers a current look at urban stream restoration practices.

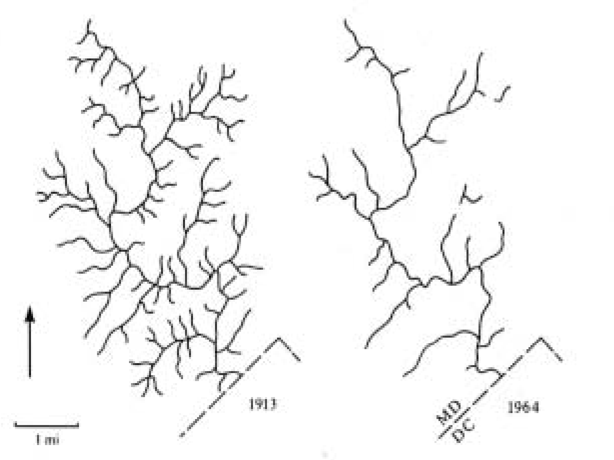

Figure 2.3: Drainage Network of Rock Creek Before and After Urbanization (Dunne and Leopold, 1978)

3.0 Study Design

No two urban stream restoration projects are exactly alike. There are any number of design approaches that vary from "hard" structural approaches to "soft" bioengineering approaches depending upon the conditions, constraints, and goals of the individual projects. One factor that all projects share, however, is the individual stream restoration practices that make up the toolbox of the restorationist. The focus of this study is on the individual stream restoration practices that make up a restoration project. The goals of the study design were to select a representative population of urban stream restoration projects, and develop a methodology to assess the function and performance of individual stream restoration practices utilized within this group.

This section describes the study design utilized in this assessment. Section 3.1 describes the methods and criteria employed to select representative stream restoration projects. Section 3.2 describes the methods used in the field assessment to evaluate each of the individual stream restoration practices within these projects.

3.1 Project Selection

Stream restoration projects were selected from an initial inventory of more than 40 urban stream restoration projects, from which 20 projects were selected for detailed field assessment. For the purpose of this study, urban streams were defined as having at least 15% impervious cover in the contributing watershed. The site selection process was limited to two regions: the Baltimore/Washington, D.C. metropolitan area and the Northeastern Illinois metropolitan area. These geographic limitations were imposed to maximize the number of projects that could be assessed while minimizing travel time and logistical costs. Over the last decade, a large number of urban stream restoration projects have been undertaken within these two regions.

3.1.1 Project Selection Criteria

Three-quarters of the restoration projects were chosen from the Washington D.C./Baltimore region and one-quarter from the Northeastern Illinois region. Emphasis was placed on selecting projects that were at least two to three years old in order to evaluate the longer term success of the practices. The project selection criteria imposed no limits on the size or extent of the restoration projects or the types of restoration practices utilized on the projects. However, projects with a variety of practice types were preferred. A cross-section of restoration design approaches was also desirable as part of the selection criteria. Table 3.1 highlights the project selection criteria.

Table 3.1: Site Selection Criteria Urban Stream Restoration Assessment	
Age of project	Select projects that are a minimum of 2-3 years old
Size of project	Include a mix of small and large projects ranging from projects that address isolated streambank erosion problems to comprehensive stream corridor restoration
Restoration practices	Include a variety of practices from vegetative stabilization to structural practices
Design approach	Select projects that represent different design approaches such as those based upon bioengineering, sediment transport, stable stream geometry, dominant discharge, etc.
Geographic area	Select 3/4 of the projects from the Baltimore/ Washington, D.C. region and 1/4 of the projects from the Northeastern Illinois region.
Urban streams	Select projects from within urbanized watersheds, with a minimum of 15% impervious coverage

Baltimore/Washington, D.C. Region

There was no single source of information regarding stream restoration projects in the Baltimore/Washington, D.C. area. Consequently, information on restoration projects was obtained by contacting state and local government agencies and restoration professionals. The Small Watershed Workgroup of the Maryland Department of Natural Resources had compiled a useful list of stream restoration projects in the State of Maryland. This list currently includes approximately 50 restoration projects and was the primary basis for assembling a candidate project list in the Baltimore/Washington, D.C. region. Non-urban projects were eliminated from the list and the responsible agency or designers for the remaining projects was contacted to obtain detailed information on each project. Additional restoration designers and agencies from across the region were also contacted. As a result of this effort, a candidate list of 37 urban stream restoration projects that met our criteria was compiled.

Northeastern Illinois Region

As with the Baltimore/Washington, D.C. region, there was no single source of information regarding stream restoration projects in the Northeastern Illinois region. The Northeastern Illinois Planning Commission and the Illinois State Water Survey were initially consulted for information regarding urban stream restoration projects. In combination, these two agencies were able to provide detailed information on six urban stream restoration projects in the region that met our initial site selection criteria.

Together, two geographic areas yielded a candidate project list of 43 urban stream restoration projects for further evaluation.

3.1.2 Final Project Selection

Detailed design plans were available for only 34 of the 43 stream restoration projects on the candidate list. It was further discovered that 12 of the projects were either too recently constructed, not constructed, or did not have the necessary detail on the plans. These 12 projects were eliminated from further consideration. Finally, two additional projects were eliminated for being located outside the geographic target areas.

The project selection process yielded a total of 20 projects for inclusion in the field assessment. The goal of the majority of the projects was to reduce stream channel erosion and promote channel stability. The means utilized to achieve this goal differed greatly between projects and was most dependent upon the level of urbanization in the watershed, the potential impacts to infrastructure/private property, and the resources available. The restoration projects selected for inclusion in the assessment are listed below. Table 3.2 provides a summary description of each project. Additional project information is included in Appendix A.

Baltimore/Washington, D.C. Region

Spring Branch
Steemer's Run
Muddy Bridge Branch
Tributary 9 to Sawmill Creek
Deep Run
Quail Creek
Piney Run
Longwell Branch
Cloverleaf Center
Churchill Community
Little Paint Branch
Elwood Smith Park North
Elwood Smith Park South
Wheaton Branch
National Institute of Standards and Technology (NIST)

Northeastern Illinois Region

Lake Zurich Stream Stabilization Project
Barrington Stream Stabilization Project
Glen Crest Creek Restoration Project
North Branch Waukegan River
South Branch Waukegan River

3.2 Assessment Methodology

A methodology was developed to assess the function and performance of the 22 individual stream restoration practice types utilized in the 20 restoration projects.

3.2.1 Stream Restoration Practice Design Groups

The 22 individual practice types were broadly classified based upon the primary restoration design objective that the practice was intended to meet. Each restoration practice within a specific design group differed in how it achieved the broad design objective, but all practices within a design group were evaluated in regard to how they fulfilled the overall design objective. This grouping allowed for comparisons among somewhat dissimilar practice types. Grouping of practice types was also needed to develop a consistent set of assessment questions that could address the basic attributes of all of the practice types, yet recognize the key significant differences among them. The four design groups are described on the following pages.

Table 3.2 Summary of Selected Stream Restoration Projects

Project	Age (yrs)	Approx. Watershed Area (acres)	Stream Order	Land Use and Approx. Impervious Cover	Physiographic Region	Project Type	Cost*	Ex. SWM**	Upstream Retrofit	Le
Spring Branch	2	800	2nd	Suburban Residential 35%	Piedmont	Stream Channel Restoration	2,200	No	No	1[illegible]
Steemer's Run	3	1,000	2nd	Suburban Res/Comm 50%	Piedmont	Stream Channel Restoration	250	No	No	1
Muddy Bridge Branch	4	300	1st	Airport, Commercial 40%	Coastal Plain	Watershed Restoration	420	No	Yes	4
Tributary 9 - Sawmill Creek	4	300	1st	Suburban Comm/Res 55%	Coastal Plain	Stream Channel Restoration	160	No	No	1
Deep Run	6	3,000	3rd	Suburban Comm/Res 25%	Piedmont/ Fall line	Stream Channel Restoration	160	Yes (-)	No	[illegible]
Quail Creek	9	500	2nd	high density Residential, Forest 15%	Piedmont	Stream Channel Restoration	170	Yes	No	1
Piney Run	3	450	2nd	Suburban Residential 30%	Piedmont	Stream Corridor Restoration	900	Yes	No	[illegible]

Table 3.2 Summary of Selected Stream Restoration Projects (Cont.)

Project	Age (yrs)	Approx. Watershed Area (acres)	Stream Order	Land Use and Approx. Impervious Cover	Physiographic Region	Project Type	Cost*	Ex. SWM**	Upstream Retrofit
Longwell Branch	3	400	2nd	Urban/ Commercial 45%	Piedmont	Watershed Restoration	500	Yes (-)	Yes
Cloverleaf Center	2	120	1st	Comm./ Office Park 50%	Piedmont	Stream Corridor Restoration	NA	yes	No
Churchill Community	2	90	1st	High Density Residential 45%	Piedmont	Stream Channel Restoration	NA	No	No
Little Paint Branch	2	7,000	2nd	Suburban 30%	Coastal Plain/ Fall line	Stream Channel Restoration	800	Yes (-)	No
Elwood Smith North	3	50	1st	Urban Res./Comm. 55%	Piedmont	Stream Channel Restoration	NA	No	No
Elwood Smith South	3	110	1st	Urban Res./Comm 45%	Piedmont	Stream Channel and Corridor Restoration	NA	No	No
Wheaton Branch	7	800	2nd	Urban Comm./Res 55%	Piedmont	Watershed Restoration	2,000	No	Yes

Table 3.2: Summary of Selected Stream Restoration Projects (Cont.)

Project	Age (yrs)	Approx. Watershed Area (acres)	Stream Order	Land Use and Approx. Impervious Cover	Physiographic Region	Project Type	Cost*	Ex. SWM**	Upstream Retrofit
NIST	1	200	1st	Office Campus 25%	Piedmont	Stream Channel Restoration	80	Yes	no
Lake Zurich	4	2,000	2nd	Suburban Med/Low Density Res. 15%	Midwest	Stream Channel Restoration	68	No	No
Barrington	4	2,400	2nd	Suburban Med/Low Density Res. 15%	Midwest	Stream Channel Restoration	100	No	No
Glen Crest Creek	8	1,300	2nd	Suburban Medium Density Res. 20%	Midwest	Stream Channel Restoration	60	No	No
North Branch Waukegan River	8	5,300	1st	Urban High density 55%	Midwest	Stream Channel Restoration	12	No	No

1) **Bank Protection Group:** Bank protection practices are designed to protect the stream bank from erosion or potential failure. For the purpose of this study, bank protection practices include practices that are structural in nature, as opposed to the bank stabilization practice group that uses nonstructural techniques such as bioengineering to stabilize streambanks. Bank protection practices are used along stream reaches where eroding streambanks threaten private property or public infrastructure, or where available space or highly erosive flows are a constraint. The most common examples of bank protection practices are rootwad and boulder revetments.

2) **Grade Control Group:** Grade control structures are designed to maintain a desired streambed elevation. They can either be used to raise the stream invert to reverse past channel incision or to maintain the channel invert at a current elevation. Common examples of grade control structures are rock vortex weirs and rock cross vanes.

3) **Flow Deflection/Concentration Group:** The purpose of this practice group is to change the direction of flow or concentrate flow within the stream channel. The practices within this group may be used to deflect flow away from eroding stream banks, concentrate the flow in the center of the channel, redirect water in and out of meanders, or enhance pool and riffle habitats. Common practices within this group include rock vanes and log vanes.

4) **Bank Stabilization/Bioengineering Group:** Bank stabilization practices employ nonstructural means to stabilize stream banks against further accelerated erosion and are frequently used in combination with bank protection practices. Bank stabilization practices generally involve re-grading the stream banks to a stable angle and geometry followed by the use of vegetative plantings and biodegradable materials to stabilize the streambank and prevent future bank erosion. Bank stabilization practices are most often utilized where there is sufficient area to re-grade the streambank and sufficient sunlight to promote the growth of stabilizing vegetation. Widely used practices within this group include coir fiber logs, live fascines and willow plantings.

Together, the four restoration design groups include 22 individual stream restoration practices. In some instances, a practice can serve multiple objectives; areas where this occurred are noted under the practice results in Section 4. The stream restoration practices associated with each design group are presented in Table 3.3. Detailed descriptions and schematics of each restoration practice are also included in Appendix B.

Table 3.3: Stream Restoration Practices Associated with Design Objectives

Bank Protection Group	**Flow Deflection/Concentration Group**
Imbricated rip-rap	Wing deflectors
Rootwad revetment	Single wing deflectors
Boulder Revetments	Double wing deflectors
Single boulder revetment	Log vane
Double boulder revetment	Rock vane/J-rock vane
Large boulder revetment	Cut-off sill
Placed Rock	Linear deflector
Lunkers	
A-jacks	**Bank Stabilization/Bioengineering Group**
	Vegetative/ bioengineering practices
Grade Control Group	Coir fiber log
Rock vortex weir	Live fascine
Rock cross vane	Brush Mattress
Step pool	Bank regrading
Log drop/V-Log Drop	

3.2.2 Assessment Protocol and Rationale

A rapid, semi-quantitative assessment protocol was developed to evaluate the individual restoration practices. The assessment protocol consists of a series of questions that address four major attributes of each practice, including structural integrity, effectiveness/function, habitat enhancement, and vegetative stability.

Practices were located in the field based on the original stream restoration design or as-built drawings. In some cases, the location of practices were only approximated on the design plans. Digital photographs were taken of each practice and the location of each practice was noted on the plans.

The visual assessment consisted of 13 questions, each of which had two parts. The first part of each question included a series of selections for the investigator to choose. The investigator chose the selection that best described the condition of the practice. The second half of each question required the investigator to describe why the question was answered as it was. Figure 3.1 presents the 13 assessment questions. An example of a completed field form is included in Appendix C.

The assessment protocol was similar to methodologies currently utilized to assess stream habitat, such as the U.S. Environmental Protection Agency Rapid Bioassessment Protocols (USEPA, 1989 and 1999a), the Metropolitan Washington Council of Government Rapid Stream Assessment Technique (Galli, 1996) and the National

Structural Integrity

1) **Percent of original practice remaining intact**
0-10% 10-25% 25-50% 50-75% 75-100%
Describe:

2) **Amount of movement or dislocation of practice**
None Slight Significant Complete
Describe:

3) **Degree of unintended erosion/scour**

Upstream	None	Slight	Moderate	Significant
Downstream	None	Slight	Moderate	Significant
At structure	None	Slight	Moderate	Significant

Describe:

4) **Degree of unintended deposition/sedimentation**

Upstream	None	Slight	Moderate	Significant
Downstream	None	Slight	Moderate	Significant
At structure	None	Slight	Moderate	Significant

Describe:

Effectiveness/Functional Assessment

5) **Is practice serving its design objective?**
Yes No Partially
Describe:

6) **Is practice providing unintended benefits?**
Yes No
Describe:

7) **Has practice resulted in unintended impacts?**
Yes No
Describe:

Habitat Enhancement

8) **If the practice is intended to enhance habitat, to what degree is it doing so?**
None Partially Fully
Describe:

9) **Is the practice providing unintended habitat benefits?**
Yes No
Describe:

10) **Is the practice providing unintended habitat impacts?**
Yes No
Describe:

Vegetation Assessment

11) **What percent of installed plant material is living?**
0-10% 10-25% 25-50% 50-75% 75-100%
Describe

12) **Is the practice fulfilling its design purpose, regardless of plant survival?**
Yes No Partially
Describe:

13) **Degree of soil erosion in planting area?**

Upstream	None	Slight	Moderate	Significant
Downstream	None	Slight	Moderate	Significant
At structure	None	Slight	Moderate	Significant

Describe:

Figure 3.1: Urban Stream Restoration Practice Assessment Questions

Resource Conservation Service Stream Visual Assessment Protocol (NRCS, 1998a). Each of these assessment protocols utilizes a series of questions that ask the investigator to determine the level of function of various habitat parameters by selecting from a series of possible answers. The stream restoration practice assessment utilized the same type of assessment approach. As with the habitat assessment techniques, the stream restoration practice assessment relied to a great extent on the "best professional judgement" of the investigator. The subjectivity of the assessment was minimized to the extent possible by the use of specific categorical answers for each assessment question and by having the lead individual on the assessment team present during all of the practice assessments.

The rationale used to answer each of the 13 questions is provided below.

Structural Integrity Factors

What percent of original practice remains intact? This question evaluated the percentage of the original practice that remained intact regardless of any movement of the practice as a whole. The investigator indicated the approximate percentage of the practice remaining in place and described what portion(s) of the practice failed and noted any conditions that might have caused failure. For example, if a rootwad revetment that originally consisted of 10 rootwads was found during the assessment to have lost two rootwads, it would be considered 80% intact and recorded as being in the 75-100% intact category. The selection choices consisted of the following: 0-10%, 10-25%, 25-50%, 50-75%, and 75-100% intact.

How much has the practice moved or been displaced? This question evaluated the degree to which a practice or its components was displaced from its original location, regardless of a practice condition. The investigator indicated the amount of movement and described the distance and direction the practice moved and the resulting conditions. For example, if a portion of a boulder revetment or imbricated rip-rap wall had shifted or moved, yet the structure remained intact and functional, the displacement was assessed based upon the extent of the movement. The assessment question consisted of five possible choices: none, slight, moderate, significant, and complete. A rating of "none" indicated no movement or dislocation of the practice. The choice of "slight" was selected when some movement of the practice or practice materials was evident, but the practice was essentially in the same position and orientation as when installed. A moderate score was supplied if the practice had moved from the original position but the orientation to the stream remained the same. "Significant" indicated that both the position and the orientation of the practice had changed. Lastly, a rating of "complete" indicated that the practice essentially no longer existed in the area where it was originally constructed.

Has the practice caused any unintended erosion/scour or sediment deposition? Many practices are designed to cause either scouring (erosion) or deposition (sedimentation). For instance, a log drop structure is designed to promote pool formation downstream of the practice. These two questions ask the investigator to assess the degree of erosion/scouring and/or deposition/sedimentation caused by the practice that was not intended in the original design. For example, a log drop that experienced significant unintended erosion around the sides of the practice was evaluated based the severity of the erosion.

The investigator described the degree and location of the erosion/scour and/or deposition/sedimentation and described the conditions under which it occurred. The selection choices included: none, slight, moderate, and significant. A choice of "none" indicated that no unintended erosion/scour or deposition/sedimentation had occurred. "Slight" was recorded when some minor unintended erosion/scour or deposition/sedimentation had occurred, but the condition had not materially impaired the practice or stream habitat. A rating of "moderate" was given when unintended erosion/scour or deposition/sedimentation had occurred to the point where it was detrimental to the practice or stream habitat. Lastly, a rating of "significant" indicated that the erosion or deposition was jeopardizing either the practice or stream habitat in the area of the practice.

Effectiveness/Functional Assessment Factors

Does the practice serve its design objective? Every practice is designed to achieve a stream restoration objective. This question asks the investigator to assess the degree to which the practice achieved the design objective of bank protection, grade control, flow deflection/concentration, or bank stabilization. The investigator indicated how well the practice fulfilled its objective and described how it was, or was not, doing so. The degree to which the design objective was achieved was subjectively rated as yes, no, or partially. For example, a double wing deflector that was structurally intact, but had not achieved the design objective of flow concentration/deflection (i.e., it had not created a narrower/deeper channel or downstream pool), was considered to not have achieved its design objective.

Has practice caused unintended benefits or unintended impacts? Even a well-designed practice can have unforeseen benefits or consequences both upstream and downstream. This question addressed whether the practice resulted in any unintended benefits or impacts. The benefits/impacts could be at the practice, downstream, or upstream. The investigator indicated whether there were any unintended benefits or impacts (yes/no) and described the nature of the benefit or impact and its areal extent. For example, the installation of a rock vortex weir that resulted in bank scouring around the sides of the structure was considered to have an unintended impact.

Stream Habitat Assessment Factors

If the practice was intended to enhance habitat, has it done so? Many practices can enhance instream or riparian habitat, while others have little or no potential to do so. This question asked the investigator to evaluate the degree to which the habitat enhancement potential of the practice was achieved. The assessment of the degree of habitat enhancement is based upon the potential of the practice to provide this function. A practice that had the potential to provide only a minor enhancement, yet fully realized that enhancement regardless of the overall amount of habitat created was considered to have fully achieved enhancement. This assessment was made independently of the overall amount of habitat enhanced. The investigator rated the degree that a practice achieved its habitat enhancement potential as fully, partially, or none, and described the nature of the enhancement on the field sheet.

For example, a rootwad revetment can greatly enhance stream habitat by creating pool habitat with overhead cover along the outside of meander bends. On the other hand, an imbricated rip-rap wall has the potential for only a modest enhancement of habitat by creating underwater void spaces as fish cover. If the habitat enhancement potential was achieved at both practices, both were considered to have fully provided habitat enhancement, without considering the relative amount of habitat created by each practice.

Did the practice create any unintended positive or negative habitat impacts? A practice can cause unforeseen benefits or impacts to stream habitat. This question asked the investigator to assess whether a practice had created any unintended positive or negative effects on stream habitat, either in the vicinity of the practice, or in an upstream or downstream direction. The investigator indicated whether the practice had caused any unintended benefits or impacts and described the type and degree of benefit or impact. For example, a vegetative bank stabilization practice that had stabilized the streambank to the point where undercut bank habitat formed, was considered to have created an unintended and positive habitat benefit. Sedimentation within the channel upstream of a practice was considered to be an unintended and negative habitat impact.

Vegetation Assessment Factors

What percent of installed plant material is living? Revegetation or tree planting is a common urban stream restoration practice. This set of questions examined the effect of plant survival on bank stabilization and the design objective of the practice. This question asked the investigator to determine whether the practice utilized any vegetative practices, and evaluate the approximate percentage of planted materials that survived. The investigator indicated which types of plant materials, if any, were used, and the percentage of live material. The investigator also described the condition of the planted materials and noted possible reasons for mortality. The assessment was based on either areal extent or specific number of plantings depending upon the design plan specifications. The selection choices consisted of 0-10%, 10-25%, 25-50%, 50-75%, and 75-100% plant survival.

Is the practice fulfilling its design purpose, regardless of plant survival? Some vegetative techniques utilize the structural properties of woody plant materials as well as the soil binding potential of living plant roots. For example, a brush mattress may no longer contain any living plant material, but the nonliving branch cuttings can still provide physical/structural protection for the streambank and/or a colonization area for other plants. The investigator rated the practice as "yes," "no," or "partially" fulfilling the design objective, regardless of plant survival, and noted on the field sheets how the practice was doing so.

What is the degree of soil erosion in planting area? The purpose of most vegetative practices is to prevent streambank soil erosion by using the soil stabilizing properties of living plant roots. The investigator assessed the degree to which soil had eroded from the planting area and described the general condition of the planting area and plant health. The selection choices consisted of: none, slight, moderate, and significant erosion. "None" indicated that no soil erosion was evident in the planting area. The choice of "slight" indicated that soil erosion within the planting area was visible but was not affecting the overall stability of the planting area. A "moderate" rating indicated that soil erosion was apparent in the planting area and was having an impact on plant health and the stability of the planting area. Lastly, "significant" was chosen when extensive soil erosion was evident in the planting area and the area was considered unstable.

In addition to the basic 13 assessment questions, the investigators recorded any additional information regarding the overall stream channel, riparian and watershed conditions that might have impacted the practice. This information was used to assess the stream conditions where the practice was placed and to possibly explain the underlying reasons for success or failure of the practice.

3.2.3 Data Assessment

After the field assessment was completed, the ratings were compiled and entered into an electronic spreadsheet for graphical and tabular analysis.

Results were also analyzed in terms of the written descriptions given for each question to discover common issues that pertain to the success or failure for each practice. The detailed analysis was conducted at three levels: the practice level, the design group level, and the project level. The majority of the analysis was at the practice level, and focused on the structural, functional, and habitat enhancement aspects of each practice. The design group analysis compared the individual practices within each objective category and examined how well each practice achieved the design objective. The project level analysis looked at practice success in terms of the overall restoration project that the practices were a part of. This analysis looked at how the project approach and design methodology affected the degree of success or failure for the individual practices. This information was then used to make recommendations on how to alter or improve stream restoration practice designs in the future.

4.0 Results and Discussion

The field evaluation was designed to focus on five key questions about individual stream restoration practices:

- Which stream restoration practices remain functional over the long term (five years)?
- Which practices consistently fail within short periods of time (less than three years)?
- Which practices exhibit some kind of failure but remain essentially functional?
- Which practices that tended to fail under current design and construction practices could be improved?
- How did the individual project design approaches and watershed conditions contribute to the success or failure of practices?

The first three questions were easily answered. The success of the practices did not appear to be related to age, as the majority of practices of varying ages were still functioning at the time of the assessment. Individual applications of the same practice type, installed on the same project, met with varying degrees of success. For example, on one four-year old stream restoration project, eight of 35 rootwad revetments evaluated were assessed as less than 75% intact, while on a nearby project of similar type and age, 12 rootwad revetments were evaluated, and all 12 were assessed as fully intact. Clearly, the specific location and application of the practice appear to exert a much greater influence on practice success than does age. For the most part, the relatively few practices that failed did so shortly after installation (within one to two years).

While encouraging, this finding must be tempered by the fact that most practices were still relatively young, and could conceivably fail in the future. The practices evaluated in the study were an average of four years old, with an age range of one to nine years. Thus, the longevity of practices cannot be extrapolated beyond this relatively narrow time frame based on our initial assessment. Age is expected to ultimately have an effect on some practices as they are continually exposed to the significant erosive and depositional forces in urban streams. Streams are dynamic landforms and change is inevitable and constant. Over time, many different factors could alter the effectiveness of a practice. For example, a tree had fallen into the stream just above a practice on one restoration site, diverting the flow of water and destroying the individual practice. The longer a practice remains in place, the greater the chance that some external force or extreme flow event will act upon it. Ultimately, the length of time that a practice will remain effective depends on the structural nature of the practice, its ability to adjust to changing conditions, and the rate of change that the stream undergoes. A more accurate picture of the longevity of these practices would be possible if this study was repeated in three to five years.

Some practices are designed to be rigid and hold up for long periods of time regardless of changing stream conditions. Generally, these are bank protection or grade control practices installed to protect private property or public infrastructure where failure of the practice has significant economic consequences. Imbricated rip-rap and step pools are good examples of practices designed to withstand severe flows and remain structurally sound over the long term. These structurally rigid practices are generally used only where this level of protection is deemed necessary, as they work in opposition to the dynamic nature of streams. Where stream conditions are less severe, the rate of change is slower, and the consequences

Table 4.1 Overall Evaluation of Stream Restoration Practices (N=458)

Partial or Total Failure of Structural Integrity	12%
Did Not Fully Achieve the Design Objective	23%
Experienced Unintended Erosion or Scour	32%
Experienced Unintended Sediment Deposition	22%
Did Not Fully Achieve Habitat Enhancement	42%

Note: The deficiencies of most practices were partial not total of practice failure are less significant, practices that can accommodate natural stream processes may be more appropriate and have similar success/failure rates. These practices (e.g., rootwad revetments, bank stabilization techniques) generally rely on wood/logs as practice materials and the ability of living plants to promote streambank stability. Selecting practices that are appropriate for stream conditions and the level of protection necessary is integral to the design and implementation of successful stream restoration practices.

Overall, nearly 90% of the individual stream restoration practices assessed remained intact after an average of four years. This result suggests that most stream restoration practices have the potential for longevity. In contrast, only 78% fully met the practice design objective, and 20 to 30% showed some early warning signs of possible future failure (i.e., unintended scouring or sediment deposition). The greatest deficiency identified was the ability of the practices to enhance habitat. Less than 60% of the practices fully achieved even limited objectives for habitat enhancement. Table 4.1 details these overall findings.

4.1 Bank Protection Practices

Bank protection practices are designed to protect the stream bank from erosion or potential failure. For the purpose of this study, bank protection practices include only practices that are structural in nature, as opposed to the bank stabilization practice group, which uses nonstructural techniques such as bio-engineering to stabilize streambanks. Bank protection practices are used along stream reaches where eroding streambanks threaten private property or public infrastructure, or where available space or highly erosive flows are a constraint. The most common examples of bank protection practices are rootwad and boulder revetments.

Each of the 20 urban stream restoration projects incorporated at least one type of bank protection practice. Five individual bank protection practice types were evaluated, which included more than 135 individual practice installations. Rootwad revetments were the most common type of bank protection practice, with 96 rootwad revetments installed. The least common bank protection practice encountered was imbricated rip-rap, with only six individual practices installed on three stream restoration projects. While no single bank protection practice fully achieved all assessed factors, no practice was found to be inappropriate for use in urban streams.

The majority of the individual practices were found to be 75 to 100% intact (Figure 4.1). Lunkers had the highest rate of failure, with 22% of the individual installations assessed exhibiting signs of structural failure (less than 75% intact). Other bank protection practice types that showed some structural integrity problems were rootwad revetments (18%) and A-jacks (10%). As a group, nearly 90% of all bank protection practices retained most or all their structural integrity. Only 19 of 135 individual bank protection practices were found to be less than 50% intact.

The majority of individual bank protection practices were also found to fully meet the design objective of bank protection (Figure 4.2). Only three practices (A-jacks, boulder revetments, and rootwad revetments) had any individual installations fail to meet this design objective, and none exceeded 10% of the total number for the practice type. Lunkers had the lowest overall percentage of individual practices fully meet the design objective (67%), but these were all partial and not total failures.

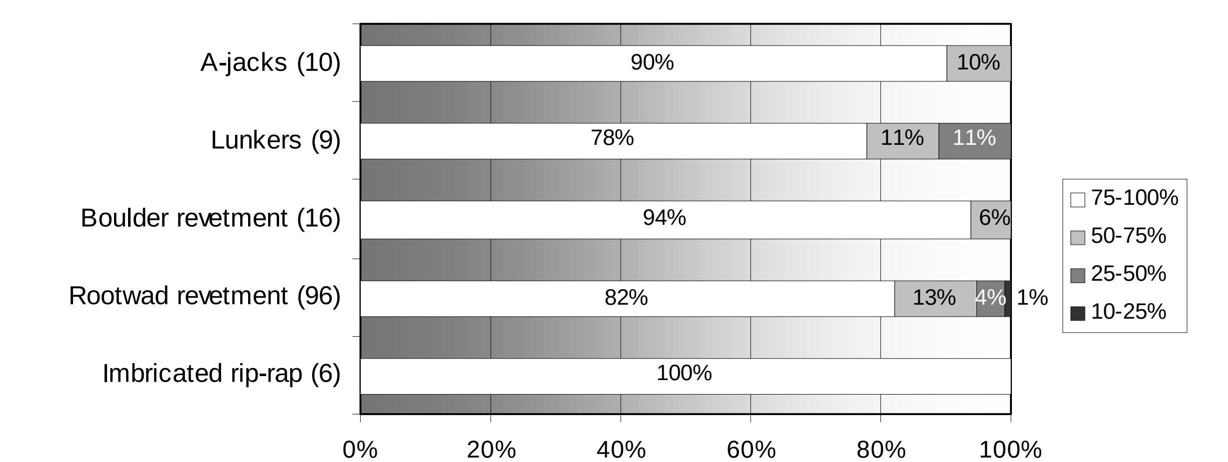

Figure 4.1: Bank Protection - Percent of Original Practice Materials Remaining Intact

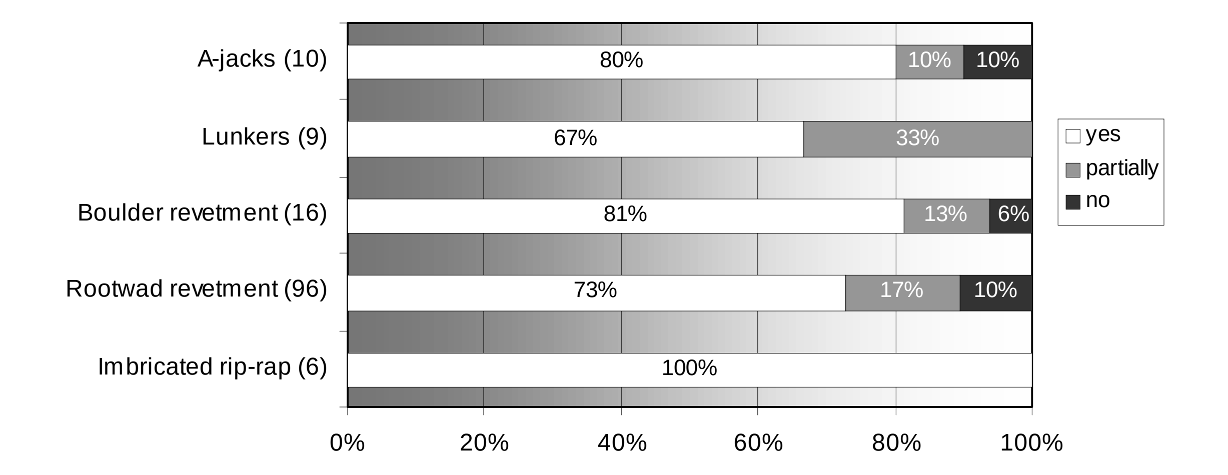

Figure 4.2: Bank Protection - Is the Practice Serving the Design Purpose?

The degree to which bank protection practices exhibited unintended erosion/scour or deposition/sedimentation was variable. Rootwad revetments were found to have the highest percentage of individual practices with moderate to significant unintended erosion/scour (36%) and the highest percentage with moderate to significant unintended deposition/sedimentation (28%). Lunkers were the only other bank protection practice that experienced significant unintended deposition/sedimentation. Lunkers experienced this at 11% of the individual installations (Figures 4.3 and 4.4).

The potential for bank protection practices to enhance habitat varies with the practice type. Rootwad revetments and lunkers have a significant potential to enhance habitat by creating meander pools and overhead cover for fish. Imbricated rip-rap and boulder revetments have a modest potential to enhance habitat by creating void spaces between the boulders beneath the water surface. A-jacks have limited potential to enhance habitat, since they only create a stable streambank toe.

Two bank protection practices, lunkers and imbricated rip-rap, consistently met the habitat enhancement potential of the practice at each installation. A-jacks, boulder revetments, and rootwad revetments fully or partially achieved the habitat enhancement potential of the practice 80% of the time (Figure 4.5).

Overall, rootwad revetments and lunker structures had a higher proportion of negative attributes than the other bank protection practices. This can be explained by two factors. First, both rootwad revetments and lunkers are predominately installed along meander bends. Meander bends are highly dynamic areas of stream channels that generally experience the highest rates of bank erosion and lateral movement. Second, both of these practices utilize woody materials rather than rock, in a complex arrangement that interacts with the stream flow to achieve the practice objective and provide a significant potential habitat enhancement.

In contrast, imbricated rip-rap, while also utilized on meander bends, uses large rock in a simple structural design to stabilize eroding streambanks with little interaction with the stream flow, thereby providing only minimal potential habitat enhancement.

It stands to reason that a structural bank protection practice constructed of large rock designed only to be highly resistant to erosion would have a lower chance of failure than a more ambitious practice utilizing woody material that attempts to interact with stream flow to provide significant habitat enhancement.

The key point is that the application of bank protection practices needs to be balanced with the specific project needs and stream management goals. In areas where bank failure may result in significant economic losses (e.g., public infrastructure or private property), site constraints limit bank re-grading, and stream habitat is a secondary consideration, a more structurally robust practice, such as imbricated rip-rap, is appropriate. However, if site constraints do not limit the choice of bank protection practices and habitat enhancement is a significant goal of a project, practices such as lunkers and rootwads are more appropriate. Between these two extremes lie the other bank protection practices that strike a compromise between structural robustness and habitat enhancement. Bank protection practices that seek greater habitat en-

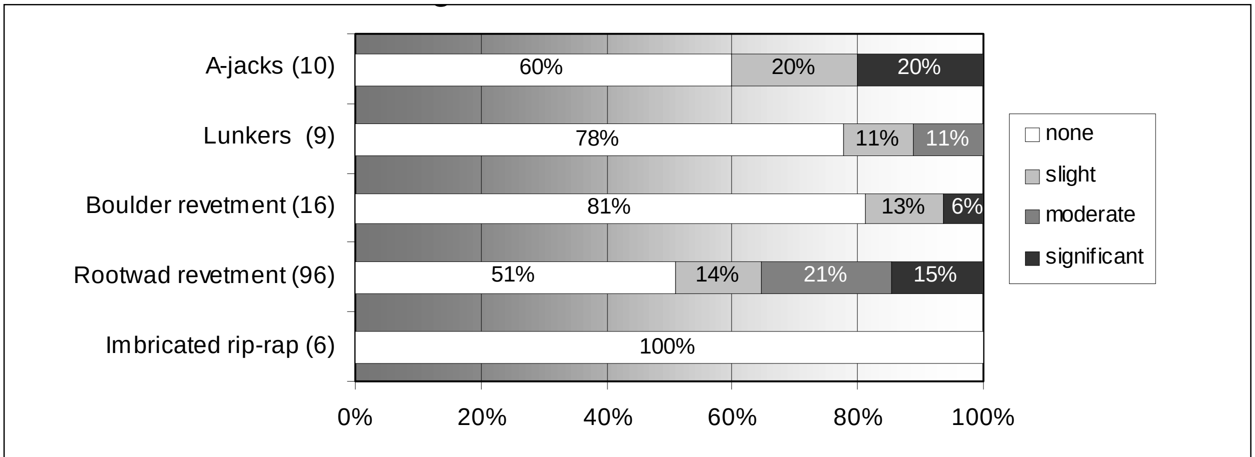

Figure 4.3: Bank Protection - Degree of Unintended Erosion/Scour

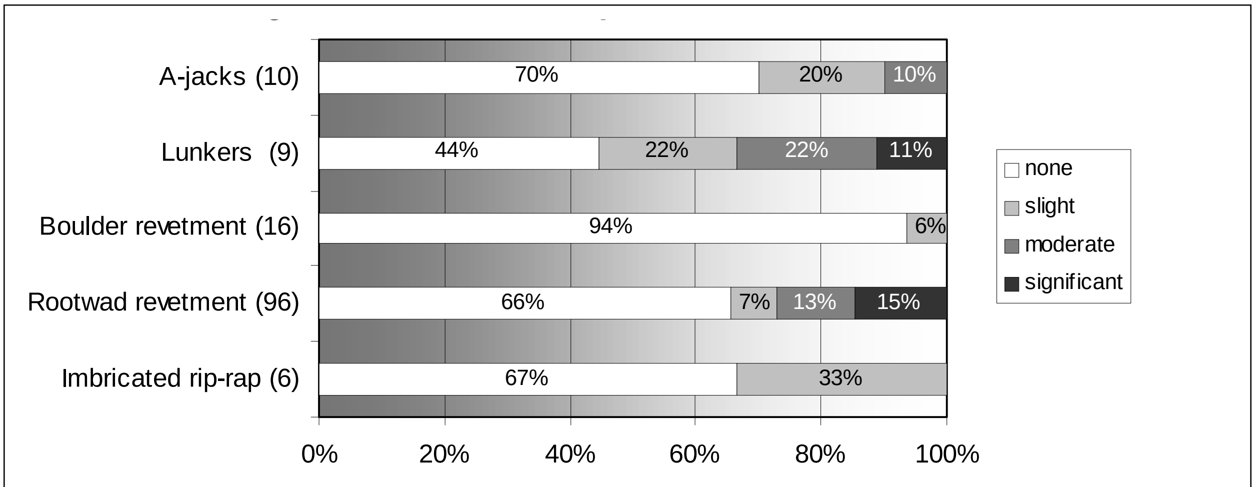

Figure 4.4: Bank Protection - Degree of Unintended Deposition/Sedimentation

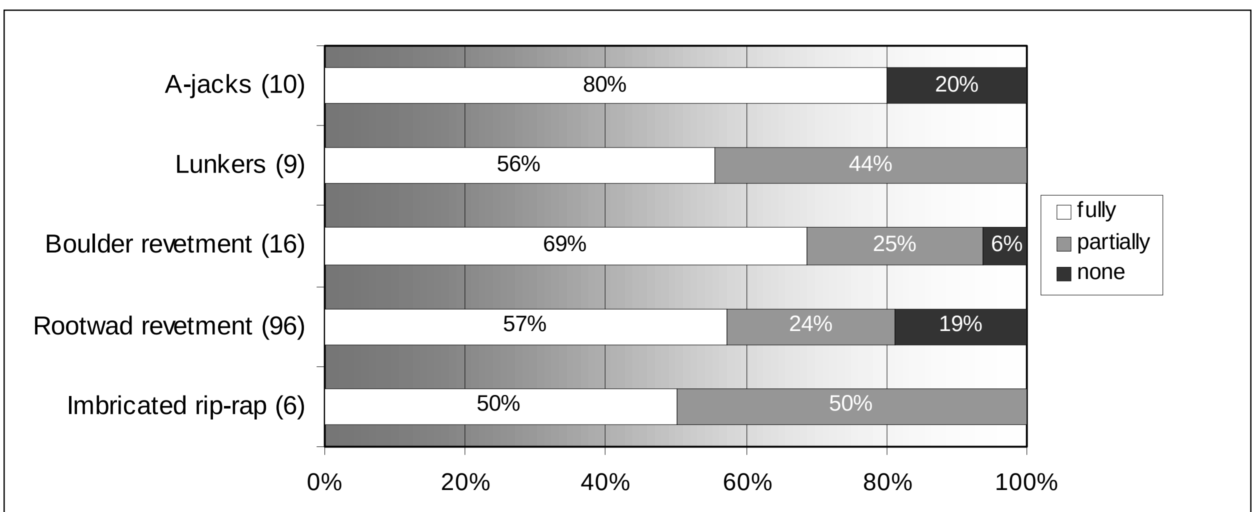

Figure 4.5: Bank Protection - Has the Practice Enhanced Habitat?

hancement tend to be more dynamic and complex, and therefore require both more detailed understanding of current stream processes, and more exacting design and construction efforts.

The following sections detail the results of the assessment for each bank protection practice type in terms of intended benefits and specific applications.

4.1.1 Rootwad Revetments

Ninety-six rootwad revetments were utilized on 10 of the stream restoration projects included in the study. Rootwad revetments were the most common form of bank protection utilized on meander bends. An individual rootwad consists of a 10 to 12 foot section of the lowermost portion of a tree trunk with the root fan still attached. These are installed in series along the streambank to form the revetment. The number of individual rootwads in the revetment evaluated ranged from two or three up to as many as 20 rootwads, with the average revetment consisting of six to nine rootwads.

Over 70% of rootwad revetments evaluated were found to be 75 to 100% intact and fully serving the design objective of streambank protection (Figure 4.2). Overall, rootwad revetments were found to be very effective at stabilizing meander bend erosion.

