US Army Corps of Engineers®
Wilmington District

STREAM MITIGATION GUIDELINES

April 2003

NRCS Project, North Toe River, Avery County, NC
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APPENDICES

1. INTRODUCTION

This guidance has been prepared by a workgroup consisting of representatives from U.S. Army Corps of Engineers, Wilmington District (District), North Carolina Division of Water Quality (DWQ), U.S. Environmental Protection Agency, Region IV (EPA), Natural Resources Conservation Service (NRCS) and the North Carolina Wildlife Resources Commission (WRC). This document is intended to provide the regulated community of North Carolina with joint and consistent, District and DWQ stream mitigation guidance.

Historically, compensatory mitigation for impacts to all aquatic systems was in the form of wetland mitigation. However, wetland mitigation does not provide appropriate replacement of aquatic functions lost due to impacts to fluvial systems. Because of this, the District and DWQ now generally require that compensatory mitigation for impacts to stream resources should be in the form of restoration and/or enhancement of degraded stream channels utilizing natural channel design and bio-engineering techniques. Channel preservation of unique or otherwise ecologically important stream segments may also play an important role in mitigating stream impacts.

Mitigation decisions are made during the permit review process. Mitigation requirements are generally determined through site evaluations that document aquatic resource losses. These site evaluations take into account the resources being impacted and the potential for compensating the public for their loss. This document provides general guidance to be applied when evaluating permit applications and proposed mitigation.

Topics addressed in this document include requirements for stream mitigation, definitions of stream mitigation terms and activities, crediting for mitigation activities and monitoring requirements. This guidance will generally apply to **non-tidal** waters. These guidelines should not be construed as affecting the applicability of the CWA 404 (b)(1) Guidelines, found at 40 CFR Part 230, the Memorandum of Agreement between the Environmental Protection Agency and the Department of the Army concerning the Determination of Mitigation Under the Clean Water Act Section 404(b)(1) Guidelines, or the review process outlined in DWQ's rules (15A NCAC 2H.0506). These guidelines require consideration and the selection of practicable alternatives to proposed project impacts that would avoid or minimize impacts to waters of the United States (including streams) prior to considering compensatory mitigation.

Primary Guidance Objectives:

a. Restore and enhance aquatic habitat.
b. Maintain and improve water quality functions.
c. Promote natural channel design and bio-engineering.

d. Maintain and restore public use of stream resources.

This document is intended to be fair and flexible and is subject to periodic revision and update as new procedures and stream mitigation monitoring data support changes. Comments and suggestions are welcomed at any time, especially during the initial 12-month period of this document's use from the publication date. Comments should be addressed to Mr. Scott McLendon (scott.c.mclendon @usace.army.mil), Ms. Becky Fox (fox.rebecca@epa.gov), or Mr. Todd St. John (todd.st.john@ncmail.net).

2. REGULATORY AUTHORITIES & GUIDELINES

A. **Section 10 of the River and Harbor Act of 1899**: In accordance with Section 10 of the River and Harbor Act, the Corps of Engineers is responsible for regulating all work in navigable waters of the United States.

B. **Section 404 of the Clean Water Act**: In accordance with Section 404 of the Clean Water Act as amended in 1977, the Corps of Engineers is responsible for regulating the discharge of dredged or fill material in waters of the United States, including wetlands. **The purpose of the Clean Water Act is to restore and maintain the physical, chemical, and biological integrity of the nation's waters**. Under both of the above programs, the Corps of Engineers is responsible for receiving and evaluating permit applications affecting waters of the United States. Frequently, the required public interest review of applications results in a finding that the public must be compensated for unavoidable aquatic resource losses, including stream resources.

C. **Section 404(b)(1) Guidelines of the Clean Water Act:** Section 230.10 (d) of the Section 404 (b)(1) Guidelines states that "… no discharge of dredged or fill material shall be permitted unless appropriate and practicable steps have been taken which will minimize potential adverse impacts of the discharge on the aquatic ecosystem."

D. **EPA/Army Mitigation Memorandum of Agreement (MOA), February 6, 1990**: The MOA interprets Section 230.10 (d) of the Guidelines to require the use of mitigation in order to be in compliance with this section of the Guidelines. As clarified in the MOA, compliance with the Section 404 (b)(1) Guidelines requires application of a sequence of mitigation -- avoidance, minimization and compensation. In other words, mitigation consists of the set of modifications necessary to avoid adverse impacts altogether, minimize the adverse impacts that are unavoidable and compensate for the unavoidable adverse impacts. Compensatory mitigation is required for unavoidable adverse impacts, which remain after all appropriate and practicable avoidance and minimization has been achieved. The Guidelines identify a number of "Special Aquatic Sites," including riffle pool complexes, which require a higher level of regulatory review and protection. This stream guidance document addresses only compensatory mitigation and should only be used after adequate avoidance and minimization of impacts associated with the proposed project has occurred

E. **401 Water Quality Certification Program:** Section 401 of the Clean Water Act provides that no Federal permit, including 404 permits, will be issued unless a 401 Water Quality Certification has been issued or waived. In North Carolina, DWQ administers the 401 program. The "401" is essentially a verification by DWQ that a given project will not degrade waters of the State or otherwise violate water quality standards (15A NCAC 2B .0200).

F. **The Fish and Wildlife Coordination Act of 1956:** The FWCA expresses the will of Congress to protect the quality of the aquatic environment as it affects the conservation, improvement and enjoyment of fish and wildlife resources. The Act requires the Corps of Engineers to coordinate its regulatory programs with the U.S. Fish And Wildlife Service and the Nation Marine Fisheries Service.

G. **Endangered Species Act:** The Endangered Species Act declares the intention of Congress to conserve threatened and endangered species and ecosystems in which those species depend. The Act requires consultation with the U.S. Fish and Wildlife Service to insure the regulated activities are not likely to jeopardize the continued existence of threatened or endangered species or result in the destruction or adverse modification of designated critical habitats. The Act also requires the Federal agencies to utilize their authorities in furtherance of the Act by carrying out programs for the conservation of endangered and threatened species.

3. TYPES OF PERMITS THAT MAY REQUIRE STREAM MITIGATION

A. **Individual Permits:** Individual permits are typically required where the level of project activities exceeds work thresholds authorized by General Permits. Individual permits require the submission of a permit application by the applicant followed by the Corps placement of the project on public notice for agency and public review.

B. **Nationwide Permits:** Nationwide Permits (NWPs) are issued by the Chief of Engineers (Headquarters) through publication in the *Federal Register* and are applicable throughout the nation. NWPs authorize a number of commonly occurring nationwide activities that typically have minimal impact on the aquatic environment. Where a proposed activity is expected to exceed minimal impact on the aquatic environment, mitigation may be required to reduce aquatic resource impacts to an acceptable, minimal level. Certain conditions attached to specific NWPs require pre-construction notification prior to starting work. The Corps generally responds to such notices within 45 days.

C. **Regional General Permits:** Regional General Permits (GPs) are developed and issued by the District or the South Atlantic Division on a regional basis. GPs typically authorize commonly occurring activities that are specific to the District/Region and that do not have NWP coverage. Certain GPs require notification prior to starting work. As with NWPs, GP activities typically cause minimal impact on the aquatic environment. Where authorized work exceeds the minimal impact threshold, mitigation may be necessary to lessen effects on aquatic resources.

D. **Letters of Permission:** Letters of Permission (LOPs) are a type of permit issued through an abbreviated processing procedure. LOPs include coordination with federal and state fish and wildlife agencies as required by the FWCA and a public interest evaluation. They do not require the publishing of an individual public notice. LOPs apply only to Section 10 authorization in North Carolina.

E. **401 Water Quality Certification:** When the District determines that a 404 Permit is required, a 401Water Quality Certification is also required. The District determines which type of permit is applicable for the project: an Individual Permit, Nationwide, or Regional General Permit. An Individual 401 Water Quality Certification is necessary if an Individual 404 Permit is required. For each Nationwide or Regional General Permit, DWQ must either issue a matching General Certification, or it must issue or waive an individual 401 Certification in order for the permit to be utilized. Once the District has determined which type of GP is needed, the matching General Certification can be reviewed on the DWQ Wetlands Unit web page http://h2o.ehnr.state.nc.us/ncwetlands/certs.html . If written concurrence is required, then a formal application and payment of the appropriate fee is needed for the 401 Water Quality Certification.

4. TERMINOLOGY

- **Compensatory Stream Mitigation** - The restoration, enhancement, or, for streams of national or state significance because of the resources they support, preservation of streams and their associated floodplains for the purpose of compensating for unavoidable adverse impacts which remain after all appropriate and practicable avoidance and minimization has been achieved. Compensatory stream mitigation may be required for impacts to perennial and intermittent streams and should be designed to restore, enhance, and maintain stream uses that are adversely impacted by authorized activities.

- **Perennial Stream** - A perennial stream has flowing water year-round during a typical year. The water table is located above the streambed for most of the year. Groundwater is the primary source of water for stream flow. Runoff from precipitation is a supplemental source of water for stream flow. (65 FR 12898). Perennial streams support a diverse aquatic community of organisms year round and are typically the streams that support major fisheries.

- **Intermittent Stream** – An intermittent stream has flowing water during certain times of the year, when ground water provides water for stream flow. During dry periods, intermittent streams may not have flowing water. Runoff from precipitation is a supplemental source of water for stream flow. (65 FR 12898). The biological community of intermittent streams is composed of species that are aquatic during a part of their life history or move to perennial water sources. For the purpose of mitigation, intermittent streams will be treated as 1st order streams.

- **Ephemeral Stream** – An ephemeral stream has flowing water only during and for a short duration after precipitation events in a typical year. Ephemeral streambeds are located above the water table year-round. Groundwater is not a source of water for the stream. Runoff from precipitation is the primary source of water for stream flow. (65 FR 12897). Ephemeral streams typically support few aquatic organisms. When aquatic organisms are found they typically have a very short aquatic life stage.

- **Stable Stream** – A stream which, over time (in the present climate), transports the sediments and flows produced by its watershed in such a manner that the dimension, pattern and profile are maintained without either aggrading or degrading (Rosgen, 1996).

- **Channelized Stream** – Stream that has been degraded (straightened) by human activities. A channelized stream will generally have increased depth, increased width, and a steeper profile, be disconnected from its floodplain and have a decreased pattern or sinuosity.

- **Ditches Acting as Streams** – Ditches that intercept enough groundwater to have either intermittent or perennial flow. These channels have enough flow to support aquatic life and would be considered waters of US.

- **Natural Channel Design** – A geomorphologic approach to stream restoration based on an understanding of the valley type, general watershed conditions, dimension, pattern, profile, hydrology and sediment transport of natural, stable channels (reference condition) and applying this understanding to the reconstruction of an unstable channel.

- **Stream Classification** – Ordering or arranging fluvial systems into groups or sets based on their similarities or relationships. A morphological classification system categorizes a stream based on its physical and geomorphic characteristics. Rosgen (1994) proposed a geomorphic classification system that is widely used in stream restoration and mitigation. Classification allows for predicting the behavior of these systems, extrapolating knowledge of one system to another, and provides a consistent and reproducible frame of reference for communication among those interested in these systems. Alternatively, for North Carolina streams, DWQ has a classification system that is based on water quality standards. This system is a regulatory convention for establishing water quality standards based on a stream's "best use". (Use-support ratings are a method to analyze water quality information and to determine whether the quality is sufficient to support the uses for which the waterbody has been classified by DWQ. The word "use" refers to such activities as swimming, fishing and water supply. All surface waters in the state have been assigned this type of classification.)

- **Stream Order** - A method for classifying, or ordering, the hierarchy of natural channels within a catchment. One of the most popular methods for assigning stream orders was proposed by Strahler (1957). The uppermost channels in a catchment with no upstream tributaries are first order downstream to their first confluence. A second order stream is formed below the confluence of two first order streams. A third order stream is formed by the confluence of 2 second-order streams and so on. The confluence of a channel with another channel of lower order does not raise the order of the stream below the confluence.

- **Reference Reach/Condition** – A stable stream reach or, in some instances, condition, generally located in the same physiographic region (see Appendix III), climatic region, and valley type as the project and serves as the blueprint for the dimension, pattern, and profile of the channel to be restored.

- **Bankfull stage** – The point at which water begins to overflow onto its floodplain. This may or may not be at the top of the stream bank on entrenched streams. Typically, the bankfull discharge recurrence interval is between one and two years. It is this discharge that is most effective at moving sediment, forming and removing bars, shaping meanders and generally doing work that results in the morphological characteristics of channels. (Dunne and Leopold, 1978)

- **Channel Dimension** – The two-dimensional, cross sectional profile of a channel taken at selected points on a reach, usually taken at riffle locations. Variables that are commonly measured include width, depth, cross-sectional area, floodprone area and entrenchment ratio. These variables are usually measured relative to the bankfull stage.

- **Channel Pattern** – The sinuosity or meander geometry of a stream. Variables commonly measured include sinuosity, meander wavelength, belt width, meander width ratio and radius of curvature.

- **Channel Profile** –The longitudinal slope of a channel. Variables commonly measured include water surface slope, pool-to-pool spacing, pool slope and riffle slope.

