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Final Report

A Two Stage Evaluation of NCDOT Stream Mitigation Practices: Stage 1—Synthesis of Current Stream Mitigation Practices Stage 2—Development of Criteria of Effective Mitigation

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16. Abstract

This project included a thorough review of scientific literature related to stream restoration techniques and practices in addition to development of a design handbook. Literature review topics included fluvial processes, bioengineering, natural channel design, habitat improvement structures, stream stability, and sediment transport. An annotated bibliography of the relevant stream restoration literature was posted to the NCSU Water Quality Group Web Site at:

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The document "Stream Restoration: A Natural Channel Design Handbook" was prepared and distributed to 35 NCDOT participants in a 4-day workshop held in Raleigh, NC, January 22-26, 2001. The Handbook includes detailed descriptions of successful current and proven stream restoration practices integrated into a usable and reliable cost-effective process for NCDOT. Chapter 11 in the Handbook is a comprehensive process to support evaluation of successful stream restoration.

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Disclaimer

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Introduction

Stream restoration and mitigation is a complex process that involves recognizing natural and human induced disturbances that degrade the form and function of stream and riparian ecosystems or prevent its recovery to a sustainable condition. Restoration includes a broad range of activities designed to enable stream corridors to recover dynamic equilibrium and function to maintain channel dimension, pattern, and profile so that over time the stream channel does not degrade or aggrade.

The Stream Corridor Restoration: Principles, Processes, and Practices manual published by the Federal Interagency Stream Restoration Working Group in 1998 identifies three levels of stream improvement: 1) restoration, 2) rehabilitation, and 3) reclamation. Restoration is defined as the reestablishment of the structure and function of ecosystems. Ecological restoration is the process of returning an ecosystem as closely as possible to predisturbance conditions and functions. Ecosystems are dynamic and therefore it is not possible to recreate a system exactly. The restoration process reestablishes the general structure, function, and dynamic but self-sustaining behavior of the ecosystem. Rehabilitation is defined in the Stream Corridor Restoration manual as a procedure for making the land useful again after a disturbance. It involves the recovery of ecosystem functions and processes in a degraded habitat. Rehabilitation does not reestablish the predisturbance condition but does establish geological and hydrologically stable landscapes that support biological diversity. Reclamation is defined as a series of activities intended to change the function of an ecosystem, such as changing wetlands to farmlands.

For this project, stream restoration is defined as returning a degraded stream ecosystem to the highest level of stream potential available for the surrounding landform. This includes reestablishment of a stream channel that maintains its dimension, pattern, and profile such that over time it does not aggrade or degrade. This definition also implies that the restoration will provide the highest level of aquatic habitat and biological diversity possible.

Background

Interest in natural channel design technologies is increasing globally. Traditional engineering approaches to maximize channel conveyance using best hydraulic sections are not considered desirable by many landowners and environmental agencies. The engineering design problem has evolved from one of water conveyance to designing a channel that is self-maintaining, aesthetically pleasing, and provides optimum biological diversity. Historically, natural channel processes have been addressed by fluvial geomorphologists and to lesser degree biologists. More recently, stream classification and bioengineering have been used to describe stream types, condition, and to develop strategies for stream improvements.

While interest in natural channel design is high, the science and technical database for accomplishing successful restoration is limited. Increasingly, land development organizations are being required to mitigate impacts to streams by utilizing natural channel design technologies. A synthesis of scientific information related to stream restoration along with a process for implementation and evaluation is greatly needed by land development organizations and resource review agencies.

Problem Definition

NCDOT is required to mitigate impacts to streams. In order to meet stream mitigation requirements, NCDOT needs to gain a thorough understanding of current, proven methods in stream restoration. In addition, NCDOT needs to develop measures of effectiveness to document stream restoration.

Project Objectives

Project objectives were to:

1. Conduct a thorough research and review of scientific literature related to stream restoration practices,
2. Develop a recommended process for stream restoration by integrating current knowledge and practices,
3. Develop measures of effectiveness for use in evaluating successful stream restoration and mitigation,
4. Conduct a workshop for NCDOT and resource review agency staff to present results of the project.

Literature Review

Existing scientific literature focuses on stream corridor analyses and restoration planning. The Stream Corridor Restoration Manual published in 1998 by the Federal Interagency Stream Restoration Working Group provides a basis for developing a stream restoration program. This project supplemented the literature review found in the Manual with work related to stream restoration design, practice selection, implementation, and evaluation.