Individual problems were encountered in about one-third of the revetments assessed. Moderate to significant movement or dislocation of rootwads was noted at 18% of the revetments. Approximately 35% of the revetments experienced moderate or significant erosion/scour along the streambank and 27% experienced moderate to significant deposition or sedimentation within the stream channel (Figure 4.6). Typically, a rootwad revetment that experienced moderate to significant erosion/scour also experienced moderate to significant sedimentation/deposition. Photo 4.1 illustrates this occurrence. In addition, about one-third of the revetments had moderate to significant soil erosion in the planting areas. Plant survival rates of less than 75% were noted at 15% of the rootwad revetments. This is noteworthy, since the construction of rootwad revetments often disturbs large areas of streambank and relies heavily on vegetative stabilization to maintain the integrity of the streambank between and around the individual rootwads.

Rootwad revetments have a much higher potential to provide meaningful habitat enhancement compared to other bank protection practices. This habitat enhancement is in the form of meander pool formation and the creation of overhead cover for fish. Full or partial habitat enhancement was provided by 80% of the rootwad revetments (Figure 4.5). The remaining rootwad revetments either did not provide any habitat enhancement, or had a negative impact on stream habitat. Again, many of the rootwad revetments had experienced sediment deposition and were no longer in contact with the low flow channel in which they were originally installed.

The majority of problems associated with rootwad revetments were observed at three of the stream restoration projects in which they were installed. Significantly, two of these three projects attempted to create new meander bend geometry as a part of the project design. The majority of revetment failures occurred on these two projects.

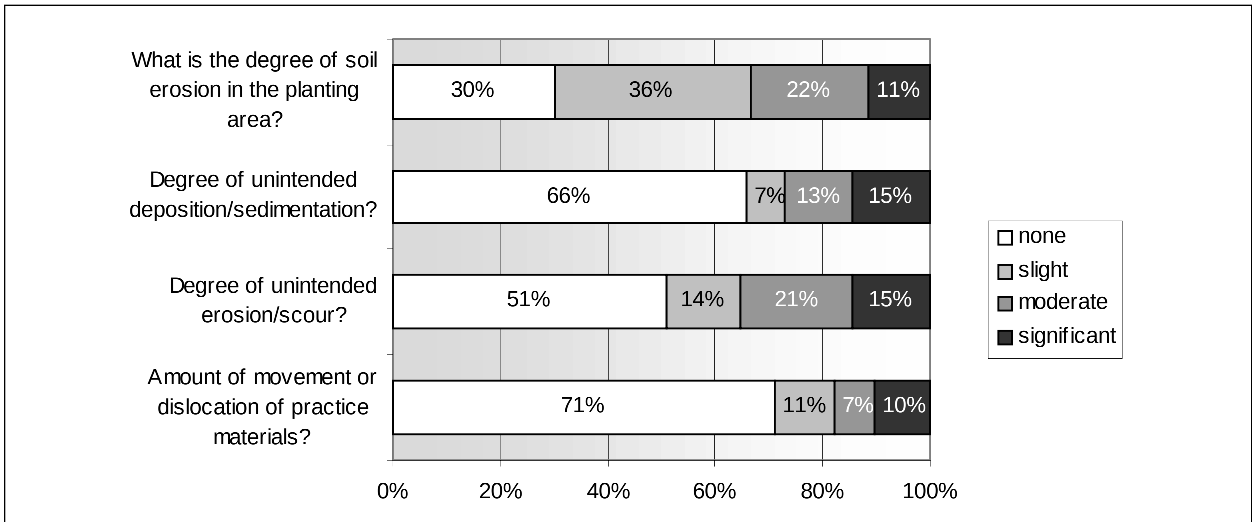

Figure 4.6: Bank Protection - Rootwad Revetment Assessment

These failures appeared to be related more to the project design than any inherent problems related to the rootwad revetments themselves. Stream confinement and design geometry at these projects were found to be the significant factors affecting rootwad stability. Rootwad revetments installed along confined stream channels (e.g., incised channels with little or no access to the floodplain) had a much greater chance of failing than those installed along unconfined or moderately confined channels. Improper channel design geometry almost always led to rootwad failure.

In the other stream restoration projects, the most common problem cited for rootwad revetments was soil erosion within and around the revetments. Photos 4.2 and 4.3 illustrate the slight to moderate erosion observed at the majority of rootwad revetments evaluated in the study.

Construction specifications for rootwad revetments were quite similar among all projects, with the only real difference being whether a cutoff log was used to secure the individual rootwads or whether large rock was substituted. No discernible difference in practice performance was seen based on this design difference. See Appendix B for recommended rootwad revetment construction details.

4.1.2 Imbricated Rip-Rap

Six imbricated rip-rap revetments were installed on three urban stream restoration projects assessed in this study. Imbricated rip-rap revetments were used almost exclusively to stabilize very steep, unstable streambanks that placed private property or public infrastructure at risk, or where there was little or no room to regrade the streambank to a stable bank angle. The imbricated rip-rap extended from the toe of the streambank to the top of the streambank and ranged in height from five to 15 feet. Imbricated rip-rap was used where “softer” bank stabilization practices would not provide the necessary level of structural streambank protection.

All six of the imbricated rip-rap revetments were 75 to 100% intact, with only one having experienced some slight movement of its component boulders. No unintended scour/erosion was noted at any of the installations. Two installations were found to have experienced slight sedimentation, but this was related more to their location along straighter reaches than to any deficiency in the practice (Figure 4.4). All of the installations were found to fully serve the design objective of bank protection.

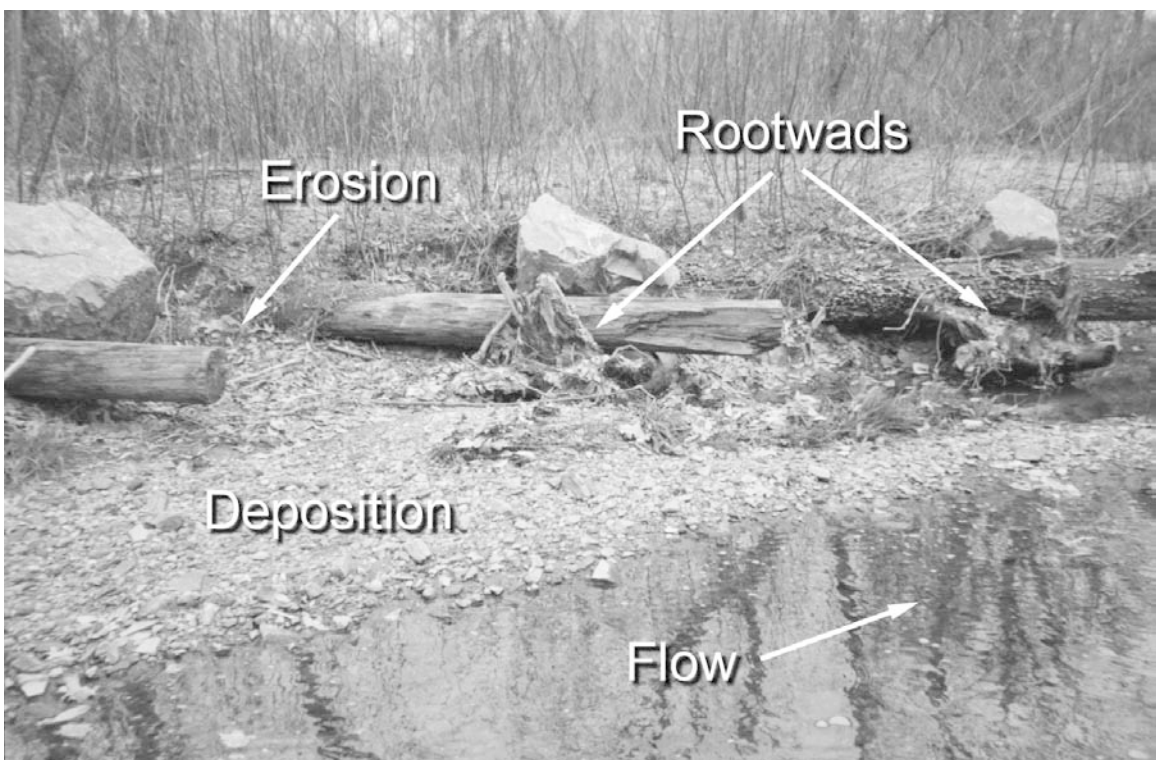

Photo 4.1: Rootwad revetment that experienced both significant erosion and significant deposition. Revetment has remained in place but failed to protect streambank.

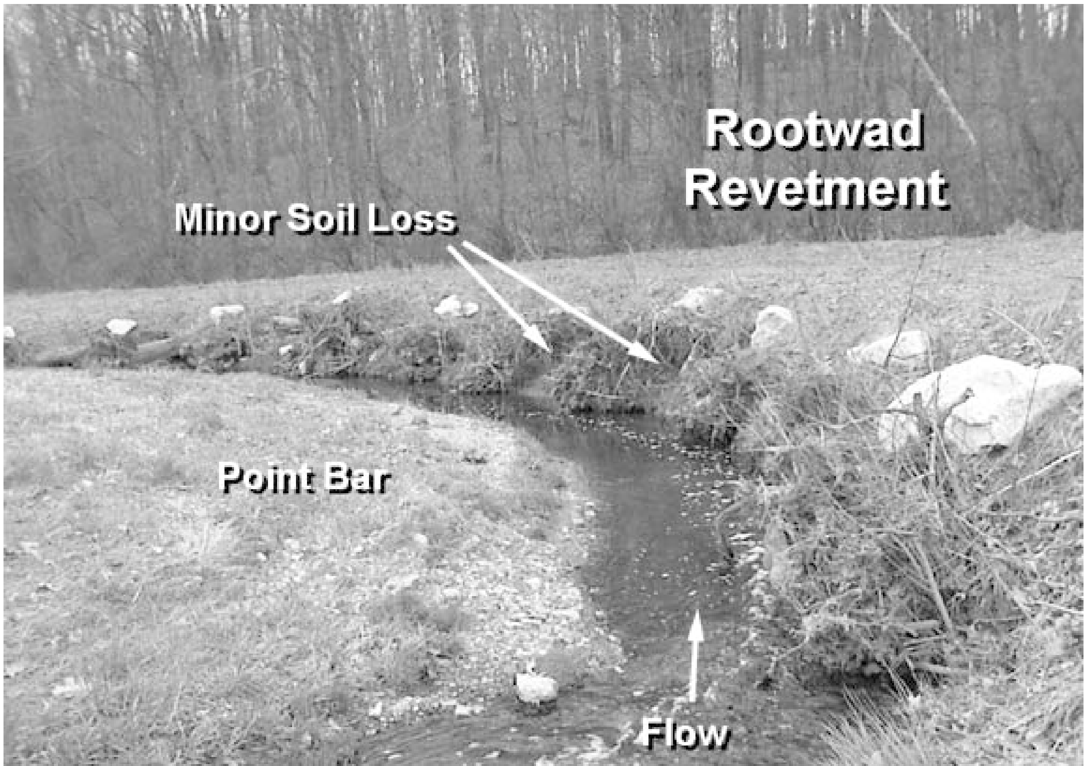

Photo 4.2: Typical rootwad revetment depicting minor soil erosion between individual rootwads. This revetment is fully serving the design objective of bank protection.

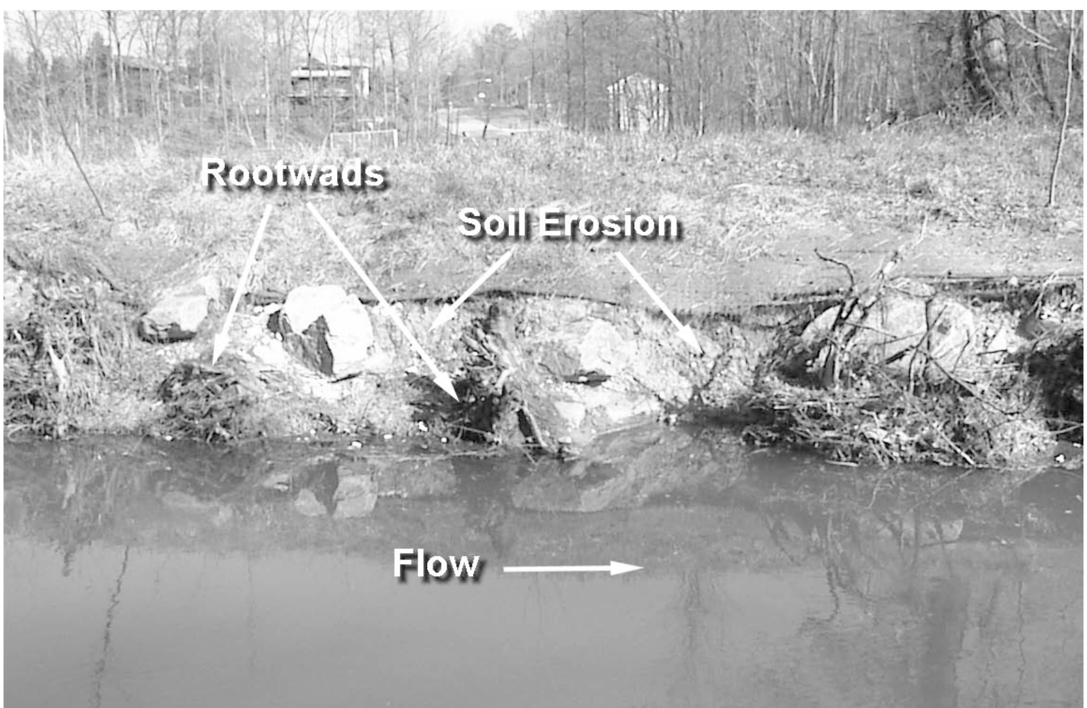

Photo 4.3: Rootwad revetment that has experienced moderate soil loss between rootwads. Erosion control netting is exposed along the top of the revetment.

Correctly installed imbricated rip-rap provides a modest level of stream habitat enhancement in the form of void spaces between the large boulders beneath the waterline. These void spaces provide overhead cover and hiding areas for fish. Three of the six imbricated rip-rap installations fully provided this habitat enhancement, and three partially provided this habitat enhancement (Figure 4.5). As with the rootwad revetments, the failure to meet the habitat objective occurred when the low flow channel had shifted away from the base of the revetment.

Based upon a limited sample size, imbricated rip-rap appears to be an effective bank protection practice where private property or public infrastructure is threatened by bank erosion and long term structural bank stabilization is required. Photos 4.4 and 4.5 depict well-constructed, appropriately sited imbricated rip-rip revetments.

Photo 4.4: Well designed and installed imbricated rip-rap revetment.

Photo 4.5: Imbricated rip-rap revetment protecting 15 foot tall unstable streambank. A parking lot lies at the top of slope.

4.1.3. Boulder Revetments

Sixteen boulder revetments were installed on four stream restoration projects included in the study. As a practice, boulder revetments included single and double layer boulder revetments, large boulder revetments, and placed rock revetments. The primary goal of boulder revetments is to ensure that no further erosion of the lower streambank occurs.

Boulder revetments were utilized on projects where vegetative stabilization alone was impractical or could not provide the necessary resistance to erosive forces along the lower portion of the streambank. This was especially true when bank protection/stabilization was required in forested stream conditions with little sunlight to support streamside vegetation growth. Nearly all boulder revetments extended up from the toe of the streambank to the bankfull height and required bank regrading and vegetative stabilization measures above the revetments to stabilize the full bank height.

Boulder revetments were predominately utilized along straight or gently curved stream reaches that were vulnerable to failure. On a few projects, they were used along meander bends where rootwad revetments would have been difficult to install because of poor equipment access, property owner concerns, or the extended height of the streambank.

Overall, few problems with boulder revetments were encountered in most applications. A full 94% of the boulder revetments installed were intact and met their primary design objective of bank protection (Figures 4.1 and 4.2). Isolated problems involving dislocation/movement and erosion/scour were noted at four installations.

Scouring of the substrate below the depth of the revetment rock was one factor that resulted in movement or partial failure of boulder revetments. In some applications, boulders were placed directly on the streambed or were only shallowly entrenched into the streambed. During high flows, substrate material at the foot of some boulders was scoured away, which caused the boulders to topple into the stream (Photo 4.6). In one installation, the entire boulder revetment slumped due to bank toe scour and saturated soil conditions in the streambank behind the revetment (Photo 4.7).

As with imbricated rip-rap, boulder revetments have a modest potential to enhance stream habitat in the form of void spaces below the waterline. These void spaces serve as overhead cover and hiding places for fish. Of the 16 boulder revetments, 11 fully achieved this modest habitat enhancement potential, and four partially achieved this enhancement (Figure 4.5).

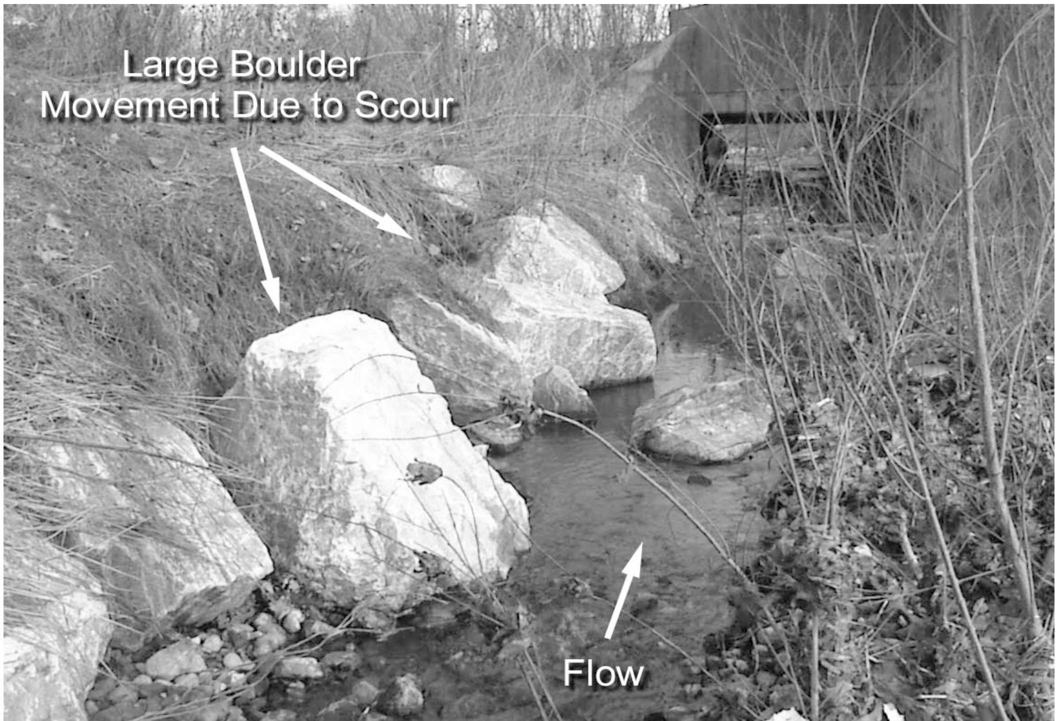

Photo 4.6: Large boulder revetment that has experienced scouring along the toe of the streambank and movement of practice materials.

Photo 4.7: Large boulder revetment that has slumped due to scouring at the streambank toe and saturated soil conditions within the streambank. Revetment moved in mass.

4.1.4 Lunkers

Lunkers were installed at all five Midwestern urban stream restoration projects assessed in the study. Lunkers protect only the toe of the stream bank and are combined with other bank protection or stabilization practices to protect the upper bank. For a detailed description of how lunkers are constructed, consult Appendix B.

Nearly 80% of lunkers installed were found to be 75 to 100% intact, and 67% were found to fully serve the design objective (figures 4.1 and 4.2). Significant dislocation/movement of lunker materials was noted at two lunker installations (Figure 4.7). These two structures had partially collapsed, either from scouring from below or rotting of the wooden structures.

Lunker structures were originally designed as habitat enhancement practices that create undercut bank habitat along meander bends. In recreational fishing streams, they have been found to be very effective at this purpose (Hunt, 1993). This study found they can also be effective in creating undercut bank habitat in urban streams. Five of the nine lunker structures evaluated in the study were able to create undercut banks and the remaining four were found to partially provide this habitat enhancement (Figure 4.5). The habitat enhancement was limited when the lunkers moved or collapsed, or sediment filled the void spaces below the waterline. Photo 4.8 depicts a good example of undercut habitat created within a lunker structure.

Since lunkers protect only the toe of the streambank, they are installed with other practices to stabilize the bank above. Most of the lunker structures had a layer of stone placed on top of them, with a layer of soil and erosion control matting placed over the stone and planted with vegetation. Success in stabilizing the upper bank was mixed, with seven lunkers having none or only slight erosion in the planting areas and two experiencing moderate erosion (Figure 4.7). Photo 4.9 depicts one method of bank stabilization above a submerged lunker structure. Additional information on the use of lunkers can be found in Newbury *et al.*, 1998 and Roseboom *et al.*, 1997.

Lunkers were installed in both less developed suburban watersheds (<20% impervious cover) and highly developed urban watersheds (>50% impervious cover). In the suburban watersheds, bank regrading and vegetative stabilization were often sufficient to stabilize the upper streambank. In the highly impervious urban watershed, both rock and vegetative stabilization were needed to stabilize the upper streambank, but this appeared less reliable. This suggests that lunkers have a greater likelihood of success in terms of both bank protection and habitat enhancement in watersheds of low to moderate impervious cover (15 to 25%).

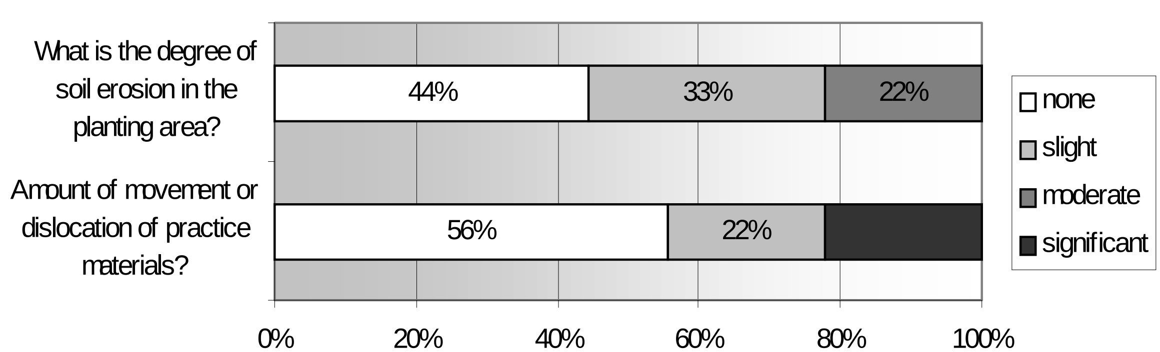

Figure 4.7: Bank Protection - Results of Lunker Assessment

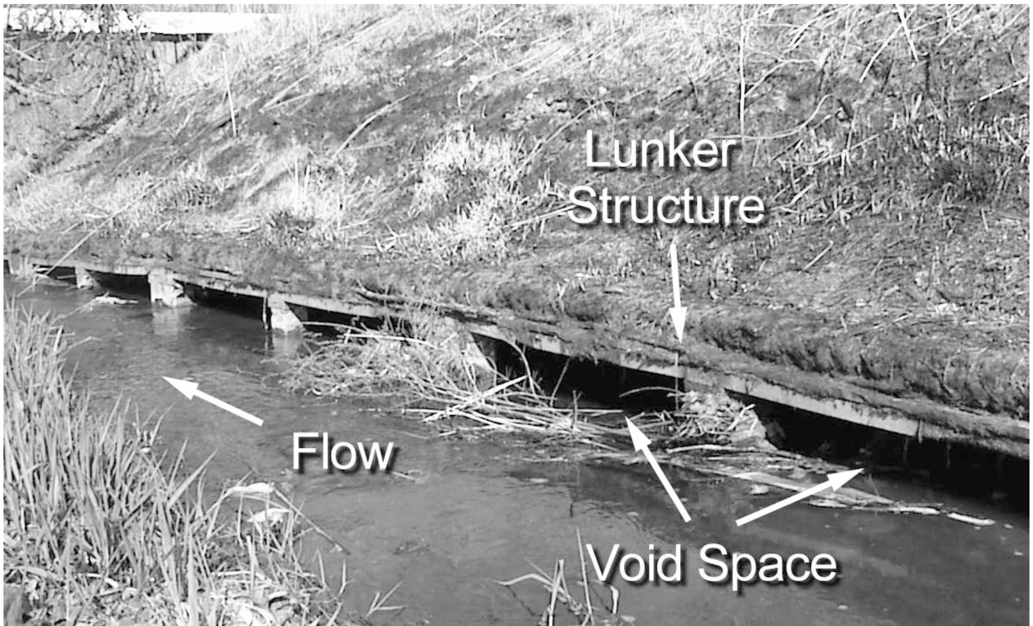

Photo 4.8: This photo depicts the void space created by a lunker structure. Upper bank slope was recently burned as part of prairie grass restoration project.

Photo 4.9: Submerged lunker structure showing rip-rap and vegetative stabilization.

4.1.5 A-jacks

A-jacks were also frequently installed on the Midwestern stream restoration projects. Nine of the 10 A-jacks installations were found to fully retain their structural integrity (Figure 4.1). Two A-jacks installations experienced extensive bank erosion above the A-jacks, with significant movement/dislocation of the A-jacks resulting at one installation. Moderate or significant erosion of the upper bank planting area was noted at 40% of the A-jacks practices (Figure 4.8). Overall, 90% of the A-jacks fully or partially served the design objective of bank protection (Figure 4.2). Photo 4.10 depicts a typical A-jacks installation.

A-jacks are predominately used to stabilize the lower portion of the streambank and are combined with other practices to stabilize the upper bank. Generally, they are backfilled with stone/soil or soil only, over which erosion control matting is placed and the area is planted with vegetation. In some cases, a coir fiber log was placed along the top edge to hold the soil/stone matrix in place and the area was planted with vegetation. Photo 4.11 depicts an A-jacks installation that utilized a coir fiber log to stabilize the bank above it. Additional information on the use of A-jacks can be found in Newbury *et al.*, 1998 and Roseboom *et al.*, 1997.

A-jacks do not have a significant habitat enhancement potential, other than stabilization of the toe of the stream bank. While this is only a minor habitat enhancement, 80% of the A-jacks achieved this habitat objective (Figure 4.5).

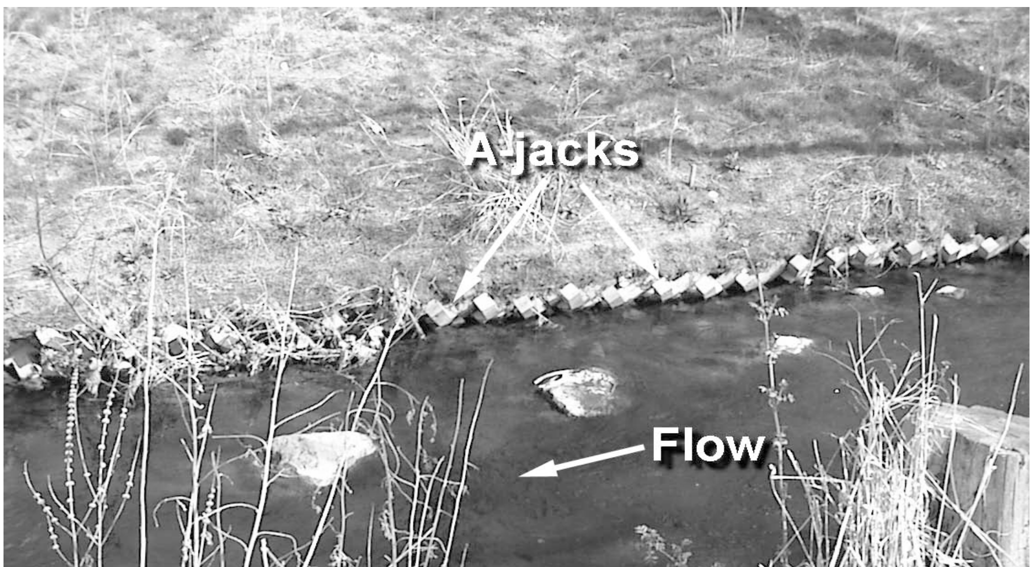

Photo 4.10: Typical A-jacks installation with vegetative bank stabilization along the upper streambank.

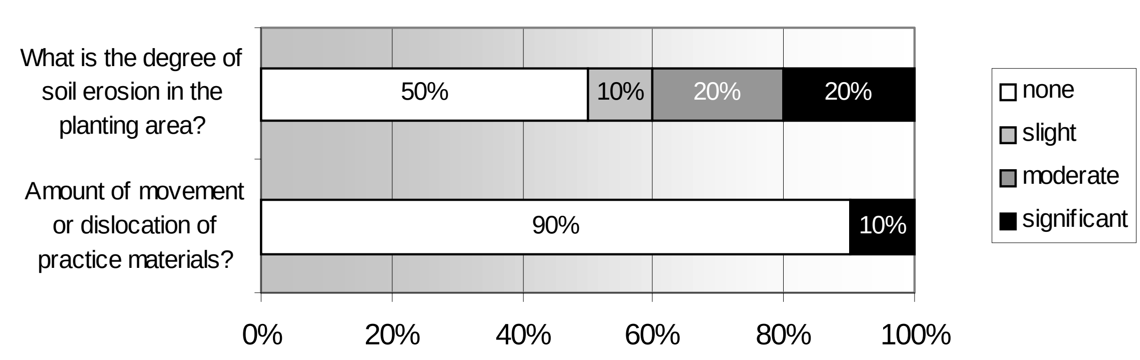

Figure 4.8: Bank Protection - Results of A-jacks Assessment

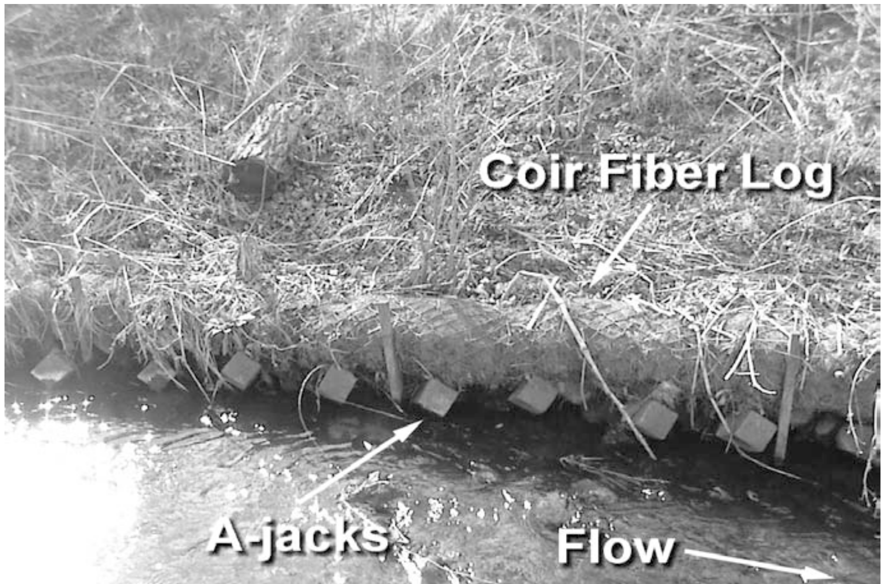

Photo 4.11: A-jacks installation utilizing coir fiber log to stabilize lower streambank. The biolog also softens the appearance of the concrete A-jacks.

4.2 Grade Control Practices

Grade control practices are installed to maintain a desired streambed elevation. These practices are used to either raise the stream invert (i.e., to reverse past channel incision) or to maintain the channel invert at a current elevation (i.e., to prevent channel incision). Nearly all of the stream restoration projects incorporated some form of grade control practice in the project design. Grade control practices create a "hardpoint" along the channel, preventing the streambed from degrading below the top elevation of the structure. The two main types of grade control practices were those that utilized logs for construction materials and those that utilized rock.

The six different types of grade control practices evaluated included nearly 250 individual practice installations. By far, the rock vortex weir (RVW) was the most common grade control practice encountered in the study. More than 200 RVWs were utilized on eight stream restoration projects. The least common grade control type encountered were log drops, having only two individual installations located on a single project. The majority of grade control practice types were found to be beneficial and appropriate for use in urban streams. Two practices, rock weirs and log drops stand out as having less utility than the others. The basis for this finding is detailed in the following sections.

About 80% of the grade control practice installations were found to be largely intact (Figure 4.9), with four of the six grade control practice types having greater than 90% of the individual installations intact. Only one grade control practice, rock weirs, was found to be consistently ineffective. Only 63% of rock weirs evaluated were rated as intact.

Nearly 80% of the grade control practices fully or partially met their design objective. Two grade control practices consistently failed to meet the design objective of grade control (Figure 4.10). Rock weirs and rock vortex weirs failed to achieve the design objective of grade control 38% and 13% of the time, respectively.

The degree to which the grade control practices experienced unintended erosion/scour and deposition/sedimentation was roughly similar, with moderate to significant erosion/scour or moderate or significant deposition/sedimentation noted at about 30% of the installations. Rock weirs and log drops consistently had the highest occurrence of erosion/scour and sedimentation/deposition (Figures 4.11 and 4.12). Almost 90% of rock weirs experienced moderate unintended deposition/sedimentation upstream of the practice and about 50% experienced moderate to significant erosion/scour along the streambanks at the practice. While the sample size was very small, it was evident that log drops experienced both unintended deposition/sedimentation upstream of the practice, as well as, unintended erosion/scour along the streambanks at the practice. By way of comparison, V-log drops, a variation on the log drop, did not experience any unintended deposition upstream of the practices and seldom experienced

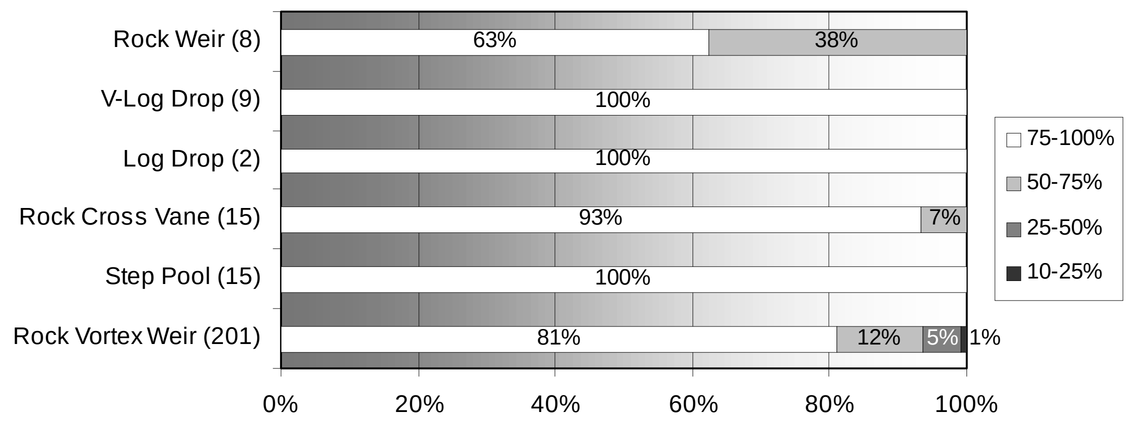

Figure 4.9: Grade Control - Percent of Materials Remaining Intact

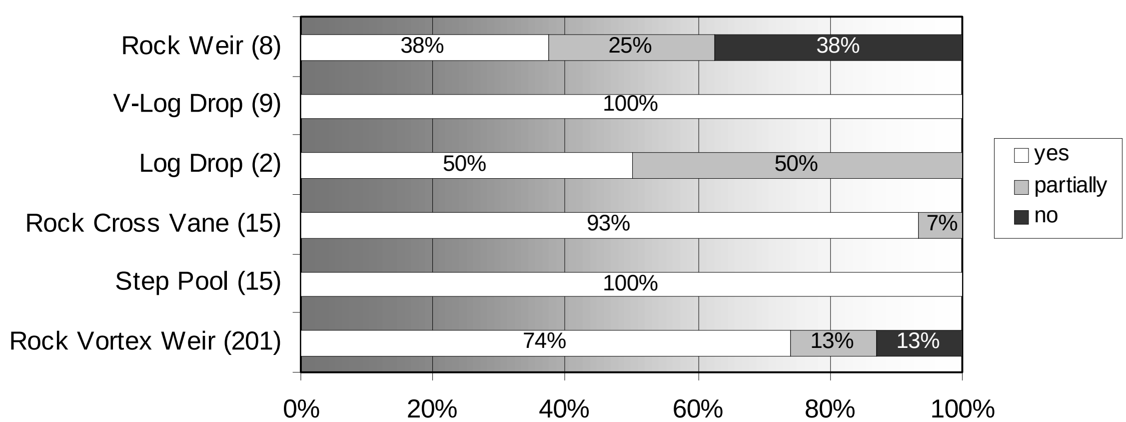

Figure 4.10: Grade Control - Is the Practice Serving the Design Objective?

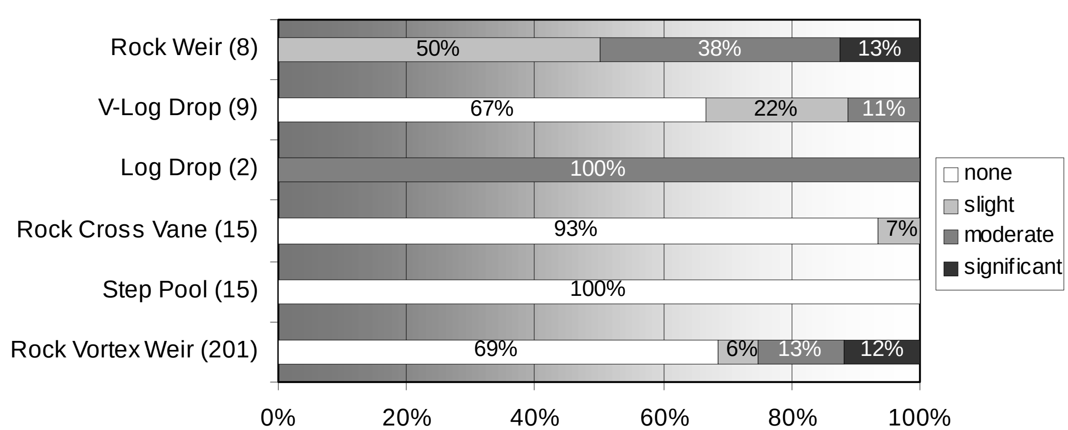

Figure 4.11: Grade Control - Degree of Unintended Erosion/Scour

unintended erosion/scour along the streambanks at the practices (11%).

Grade control practices exhibited mixed ability to enhance stream habitat. Traditionally, rock weirs, V-log drops, and log drops are installed to improve instream habitat. Rock vortex weirs have somewhat less habitat enhancement potential, and the step pool and rock cross vanes have little or no enhancement potential. Rock weirs and the rock vortex weirs were the only two grade control practices that had any individual practices fail to improve habitat functions (13% and 24% of the installations, respectively) (Figure 4.13). The majority of the time, these two grade control practices achieved only partial habitat enhancement. And indeed, habitat enhancement was only partially achieved at the log drops evaluated. By way of comparison, V-log drops achieved their habitat enhancement potential at each of the installations examined.

The following sections detail the results of the assessment for each grade control practice type in terms of intended benefits and specific applications.

4.2.1 Rock Vortex Weirs

Rock vortex weirs were the most-encountered stream restoration practice in the entire study. A total of 201 RVWs were installed in eight stream restoration projects. Grade control was the primary objective of RVWs, along with the secondary objective of flow deflection/concentration

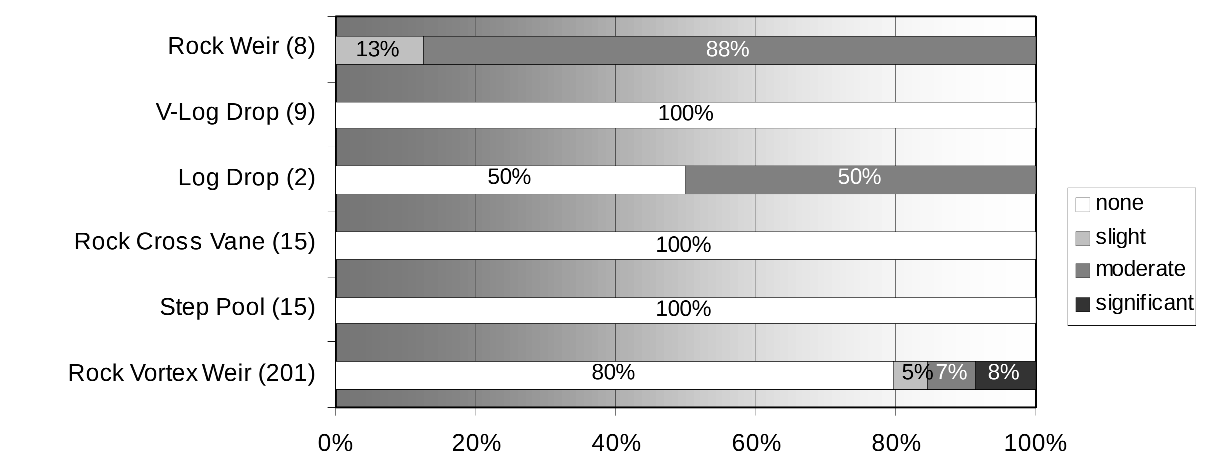

Figure 4.12: Grade Control - Degree of Unintended Sedimentation/Deposition

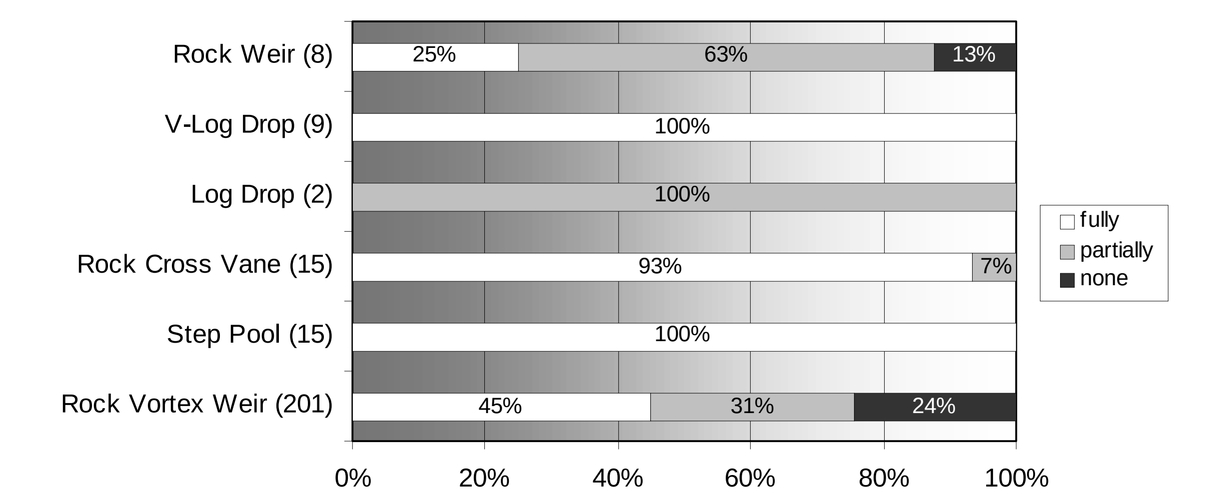

Figure 4.13: Grade Control - Degree of Habitat Enhancement

in some cases. Of the 201 RVWs assessed, 163 were found to be structurally intact (Figure 4.9). About 80% of all RVWs exhibited no or only slight movement/dislocation of their component rocks. RVWs were found to fully meet the design objective of grade control at 74% of the installations (Figure 4.10).