- **Flood-Prone Area** – Floodplain width measured at an elevation corresponding to twice the maximum bankfull depth. This area often correlates to an approximate 50-year flood or less. (Rosgen, 1994)

- **Stream Restoration** - The process of converting an unstable, altered, or degraded stream corridor, including adjacent riparian zone (buffers) and flood-prone areas, to its natural stable condition considering recent and future watershed conditions. This process should be based on a reference condition/reach for the valley type and includes restoring the appropriate geomorphic dimension (cross-section), pattern (sinuosity), and profile (channel slopes), as well as reestablishing the biological and chemical integrity, including transport of the water and sediment produced by the stream's watershed in order to achieve dynamic equilibrium[1].

- **Stream Enhancement** - Stream rehabilitation activities undertaken to improve water quality or ecological function of a fluvial system. Enhancement activities generally will include some activities that would be required for restoration. These activities may include in-stream or stream-bank activities, but in total fall short of restoring one or more of the geomorphic variables: dimension, pattern and profile. Any proposed stream enhancement activity must demonstrate long-term stability.

- **Enhancement Level I** – Mitigation category that generally includes improvements to the stream channel and riparian zone that restore dimension and profile. This category may also include other appropriate practices that provide improved channel stability, water quality and stream ecology. Work will be based on reference reach information.

- **Enhancement Level II** – Mitigation category for activities that augment channel stability, water quality and stream ecology in accordance with a reference condition but fall short of restoring both dimension and profile. Examples of enhancement level II activities may include stabilization of streambanks through sloping to restore the appropriate dimension and vegetating a riparian zone that is protected from livestock by fencing, construction of structures for the primary purpose of stream bank stabilization and, when appropriate, reattaching a channel to an adjacent floodplain.

- **Streambank Stabilization** – The in-place stabilization of an eroding streambank. Stabilization techniques, which include primarily natural materials, like root wads and log crib structures, as well as sloping stream banks and revegetating the riparian zone may be considered for mitigation. When streambank stabilization is proposed for mitigation, the completed condition should be based on a reference condition. Stream stabilization techniques that consist primarily of "hard" engineering, such as concrete lined channels, rip rap, or gabions, while providing bank stabilization, will not be considered for mitigation. An exception to this may be considered for short reaches when mitigating for urban stream impacts.

- **Stream Relocation** – Movement of a stream to a new location to allow an authorized project to be constructed in the stream's former location. In general, relocated streams must reflect the dimension, pattern and profile indicated by a natural reference reach/condition in order to be adequate compensation for the authorized stream impact. Relocated streams will generally require wooded protected buffers of sufficient width (see buffer section). Relocations resulting in a reduced channel length will generally require mitigation.

[1]This definition of stream restoration describes a category of mitigation for use with this guidance, rather than a generic definition of stream restoration.
slope according to a reference reach and, when appropriate, reattaching to an adjacent floodplain.

- **Stream Preservation** – Protection of ecologically important streams, generally, in perpetuity through the implementation of appropriate legal and physical mechanisms. Preservation may include the protection of upland buffer areas adjacent to streams as necessary to ensure protection or enhancement of the overall stream. Preservation must protect both sides of the channel. Generally, stream preservation should be in combination with restoration or enhancement activities. Under exceptional circumstances, preservation may stand-alone where high value waters will be protected or ecologically important waters may be subject to development pressure (Refer to Section 6 regarding preservation criteria). Stand-alone preservation may generally be most acceptable in mitigating impacts associated with nationwide and regional general permits. Preservation may be utilized for relatively undisturbed areas that require little or no enhancement activities other than protective measures. Although minimal streambank revegetation may be required in some cases, if mitigation requires extensive streambank revegetation, the mitigation will be considered to be Enhancement Level II.

- **Vegetated Buffer** – An upland or wetland area vegetated with native trees and shrubs next to rivers, streams, lakes, or other open waters that separate aquatic habitats from developed areas, including agricultural land.

- **Stream Riparian Zone** – A riparian zone is the area of vegetated land along each side of a stream or river that includes, but is not limited to, the floodplain. The quality of this terrestrial or wetland habitat varies depending on width and vegetation growing there. As with vegetated buffers, functions of the riparian zone include reducing floodwater velocity, filtering pollutants such as sediment, providing wildlife cover and food, and shading the stream. The ability of the riparian zones to filter pollutants that move to the stream from higher elevations results in this area being referred to as a buffer zone. The riparian zone should be measured landward from the bankfull elevation on each side of a stream or river.

- **Biological Integrity** – A measure of the state of health in aquatic communities. A healthy aquatic community is a balanced community of organisms having a species composition, diversity and functional organization comparable to that found in natural (unimpaired) habitats in the region (Karr, et al. 1986).

- **Best Management Practices (BMPs)** – Policies, practices, procedures, or structures implemented to mitigate the adverse environmental effects on surface water quality resulting from development and other land disturbing activities. BMPs are categorized as structural or non-structural. (See Section 10 for further BMP discussion.)

- **Conservation Easement** – A legally binding, recorded instrument approved by the District and DWQ offices of counsel to protect and preserve mitigation sites.

- **303 (d) Listed Waters** – Section 303(d)(1) of the Clean Water Act, requires states/tribes to provide a list of impaired waters to EPA every two years. Waterbodies are designated as impaired by a state or tribe when existing pollution controls are not stringent enough to attain and maintain the water quality standards the state/tribe has set for them.

- **Mountain Counties** – Counties in which the WRC has Designated Public Mountain Trout Waters and consists of the following: Alleghany, Ashe, Avery, Buncombe, Burke, Caldwell, Cherokee, Clay, Graham, Haywood, Henderson, Jackson, Macon, Madison, McDowell, Mitchell, Polk, Rutherford, Stokes, Surry, Swain, Transylvania, Watauga, Wilkes and Yancey.

5. MITIGATION REQUIREMENTS

Final compensatory mitigation requirements of Department of the Army permits will be commensurate with the type and amount of impact associated with the permitted activity. Proposed compensatory mitigation will be coordinated with the appropriate review agencies and final mitigation requirements will be determined on a project-by-project basis. DWQ may also require stream mitigation for its 401 Certification. For the purposes of defining compensatory stream mitigation options, this guidance establishes four levels or types of mitigation (Restoration, Enhancement Level I, Enhancement Level II and Preservation) that may be used to compensate for unavoidable impacts to intermittent and perennial streams. These mitigation categories are defined in the Terminology Section (Section 4) and do not directly relate to the Rosgen Priority Levels of Stream Restoration.

A. General mitigation requirements associated with direct impacts to stream channels including culvert/pipe installations. This section provides the basic compensatory mitigation requirements (ratios) based solely on the quality of the stream being impacted and are intended to ensure that impacts to higher quality streams are adequately compensated. Stream quality determinations will be made on a case-by-case basis and site-specific conditions may warrant the adjustment of these ratios up or down.

Table 1. Basic Compensatory Mitigation Requirements Associated with Impacts to Poor to Fair, Good, and Excellent Quality Streams.

Existing Channel Quality/Conditions* (Aquatic habitat/water quality)	Proposed Unavoidable Stream impacts** (Linear feet)	Compensatory Mitigation Ratio	Basic Compensatory Mitigation Requirement
Poor to Fair	100	1:1	100 lf
Good	100	2:1	200 lf
Excellent	100	3:1	300 lf

***Refer to section "C" for a discussion of stream quality determinations**

****100 linear feet of proposed channel impacts in column 2 was selected for demonstration purposes only.**

B. Mitigation requirements based on mitigation type.

Table 2 provides guidance on the amount of Restoration, Enhancement I, Enhancement II, and Preservation that would satisfy a requirement of 100 lf of mitigation based on the basic compensation ratios provided in Table 1. Ranges have been established within the Enhancement and Preservation categories to allow flexibility during the evaluation of plans to account for the wide range of potential enhancement, and preservation opportunities that may be available at a particular mitigation site. In addition, for a given impact, compensatory mitigation requirements will generally increase from restoration to preservation to account for the decrease in functional improvements in aquatic habitat and water quality that is expected to occur with enhancement and preservation level projects compared to restoration.

Note: Factors influencing the adjustment of preservation ratios may include the presence of Federally threatened or endangered species, presence of critical habitat, other Federal or state species of concern, outstanding resource waters and other high quality waters, high quality aquatic habitat potentially subject to development impacts, streams with high quality adjacent wetlands and water supply streams. (See Section 6 for preservation site selection criteria and criteria that may enhance stream preservation crediting.)

Table 2. General Mitigation Requirements Based on Restoration, Enhancement I, Enhancement II, and Preservation.

Mitigation Type	Mitigation Activity Multiplier*	Linear Feet of Mitigation Required (from Table 1)	Linear Feet of Mitigation Work Required (by type)
Restoration	**1.0**	**100**	**100 lf**
Enhancement I	**1.0 to 1.5**	**100**	**100 lf to 150 lf**
Enhancement II	**1.5 to 2.5**	**100**	**150 lf to 250 lf**
Preservation	**2.5 to 5.0**	**100**	**250 lf to 500 lf**

***The Mitigation Activity Multiplier is applied to each mitigation type to recognize, that for a given reach, the functional improvement associated with mitigation projects increase along the continuum from preservation to enhancement to restoration.**

Impacts due to impounding stream channels will generally require stream mitigation by the US Army Corps of Engineers. Mitigation requirements will be determined on a case-by-case basis for these impacts.

Table 3 provides a summary of the range of compensatory mitigation requirements based on the quality of the stream being impacted and the type of mitigation (Restoration, Enhancement I, Enhancement II, Preservation) that is proposed to compensate for the authorized impacts.

Table 3. Mitigation Requirements for 100 lf of Impact to Poor to Fair, Good, and Excellent Quality Streams.

Stream Quality	Restoration	Enhancement I	Enhancement II	Preservation
Poor to Fair	**100 lf**	**100 to 150 lf**	**150 to 250 lf**	**250 to 500 lf**
Good	**200 lf**	**200 to 300 lf**	**300 to 500 lf**	**500 to 1000 lf**
Excellent	**300 lf**	**300 to 450 lf**	**450 to 750 lf**	**750 to 1500 lf**

Combinations of mitigation types in one project are acceptable provided these ratios are generally followed. In all cases, the goal of a mitigation project should be to provide for the replacement of those aquatic functions being lost or adversely impacted by the authorized activity.

Channel relocations, where a stable channel is re-established on the project site and is designed and implemented according to natural stream channel design criteria, will generally result in a 1:1 restoration ratio provided the channel satisfies all success criteria.

B. Stream Quality Determinations

1. Channel Quality/Conditions for large streams and rivers (wet width of 4 meters or more).

Bioclassification criteria and rating protocols have been successfully developed for three major ecoregion types over the past several decades by DWQ. These criteria are based on the community composition of benthic macroinvertebrates and include taxa richness (primarily EPT, or Ephemeroptera, Plecoptera, and Trichoptera) and biotic index values. Habitat quality and fish community conditions are also metrics that are commonly used to assess channel quality for large streams and rivers in NC. These criteria are discussed in the Standard Operating Procedures manual for the Biological Assessment Unit of the Environmental Sciences Branch and can be downloaded from the following website (http://www.esb.enr.state.nc.us/BAU.html). These criteria are used to define 5 stream quality conditions as Excellent, Good, Good-Fair, Fair, and Poor.

DWQ and the Corps believe that these rankings can be used to determine stream quality conditions with respect to both impact and mitigation sites. However, the time intensive methodology required for these rankings will probably be prohibitive in most cases. DWQ and the Corps are committed to developing a simpler yet still accurate rapid stream assessment methodology for stream quality conditions.

2. Channel Quality/Conditions for small streams (<3 meter wet width).

A. Small Perennial Streams: Research to determine water quality conditions within small streams has been conducted by DWQ and reported in a series of memos by the Biological Assessment Unit. This research has noted that number of benthic macroinvertebrate taxa decrease as streams become smaller, and this decrease in taxa richness is predictable in reference systems. Decreases in taxa richness in reference catchments is directly related to the loss of habitat diversity as streams become smaller. Biotic index values showed little relationship to stream size and therefore may be a very useful metric to determine water quality conditions in small stream systems. These data also suggest that benthic macroinvertebrate communities can be used to determine impacts from reference reaches. In addition to these data, stream functional assessment forms have been developed with the assistance of a technical advisory committee. However, these forms have not yet been field tested to determine their reliability and accuracy. DWQ and the Corps believe that these forms (or derivatives of them) will be able to be used to assess channel quality conditions for small perennial streams. These assessment forms incorporate stream morphology, riffle material, streambank stability, and biological components.

B. Intermittent Streams: Research is currently being conducted by DWQ with assistance of an EPA Wetland Program Development Grant to define the ecological functions of intermittent streams. Work is focusing on intermittent streams in the piedmont and mountains of North Carolina. As part of this work, benthic macroinvertebrate communities are being collected and analyzed. It is anticipated that these data will help define channel quality conditions of intermittent streams.

Until an acceptable methodology is available, DWQ and the Corps will evaluate and determine stream quality on a case-by-case basis with applicants based on the best information that is available at the time of the evaluation.

6. SELECTION OF MITIGATION SITES

Stream mitigation should generally be performed on a stream system with the same habitat as the impacted stream, i.e. cold, cool, and warm water habitat. The following criteria should be used to provide general guidance for selecting streams and justifying selections to the District and DWQ. All three criteria apply to any stream being proposed for impact and do not refer to the quality of the stream. Higher mitigation ratios may be required if the mitigation project is in a different 8-digit HUC than the impact site.