Research Methodology & Tasks

The following four tasks were conducted to meet the objectives of this study:

Task 1: Literature Review

A thorough research and review was conducted of scientific literature related to stream restoration practices. Topics include fluvial processes, bioengineering, natural channel design, habitat improvement structures, stream stability, and sediment transport. An annotated bibliography of the relevant stream restoration literature is provided in the Final Report. The bibliography includes title, author, and source of publication, as well as a short summary of the publication's content. All copies of publications are stored in the NCSU Water Quality Group's library.

Task 2: Stream Restoration Practices

Successful current and proven stream restoration practices were integrated into a usable handbook for NCDOT that was presented to 35 staff at a January 2001 workshop.

Task 3: Stream Restoration Evaluation

As part of the handbook developed in Task 2, a measure of effectiveness for use in evaluating successful stream restoration and mitigation was developed. This method allows NCDOT to determine the level of restoration achieved for an individual project reach.

Task 4: Workshop

The results of this study were presented to 35 NCDOT staff in a four-day workshop held in Raleigh, NC, January 23-26, 2001. The agenda for this workshop was as follows:

Tuesday, January 23, 2001

Review of Stream Restoration Principles and Practices
Bankfull Channel Indicators and Regional Curves
Review of Rosgen Stream Classification
Riparian Vegetation Assessment
FIELD EXERCISES: Stream Classification and Bankfull Verification - Kentwood Park

Wednesday, January 24, 2001

Causes of Stream Instability
Stability Measurements
Channel Evolution
Priority Levels of Restoration
Restoration Case Studies
FIELD EXERCISES: Stability Measurements and Priority Levels - Yates Mill

Thursday, January 25, 2001

Reference Reach Overview and Survey Procedures
Reference Reach Vegetation Survey
FIELD EXERCISES: Reference Reach Survey - Sal's Branch, Umstead Park
Reference data analysis and discussion

Friday, January 26, 2001

Stream Channel Geometry Design
Sediment Transport
In-stream Structures
Vegetation
FIELD EXERCISES: Visit Restoration Sites - Abbott and Speight

Literature Review

Project personnel completed a thorough research and review of scientific literature related to stream restoration practices. Topics include fluvial processes, bioengineering, natural channel design, habitat improvement structures, stream stability, and sediment transport. An annotated bibliography of the relevant stream restoration literature was posted to the NCSU Water Quality Group Web Site at:

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Overview

The search and review of scientific literature related to stream restoration included the following steps:

1. Collect papers from peer-reviewed journal articles published since 1990
2. Review and comment on suitability for database
3. Categorize according to overall topic
4. Develop draft annotations
5. Database entry
6. Inventory/review papers
7. Determine gaps in topics and/or subtopics
8. Collect additional papers to include proceedings and articles published since 1975
9. Review/edit draft annotations
10. Review/edit topics and add subtopics
11. Complete final database
12. Post database on NCSU Water Quality Group Web Site for public access

A total of 135 articles were initially identified. Of these, 65 were selected for inclusion in the database. Sources included the following:

1. American Journal of Science
2. Aquatic Conservation: Marine and Freshwater Ecosystems
3. Bioscience
4. Canadian Journal of Fisheries and Aquatic Sciences
5. Ecological Engineering
6. Environmental Geology
7. Environmental Management
8. Environmental Restoration
9. Freshwater Biology
10. Fisheries
11. Geological Society of America Bulletin
12. Geomorphology
13. Journal of the American Water Resources Association
14. Journal of Environmental Engineering
15. Journal of Geology
16. Journal of Hydraulic Engineering
17. Journal of Hydrology
18. Journal of Soil and Water Conservation
19. Land and Water
20. North American Journal of Fisheries Management
21. Public Works

22. Water Resources Bulletin
23. Water Resources Research

References were grouped based on topic similarities, annotated and cataloged using a standard format developed by the North Carolina State University Water Quality Group.

A distribution of topics (Table 1) suggests a disparity between scientific research of stream and the abundance of restoration projects completed or in progress across the country. The increasing need for restoration associated with water quality and aquatic habitat demands scientific evaluation to maximize the success rate of restoration practices. As stream restoration research increases, the literature database will be updated to reflect the growing interest in understanding restoration practices.

Table 1: Distribution by Topic of Accepted Literature Related to Stream Restoration.

Topic Number	Topic Description	Number of Articles
1	Approach/Guides	16
2	Channel Process and Geometry	22
3	Classification Systems	3
4	Design Principles/Structures	14
5	Evaluation and Monitoring	6
6	Biological Habitat	6
Total		**67**

Concepts Common Among Restoration Study

Concepts common throughout published literature emphasize overall approach and design. Most authors agree that the basic principles of stream restoration should include:

- analysis of channel history and evolution
- analysis of cause and effect of change
- analysis of current condition
- development of specific restoration goals and objectives prior to design
- holistic approach to account for channel process, riparian and aquatic function
- consideration of passive practices (such as fencing against livestock)
- natural channel design to restore function.