The most common problem encountered with RVWs was erosion/scour. Frequently, the streambanks were scoured around the sides of the weir structures, an occurrence referred to as "outflanking." Outflanking occurred to some degree at approximately 25% of the RVWs assessed (Figure 4.11). Upstream sediment deposition was observed at 15% of the structures (Figure 4.12).

RVWs can potentially enhance habitat by creating downstream scour pools, enhancing riffle habitat, and/or by creating a variety of flow velocities as water passes over them. Based on the results of this study, however, RVWs do not provide a significant habitat enhancement function. Habitat enhancement was created chiefly in the form of scour pool creation below the weir, but was only achieved at 45% of the RVW practices (Figure 4.13).

Several factors may explain the greater than expected erosion/scouring, movement/dislocation, sedimentation/deposition and lower habitat enhancement of the RVWs. The major factor involves the design and construction of the RVWs. Field observations suggest that a large number of RVWs were constructed with weir rocks that extended up too high into the channel cross section (Photo 4.12), reducing the channel cross sectional area, which in turn caused scouring around the structures, deposition of sediment upstream, and displacement of individual weir rocks. Additional observations relate some RVW failures to overall project design and the relation of RVWs to other practices immediately up and downstream. In some instances, improper channel geometry led to RVW failure or the failure of other practices. Photo 4.13 depicts a properly designed RVW.

4.2.2 Rock Cross Vanes

Only two stream restoration projects installed rock cross vanes (RCVs), with a total of 15 RCV installations. Overall, RCVs were found to be an effective grade control

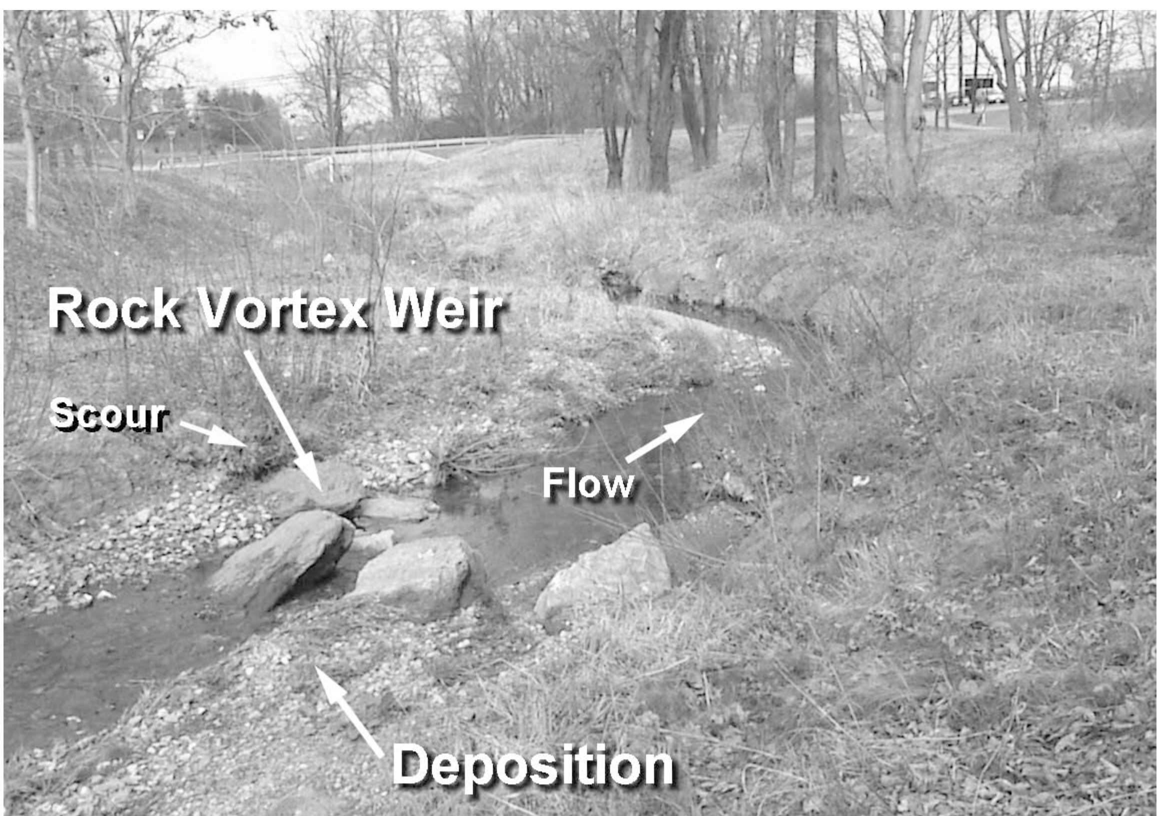

Photo 4.12: Rock vortex weir experiencing both upstream sediment deposition and scouring around the structure.

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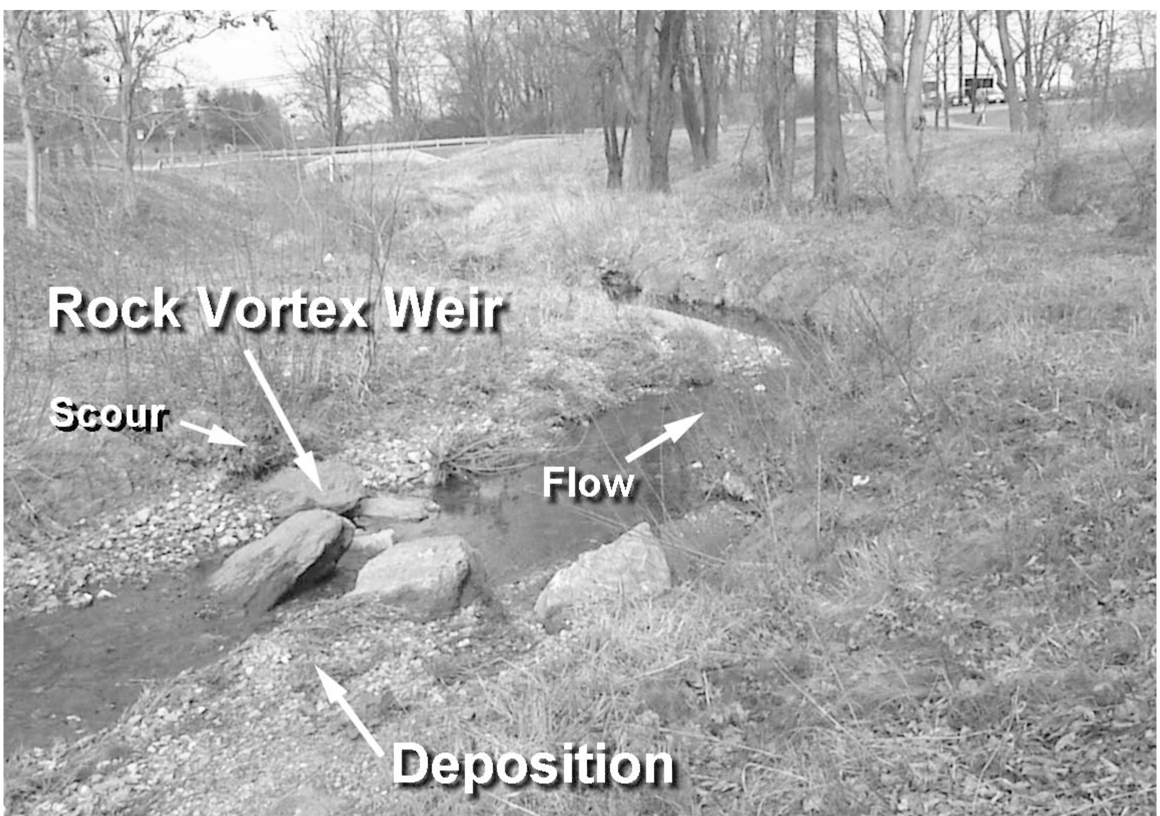

Photo 4.12: Rock vortex weir experiencing both upstream sediment deposition and scouring around the structure.

Photo 4.13: Properly designed and installed rock vortex weir.

practice. No RCVs failed to meet the design objective, and only one was deemed to have only partially met the design objective (Figure 4.10). This single RCV had one side scoured out due its close proximity to a rootwad revetment just upstream. Photos 4.14 and 4.15 depict typical, well-designed RCV installations.

Rock cross vanes have only minimal habitat enhancement potential. Their primary purpose is to prevent future channel degradation that can lead to habitat impacts (Figure 4.13).

4.2.3 Rock Weirs

Only one project utilized rock weirs as a stream restoration practice. Rock weirs should not be confused with rock vortex weirs. Rock vortex weirs are structures designed to prevent the creation of backwater conditions and to allow normal bedload sediment transport processes to occur. Rock weirs are basically check dams that raise the invert of the stream in an attempt to enhance pool/riffle habitat. In the process, they create backwater conditions and alter bedload sediment transport processes. Rock weirs are essentially grade control structures utilized to enhance habitat.

Of the eight rock weirs, only five were found to be largely intact. The most common problems observed with rock weirs were unintended erosion/scour and sedimentation/deposition (Figures 4.11 and 4.12). As a result of these problems, only three of the eight rock weirs were considered to fully meet the design objective of grade control (Figure 4.10).

Rock weirs attempt to enhance habitat by recreating the natural pool/riffle sequence found in undisturbed streams. Only 25% of rock weirs evaluated in this study accomplished this basic habitat objective (Figure 4.13). The single project that used rock weirs created a series of slow run/pools between the rock weirs. The rock weirs resulted in significant silt deposition in the pools upstream of the weirs and scouring of the streambanks around the weirs (Photo 4.16). Riffle habitat only formed on the downstream side of 25% of the weirs. The two weirs that created riffle habitat were much lower in profile and appeared more as cobble/gravel accumulations than weirs (Photo 4.17). In addition, the placement of the weirs created backwater conditions, which caused sedimentation within the upstream lunkers.

4.2.4 Step Pools

A total of 15 step pools were installed on four projects. Step pools are typically constructed of large stone and are heavily armored to withstand very large flows without failing. Step pools were typically installed in two stream conditions. In the first condition, a high gradient urban stream channel subject to degradation (incision) from uncontrolled urban stormwater flows was protected by step pools. A series of step pools allowed the incision to be remedied and storm flows to be conveyed while preventing future channel incision. The second condition was when a sudden drop occurred in the stream invert, such as downstream of a road culvert or a stormwater outfall. The step pools were installed to allow the water to flow down a series of steps, dissipating energy and reestablishing fish passage.

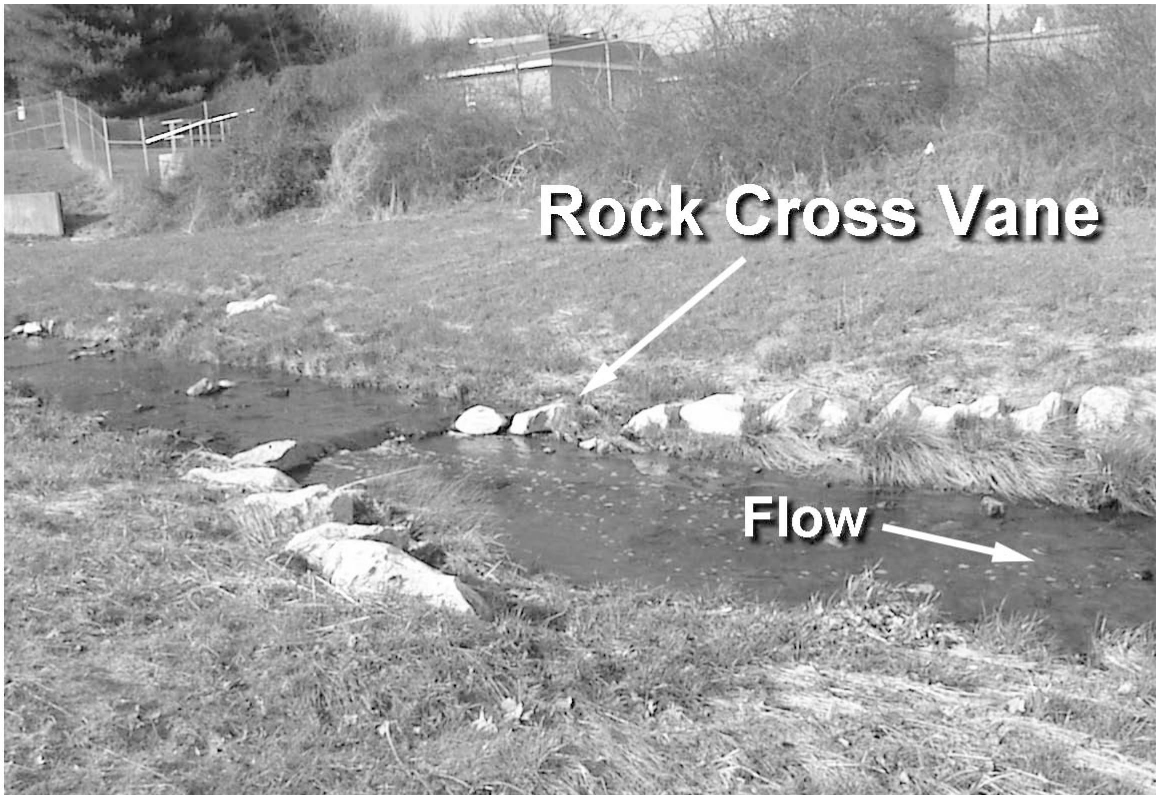

Photo 4.14: Effective, low profile rock cross vane installed on a small stream.

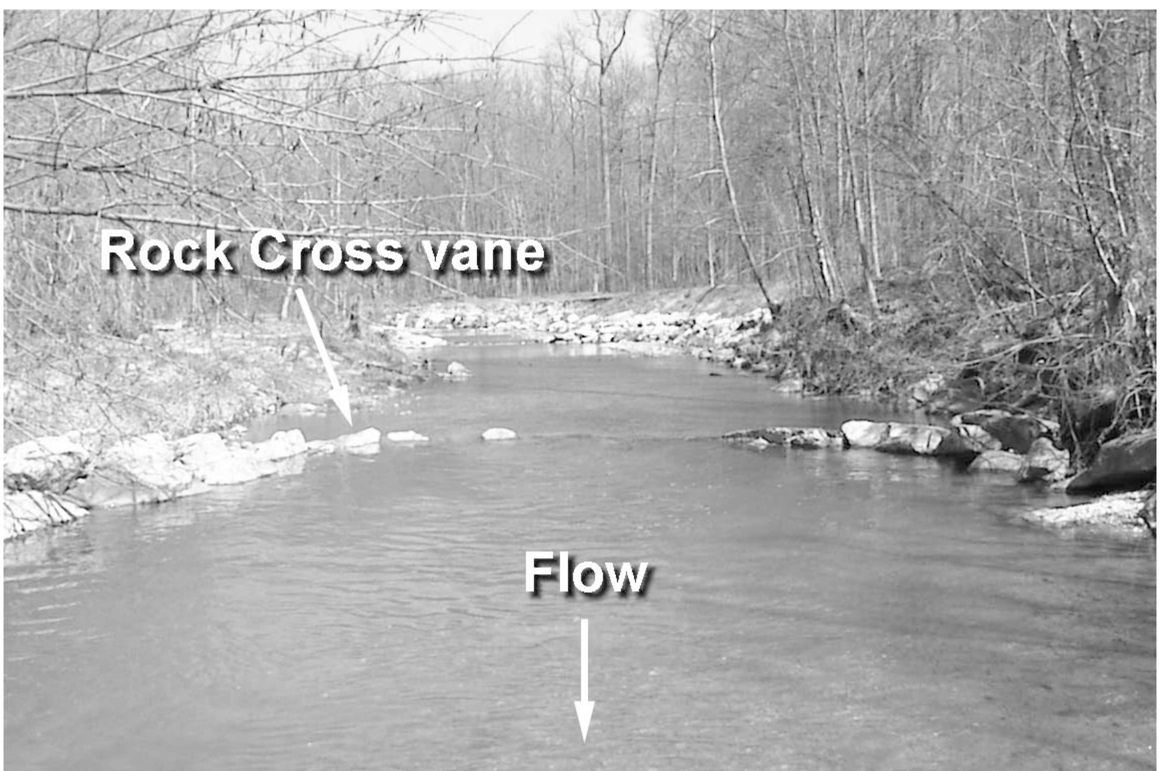

Photo 4.15: Well designed and constructed rock cross vane on large stream.

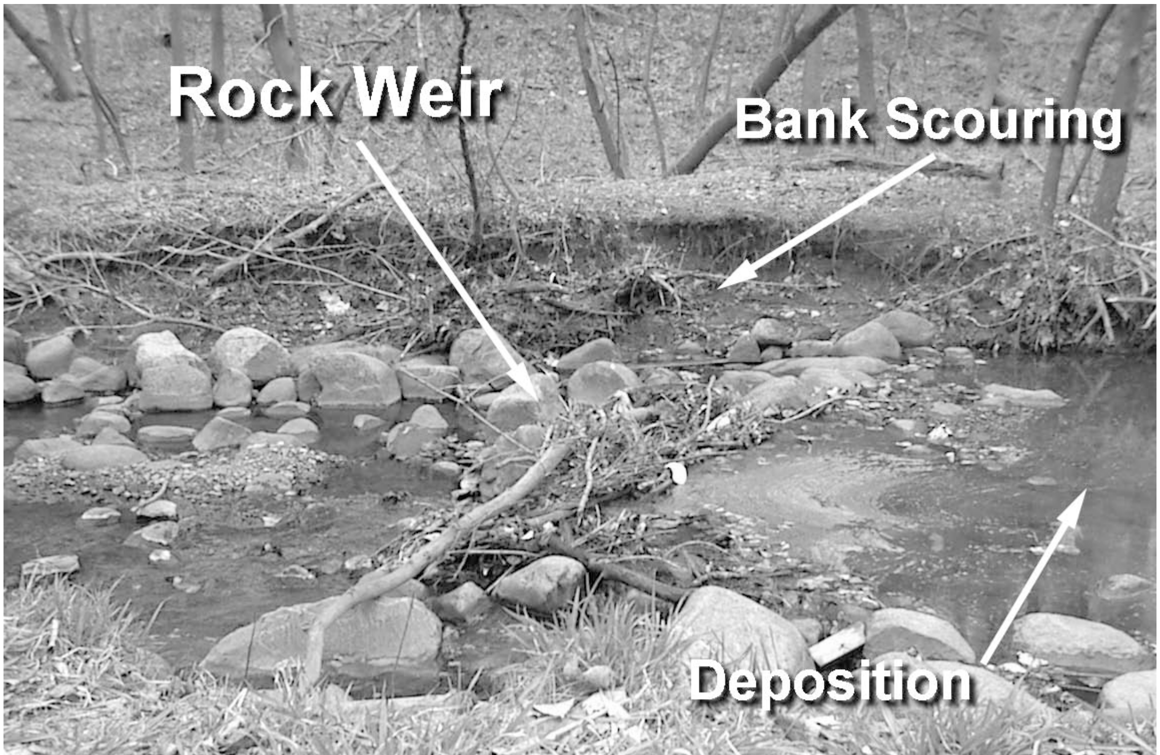

Photo 4.16: Rock weir installation that resulted in upstream deposition and streambank scouring. Note accumulation of debris on top of weir.

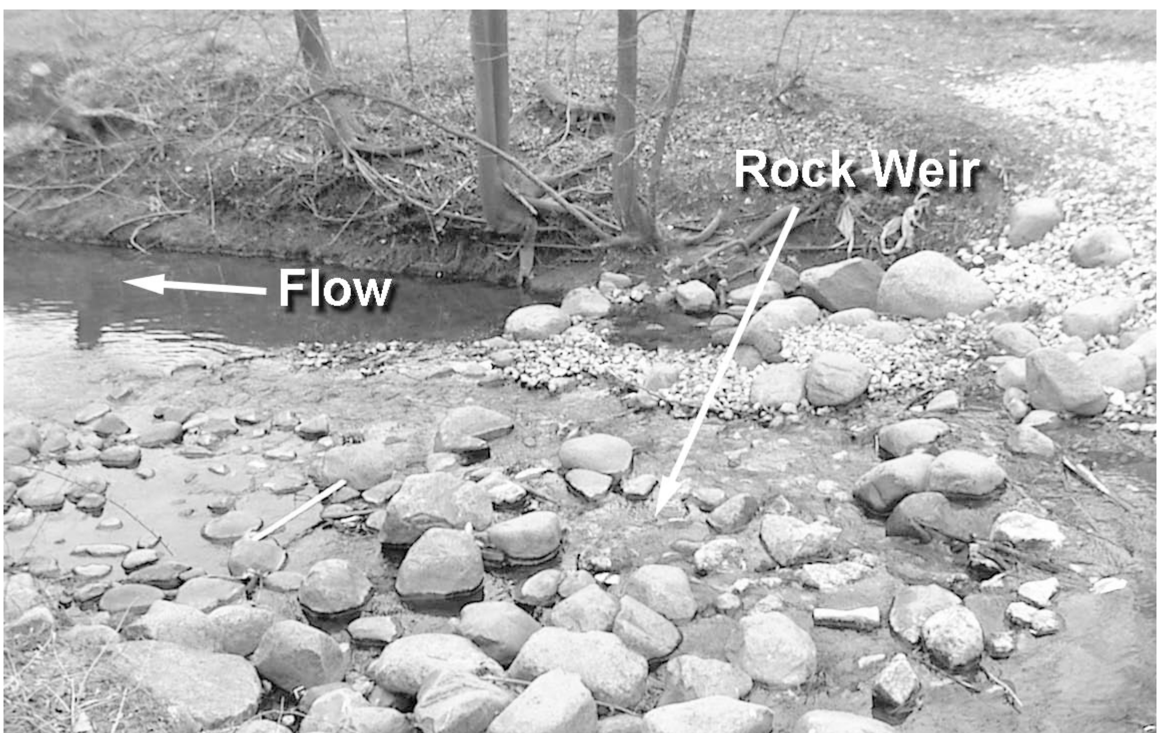

Photo 4.17: Low profile rock weir experiencing only minor upstream sediment deposition and bank scouring.

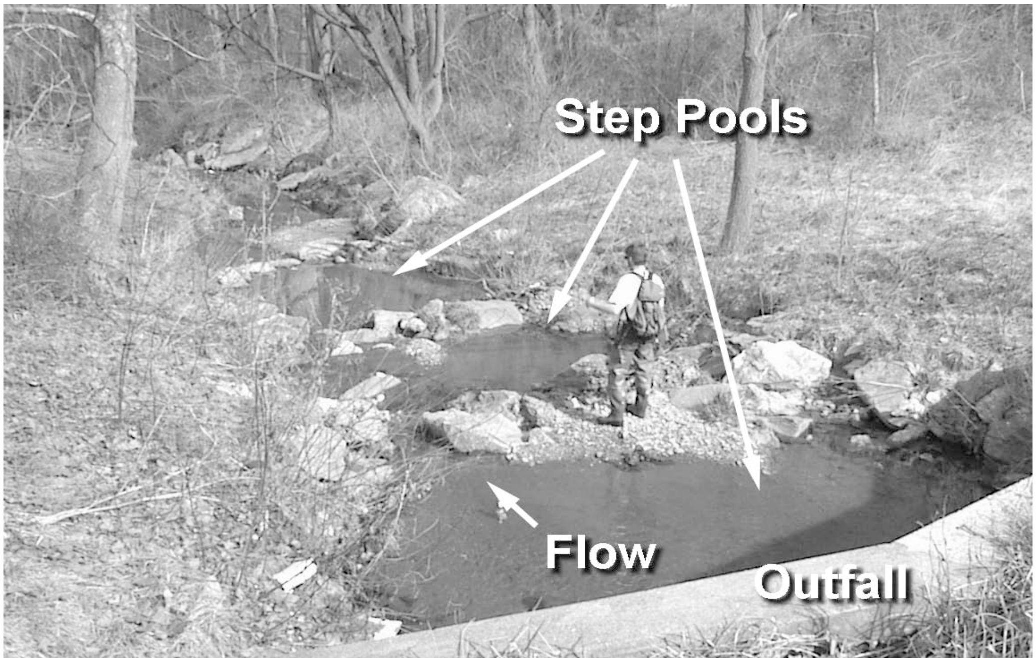

Photo 4.18: Typical, well designed step pool below elevated road culvert.

Essentially all 15 step pools were intact and performing as intended (Figures 4.10 and 4.11). No deficiencies were noted at any of the structures. Each of the step pool installations fully achieved the rather limited habitat enhancement potential of reestablishing/maintaining fish passage. Photos 4.18 and 4.19 depict typical step pool designs.

4.2.5 Log Drops and V-Log Drops

Log drop structures consisting of sections of tree trunks installed across the channel perpendicular to the flow were installed at two locations on one project (Photo 4.20). While these structures were very effective at creating scour pools below them, they tended to result in streambank scouring and upstream sediment deposition.

When constructed, the logs extend up into the channel cross section and reduce the cross sectional area, which can promote channel widening to make up for the lost channel capacity. Bank scouring was evident at both log drop installations (Figure 4.11). The reduction in stream gradient upstream of the structure resulted in significant sediment deposition at one installation (Figure 4.12).

In terms of habitat enhancement, log drops have a high potential to create downstream scour pools. Both structures created large scour pools downstream. On the other hand, the height of the drop at one of the log drops was approximately one foot, which may create a blockage to fish passage. The log drops were considered to have only partially achieved the potential habitat enhancement due to the negative effects of bank scouring, upstream sediment deposition, and potential fish passage issues. It should be noted that only two log drop structures were assessed and these structures were located on a stream with a highly impervious watershed. These results are considered preliminary.

The V-log drop was developed to lessen the chance of stream bank scouring and the potential for creating fish barriers. Rather than a single log spanning the stream perpendicular to the flow, two logs are used that meet at a 90-degree angle. The V formed by the logs points upstream, with the apex set at or below the invert of the stream and the arms of the V rising downstream into the streambanks. Nine V-log drops were used on only one project, but achieved significantly better results than those of the traditional log drop. Little or no streambank scouring or upstream sediment deposition was observed and adequate (one to 1.5 foot deep) downstream scour pools were created (Figure 4.12). As the apex of the V rests at or below the stream invert, the creation of a fish barrier was not an issue. The advantage of the V-log drop is that high flows are directed toward the center of the stream rather than toward the streambanks as with the traditional log drop design. This greatly reduces the potential for stream bank scouring. All of the V-log drops were found to have achieved the habitat enhancement potential of the practice (Figure 4.13).

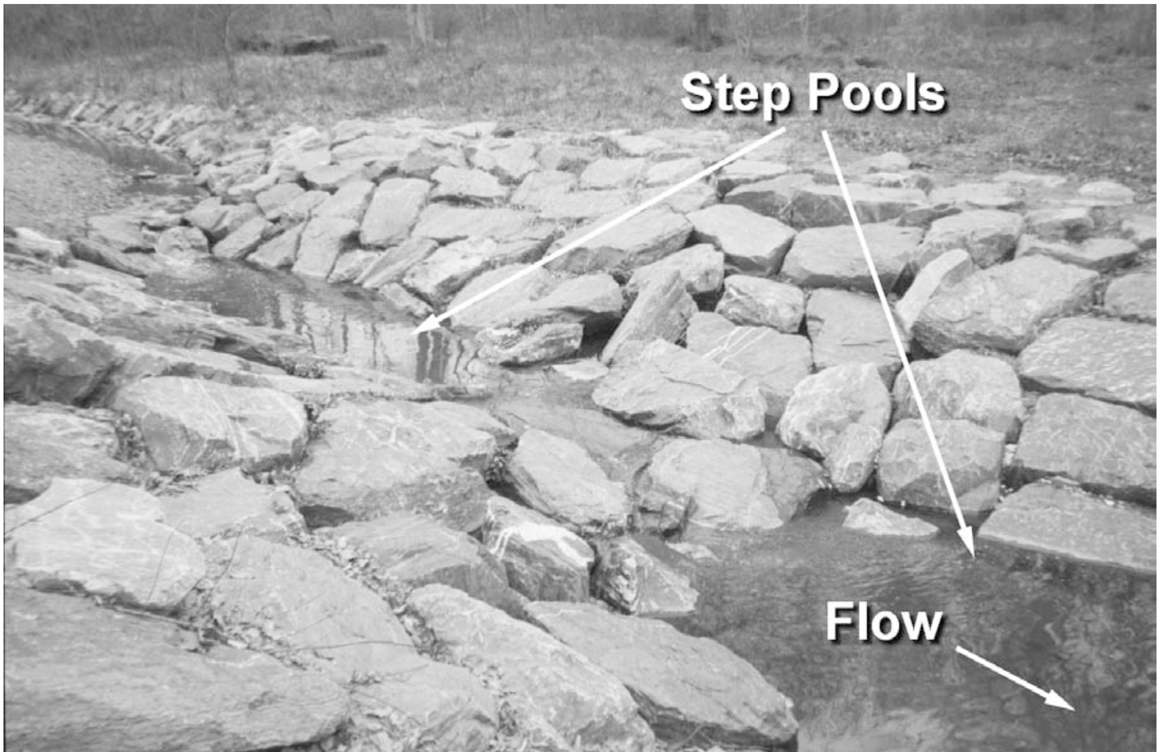

Photo 4.19: Large step pool installed to arrest active channel degradation.

Photo 4.20: Log drop structure.

4.3 Flow Deflection/Concentration Practices

The purpose of flow deflection/concentration practices is to change the direction of stream flow or to concentrate stream flow. These structures are predominately used to deflect flow away from eroding stream banks, concentrate the flow in the center of the channel, redirect water in and out of meanders, and/or enhance pool and riffle habitats. Interestingly, only 20% of the 20 stream restoration projects included in the study sought to incorporate this design objective. Six flow deflection/concentration practices were assessed in the field, for a total of 47 individual installations. Rock vanes were the most common flow deflection/concentration practice utilized (40%), followed by log vanes (32%).

Overall, the vast majority of individual flow deflection/concentration practices retained their structural integrity (Figure 4.14). Notably, only one practice, a rock vane, was rated as less than 75% intact. With the exception of one practice type, double wing deflectors, all of the practices fully or partially achieved the design objective of flow deflection/concentration (Figure 4.15). Only two of the double wing deflectors fully achieved their design objective.

In general, flow deflection/concentration practices exhibited less unintended erosion/scour and deposition/sedimentation than other practice groups. Scour or deposition was noted at 10% or less of most practices. Double wing deflectors experienced the greatest scour/erosion (33%) and deposition (67%) of any practice in the this group (Figures 4.16 and 4.17). Log vanes also experienced these same conditions, but to a lesser degree. No other practice types were observed to experience any degree of sedimentation/deposition.

Only two practice types, log vanes and double wing deflectors, had any individual installations where the habitat enhancement potential was not achieved (Figure 4.18).

The following sections detail the results of the assessment for each grade control practice type in terms of intended benefits and specific applications.

4.3.1 Wing Deflectors - Single and Double

Wing deflectors were originally developed as fish habitat improvement structures for trout streams. Double wing deflectors are designed to narrow and deepen the baseflow channel and create pool habitat downstream of the structure. The single wing deflector is designed to narrow and deepen the baseflow channel and deflect water toward the opposite bank either to add sinuosity to the channel or direct water toward overhanging bank cover.

Six double and one single wing deflector were installed on two stream restoration projects evaluated in the study. All seven of the deflectors were found to be 75 to 100% intact (Figure 4.14), with one double wing deflector experiencing some slight dislocation of practice materials.

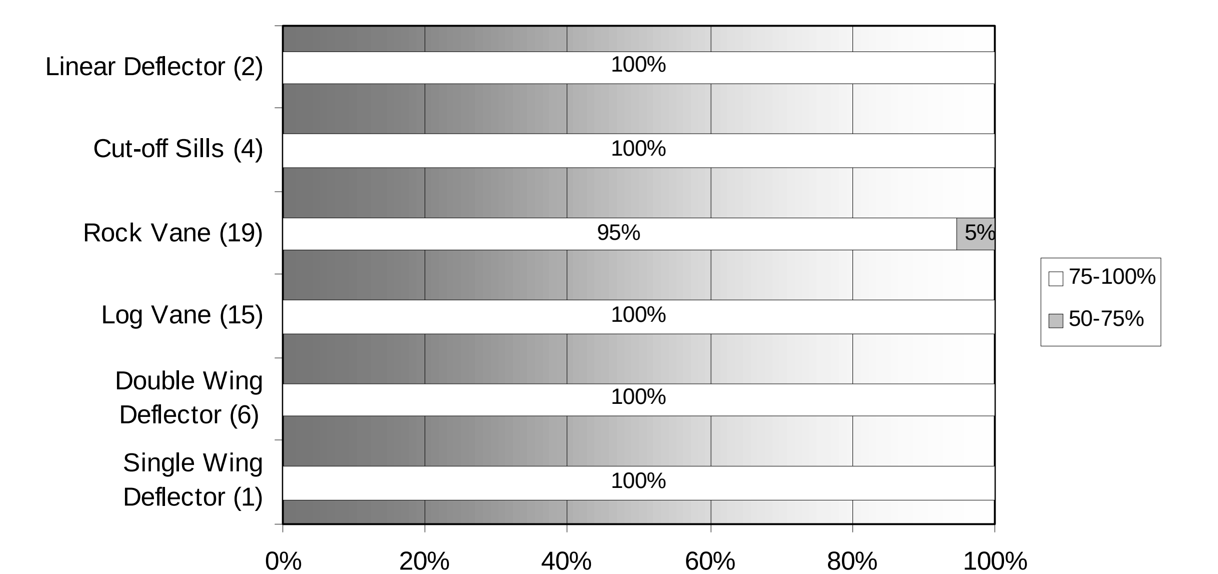

Figure 4.14: Flow Deflection/Concentration - Percent of Practice Remaining Intact

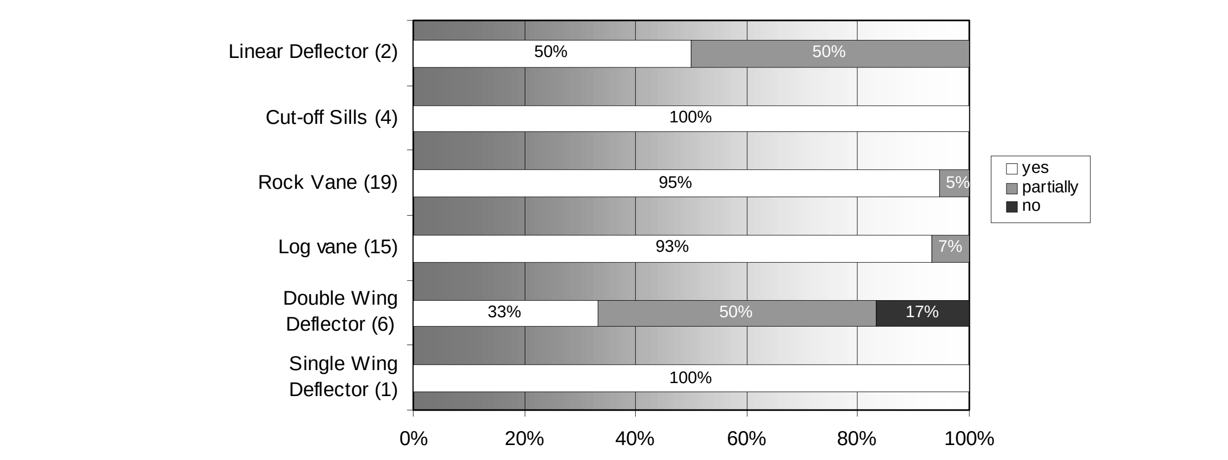

Figure 4.15: Flow Deflection/Concentration - Is the Practice Serving the Design Purpose?

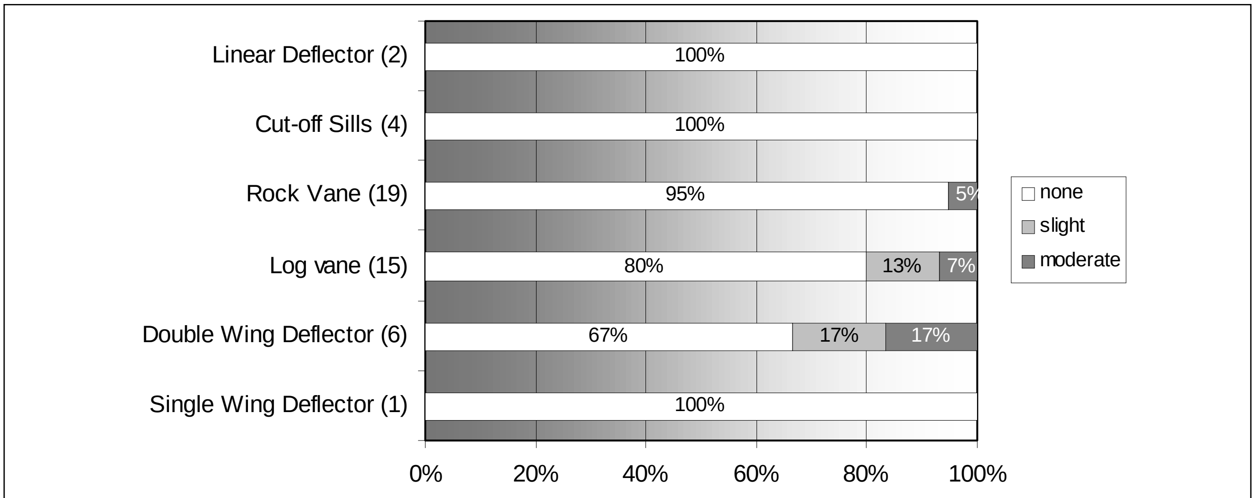

Figure 4.16: Flow Deflection/Concentration - Degree of Erosion Scour

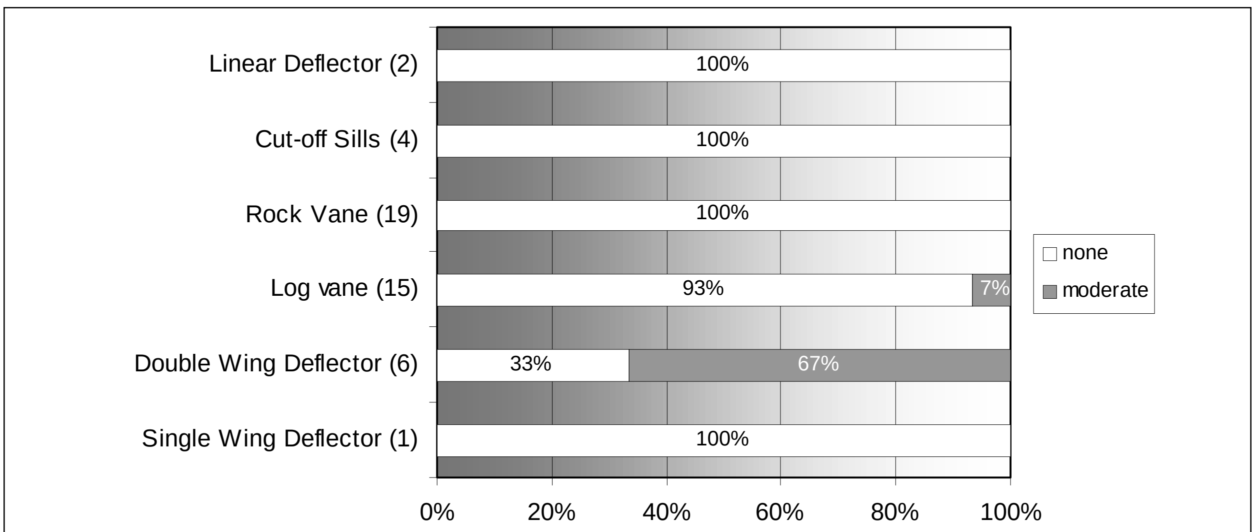

Figure 4.17: Flow Deflection/Concentration - Degree of Deposition/Sedimentation

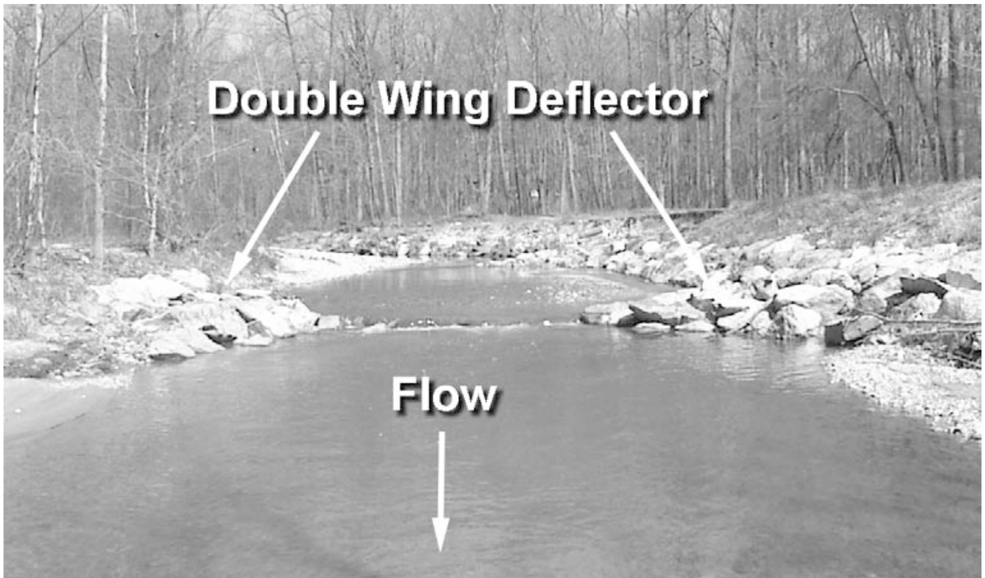

Photo 4.21: Double wing deflector installed on large stream. The connecting sill can be seen at the water surface between the two wings.

