Urban Stream Restoration Practices: An Initial Assessment

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Abstract

Urban stream restoration projects are being designed and constructed in increasing numbers across the country. Numerous stream restoration techniques are being employed that vary from "hard" structural approaches to "soft" bioengineering approaches. The one factor that all stream restoration projects share, however, are the individual stream restoration practices that together make up a stream restoration project.

A recent study by Brown (2000) examined 24 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 24 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, indicating the potential for future failure. 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.

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.
This paper presents only a summary of the findings from the study. The complete study methodology and detailed findings are presented in *Urban Stream Restoration Practices: An Initial Assessment* published by The Center for Watershed Protection, Ellicott City, MD.

Introduction

Urban stream restoration projects are being designed and constructed in increasing numbers across the country. Numerous stream restoration techniques are being employed 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, are the individual stream restoration practices that together make up a stream restoration project.

Brown (2000) examined 24 different types of stream restoration practices and included over 450 individual practice installations. A stream restoration practice is defined in the study as one component of an overall restoration project, such as a single rootwad revetment or rock vortex weir. The focus of the study is on the performance of these individual practices. 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.

Study Design

Stream restoration projects were selected from an initial inventory of more than 40 urban stream restoration projects. For the purpose of the study, an 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. Table 1 highlights the project selection criteria.

The project selection process yielded a total of twenty 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 ranged widely in size, age, cost, and land use. Land use within the project watersheds ranged from relatively low density residential (15% impervious cover) to high density urban land use with over 50% impervious cover. Watershed size ranged from less than 100 acres to over 5,000 acres and total project costs ranged from a low of $12,000 to over $2,000,000. The smallest project involved only 200 linear feet of stream channel while the most extensive project encompassed over 10,000 feet.

Table 1. Urban Stream Restoration Assessment - Site Selection Criteria	
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

Assessment Methodology

A methodology was developed to assess the function and performance of the 24 individual stream restoration practice types. The 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 achieves 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 necessary to develop a consistent set of assessment questions that could address the basic attributes of all of the practice types, yet recognize the key differences among them. The four design groups are described below.

I. **Bank Protection Group** - Bank protection practices are designed to protect the stream bank from erosion or potential failure. For the purpose of the study, bank protection practices include practices that are structural in nature, as opposed to the bank stabilization practice group that uses non-structural 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.

I. **Grade Control Group** - Grade control structures are designed to maintain a desired streambed elevation. They can be either 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.

I. **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.

I. **Bank Stabilization/Bioengineering Group** - Bank stabilization practices employ non-structural means to stabilize stream banks against further accelerated erosion and are frequently used in combination with bank protection practices. Bank stabilization practices generally involve regrading 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. Widely used practices within this group include coir fiber logs, live fascines and willow plantings.

The stream restoration practices associated with each design group are presented in Table 2.

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. The four major attributes include structural integrity, effectiveness/function, habitat enhancement, and vegetative stability.

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, 1999), the Metropolitan Washington Council of Governments Rapid Stream Assessment Technique (Galli, 1996) and the National Resource Conservation Service Stream Visual Assessment Protocol (NRCS, 1998). Each of these assessment protocols utilizes a series of questions that asks 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.

Table 2. 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	

Results

After completion of the field assessment, the scores 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, 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. The 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.

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

1) Which stream restoration practices remain functional over the long term (five years)?

2) Which practices consistently fail within short periods of time (<three years)?

3) Which practices exhibit some kind of failure but remain essentially functional?

4) Which practices, that tend to fail under current design and construction practices, could be improved?

5) 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 instance, 35 rootwad revetments were evaluated on a four year old stream restoration project, 8 of the 35 were assessed as less than 75% intact. While on a nearby project of similar type and age, 12 rootwad revetments were evaluated, with all twelve assessed as fully intact. The specific location and the 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 1-2 years).

This finding must be tempered by the fact that most practices were still relatively young, and could conceivably fail in the future. The average age of practices evaluated in the study was four years, with a range of 1 to 9 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 ongoing. Over time, many different factors can occur that could alter the effectiveness of a practice. This was evident on at least one restoration site, where a tree had fallen into the stream just above a practice. The tree diverted the flow of water and destroyed 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 the 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. These types of practices work in opposition to the dynamic nature of streams. Where stream conditions are less severe, the rate of change is slower, and the consequences 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 appropriate practices for stream conditions and the level of protection necessary is one of the most significant factors in designing and implementing 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 3 details these overall findings.

Recommendations

When sized, located, and installed correctly, the majority of practices analyzed in the study were found to be effective and appropriate for use in urban stream restoration. Most practices did encounter some problems, and their application can be improved. Of the 24 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 project design, installing practices where channel conditions were inappropriate, or poor practice construction. Most importantly, the study found that the key factors for practice success were a good understanding of stream processes and an accurate assessment of current and future stream channel conditions.

Table 3. 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	

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 inaccurate 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 cause practice failure. 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 reconsidered in urbanized watersheds.

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 and practice failure. The project designer must work with the contractor to insure that practices are properly constructed.

Lastly, some failures were related to the failure of the designer to recognize that the project stream was actively adjusting to altered hydrology and had not yet reached ultimate channel enlargement. Most urban streams 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.

More research is needed in 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 3 to 5 years on the same set of restoration practices would go a long way in answering this question. Lastly, the true measure of success in stream restoration is how the aquatic community responds. A detailed study of the aquatic communities response to stream restoration is necessary to truly assess the success of urban stream restoration projects.

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