In most cases, the above concepts are widely accepted, however, there is limited published work in showing how these concepts can be implemented.

Channel Process and Geometry

Channel process, form and function related to water quality and aquatic resources are intensely researched, although few are specifically related to stream restoration. While limited in the scope of restoration, these references can be used to gain further understanding of channel networks. The selected literature for this review was chosen based on its potential use in stream restoration since it most closely relates to issues faced in restoration design.

North Carolina Piedmont and coastal streams are predominantly low gradient (<5%), meandering channels incising through the finer fraction of sediment size distribution (small gravel, sand, silt and clay). Relevant literature includes meander geometry relationship to stream discharge, planform and bank erosion (Carlston et.al 1965, Begin et.al. 1981, Carson et.al. 1983). Rinaldi et.al. (1997) specifically address meander restoration by testing the suitability of empirical equations used in restoration practices. They found a large bias when comparing measured meander parameters to those computed by Leopold and Wolman equations. They investigated appropriate equations for use and recommended a combination of stream reconnaissance and analysis for determining appropriate regression equations for use in restoration design.

Several studies have been conducted specifically for North Carolina streams including bankfull identification (Harman et.al. 1999, Henson et.al, unpublished), rhythmic spacing and origin of pools and riffles (Keller et.al. 1978), channel geometry of the North Carolina Piedmont as related to flood frequency (Kilpatrick et.al. 1964), and active channel geometry and discharge relations (Kolberg et.al. 1997). These studies are important in application to stream restoration in North Carolina since they are specific to the region and include field reconnaissance and verification. The most revealing of these articles is the finding by Kolberg and Howard (1997) that the least-squared regression relationships between channel geometry and discharge deviated significantly between channels with high silt and clay, gravel or cobble beds, and those with 30% or greater sand beds. This finding has implications to stream restoration in obtaining accurate discharge-width relationships for restoration design.

Stream Classification

Two stream classifications were included in the review based on their popularity and use in the United States. Montgomery and Buffington (1993) developed a classification system based on channel process that is most useful in high relief regions. Rosgen (1994) developed a classification system that includes mountain streams, but is most useful in its explanation of low gradient streams and techniques for restoration. Classification systems are invaluable for use in various stream studies, including restoration, since they aid in dividing stream networks into discrete working units, allowing for better understanding of the whole network. However, Kondolf (1995) warns against the application of classification systems in oversimplifying channel form and process and in confusing the stream classification exercise with understanding channel process.

Restoration Structures

Structures used in stream restoration include vegetation, wood, and constructed rock and wood structures. The majority of research has been conducted on vegetative and wood structures, including both natural and engineered installments. Brone et.al (1998) examined the effectiveness of vegetative filter strips in reducing nonpoint source pollution. They found the strips were highly effective in reducing runoff volumes and concentrations of sediment and nutrients, but were not as effective in reducing total fecal contaminants. They suggest vegetative strips be used in conjunction with pre-treatment of animal waste. Similar findings are reported by Osborne et al (1993) in a literature review of vegetated buffer strips used in restoration.

Shields et al (1995) studied the effect of specific woody vegetation combined with rock bank protection finding native woody species, especially willow, to be best adapted to streambank environments. However, success of vegetation was successful only in reaches where the streambed was not degrading and banks were stabilized by grading or toe protection. In a similar study, Shields et al (1995) combined stone placement with willow planting in a deeply incised sand channel. Stage-discharge, channel geometry and grain size were unaffected, though average depth of scour holes and pool habitat increased along with fish number and size, woody vegetation cover, mean depth and width. Additionally, they reported the occurrence of erosion beneath stones. Shields et.al. (1998) also conducted a study on the addition of spurs to stone toe protection indicating a modest increase in overall pool width and habitat availability, and local effects on depth.

Research on the effect of wood structures includes both biological and hydraulic study. Large organic debris or large woody debris has an important influence on stream process and morphology by hydraulically controlling areal sorting and storage of sediment, spacing of pool-riffle sequences and channel geometry (Thompson 1985). Wallace et.al. (1995) examined the influence of log additions on physical and biotic characteristics of a mountain stream in North Carolina. They added logs to the downstream riffle on three, 2^{nd} order, cobble-bed streams. They reported an increase in stream depth and sand/silt deposition, a decrease in velocity. Both coarse and fine particulate organic matter also increased dramatically. They do not report the spatial variability of fine sediment deposition, or the change in other channel dimensions.