There were mixed results in terms of whether the practices achieved the design objective of flow deflection/concentration. Only two of the double wing deflectors fully met the design objective, and three partially did so (Figure 4.15). The only single wing deflector included in the assessment was found to fully meet the design objective of flow deflection/concentration. Photos 4.21 and 4.22 depict two of the double wing deflectors included in the assessment.

The only single wing deflector assessed narrowed and deepened the baseflow channel without causing erosion of the opposite bank. The double wing deflectors tended to result in greater scour along the streambank than the single wing deflector, but only one double wing deflector was found to have exhibited moderate erosion/scour. In contrast, four of the six double wing deflectors caused upstream sediment deposition. The single wing deflec-

Photo 4.22: Low profile double wing deflector installed on small stream. Note deposition just downstream.

tor did not result in any upstream deposition/sedimentation (Figure 4.16 and 4.17).

Only two of the six double wing deflectors assessed were considered to achieve their full habitat enhancement potential, with three partially achieving this potential. The lone single wing deflector assessed fully met the habitat enhancement potential of the practice (Figure 4.18).

4.3.2 Log Vanes

Only one stream restoration project included in the study used log vanes. This one project installed 15 log vanes with apparent success. The log vanes were generally installed at the downstream end of rootwad revetments with the primary purpose of deflecting the stream flow toward the opposite bank and into the next meander bend. All 15 log vanes were found to be 75 to 100% intact (Figure 4.14) and none experienced any significant movement or dislocation. Unintended erosion/scour was noted at only one log vane (Figure 4.16), and only occurred where the log vane entered the streambank. Unintended sediment deposition was associated with one log vane, but this appeared to be due to the influence of another practice immediately downstream (Figure 4.17). All but one of the 15 log vanes met the practice objective of flow deflection/concentration (Figure 4.15). The one log vane that only partially met the practice objective caused moderate streambank scouring (eddy scouring) on the upstream side where it entered the streambank.

Nearly all of the log vanes fully achieved the habitat enhancement potential (Figure 4.18) by creating downstream scour pools. One log vane did not form a downstream scour pool because of its close proximity to a failed root wad revetment immediately upstream.

4.3.3 Rock Vanes - Straight Vanes and J-vanes

Nineteen rock vanes were installed within two stream restoration projects evaluated in the study. Rock vanes are typically installed along the streambanks of relatively straight reaches experiencing bank erosion. As with log vanes, rock vanes were found to be very effective practices. Two types of rock vanes were installed: straight vanes and J-vanes. Both types of vanes extend out from the bank in an upstream direction. The J-vane differs only in that the end of the vane curls around in a downstream direction to enhance downstream scour pool formation (see Appendix B for a detailed description of rock vane types). About 25% of the vanes assessed were J-vanes.

Overall, 95% of the rock vanes were intact, with the lone exception rated as 50 to 75% intact (Figure 4.14). Rock vanes were very successful at creating downstream scour pools and deflecting high flows away from erodible streambanks. Photos 4.23 and 4.24 depict typical, well-constructed rock vanes. An added benefit of the rock vane is that it encourages sediment deposition along the toe of the streambank. This deposition reinforces the toe, preventing toe failure and subsequent failure of the upper bank. Photo 4.25 illustrates this benefit.

Rock vanes did not exhibit a tendency to promote unintended erosion/scour (i.e., similar to log vanes), with unintended erosion/scour noted at only one rock vane installation (Figure 4.16). Similarly, unintended deposition/sedimentation was not observed at any rock vanes evaluated (Figure 4.17).

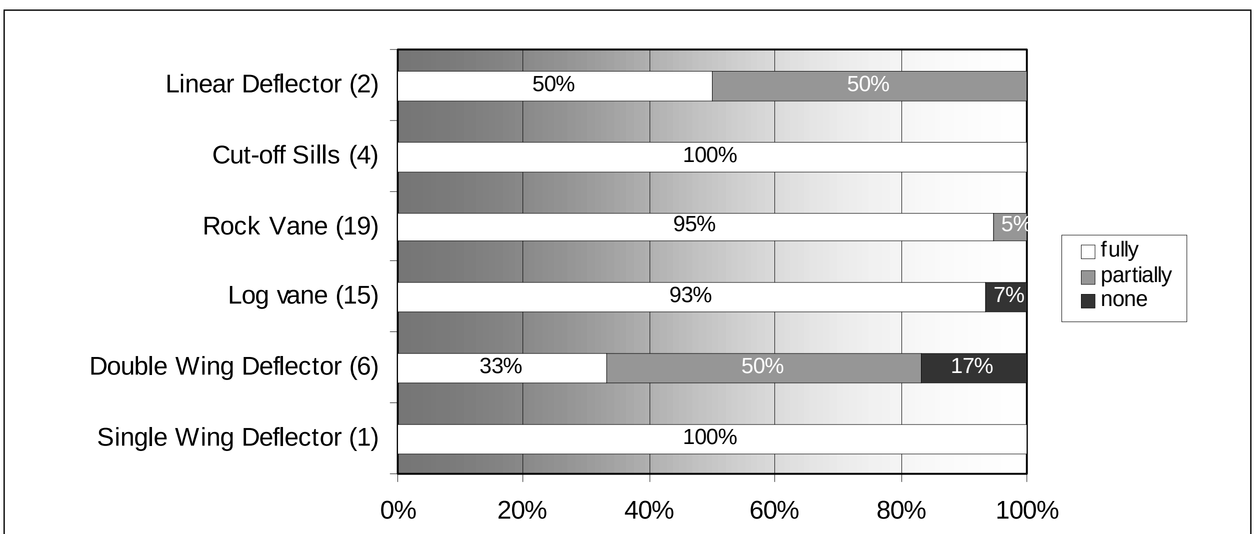

Figure 4.18: Flow Deflection/Concentration - Degree of Habitat Enhancement

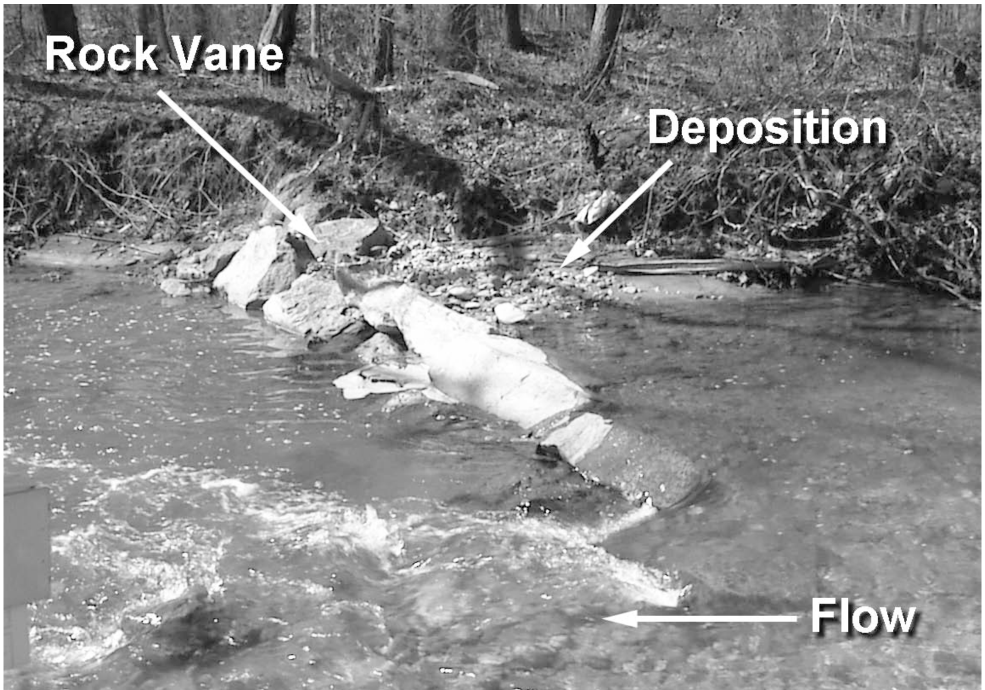

Photo 4.23: Well designed and constructed rock vane. Deposition along the streambank toe is evident. Riffle habitat has been enhanced in lower left of photo.

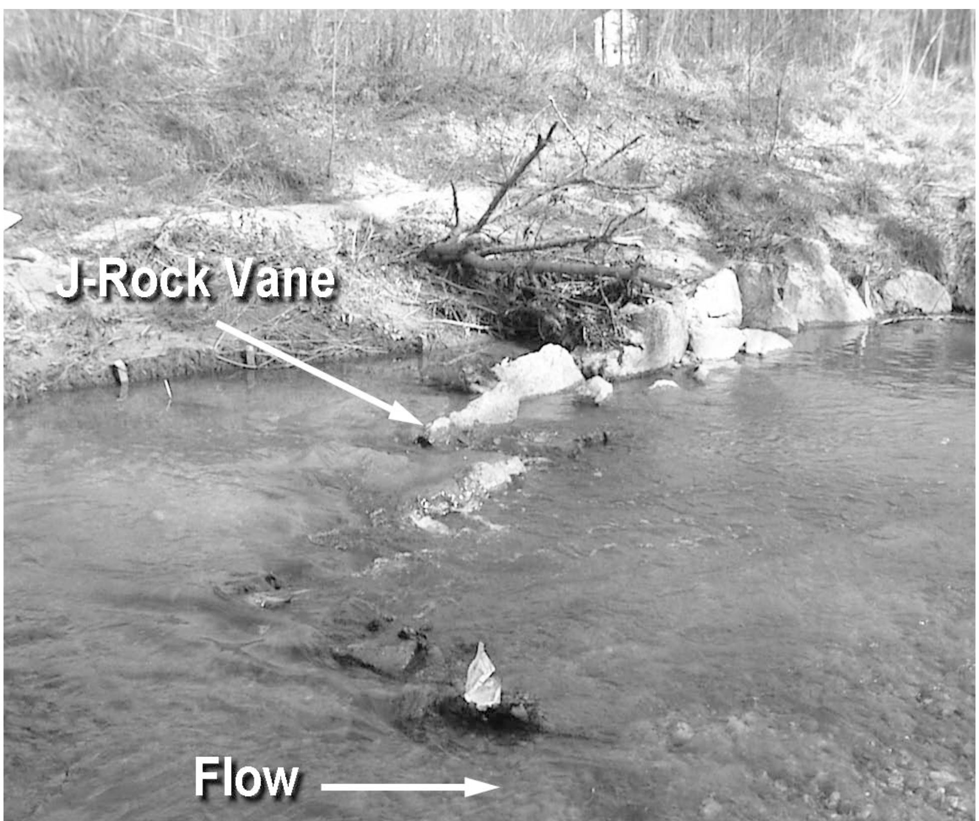

Photo 4.24: Typical J-rock vane.

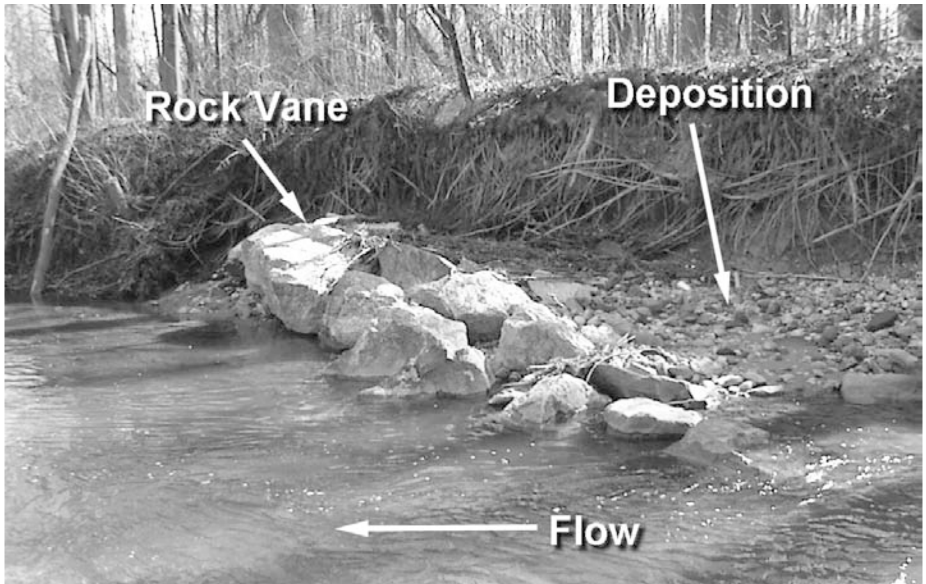

Photo 4.25: Rock vane installed on large stream. Sediment deposition is evident upstream along toe of streambank.

Rock vanes achieved their habitat enhancement potential at nearly all the installations assessed (95%). Habitat was enhanced by scour pool formation downstream of the structure, as well as by riffle habitat creation along the structure. Both types of vanes (straight and J) created good downstream scour pools. There was some added downstream scour pool formation with the J-vane, but this difference did not appear significant.

4.3.4 Cut-Off Sills

Cut-off sills are generally utilized in larger, gravel bed streams that have undergone significant channel widening and thus experience shallow baseflow. Cut-off sills narrow and better define the baseflow channel by encouraging sediment deposition along lateral bars and/or meander point bars. The sills extend out from the streambank in an upstream direction (see Appendix B for design details).

Cut-off sills were not a frequently used practice in this study, with only four cut-off sills installed on a single project. Despite this limited sample size, no negative aspects were associated with cut-off sills. All were found to be intact, to have fully met their design objective, and to have experienced no unintended erosion/scour. Photos 4.26 and 4.27 depict cut-off sills installed in lateral bars.

4.3.5 Linear Deflectors

Linear deflectors are similar to boulder revetments, but differ in that linear deflectors are installed within the channel parallel to the flow rather than along the streambank. The goal of this practice is to narrow and better define an overly wide and shallow baseflow channel. Linear deflectors were installed twice within a single stream restoration project. Both of the linear deflectors were intact, with no dislocation, erosion/scour or unintended deposition/sedimentation. One of the linear deflectors fully met the design objective of flow deflection/concentration, while the other only partially met this design objective (Figure 4.15). The linear deflector that partially met the design objective did not fully succeed in narrowing the baseflow channel due to the lack of sediment deposition behind the deflector.

Habitat improvement is in the form of a narrower and better defined baseflow channel in shallow, overly wide channels. This habitat enhancement potential was fully achieved at one of the two linear deflectors. The second linear deflector only partially achieved the habitat enhancement potential due to a lack of sediment deposition behind the deflector.

Photo 4.26: Cut-off sill installation that has caused sediment deposition along channel margin.

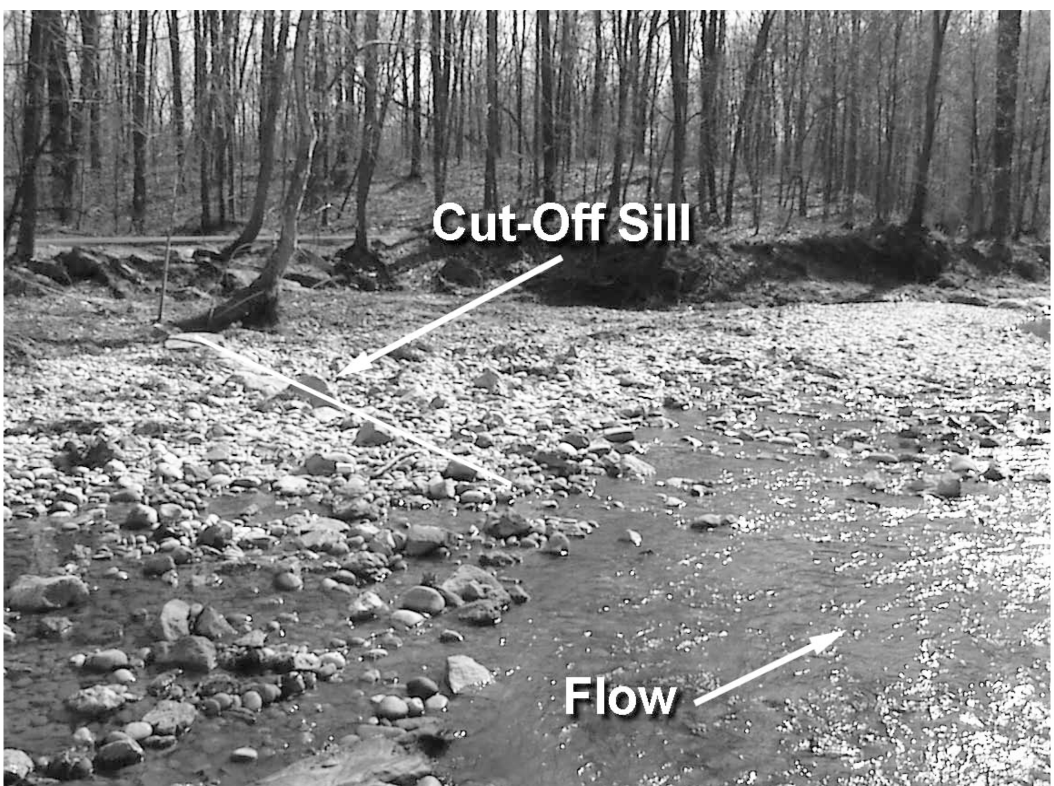

Photo 4.27: Cut-off sill within new lateral bar.

4.4 Bank Stabilization Practices

Bank stabilization practices, often referred to as bioengineering, are a nonstructural means of stabilizing streambanks from further accelerated erosion. Few of the urban stream restoration projects relied heavily on bank stabilization practices to restore and protect streambanks. Bank stabilization practices that rely on vegetation to protect streambanks are much more sensitive to the effects of urbanization than the more structural practices included in the study. While the effects of increasing imperviousness were less noticeable with structural practices, bank stabilization practices in highly impervious watersheds tended to be less successful. This is the primary reason bank stabilization (e.g., nonstructural) practices were less utilized or used in combination with bank protection practices. While these practices have been found to be very effective on rural and agricultural stream channels (i.e., low impervious cover), they are less able to withstand the elevated storm flows, high stream velocities, and rapid water level fluctuations that occur in urban streams.

Bank stabilization techniques are often used in combination with bank protection practices (see section 4.1) in urban streams. Bank stabilization practices generally involve regrading the streambanks to a stable angle and geometry and the utilization of vegetative plantings and biodegradable materials to stabilize the streambank and prevent or reduce future streambank erosion. These practices are most effective where there is sufficient area to regrade the streambank, there is sufficient sunlight to promote the growth of stabilizing vegetation, and the streambanks are not exposed to frequent, erosive stream conditions.

Bank stabilization practices were difficult to quantitatively assess for several reasons. First, it was difficult to establish the limits of bank stabilization and vegetative planting areas many years after completion. Second, the limits of many planting areas were not clearly specified on the plans, and finally, vegetative practices were often installed with no specific reference to the original plans. Consequently, many bank stabilization practices can only be qualitatively assessed, based upon the overall success of the practice at the project level. The most common form of bank stabilization encountered in the assessment was bank regrading stabilized with erosion control netting/matting and vegetation. The two bank stabilization techniques that were installed as discrete units (coir fiber logs and live fascines) could be assessed in the same manner as the other practice types in the study.

4.4.1 Coir Fiber Logs

Coir fiber logs are commercially-made erosion control products. They consist of tightly bound cylinders of coconut (coir) fiber held together by a coir fiber netting. They generally are available in 10 to 20 foot lengths and range from 10 to 20 inches in diameter. There were 16 applications of coir fiber logs in this study. Applications ranged from just a few individual coir fiber log sections, to applications where coir fiber logs were installed along several hundred feet of streambank.

Thirteen of the 16 coir fiber log installations were found to be greater than 75% intact (Figure 4.19). The remaining coir fiber logs had lost 25 to 75% of their integrity. An intact coir fiber log was indicated by the presence of either a coir fiber log or by the decomposition of a log that been replaced by plant materials serving the same function. Moderate or significant movement/dislocation or erosion/scour were all noted at three problem installations (Figure 4.20). Moderate sediment deposition was also observed at three installations, with the remaining 13 coir fiber log installations found to have experienced little or no sediment deposition. Only one of the 16 coir fiber log installations did not achieve the practice objective of bank stabilization, with six only partially achieving this objective (Figure 4.21). Photos 4.28 and 4.29 depict a typical coir fiber log installation.

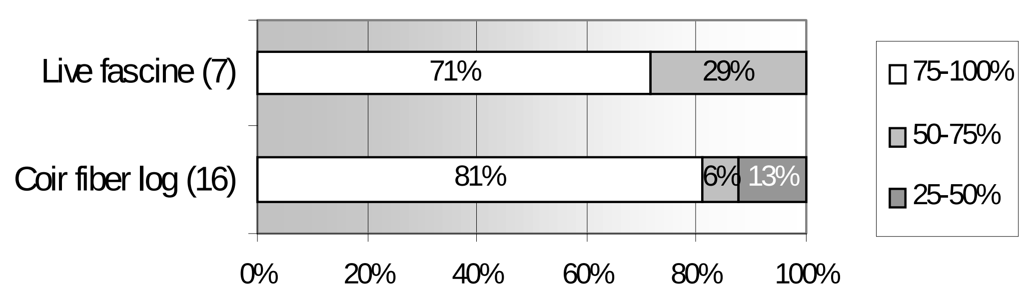

Figure 4.19: Bank Stabilization - Percent of Original Practice Intact

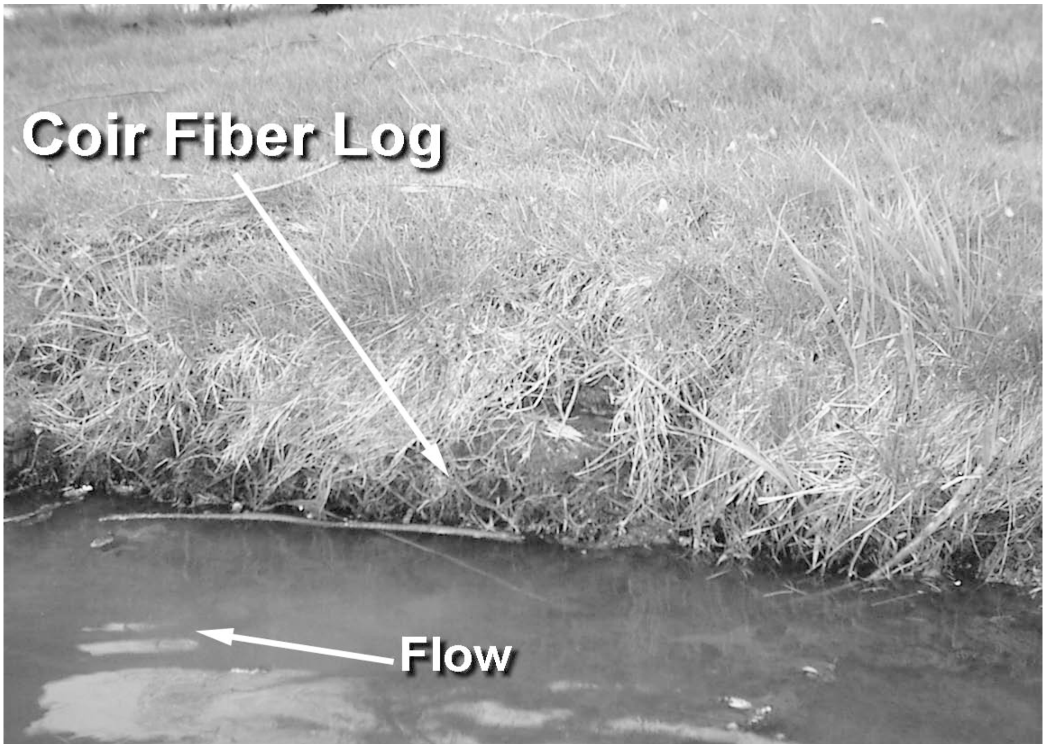

Photo 4.28: Well vegetated coir fiber log installation.

Photo 4.29: Coir fiber log installation with shrub plantings.

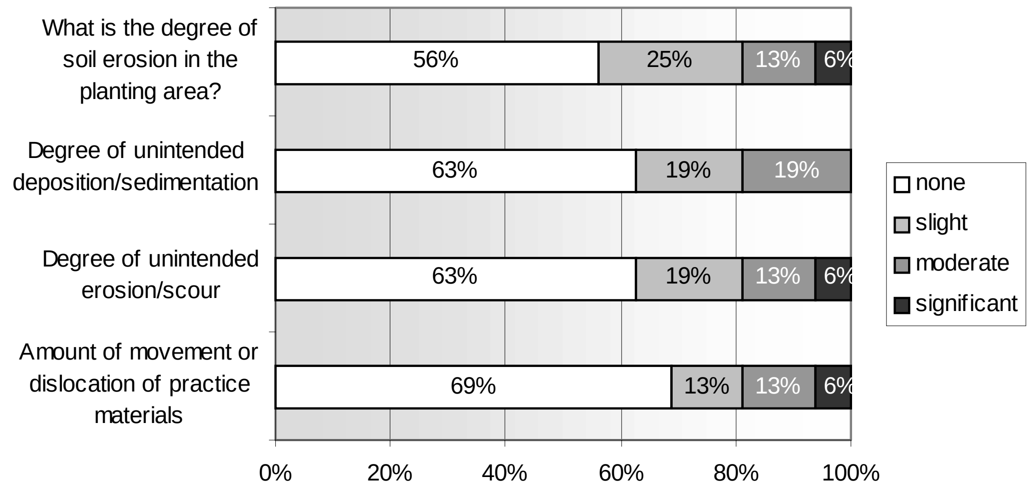

Figure 4.20: Bank Stabilization - Results of Coir Fiber Log Assessment

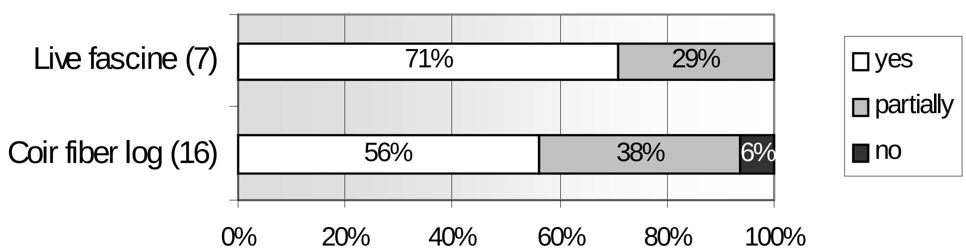

Figure 4.21: Bank Stabilization - Is the Practice Serving the Design Objective?

The habitat enhancement objective of a vegetated, stable streambank toe was fully or partially attained at only half of the coir fiber log installations (Figure 4.22). The remaining coir fiber log installations did not create a stable, vegetated streambank toe. This is indicated by only eight installations having 75 to 100% plant survival (Figure 4.23). Almost all of the coir fiber logs partially or fully stabilized the toe of the streambank, despite the relatively poor plant survival (Figure 4.24). However, it is not clear how long the streambank toe will remain stable once the poorly vegetated coir fiber logs decompose and leave the streambank unprotected and subject to erosion.

Two conditions primarily determine the success or failure of most coir fiber log installations. The first condition is adequate sunlight needed for the growth of plants, and the second is stream velocities that do not inhibit the establishment of vegetation on the logs. If these conditions are met, then coir fiber logs were usually an effective practice. If the riparian canopy shades out the streambank, or stormwater flows exert to great a force on the toe of the streambank practice failure is likely.

4.4.2 Live Fascines

Live fascines are bundles of dormant woody cuttings of willow (*Salix spp.*), alder (*Alnus spp.*), or dogwood (*Cornus spp.*) branches bound together with twine or wire. The bundles are typically six to 10 feet long and eight to 10 inches in diameter. Willow, alder and dogwood are used because when planted in moist soils, these species have the ability to root and grow from dormant cuttings (Photo 4.30). Live fascines have an inherent advantage in bank stabilization since they utilize both the structure of the woody material (e.g., the bundled branches) and the future growth of the cuttings. While live fascines are intended to take root and grow, they can still provide many years of structural stabilization to a streambank even if they fail to grow.

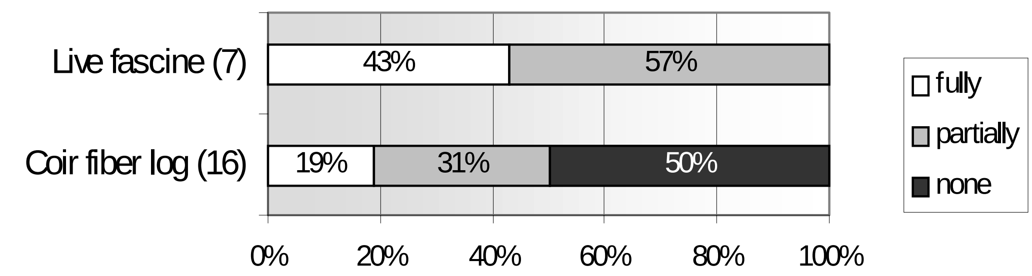

Figure 4.22: Bank Stabilization - Degree of Habitat Enhancement

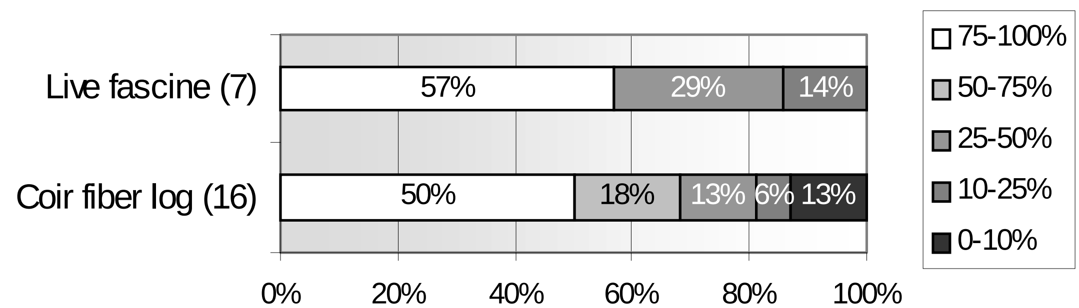

Figure 4.23: Bank Stabilization - What Percent of Plant Material Is Living?

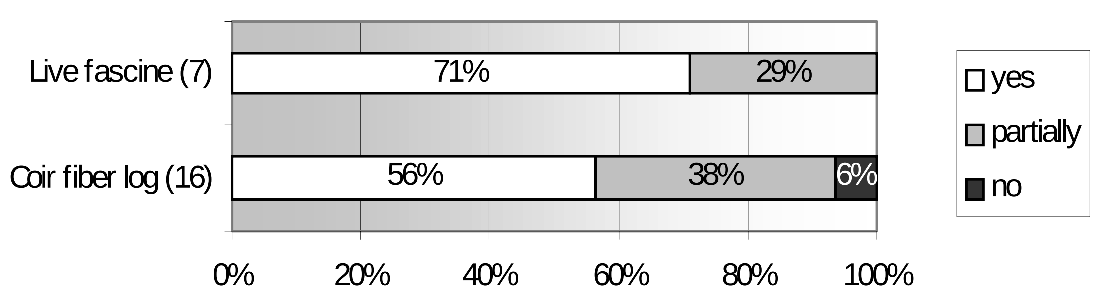

Figure 4.24: Bank Stabilization - Is the Practice Serving the Design Objective Regardless of Plant Survival?

The number of live fascines installed on each project was quite variable. One project used less than a dozen fascines to stabilize a small portion of a streambank toe, while another project installed hundreds of fascines along nearly the entire length of the project.

Seven live fascine installations were evaluated in the field. Although this is a rather small sample size, live fascines were generally found to be an effective practice for protecting the toe of streambanks, as well as for stabilizing soils higher up on the streambank. Over 70% of the live fascine installations were mostly intact (75 to 100%), with the remainder between 50% and 75% intact (Figure 4.19). No significant movement or displacement of the live fascines was noted (Figure 4.25). Two live fascine installations experienced slight or moderate erosion/scour. One live fascine application experienced slight sediment deposition. Overall, 70% of the live fascine installations fully achieved the design objective of bank stabilization, and the remainder partially achieved this objective (Figure 4.21).

The habitat enhancement potential of live fascines depends on the way they are installed. When fascines are used to stabilize the toe of a streambank, they have the same habitat enhancement potential as coir fiber logs (i.e., the formation of a stable, vegetated streambank toe) (Photo 4.31). In other installations, live fascines are installed further up the streambank to stabilize the entire slope. In these cases, fascines have less direct habitat enhancement potential. Fascines were observed to fully achieve their modest habitat potential at 43% of the installations, and to partially achieve it at 57% of the installations (Figure 4.22).

Both rooting success and plant survival were mixed. More than half of the fascine installations achieved 75 to 100% plant growth and survival (Figure 4.23), but three installations encountered problems. Plant survival did not play a large role in whether or not the fascines met the design objective, but it did influence how much habitat was created. In general, the fascines that fully achieved their habitat enhancement potential had at least 75% plant survival. Some fascine installations had less than 50% plant survival, but still achieved their bank stabilization objective because of colonization by other plants (Figure 4.24).

The species chosen to create live fascines appeared to play a role in the success of the practice. The native woody shrub, swamp dogwood (*Cornus amomum*) was used on several Mid-Atlantic region projects. Swamp dogwood, however, was found to have a rather low rate of successful sprouting and growth in the fascines (Photo 4.30). Most of fascines constructed with swamp dogwood had 10 to 50% plant survival. In the Midwest, sandbar willow (*Salix exigua*) was used for live fascines. Rooting/sprouting success of this shrub was somewhat better than that of swamp dogwood (Photo 4.31).

Photo 4.30: Live fascine installation with moderate sprouting of branches (swamp dogwood).

The National Resource Conservation Service has developed two riparian shrub cultivars for use in streambank stabilization projects: purpleosier (streamco) willow (*Salix purpurea*) and dwarf (bankers) willow (*Salix x cotteti*). These two willow species were used for fascine materials on several projects. Both species had a higher rate of growth and survival than did swamp dogwood. Fascines that used these two cultivars typically had greater than 75% plant survival (Photo 4.32).

4.4.3 Brush Mattresses

Only one brush mattress was installed at the 20 stream restoration projects assessed in the study. The evaluation of this single practice is included here for informational purposes only.

A brush mattress consists of a dense layer of dormant branch cuttings that cover the streambank. The dormant branches are intended to root and grow, thus forming a dense growth of woody shrubs along the streambank. Brush mattresses are generally combined with another practice type (e.g., coir fiber logs, live fascines, a-jacks) to stabilize the toe of the streambank.

The brush mattress assessed provided good structural protection to the streambank, but had only marginal growth of the sandbar willow cuttings (10 to 25% survival). The surviving plant material appeared healthy and may eventually provide adequate vegetative stabilization for the entire streambank. Photo 4.33 depicts the brush mattress that was evaluated.

4.4.4 Bank Regrading and Vegetative Stabilization

Bank regrading and vegetative stabilization were employed to some degree in all of the stream restoration projects assessed. This practice type was extremely difficult to evaluate for several reasons. First, given the nature of construction plans, it was difficult to determine the extent of stabilization after several years, the type of material actually utilized (e.g., with or without erosion control fabric or matting) and whether current vegetation was volunteer or planted.

It appeared that on the majority of graded streambanks, some form of erosion control netting or matting was used. The most common product utilized was coir fiber netting. This product appeared effective at holding bank soils in place where it made good contact with the soil. However, in places where the netting did not contact the soil, either due to soil erosion shortly after installation or poor installation, the netting worked poorly. Coir netting that was not in contact with the soil tended to prevent further vegetation growth as the netting shaded the soil surface and led to further soul erosion.

Coir fiber netting that was in contact with moist soils with good vegetative cover generally decayed within one to three growing seasons. In contrast, coir fiber netting that was not in contact with soil, or that was in contact with very dry soils with poor vegetative cover, tended to remain dry, resisting decay, and needed more than three growing seasons to biodegrade.

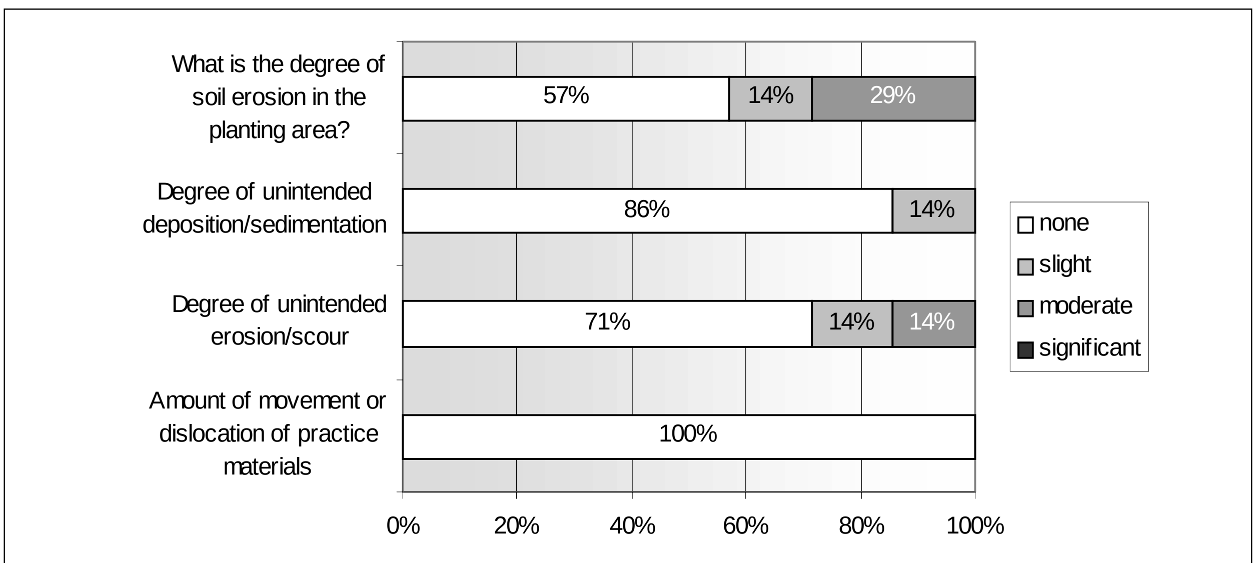

Figure 4.25: Bank Stabilization - Results of Live Fascine Assessment

Photo 4.31: Live fascine installation along streambank toe with good branch sprouting (sandbar willow).

The primary means of establishing vegetative cover on graded streambanks was the seeding of grasses. When soil conditions were appropriate, seeding was very effective in establishing a stable and dense vegetative cover to prevent soil erosion. The most common cause of poor vegetative success was inadequate soil moisture, which occurred most frequently on south-facing streambanks exposed to full sunlight.

Most bank grading and vegetative treatment practices were installed on streambanks that were not subjected to highly erosive conditions, such as the inside of meander bends or areas above the bankfull elevation. In these areas, almost all streambanks graded to 3:1 (horizontal:vertical) or gentler slopes were found to be stable. However, this was dependent on soil composition, with non-cohesive sandy soils requiring gentler slopes than highly cohesive silty/clay soils.

In many cases, bank stabilization practices were combined with bank protection practices. The bank protection practices were usually installed along the lower portion of the streambank, while bank stabilization practices were used along the upper streambanks. This combination of practice types yielded the best results in terms of creating stable streambanks while minimizing some of the potential negative attributes of structural bank protection.

Photo 4.32: Live fascine installation along streambank toe with excellent branch sprouting (Streamco willow).

Photo 4.33: Brush mattress installation using sandbar willow cuttings.

5.0 Recommendations

The recommendations in this section are organized into three parts. Section 5.0 discusses recommendations pertaining to the stream restoration practices in general. Sections 5.1 through 5.4 present recommendations for each practice objective group and the practices individually. Section 5.5 offers a summary of the recommendations and needs for future research.

When sized, located, and installed correctly, the majority of practices analyzed in this study were found to be effective and appropriate for use in urban stream restoration. Of the 22 practices, only two (rock weirs and log drops) are not recommended for use in urban streams, primarily because more reliable practices exist. The design specifications for most individual practices did not appear to cause practice failure. Rather, practice failure was caused by poor design, the installation of practices where channel conditions were inappropriate, or poor practice construction.

In particular, projects that attempted to reestablish or recreate natural channel geometry had the highest number of practice failures. These failures resulted not from the practices themselves, but from inappropriate predictions regarding design parameters (width, depth, meander radii, etc.) for the redesigned channels. It is very difficult to predict stable stream channel geometry in urban streams and unless the geometry is correct from the start, any subsequent channel adjustment can and will probably cause practice failure.

Each practice type has a relatively narrow range of stream conditions for which it is best suited. In some instances, practices were placed in conditions that were outside this appropriate range and failure resulted. For example, vegetative stabilization was sometimes used along portions of streams subject to highly erosive flows, and since this practice is not well suited to these flow conditions, failure occurred. Selecting the right practice for both current and future stream channel conditions is essential for practice success.

The manner by which practices are installed/constructed was found to be a cause of failure for several practices. This was particularly evident in the construction of some rock vortex weirs. Contractors and/or designers did not consider the impact of the weirs on storm flow conveyance (i.e., the reduction in channel cross section caused by the weir), which led to bank scouring. The project designer must work with the contractor to insure that practices are properly constructed. Lastly, some failures were related to the designer's failure to recognize that some urban streams were actively adjusting to altered hydrology and had not yet reached ultimate channel enlargement.

Practices designed to current channel dimensions are not appropriate when major channel adjustment and enlargement is expected because of ongoing watershed urbanization (Caraco, 2000). The predicted future channel dimensions should be considered when designing stream restoration projects in currently urbanizing watersheds.

5.1 Bank Protection Practice Recommendations

Most bank protection practices exhibited excellent structural integrity and met the design objective. For example, less than 10% of 137 bank protection practices failed to achieve the design objective of protecting the stream bank from further erosion, 17% partially achieved this practice objective. When located and installed correctly, most bank protection practices were effective and appropriate for use in urban streams. The basic design concepts of the individual practices did not appear to be a cause of failure. The dominant factors relating to practice failure were overall project design and inappropriate channel conditions for the selected practice.

Each bank protection practice provides a level of structural protection from bank erosion. There are trade-offs between the level of structural protection and the negative impacts of preventing stream channels from adjusting to changing conditions. Stream channels adapt to changing watershed conditions by altering channel cross section and plan form dimensions. Even in the absence of changing watershed conditions, meander bends erode and channels migrate within flood plains. When bank protection practices are extensively used, the ability of the stream channel to adjust to changing conditions is limited. Often, this forces the stream channel to adjust above or below the bank protection practices and can cause formerly stable channel reaches to become unstable or cause upstream or downstream restoration practices to fail.

Imbricated rip-rap offers the highest level of structural protection for eroding streambanks, but it can also have the most adverse impacts due to channel confinement and the prevention of normal channel adjustments. Rootwad revetments, by virtue of their woody materials, offer less in terms of long term integrity, but allow the channel to adjust to changing watershed conditions over the long term. The type of bank protection practice selected must balance the level of bank protection with the potential negative impact of artificially confining the channel.