<u>Selection Criteria 1</u>. Mitigation should be accomplished within one stream order of the impacted stream, within the same subbasin (8 digit H.U.C) and as close to the impacted stream as possible. For the purpose of mitigation, intermittent streams will be treated like 1st order streams.

<u>Selection Criteria 2</u>. Stream mitigation should be performed on streams with similar habitat designations (cold, cool and warm water as defined in WRC habitat guidance, see Appendix I). Mitigation will be conducted in trout waters if any trout species are found in project stream reaches.

<u>Selection Criteria 3.</u> Mitigation should be performed within the same Physiographic Region (Appendix III) and priority should be given to mitigation sites that have the potential to improve habitat for state or Federally threatened and endangered (T&E) species.

To qualify for stream mitigation, the project plan shall be designed to achieve the maximum level of improvement and should result in the restoration of the channel to its most probable natural state, given the individual constraints of the project location. This acknowledges that the maximum level of improvement may be constrained by water withdrawals, altered precipitation-runoff relationships, adjacent land use and other factors. It is not necessarily the goal of stream mitigation to return stream segments to some pre-impact condition. While site-specific constraints may reduce the potential of mitigation sites (and correspondingly increase the mitigation ratios), mitigation goals should be to establish the maximum biological, chemical and physical integrity possible in the current environment. However, under no circumstances should stream restoration and enhancement projects be “over” designed in order to generate stream mitigation credit.

For preservation to be an acceptable mitigation option the channel should generally be ecologically important and in a relatively undisturbed condition. The following list of criteria may be used as a guide for selecting high value preservation sites.

Recommended priority areas for channel preservation: *

- **Streams in a watershed that are adjacent to, or within a unique wetland as identified by NC Administrative Code 15A 2B .0100.**
- **Streams in a watershed that contains Critical Habitat Areas identified by the Coastal Habitat Protection Program of the Division of Marine Fisheries.**
- **Streams in a watershed that contains a significant Natural Heritage Area as identified by the Natural Heritage Program of the Division of Parks and Recreation, provided the Natural Heritage Area contributes to the overall quality of the stream.**
- **Streams in a watershed that is known to provide habitat for state or federally listed endangered or threatened species.**
- **Streams in a watershed that contains fishery nursery areas, High Quality Waters, Outstanding Resource Waters, Trout Waters, or Water Supply Watersheds.**
- **Streams in a watershed that meets the criteria for Exceptional Significance rating under the Division of Coastal Management’s NC CREWS (NC Coastal Region Evaluation of Wetland Significance).**
- **Streams in a watershed that contains unique and/or high quality habitat (stream and/or wetland) that is adjacent or within an area experiencing a rapid increase in population or development trend.**
- **Streams in a watershed that contain stream reaches designated as critical habitat by the US F&WS.**

* The above are not listed in order of selection priority.

7. MITIGATION PLANS AND SCHEDULING

Except as specifically allowed by permit conditions, authorized projects will not proceed until final mitigation plans have been reviewed and approved by the District. Under most circumstances, mitigation will be implemented either prior to or concurrent with authorized activities. DWQ requires a mitigation site that is available to the applicant and ecologically viable as well as a conceptual mitigation plan before the 401 Water Quality Certification will be issued. A final mitigation plan must then be approved before impacts occur. A review of these plans will be coordinated with state and federal review agencies. Authorized activities that will be mitigated through an approved bank program or in-lieu fee program may start work once the District receives notification that the mitigation request has been accepted and financial documentation has been provided. Use or compliance with these guidelines does not relieve the permittee of the need to obtain other federal, state or local authorizations required by law. (Appendix VIII contains relevant agency websites).

Mitigation options relative to commencing permit activities. These options are not listed in any particular order of priority or preference:

A. NC Wetland Restoration Program – Determined by WRP/District MOA (November 4, 1998)

B. Private non-bank – Prior to a permit being issued a final mitigation plan should be approved and the site secured. Plan implementation must commence either prior to or concurrent with authorized activities. A preservation mechanism will be in place before commencing authorized activities.

C. Federal/State Government – Before a permit is issued a mitigation plan must be approved. Plan implementation must commence either prior to or concurrent with authorized activities. Contractual agreements or MOAs between government bodies addressing mitigation requirements and implementation may be acceptable. Except where these agreements are signed and approved by the District and DWQ, a preservation mechanism should be in place before commencing authorized activities.

D. Approved Private Mitigation Bank - Credits must be available and payment documented prior to permit activity and in compliance with the established mitigation-banking instrument.

8. BUFFER WIDTHS & RIPARIAN RESTORATION

Buffer protection for stream mitigation is intended to enhance the recovery and protection of stream mitigation projects. In most cases, a protected buffer of a minimum of 50 feet on piedmont/coastal plain streams and 30 feet on mountain streams extending landward from the bankfull elevation on each side of the stream will be required at stream mitigation sites (See Section 4 for list of mountain counties). It is generally acknowledged that wider buffers provide increased benefits to adjacent waters and, where appropriate and practicable, the acquisition of wider buffers will be encouraged. Under certain conditions, wider buffers may be required, based on comments from reviewing agencies or due to construction requirements. Increased buffer widths may be sought to protect sensitive riparian or instream environments, threatened or endangered species, or historical or cultural resources. Consideration for reduced buffer widths will be based on issues related to construction constraints and land ownership and may result in increased mitigation ratios. Such requests will be considered on a case-by-case basis. Justification for reduced buffer widths must be provided by the permit applicant and receive approval by the District and DWQ. Where stand-alone stream preservation is proposed as mitigation, additional buffer width of at least two times the base requirement may be required. When the project applicant proposes buffers that exceed the minimum requirement, the District may, with agreement of the permit review agencies, grant additional channel mitigation credit proportionate with expected benefits. Proposed buffers containing stable riparian wetlands are generally viewed as highly functional ecological areas that often justify enhanced crediting.

Planting the riparian zone should be done as work proceeds or at the latest, immediately upon completion of stream construction activities. Stream banks will be planted with native vegetation that represents both woody (trees and shrubs) and herbaceous species. Species selection will be based on a survey of the vegetation from the reference reach; from less degraded sections of the stream being restored or from reference literature that details native species. The result should be an appropriate vegetative community for the site. Live staking, with such species as willow or dogwood, or the application of other bioengineering methods is recommended to provide bank stability and shade soon after project completion. Survival of woody species planted at mitigation sites should be at least 320 stems/acre through year three. A ten percent mortality rate will be accepted in year four (288 stems/acre) and another ten percent in year five resulting in a required survival rate of 260 trees/acre through year five. This is consistent with Wilmington District (1993) guidance for wetland mitigation. It is critical that disking and/or ripping of the flood prone area be done prior to planting. As knowledge of other systems is published or as reference reach information is developed, it will be incorporated into updated versions of this guidance.

Herbaceous vegetation should be established through plantings of existing plants by relocating sod mats or by seeding with a native riparian seed mix. An annual cover crop (barley, millet, wheat, rye, etc.) should be sowed to stabilize the banks until the other vegetation can become established. A cover crop should be selected whose germination season matches the time of application. Evaluations of the cover crop and perennial herbaceous vegetation should be made regularly to ensure good germination and establishment of the herbaceous community. A project site vegetation plan is required as part of the mitigation proposal.

Where appropriate, stream buffers should be protected from livestock through fencing and, if necessary, the installation of livestock watering facilities and managed stream crossings. The installation of signs or other acceptable forms of demarcation will identify buffers as a protected conservation area.

Wetlands occurring within stream buffers may be used for wetland mitigation purposes.

9. EASEMENTS AND HOLDING MITIGATION SITES

Stream mitigation sites will generally be held and protected in perpetuity. Permanent conservation easements are acceptable methods of providing long-term protection. Where practicable, either the mitigation site or a conservation easement over the mitigation site must be transferred to a government entity or non-profit conservation organization capable of holding and managing the site for conservation purposes. The organization accepting the property or easement over the property must be acceptable to the District.

Long-term protection through restrictive covenant or deed restriction may be acceptable, provided the mitigation site is owned by the permit applicant and is part of the property for which the permit is issued. The applicant must show that other preservation mechanisms are not practical before the District will consider this option.

Long-term protection methods for all mitigation activities must receive approval by the District prior to implementation. A licensed attorney must draft easements, deeds, and restrictive covenants. Landowners must approve these agreements. Generally speaking, mitigation cannot be used for more than one purpose. Sites that are part of a landowner incentive program, or a federal or state ecosystem restoration program site are therefore unlikely to be acceptable as mitigation for Department of the Army permits. Except for very small sites, all mitigation sites must be surveyed, and an acceptable title opinion must be provided to the grantee of the property, with a copy to the District.

While the purpose of stream mitigation is to achieve long-term restoration, this may not always occur. In some instances, factors that are beyond the control of designers and the regulatory agencies may cause degradation. In those situations further restoration activities may reestablish stability. If the stream mitigation activities have been fully successful through 5 years and at least 2 bankfull events, the mitigation will generally be considered successful.

ACTIVITIES GENERALLY PROHIBITED WITHIN STREAM MITIGATION EASEMENTS:

- **Any change in, disturbance, alteration or impairment of the restored and natural features of the property, or any introduction of non-native plants or animals.**
- **Except as specifically authorized, construction or placement of any building, mobile home, road, trail, path, asphalt or concrete pavement, antenna, utility pole, or any other temporary or permanent structure or facility on the property.**
- **Agricultural, grazing, or horticulture use of property.**
- **Irrigation structures, dams, intakes and outfalls.**
- **Destruction, cutting, mowing, or harming any native vegetation on the easement property.**
- **Display of billboards, signs or advertisements, except the posting of no trespassing signs, or signs identifying the site as a conservation/ mitigation area.**
- **Dumping or storage of soil, trash, ashes, garbage, waste, abandoned vehicles, appliances, machinery, or hazardous substances, or toxic hazardous waste, or any placement of any underground or aboveground storage tanks on the property.**
- **Filling, excavation, dredging, mining or drilling, diking, removal of topsoil, sand, gravel, rock, peat, minerals or other materials, and any change in the topography of the land.**
- **Pollution, alteration, depletion or extraction of surface, natural watercourses or subsurface water. Any activity detrimental to water purity, or that would alter**

natural flows or water levels, drainage, increased in-stream sedimentation, or cause soil degradation or erosion.

- **Operation of motorcycles, dirt bikes, all-terrain vehicles, and any other type of motorized vehicles.**
- **Removal, relocation, modification, or general destruction of grade control, habitat, bank stabilization, or any other channel restoration and enhancement structures.**

10. FLEXIBLE STREAM MITIGATION

A. Urban Watershed Management

The District, DWQ and participating agencies fully support the implementation of stream mitigation within urban municipal areas. As a general rule, mitigation sites within urban areas will be utilized to compensate for unavoidable impacts to urban streams and such mitigation projects will generally comply with the guidance set forth by this document. In urban areas, traditional stream mitigation may not be possible due to multiple landowners, physical constraints, or hydraulic (flooding) concerns. As it is also recognized that innovative approaches to stream mitigation may provide benefits to water quality and aquatic life where traditional mitigation is not possible, these concepts are included in the category of Flexible Stream Mitigation and are described in the following sections. Where innovative approaches are approved, it will be expected that the project proponent will be required to document the benefits of the mitigation through monitoring. The specific mitigation credit that is generated from these innovative approaches will be determined by the District and DWQ on a case-by-case basis.

Watershed mitigation is essentially a program to provide long-term improvement and protection of an urban watershed (usually ½ square mile or larger) with a variety of best management practices (BMPs), installation of aquatic habitat structures, and measures for improving public access and enjoyment. Watershed mitigation planning will involve a two-step process: an overall watershed assessment that evaluates existing stream channel conditions, and a watershed-level stream channel and floodplain mitigation plan. The watershed analysis should include a detailed assessment of the tributaries and adjacent upland riparian/floodplain areas. The assessment will include information concerning stream classifications, current channel conditions, stream bank erosion potential, pollutant sources, information concerning watershed build-out, existing water quality data (if any) and data on fish and invertebrate species. The watershed assessment will identify needed mitigation measures and activities necessary to achieve the restoration goals stated in the watershed mitigation plan. The assessment will enable the project sponsor to generate a detailed watershed mitigation and management plan.

The use of BMPs for mitigation credit must be validated by conducting water quality and/or ecological surveys of benthic macroinvertebrate and/or fish communities to determine if the stated goals of the project have been met. These data should be supported by reviews of scientific literature prior to assigning credits. BMPs including, but not limited to, detention and retention wetlands, ponds or basins should not be placed in waters of the US. Stand-alone BMP activities will not be credited where other mitigation activities are needed and can be reasonably implemented. Mitigation credits will not be granted on linear areas that are not protected by an approved conservation easement or other approved legal mechanism. Watersheds containing waters on the State of North Carolina's 303(d) list or classified as a High Quality Water/Outstanding Resource Water (or group of tributaries to the same), Trout Waters or tributaries, or similar classifications should be targeted under this watershed mitigation program. Development, implementation, and coordination of watershed mitigation plans will closely follow procedures already established for mitigation banks. This generally includes requirements relative to establishing mitigation review teams, use of banking instruments, and release of mitigation credits.