Two studies in wood placement examine the effect on trout habitat (Culp et.al. 1996, Fiebbe et.al. 1995). Both papers report increases of trout fry and biomass associated with large woody debris. Hilderbrand et.al (1997) compared the effect of random design and human judgment-based placement of large wood structures. Their most significant finding was the 146% increase in pool area associated with systematic placement opposed to 32% pool area increase in random placement.

Research on structures used in stream restoration has mixed results. Overall, research reveals the need for understanding the goals of restoration, spatial and temporal aspects of structure use and placement, and the reach level hydraulic effects of structures.

Monitoring and Evaluation

Monitoring and evaluation of stream restoration is considered by most authors to be extremely important. It also presents one of the largest voids in published and unpublished literature. Although a selected number of short-term restoration project results have been reported (Culp et.al. 1996, Shields et.al. 1997, Gortz 1998, Myers et.al 1996), long-term studies are lacking. The absence of long-term evaluation may be partially due to the lack of restoration projects prior to the 1970s, and the relatively recent onset of the restoration movement.

Several papers have been published indicating the importance of monitoring and evaluation (Kondolf et.al. 1995, Bryant 1995) and most authors agree on the basic need and principles. These include:

- planning for monitoring and evaluation in the overall restoration design
- setting clear goals and objectives
- planning for long-term (at least a decade) of monitoring
- collecting baseline data
- developing good study design
- willingness and commitment to acknowledge failure as well as success.

Research Gaps and Needs

Overall, the gaps in stream restoration research lie in systematic scientific validation of restoration designs and schemes. This research need can be conducted in the context of monitoring and evaluation as well as in specific channel-oriented process applicable to stream restoration. Among the published literature attempts to address these gaps, at present, most only succeed in suggesting what needs to be done for restoration rather than actually doing what is suggested. On the other end of the spectrum, restoration specialists involved specifically in stream restoration are not publishing their findings, either due to time, monetary constraints or disinterest. The disparity between these two groups may simply be the disconnection between science and management, however, the need for cooperation still exists. A short list of future research needs include examination of the following:

- Comparison between holistic and non-holistic approaches to restoration
- Designing for the bankfull channel
- Testing regional curves
- Region specific restoration in terms of past and present land use change
- The significance of channel change history to restoration design (Does it really make a difference?)
- Specific limitations of classification systems in restoration design (Are there any, and if so, what are they?)
- Multi-goal restoration: Consideration for combined physical and biological function
- Success rates of stream restoration: What works where?
- Failure rates of stream restoration: What does not work where?
- Spatial and Temporal effects of in-stream structures

Example Reference Citations and Draft Annotations

Gore, J.A. and F.D. Shields 1995. Can Large Rivers Be Restored? Bioscience, 45(3):142-152.

Specifically addresses the restoration of large rivers and their adjacent floodplains, side channels and wetland areas. The authors acknowledge the unique problems associated with large river restoration due to human population and habitation, and suggest a goal of restoring selected areas for biological and ecological function. Topics addressed include vegetative cover, hydraulic conditions, backwater treatment and riparian zones.

Gortz, Per 1998. Effects of stream restoration on the macroinvertebrate community in the River Esrom, Denmark. Aquatic Conservation: Marine and Freshwater Ecosystems, 8:115-130.

The macroinvertebrate fauna of three restored and two reference reaches were compared 4 years after completion of restoration. Five times as many trout spawning redds occurred in the restored reaches. However, electroshocking revealed few young-of--the-year trout and did not reflect spawning success. It was concluded that attempts to improve physical structure and spawning environment altered invertebrate composition, but did not enhance trout production.

Helfield, J.M. and M.L. Diamond. 1997. Use of Constructed Wetlands for Urban Stream Restoration: a critical analysis. Environmental Management 21(3):329-341.

Investigation of a delta marsh restoration project underlines concerns about constructed wetland projects designed for water quality improvement and habitat enhancement. Rather than providing permanent removal of urban contaminants, wetland processes offer a limited capacity for temporary storage, and potential reactions may actually produce more toxic and/or bioavailable forms of some chemicals. Accordingly, wetland systems are not suited to the dual purposed of water quality improvement and aquatic habitat enhancement. Upland controls, including source reduction of contaminated inputs are recommended as essential components of all constructed wetland projects.

Kauffman, J.B., R.L. Beschta, N. Otting and D. Lytjen 1997. An Ecological Perspective of Riparian and Stream Restoration in the Western United States. Fisheries 22(5):12-24.