Ultimate stream channel dimensions must be carefully considered when any bank protection practice is installed. Channel enlargement caused by current and future watershed urbanization may take decades to complete. Thus, a bank protection practice installed at the beginning of the enlargement process may fail prematurely as channel dimensions enlarge. Many urban streams are still actively adjusting their channel dimensions, and it is necessary to anticipate this enlargement and design bank protection practices accordingly.

A stream channel should not be significantly narrowed in the course of practice installation unless upstream stormwater management retrofits are present, regardless of the bank protection practice type utilized. Upstream stormwater management retrofits can reduce the magnitude of storm flows to the extent that a narrower channel (e.g., reduced cross sectional area) can convey the expected flows and not result in renewed streambank erosion.

5.1.1 Rootwad Revetment Recommendations

Rootwads emerged as both a common and reliable practice to protect streambanks along meander bends. Although partial and even total failures were noted for some rootwad revetments, these problems were generally the result of inappropriate project design, and not inherently related to the design concept of the practice.

Rootwads appear to work best on existing stream meanders that have already experienced a significant level of adjustment to altered watershed hydrology. In other words, rootwad revetments work best in older urban areas, that have more or less adjusted to past watershed development. Meanders in older urban streams have had time to adjust their radii, cross section and grade and stream dimensions are no longer rapidly adjusting. Rootwads do not adjust to significant or rapid geomorphic changes, and thus work best where major channel adjustments are not expected.

Rootwad revetments can work on meanders that have not fully adjusted or are newly adjusted. However, there is a much higher potential for failure under these conditions. Using rootwads on non-adjusted or minimally adjusted meanders may also transfer channel adjustment upstream or downstream, assuming the revetment itself does not fail. When used in these instances, designers should place special attention on accurately predicting the direction and dimensions of future stream channel adjustments.

The greatest number of rootwad failures occurred in newly created meanders. Rootwad revetments only work in newly created meanders if design geometry is accurately predicted for current and future channel conditions. The majority of rootwad failures were caused by incorrect as-

Photo 5.1: Rootwad failure due to incorrect meander geometry. Meander radius was too small for existing stream conditions.

sumptions about cross sectional and plan form geometry. In particular, designers had problems in accurately predicting meander radius, sinuosity and channel width. When channel geometry or design flows are underestimated or incorrect, a rootwad revetment will probably fail (Photo 5.1). Rootwad revetment installations are extremely sensitive to the altered hydrology found in urban watersheds. How these hydrologic alterations should be estimated is currently a matter of great debate. Simply relying on a standard recurrence interval storm event (i.e., the 1.5 year storm) and regional curves to establish geometry may not be sufficient to insure success (Doyle *et al., 1999).* Designers are advised to utilize multiple methods of computing design flows and meander geometry to test the sensitivity of various parameters.

Stream confinement, whether in a newly created or existing meander, was also found to be a significant factor in rootwad stability. Rootwad revetments installed along well confined stream channels (e.g., incised channels with little or no access to the floodplain) failed more frequently than those installed along unconfined or moderately confined channels. When substantial bank height exists above the rootwad revetment in a confined channel, the rootwads are potentially subject to complete inundation by storm flows. Storm flows within confined channels are extremely erosive, and tend to scour out rootwads from above and/or behind (Photo 5.2). A better design approach would be to grade the streambank back above the rootwad revetment to create a floodplain terrace that dissipates the energy of storm flows (Photo 5. 3). Any bank area above the rootwads must be well stabilized and extensively planted, preferably with woody shrubs. If the area behind the rootwad cannot be graded back, then designers should create a wide, low point bar on the inside of the meander bend. The elevation of this point bar should be lower than the top of the rootwads, so that stream power is dissipated and rootwads are subject to less stress. This will allow for energy dissipation and reduce the chance of rootwad failure.

5.1.2 Imbricated Rip-Rap Recommendations

Imbricated rip-rap is a structural solution for stabilizing high, eroding streambanks where site constraints limit the ability to grade the streambank to a lower angle and apply other "softer" streambank stabilization measures. Imbricated rip-rap should be used only where bank failure would have significant economic consequences or would result in large scale sediment movement into the stream (e.g., valley slope failure). The use of imbricated rip-rap should be limited to these more extreme cases where no other alternatives exist. Hard, structural practices, such as imbricated rip-rap, eliminate the ability of stream channels to adjust. Extensive use of imbricated rip-rap simply forces these adjustments to occur upstream

Photo 5.2: Rootwad failure due to channel confinement in meander bend. Lack of access to the floodplain resulted in highly erosive conditions and failure of rootwad revetment.

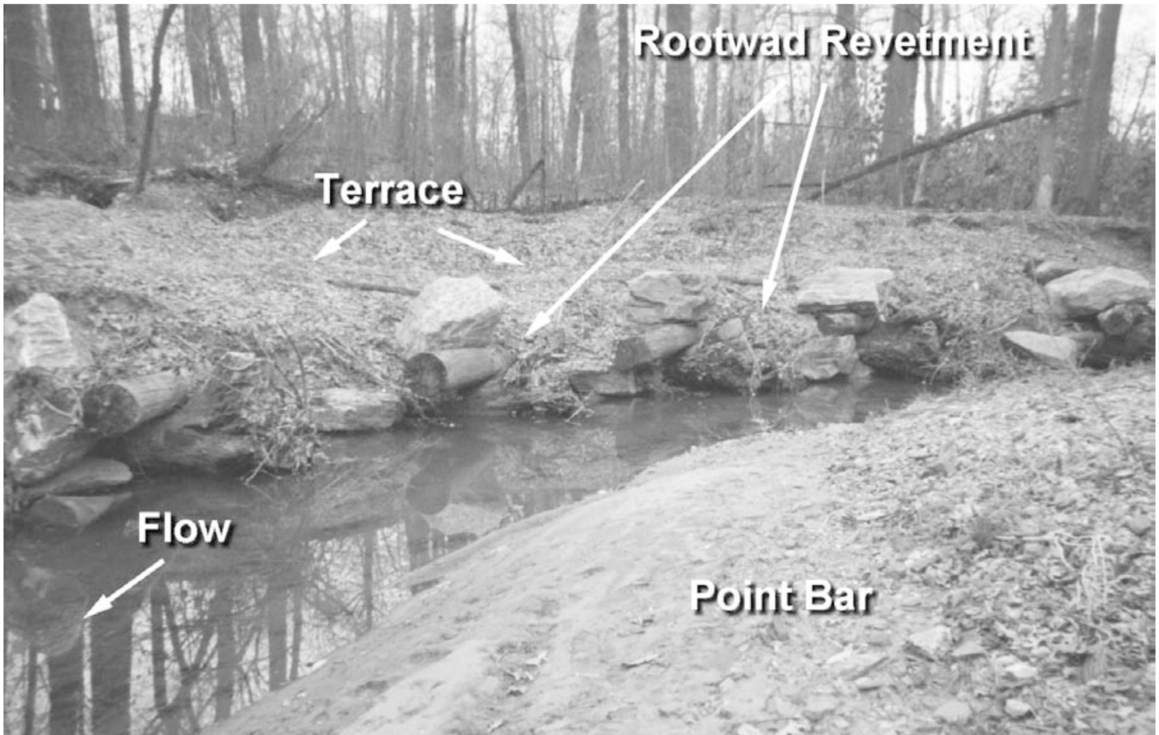

Photo 5.3: Creation of floodplain terrace above the rootwad revetment allowed for dissipation of erosive energy. Rootwad revetment is fully intact.

or downstream of the practice. A designer should first investigate whether other stream bank protection practices are suitable before considering imbricated rip-rap.

5.1.3 Boulder Revetment Recommendations

Boulder revetments are appropriate bank protection practices when little or no lateral movement of the streambank toe is desired and vegetation alone would not provide adequate toe stabilization. Designers should always use the minimum size and amount of rock needed to protect this erosion prone portion of the streambank.

As stated previously, stream channels are dynamic landforms and hard structural practices, such as boulder revetments, eliminate the ability of channels to adjust to changing conditions. The over-reliance on boulder revetments may transfer future channel adjustments to portions of the channel that are presently stable. In urban streams, boulder revetments are best used to protect the toe of the streambank, with bioengineering techniques better suited to protect the streambank above the toe. Photos 5.4 and 5.5 depict well-designed and installed boulder revetments.

The primary reason for full or partial boulder revetment failure was scouring beneath the boulders. This problem was frequently encountered where large boulder revetments lacked footer rocks. Designers often fail to consider that the current stream channel invert may adjust in response to the restoration practice, thus creating the potential for bed scouring. This design issue is critical in streams that have highly mobile bed sediments (USDA, 1998b). The revetment boulders must extend down at least six inches below the expected depth of scouring. Detailed geomorphic and mathematical models exist to estimate the depth of potential scouring. However, in the absence of these models, there are some general rules of thumb that designers can use. For example, for revetments located on generally straight reaches with mobile bed sediments, the difference between the maximum channel invert (thalweg) at the revetment location and the water depth at the streambank toe is a good indication of the potential depth of scouring (Figure 5.1). For revetments located on meander bends, the maximum scour depth can be estimated by finding the greatest pool depth on similar radius meander bends in the same reach and ensuring the revetment extends a foot below this depth. Depth of scouring is less important in streams with less mobile bed sediments.

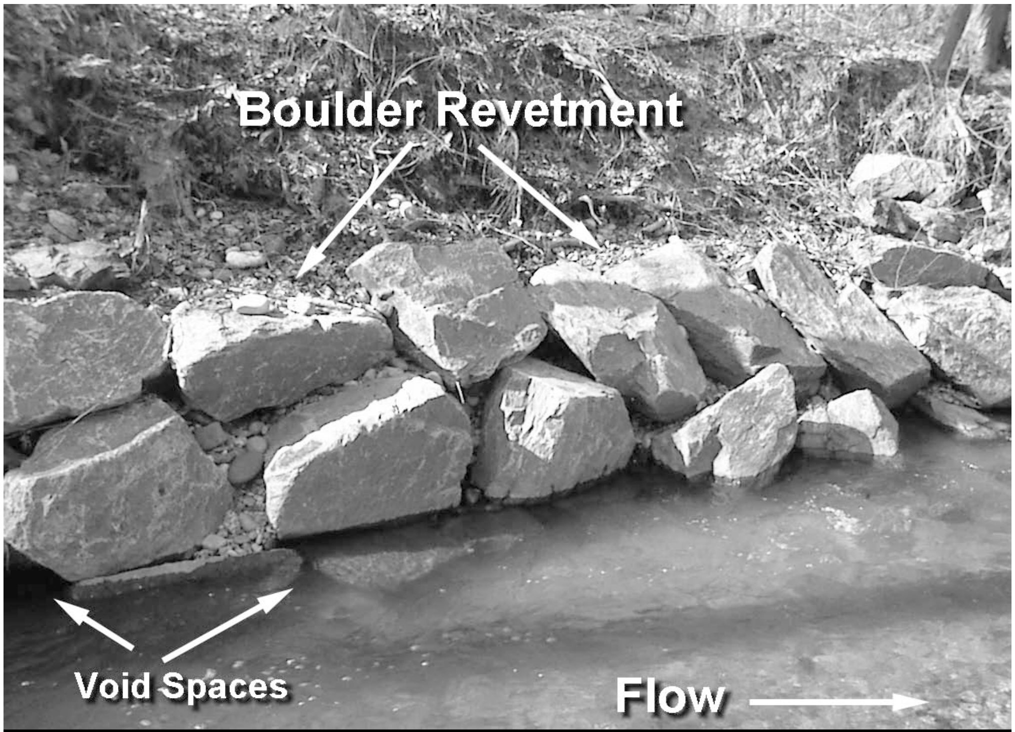

Photo 5.4: Well designed and built double boulder revetment. Note void space created below waterline.

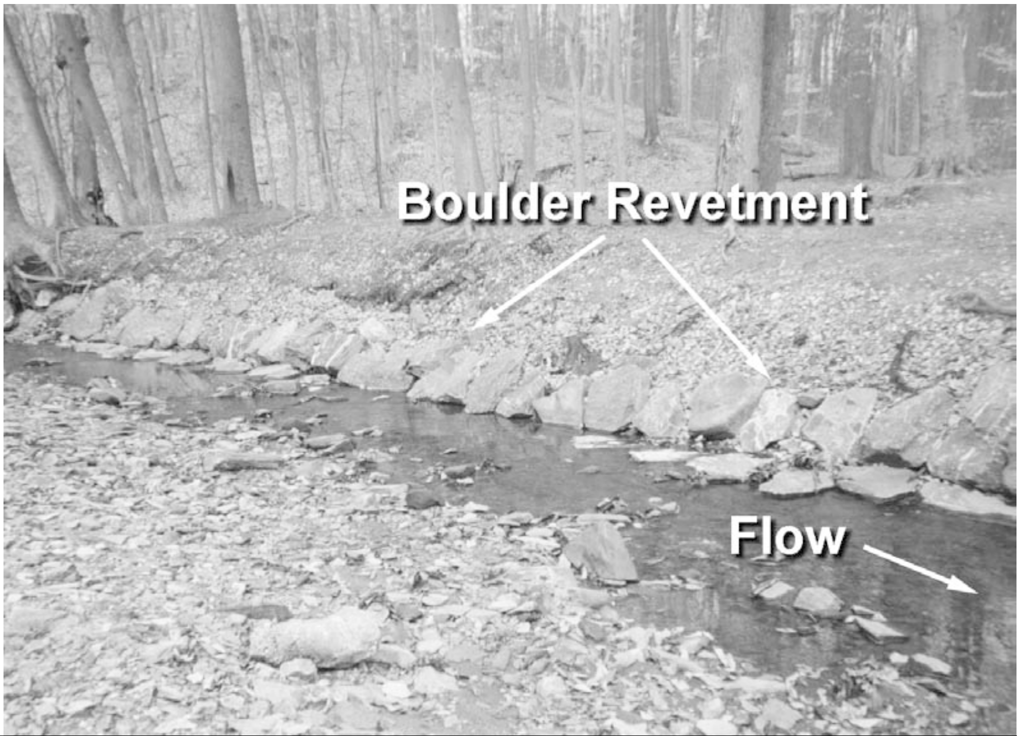

Photo 5.5: Large boulder revetment along gently curving streambank. Boulders are placed on footer stones to prevent movement due to bed scour.

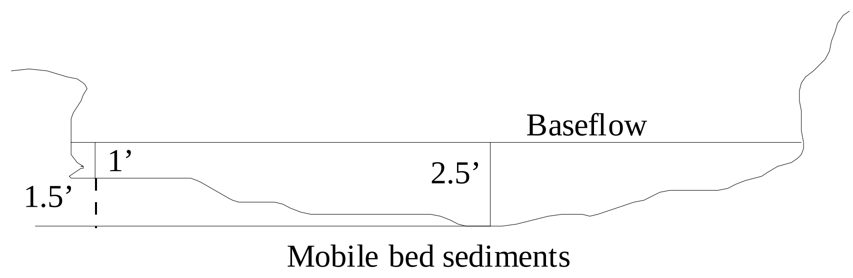

Figure 5.1: Estimating the Potential Depth of Scour

5.1.4 Lunker Recommendations

Lunkers can be an effective lower bank protection practice that also provides significant habitat enhancement, when combined with suitable practices to stabilize the upper bank. These upper bank protection practices generally determine the overall success of a lunker installation in terms of bank protection. The upper bank stabilization measures should be designed to withstand the expected high flows. Designers should consider lunkers with watershed imperviousness in mind. Lunkers were installed in both less developed suburban watersheds (<20% impervious cover) and highly developed urban watersheds (>50% impervious cover). In the suburban watersheds, bank regrading and vegetative stabilization were often sufficient to stabilize the upper streambank. In the highly impervious urban watershed, both rock and vegetative stabilization were needed to stabilize the upper streambank, but this appeared less reliable. Designers hoping to maximize the potential for success may want to consider installing lunkers in watersheds of low to moderate imperviousness (impervious cover 15 to 25%).

Wood and recycled plastic lumber were the two materials used to construct lunker structures. In urban streams, water levels fluctuate to a large degree. This fluctuation can expose the lunker structures to air during low flows and, when the structures are made of wood, can lead to rotting and decay. The fact that none of the lunker structures made with recycled plastic collapsed supports this point. It is recommended that recycled plastic lumber be utilized for lunkers in most urban watersheds.

5.1.5 A-jacks Recommendations

A-jacks are fairly simple to install, and no major deficiencies in the installations were noted. As with the lunker structures, the bank stabilization above the A-jacks plays a large role in the success of the practice. The upper bank stabilization must be sufficient to withstand the expected high flows. Greater success was achieved with A-jacks when the bank above was regraded to a gentle angle (3:1 or gentler). In addition, the channel should not be narrowed in the course of A-jacks installation unless upstream stormwater management retrofits are utilized to reduce the magnitude of storm flows so that a narrower channel can convey the expected flows without renewed streambank erosion.

5.2 Grade Control Practice Recommendations

Nearly all of the urban stream restoration projects employed some type of grade control practice to limit channel incision. The use of grade control practices is recommended on most urban stream restoration projects. Only one practice, step pools, showed the capability for arresting major grade adjustments in urban streams (e.g., large scale nick point migration). The remaining grade control practices are best suited for reducing smaller scale grade adjustment and preventing future grade adjustments. The most effective means of preventing grade adjustment, however, is the use of appropriate stormwater management practices to reduce the frequency and magnitude of stormwater flows in urban watersheds.

Grade controls must be carefully designed and installed to maintain adequate cross-sectional area. In practice, many of the grade controls reduced the channel cross section and negatively impacted both the stream channel and the practice. Grade controls should not reduce the channel cross sectional area to the point that frequent storm flows cannot easily pass through practice. Grade controls that reduce the cross-sectional area of the stream often cause scour/erosion of the stream banks adjacent to the practice (outflanking), and may cause the practice itself to fail.

Of the six grade control practices assessed, only two were found to have limited applicability in urban streams. Although rock weirs and log drops have been documented as being effective in rural streams, this study indicated they had major problems and significant negative attributes when used in urban streams.

5.2.1 Rock Vortex Weir Recommendations

When designed and located properly, rock vortex weirs (RVWs) were effective grade control structures. However, poor design used on many projects caused "outflanking" of the structures.

The original design for rock vortex weirs was developed by hydrologist Dave Rosgen (1993). A comparison of the original design to what was observed at many installation in urban streams, revealed some significant differences. One of the original objectives of an RVW was to avoid creating backwater conditions and disrupting sediment transport processes. This can only be accomplished by maintaining a distance between the weir rocks of 1/3 to 1/2 of the rock diameter and having the rocks extend no higher than 10 to 15% of the bankfull stage elevation. At many project sites, RVWs were constructed with the weir rocks spaced too close and extending too high into the channel. Thus, the RVWs greatly reduced the channel cross-sectional area, which caused outflanking of the structures (scouring around the sides of the practice), the loss of structural integrity, as well as, upstream sediment deposition. (Photos 5.6 and 5.7). In some instances, minor outflanking of the structure could have been prevented by keying the rocks along the streambank further into the streambank rather than just positioning them along the streambank. Photos 5.8 and 5.9 depict properly designed and installed rock vortex weirs.

5.2.2 Rock Cross Vane Recommendations

Based on this study, rock cross vanes appeared to work at least as well as rock vortex weirs to maintain invert elevations on urban streams. The lower profile of rock cross vanes makes them less prone to scouring along their side wings and also reduces the chance of sediment deposition upstream. Our study found that RCVs do not form a scour pool downstream as deep as rock vortex weirs, but they can create a deeper baseflow channel. Since most of the rock cross vanes were functioning effectively, without notable negative attributes, they are highly recommended as an urban grade control practice. Photo 5.10 depicts a properly constructed rock cross vane.

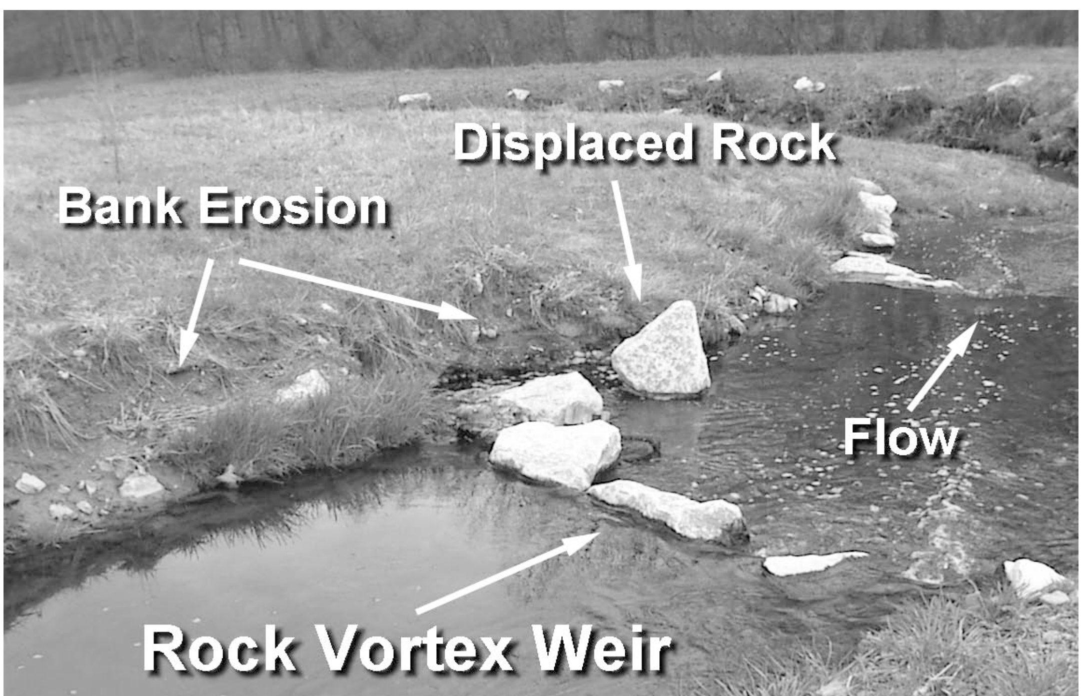

Photo 5.6: Rock vortex weir that reduced channel cross section to the point of causing bank erosion and displacement of weir rocks. Note distance between rocks and height of rocks above water level.

Photo 5.7: Reduction in channel cross section at this rock vortex weir caused channel widening and practice failure.

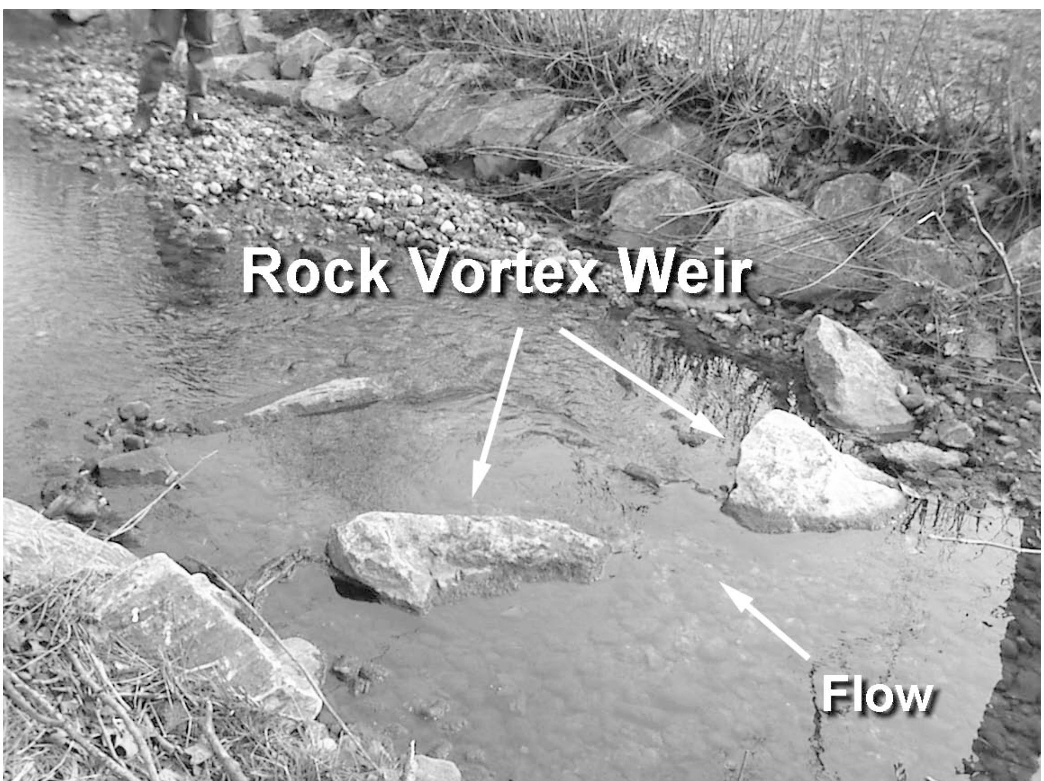

Photo 5.8: Properly designed and built rock vortex weir. Note distance between weir rocks.

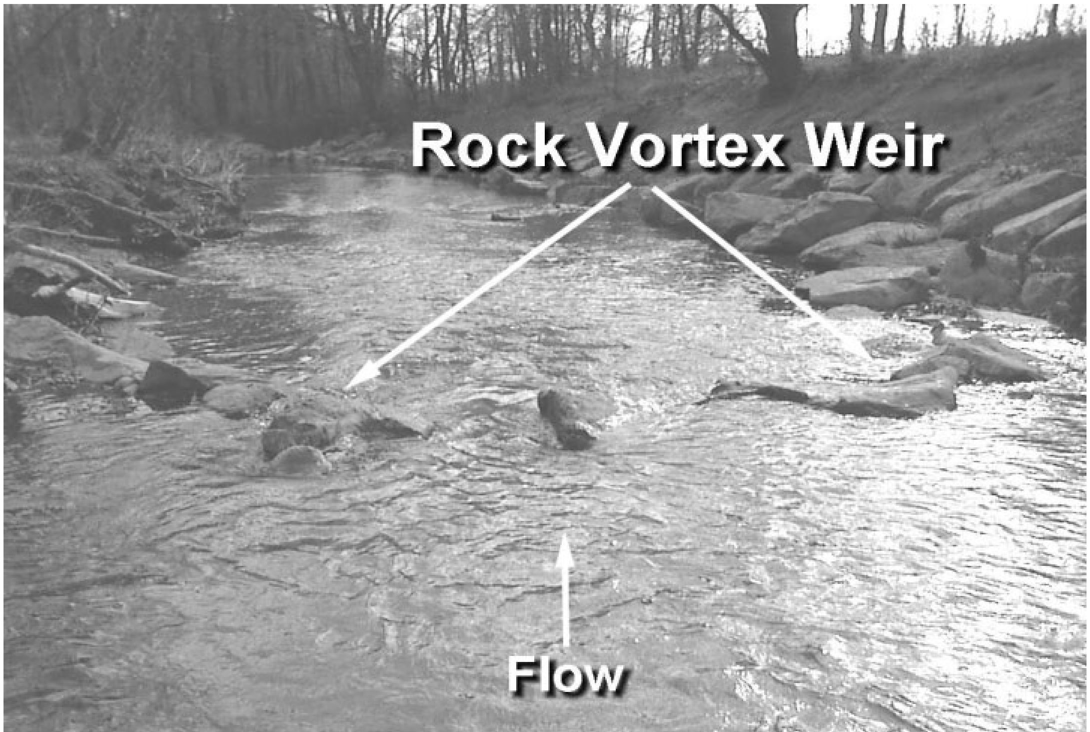

Photo 5.9: Properly designed rock vortex weir on large stream. Proper height and distance between weir rocks are shown.

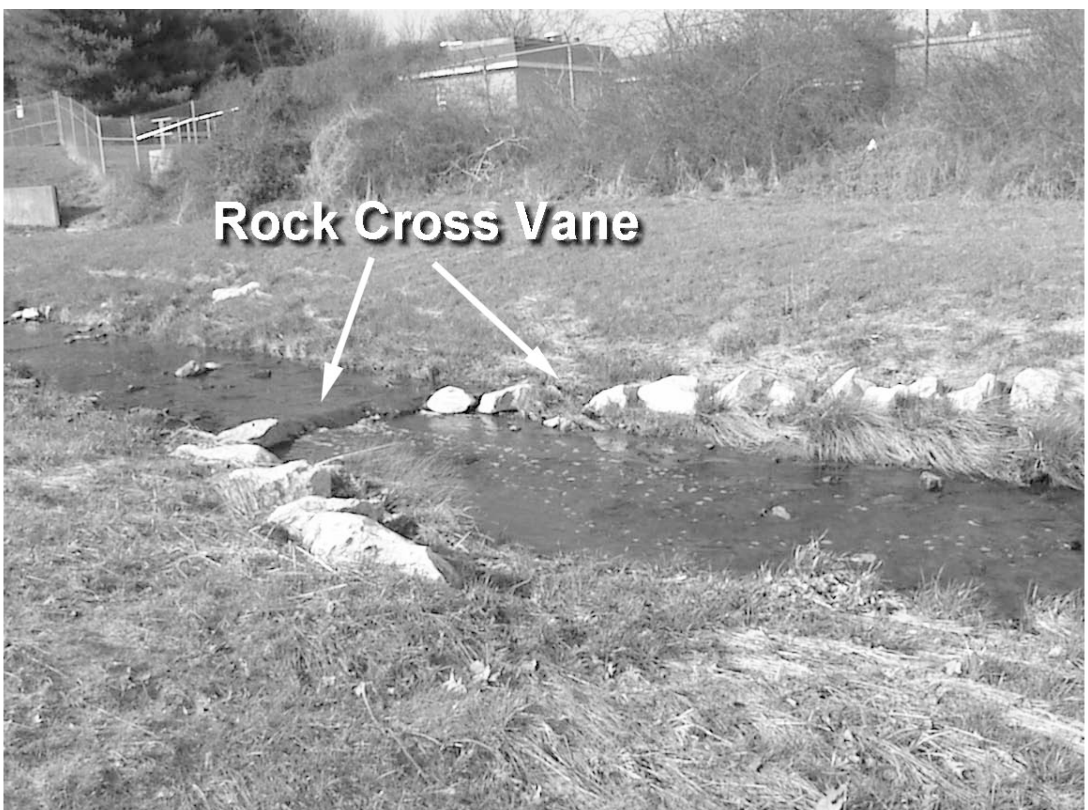

Photo 5.10: Well designed and built rock cross vane.

5.2.3 Rock Weir Recommendations

This study indicated that rock weirs frequently had negative attributes. The purpose of a rock weir is to provide grade control and recreate the natural pool/riffle habitat sequence found in undisturbed streams. In practice, the rock weirs assessed in this study functioned like check dams and created a series of slow runs/pools upstream. The rock weirs did not effectively create riffle habitat downstream. This conclusion is limited by the fact all of the rock weirs evaluated in this study were installed on a stream draining a highly urbanized watershed (>50% impervious cover). The stream alterations caused by such watershed alteration could not be reversed with the placement of a few rock weirs. Given that rock weirs provided little benefit and were associated with chronic problems, such as bank scouring and upstream sediment deposition, they are not recommended for use in highly urban watersheds. Properly designed rock vortex weirs appear to be a more promising option under these conditions.

5.2.4 Step Pool Recommendations

Step pools can be used to reconnect stream reaches separated by large drops in the channel invert and prevent the further upstream migration of nick points. The results of this assessment indicate that step pools are effective at achieving this purpose. The only significant potential drawback to step pools is the possibility that they can create a permanent fish barrier. In order to prevent this, each step above the pools should be one foot or less in height and the pools should be large enough to allow fish sufficient depth to maneuver.

5.2.5 Log Drop and V-Log Drop Structure Recommendations

Log drops extend up into the channel cross section and significantly reduce the cross sectional area; consequently, stream channels tend to widen to make up for this lost channel capacity. Extensive bank protection measures (e.g., rip-rap) are necessary to prevent bank scouring and erosion. In addition, the height of the drop structure can create a potential barrier to fish movement and/or cause significant sediment deposition upstream. Although log drops did create downstream scour pools, the potential drawbacks merit caution in their use.

V-log drops are recommended as an alternative to the traditional log drop structure. The design of a V-log drop reduces the risk of channel widening since high flows are directed toward the center of the channel. The V-log drop design, with its low point at the thalweg of the stream channel, also minimizes the risk of fish barrier creation and upstream sediment deposition.

5.3 Flow Deflection/Concentration Practice Recommendations

Flow deflection/concentration practices were used on only 20% of the stream restoration projects in the study. Six flow deflection/concentration practices, comprising 47 individual practice installations, were evaluated in the field.

The majority of flow deflection/concentration devices were originally developed for use in trout streams to improve fish habitat. They have been adapted to urban streams to serve not only as habitat improvement devices, but to deflect flows away from unstable or eroding stream banks, concentrate the flow in the center of the channel, and redirect water in and out of meanders.

Most flow deflection/concentration practices did function as designed with few negative impacts. This conclusion must be tempered by the fact that only two of the practices (log vanes and rock vanes), had more than 10 installations. Our conclusions should be considered preliminary where only a few installations of a particular practice type were assessed.

5.3.1 Wing Deflector Recommendations

Wing deflectors can be effective at deepening and narrowing the baseflow channel and improving habitat in urban streams. The two projects that utilized wing deflectors were very different and generated different results. One was a small highly urbanized Piedmont stream with a cobble substrate, while the second was a large coastal plain urban stream with a highly mobile gravel substrate. The wing deflectors located on the large urban coastal plain stream were easily able to direct high flows to scour and alter the stream channel. The wing deflectors located on the small highly urbanized stream were not able to influence the channel dimensions to a great degree.

The reasons for the differences in performance are attributed to the design of the structures. The structures located on the highly urbanized Piedmont stream were constructed low in profile so as not to excessively reduce channel capacity. This, combined with the installation of upstream stormwater management controls, limited the ability of the deflector to move the cobble substrate and alter the channel shape (Photo 5.11). This illustrates the difficulties in designing stream restoration structures for urban streams. In this instance, a wing deflector higher in profile but extending out only one-quarter of the channel width from each bank, rather than one-third of the way out from each bank, might be a better alternative. Further design guidance requires monitoring of more wing deflectors of different designs, but installed under similar stream conditions.

The double wing deflectors on the large urban stream were also limited somewhat in performance by a sill at the stream invert connecting the opposing deflectors. While this sill did not impede downstream scour pool formation, it did result in sediment deposition upstream at two sites. At two other locations, where the sill had washed out, the deflectors met with greater success in fulfilling the design objectives with no upstream sediment deposition. Photos 5.12 and 5.13 depict these structures. As there does not appear to be an advantage in having this sill, the use of a connecting sill is not recommended.

5.3.2 Log Vane Recommendations

Log vanes were found to be very successful practices that reduced erosive forces along the streambank, encouraged deposition along the streambank, and enhanced stream habitat. There is little to recommend as far as improvements to their application. An important construction note is that the vanes need to be well keyed into both the streambank and streambed to maintain long term integrity. It may also be advisable to place rock against the streambank on the upstream side of the vane to encourage more deposition and prevent bank scouring.

5.3.3 Rock Vane Recommendations

Rock vanes appear to be very successful flow deflection/concentration practices. Few improvements are recommended for rock vanes, other than to encourage their wider use. Rock vanes have a demonstrated ability to reduce the erosive forces along the streambank, enhance habitat, and encourage deposition along the streambank (Photo 5.14).

The choice of whether to use rock or logs for vane construction should be based upon the size of the channel being restored. If a channel does not naturally contain large rock, then log vanes may be more appropriate. This must be balanced against the expected erosive forces of larger channels. Where erosive forces are expected to be great, the individual rocks that make up the vanes have the ability to shift and move somewhat without resulting in the complete destruction of the practice. In this instance, rock vanes may be a better alternative.

Photo 5.11: Double wing deflector constructed low in profile. Note lack of pool formation downstream of structure.

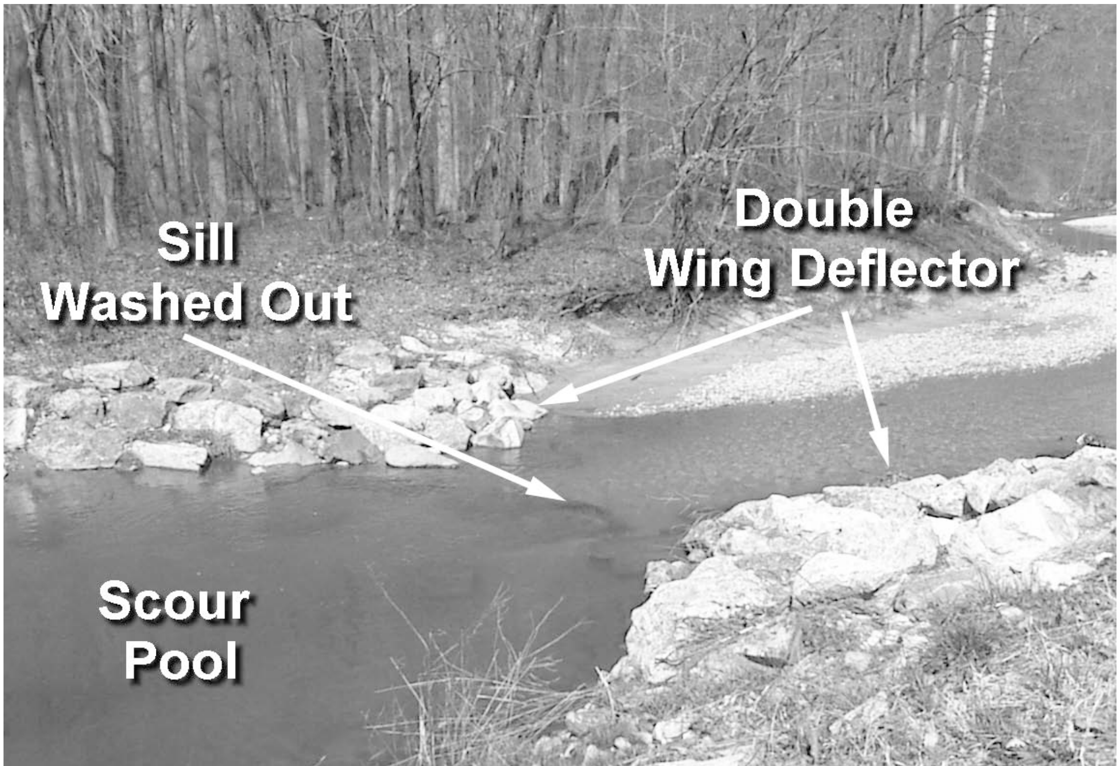

Photo 5.12: Double wing deflector with washed out connecting sill. No upstream sedimentation is evident.

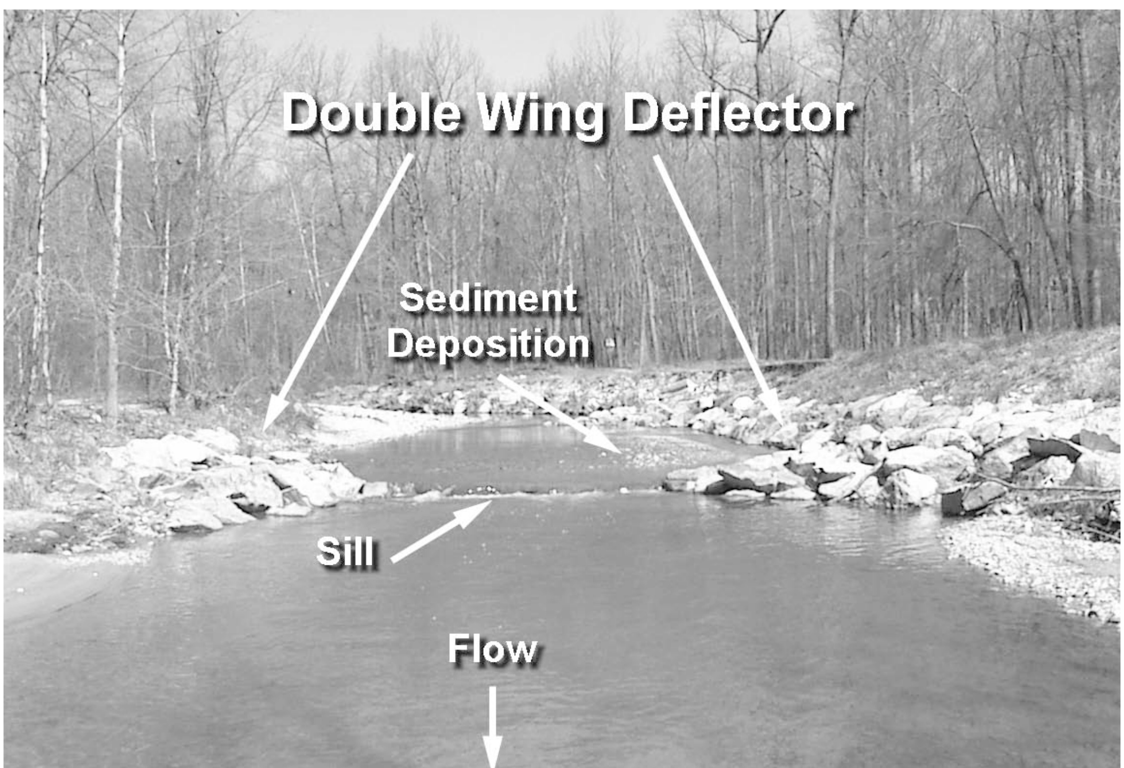

Photo 5.13: Double wing deflector with intact connecting sill. Upstream sedimentation is evident.