Watershed assessments will evaluate current stream channel conditions and identify mitigation measures to promote stable channel geometry. The plan will employ priority levels of restoration to the maximum extent practicable. In order for channel areas to receive mitigation credit, an approved conservation easement or other preservation mechanism must be in place.

MITIGATION ACTIVITIES THAT MAY BE IMPLEMENTED IN WATERSHEDS	
CHANNEL RESTORATION	✓
ENHANCEMENT LEVEL I	✓
ENHANCEMENT LEVEL II	✓
BANK STABILIZATION	✓
CHANNEL PRESERVATION	✓
BEST MANAGEMENT PRACTICES	✓
PUBLIC ACCESS	✓

The most important consideration for BMP selection for the watershed approach is the ability of the BMP to remedy the problem(s) identified in the watershed or sub-watershed assessment. For instance, if the problem identified is excess nutrient loading, one might consider utilizing an extended detention wetland, which is considered to be one of the better BMPs for nutrient removal. Similarly, it may be inappropriate to consider a dry detention pond, which is less effective at removing nutrients than other BMPs. In any event, BMPs must be considered on a case-by-case basis. The following table is meant to provide some guidance based on current literature reviews as to appropriateness of certain BMPs for certain situations.

BMP	POLLUTANTS
Extended detention wetlands	Total Suspended Solids (TSS), nutrients, heavy metals, hydrology
Extended detention wet ponds	TSS, nutrients, hydrology
Extended dry detention basins	TSS, hydrology
Forested filter strips or forested buffers	Nutrients, TSS
Bio-retention areas or rain gardens	TSS, nutrients
Grassed swales or open channel practices	Nutrients, TSS
Infiltration basins	TSS, nutrients (only appropriate in proper soils)
Sand filters	TSS, nutrients (only appropriate in special circumstances, very high maintenance required)

Reference: NCDENR Stormwater BMP Manual, April 1999
2000 Maryland Stormwater Design Manual Volumes I & II

B. Other Approaches

Other actions that result in demonstrable stream improvements may also be eligible for stream mitigation crediting on a case-by-case basis. However, these measures (BMPs or any other activity) must not be a requirement of a NPDES permit or other regulatory requirement. These options would have to be beyond those measures required by regulations and should be part of a local watershed restoration plan. These other options can provide long-term protection for a stream segment or a watershed and therefore have a role in stream mitigation. However, the US Army Corps of Engineers and the NC Division of Water Quality may limit the use of these other options in the context of stream mitigation since these agencies need to ensure that aquatic life uses are being replaced. These options must receive case-by-case approval from the US Army Corps of Engineers and the NC Division of Water Quality and must include a provision for monitoring that will demonstrate the water quality and aquatic life benefits of the project. As such, projects that target waters with impaired water quality such as 303(d) waters, closed SA waters and Nutrient Sensitive Waters are more likely to be approved.

11. MONITORING

The purpose of monitoring is to determine the degree of success a mitigation project has achieved in meeting the objectives of providing proper channel function and increased habitat quality. Specific objectives must be included in a project design and may also be evaluated. In general, monitoring data should provide the District and DWQ with evidence that the goals of the project were met. Monitoring should be directed at evaluating primary activities accomplished through mitigation projects. Monitoring secondary benefits or accomplishments may also be appropriate for large-scale projects, when projects are done in ecologically important areas or when secondary benefits are a primary objective. Secondary benefits are those that are not directly accomplished or established during site construction. For example: a primary activity would be constructing a root wad revetment, the secondary benefit would be the enhancement of aquatic populations. Three levels of monitoring will be required based on the complexity of the mitigation project being proposed.

Upon completion of the project, an as-built channel survey shall be conducted. It is recommended that stream surveys, for both project construction and project monitoring, follow the methodology contained in the USDA Forest Service Manual, *Stream Channel Reference Sites* (Harrelson, et.al, 1994). The survey should document the dimension, pattern and profile of the restored channel. Permanent cross-sections should be established at an approximate frequency of one per 20 (bankfull-width) lengths. In general, the locations should be selected to represent approximately 50% pools and 50% riffle areas. Flexibility in the location and frequency will be allowed for cross-sections and should be based on best professional judgment. The selection of locations should always include areas that may be predisposed for potential problems. In the case of very narrow streams, two cross-sections per 1,000 lf will generally be sufficient. The as-built survey should also include photo documentation at all cross-sections and structures, a plan view diagram, a longitudinal profile, vegetation information and a pebble count for at least six cross-sections (or all cross sections if less than six required for project). If the restored stream section is less than 3,000 lf, the longitudinal profile should include the entire 3,000 lf, if the stream section is greater than 3,000 lf, the profile should be conducted for either 30 % of the restored stream or 3,000 lf (whichever is greater). Subsequent annual surveys will be required per instructions on the monitoring forms (biannual for photo documentation). It should be noted that different levels of mitigation would require different levels of monitoring. The as-built survey described above will generally be required only for Restoration and Enhancement Level I projects. The following paragraphs describe the specific requirements for the different levels of mitigation.

Monitoring Level I: This level of monitoring will apply to Restoration and Enhancement Level I projects. Because these projects involve the greatest degree of complexity they will require a more complex monitoring protocol. The required monitoring shall be performed each year for the 5-year monitoring period and no less than two bankfull flow events must be documented through the monitoring period. If less than two bankfull events occur during the first 5 years, monitoring will continue until the second bankfull event is documented. The bankfull events must occur during separate monitoring years. In the event that the required bankfull events do not occur during the five-year monitoring period, the Corps and DWQ, in consultation with the resource agencies, may determine that further monitoring is not required. It is suggested that all bankfull occurrences be monitored and reported through the required monitoring period. Monitoring data collected at level I sites should include the following: reference photos, plant survival analysis, channel stability analysis, and biological data if specifically required by permit conditions. Biological sampling evaluates secondary impacts of restoration projects. DWQ plans to evaluate 80 projects across the state to determine the benefits of these data in a mitigation monitoring protocol (see “Interim, Internal Technical Guide Summary – Benthic Macroinvertebrate Monitoring Protocols For Compensatory Stream Restoration Projects, dated July 2002, Version 1.3) which is available on DWQ’s website http://h2o.enr.state.nc.us/ncwetlands/. These data will be required for those projects that are recommended by DWQ. Biological data may be required for other projects on a case-by-case basis. Data are to be collected prior to construction and for at least 3 years following construction. A 1-year recolonization/population adjustment time of biological monitoring following construction is usually warranted. In addition, the yearly data should be collected during the same season. (Photo documentation will be required twice a year – summer and winter.) Deviations from the required monitoring protocol will generally not be acceptable. However, proposed exceptions will be evaluated on a case-by-case basis by the District and DWQ, and will be coordinated with appropriate permit review agencies.

Monitoring Level 2: This level of monitoring will apply to Enhancement Level 2 projects. Because these projects will generally be on a smaller scale and less complex a simpler protocol is required. Monitoring data at these sites should include the following: reference photos and plant survival. Channel stability should also be evaluated when the mitigation project alters the bankfull channel. Additional types of information may be required from mitigating parties if recommended and justified by project reviewers. Data must be collected each year for 5 years at the same time of year. No less than two bankfull flow events must be documented through the required 5-year monitoring period. If less than two bankfull events occur during the first 5 years, monitoring will continue until the second bankfull event is documented. The bankfull events must occur during separate monitoring years. It is suggested that all bankfull occurrences be monitored and reported through the required monitoring period. Deviations from this protocol may be acceptable when they can be justified.

Monitoring Level 3: This level of monitoring will apply to mitigation consisting only of preservation. Since the only action in this case is administrative, protecting a reach, a 5-year monitoring plan is not required. However, reference photos should be taken and provided to the District and DWQ. These should well document the reach, including the riparian zone being preserved. As for all photo reference sites, a detailed description of the location at which the photo was taken should also be provided. Additional types of information may be required from mitigating parties if recommended and justified by project reviewers.

Success Criteria: As described above, this guidance requires three forms of monitoring to evaluate the success of the project; photo documentation, ecological function, and channel stability measurements. These criteria will be used to evaluate success by considering the following:

<u>Photo documentation</u>
Channel aggradation or degradation
Bank erosion
Success of riparian vegetation
Effectiveness of erosion control measures
Presence or absence of developing instream bars (should be absent)

<u>Ecological Function</u>
Health and survival of vegetation (80% survival of planted species required after 5 years)
Restoration reach should mimic upstream conditions (or reference reach when applicable)

<u>Channel Stability</u>
Should be insignificant change from the as-built dimension
Do changes represent a movement in the direction of instability (e.g. increased width to depth ratio or a decreased width to depth ratio with decreased entrenchment ratio) or are changes minor and represent an increase in stability (e.g. decreased width to depth ratio without a decrease in entrenchment ratio)?
Should be little change from the as-built longitudinal profile

Pool/riffle spacing should remain fairly constant
Pools should not be filling in (aggradation) or riffles starting to change to pools (degradation)
Pebble count should show a change in the size of bed material toward a desired composition.

Annual monitoring forms require as-built plans and current data. Monitoring reports should contain a discussion of any deviations from as-built and an evaluation of the significance of these deviations and whether they are indicative of a stabilizing or destabilizing situation. Appendix II summarizes the measures of success, failure, and required remedial actions.

Specific biological success criteria are currently a subject of applied research being coordinated by the NC Division of Water Quality. Formal development and adoption of biological success criteria (if any) will be done upon completion of that research.

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Appendix I

Stream Habitat Designation Criteria

Cold, Cool, and Warmwater Habitat Designations

I. Fish Species Composition

Fish species commonly associated with habitat types and widely distributed within those habitat types in North Carolina:

Coldwater – brook, brown, and rainbow trout, mottled sculpin, longnose dace, blacknose dace, and central stoneroller.

Coolwater – small mouth bass, rock bass, walleye, sauger, creek chub, river and bluehead chub, whitetail shiner, white sucker, Tennessee shiner, mirror shiner, warpaint shiner, northern hog sucker, fantail darter, greenside darter, greenfin darter.

Warmwater – largemouth bass, striped bass, Roanoke bass, white bass, black crappie, yellow perch, variety of catfish species and bullheads, redbreast sunfish, bluegill, pumpkinseed, variety of redhorse suckers, American eel, redfin pickerel, chain pickerel, golden shiner, creek chubsucker, margined madtom, pirate perch, warmouth, tessellated darter.

NOTE: These lists do not include many species with limited distributions. They are only intended to provide generalized fish community structures that would be encountered in North Carolina.

II. Temperature Regimes

Suggested temperatures thresholds conform to the generally accepted maximum temperatures that will sustain each community structure type. In reality, there is overlap in these tolerances and, in some cases; physical habitat may have a greater influence on species present. For example, a stream may have a temperature regime suitable for trout, but high silt load or channel degradation may prevent trout from inhabiting an area. Therefore, temperature regimes alone may not be the determining factor for classifying a certain stream or stream segment. These cases would also serve to identify places where stream restoration or watershed projects would result in a given stream being able to reach its full potential in terms of fishery resources. Suggested temperatures thresholds are as follows:

Coldwater: Summer temperatures generally do not exceed 20 C (68F).

Coolwater: Summer temperatures generally do not exceed 25 C (76 F).

Warmwater: Summer temperatures generally do not exceed >25 C (>76 F).

III. Geographic Guidelines

The following geographic list is intended to be a guide to the location of cold-, cool-, and warm water habitats in North Carolina. While the list provides a generalized guide to the location of these habitats, the user must remember that tributaries and headwater streams, particularly in the mountains may fall in different categories due to such things as elevation, slope, aspect, and land use within the watershed. However, it is appropriate to assume that all tributaries to trout waters/cold waters are to be categorized as cold-water streams.