The first and most critical step in ecological restoration is passive restoration, the cessation of those anthropogenic activities that are causing degradation or preventing recovery. Prior to implementation of active restoration approaches (e.g., instream structures, channel and stream bank reconfiguration, and planting programs), a period of time sufficient for natural recovery is recommended.

Knapp, Leslie H. 1998. Use of Soft Armor Manufactured Materials in Shoreline Protection. Land and Water, 44-46.

Describes the function and benefits of various soft armor materials including mulches, meshes, synthetic turf mats, erosion control blankets, and pre-vegetated mats.

Kondolf, G.M. 1995. Hydraulic and Channel Stability Considerations in Stream Habitat Restoration, Environmental Restoration pp.214-227.

When restoration projects are planned where habitat has been degraded as a result of water diversion, changes in sediment load or other such factors, these factors must be studied, understood and explicitly accounted for in the design. If they are not, the forces that destroyed the original channel are likely to undo the restored channel.

Kondolf, G.M. Larson, M.1995. Historical Channel Analysis and its Application to Riparian and Aquatic Habitat Restoration. Aquatic Conservation:Marine and Freshwater Ecosystems 5:109-126.

A historical analysis can reveal underlying causes of channel changes and document prior habitat conditions, both useful in setting appropriate objectives for restoration. Channel changes in form and process can be documented from several sources, including historical maps, boundary lines, aerial photography, bridge and pipeline surveys, gauging records, field evidence and archival sources. Historical analysis should cover a large enough area to capture all events potentially influencing the project, including upstream and downstream reaches.

Williams, Garnett, P. 1986. River Meanders and Channel Size, Journal of Hydrology, 88:147-164.

This study used an enlarged dataset to compare measured meander geometry to that predicted by Lanbein and Leopold (1966) theory, to examine the frequency of the ratio radius curvature to channel width and derive 40 empirical equations involving meander and channel size features. The dataset includes 194 sites from a wide variety of physical environments. The Langbein-Leopold theory agreed well with these field data. The authors suggest that although channel width traditionally has served as a scale indicator, bankfull cross-sectional area and mean depth can be used for analyzing meander patterns.

Stream Restoration Practices

Project personnel completed the document: "Stream Restoration: A Natural Channel Design Handbook" and distributed it to 35 participants in the January, 2001, NCDOT workshop (see Task 4). The Handbook includes detailed descriptions of successful current and proven stream restoration practices integrated into a usable and reliable cost-effective process for NCDOT. Below is the outline of the manual which is available from the NCSU Water Quality Group.

Outline

Stream Restoration: A Natural Channel Design Handbook
Prepared for North Carolina Department of Transportation

1. Introduction to Fluvial Processes
2. Existing Condition Survey
3. Gage Station Analyses and Bankfull Verification
4. Restoration Priority Options for Incised Streams
5. Reference Reach Survey
6. Design Procedures
7. Structures
8. Vegetation Stabilization and Riparian Buffer Re-establishment
9. Erosion and Sediment Control Plan
10. Flood Studies
11. Evaluation
12. References

Appendices

1. River Course Fact Sheets
2. NRCS Curve Number Information
3. US Forest Service Stream Channel Reference Sites
4. Gage Station Data
5. Regional Hydraulic Geometry Relationships
6. Priority Levels of Restoration
7. Stream Structure Details
8. Vegetation Specifications and Plant Lists
9. FEMA Floodplain Analysis Procedures

Stream Restoration Evaluation

Project personnel developed a comprehensive evaluation process and included this information as Chapter 11 in the document: “Stream Restoration: A Natural Channel Design Handbook” as described above. This chapter is excerpted below.

Each stream restoration design should have a monitoring plan that will insure that the design implementation will be evaluated to:

1. Determine if stabilization and grade control structures are functioning properly.
2. Monitor channel stability by measuring dimension, pattern and profile, particle size distribution of channel materials, sediment transport and streambank erosion rates.
3. Determine biological response (i.e. vegetation and macroinvertabrates).
4. Determine if the specific objectives of the restoration have been met.

The monitoring plan assists others in knowing what to measure. Included in the monitoring plan are items that are presented in levels 3 and 4 of the stream hierarchical levels that predict and validate natural channel stability.

Monitoring and evaluation also allow for any necessary adjustments to design parameters, installation procedures, and/or stabilization methods; as well as help to determine whether the design objectives have been met.