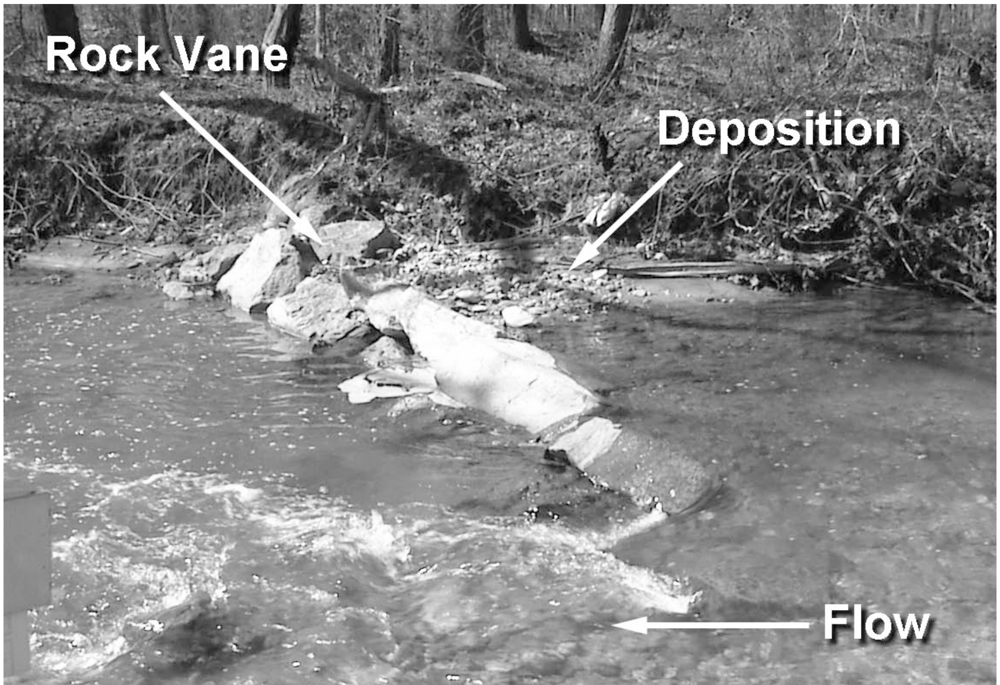

Photo 5.14: Well constructed rock vane. Sediment deposition along streambank toe is evident.

5.3.4 Cut-Off Sill Recommendations

The effectiveness of cut-off sills could not be comprehensively assessed since only a few cut-off sills were evaluated on a single project. Cut-off sills can be useful where stream channels have widened to the point where baseflow no longer fills the channel bottom and a narrower baseflow channel is desired. Cut-off sills are most applicable where significant bedload sediment movement occurs and active lateral or meander bar formation is present.

5.3.5 Linear Deflector Recommendations

As with cut-off sills, this study does not represent a comprehensive assessment of linear deflectors. Even though only two linear deflectors were evaluated, they appear to be effective practices in streams where there is sufficient sediment movement/deposition to fill the area between the deflector and the stream bank. In streams that have low sediment or predominately suspended sediment loads, linear deflectors are less applicable. If linear deflectors are used in these instances, the area between the bank and the deflector will likely have to be filled with stone during construction. The practitioner should also be careful to not narrow the baseflow channel too much or install the deflectors too high, as this may reduce the overall channel cross-section to a degree that results in channel erosion on the opposite bank.

5.4 Bank Stabilization Practice Recommendations

Bank stabilization practices, often referred to as bioengineering, are nonstructural means of stabilizing streambanks against further accelerated erosion. Interestingly, few of the urban stream restoration projects relied heavily on bank stabilization practices to restore and protect streambanks. Bank stabilization practices that rely on vegetation to protect streambanks are much more sensitive to the effects of urbanization than other more structural bank protection practices. Bank stabilization practices are often less successful in highly impervious watersheds. While bank stabilization practices are often very effective on rural and agricultural streams (i.e., with low impervious cover), they are less able to withstand the increased storm flows, high stream velocities, and rapid water level fluctuations that occur in highly urbanized streams.

Bank stabilization practices generally involve regrading the streambanks to a stable angle and geometry and utilizing vegetative plantings and biodegradable materials to stabilize the streambank and prevent or reduce future streambank erosion. These practices are most effective where there is sufficient area available to regrade the streambank, sufficient sunlight to promote the growth of stabilizing vegetation, and where the streambanks are not exposed to frequent, erosive stream conditions.

Bank stabilization techniques were rarely used as the sole means to protect and restore streambanks. In less impervious watersheds (15 to 20% imperviousness), bank stabilization techniques were utilized more frequently and achieved high success rates. In contrast, bank stabilization practices in more urban watersheds (20 to 35% imperviousness) must usually be combined with bank protection practices to be effective (see Section 4.1). In these watersheds, bank protection practices are best suited to protect the lowermost portion of the streambank, while bank stabilization practices are more appropriate for the upper streambank. This combination appears to work well in all but the most highly urban watersheds. Once watersheds exceed 50% imperviousness, bank stabilization practices were largely abandoned, and a greater emphasis was placed on bank protection practices.

The use of bank stabilization practices requires a more comprehensive assessment of stream conditions than most other stream restoration practices. While most structural practices can withstand a wider range of stream conditions, bank stabilization practices can only tolerate a fairly narrow range of sunlight, moisture, and soil fertility conditions. In addition, the season and the length of time available to establish vegetative bank stabilization practices is a critical factor on many projects. The best time of year for installing vegetative practices is when the plants are dormant. Construction scheduling must be coordinated to ensure that plant materials are obtained at the proper time of year and delivered to the site as close to installation as possible. This may require both several months of lead time and temporary storage of dormant plant materials. Clearly, many factors must be considered when planning bank stabilization projects. It is recommended that a practitioner seek out expert help before undertaking such a task.

Bank stabilization practices also require more follow-up monitoring than do other more structural practice types. Many months may be required for plants to properly establish, During these critical months close attention must be paid to prevent minor issues from affecting the overall success of the project. Follow-up inspections should focus on replacement of dead or dying plant materials and soil stabilization.

5.4.1 Coir Fiber Log Recommendations

Two factors consistently determined the success of coir fiber log installations. The first factor was how the coir fiber log was installed along the toe of the streambank. Often, the coir fiber log was simply laid along the toe of the streambank and staked in place, and did not achieve sufficient contact with the substrate or bank soils. Consequently, the coir fiber logs were too exposed and too dry for good plant survival (Photo 5.15). On streams that were less than 10 feet wide, this narrowed the channel, subsequently causing scouring of the coir fiber logs (Photo 5.16). The second factor limiting the success of the coir fiber logs was the lack of scour protection beneath the coir fiber logs. Scouring beneath the coir fiber logs was common in many installations, and these would have benefitted from some form of scour protection such as rock laid in a trench below the coir fiber log (Photo 5.17).

Coir fiber logs should be installed in a shallow trench cut along the toe of the streambank. The toe of the streambank should also be cut back to allow the coir fiber log to make soil contact along the full height of the log. This installation technique helps ensure that the log remains moist, promotes vegetation establishment, transitions into the existing streambank, and does not narrow the stream. Also, it may be useful to delay planting of the coir fiber logs for several months after initial installation, to allow time for the sediments/soil to infiltrate the logs and improve nutrient availability and planting success.

5.4.2 Live Fascine Recommendations

Live fascines were found to be an effective vegetative practice. Live fascines are intended to take root and grow, stabilizing the streambank through the soil binding abilities of live plant roots. Live fascines also provide insurance in that even if they fail to take root and grow, they still provide structural support to the streambank and promote colonization by other riparian plants.

The majority of live fascine installations evaluated were intact and achieved the design objective of bank stabilization, even though rooting success and growth of the fascines was often less than desirable. The limited rooting and growth prevented over 50% of the fascines from fully achieving the habitat enhancement potential.

The key to successful rooting and growth of fascines is thought to lie in how the branch cuttings are collected and handled before and after the fascines are created, the time of year the materials are installed, and the suitability of the soil conditions into which they are placed.

To insure rooting success and growth, branch cuttings should be harvested in the dormant season (late fall/winter) and stored in a cool, dry place or refrigerated until needed in spring. Once the fascines are created from the branch cuttings, they should be stored out of direct sunlight in a cool place for as short a period of time as practical. Fascines should be placed in water (pond/stream) for several days prior to installation. This will aid in initiating growth.

Photo 5.15: Unvegetated coir fiber log installation. Note lack of contact with streambank and baseflow.

Photo 5.16: Coir fiber log installation that narrowed channel and resulted in scouring and failure of the practice. (Stakes mark former location of coir fiber log.)

Fascines should be installed only where there is adequate soil moisture (moist to wet soils). If streambank soils are excessively dry, live, rooted plants are recommended rather than fascines. Live plants, if watered appropriately, have a greater chance of survival under these conditions. Fascines should be installed so that only the tops of the bundles are above the soil surface, and soil should be tamped down into the fascine to the greatest degree possible. Fascines installed near the toe of the streambank should be well secured (staked) and should never be completely submerged, since this inhibits growth.

It is beyond the scope of this assessment to provide complete guidance on the proper installation of bioengineering practices. There are numerous printed and internet resources on the proper installation and utilization of fascines and other bioengineering techniques. One comprehensive resources is *Stream Corridor Restoration Principles, Processes, and Practices* (1999) published by the Federal Interagency Stream Restoration Working Group.

5.4.3 Bank Regrading and Vegetative Stabilization Recommendations

Almost all of the stream restoration projects assessed utilized bank regrading and vegetative stabilization to some degree. When properly designed and constructed, this practice is very effective at stabilizing eroding streambanks on channels that are not actively enlarging or subject to severe erosive forces. Some key considerations that go into properly grading a streambank and establishing a vegetative cover include the following:

C *Are the site conditions conducive to the establishment of healthy/dense vegetative cover on the streambank?*

Soil conditions (fertility/moisture) and the amount of available sunlight largely determine whether vegetation will grow and subsequently stabilize the streambank. Soil moisture and fertility can vary greatly depending on the soil type, location on the streambank, depth of water table and exposure of the streambank. Sunlight and soil conditions should be carefully evaluated before selecting either the practice type or specific plants species.

C *Can the streambank be graded to a angle that will be stable under current and future conditions?*

If the stream channel is actively enlarging or is expected to enlarge due to past watershed urbanization, then a stable channel that is larger than currently present may be required. The regraded streambank should be designed to be stable under current as well as future conditions. Restoring a channel to a previous condition is only possible if sufficient measures are taken at the watershed level to

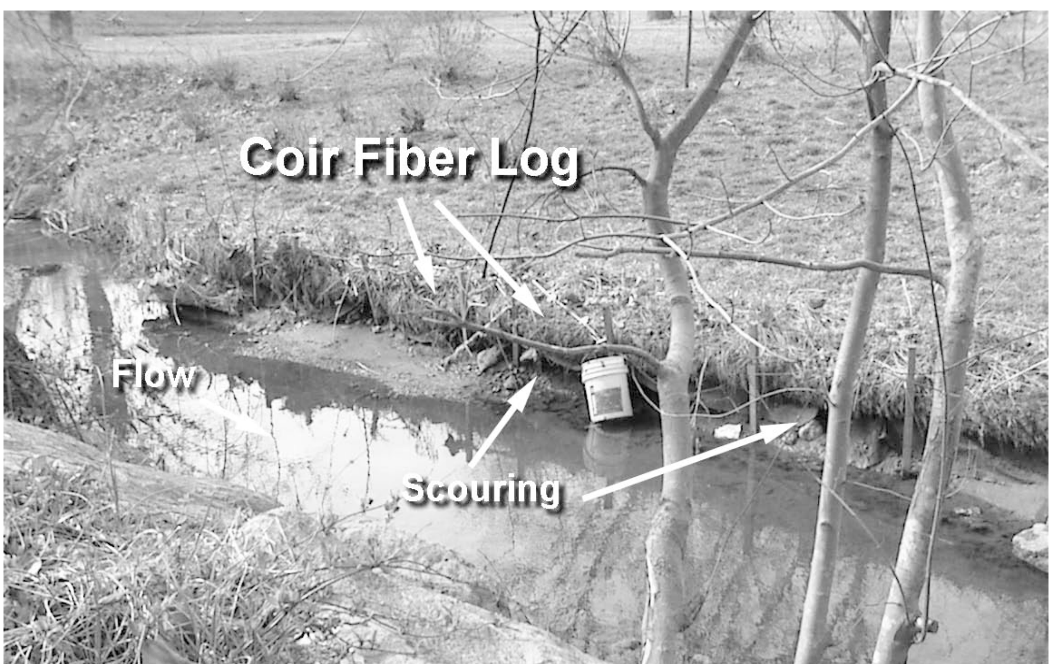

Photo 5.17: Toe scour resulting in the undermining of coir fiber log installation.

reduce the frequency and magnitude of storm flows (i.e., stormwater management retrofits).

Based upon the observations made during the assessment, under conditions with good soil fertility, moisture and adequate sunlight, healthy stabilizing vegetative cover may be established on streambank slopes as steep as 2:1 (horizontal:vertical) provided some form of streambank toe protection is provided and appropriate erosion control matting or netting is used. However, as these conditions were not often encountered in the field, it is recommended that streambank slopes no steeper than 3:1 be utilized for planting.

C *Will the toe of the streambank be stable under future conditions?*

The lowermost portion of the streambank is the most common point of failure. If vegetation alone cannot protect this area, then other bank protection practices should be utilized in combination to prevent toe failure and subsequent failure of the upper streambank.

5.5 Summary

Our initial assessment of urban stream restoration practices found that most practices, when sized, located, and installed correctly, worked reasonably well and are appropriate for use in urban streams. Of the 22 practices evaluated, only two, rock weirs and log drops, appeared to have questionable value in urban stream restoration, primarily because more effective practices exist. Most practices did encounter some problems, and their application can be improved. However, the basic design of most individual practices did not appear to cause practice failure. Rather, practice failure was caused by inappropriate channel conditions for the practice, poor practice installation, and/or the improper overall project design. Most importantly, this study found that the key factors for practice success were a thorough understanding of stream processes and an accurate assessment of current and future stream channel conditions.

Each practice type has a relatively narrow range of stream conditions for which it is best suited. In some instances, practices were placed in conditions that were outside this appropriate range and failure resulted. For example, vegetative stabilization was sometimes used along portions of streams subject to highly erosive flows and, since this practice is not well suited to these flow conditions, failure occurred. Selecting the right practice for the channel conditions is essential for success.

The manner in which practices were installed was found to be a cause of failure for some practices. This was particularly evident in the construction of grade control practices, particularly rock vortex weirs. Designers and contractors must be familiar with the practices specified and the designer must work with the contractor in the field to ensure proper installation. In particular, they should make sure that the installed practice does not reduce channel cross section to the point that the channel can no longer convey frequent storm flows. Practices that reduced the channel cross section to this point often caused renewed streambank erosion, sediment deposition and/or failure of the practice itself. Reductions in channel cross section can only be accommodated when upstream stormwater management retrofits are installed that reduce the magnitude and frequency of storm flows to a level that a narrower channel can convey without adverse channel impacts.

Some practice failures were related to the designer's failure to recognize that most urban stream channels are in a state of adjustment in response to an altered, urban hydrologic regime. The larger, more frequent discharges that accompany urbanization cause downstream channels to enlarge and adjust their plan form dimensions. This process can take decades to complete. Practices designed to current channel dimensions are not appropriate when major channel adjustment and enlargement is expected because of ongoing watershed urbanization (Caraco, 2000). The predicted future channel dimensions should be considered when designing stream restoration practices in currently urbanizing watersheds.

In some older urbanized watersheds, this channel evolution or adjustment process has progressed to where the rate of change has slowed considerably. Most of the projects in these watersheds utilized the existing channel geometry and the restoration practices had a higher rate of success. These types of watersheds may currently be the best candidates for urban stream restoration.

In some watersheds, the predicted future channel condition may cause unacceptable impacts to public infrastructure and/or private property. While every attempt should be made to provide the stream channel with the necessary buffer to accommodate future conditions, this is often not possible due to current and past land use practices. In these circumstances, practices incorporating more structural elements are often needed. This creates a trade-off between stream channel protection/control and potential negative impacts when normal stream channel adjustments are prevented. Stream channels adapt to changing watershed conditions by altering channel cross-sectional and plan form dimensions. Even in the absence of changing watershed conditions, meander bends erode and channels migrate within flood plains. When structural stream restoration practices are extensively used, the stream channel is often forced to adjust either downstream or upstream of the practices, and can result in formerly stable channel sections becoming unstable. The extensive use of hard structural practices must be carefully evaluated.

In terms of overall project design, projects that attempted to create a new channel plan form geometry accounted for the majority of practice failures. The creation of an entirely new channel plan form requires the integration of many hydrologic, hydraulic, and geomorphic variables and is a difficult task in an undisturbed watershed. This task is made even more difficult in an altered/urbanized watershed where uncontrolled stormwater runoff and a history of watershed disturbance have altered the relationships between these variables. Most of these projects attempted to create a natural (e.g., pre-disturbance) type of channel morphology in an unnatural, disturbed watershed. While natural channel restoration has been successful in many rural and agricultural watersheds (Rosgen, 1994), this design approach needs to be reconsidered in urbanized watersheds.

It is not that the natural design approach is inappropriate, but that it requires much more complex predictions of channel design parameters, which can vary greatly in urban stream environments. Most urban stream channels are unstable and evolving to adapt to a new urban hydrologic regime. Consequently, channel geometry and plan form dimensions are in a state of flux and likely to change over time. Rather than attempt to create a channel that is appropriate for the current or a natural condition, designers should look to what the ultimate channel form will likely be in the future and design with this future condition in mind.

The challenge comes in dealing with current and future watershed urbanization, where decades will pass while large scale channel adjustments occur. Implementation of modern stormwater management techniques can help reduce the impacts of urbanization and subsequent channel adjustments. Current efforts in refining stormwater management techniques offer hope in reducing the rate and magnitude of these channel adjustments. Stormwater management design criteria that are based on maintaining the current flow regime in the channel rather than simply managing the flows from large storm events (i.e., two-, 10-, and 100-year events) may help minimize the rate of channel adjustment (Caraco, 2000).

More research is needed into the relationships between channel geometry and flow regime for urban streams. This research should look at how the altered flow regime, sediment transport, and landscape processes in an urban watershed affect channel geometry, and how this information can be incorporated into stream restoration project planning. Along with this, further evaluation of urban stream restoration practices is necessary before the question of long term effectiveness can truly be answered. Repeating this study in three to five years on the same set of restoration practices would go a long way towards answering this question. Furthermore, as the true measure of stream restoration success is how the aquatic community responds, a detailed study of the aquatic community's response to stream restoration is necessary to truly assess the success of urban stream restoration projects.

6.0 References

Bovee, K.D. 1982. *A Guide to Stream Habitat Analysis Using the Instream Flow Incremental Methodology*. U.S. Department of the Interior, Fish and Wildlife Service, Office of Biological Services. FWS/OBS-82/26

Booth, Derek. 1990. "Stream Channel Incision Following Drainage Basin Urbanization." *Water Resources Bulletin* 26(3): 407-417. American Water Works Association.

Brown, E and R. Claytor. 2000. *Draft Watershed Assessment Study for Watts Branch*. Watts Branch Watershed Plan. City of Rockville, MD. Center for Watershed Protection, Ellicott City, MD.

Caraco, Deb. 2000. "The Dynamics of Urban Stream Channel Enlargement." *Watershed Protection Techniques* 3(3):729-734. Center for Watershed Protection.

Doyle, W.D., K. Boyd, P. Skidmore. 1999. "River Restoration Channel Design: Back to the Basics of Dominant Discharge." Second Conference on Natural Channel Design. Niagara Falls, Canada.

Dunne, T and L. Leopold. 1978. *Water in Environmental Planning*. W.H. Freeman and Company. New York, NY.

Galli, J. 1996. *Final Technical Memorandum: Rapid Stream Assessment Technique (RSAT) Field Methods*. Department of Environmental Programs, Metropolitan Washington Council of Governments. Washington, DC.

Galli, J. 1999 "Monitoring the Effectiveness of Urban Retrofit BMPs and Stream Restoration" *Proceedings of the National Conference on Retrofit Opportunities for Water Resource Protection in Urban Environments*. United States Environmental Protection Agency, Office of Research and Development. Washington, DC. EPA/625/R-99/002.

Georgia Soil and Water Conservation Commission. 1994. *Guidelines for Streambank Stabilization*. Atlanta, Georgia.

Gordon, N., T. McMahon and B. Finlayson. 1992. *Stream Hydrology, An Introduction for Ecologists*. John Wiley and Sons Ltd. Chichester, England.

Harvey, M. and C. Watson. 1986. "Fluvial Processes and Morphological Thresholds in Incised Channel Restoration." *Water Resources Bulletin* 22(3):359-368. American Waters Works Association.

Hunt, Robert. 1993. *Trout Stream Therapy*. University of Wisconsin Press. Madison, WI.

Hunter, Christopher. 1991. *Better Trout Habitat*. Island Press. Washington, DC.

Lane, E.W. 1955. *The Importance of Fluvial Morphology in Hydraulic Engineering.* American Society of Civil Engineering, Proceeding 81. Paper 745. pp. 1-17.

Leopold, Luna. 1994. *A View of the River*. Harvard University Press. Cambridge, MA.

MacRae, C. and M. DeAndrea. 1999. *Assessing the Impact of Urbanization on Channel Morphology*. 2nd International Conference on Natural Channel Systems. Niagara Falls, Ontario. 1999.

Maryland Department of Natural Resources (MDDNR). 1997. S*awmill Creek Targeted Watershed Project*. Watershed Restoration Division. Annapolis, MD.

Morisawa, M. and Laflure. 1979. "Hydraulic Geometry, Stream Equilibrium and Urbanization, In Adjustments of the Fluvial System." *Proceedings of the 10th Annual Geomorphology Symposium*. Binghampton, NY. pp. 333-350.

National Research Council (U.S.). 1992. *Restoration of Aquatic Ecosystems*. National Academy of Sciences. Washington, DC.

Newbury, R, M. Gaboury, and *C. Watson*. 1998. *Field Manual of Urban Stream Restoration*. Illinois State Water Survey. Champaign, IL.

Price, Thomas. 1997. *Flint Creek Watershed Restoration Projects*. Northeastern Illinois Planning Commission (NIPC) Chicago, IL.

Roseboom, D., T. Hill, J. Beardsley, J. Rodsater, and L. Duong. 1997. *Waukegan River National Monitoring Program*. Illinois State Water Survey. Champaign, IL.

Roseboom, D., R. Hisabeck, T. Hill, J. Rodsater, J. Beardsley, and L. Duong*l.* 1993. *An Evaluation of the Pilot Glen Crest Stream Restoration*. Illinois State Water Survey. Peoria, IL.

Rosgen, David. 1993. *Applied Fluvial Geomorphology, A Training Manual*. River Short Course. Wildland Hydrology.

Pogosa Springs, CO.

Rosgen, David. 1994. *Applied River Morphology*. Wildland Hydrology. Pogosa Springs, CO.

Schueler, Thomas. 1997. "Impact of Suspended and Deposited Sediment." *Watershed Protection Techniques* 2(3):443-445. Center for Watershed Protection.

Thorne, C.R., R.D. Hey, and M.D. Newson. 1997. *Applied Fluvial Geomorphology for River Engineering and Management*. John Wiley and Sons, Ltd. Chichester, England.

Trimble, Stanley. 1997. "Contribution of Stream Channel Erosion to Sediment Yield from an Urbanizing Watershed." *Science* 278:1442-1444.

United States Department of Agriculture (USDA). 1998a. *Stream Visual Assessment Protocol*. USDA Natural Resource Conservation Service, National Water and Climate Center Technical Note 99-1.

United States Department of Agriculture (USDA). 1998b. *The Practical Streambank Bioengineering Guide*. USDA Natural Resource Conservation Service, Plant Materials Center. Aberdeen, ID.

United States Environmental Protection Agency (USEPA). 1999a. *Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, Second Edition*. Office of Water; Washington, D.C. EPA/841-B-99-002.

United Sates Environmental Protection Agency (USEPA). 1999b. *Proceedings National Conference on Retrofit Opportunities for Water Resource Protection in Urban Environments*. Office of Research and Development. Washington, DC.

United States Environmental Protection Agency (USEPA). 1989. *Rapid Bioassessment Protocols for Use in Streams and Rivers*. Office of Water, Washington, DC. EPA/440/4-89/001.

7.0 Glossary

Aggradation: The process by which streambeds, floodplains, and the bottoms of other water bodies are raised in elevation by the deposition of material eroded and transported from other areas. It is the opposite of degradation.

Armor: (1) An erosion-resistant layer of relatively large particles on the surface of the streambed that resists degradation by water currents. (2) The application of various materials to protect streambanks from erosion.

Bar: A bed form that is created by deposition of sediments within the channel and extends above water at low flow. Typical bar types include lateral, point, and mid-channel.

Baseflow: The portion of the stream discharge that is derived from natural storage (i.e., groundwater outflow and drainage from large lakes and swamps or other sources, not resulting from rainfall).

Base level: The level or elevation to which a stream-channel profile has developed.

Bedload: Sediment that slides, rolls or bounces along the streambed at high flows.

Benthic macroinvertebrate: Aquatic insects large enough to be seen by the unaided eye that live in or on the bottom of a body of water.

Bioengineering: The use of live and dead plants materials in combination with biodegradable support materials for streambank stabilization.

Channelization: Straightening of a stream or the dredging of a new channel to which the stream is diverted.

Coastal Plain: The geologic province that lies along the Atlantic coast and extends inland to the Piedmont geologic province. Streams within the Coastal Plain are generally characterized as low gradient, meandering, with mobile sand/silt or gravel substrates.

Degradation: The process by which streambeds and floodplains are lowered in elevation by the erosion of material. It is the opposite of aggradation.

Deposition: The accumulation of sediment on the channel bed and banks.

Discharge: Volume of water flowing in a given stream at a given place and within a given period of time, usually expressed as cubic meters or cubic feet per second (cms/cfs).

Dormant season: The time of year when plants are not growing and deciduous plants shed their leaves.

Dynamic equilibrium: The stream condition in which there is a balanced inflow and outflow of sediment.

Eddy: A circular current of water, sometimes quite strong, diverging from and initially flowing contrary to the main current. It is usually formed at the point where water passes over or around an obstruction.

Embeddedness: The degree that larger particles, such as boulders, rubble, or gravel, are surrounded or covered by fine sediment. Usually measured in classes according to percent coverage of larger particles by finer sediments.

Erosion: The wearing away of rock or soil by the gradual detachment of particles by water, wind, ice, or other mechanical or biological forces.

Fall line: The boundary between the Atlantic Coastal Plain Province and the Piedmont Province. This boundary is characterized by high gradient stream reaches, rapids, and water falls (e.g., the Great Falls of the Potomac).

Fish barrier: An obstacle in a stream or river, such as a dam or elevated culvert, that prevents the up and downstream movement of fish and other aquatic species.

Floodplain: Any flat, or nearly flat, lowland that borders a stream that is periodically covered by water at flood stage.

Flow rate: Volume of flow per unit time. Usually expressed as cubic feet per second.

Geomorphology: The branch of geology that deals with the origin and nature of landforms. The active forces that shape landforms are water, ice, wind, and gravity.

Gradient: The general slope or rate of change in vertical elevation per unit of horizontal distance.

Habitat: A specific type of area in which a particular type of plant or animal lives.

Habitat attribute: A single element, such as velocity, depth, cover, etc., of the habitat or environment in which plants or animals live.

Impervious cover: Man-made surfaces, such as roads, parking lots, and buildings, that prevent the infiltration of rainfall and increase the amount of stormwater runoff in a watershed.

Incised channel: A stream that, through degradation, has cut its channel into the bed of the stream valley.

Large woody debris (LOD): Any large piece of relatively stable woody material having a diameter greater than four inches and a length greater than three feet that intrudes into the stream channel.

Lateral bar : A bed form that is created by deposition of sediments along the margins of a stream channel and extends above water at low flow.

Limiting factor: The total biomass of any organism will be determined by the abundance of the element that, in relation to the needs of the community, is least abundant. This element is the limiting factor.

Lower bank: The periodically submerged portion of the channel cross section from the normal high water line to the water's edge during the summer low-flow period (below bankfull).

Meander: A broad, looping bend in a stream channel.

Meandering: A stream characterized by a clearly repeated pattern of meanders as seen from above.

Native vegetation: Vegetation that is indigenous to an area and adapted to local conditions.

Nick point: The point at which a stream is actively eroding the streambed downward to a new base level.

Non-cohesive: Friable, loose, or lacking internal strength.

Piedmont: A geologic province bordered by the Atlantic Coastal Plain to the east and the Appalachian Mountains to the west. The Piedmont province is generally characterized by rolling terrain with streams of moderate gradient and cobble/gravel substrates

Point bar: A bed form that is created by deposition of sediments along the inside of meander bends.

Pool: A portion of a stream with reduced current velocity and water deeper than the surrounding areas.

Revetment: A layer of large stone or other durable materials placed along a streambank to prevent erosion.

Riffle: A topographical high area in a channel created by the accumulation of relatively coarse-grained sediments, characterized by turbulent flow.

Riparian buffer: An undisturbed, vegetated strip of land adjacent to a water course.

Rip-rap: Randomly placed rock used to protect streambanks from erosion.

Rootwad: The lowermost portion of a tree trunk with the root mass attached.

Roughness: A measure of the irregularity of stream channel materials as they contribute to flow resistance. Commonly measured in terms of Manning's roughness coefficient.

Scour: The erosive action of flowing water that removes and carries away material from the streambed and banks.

Scour pool: An area of deeper water created by the scouring action of water. These generally occur downstream of obstructions or along a meander bend.

Sediment control: Measures taken to limit the amount of soil lost when grading and land development activities are undertaken. These measures can include sediment basins and traps, silt fence, berms, mulching, etc.

Seepage: Groundwater emerging from a slope or the face of a streambank.

Sinuous: A stream or river channel characterized by a gently curving channel as seen from above.

Stormwater management: Measures taken to limit the amount of stormwater runoff from impervious surfaces. These measures can include man-made ponds, created wetlands, infiltration facilities, etc.

Stream: A natural watercourse containing flowing water at least part of the year.

Streambank: The portion of the channel cross section that restricts lateral movement of water at normal water levels.

Streambank toe: The break in the slope at the foot of a bank where the bank meets the streambed.

Streambed: The substrate plane, bounded by the stream banks, over which the water column moves.

Stream invert: The elevation of the deepest portion of the streambed (thalweg).

Substrate: The mineral and/or organic material that forms the bed of the stream.

Thalweg: A line connecting the deepest points along a stream channel.

Upper bank: That portion of the topographic cross section of the channel above the normal high water line (above bankfull).

Velocity: The speed at which water is flowing typically measured in feet or meters per second.

Watershed: The area that contributes runoff to a stream.

Water table: The depth or level below which the ground is saturated with water.

Appendix A: Project Descriptions

Spring Branch

Spring Branch is a second order tributary draining an 800-acre, predominately residential watershed in Timonium, MD. Spring Branch drains to the Loch Raven Reservoir, a drinking water reservoir for Baltimore City and County, MD. The project entailed 2.5 miles of stream rehabilitation that utilized root wads, boulder revetments, step pools, live fascines, bank regrading, and other vegetative techniques. Uncontrolled stormwater runoff had degraded this channel resulting in eroding streambanks, poor instream habitat, and poor water quality. The project was completed in 1997.

Stemmer's Run

Located just outside the city limits of Baltimore, Maryland, Stemmer's Run is a second order stream draining approximately 1,000 acres of older residential and commercial development. Extensive channelization and piping of streams occurred within the headwaters and led to severe channel erosion and the loss of stream habitat. The majority of the restoration work took place in forested lower portion of the watershed. The project, completed in 1997, used rootwad revetments, boulder revetments, step pools, live fascines, bank regrading, and other vegetative techniques to restore a 1,900 foot reach of the stream.

Tributary 9 to Sawmill Creek
Muddy Bridge Branch of Sawmill Creek

The Sawmill Creek Watershed encompasses 5,400 acres of land within the coastal plain geologic province. Sawmill Creek is a tributary to the Patapsco River, which flows into the Chesapeake Bay. Land use in the watershed consists of a mix of older low and medium density residential land along with a growing commercial/industrial zone centered around the Baltimore/Washington International Airport. The watershed suffers from the common impacts of uncontrolled urban runoff.

Sawmill Creek was chosen as one of four watersheds to be included in Maryland's Targeted Watershed Program. The Targeted Watershed Program is a multi-agency, state initiative to improve water quality and restore living resources in key tributaries to the Chesapeake Bay. The goal of the program is to demonstrate that improvements in water quality and conditions can be made by coordinating the monitoring, pollution control, and restoration programs of public and private organizations. Both of these restoration projects also served as compensatory mitigation for impacts associated with Maryland Route 100 highway construction.

The Tributary 9 to Sawmill Creek stream restoration project encompassed 1,100 feet of channelized, highly degraded coastal plain stream channel. The project utilized rootwads, rock weirs, and dense vegetative plantings, along with bank grading and the reshaping of the stream geometry. The flow capacity of the channel was sized to match the uncontrolled urban stormwater runoff regime. The project was completed in 1994 by the Maryland State Highway Administration at a cost of $162,000.

The Muddy Bridge Branch stream restoration project encompassed 4,440 feet of degraded and eroding stream channel. Muddy Bridge Branch drains a substantial portion of the Baltimore/Washington International Airport The project utilized the same restoration techniques as used in the Tributary 9 to Sawmill Creek project, but also included an upstream stormwater management retrofit. Several retrofit actions were taken including increasing storage capacity in existing ponds, modifying pond outlet structures, and creating additional wetlands. The project was completed in 1996 by the Maryland State Highway Administration at a cost of $420,000 (MDDNR, 1997).

Deep Run

Deep Run is a third order tributary to the Patapsco River draining a watershed composed of predominately suburban land use in Howard County, Maryland. The headwaters of Deep Run are located in the Piedmont geologic province and the stream crosses the fall line and enters the Coastal Plain province a short distance upstream of the project reach. The project, completed in 1994, involved the reestablishment of a meandering stream channel and utilized rootwad revetments, rock vortex weirs, and vegetative stabilization.

Quail Creek

Quail Creek is a tributary to the Gunpowder River in Baltimore County, Maryland. Prior to 1989, the stream supported a healthy brown trout population. In 1989, an inline regional stormwater management pond draining 500 acres of land breached in the headwaters during an intense thunderstorm. The torrent of water released downstream scoured the channel and resulted in severe channel degradation and the near complete loss of instream habitat.

The project was completed in 1991 and involved the restoration of eroded streambanks and the creation of instream habitat using natural materials along 1,500 feet of stream channel. The practices included rootwads, rock weirs, boulder placement, bank regrading and vegetative plantings. Total cost for the project was $130,000.

Piney Run

Piney Run is located in the Town of Manchester in Carrol County, Maryland. The project was undertaken in the headwaters of Piney Run and involved removing a 500 foot concrete trapezoidal channel and the reestablishment of a meandering stream channel. The 450 acre watershed consists almost entirely of single family detached homes on quarter-acre lots. The stream has a low baseflow, but is augmented by the outfall of a wastewater treatment plant located just upstream of the project reach. The wastewater treatment plant provides the majority of the baseflow through the project reach. The project was completed in 1997 and utilized rock vortex weirs, rock cross vanes, rootwad revetments, and bank stabilization measures in a natural channel design concept.

Longwell Branch

The Longwell Branch watershed is located in Carrol County, Maryland and encompasses approximately 1,000 acres of mostly urbanized land in the City of Westminster. The aquatic community in Longwell Branch had poor aquatic diversity and showed evidence of stress. Stormwater runoff, pollutants, fish barriers, lack of instream habitat (e.g., good quality pools, riffles, and runs) and poor riparian habitat were the primary factors responsible for the degraded condition of the stream. Much of the degradation was linked to a lack of stormwater management, as most of the development within Longwell Branch occurred before stormwater management regulations went into effect. The Longwell Branch Project was initiated in 1993 in an effort to combine local, state, and federal resources to address water quality and quantity problems impacting the stream segments in the City of Westminster.

The stream restoration project consisted of the de-channelization of a 500-foot reach of stream. The project is located in an urban/commercial area. A road adjacent to the stream encroached on the riparian area and the floodplain. A sewer line between the stream and the road further constrained the project. The project included a stormwater management retrofit facility adjacent to the project reach. The stream restoration project created a sinuous channel and utilized large boulder revetments, rock vortex weirs, streambank grading and vegetative plantings.

Cloverleaf Center

The Cloverleaf Center stream restoration project differs from most projects in that there was no stream channel prior to the project. The project is located on the grounds of a former golf course in Germantown, Maryland. When the golf course was developed many years, ago the stream channel was replaced by two instream ponds. The remaining stream channel was piped. The restoration project was undertaken as part of a commercial office development project The stream restoration was completed in 1998 and involved removing the two ponds and constructing 1,500 feet of new, meandering stream channel. In addition, the project also created over two acres of non-tidal forested and emergent wetlands. Practice types used on this project consisted entirely of biologs, coir fiber matting, and vegetative plantings.

Churchill Community

The Churchill Community stream restoration project is located in Germantown, Maryland. This project involved stabilizing a 1,000 foot section of ephemeral/intermittent stream channel. The channel conveys uncontrolled runoff from a townhouse development to a regional stormwater management facility. The channel has experienced downcutting in the upper portion and poor bank stability in the lower section. The project was completed in 1998 and utilized V-log drop structures, biologs, step pools, and vegetative stabilization.

Little Paint Branch Stream Restoration Demonstration Project

Little Paint Branch drains a 7,000 acre urban/suburban watershed located along the fall line between the Piedmont and Coastal Plain geologic provinces in Montgomery and Prince George's County, Maryland. The goal of the project was to re-establish stable stream geometry and improve the aquatic and riparian habitat along a degraded 5,700 foot reach of the stream. Impervious cover in the subwatersheds draining to Little Paint Branch averages approximately 25%, with a range of seven to 28%. Ultimately Little Paint Branch is predicted to have an overall impervious cover of approximately 35%.

The project utilized rock cross vanes, wing deflectors, cut-off sills, boulder revetments, rootwads, biologs, bank regrading, and vegetative plantings. Several unique challenges were encountered in this project, including high bed load, the fall line, and the size of the stream. Work was completed in 1998 at a cost of $800,000.

Elmwood Smith Park North and South

Elmwood Smith Park is located along a first order tributary to Cabin John Creek in the City of Rockville, Maryland. The stream drains the highly urbanized town center area. Along most of the stream length, public infrastructure, private property, and utilities constrain the ability of the channel to adjust and reach a stable condition. These two projects were completed in 1997 and involved the use of imbricated rip-rap, rootwad revetments, and coir fiber logs to stabilize and protect streambanks.

Wheaton Branch

The Wheaton Branch stream restoration project is one phase of a three phase effort to restore Upper Sligo Creek in Montgomery County, Maryland. Wheaton Branch is the largest and most degraded of the Sligo Creek tributaries. Wheaton Branch drains a 805 acre watershed that is approximately 55% impervious and consists mainly of older moderate to high density residential and commercial development. The Wheaton Branch restoration is notable because it incorporates urban stormwater management retrofitting with stream restoration.

The first step in the project was the construction of a 5.9 acre stormwater management pond/marsh facility on Wheaton Branch above the 900 linear foot restoration area. After construction of the stormwater management facility, work on restoring the creek began. Practice types on this project include imbricated rip-rap, log drop structures, wing deflectors, boulder placements, and vegetative plantings. Completed in 1993, the restoration work was followed by the re-introduction of native fish species to the creek. To date, monitoring results have been very positive. Many of the fish species re-introduced to the creek have re-established viable populations and increases in the benthic macroinvertebrate populations have been noted.

NIST

The National Institute of Standards and Technology's (NIST) 600-acre Gaithersburg, Maryland campus includes two stream channels that have experienced significant degradation due to inadequate stormwater management. In 1998, NIST undertook a project to restore these two stream channels. The smaller of the two channels originated in an aesthetic pond and flowed for 800 feet into another pond, before flowing offsite. The second stream channel on the site originates from spring seepage and overland flow and flows for 1,500 feet before entering a new onsite stormwater management wet pond. Both channels had experienced severe channel degradation and widening. Stream banks were as high as eight feet along portions of the channel. The restoration utilized, erosion control matting, vegetative plantings, biologs, rock cross vanes, rock weirs, step pools, boulders, rock vanes, and rootwad revetments. The restoration approach utilized a fluvial geomorphic approach to establish stable stream morphology for the streams altered hydrology.

Lake Zurich Stream Stabilization Project

The Village of Lake Zurich is located in Lake County, Illinois. Lake County is located in northeastern Illinois approximately 12 miles northwest of Chicago. The Flint Creek watershed encompasses an area of approximately 28 square miles in Lake County and five square miles in adjacent Cook County. A significant tributary is the Glassy Lake Tributary (7.5 miles long), which originates from numerous small lakes and wetland areas in its headwaters. Land use in the watershed is predominately low density residential, with the exception of Lake Zurich, which is much more urban. In 1994 the Lake County Stormwater Management Commission and the Northeastern Illinois Planning Commission developed a watershed management plan for the Flint Creek watershed. This plan identified several limiting factors in the watershed, including urban runoff, excessive streambank erosion and subsequent sedimentation. The origin of these problems is primarily uncontrolled urban runoff.

In 1995, a Section 319 grant was awarded to the Northeastern Illinois Planning Commission, the Villages of Lake Zurich and Barrington, the Lake County Forest Preserve and Citizens for Conservation to design and implement restoration projects in the watershed. The Lake Zurich stream stabilization project was undertaken as part of this grant.

The Lake Zurich Stream stabilization project encompassed 1,400 feet of stream channel (2,800 feet of streambank) in the Village. This portion of stream channel was chosen for restoration because it was identified as being one of the worst erosional areas in the watershed. The 1,400 foot project reach abuts both residential backyards and park land.

The main purpose of this project was to stabilize and restore eroding streambanks. Four practice types were chosen for this project including: A-Jacks, biologs, lunker structures, and brush mattresses. Erosion control matting, seeding and live plantings were also utilized as elements of this project. A significant additional consideration for the project was the dominance of non-native-invasive plant species along the stream corridor. An additional goal of the project was to re-establish a native community along the stream corridor. The majority of the creek abutted by residential yards was treated using A-jacks, biologs, brush mattresses and vegetative techniques. Downstream where the stream corridor was less constrained, lunker structures were used in place of A-jacks.

Barrington Streambank Stabilization Project

The Village of Barrington is located just a few miles southwest of Lake Zurich in Lake County, Illinois. As part of the overall Flint Creek Watershed restoration, the village of Barrington carried out a stream restoration project on a tributary to Flint Creek within the Village of Barrington. This tributary was chosen for restoration because it had been identified in the Flint Creek Watershed Management plan as experiencing significant streambank erosion and because it is a highly visible corridor traversing village, school district, and park properties.

This project, completed in 1996, utilized A-Jacks, biologs, lunker structures, bank regrading, planting and seeding, and the use of erosion control matting A significant additional consideration of the project was the dominance of non-native-invasive plant species along the stream. In areas where streambank erosion was not severe, removal of non-native plants and planting and seeding with native riparian plants was undertaken. In areas where streambank erosion was more severe, biologs were added as toe protection and minor bank regrading was included along with the vegetative techniques. Where streambank erosion was worst, A-jacks were added to increase streambank stability. Where significant erosion was occurring along a meander bend lunkers were used to protect the toe of the bank and to enhance fish habitat (Price, 1997).