Hiwassee River Drainage

- Hiwassee River (Chatuge Dam to Mission Dam, including all tributaries) – coldwater
- Hiwassee River (Mission Dam to Hiwassee Reservoir, excluding tributaries) – coolwater
- Hiwassee River tributaries, except Nottely River (Mission Dam to Hiwassee Reservoir) – coldwater
- Hiwassee River (Hiwassee Reservoir dam to Tennessee state line, including tributaries) – coldwater
- Nottely River (Georgia state line to Hiwassee Reservoir, including tributaries) - coolwater
- Tellico River (headwaters to Tennessee state line, including tributaries) – coldwater

Savannah River Drainage

- All streams – coldwater

Little Tennessee River Drainage

- Little Tennessee River (excluding tributaries) from Georgia state line to Fontana Reservoir – coolwater.
- Little Tennessee River tributaries (Georgia state line to Fontana Reservoir) – coldwater
- Cullasaja River (headwaters to Ellijay Creek, including tributaries) - coldwater
- Cullasaja River (Ellijay Creek to Little Tennessee River, excluding tributaries) – coolwater
- Cullasaja River tributaries (Ellijay Creek to Little Tennessee River) – coldwater
- Nantahala River – (headwaters to Fontana Reservoir, including tributaries) – coldwater
- Tuckaseegee River (Barkers Creek to Fontana Reservoir, excluding tributaries) – coolwater
- Tuckaseegee River tributaries (Barkers Creek to Fontana Reservoir) - coldwater
- Tuckaseegee River (headwaters to Barkers Creek, including tributaries) – coldwater
- Cheoah River (headwaters to Santeetlah Reservoir, including tributaries) – coldwater
- Cheoah River (Santeetlah Reservoir to Little Tennessee River, excluding tributaries) – coolwater
- Cheoah River tributaries (Santeetlah Reservoir to Little Tennessee River) - coldwater

French Broad River Drainage

- French Broad River (headwaters to US 276 bridge, including tributaries) – coldwater
- French Broad River (US 276 bridge to Tennessee state line, excluding tributaries) – coolwater
- French Broad River tributaries (includes all tributaries unless stated otherwise)
  - Mills River (entire basin) - coldwater
  - Cane Creek (headwaters to SR 3138 bridge) – coldwater
  - Cane Creek (SR 3138 bridge to French Broad River) - coolwater
  - Bent Creek (entire basin) - coldwater
  - Swannanoa River (headwaters to Sayles Bleachery) – coldwater
  - Reems Creek (entire basin) - coldwater
  - Ivy River (headwaters to US 19-23 bridge) – coldwater
  - Ivy River (US 19-23 bridge to French Broad River) – coolwater
  - Big Laurel Creek (headwaters to US 25-70 bridge) – coldwater
  - Big Laurel Creek (US 25-70 bridge to French Broad River) – coolwater
  - Spring Creek (entire basin) - coldwater
  - Shut-In Creek (entire basin) – coldwater
  - All other tributaries – coolwater (Note: Trout may be present in headwaters of some of these streams. A field survey would be required to confirm their presence)
- Pigeon River (headwaters to confluence of East and West Forks, including tributaries) – coldwater
- Pigeon River (confluence of East and West Forks to Tennessee state line, excluding tributaries) – coolwater
- Pigeon River tributaries (confluence of East and West Forks to Tennessee state line - coldwater
- Nolichucky River (confluence of North Toe River and Cane River to Tennessee state line, excluding tributaries) – coolwater
- Nolichucky River tributaries (confluence of North Toe River and Cane River to Tennessee state line) - coldwater
- North Toe River (headwaters to SR 1121 bridge, including tributaries) - coldwater
- North Toe River (SR 1121 bridge to Nolichucky River, excluding tributaries) – coolwater
- North Toe River tributaries (SR 1121 bridge to Nolichucky River) – coldwater
- Cane River (headwaters to US 19E bridge) – coldwater
- Cane River (US 19E bridge to Nolichucky River, excluding tributaries) – coolwater
- Cane River tributaries (US 19E bridge to Nolichucky River) – coldwater

Broad River Drainage

- Broad River (headwaters to Lake Lure, including all tributaries) – coldwater
- Broad River (Lake Lure to South Carolina state line, including tributaries) – coolwater
- North Pacolet River – (headwaters to NC 108 bridge, including tributaries) – coldwater
- North Pacolet River – (NC 108 bridge to South Carolina state line, including tributaries) – coolwater
- First Broad River (entire basin) – warmwater

Watauga River Drainage
- Elk River (entire basin) – coldwater
- Watauga River (headwaters to NC 105 bridge, including tributaries) - coldwater
- Watauga River (NC 105 bridge to Tennessee state line, excluding tributaries) – coolwater
- Watauga River tributaries (NC 105 bridge to Tennessee state line) – coldwater

New River Drainage
- North Fork New River (headwaters to Sharp Dam, including tributaries) – coldwater
- North Fork New River (Sharp Dam to New River, excluding tributaries) – coolwater
- North Fork New River tributaries (Sharp Dam to New River) – coldwater
- South Fork New River (headwaters to Middle Fork New River, including tributaries) coldwater
- South Fork New River (Middle Fork New River to New River, excluding tributaries) – coolwater
- South Fork New River tributaries Middle Fork New River to New River) – coldwater
- New River (excluding tributaries) – coolwater
- New River tributaries – coldwater

Catawba River
- Catawba River (headwaters to Curtis Creek, including tributaries) – coldwater
- Catawba River (Curtis Creek to Lake James, excluding tributaries) – coolwater
- Catawba River tributaries (Curtis Creek to Lake James) – coolwater unless noted below
  - Mackey Creek (entire basin) – coldwater
  - Buck Creek (headwaters to Lake Tahoma, including tributaries) – coldwater
  - Buck Creek (Lake Tahoma to Catawba River, including tributaries) - coolwater
- Catawba River tributaries to Lake James (unless listed below) - coolwater
- North Fork Catawba River (headwaters to SR 1569 bridge, including tributaries) coldwater
- North Fork Catawba River (SR 1569 bridge to Lake James, including tributaries) –coolwater
- Linville River (headwaters to Lake James, including tributaries) - coldwater
- Catawba River (Lake James to John's River, excluding tributaries) – coldwater
- Catawba River tributaries (Lake James to John's River, excluding Warrior Fork and John's River) – warmwater
- Warrior Fork and tributaries (unless listed below) – coolwater
- Steels Creek (headwaters to SR bridge) – coldwater
- Irish Creek (headwaters to NC 181 bridge) - coldwater
- John's River (headwaters to Mulberry Creek, including tributaries) coldwater
- John's River (Mulberry Creek to Catawba River, excluding tributaries) – coolwater
- John's River tributaries (Mulberry Creek to Parks Creek) – coldwater

Catawba River (John's River to South Carolina state line, except South Fork Catawba River and its tributaries) – warmwater
- South Fork Catawba River and tributaries (unless listed below) - warmwater
  - Henry Fork (headwaters to SR 1919 at Ivy Creek, including tributaries) – coldwater
  - Henry Fork (SR 1919 at Ivy Creek to South Fork Catawba River, including tributaries) – coolwater
  - Jacob's Fork (headwaters to South Mountains State Park Boundary, including tributaries) – coldwater
  - Jacob's Fork (South Mountains State Park Boundary to South Fork Catawba River, including tributaries) – coolwater

Yadkin River
- Yadkin River (headwaters to Jackson Camp Creek, including tributaries) – coldwater
- Yadkin River (Jackson Camp Creek to W. Kerr Scott Reservoir, including all tributaries except as listed below) – coolwater
- Yadkin River Tributaries
  - Buffalo Creek (headwaters to confluence with Joe's Creek, including tributaries) – coldwater
  - Buffalo Creek (Joe's Creek to Yadkin River, including tributaries) - coolwater
  - Elk Creek (headwaters to confluence with Dugger Creek, including tributaries) – coldwater
  - Elk Creek (Dugger Creek to Yadkin River, including tributaries) - coolwater
  - Stony Fork (headwaters to confluence with Left Prong, including tributaries) – coldwater
  - Stony Fork (Left Prong to Yadkin River, including tributaries) – coolwater
  - South Prong Lewis Fork (headwaters to confluence with Pumpkin Run, including tributaries) – coldwater
  - South Prong Lewis Fork (Pumpkin Run to confluence with North Prong Lewis Fork, including tributaries) – coolwater
  - North Prong Lewis Fork (headwaters to Little Fork Creek, including tributaries) – coldwater
  - Lewis Fork (confluence of South and North prongs to Yadkin River, including tributaries) - coolwater
  - Reddies River (headwaters to confluence of Middle and North Forks, including tributaries) – coldwater

Reddies River (confluence of Middle and North Forks to Yadkin River, including tributaries) – coolwater
Yadkin River (W. Kerr Scot Reservoir to Ararat River, including tributaries except as listed below) – coolwater
Yadkin River Tributaries
West Prong Roaring River (headwaters to confluence with Dungeon Creek, including tributaries) – coldwater
West Prong Roaring River (Dungeon Creek to Roaring River) – coolwater
Middle Prong Roaring River (headwaters to Double Creek, including tributaries) – coldwater
Middle Prong Roaring River (Double Creek to Roaring River) – coolwater
East Prong Roaring River (headwaters to confluence with Big Sandy Creek) – coldwater
East Prong Roaring River (Big Sandy Creek to Roaring River) – coolwater
Roaring River (confluence of West and Middle Prongs to Yadkin River, including tributaries) – coolwater
Mitchell River (headwaters to Kapps Mill Dam, including tributaries) – coldwater
Mitchell River (Kapps Mill Dam to Yadkin River, including tributaries) – coolwater
Fisher River (Virginia state line to NC 89 bridge, including tributaries) – coldwater
Fisher River (NC 89 bridge to Yadkin River, including tributaries) – coldwater
Little Fisher River (Virginia state line to NC 89 bridge, including tributaries) – coldwater
Little Fisher River (NC 89 bridge to Fisher River) – coolwater
Ararat River (headwaters to confluence with Yadkin River) – coolwater

Yadkin/Pee Dee Rivers (Ararat River to South Carolina state line, including tributaries) – warmwater
Dan River (Virginia state line to SR 1432, including tributaries) – coldwater
Dan River (SR 1432 to SR 1652 at Danbury, including tributaries) – coolwater
Dan River (SR 1652 at Danbury to Virginia state line, including tributaries) - warmwater

Lumber River (entire basin) – warmwater

Cape Fear River (entire basin) – warmwater

Neuse River (entire basin) – warmwater

Tar River (entire basin) – warmwater

Roanoke River (entire basin) – warmwater

Chowan River (entire basin) – warmwater

Minor Coastal Rivers and Tributaries (including, but not limited to) - warmwater
North River
Newport River
White Oak River
New River
Lockwood Folly River
Shallotte River
Pamlico River
Pungo River

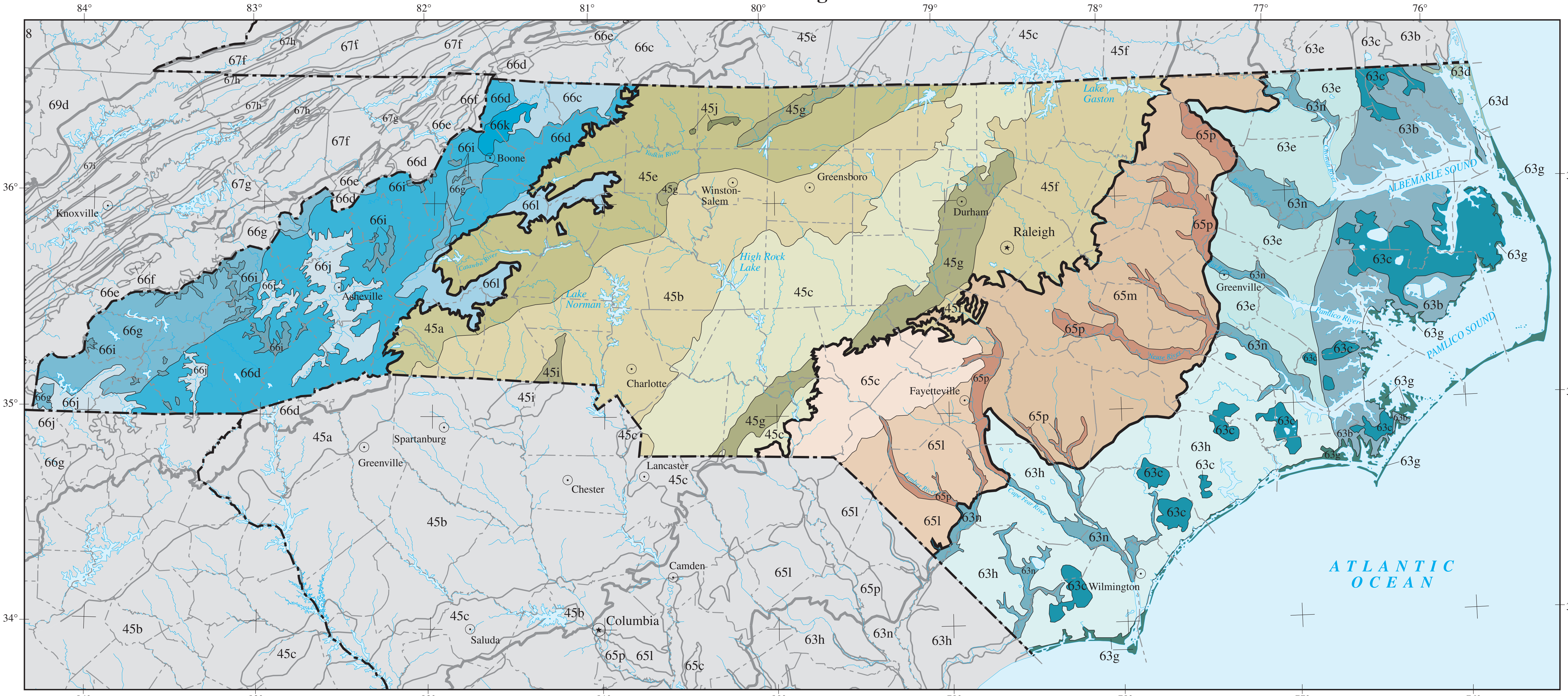
Appendix II. General criteria used to evaluate the success or failure of activities at mitigation sites and required remedial actions to be implemented should monitoring indicate failure of a component.