Morphological field investigation and data analysis is necessary in order to establish a procedure for post construction monitoring on a project site. A geomorphic survey should be completed. A monitoring plan should include an assessment of stream bank stability as well as stream morphology. Field reconnaissance involves the establishment of permanent cross-sections at riffles and pools, longitudinal profiles, and pebble counts. Vegetation plots and photographic reference points should also be established for continued monitoring.

Methodology

The following is a discussion of the methodologies used in field reconnaissance and summary report documentation. A monitoring report will facilitate continued monitoring efforts and enable annual replication of the field reconnaissance that is performed.

The geomorphology of the stream should be classified using the Rosgen classification system, and assessed based on the results of the survey data. The morphology of the stream is to be monitored a minimum of once a year for 5 years after construction.

Morphology

Cross-section geometry, longitudinal profile, and pebble count data are gathered during the field reconnaissance. Distinctive areas (upstream to downstream) along the stream corridor should be denoted as individual sections or reaches for reference, and surveyed and established for monitoring. These areas should be denoted on the Plan View Drawings.

Cross-Sections

For monitoring purposes, permanent cross sections should be established in each of the reaches along the stream corridor of the restoration site. A minimum of one riffle and one pool cross-section should be surveyed for each of the reaches established. The location of each cross-section is noted to establish the exact transect location along the longitudinal profile.

Rebar is used to mark the established location of each cross-section. Each rebar is referenced by left and right bank pin of each cross-sections surveyed (i.e. Left pin and Right pin for cross section 1). Each endpin (left and right) is driven vertically flush to ground on each side of bank to establish the outer limits of each cross-section surveyed. Wooden stakes (wrapped with surveyors tape) are also placed adjacent to the rebar marker to aid in locating the cross-sections in the field. All cross-section locations should be shown on the Plan View Drawings.

The following steps should be executed to ensure successful replication of cross-section location and surveying parameters. Data is collected once a year for at least five (5) years post construction. Cross-sections should be plotted over that of previous year(s) for comparison and evaluation.

General procedure for permanent cross section survey:

- Locate cross section on Plan View Drawing and in field
- Locate end points on banks marked with rebar
- Pull tape (100’ tape) from left bank to right bank looking downstream at cross-section location between the two rebar endpins. The end of the tape (0’0”) should be directly over the left rebar
- Locate permanent/temporary benchmark
- Set up Level/surveying equipment in location to limit visual constraints
- Survey any permanent/temporary benchmarks (refer to Plan View Drawings)
- Survey from left to right bank
- Survey distinctive points (i.e. top of bank, edge of water, bankfull features, thalweg, etc.) and any other breaks in slope.

Survey elevations in the area can be based on any of the rebar pins (TBM) set in field. The relative elevation at each pin is located on the cross section survey data.

Measure all significant breaks of slope that occur across the channel. Outside the channel, measure important features including the active floodplain, and terraces.

Longitudinal Profile

The longitudinal profile measures points along the thalweg of the stream channel. The profile indicates the elevations of water surface, channel bed, floodplain (bankfull), and terraces. The elevations and positions of channel defining indicators and in-stream structures can also be monitored with this profile.

Longitudinal profiles are taken along the stream corridor of the restoration site for each reach of the project. The longitudinal profile survey is conducted at the same time as the cross-section surveys. The beginning of the longitudinal profile tape is at the established STA 0 point and continues downstream the established length of stream. Survey points at each station should include the thalweg, water surface, bankfull, and if appropriate, top of low bank. The start and end points of each longitudinal profile should be located on the Plan View Drawings. Each profile should run from up to downstream the entire length of the restored channel. This data is collected once a year for at least five (5) years. Longitudinal profiles should be plotted over that of previous year(s) for comparison.

Modified Wolman Pebble Count

The composition of the streambed and banks is a good indicator of changes in stream character, channel form, hydraulics, erosion rates, and sediment supply. A pebble count gives a quantitative description of the bed material.

Pebble counts should be performed at permanent cross sections within each reach of the project. Each pebble count consists of 100 counts from left bankfull to right bankfull. Follow the basic steps for the Modified Wolman Pebble Count (Rosgen, 1996). Perform count at each of the reaches along the stream channel. Measure a minimum of 100 particles at a permanent cross section to obtain a valid count. Use a tally sheet to record the count. Data will be collected once a year for at least five (5) years. Pebble counts should be plotted over previous year(s) for comparison.

Success Criteria

Judgments on success or failure of restoration activities using this data will be subjective. It is expected that there will be some minimal changes in the cross sections, profile and/or substrate composition. Changes that may occur during the monitoring period will be evaluated to determine if they represent a movement toward a more unstable condition or represent an increase in stability.