Glencrest Creek Restoration Pilot Project

The Glencrest Creek Restoration Pilot Project was completed in 1992. Glencrest, Illinois is located in DuPage County about 20 miles west of Chicago. The Glencrest Creek watershed encompasses approximately 1,300 acres of land. Land use in the watershed consists of approximately 85% residential use, 5% commercial use, and 10% open space. Most of the open space is located in the uppermost portion of the watershed. Approximately one-quarter of the creek length is contained in either underground storm drains or concrete channels (Roseboom *et al.*, 1993).

Glencrest Creek has suffered the familiar effects of urban development, uncontrolled urban runoff, stream encroachment, channelization and piping. Many areas of the creek are suffering severe bank erosion, downcutting, and habitat loss. Areas where houses were constructed in close proximity to the creek were threatened by erosion and lateral channel migration. In 1989 the DuPage County Department of Environmental Concerns (DCDEC) developed a stormwater management plan. One of the objectives of the plan was to control channel erosion and sedimentation in local streams, while at the same time encouraging the preservation of aquatic and riparian habitats. The stormwater management plan encouraged the use of simple cost effective technologies to achieve the plan objectives.

DCDEC sought to develop pilot projects which adhered to the goals and policies of the stormwater management plan. Glencrest Creek was chosen as one of the pilot projects. The Illinois State Water Survey in cooperation with DCDEC developed a work plan for the project that emphasized maintaining a "natural" channel appearance, stabilizing eroding streambanks, and utilizing locally obtainable materials. The creek was surveyed and the areas of greatest streambank erosion identified. The majority of severe streambank erosion sites were located along a 2,000 foot section of creek that coursed through residential backyards. An interesting point of this project is that the stream ran across private property and an easement from each homeowner was required for the work to be completed and for future maintenance work.

The Glencrest Creek project utilized A-jacks, lunkers, rip-rap, rock vortex weirs, vegetation, and existing gabions. Lunkers in combination with rip-rap and vegetative stabilization were utilized in the most severely eroding sections while A-jacks, rip-rap and vegetative techniques were used at less severe stream bank erosion sites. Rock vortex weirs were utilized to prevent streambed degradation. Rock vortex weirs were constructed in areas of intensive streambank stabilization in order to prevent further grade adjustments.

North Branch Waukegan River
South Branch Waukegan River

In the earlier 1990s, the Waukegan, Illinois Park District implemented a stream restoration program using Section 319 funding. The program was developed to address severe bank erosion that was threatening park infrastructure, sewer lines and pedestrian access. Waukegan, Illinois is located on the shore of Lake Michigan in Lake County, Illinois. The Waukegan River drains a 7,600 acre largely urbanized watershed that includes 80% of the city of Waukegan (pop. 60,000). The Waukegan Park District asked the Illinois State Water Survey (ISWS) to develop a stream restoration plan that would protect park infrastructure while restoring streambank stability along the river. The Park District chose two locations, Powell Park and Washington Park, for the initial restoration work. Both parks are located in older highly urbanized areas. The ISWS chose A-jacks and lunkers combined with vegetative stabilization as their primary practices for restoring streambanks.

In 1991 and 1992, stream restoration work was conducted along the North Branch of the Waukegan river in Powell and Washington Parks. Lunkers and A-jacks were installed at three major bank erosion sites and willows, dogwoods, and grasses were planted to hold the newly restored banks in place. Excelsior blanket (erosion control matting) and wood chips were used as mulch. Additional lunkers were installed along the North Branch in 1993 and 1996.

In 1994, lunkers, A-jacks, stone and vegetative plantings were used to stabilize a major streambank erosion site along the South Branch of the Waukegan River in Washington Park, three smaller streambank erosion sites along the South Branch were stabilized using biologs, and vegetative plantings. Approximately 1,000 feet of streambank received treatment along the South Branch.

Appendix B: Practice Descriptions

Bank Protection Practices

Rootwad Revetment

A rootwad is the lower trunk and root fan of a large tree. Individual rootwads are placed in series and utilized to protect stream banks along meander bends. A revetment can consist of just one or two rootwads or up to 20 or more on larger streams and rivers.

Rootwads are constructed by grading the streambank back and establishing a desired meander radius. A trench is excavated parallel with the streambank along the radius. Starting at the downstream end of the meander, a footer log (18-24" diameter, 8-10' long) is placed in this trench. A second trench is cut perpendicular to the first back into the streambank angling downstream. The rootwad is placed in this trench so the trunk side of the root fan rests against the footer log and the bottom of the root fan faces into the flow of water. Large boulders are then placed on the top and sides of the footer and rootwad to hold them in place. Moving upstream, the next footer log is placed in the trench with its downstream end extending behind the first footer log and the next root wad is put in place. This process continues until all rootwads have been installed. Some installation methods utilize a cut-off log on top of each rootwad to hold it in place, rather than boulders.

Once the rootwad revetment is in place the area between and behind the rootwads is backfilled with rock/fill. The top of the stream bank is graded to transition into the rootwads and this area and the area between the rootwads is stabilized with vegetation.

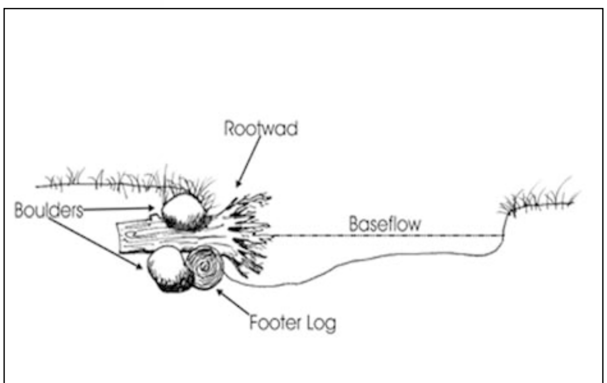

Figure B.1: Profile of Rootwad Revetment

Rootwad revetments have the potential to greatly enhance instream habitat. Rootwad revetments promote the formation of pool habitat along the outside of meander bends and the root fan portion of the rootwads provides overhead cover for the pools (Figures B.1 and B.2).

Imbricated Rip-Rap

Imbricated rip-rap consists of large two to three foot-long boulders arranged like building blocks to stabilize the entire streambank. This practice requires boulders that are generally flat or rectangular in shape to allow them to be stacked with structural integrity.

Imbricated rip-rap is installed similar to a boulder revetment, but rises to completely protect the stream bank. The first step in construction is to grade the stream bank to the desired slope. This slope is generally near vertical, as one of the main reasons for using imbricated rip-rap is the lack of space necessary to grade the streambank to a stable angle. Imbricated rip-rap is one of the few practices that can be installed on almost vertical streambanks, where most other measures would fail. After grading the slope, a trench is cut along the toe of the bank for instal-

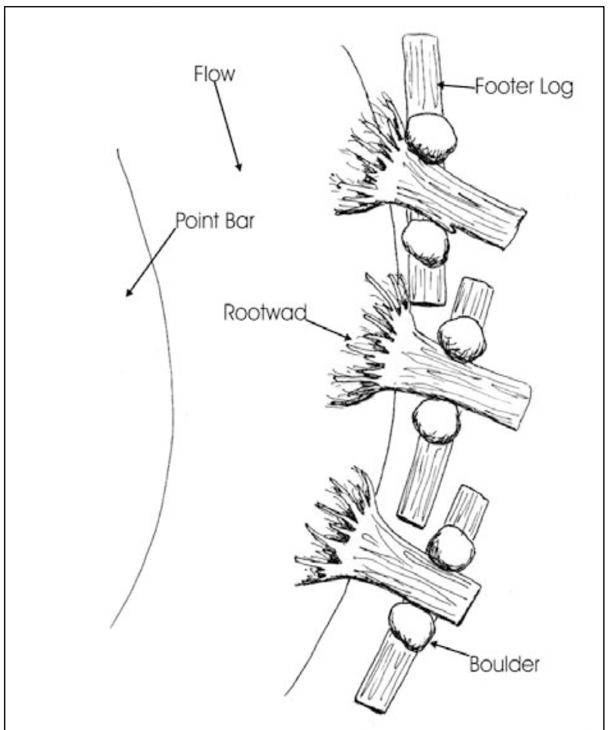

Figure B.2: Plan View of Rootwad Revetment

lation of the footer stones. Before placing footer stones in the trench, a layer of geotextile material is secured from the top of the streambank down into the footer trench. The individual footer stones are then placed on top of the filter cloth in the trench. Once a layer of footer stone is in place, the wall can be built with each stone overlapping the one underneath it by half. The stones that are placed above the footer stones but below baseflow level should be set so as to create void space between the adjacent stones. The process is continued until the desired wall height is reached. The top of the bank is then transitioned into the imbricated rip-rap wall and stabilized (Figures B.3 and B.4).

Imbricated rip-rap has only a modest potential to enhance stream habitat. The void spaces between the rocks that lie below the waterline provide hiding and cover areas for fish.

Boulder Revetment (single, double layer, large boulder, placed rock)

Along streams, the most erosion prone area is the toe of the streambank. Generally, the lowest third of the stream bank experiences the highest erosive forces. Failure at the toe of the streambank can result in failure of the entire bank and lead to large influxes of sediment to the stream. Boulder revetments serve to protect the most vulnerable portion of the stream bank. Boulder revetments are often combined with bank stabilization for the streambank area above the revetment. On smaller streams, where bank heights may not exceed a few feet, boulder revetments (single, double, and large) can provide both lower and upper bank protection.

A boulder revetment consists of a series of boulders placed along a streambank to prevent erosion of the toe of the bank and in some cases to protect the entire bank. A single boulder revetment is created by first excavating a trench below the invert of the stream along the toe of the

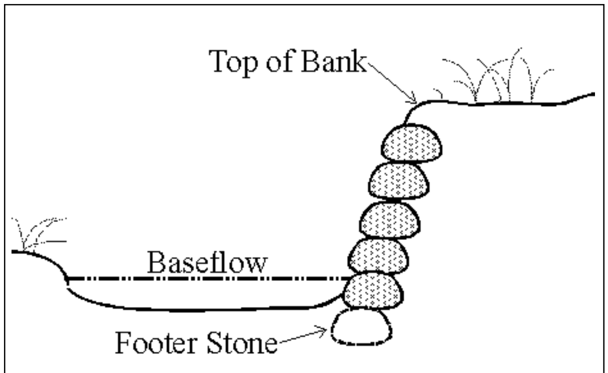

Figure B.3: Profile of Imbricated Rip-Rap

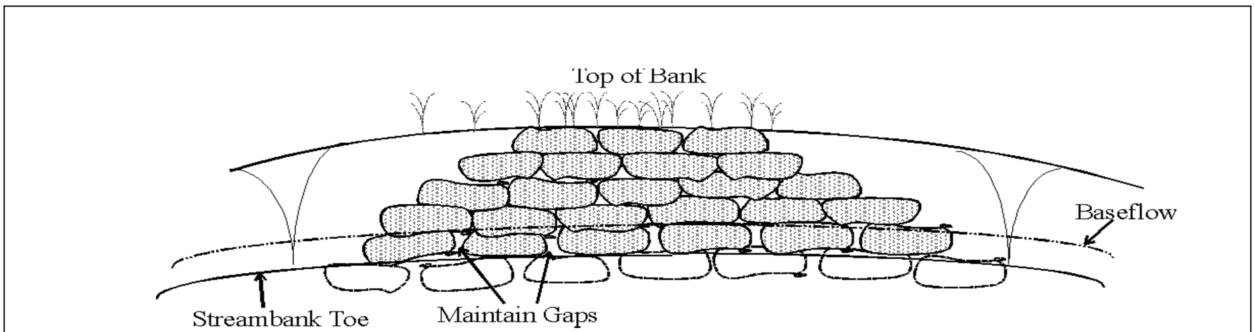

Figure B.4: Section View of Imbricated Rip-Rap

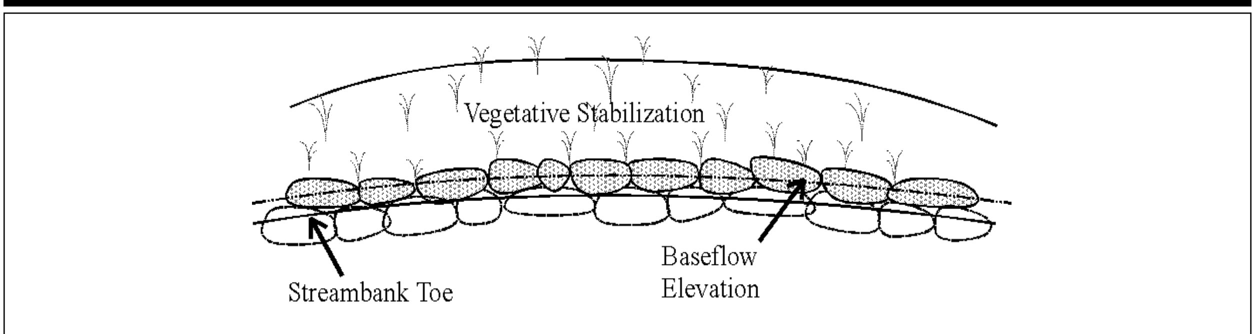

Figure B.5: Section View of Single Boulder Revetment stream bank. In this trench, a series of generally large flat or rectangular boulders is placed as a foundation for the revetment stones. Once the foundation stones have been installed, the revetment stones are placed on top the foundation. If protection is needed higher on the bank, a second set of stone may be placed on top of the first (e.g., double stone revetment) (Figures B.5 - B.8).

Often, a single row of large boulders three to four feet tall are used to create a revetment. If large boulders are used, it is important that they be entrenched below the stream invert to prevent scour from dislodging them. Otherwise, the construction of a large boulder revetment is similar to single and double boulder revetments (Figures B.9 and B.10).

Boulder revetments have only a modest potential to enhance stream habitat. As most boulder revetments are made of variously shaped boulders there is less potential to create void space below the waterline than with, for example, imbricated rip-rap. Boulder revetments have a more indirect role in habitat enhancement by reducing streambank erosion and subsequent sediment influx to the stream.

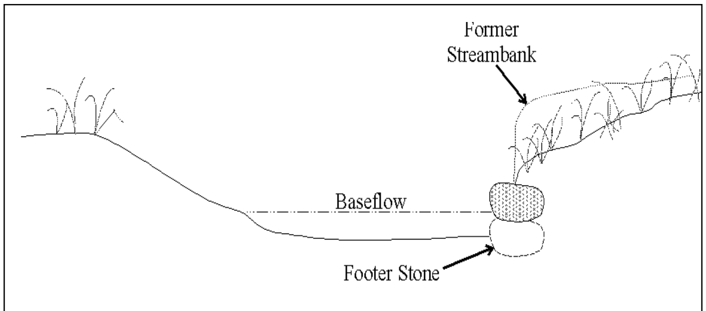

Figure B.6: Profile View of Single Boulder Revetment

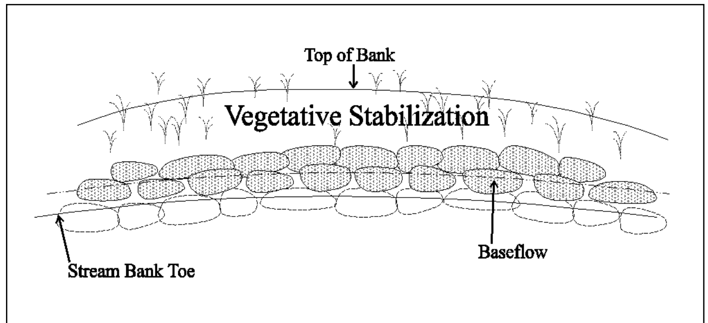

Figure B.7: Section View of Double Boulder Revetment

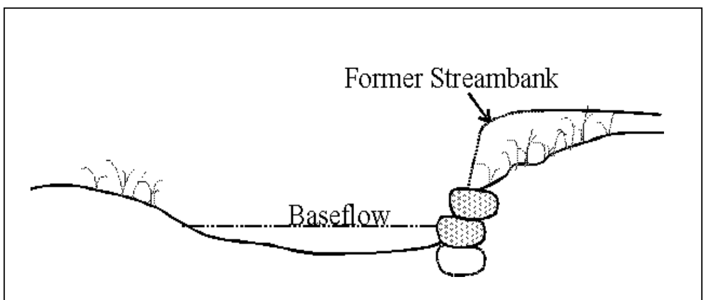

Figure B.8: Profile View of Double Boulder Revetment

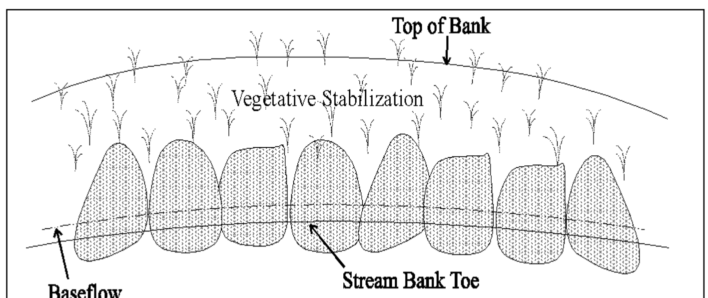

Figure B.9: Section View of Large Boulder Revetment

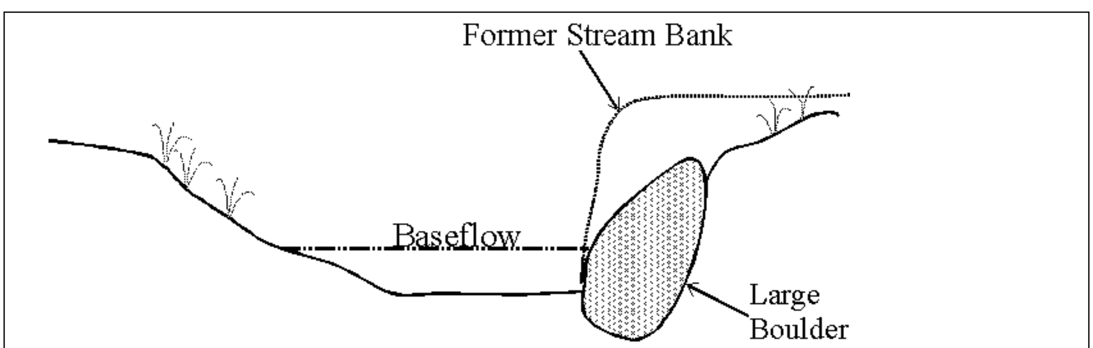

Figure B.10: Profile View of Large Boulder Revetment

Lunkers

Lunkers are crib-like, wooden structures installed along the toe of a stream bank to create overhead bank cover and resting areas for fish. These structures were originally developed in Wisconsin for trout stream habitat improvement projects, but have been found to work well in Midwestern streams as bank protection devices. A lunker consists of two planks with wooden spacers nailed between them. Additional planks are nailed across the spacers perpendicular and a crib like structure is formed.

The structure is installed by first grading the streambank back and creating a trench along the new bank line. This trench must be wide and deep enough so that the lunkers lay flat and are completely covered by water. The lunkers are secured to the stream bottom with rebar. Once in place, rock is placed on top of and behind the lunkers and the streambank is graded down to meet the front edge of the lunker. The upper bank is then stabilized using bank stabilization techniques (Figures B.11 and B.12).

Lunkers were originally developed as habitat enhancement structures. As such, they have a significant potential to improve stream habitat in the form of undercut banks and overhead cover.

A-jacks

A-jacks are three two-foot long cement stakes joined at the middle (six one-foot legs). They are a commercially made concrete product, originally made much larger (10-foot legs) to serve as breakwaters along shore fronts. They have been in use in the Midwest for several years. They serve to add structural stability to the lower stream bank.

A-jacks are manufactured in two pieces each weighing 45 lbs and are assembled onsite. The first step in the installation is to excavate a shallow trench along the toe of the stream bank. The A-jacks are assembled and placed in a row(s) along the trench so that each a-jack is interconnected with its neighbor. Rock, geotextile material or coir fiber is placed in the voids between the legs, and

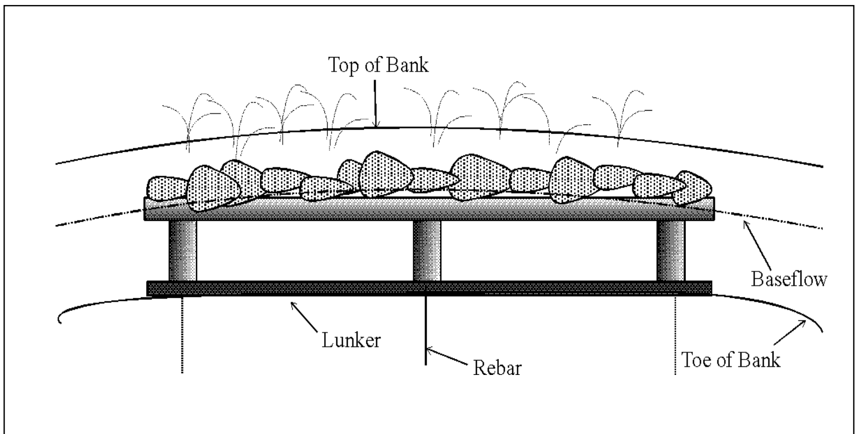

Figure B.11: Section View of Lunker Structure

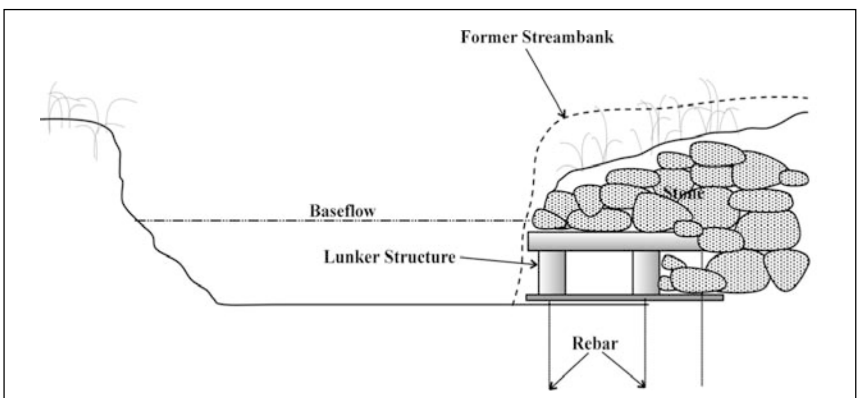

Figure B.12: Profile View of Lunker Structure

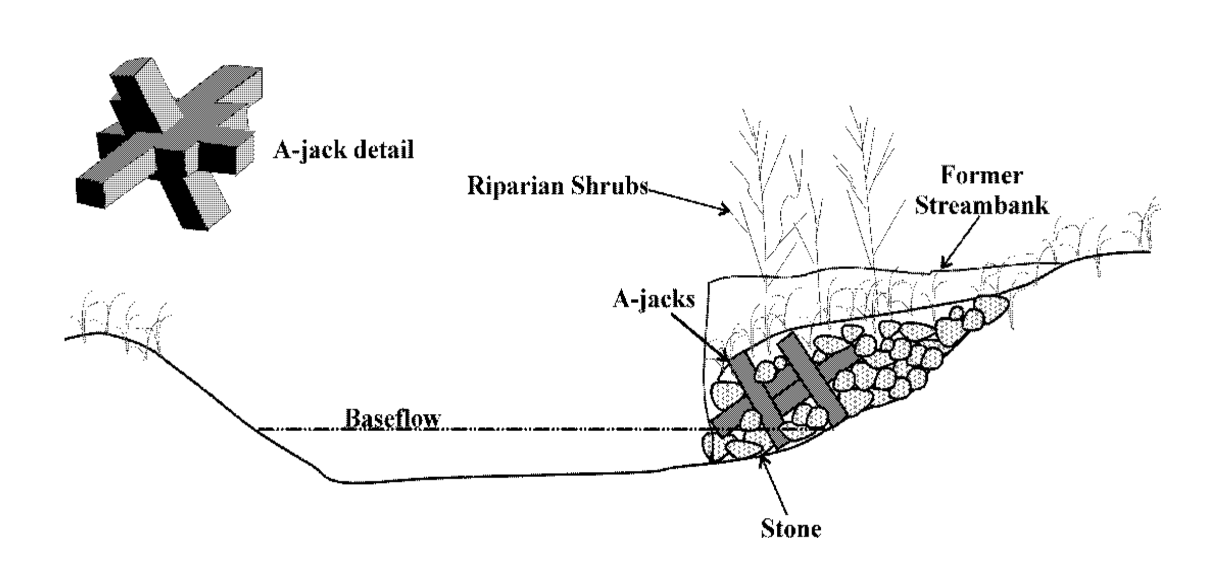

Figure B.13: Profile View and Section View of A-jacks

the a-jacks are backfilled. The upper bank is then stabilized using other bank stabilization techniques Figure B.13).

A-jacks have a modest potential to improve stream habitat, similar to that of placed rock or boulder revetments.

Grade Control Practices

Rock Vortex Weirs

A rock vortex weir is a structure designed to serve as grade control and create a diversity of flow velocities, while still maintaining the bed load sediment transport regime of the stream. The weir points upstream with the legs angling downstream at anywhere from a 15 to 30 degree angle relative to the stream bank. The legs are carried up the streambank to just above the bankfull elevation. The key component of the rock vortex weir is that the weir stones do not touch each other. Most design details call for a distance of between 1/3 and ½ the stone diameter separating each stone. An additional key design feature is that the weir stones do not rise above the channel invert more than 10 to 15% of the bankfull height.

During baseflow conditions water is forced to flow around and between the stones creating a greater diversity of flow velocities and depths. During high flows the water rises over the weir stones creating a scour pool below the structure but allowing bed load sediments to move through. Built in this way, the weir will not cause significant sedimentation upstream or reduce the channel cross section to the point of causing the channel to widen or erode around the structure, as is sometimes the case with structures that span the stream above the invert (e.g., log drop structures).

The rock vortex weir is constructed first by placing a foundation of boulders two to three feet in size in a trench excavated along the stream bottom. Large stones are then placed in the trench behind and against the footer stones so that they extend up to the desired elevation. A distance of 1/3 to ½ the stone width should be maintained between each stone. The rocks should extend up no more than 10 to 15% of the bankfull channel depth (Figures B.14 - B.16).

During baseflow, the interaction of the stream and rocks creates differing flow velocities, with higher flows creating a scour pool below the structure. By shifting the apex of the structure toward one bank or the other it can be used to direct flows into or out of a meander bend or away from an eroding bank. This device also works best as a grade control structure. Although, this must be judged against the amount of channel degradation expected. If a large nick point is migrating upstream toward the structure, measures must be taken to insure that the migrating nick point does not undermine the structure. In such cases a different type of structure such as a step pool should be utilized to halt the advance of the nick point. Rock vortex weir structures are more effective at preventing grade adjustments than halting them.

Rock vortex weirs have a moderate potential to enhance stream habitat. Correctly sited and constructed, they tend form scour pools downstream of the structure and increase the diversity of flow velocities above and within the structure.

Rock Cross Vanes

A rock cross vane is similar to a rock vortex weir, but differs in that the stones extend little if at all above the stream invert. These structures are predominately used to provide grade control and to narrow the base flow channel. If they are designed to narrow the channel sufficiently, they work to create scour pools downstream. Often a cross vein or a vortex weir will be placed at the top and bottom of a meander bend to establish invert elevations for pool/riffle formation.

The rock cross vane consists of a rock sill perpendicular to the stream flow located at the invert elevation of the stream. Two arms of the sill extend downstream along the banks, rising in elevation to the bankfull height as they extend downstream.

The rock sill is constructed by first excavating a trench below the stream invert. The width of this trench should be 2/3 to 3/4 of the channel width. The width is based upon the desired characteristics of the channel. Large flat rectangular boulders are placed in the trench so that they are touching. The number of stones and their size will depend on the size of the channel and the erosive capacity of the stream. The trench should be three times as deep as the stones are high and just wide enough to place the stones. Once these stones are in place, the trench is extended upstream of the placed stones so that a second layer of stones can be placed, half on substrate and half overlapping the first set of stones. A third set of stones is then placed so that 2/3 overlap the second course and 1/3 lie on the substrate, with there tops even or slightly above the desired invert. In smaller streams, only two courses of stone may be necessary. The number of courses and the size of the stone will depend on the size of the stream, the potential for scouring, and the composition of the substrate (Figures B.17 - B.19).

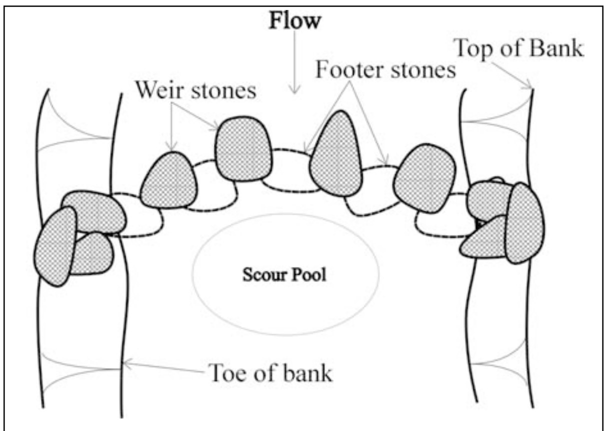

Figure B.14: Plan View of Rock Vortex Weir

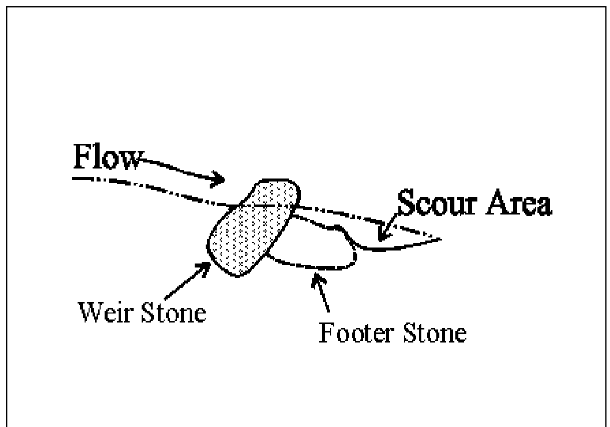

Figure B.16: Profile View of Rock Vortex Weir

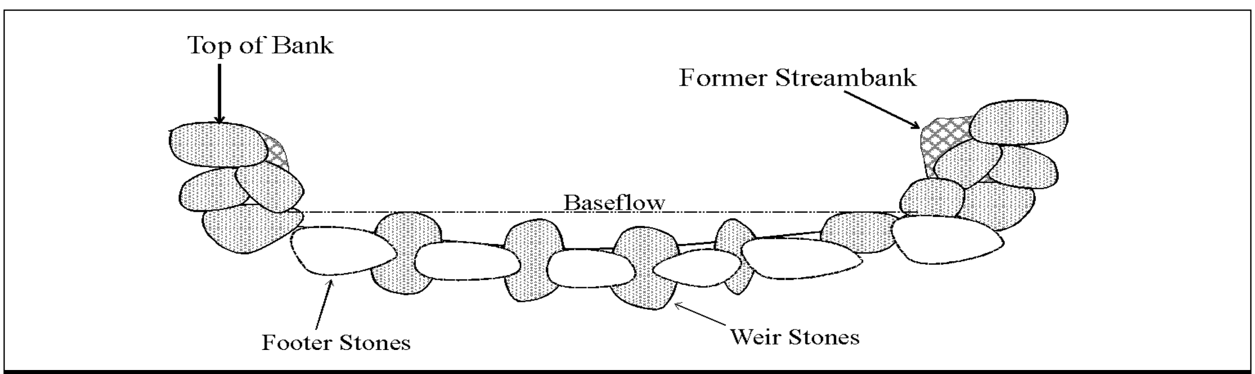

Figure B.15: Section View of Rock Vortex Weir

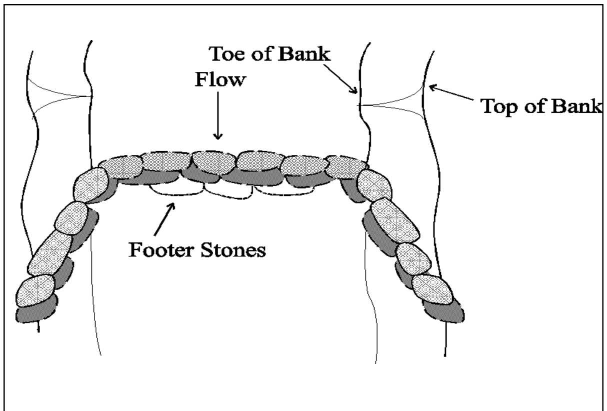

Figure B.17: Plan View of Rock Cross Vane

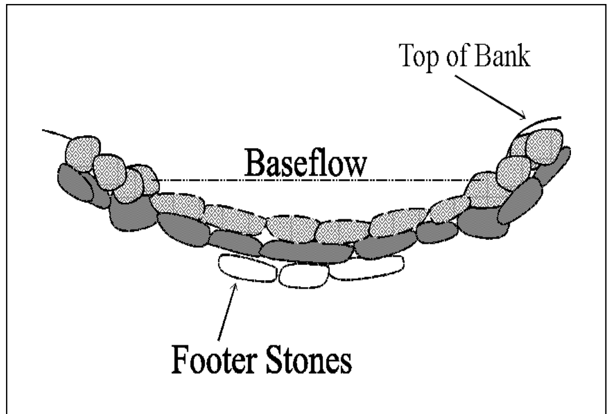

Figure B.18: Section View of Rock Cross Vane

Rock cross vanes have a modest potential to enhance stream habitat. Unlike the rock vortex weir, rock cross vanes interact little with baseflow but can promote pool formation downstream and the narrowing/deepening of the baseflow channel.

Step Pools

Step pools consist of a series of structures designed to dissipate energy in steep gradient sections of a stream. They are often used where a large nick point has formed and is migrating headward or where a channel has degraded below a culvert or outfall. They are made of large rock in alternating short steep drops and longer low or reverse grade sections. The number of steps is determined by the extent of the drop in invert of the stream. There are various configurations and arrangements of rock that can be utilized. The requirement is that whatever the design configuration chosen it must be stable at all flows, the rock must be large enough to be essentially immobile, and the drops should be low enough to allow aquatic life to migrate upstream (Figure B.20).

Step pools are not generally considered a habitat enhancement practice. The enhancement potential is in the form of maintaining fish passage and expanding the total amount of habitat available for fish.

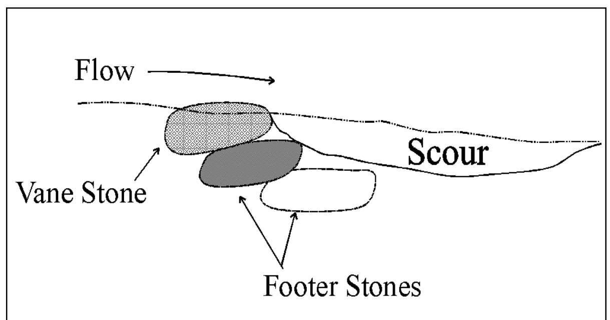

Figure B.19: Profile of Rock Cross Vane

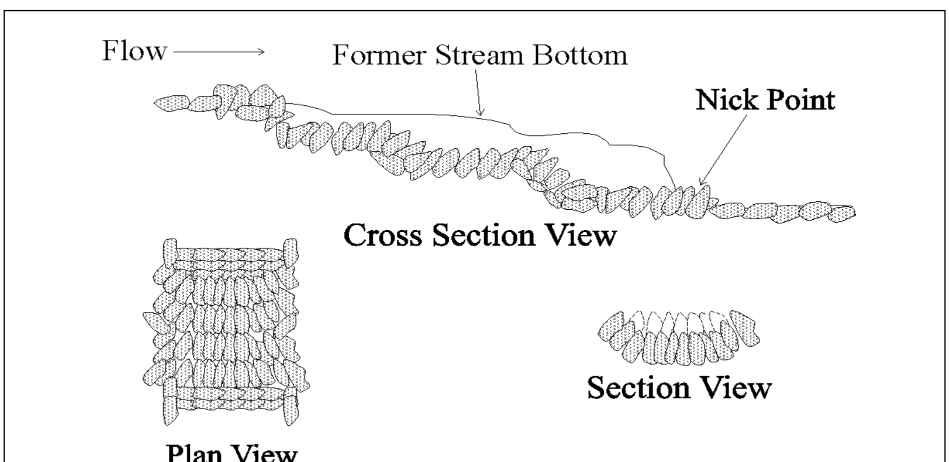

Figure B.20: Step Pool Details

Log Drops and V- Log Drops

A log drop is a simple pool forming and grade control structure. Log drops mimic the influence of large woody debris (trees) that fall into the stream. Most log drops are formed of two 16" or greater diameter logs. The first log is laid in a trench perpendicular to the flow so that the top of the log is at or slightly below the stream invert and the ends of the log extend several feet into the streambank. A second log is placed atop the first until the logs rise in height to just above the baseflow level of the stream. Once the desired elevation is achieved, a weir notch is cut in the top log. The notch serves to concentrate the baseflow. Higher flows will form a scour pool below the log drop. It is important that the logs be keyed into the stream banks far enough to prevent them from being scoured out at high flows. The log/streambank interface must also be sufficiently stabilized with rip-rap or boulders to prevent washout around the sides (Figures B.21 and B.22).

Logs drops are little used today because they can become fish barriers even if installed carefully and they tend to cause upstream sedimentation and channel widening due to the reduction in bankfull cross sectional area. During flows that exceed the capacity of the weir notch, there is no flow concentration and consequently the flows tend to spread over the whole length of the log promoting erosion at the streambanks.

If grade control, and not pool formation, is the primary function of a log drop, the footer log should be placed lower in the streambed and the top log should not rise above the invert of the stream. In this way they can provide grade control without the potential negative impacts when constructed as pool-forming structures.

A variation of the standard log drop structure is the V-log structure. Rather than having a single log that extends straight across the channel, two logs are used that form a V pointing upstream. The logs are lowest (at or below the stream invert) at the apex and rise into the stream banks. This structure has the advantage of not potentially creating a fish barrier and is more effective at concentrating flows and creating scour pools below the structure. Since it concentrates larger flows toward the middle of the channel, it is not likely to cause channel widening and bank erosion or deposition upstream (Figure B.23).

Both the standard log drop structure and the V-log drop structure have a significant potential to enhance stream habitat through pool formation downstream of the structure.

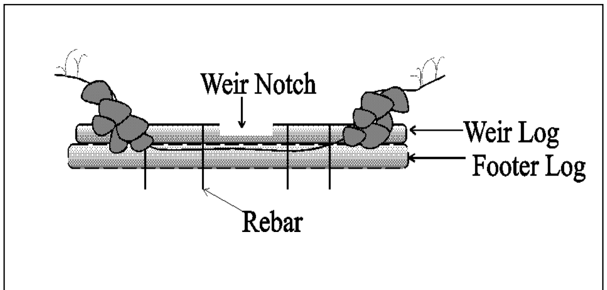

Figure B.21: Section View of Log Drop

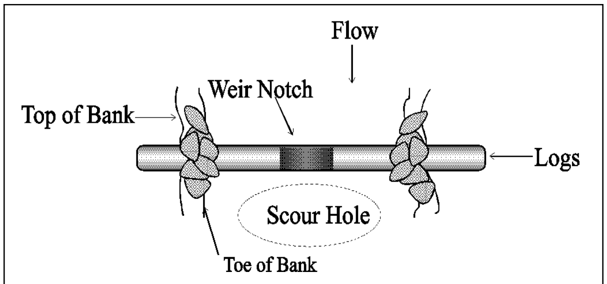

Figure B.22: Plan View of Log Drop

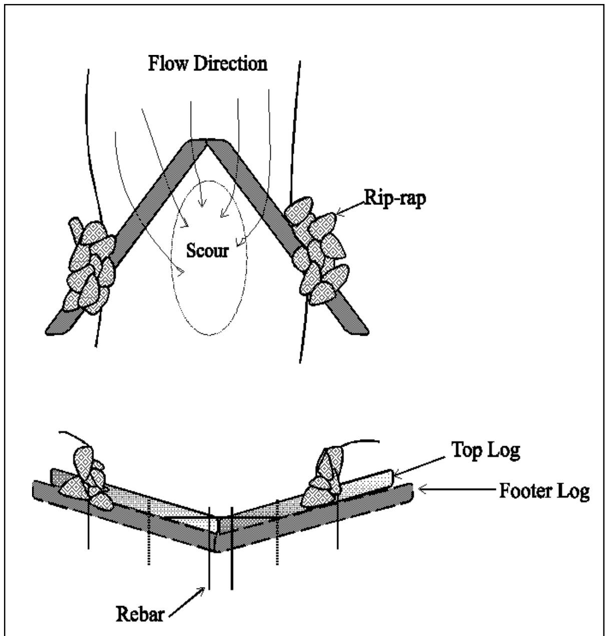

Figure B.23: Plan and Section View of V-Log Drop

Flow Deflection/Concentration Practices

Wing Deflectors (single)

A single wing deflector is a triangular structure that extends out from the streambank into the stream, with the widest portion along the bank and the point extending into the channel. The purpose is to change or (deflect) the direction of stream flow either to narrow and deepen the baseflow channel or to create sinuosity in the channel. When used to narrow and deepen the baseflow channel they can also promote the formation of overhead cover (undercut banks) on the opposite bank.

Wing deflectors can consist of a rock filled log frame or they can be made entirely of rock. In urban stream applications they more often consist entirely of rock. Single wing deflectors are not often used in urban applications as they tend to force water toward the opposite bank, and unless the opposite bank is sufficiently stable or armored, bank erosion can ensue.

They are constructed by first digging two trenches that meet at the apex for installation of the footer stones. The footer stones should be spaced so that there is about 1/3 of the stone diameter separating them. This allows the weir stones to interlock when placed on top. Once the weir stones have been placed to form the two arms of the triangle, the central portion can be back filled with excavated material and large stone placed on top to achieve the desired elevation.

The wing deflector should extend up to the bankfull elevation at the streambank or to the height of the streambank which ever is higher. The structure grades down to the channel invert about 1/3 of the way across the channel. However, the distance the deflector extends out into the channel will depend upon the site specific circumstances of the application (Figure B.24).

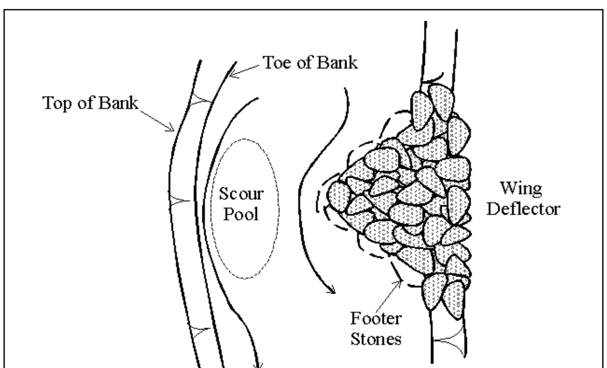

Figure B.24: Plan View of Single Wing Deflector

Wing Deflectors (double)

When two wing deflectors are placed opposite each other they serve to narrow or constrict the flow of water. The double wing deflector is more often used in urban applications as it forces the water toward the center of the channel and deepens the baseflow channel. Double wing deflectors also create an area of increased velocity between them, enhancing riffle habitat between and just upstream of the structure. This increased velocity also creates an area of scour, creating pool habitat downstream of the structure. The construction is the same as a single wing deflector except that in some instances, a rock sill at the stream invert may connect the two structures (Figures B.25 and B.26).