Mitigation Component	Success (requires no action)	Failure →	Action
(1.) <u>Photo Reference Sites</u> Longitudinal photos Lateral photos	No substantial* aggradation, degradation or bank erosion.	Substantial aggradation, degradation or bank erosion.	When substantial aggradation, degradation or bank erosion occurs, remedial actions will be planned, approved, and implemented.
(2.) <u>Plant Survival</u> Survival plots Stake counts Tree counts	≥ 75% Coverage in Photo Plots Survival and growth of at least 320 trees/acre through year 3, then 10% mortality allowed in year 4 (288 trees/acre) and additional 10% mortality in year 5 for 260 trees/acre through year 5.	< 75% coverage in photo plots for herbaceous cover. Survival of less than 320 trees per acre through year 3 and then less than the success criteria for years 4 and 5.	Areas of less than 75% coverage will be re-seeded and or fertilized, live stakes and bare rooted trees will be planted to achieve desired densities.
(3.) <u>Channel Stability</u> Cross-sections Longitudinal profiles Pebble counts	Minimal evidence of instability (down-cutting, deposition, bank erosion, increase in sands or finer substrate material).	Substantial* evidence of instability.	When Substantial evidence of instability occurs, remedial actions will be planned, approved, and implemented.
(4.) <u>Biological Indicators</u> Invertebrate populations Fish populations	Population measurements remain the same or improve, and species composition indicates a positive trend.	Population measurements and species composition indicate a negative trend.	Reasons for failure will be evaluated and remedial action plans developed, approved, and implemented.

***Substantial or subjective determinations of success will be made by the mitigation sponsor and confirmed by COE and review agencies.**

Monitoring Level 1 will include items 1, 2, and 3, and may include item 4 based on the project review.
Monitoring Level 2 will include items 1 and 2, and may include item 3 based on the project review.
Monitoring Level 3 will include only item 1.

Draft Level III and IV Ecoregions of North Carolina



45 Piedmont
- 45a Southern Inner Piedmont
- 45b Southern Outer Piedmont
- 45c Carolina Slate Belt
- 45e Northern Inner Piedmont
- 45f Northern Outer Piedmont
- 45g Triassic Basins
- 45i Kings Mountain
- 45j Sauratown Mountains

63 Middle Atlantic Coastal Plain
- 63b Chesapeake-Pamlico Lowlands and Tidal Marshes
- 63c Swamps and Peatlands
- 63d Virginian Barrier Islands and Coastal Marshes
- 63e Mid-Atlantic Flatwoods
- 63g Carolinian Barrier Islands and Coastal Marshes
- 63h Carolina Flatwoods
- 63n Mid-Atlantic Floodplains and Low Terraces

65 Southeastern Plains
- 65c Sand Hills
- 65l Atlantic Southern Loam Plains
- 65m Rolling Coastal Plain
- 65p Southeastern Floodplains and Low Terraces

66 Blue Ridge Mountains
- 66c New River Plateau
- 66d Southern Crystalline Ridges and Mountains
- 66e Southern Sedimentary Ridges
- 66g Southern Metasedimentary Mountains
- 66i High Mountains
- 66j Broad Basins
- 66k Amphibolite Mountains
- 66l Eastern Blue Ridge Foothills

SCALE 1:2 000 000

10 0 20 40 mi

20 0 20 40 60 km

Albers Equal Area Projection

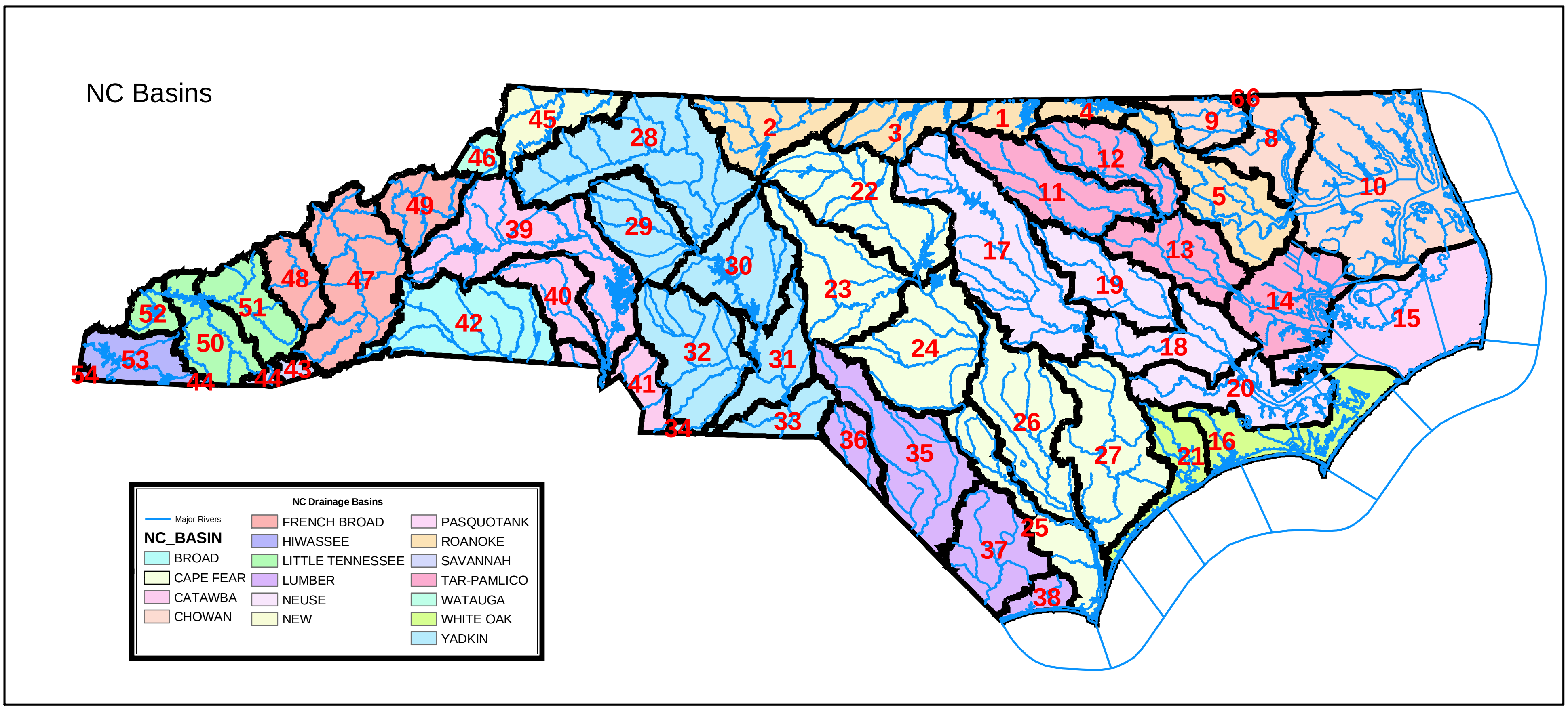
- Level III Boundary
- Level IV Boundary
- State Boundary
- County Boundary

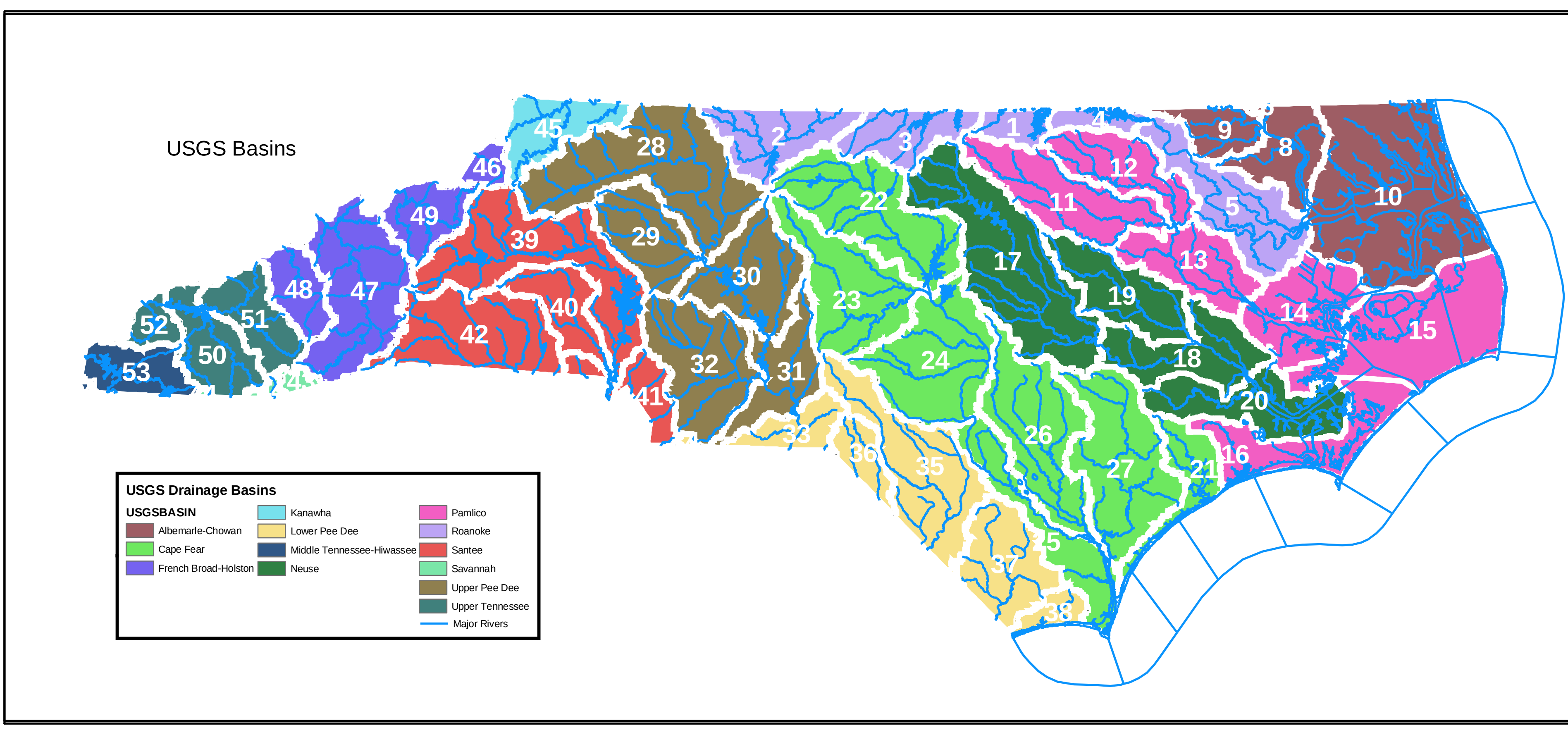
Ecoregions denote areas of general similarity in ecosystems and in the type, quality, and quantity of environmental resources. They are designed to serve as a spatial framework for the research, assessment, management, and monitoring of ecosystems and ecosystem components. The ecoregions are identified through analysis of patterns of biotic and abiotic phenomena, including geology, physiography, vegetation, climate, soils, land use, wildlife, and hydrology. The map was compiled at a scale of 1:250,000, as part of collaborative project primarily between the U.S. EPA, USDA-NRCS, and NCDENR. Comments and suggestions regarding this DRAFT Level III and IV Ecoregions of North Carolina map should be addressed to Glenn Griffith, USDA-NRCS, 200 SW 35th Street, Corvallis, OR 97333, (541) 754-4465, FAX: (541) 754-4716, email: glenn@mail.cor.epa.gov, or to James Omernik, U.S. EPA - NHEERL, 200 SW 35th Street, Corvallis, OR 97333, (541) 754-4458, email: omernik@mail.cor.epa.gov.

jc/gg //disk/jory1/data/jobs/j379.glenn.nc/zaml/reg4nc.aml //feathers/ecoregions/jobs/j379.glenn.nc/nc_eco_v2_tbld.ai 8/17/2000

US Army Corps of Engineers ®

Hydrologic Basins and 8-Digit Accounting Units in NC





Look Up Table for Maps

NC BASIN	ID	HUCODE-8	HUC8 NAME	USGS BASIN
BROAD	42	03050105	Upper Broad	Santee
CAPE FEAR	22	03030002	Haw	Cape Fear
	23	03030003	Deep	
	24	03030004	Upper Cape Fear	
	25	03030005	Lower Cape Fear	
	26	03030006	Black	
	27	03030007	Northeast Cape Fear	
CATAWBA	39	03050101	Upper Catawba	Santee
	41	03050103	Lower Catawba	
	40	03050102	South Fork Santee	Catawba
CHOWAN	6	03010201	Nottoway	Albemarle-Chowan
	7	03010202	Blackwater	
	8	03010203	Chowan	
	9	03010204	Meherrin	
	10	03010205	Albemarle	
FRENCH BROAD	47	06010105	Upper French Broad	French Broad-Holston
	48	06010106	Pigeon	
	49	06010108	Nolichucky	
HIWASSEE	53	06020002	Hiwassee	Middle Tennessee-Hiwassee
	54	06020003	Ocoee	
LITTLE TENNESSEE	50	06010202	Upper Little Tennessee	Upper Tennessee
	51	06010203	Tuckasegee	
	52	06010204	Lower Little Tennessee	