Reference Photographs

Locations of the photograph points should be established at distinguishing points along stream, including in-stream structures.

The order of photos taken is taken from upstream to downstream points along the stream corridor. Each photo point should be established and either marked in field with a wooden stake or referenced by cross-section or stream feature/structure (i.e. rock vane). All photo points should be located on the Plan View Drawings. For future reference, refer to and Plan View Drawings for location of photo points.

Photographs should be taken standing at the approximate location of established photo point, cross section location, and/or referenced stream feature/structure. Photographs are taken throughout the monitoring period. Photos should be compared to previous year(s) photos to evaluate vegetative growth along the stream corridor of the restoration site and channel stability. All follow up monitoring photos should be taken at approximately the same location as in the initial photo point locations as established in this report. This aspect of monitoring will last for at least five (5) years.

Photographs will be used to subjectively evaluate channel aggradation or degradation, bank erosion, success of riparian vegetation and effectiveness of in-stream structures and erosion control measures. Photos will indicate the presence or absence of developing bars within the channel or an excessive alteration in channel depth or width. Photos will also indicate the presence of any excessive bank erosion or continuing degradation of the bank over time. The series of photos over time should indicate successional maturation of riparian vegetation.

Vegetation

Survival of vegetation should be evaluated using survival plots and/or direct counts along the entire stream corridor of the restoration site. The vegetation should be monitored for at least five (5) years post construction and planting.

Vegetation survival inside the riparian buffer may be documented for the monitoring period through stem counts and photographic documentation of the entire length of the corridor in which buffers are planted. Documentation should occur at pre-established stations/plot areas. Determination of survival rates after initial (year one) survey should show 80 percent survival. If not, supplemental planting should be performed in winter following first year.

Plot Locations

Plots should be located adjacent to the stream and surveyed for future replication. Plots should be located in areas large enough to obtain a representative sample of the planted population. Ideally, a sample size of 10 percent of the planted area should be surveyed. In some cases, plots will be located in areas such as outside meander bends or atop bankfull benches into the riparian buffer.

Plot Size

Two different types of plots need to be established to determine survivorship of stakes and bare root seedlings. Sizes and numbers of plots will depend on site conditions, particularly buffer width and project size. Ideally, rectangular plots up to 100 meters square will be used in determining survivability for bare root trees. These should be linear and parallel the stream channel. Stakes should be counted from beginning to end of outside meander bends if this is the sole location of stakes. If stakes are planted along runs, riffles, or glides, rectangular plots should again be used as with the bare root trees. Plot size will depend on site conditions and project size. Herbaceous cover can be incorporated into one of the two plots. Plot size for herbaceous cover should be no more than one meter square in size.

Timing

Vegetation sampling should be completed during the growing season. Ideally, this would be mid-summer in June or July. Sampling should be complete before the end of the growing season from August 1 to October 31.

Additional Monitoring Opportunities

Shading and Temperature

The ability of planted vegetation to thermally stabilize restoration site riparian zones may be evaluated by monitoring both water temperature and air temperature. Water temperature may be sampled using StowAway® XTI recording thermometers made by Onset Computer Corporation. These thermometers may be placed in the steams at the beginning and at the end of each site, and they may be set to record the water temperature every hour. Water temperature recording can continue each year until desired stream shading is accomplished. Shading effects on air temperature will be evaluated by recording air temperature along each reference transect established for lateral photo reference. Air temperature may be recorded at each location that light penetration is measured with each measurement taken 1 meter above the ground or water surface.

Temperature stability can be measured using the StowAway recorders to measure air temperature in the shade for seven consecutive days. This temperature stability measurement may be done within the easement or buffer area at the top of the streambank, and outside of the easement, both along one of the established transect lines.

Comparisons of air temperature and shading along each transect (from edge of buffer to mid-stream) should indicate a lower temperature and increased shading. Water temperature should decrease, or at least be constant, as it moves through the restoration site. This difference may not be found until riparian vegetation grows to the point that it is shading the stream and riparian zone. Temperature stability data should indicate that the riparian zone has a more stable (less variation) temperature regime than a site outside of the vegetated buffer. Reference data from existing riparian zones in excellent condition, needs to be developed to provide targets for shading and thermal buffering.

Fish and Invertebrate Data

Information on fish and aquatic macroinvertebrate populations (density and diversity) may be used to guide decision making in the restoration planning and monitoring process. These populations can provide insights on the overall health of the stream and the need for habitat improvement. When restoration work can be done throughout the watershed, these populations can provide a tool for assessing the success of the work. When these populations can be evaluated on a watershed basis and at the restoration site, a marked difference at the site might indicate that local conditions are limiting populations. In this case, on site work may improve the populations. In this case monitoring of important populations is warranted.