Both single and double wing deflectors have significant habitat enhancement potential. These structures enhance habitat through pool formation, the narrowing and deepening of the baseflow channel, and the enhancement of riffle habitat.

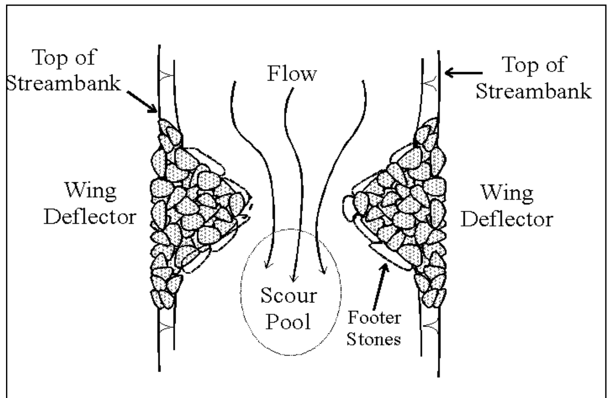

Figure B.25: Plan View of Double Wing Deflector

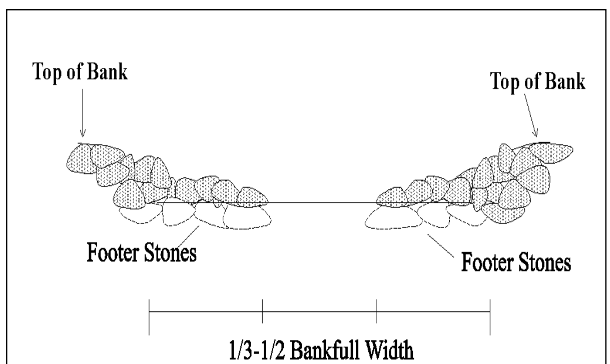

Figure B.26: Section View of Double Wing Deflector

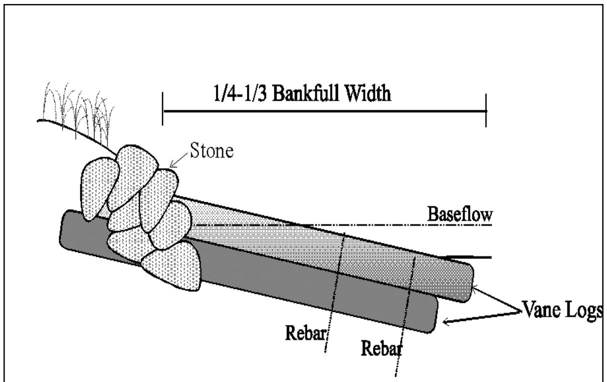

Figure B.27: Section View of Log Vane

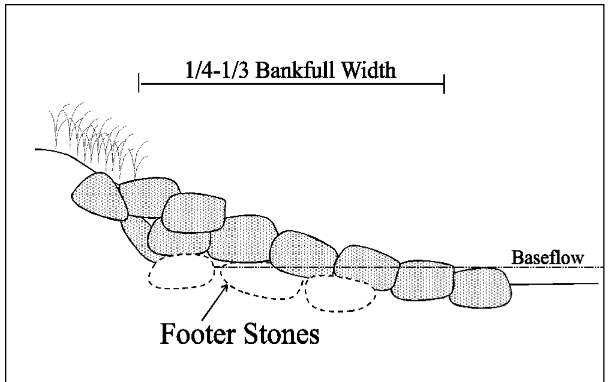

Figure B.28: Section View of Rock Vane

Log, Rock, and J- Rock Vanes

Vanes are linear structures that extend out from the streambank into the stream channel in an upstream direction. They essentially mimic the effect of a tree partially falling into the stream. They are usually placed along the streambank where erosion is occurring along the toe of the slope. The purpose of vanes is to reduce erosion along the streambank by redirecting the stream flow toward the center of the stream. In addition, they tend to create scour pools on the downstream side. Vanes can be made of rock or log. They grade down from the bankfull elevation at the streambank to the channel invert at their terminus in the stream. Vanes generally extend out from the stream bank 1/3 of the bankfull width and are angled upstream from the bank at a 20 to 30 degree angle. They should be carefully located and installed so as not to produce additional erosion on the upstream side where they meet the bank (eddy scour) or allow flows to outflank them, exacerbating existing bank erosion problems. The only difference between the log vane and the rock vane is the material used. The J - vane is basically the same as a rock vane with the exception that it curls around at the end in the shape of a "J." The curved end portion serves to enhance downstream scour pool formation (Figures B.27 - B.29).

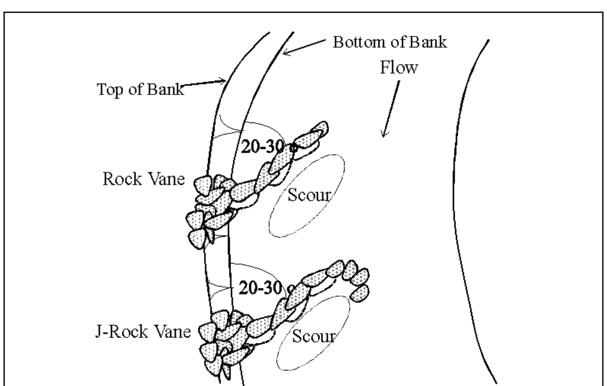

Figure B.29: Plan View of Rock Vane and J-Rock Vane

The rock vane is constructed by first excavating a trench for the footer stones. The footer stones are then placed in the trench so that there is a gap between them equal to 1/3 of the stone diameter. This gap will allow the vane stones to interlock with the footer stones. The vane stones should be placed on top of the footer stones so they are staggered over two adjacent footer stones and skewed slightly upstream of the footer stones. As the vane is built out and slopes down from the bank, footer stones will become unnecessary when the vane stones can be placed in the trench and extend up to achieve the desired elevation.

Rock, log and J-vanes have significant habitat enhancement potential through the creation of downstream scour pools, narrowing and deepening of the baseflow channel, and the enhancement of riffle habitat along the upstream side.

Cut-off Sills

Cut-off sills are low rock sills similar to a linear deflector and often used in conjunction with linear deflectors. They extend out from the streambank into the stream channel at an angle of 20 to 30 degrees from the bank in an upstream direction. They can either intersect with a linear deflector or terminate at the baseflow channel. The purpose of a cut-off sill is to promote deposition and bar formation along the edge of a channel in order to narrow and better define the baseflow channel. They do not extend above bankfull height and are usually much below it. They are also used to stabilize existing bars. In such instances they are installed in the existing bar and extend only slightly above it (Figures B.30 and B.31).

Cut-off sills have a modest potential to enhance stream habitat. When utilized in channels with shifting base-flow channels and high bedload movement they can be very effective at stabilizing lateral bars and better defining the baseflow channel.

Linear Deflector

A linear deflector is simply a line of boulders placed within the stream channel rather than along the bank. The purpose of this structure is to narrow, deepen and better define the base flow channel. The top of the deflector generally does not extend above the bankfull elevation and is usually much below it. The area between the deflector and the stream bank either is back filled with materials excavated during the installation, imported stone/fill, or allowed to naturally sediment in (Figure B.32).

Placement of a linear deflector must take into consideration the condition of the opposite stream bank. If the opposite bank is potentially unstable, bank stabilization measures may be necessary. If the opposite bank is unstable and left untreated, there is the potential for bank erosion and channel widening. Linear deflectors are most often used in stream channels that are overly wide, have shallow or shifting base flow channels and high bed load sediment movement.

Linear deflectors have a significant potential to enhance stream habitat in streams with shallow, poorly defined baseflow channels. By better defining and deepening the baseflow channel, linear deflectors improve fish passage and expand the total amount of habitat available for fish.

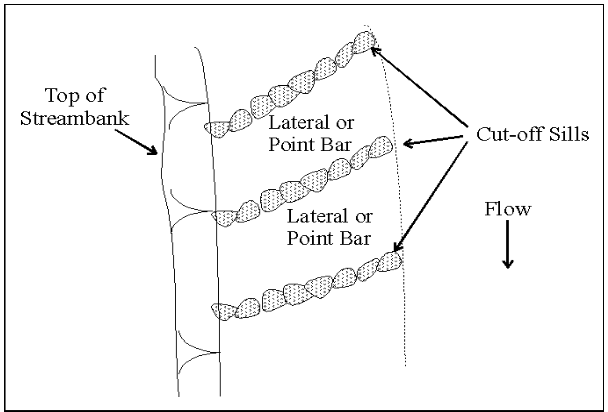

Figure B.30: Plan View of Cut-Off Sill

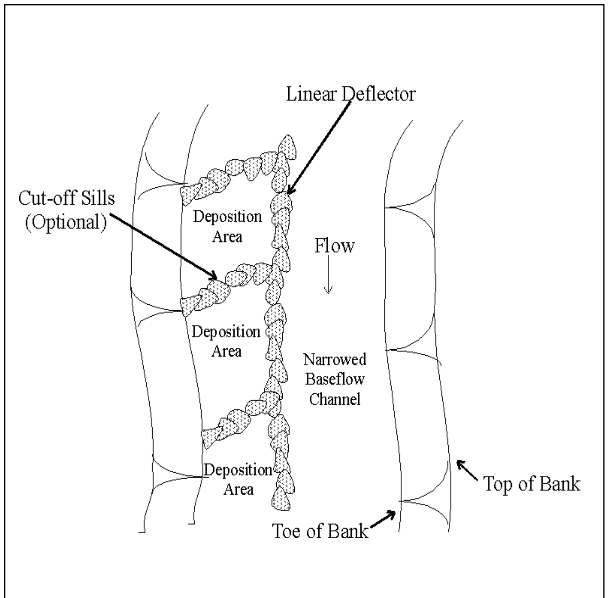

Figure B.32: Plan View of Linear Deflector

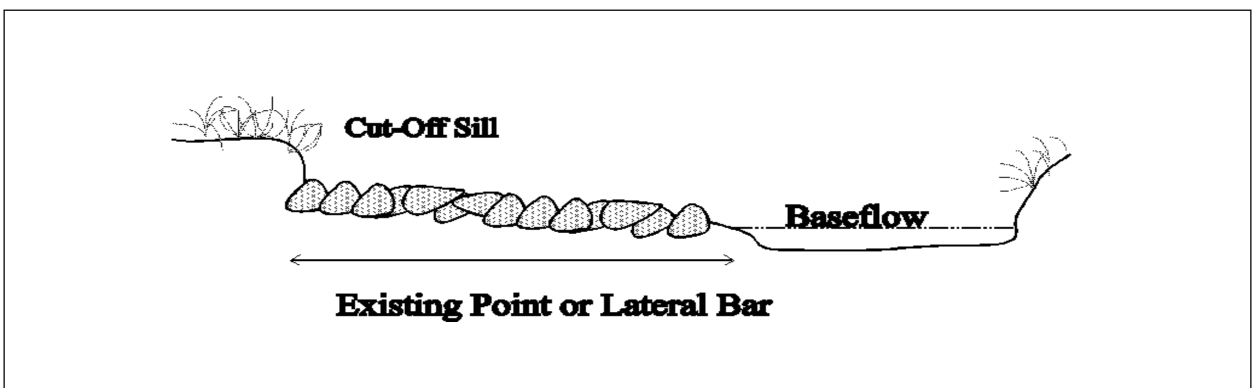

Figure B.31: Section View of Cut Off Sill

Bank Stabilization Practices

Coir Fiber Rolls

Coir fiber rolls are commercially made erosion control products. They consist of tightly bound cylinders of coconut fiber (coir fiber) held together by a coir fiber netting. They are generally available in 10 to 20 foot lengths and are 10 to 12 inches in diameter. They are excellent at providing toe protection where scour is not severe. Once installed, the coir fiber log becomes saturated with water and vegetation can be planted directly in them. Coir fiber rolls provide a natural, unobtrusive appearance and decompose over a three to six-year period leaving the roots of colonizing vegetation to secure the toe of the streambank. They are relatively lightweight (10' length = 75 lbs) and can be installed with a minimum of site disturbance. The only limitations to coir fiber rolls are that in areas of severe scour they are not appropriate and there must be sufficient sunlight available for colonizing plant growth.

Coir fiber rolls are installed by excavating a shallow (3 to 4 inches deep) trench along the toe of the stream bank. The coir fiber log is placed in the trench so that the bottom and back are in tact with the stream substrate and the streambank. Stakes are then driven down along its sides. Coir or nylon twine is woven between and around the stakes and the stakes are driven in firmly, securing the coir fiber log to the streambed. The streambank above the coir fiber log is stabilized using other bank stabilization techniques (Figures B.33 and B.34).

Live Fascines

Live fascines are tightly bound bundles of live but dormant willow, alder, or dogwood branch cuttings. Each fascine is approximately eight to 10 feet long and eight to 10 inches in diameter. The bundles are bound with either wire or twine. The fascines can be used as toe protection in areas where toe scour is not severe, or combined with bank protection measures and placed higher on the bank where scour is a greater threat. The typical installation is to place the fascines in a shallow trench along the streambank parallel to the stream. Once installed the dormant cuttings will root and grow, adding structural stability to the streambank and preventing down slope erosion and rill formation. On taller streambanks, multiple rows of fascines can be installed for stabilization. Live fascines are intended to take root and grow, but should this not happen, the woody cuttings will still provide several years of physical stabilization to the streambank. As live fascines utilize dormant cuttings, they must be installed during the non-growing season; generally early spring is best (Figures B.35 and B.36).

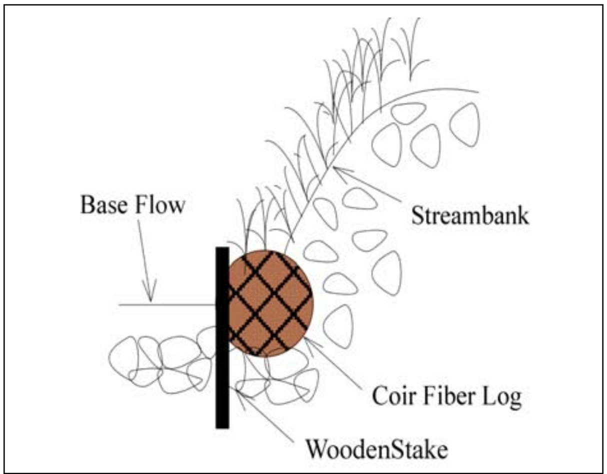

Figure B.34: Profile of Coir Fiber Log Installation

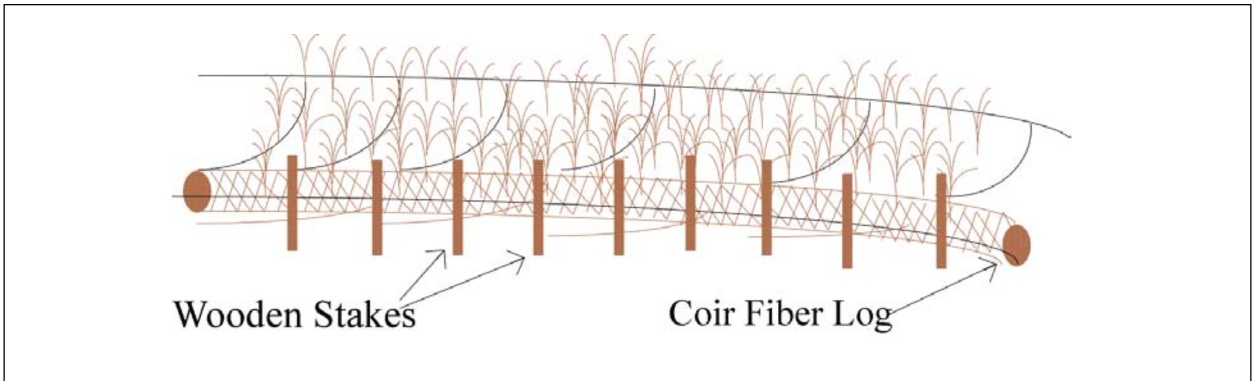

Figure B.33: Section View of Coir Fiber Log Installation

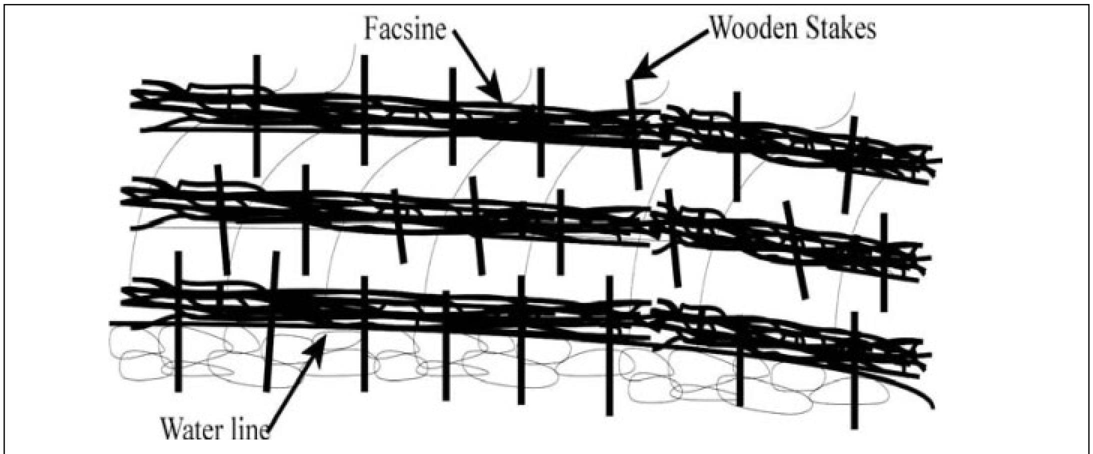

Figure B.35: Section View of Live Fascine Installation

When used along the toe of the streambank, live fascines have significant potential to enhance stream habitat by promoting the creation of undercut banks and overhanging bank cover. When used higher on the streambank they can provide overhanging bank cover and a source of organic material to the stream.

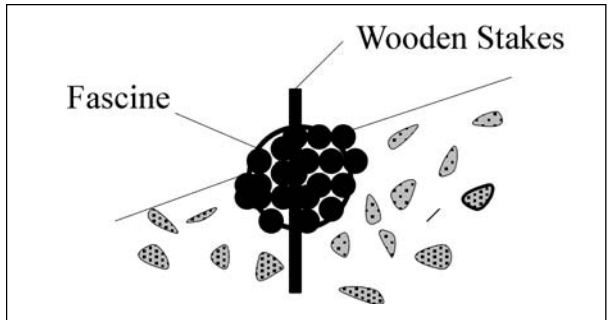

Figure B.36: Profile of Live Fascine Installation

Brush Mattresses

A brush mattress is another technique that utilizes dormant branch cuttings. Rather than a tight bundle, a brush mattress is a thick mat of dormant cuttings placed on the bank and held down with stakes. The intention of a brush mattress is to create structural streambank protection that in time will root and provide vegetative stabilization.

The brush mattress is installed by first grading the streambank to the desired stable angle. Brush mattresses are most successful on slopes not exceeding 2:1. A shallow trench is then cut behind the toe protection (coir fiber log, boulder revetment, etc.) and the cut ends of the branch cutting placed in the trench. This trench is to ensure good soil contact and water for the branches to root. The branches are laid down perpendicular to the stream flow until the bank is barely visible through the branches. Stakes are then driven partially into the brush mat on two-foot centers. Wire or strong twine is then woven between and around the stakes. In order to insure good soil contact, as much loose dirt as possible is then agitated into the brush mat. Once the dirt has been added, the stakes are driven in fully to tightly press the brush mattress against the streambank. It is important for the growth of the brush mattress that as much brush mat/bank soil contact is made as possible. As brush mattresses utilize dormant cuttings, they must be installed during the non-growing season; early spring is best (Figures B.37 and B.38).

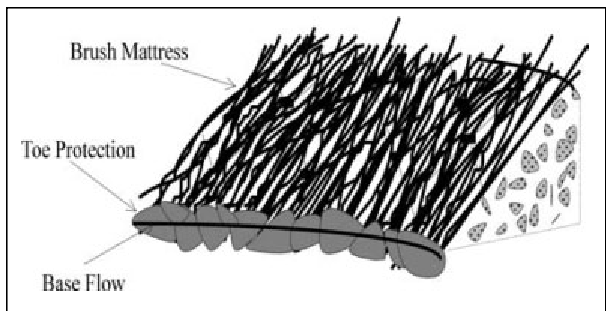

Figure B.37: Section View of Brush Mattress

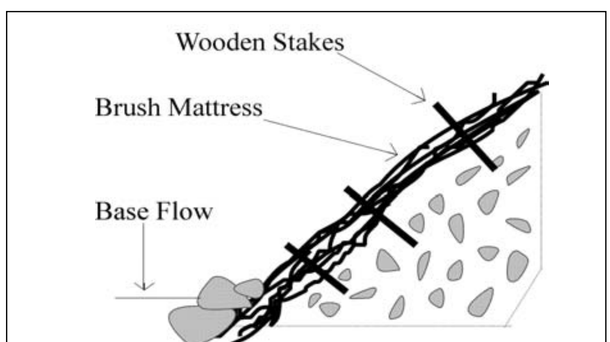

Figure B.38: Profile of Brush Mattress

Erosion Control Matting

Erosion control matting is a geotextile fabric made of either natural or man-made material with the purpose of providing temporary soil stabilization while vegetative stabilization germinates or roots.

Erosion control matting is manufactured in many forms. A commonly used product in stream restoration is matting made from coir (coconut) fiber. The advantage of coir fiber is that it is long lasting but biodegradable. Similar matting is also made out of wood fiber (curlex). However, many of the wood fiber products are not fully biodegradable, as they utilize a nylon mesh to hold the fibers in place. There are also several types of non biodegradable erosion control matting, generally made of plastic. These mats are utilized in the same way.

Appendix C: Field Assessment Sheet

WATERSHED FEATURES	**Predominant Surrounding Landuse** X Forest ‘ Commercial ‘ Field/Pasture ‘ Industrial ‘ Agricultural X Residential ‘ Turf ‘ Other **Local Watershed NPS Pollution** ‘ No evidence ‘ Some potential sources X Obvious sources **Local Watershed Erosion** ‘ None X Moderate ‘ Heavy
RIPARIAN VEGETATION (18 meter buffer)	**Indicate the dominant type and record the dominant species present** X Mature Trees X Young Trees ‘ Shrubs ‘ Grasses ‘ Herbaceous **dominant species present** Sycamore, River Birch, Maple
INSTREAM FEATURES	**Stream Length effected by Practice** **Upstream** 100 ft **Downstream** 100 ft **Stream Width at Practice** 50ft **Ave. thalweg Depth at Practice** 2 ft **Canopy Cover** x Open ‘ Partly shaded ‘ Shaded **Amount of Trash and debris** some **StreamType** ‘ Coastal Plain ‘ Piedmont x Fall Line **Channelized** ‘ Yes X No **SW Control Present** ‘ ‘ (-) **High Water Mark** _9_ft
LARGE WOODY DEBRIS	**# of LWD Pieces** 2 **Est. Stream Distance** 300 ft (Min. 3ft long, 6 inches Dia., within site of practice area, U/D stream)
AQUATIC VEGETATION	**Indicate the dominant type present** ‘ Rooted emergent ‘ Rooted submergent ‘ Attached Algae **Portion of the practice length with aquatic vegetation** 0 %

RIPARIAN CONDITION: (Describe)

Forested buffer with trails and some open areas (parkland). Narrow in places, but Good condition buffer

Urban Stream Restoration Practice - Field Assessment Sheet (Page 2)	
Site Name: Little Paint Branch	Date: 3/14/00
Station #	
Practice Objective: Flow Deflection/Concentration	Practice Type: Wing Deflector

Structural Assessment

1. Percent of original practice materials remaining intact

0-10%   10-25%   25-50%   50-75%   75-100%

Describe: 1,2,3,4

all practices intact, large rock structures

2. Amount of movement or dislocation of practice materials

None   Slight   Significant   Complete

Describe: 1,3   2,4
(Cross sills only)

#2 and 4 had the cross sills scoured and moved downstream. This turned out to be a good thing

3. Degree of unintended erosion/scour

Upstream	None	Slight	Moderate	Significant
Downstream	None	Slight	Moderate	Significant
Within practice	None	Slight	Moderate	Significant

Describe: 2,3   1   4

#4 has scouring above wing on left, this is part of rootwad scour.
some slight scouring on wing at #1, not a problem

4. Degree of unintended deposition/sedimentation

Upstream	None	Slight #1	Moderate #3,4	Significant
Downstream	None	Slight	Moderate	Significant
Within practice	None	Slight	Moderate	Significant

Describe: #1 had upstream depostition from cross sill, it was acting more like a weir
#2 is good, #3 had sedimentation upstream due to cross sill and proximity to next upstream wing def., #4 had one wing sedimented into bar

Urban Stream Restoration Practice - Field Assessment Sheet (Page 3)

Site Name: Little Paint Branch	Date: 3/14/00
Station #	
Practice Objective: Flow Deflection/Concentration	Practice Type: D Wing Def.

Effectiveness/Functional Assessment

1. Is the practice serving its design purpose?

Yes No Partially

Describe: 2,4 1,3
#2,4 had sill washed away, so they functioned to narrow and deepen channel
#1,3 had cross sills intact so while they created scour holes they did not deepen and confiend channel as they should have.

Stream Habitat Assessment

1. If the practice is intended to enhance habitat, to what degree is it doing so?

None Partially Fully

Describe: 1,3 2,4
2 and 4 are creating both deep water below and narrowing channel at the structure
1 and 3 due to cross sills are only creating scour holes below

2. Is the practice providing unintended habitat benefits?

Yes No

Describe:

Urban Stream Restoration Practice - Field Assessment Sheet (Page 4)

Site Name: Little Paint Branch	Date: 3/14/00
Station #	
Practice Objective: Flow Deflection/Concentration	Practice Type: D Wing Def.

Stream Habitat Assessment

3. Is the practice providing unintended habitat impacts?

Yes xx No

Describe:

upstream sedimentation from cross sill

Vegetative Practice Assessment

1. What percent of installed plant material is living?

0-10% 10-25% 25-50% 50-75% 75-100%

Describe:

no real planting associated with practices, area around is stabilized

2. Is the practice fulfilling its design purpose, regardless of plant survival?

Yes No Partially

Describe:

yes, large rock structures

3. What is the degree of soil erosion in the planting area?

Upstream	None	Slight	Moderate	Significant
Downstream	None	Slight	Moderate	Significant
Within practice	None	Slight	Moderate	Significant

Describe:

Appendix D: Results Tables

STREAM RESTORATION ASSESSMENT PRACTICE RESULTS

Objective: **Bank Protection**

# of practice types 5
# of ind. Practices 137

Structural Assessment

Question: **Percent of original practice materials remaining intact?**

	0-10%	10-25%	25-50%	50-75%	75-100%
Imb. rip-rap (6)					6
rootwad revet.(96)		1	4	12	79
Boulder revet.(16)				1	15
Lunkers (9)			1	1	7
A-jacks (10)				1	9
	0	1	5	15	116

Question: **Amount of movement or dislocation of practice materials?**

	none	slight	moderate	significant	complete
Imb. rip-rap (6)	5	1			
rootwad revet.(96)	68	11	7	10	
Boulder revet.(16)	12	2	1	1	
Lunkers (9)	5	2		2	
A-jacks (10)	9			1	
	99	16	8	14	0

Question: **Degree of unintended erosion/scour?**

	none	slight	moderate	significant
Imb. rip-rap (6)	6			
rootwad revet.(96)	49	13	20	14
Boulder revet.(16)	13	2		1
Lunkers (9)	7	1	1	
A-jacks (10)	6	2		2
	81	18	21	17

Question: **Degree of unintended deposition/sedimentation?**

	none	slight	moderate	significant
Imb. rip-rap (6)	4	2		
rootwad revet.(96)	63	7	12	14
Boulder revet.(16)	15	1		
Lunkers (9)	4	2	2	1
A-jacks (10)	7	2	1	
	93	14	15	15

Effectiveness/Functional Assessment

Question: **Is the practice serving its design purpose?**

	yes	no	partially
Imb. rip-rap (6)	6		
rootwad revet.(96)	70	10	16
Boulder revet.(16)	13	1	2
Lunkers (9)	6		3
A-jacks (10)	8	1	1
	103	12	22

Question: **Has the practice resulted in unintended benefits?**

	yes	no
Imb. rip-rap (6)		6
rootwad revet.(96)		96
Boulder revet.(16)		16
Lunkers (9)		9
A-jacks (10)		10
	0	137

Question: **Has the practice resulted in unintended impacts?**

	yes	no
Imb. rip-rap (6)		6
rootwad revet.(96)	20	76
Boulder revet.(16)	1	15
Lunkers (9)		9
A-jacks (10)		10
	21	116

Stream Habitat Assessment

Question: **If the practice is intended to enhance habitat, to what degree is it doing so?**

	none	partially	fully
Imb. rip-rap (6)		3	3
rootwad revet.(96)	18	23	55
Boulder revet.(16)	1	4	11
Lunkers (9)		4	5
A-jacks (10)	2		8
	21	34	82

Question: **Is the practice providing unintended habitat benefits?**

	yes	no
Imb. rip-rap (6)		6
rootwad revet.(96)		96
Boulder revet.(16)		16
Lunkers (9)		9
A-jacks (10)		10
	0	137

Question: **Is the practice providing unintended habitat impacts?**

	yes	no
Imb. rip-rap (6)		6
rootwad revet.(96)	22	74
Boulder revet.(16)		16
Lunkers (9)		9
A-jacks (10)		10
	22	115

Vegetative Practice Assessment

Question: **What percent of installed plant material is living?**

	0-10%	10-25%	25-50%	50-75%	75-100%
Imb. rip-rap (6)				1	5
rootwad revet.(96)	2	5	9	20	60
Boulder revet.(16)		2		3	11
Lunkers (9)				1	8
A-jacks (10)	2		1	2	5
	4	7	10	27	89

Question: **Is the practice fulfilling its design purpose regardless of plant survival?**

	yes	partially	no
Imb. rip-rap (6)	6		
rootwad revet.(96)	70	16	10
Boulder revet.(16)	13	1	2
Lunkers (9)	6	3	
A-jacks (10)	8	1	1
	103	21	13

Question: **What is the degree of soil erosion in the planting area?**

	none	slight	moderate	significant
Imb. rip-rap (6)	3	3		
rootwad revet.(96)	29	35	21	11
Boulder revet.(16)	10	5		1
Lunkers (9)	4	3	2	
A-jacks (10)	5	1	2	2
	51	47	25	14

STREAM RESTORATION ASSESSMENT PRACTICE RESULTS 5/5/2000

Objective: **GRADE CONTROL**

# of practice types 5
# of ind. Practices 241

Structural Assessment

Question: **Percent of original practice materials remaining intact?**

	0-10%	10-25%	25-50%	50-75%	75-100%
Rock Vortex Weir (201)		2	11	25	163
Step Pool (15)					15
Rock Cross Vane (15)				1	14
Log Drop (2)					2
V-Log Drop (9)					9
Rock Weir (8)				3	5
	0	2	11	29	208

Question: **Amount of movement or dislocation of practice materials?**

	none	slight	moderate	significant	complete
Rock Vortex Weir (201)	147	14	13	13	14
Step Pool (15)	15				
Rock Cross Vane (15)	14	1			
Log Drop (2)	2				
V-Log Drop (9)	9				
Rock Weir (8)	1	4	1	2	
	188	19	14	15	14

Question: **Degree of unintended erosion/scour?**

	none	slight	moderate	significant
Rock Vortex Weir (201)	138	12	27	24
Step Pool (15)	15			
Rock Cross Vane (15)	14	1		
Log Drop (2)			2	
V-Log Drop (9)	6	2	1	
Rock Weir (8)		4	3	1
	173	19	33	25

Question: **Degree of unintended deposition/sedimentation?**

	none	slight	moderate	significant
Rock Vortex Weir (201)	160	10	14	17
Step Pool (15)	15			
Rock Cross Vane (15)	15			
Log Drop (2)	1		1	
V-Log Drop (9)	9			
Rock Weir (8)		1	7	
	200	11	22	17

Effectiveness/Functional Assessment

Question: **Is the practice serving its design purpose?**

	yes	partially	no
Rock Vortex Weir (201)	149	26	26
Step Pool (15)	15		
Rock Cross Vane (15)	14	1	
Log Drop (2)	1	1	
V-Log Drop (9)	9		
Rock Weir (8)	3	2	3
	191	30	29

Question: **Has the practice resulted in unintended benefits?**

	yes	no
Rock Vortex Weir (201)		201
Step Pool (15)		15
Rock Cross Vane (15)		15
Log Drop (2)		2
V-Log Drop (9)		9
Rock Weir (8)		8
	0	250

Question: **Has the practice resulted in unintended impacts?**

	yes	no
Rock Vortex Weir (201)	31	170
Step Pool (15)		15
Rock Cross Vane (15)	1	14
Log Drop (2)	2	
V-Log Drop (9)		9
Rock Weir (8)	4	4
	38	212

Stream Habitat Assessment

Question: **If the practice is intended to enhance habitat, to what degree is it doing so?**

	none	partially	fully
Rock Vortex Weir (201)	49	62	90
Step Pool (15)			15
Rock Cross Vane (15)		1	14
Log Drop (2)		2	
V-Log Drop (9)			9
Rock Weir (8)	1	5	2
	50	70	130

Question: **Is the practice providing unintended habitat benefits?**

	yes	no
Rock Vortex Weir (201)		201
Step Pool (15)		15
Rock Cross Vane (15)		15
Log Drop (2)		2
V-Log Drop (9)		9
Rock Weir (8)		8
	0	250

Question: **Is the practice providing unintended habitat impacts?**

	yes	no
Rock Vortex Weir (201)	4	197
Step Pool (15)		15
Rock Cross Vane (15)		15
Log Drop (2)	1	1
V-Log Drop (9)		9
Rock Weir (8)	6	2
	11	239

Vegetative Practice Assessment

Question: **What percent of installed plant material is living?**

	0-10%	10-25%	25-50%	50-75%	75-100%
Rock Vortex Weir (201)					
Step Pool (15)				2	13
Rock Cross Vane (15)					
Log Drop (2)					
V-Log Drop (9)					
Rock Weir (8)					
	0	0	0	2	13

Question: **Is the practice fulfilling its design purpose regardless of plant survival?**

	yes	no	partially
Rock Vortex Weir (201)			
Step Pool (15)	15		
Rock Cross Vane (15)			
Log Drop (2)			
V-Log Drop (9)			
Rock Weir (8)			
	15	0	0

Question: **What is the degree of soil erosion in the planting area?**

	none	slight	moderate	significant
Rock Vortex Weir (201)	130	16	27	28
Step Pool (15)	11	4		
Rock Cross Vane (15)	12	2	1	
Log Drop (2)			2	
V-Log Drop (9)	7	2		
Rock Weir (8)		3	5	
	160	27	35	28

STREAM RESTORATION ASSESSMENT PRACTICE RESULTS

Objective: **FLOW DEFLECTION/CONCENTRATION**

# of practice types 6
# of ind. Practices 47

Structural Assessment

Question: **Percent of original practice materials remaining intact?**

	0-10%	**10-25%**	**25-50%**	**50-75%**	**75-100%**
Single Wing Deflector (1)					1
Double Wing Deflector (6)					6
Log Vane (15)					15
Rock Vane (19)				1	18
Cut-off Sills (4)					4
Linear Deflector (2)					2
	0	0	0	1	46

Question: **Amount of movement or dislocation of practice materials?**

	none	**slight**	**moderate**	**significant**	**complete**
Single Wing Deflector (1)	1				
Double Wing Deflector (6)	5	1			
Log vane (15)	15				
Rock Vane (19)	17	1	1		
Cut-off Sills (4)	4				
Linear Deflector (2)	2				
	44	2	1	0	0

Question: **Degree of unintended erosion/scour?**

	none	**slight**	**moderate**	**significant**
Single Wing Deflector (1)	1			
Double Wing Deflector (6)	4	1	1	
Log vane (15)	12	2	1	
Rock Vane (19)	18		1	
Cut-off Sills (4)	4			
Linear Deflector (2)	2			
	41	3	3	0

Question: **Degree of unintended deposition/sedimentation?**

	none	slight	moderate	significant
Single Wing Deflector (1)	1			
Double Wing Deflector (6)	2		4	
Log vane (15)	14		1	
Rock Vane (19)	19			
Cut-off Sills (4)	4			
Linear Deflector (2)	2			
	42	0	5	0

Effectiveness/Functional Assessment

Question: **Is the practice serving its design purpose?**

	yes	partially	no
Single Wing Deflector (1)	1		
Double Wing Deflector (6)	2	3	1
Log vane (15)	14	1	
Rock Vane (19)	18	1	
Cut-off Sills (4)	4		
Linear Deflector (2)	1	1	
	40	6	1

Question: **Has the practice resulted in unintended benefits?**

	yes	no
Single Wing Deflector (1)		1
Double Wing Deflector (6)		6
Log vane (15)		15
Rock Vane (19)		19
Cut-off Sills (4)		4
Linear Deflector (2)		2
	0	47

Question: **Has the practice resulted in unintended impacts?**

	yes	no
Single Wing Deflector (1)		1
Double Wing Deflector (6)	1	5
Log vane (15)	1	14
Rock Vane (19)		19
Cut-off Sills (4)		4
Linear Deflector (2)		2
	2	45

Stream Habitat Assessment

Question: **If the practice is intended to enhance habitat, to what degree is it doing so?**

	fully	partially	none
Single Wing Deflector (1)	1		
Double Wing Deflector (6)	2	3	1
Log vane (15)	14		1
Rock Vane (19)	18	1	
Cut-off Sills (4)	4		
Linear Deflector (2)	1	1	
	40	5	2

Question: **Is the practice providing unintended habitat benefits?**

	yes	no
Single Wing Deflector (1)	1	
Double Wing Deflector (6)		6
Log vane (15)		15
Rock Vane (19)		19
Cut-off Sills (4)		4
Linear Deflector (2)		2
	1	46

Question: **Is the practice providing unintended habitat impacts?**

	yes	no
Single Wing Deflector (1)		1
Double Wing Deflector (6)	1	5
Log vane (15)	2	13
Rock Vane (19)	1	18
Cut-off Sills (4)		4
Linear Deflector (2)		2
	4	43

Vegetative Practice Assessment

Question: **What percent of installed plant material is living?**

	0-10%	10-25%	25-50%	50-75%	75-100%
Single Wing Deflector (1)					
Double Wing Deflector (6)					
Log vane (15)				1	14
Rock Vane (19)					
Cut-off Sills (4)					
Linear Deflector (2)					
	0	0	0	1	14

Question: **Is the practice fulfilling its design purpose regardless**

of plant survival?

	yes	no	partially
Single Wing Deflector (1)	1		
Double Wing Deflector (6)	2	2	2
Log vane (15)	14	1	
Rock Vane (19)	18	1	
Cut-off Sills (4)	4		
Linear Deflector (2)	1	1	
	40	5	2

Question: **What is the degree of soil erosion in the planting area?**

	none	slight	moderate	significant
Single Wing Deflector (1)	1			
Double Wing Deflector (6)	4	1	1	
Log vane (15)	11	3	1	
Rock Vane (19)	17		1	1
Cut-off Sills (4)	4			
Linear Deflector (2)	2			
	39	4	3	1

STREAM RESTORATION ASSESSMENT PRACTICE RESULTS

Objective: **Bank Stabilization**

# of practice types 6
# of ind. Practices 47

Structural Assessment

Question: **Percent of original practice materials remaining intact?**

	0-10%	10-25%	25-50%	50-75%	75-100%
Biolog (16)			2	1	13
Brush mattress (1)					1
Live fascine (7)				2	5
	0	0	2	3	19

Question: **Amount of movement or dislocation of practice materials?**

	none	slight	moderate	significant	complete
Biolog (16)	11	2	2	1	
Brush mattress (1)	1				
Live fascine (7)	7				
	19	2	2	1	0

Question: **Degree of unintended erosion/scour?**

	none	slight	moderate	significant	complete
Biolog (16)	10	3	2	1	
Brush mattress (1)	1				
Live fascine (7)	5	1	1		

16	4	3	1	0

Question: **Degree of unintended deposition/sedimentation?**

	none	slight	moderate	significant
Biolog (16)	10	3	3	
Brush mattress (1)	1			
Live fascine (7)	6	1		
	17	4	3	0

Effectiveness/Functional Assessment

Question: **Is the practice serving its design purpose?**

	yes	no	partially
Biolog (16)	9	1	6
Brush mattress (1)	1		
Live fascine (7)	6		1
	16	1	7

Question: **Has the practice resulted in unintended benefits?**

	yes	no
Biolog (16)		16
Brush mattress (1)		1
Live fascine (7)		7
	0	24

Question: **Has the practice resulted in unintended impacts?**

	yes	no
Biolog (16)		16
Brush mattress (1)		1
Live fascine (7)		7
	0	24

Stream Habitat Assessment

Question: **If the practice is intended to enhance habitat, to what degree is it doing so?**

	none	partially	fully
Biolog (16)	8	5	3
Brush mattress (1)		1	
Live fascine (7)		4	3
	8	10	6

Question: **Is the practice providing unintended habitat benefits?**

	yes	no
Biolog (16)		16
Brush mattress (1)		1
Live fascine (7)		7
	0	24

Question: **Is the practice providing unintended habitat impacts?**

	yes	no
Biolog (16)		16
Brush mattress (1)		1
Live fascine (7)		7
	0	24

Vegetative Practice Assessment

Question: **What percent of installed plant material is living?**

	0-10%	10-25%	25-50%	50-75%	75-100%
	2	1	2	2	9
Biolog (16)	2	1	2	2	9
Brush mattress (1)			1		
Live fascine (7)		1	2		4
	2	2	5	2	13

Question: **Is the practice fulfilling its design purpose regardless of plant survival?**

	yes	no	partially
Biolog (16)	9	1	6
Brush mattress (1)	1		
Live fascine (7)	6		1
	16	1	7

Question: **What is the degree of soil erosion in the planting area?**

	none	slight	moderate	significant
Biolog (16)	9	4	2	1
Brush mattress (1)		1		
Live fascine (7)	4	1	2	
	13	6	4	1