NC BASIN	ID	HUCODE-8	HUC8 NAME	USGS BASIN
LUMBER	35	03040203	Lumber	Lower Pee Dee
	36	03040204	Little Pee Dee	
	37	03040206	Waccamaw	
	38	03040207	Carolina Coastal-Sampit	
NEUSE	17	03020201	Upper Neuse	Neuse
	18	03020202	Middle Neuse	
	19	03020203	Contentnea	
	20	03020204	Lower Neuse	
NEW	45	05050001	Upper New	Kanawha
PASQUOTANK	15	03020105	Pamlico Sound	Pamlico
ROANOKE	1	03010102	Middle Roanoke	Roanoke
	2	03010103	Upper Dan	
	3	03010104	Lower Dan	
	4	03010106	Roanoke Rapids	
	5	03010107	Lower Roanoke	
SAVANNAH	43	03060101	Seneca	Savannah
	44	03060102	Tugaloo	
TAR-PAMLICO	11	03020101	Upper Tar	Pamlico
	12	03020102	Fishing	
	13	03020103	Lower Tar	
	14	03020104	Pamlico	
WATAUGA	46	06010103	Watauga	French Broad-Holston
WHITE OAK	16	03020106	Bogue-Core Sounds	Pamlico
	21	03030001	New	Cape Fear
YADKIN	28	03040101	Upper Yadkin	Upper Pee Dee
	29	03040102	South Yadkin	
	30	03040103	Lower Yadkin	
	31	03040104	Upper Pee Dee	
	32	03040105	Rocky	
	33	03040201	Lower Pee Dee	Lower Pee Dee
	34	03040202	Lynches	

Stream Mitigation Plan Check List
STREAM CHANNEL MITIGATION PLANNING CHECKLIST
(08APRIL02)

ACTION ID:____________________________

SITE/BANK
NAME:____

LOCATION/STREAM/COUNTY:____
USGS QUAD(S):____
WARMWATER____ COOLWATER____ COLDWATER____

PREPARED BY:____________________________________ DATE:______________________

I. INTRODUCTION

A. Type of Mitigation (Circle/A separate checklist may be prepared if more than one type)

1. Restoration Enhancement Preservation

   a. In-Kind Out-of-Kind Both (i.e. warm for warm, cold for warm, etc.)

   b. On-Site Off-Site Both

2. Up-Front Concurrent After-The-Fact Bank In-Lieu-Fee

B. Stream type/s and linear feet Impacted: Attach or Describe: ______________________
____
____

C. Stream types and linear footage mitigated: Attach or Describe: _______________________
____
____

D. Describe mitigation ratios: ____
____

E. Will any Endangered Species, Archeological Resources, or Haz/Tox sites be impacted by this effort?
Y/N ________

F. Has stream class been determined on both the impacted stream and the mitigation site? Y/N ______
Explain:____
____

II. TARGET GOALS AND FUNCTIONS

A. Are there stated GOALS? Y/N___________
Describe: ____
____

B. Describe Success Criteria: ____
____

		YES	NO
Are they:	1.Specific	___	___
	2.Measurable	___	___
	3.Attainable	___	___

C. Target **FUNCTIONS** chosen and indicated? Y/N___
Describe:____
____

D. Was a Stream Reference Reach Evaluated/Surveyed (RE) report prepared? Y/N___
(Attach reference reach data)
Describe comparison between the RE and the Mitigation Plan: ____________________________
____
NOTES:____
____
____
____
____

III. STRUCTURAL COMPONENTS AND MORPHOLOGY

A. **HYDROLOGY**:

1. What is the current and proposed stream classification based on water quality, morphology, and hydrology? Describe: ____
____

2. Are natural channel design concepts and methods to be utilized for the proposed channel construction activity? Y/N___ Describe: ____
____

3. Have reference and/or regional curves for stream morphology and discharge been applied to this channel design? Y/N___ Describe: ____
____
Describe the drainage area above the mitigation site: ______________________________________
____
____

4. Has sediment transport equilibrium been addressed in the design: Y/N___
Describe the method used: ____
____

5. Have water quality concerns been addressed in this plan? Y/N____
Describe: ____
____

B. **INSTREAM BANK STABILIZATION HABITAT STRUCTURES**

1. Are bank and channel stabilization structures planned? Y/N___
Describe:____
____
____
(attach typical plan)

2. Are separate fish or other aquatic habitat structures planned? Y/N______

Describe:____
____
____

3. Will native/natural materials be used for stabilization, habitat, and other general channel construction? Y/N____
List:____
____

C. **VEGETATION**

1. Is streamside/riparian re-vegetation planned? Y/N_____
Describe:____
____

2. Is there a plan or need to expand the riparian buffer/corridor? Y/N___
Describe:____
____

3. Are the proposed riparian' plantings listed to species? Y/N_____

4. Are "local" (200 Miles North/South) propagules to be planted and verified by a nursery certificate? Y/N_____

5. Have diversity and densities of species within the RE been considered in the plan? Y/N_____

6. Will vegetative plantings and the channel construction area be protected from off site impacts? (i.e. livestock, vegetation cutting, etc.) Y/N_____
Describe:____
____

7. Discuss Quality Control during planting: ____
____
____

IV. MONITORING

A. Name and number of person responsible for the success of this project:
Name: ________________________________ Telephone (___)____________________________

B. Is there a Monitoring Plan? Y/N_____
Describe:____
____
____
____

C. As Built Report provided? Y/N______

D. Procedure to account for beneficial natural regeneration? Y/N______
Describe: ____
____
____

V. CONSIDERATION OF CAUSES OF FAILURE

A. How does project rate regarding the following:

1. **Elevation**: ____
____

	YES	NO	N/A
a. Have **Biological Benchmarks** been established?	___	___	___
b. Is there a **Grading Plan**?	___	___	___
c. Is the grading plan specific?	___	___	___
d. Is discing or ripping proposed after grading and prior to planting?	___	___	___

2. Describe provisions for **Drainage**: ____
____

3. Describe **Erosion** Control Measures: ____
____

4. Describe management of **human impacts and livestock:** ______________________________
____

5. Describe management of **Herbivory/Noxious Plants**: ______________________________
____
____

B. Are there **Contingency Plans** built into the proposal to address these factors? Y/N__________
Describe when and how will these contingencies be implemented: ________________________
____
____

VI. SITE MANAGEMENT

A. Describe **Final Disposition** of the property:____
____
____

B. Who will manage the site after the mitigation effort is deemed a success?
Name: ______________________________ Telephone (___)______________________________

C. Describe **Financial Assurances** that will be established:_________________

____

____

D. Will stream functions be impacted by current or future land use patterns? Y/N___________
Describe:____
____
____

E. Will this site have the opportunity to function as planned? Y/N_____
Describe: ____
____
____

F. Describe how this project rates ecologically:

NOTES:

HIGHLIGHT AND ADDRESS ALL PROBLEMS OR ALL INADEQUACIES WITH THE MITIGATION PLAN / SITE AS INDICATED BY THIS CHECKLIST.

Channel Mitigation Monitoring Sheets I, II, III, AND IV

Monitoring Data Record

Project Title: ____ COE Action ID: ___________________________
Stream Name: _____________________________________ DWQ Number: _____________________
City, County and other Location Information: ____
Date Construction Completed:________________________________ Monitoring Year: ( ) of 5
Ecoregion:___________________________ 8 digit HUC unit_____________________________
USGS Quad Name and Coordinates: ____
Rosgen Classification: ____
Length of Project: ____________________ Urban or Rural: ______________ Watershed Size: ____________________
Monitoring DATA collected by: ____________________________________ Date: _______________________
Applicant Information:
Name: ____
Address: ____
Telephone Number: __________________________ Email address:_____________________________
Consultant Information:
Name: ____
Address: ____
Telephone Number: __________________________ Email address:_____________________________
Project Status: ____
____

Monitoring Level required by COE and DWQ (404/Sect. 10 permit/ 401 Cert.: Level 1 2 3 *(circle one)*
Monitoring Level 3 requires completion of *Section 1*
Monitoring Level 2 requires completion of *Section 1 and Section 2*
Monitoring Level 1 requires completion of *Section 1, Section 2 and Section 3*
If biological monitoring is required by DWQ, then Section 4 should also be completed

Section 1. PHOTO REFERENCE SITES
(Monitoring at all levels must complete this section)

Attach site map showing the location and angle of all reference photos with a site designation (name, number, letter, etc.) assigned to each reference photo location. Photos should be provided for all structures and cross section locations, should show both banks and include an upstream and downstream view. Photos taken to document physical stability should be taken in winter. Photos taken to document vegetation should be taken in summer (at representative locations). Attach photos and a description of each reference photo or location. We recommend the use of a photo identification board in each photo to identify location.

Total number of reference photo locations at this site: _______________________________________
Dates reference photos have been taken at this site: ____
____
Individual from whom additional photos can be obtained (name, address, phone):____________________
____
Other Information relative to site photo reference: ____
____

If required to complete Level 3 monitoring <u>only</u> stop here; otherwise, complete section 2.

Section 2. <u>PLANT SURVIVAL</u>
Attach plan sheet indicating plots and sample area locations and reference photos.

Survival plots:

DATE:					
Area within the easement is:					
Area sampled by survival plots:					
Number of survival plots sampled:					
Random or nonrandom site selection:					
% Coverage within survival plots is:					
Photos of reference plots taken: yes/no					

Provide a written description of specific data or findings and photos as needed for clarity.

Live Stake counts:

DATE:					
Area within the easement is:					
Area sampled for stake survival:					
Number of plots sampled:					
Random or nonrandom site selection:					
Average number of surviving stakes:					
Range of survival for all plots:					

Provide a written description of specific data or findings as needed for clarity.

Tree counts:

DATE:					
Area within the easement is:					
Area sampled for tree survival:					
Number of plots sampled:					
Random or nonrandom site selection:					
Average number of surviving trees:					
Range of survival for all plots:					

Provide a written description of specific data or findings as needed for clarity.

Bankfull Events:

Date measured:					
Method of Verification:					

COMMENTS: ____
____
____
____

If required to complete Level 1 and Level 2 monitoring <u>only</u> stop here; otherwise, complete section 3.

Section 3. <u>CHANNEL STABILITY</u>
Attach plan sheet(s) indicating the locations of cross-sections and beginning and ending of longitudinal profiles if the entire reach is not profiled. Year to year changes in cross-sections, longitudinal profile and bed material should be plotted and submitted. Comparison overlays from previous years for profile and cross-section monitoring should be provided.

Cross-sections: attach plots of each cross-section showing year to year changes.
Provide the following data for each cross-section:

Date measured					
Cross-section being measured					
Cross-sectional area: as-built/present					
Bankfull width: as-built/present					
Floodprone Width: as-built/present					
Width/depth: as-built/present					
Entrenchment ratio: as-built/present					
Stream Type: as-built/present*					

* only required for riffle cross-sections

Longitudinal profiles: attach plots of the longitudinal profile showing year to year changes and the locations of installed or natural structures that affect profile.

Date measured	
Avg. slope riffles: as-built/present	
Avg. slope pools: as-built/present	
Number of riffles: as-built/present	
Number of pools: as-built/present	

Pebble counts: Attach a printout of pebble count data and a graphical plot of bed material showing the cumulative % finer than X millimeters and the number of particles in standard size classes. Year to year changes in bed material should also be plotted and provided.

Date measured					
Cross-section being measured					
D16: as-built/present					
D50: as-built/present					
D84: as-built/present					

Visual Inspection: The entire stream project as well as each in-stream structure and bank stabilization/revetment structure must be evaluated and problems addressed.

Date Inspected	Station Number	Station Number	Station Number	Station Number	Station Number
Structure Type					
Is water piping through or around structure?					
Head cut or down cut present?					
Bank or scour erosion present?					
Other problems noted?					

NOTE: Attach separate narrative sheets to each monitoring report describing/discussing the overall monitoring results. Include the identification of specific problem areas/channel failures, estimated cause and proposed/required remedial action. This should include a brief discussion of any parameter that has changed significantly from as-built. (See success criteria discussion in Section 11.)

In performing monitoring Level 1, determine if the DWQ Certification conditions require biological monitoring. Should conditions require monitoring of biological communities, complete section 4; otherwise, stop here.

Section 4. BIOLOGICAL INDICATORS (may be required for monitoring level 1, see permit requirements)

Attach a map and narrative showing locations where biological samples were collected, list of taxa collected, explaining conditions during sampling, the types of samples taken, an explanation of the data collected and all other information pertinent to understanding this data set. If the sample is a follow-up too earlier samples discuss any differences found or statistical comparisons.