When sampling fish and invertebrate populations, standard procedures should be used. Quantitative fish population samples can be evaluated using the 3-pass depletion method that the North Carolina Wildlife Resources Commission (NCWRC) uses to evaluate trout populations. The Index of Biotic Integrity used by the Division of Water Quality is a good method for qualitative fish population sampling. Invertebrate sampling should follow the methods prescribed by the Division of Water Quality. Monitoring reports should explain the need for the fish and invertebrate data and how it will be used to evaluate any restoration work.

Conclusions and Recommendations

Stream restoration research is needed in many areas to evaluate the techniques currently being applied for natural channel design. This research need can be conducted in the context of monitoring and evaluation as well as in specific channel-oriented process applicable to stream restoration. Among the published literature attempts to address these gaps, at present, most only succeed in suggesting what needs to be done for restoration rather than actually doing what is suggested. On the other end of the spectrum, restoration specialists involved specifically in stream restoration are not publishing their findings, either due to time, monetary constraints or disinterest. The disparity between these two groups may simply be the disconnection between science and management; however, the need for cooperation still exists. A short list of future research needs include examination of the following:

- Comparison between holistic and non-holistic approaches to restoration
- Designing for the bankfull channel
- Testing regional curves
- Region specific restoration in terms of past and present land use change
- The significance of channel change history to restoration design (Does it really make a difference?)
- Specific limitations of classification systems in restoration design (Are there any, and if so, what are they?)
- Multi-goal restoration: Consideration for combined physical and biological function
- Success rates of stream restoration: What works where?
- Failure rates of stream restoration: What does not work where?
- Spatial and Temporal effects of in-stream structures

Implementation & Technology Transfer Plan

Thirty-five NCDOT staff members participated in a four-day workshop on stream restoration design January 23-26, 2001, at the NC State University McKimmon Center. Instructors were Greg Jennings, PhD, PE, Barbara Doll, PE, Dani Wise-Frederick, and Karen Hall. All instructors are faculty members of NCSU's Stream Restoration Institute, an interdisciplinary group focused on education and applied research to promote natural channel design approaches to restoring and enhancing streams and rivers. Participants included several Natural Systems staff members, the Division Environmental Officers from all 14 divisions, and staff from Roadside Environmental and Hydraulics.

Workshop topics included the Rosgen stream classification system, stream condition assessment, causes of stream instability, restoration options, case studies of North Carolina projects, reference reach surveys, and natural channel design processes. In addition to daily classroom sessions, Workshop participants visited local streams each day to collect data and observe construction of two active restoration projects in the Raleigh area. Participants learned by example about stream channel geometry measurements, design and installation of in-stream boulder and log structures, streambank stabilization techniques, and riparian vegetation management. All of these project components are essential to successfully restore the natural functions of impaired stream systems.

The project case studies were valuable for helping staff members understand what is involved in project planning, design, construction management, and monitoring. These also provided information about project costs for various types of restoration in several different landscape settings. For example, participants learned that urban stream projects may be much more expensive than rural projects due to land use constraints, utilities, road crossings, and construction management issues. Participants also learned that watershed size and length of restored channel greatly affect the complexity and cost of stream projects.

The agenda for this workshop was as follows:

Tuesday, January 23

8:00 am Review of Stream Restoration Principles and Practices
Bankfull Channel Indicators and Regional Curves
Review of Rosgen Stream Classification
Riparian Vegetation Assessment
12:00 LUNCH BREAK
1:00 pm FIELD EXERCISES
Stream Classification and Bankfull Verification - Kentwood Park

Wednesday, January 24

8:00 am Causes of Stream Instability
Stability Measurements
Channel Evolution
Priority Levels of Restoration
Restoration Case Studies
12:00 LUNCH BREAK
1:00 pm FIELD EXERCISES
Stability Measurements and Discussion of Priority Levels - Yates Mill

Thursday, January 25

8:00 am Reference Reach Overview and Survey Procedures
Reference Reach Vegetation Survey
10:00 am FIELD EXERCISES
Reference Reach Survey - Sal's Branch, Umstead Park
3:00 pm CLASSROOM
Reference data analysis and discussion

Friday, January 26

8:00 am Stream Channel Geometry Design
Sediment Transport
In-stream Structures
Vegetation
12:00 LUNCH BREAK
1:00 pm FIELD EXERCISES
Visit Restoration Sites - Abbott and Speight

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