Invertebrate populations

Date sampled:												
Site	1	2	3	4	1	2	3	4	1	2	3	4
Qualitative Metrics:												
EPT Taxa Richness												
EPT Abundance												
Total Taxa Richness												
Biotic Index value												
Quantitative Metrics:												
Standing Crop/Density (#/m^2)												
Biomass (g/m^2)												
Biotic Index value												
Species (taxa) Diversity												

Fish populations

Date sampled:												
Site	1	2	3	4	1	2	3	4	1	2	3	4
Qualitative Metrics:												
Number of fish												
Number of species												
% of tolerant fish sp.												
% of intolerant fish sp.												
% with disease or wounds												
Catch per unit effort												
NC IBI score												
NC IBI rating												
Quantitative Metrics:												
Standing Crop/Density (#/m^2)												
Biomass (g/m^2)												
Species (taxa) Diversity												

USACE AID#______________________ DWQ #______________________ Site #____ (indicate on attached map)

STREAM QUALITY ASSESSMENT WORKSHEET

Provide the following information for the stream reach under assessment:

1. Applicant's name:________________________________ **2.** Evaluator's name:________________________________

3. Date of evaluation:________________________________ **4.** Time of evaluation:________________________________

5. Name of stream:________________________________ **6.** River basin:________________________________

7. Approximate drainage area:________________________ **8.** Stream order:________________________________

9. Length of reach evaluated:________________________ **10.** County:________________________________

11. Site coordinates (if known): prefer in decimal degrees. **12.** Subdivision name (if any):________________________

Latitude (ex. 34.872312): ________________________________ Longitude (ex. –77.556611):________________________________

Method location determined (circle): GPS Topo Sheet Ortho (Aerial) Photo/GIS Other GIS Other________________________

13. Location of reach under evaluation (note nearby roads and landmarks and attach map identifying stream(s) location):___________

____

14. Proposed channel work (if any):____

15. Recent weather conditions:____

16. Site conditions at time of visit:____

17. Identify any special waterway classifications known: ____Section 10 ____Tidal Waters ____Essential Fisheries Habitat

____Trout Waters ____Outstanding Resource Waters ____ Nutrient Sensitive Waters ____Water Supply Watershed ____(I-IV)

18. Is there a pond or lake located upstream of the evaluation point? YES NO If yes, estimate the water surface area:___________

19. Does channel appear on USGS quad map? YES NO **20.** Does channel appear on USDA Soil Survey? YES NO

21. Estimated watershed land use: ____% Residential ____% Commercial ____% Industrial ____% Agricultural

____% Forested ____% Cleared / Logged ____% Other (________________________)

22. Bankfull width:________________________________ **23**. Bank height (from bed to top of bank):____________________

24. Channel slope down center of stream: ____Flat (0 to 2%) ____Gentle (2 to 4%) ____Moderate (4 to 10%) ____Steep (>10%)

25. Channel sinuosity: ____Straight ____Occasional bends ____Frequent meander ____Very sinuous ____Braided channel

Instructions for completion of worksheet (located on page 2): Begin by determining the most appropriate ecoregion based on location, terrain, vegetation, stream classification, etc. Every characteristic must be scored using the same ecoregion. Assign points to each characteristic within the range shown for the ecoregion. Page 3 provides a brief description of how to review the characteristics identified in the worksheet. Scores should reflect an overall assessment of the stream reach under evaluation. If a characteristic cannot be evaluated due to site or weather conditions, enter 0 in the scoring box and provide an explanation in the comment section. Where there are obvious changes in the character of a stream under review (e.g., the stream flows from a pasture into a forest), the stream may be divided into smaller reaches that display more continuity, and a separate form used to evaluate each reach. The total score assigned to a stream reach must range between 0 and 100, with a score of 100 representing a stream of the highest quality.

Total Score (from reverse):______________ **Comments:**____

____

____

____

____

Evaluator's Signature____ **Date**________________________

This channel evaluation form is intended to be used only as a guide to assist landowners and environmental professionals in gathering the data required by the United States Army Corps of Engineers to make a preliminary assessment of stream quality. The total score resulting from the completion of this form is subject to USACE approval and does not imply a particular mitigation ratio or requirement. Form subject to change – version 06/03. To Comment, please call 919-876-8441 x 26.

STREAM QUALITY ASSESSMENT WORKSHEET

	#	CHARACTERISTICS	ECOREGION POINT RANGE			SCORE
			Coastal	Piedmont	Mountain	
PHYSICAL	1	**Presence of flow / persistent pools in stream** (no flow or saturation = 0; strong flow = max points)	0 – 5	0 – 4	0 – 5	
	2	**Evidence of past human alteration** (extensive alteration = 0; no alteration = max points)	0 – 6	0 – 5	0 – 5	
	3	**Riparian zone** (no buffer = 0; contiguous, wide buffer = max points)	0 – 6	0 – 4	0 – 5	
	4	**Evidence of nutrient or chemical discharges** (extensive discharges = 0; no discharges = max points)	0 – 5	0 – 4	0 – 4	
	5	**Groundwater discharge** (no discharge = 0; springs, seeps, wetlands, etc. = max points)	0 – 3	0 – 4	0 – 4	
	6	**Presence of adjacent floodplain** (no floodplain = 0; extensive floodplain = max points)	0 – 4	0 – 4	0 – 2	
	7	**Entrenchment / floodplain access** (deeply entrenched = 0; frequent flooding = max points)	0 – 5	0 – 4	0 – 2	
	8	**Presence of adjacent wetlands** (no wetlands = 0; large adjacent wetlands = max points)	0 – 6	0 – 4	0 – 2	
	9	**Channel sinuosity** (extensive channelization = 0; natural meander = max points)	0 – 5	0 – 4	0 – 3	
	10	**Sediment input** (extensive deposition= 0; little or no sediment = max points)	0 – 5	0 – 4	0 – 4	
	11	**Size & diversity of channel bed substrate** (fine, homogenous = 0; large, diverse sizes = max points)	NA*	0 – 4	0 – 5	
STABILITY	12	**Evidence of channel incision or widening** (deeply incised = 0; stable bed & banks = max points)	0 – 5	0 – 4	0 – 5	
	13	**Presence of major bank failures** (severe erosion = 0; no erosion, stable banks = max points)	0 – 5	0 – 5	0 – 5	
	14	**Root depth and density on banks** (no visible roots = 0; dense roots throughout = max points)	0 – 3	0 – 4	0 – 5	
	15	**Impact by agriculture, livestock, or timber production** (substantial impact =0; no evidence = max points)	0 – 5	0 – 4	0 – 5	
HABITAT	16	**Presence of riffle-pool/ripple-pool complexes** (no riffles/ripples or pools = 0; well-developed = max points)	0 – 3	0 – 5	0 – 6	
	17	**Habitat complexity** (little or no habitat = 0; frequent, varied habitats = max points)	0 – 6	0 – 6	0 – 6	
	18	**Canopy coverage over streambed** (no shading vegetation = 0; continuous canopy = max points)	0 – 5	0 – 5	0 – 5	
	19	**Substrate embeddedness** (deeply embedded = 0; loose structure = max)	NA*	0 – 4	0 – 4	
BIOLOGY	20	**Presence of stream invertebrates** (see page 4) (no evidence = 0; common, numerous types = max points)	0 – 4	0 – 5	0 – 5	
	21	**Presence of amphibians** (no evidence = 0; common, numerous types = max points)	0 – 4	0 – 4	0 – 4	
	22	**Presence of fish** (no evidence = 0; common, numerous types = max points)	0 – 4	0 – 4	0 – 4	
	23	**Evidence of wildlife use** (no evidence = 0; abundant evidence = max points)	0 – 6	0 – 5	0 – 5	
		Total Points Possible	100	100	100	
		TOTAL SCORE (also enter on first page)				

* These characteristics are not assessed in coastal streams.

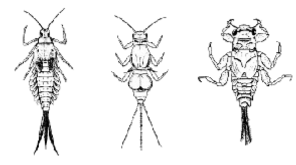
Notes on Characteristics Identified in Assessment Worksheet

1. Consider channel flow with respect to channel cross-sectional area (expected flow), drainage area, recent precipitation, potential drought conditions, surrounding land use, possible water withdrawals, presence of impoundments upstream, vegetation growth in channel bottom (as indicator of intermittent flow), etc.
2. Human-caused alterations may include relocation, channelization, excavation, riprap, gabions, culverts, levees, berms, spoil piles adjacent to channel, etc.
3. The riparian zone is the area of vegetated land along each side of a stream or river that includes, but is not limited to, the floodplain. Evaluation should consider width of riparian area with respect to floodplain width, vegetation density, maturity of canopy and understory, species variety, presence of undesirable invasive species (exotics), breaks (utility corridors, roads, etc.), presence of drainage tiles, logging activities, other disturbances which negatively affect function of the riparian zone.
4. Evidence of nutrient or chemical discharges includes pipes, ditches, and direct draining from commercial and industrial sites, agricultural fields, pastures, golf courses, swimming pools, roads, parking lots, etc. Sewage, chlorine, or other foul odors, discolored water, suds, excessive algal growth may also provide evidence of discharge.
5. Groundwater discharge may be indicated by persistent pools and saturated soils during dry weather conditions, presence of adjacent wetlands, seeps, and springs feeding channel, reduced soils in channel bottom.
6. Presence of floodplains may be determined by topography and the slope of the land adjacent to the stream, terracing, the extent of development within the floodplain, FEMA designation if known, etc.
7. Indicators of floodplain access include sediment deposits, wrack lines, drainage patterns in floodplain, local stream gauge data, testimony of local residents, entrenchment ratio, etc. Note that indicators may relic and not a result of regular flooding.
8. Wetland areas should be evaluated according to their location, size, quality, and adjacency relative to the stream channel, and may be indicated by beaver activity, impounded or regularly saturated areas near the stream, previous delineations, National Wetland Inventory maps, etc. (Wetlands must meet criteria outlined in 1987 delineation manual and are subject to USACE approval.)
9. Channel sinuosity should be evaluated with respect to the channel size and drainage area, valley slope, topography, etc.
10. To evaluate sediment deposition within the channel consider water turbidity, depth of sediment deposits forming at point bars and in pools, evidence of eroding banks or other sediment sources within watershed (construction sites, ineffective erosion controls). In rare cases, typically downstream of culverts or dams, a sediment deficit may exist and should be considered in scoring.
11. When looking at channel substrate, factor in parent material (presence of larger particles in soil horizons adjacent to the stream), average size of substrate (bedrock, clay/silt, sand, gravel, cobble, boulder, etc.), and diversity of particle size (riprap is excluded).
12. Indications of channel incision and deepening may include a v-shaped channel bottom, collapsing banks, evidence of recent development and increased impervious surface area resulting in greater runoff in the watershed.
13. Evaluation should consider presence of major bank failures along the entire reach under evaluation, including uprooted trees on banks, banks falling into channel, formation of islands in channel as they widen, exposed soil, active zones of erosion, etc.
14. Increased root depth and density result in greater bank stability. Consider the depth and density that roots penetrate the bank relative to the amount of exposed soil on the bank and the normal water elevation.
15. Assessment of agriculture, livestock, and/or timber production impacts should address areas of stream bank destabilization, evidence of livestock in or crossing stream, loss of riparian zone to pasture or agricultural fields, evidence of sediment or high nutrient levels entering streams, drainage ditches entering streams, loss of riparian zone due to logging, etc.
16. Riffle-pool steps can be identified by a series of alternating pools and riffles. Abundance, frequency, and relative depth of riffles and pools should be considered with respect to topography (steepness of terrain) and local geology (type of substrate).
    Coastal plain streams should be evaluated for the presence of ripple-pool sequences. Ripples are bed forms found in sand bed streams with little or no gravel that form under low shear stress conditions, whereas, dunes and antidunes form under moderate and high shear stresses, respectively. Dunes are the most common bed forms found in sand bed streams.
17. Habitat complexity is an overall evaluation of the variety and extent of in-stream and riparian habitat. Types of habitat to look for include rocks/cobble, sticks and leafpacks, snags and logs in the stream, root mats, undercut banks, overhanging vegetation, pool and riffle complexes, wetland pockets adjacent to channel, etc.
18. Evaluation should consider the shading effect that riparian vegetation will provide to the stream during the growing season. Full sun should be considered worst case, while good canopy coverage with some light penetration is best case.
19. Stream embeddedness refers to the extent that sediment that has filled in gaps and openings around the rocks and cobble in the streambed. The overall size of the average particle in the streambed should be considered (smaller rocks will have smaller gaps).
20. Evaluation should be based on evidence of stream invertebrates gathered from multiple habitats. Scores should reflect abundance, taxa richness, and sensitivity of stream invertebrate types. (see attached examples of common stream invertebrates on page 4).
21. Evaluation should include evidence of amphibians in stream channel. Tadpoles and frogs should receive minimum value, while salamanders, newts, etc. may be assigned higher value.
22. Evaluation of fish should consider the frequency and, if possible, the variety of different fish taxa observed.
23. Evaluation of wildlife should include direct observation or evidence (tracks, shells, droppings, burrows or dens, hunting stands, evidence of fishing, etc.) of any animals using the streambed or riparian zone, to include small and large mammals, rodents, birds, reptiles, insects, etc.

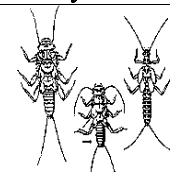
Common Stream Invertebrates

Sensitive Taxa – Pollution sensitive organisms that may be found in good quality water.

Caddisfly

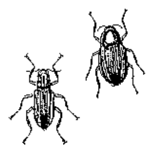


Mayfly

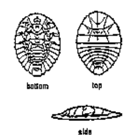


Stonefly

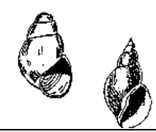
Dobsonfly



Riffle Beetle



Water Penny

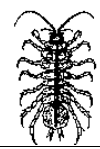


Gilled Snail

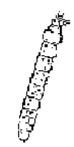
Somewhat Tolerant Taxa – Somewhat pollution tolerant organisms that may be found in good or

Beetle Larva

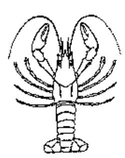
Clam



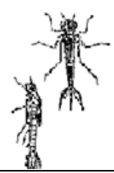
Sowbug



Cranefly

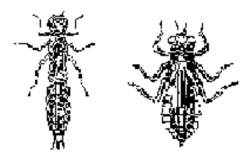


Crayfish



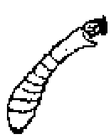
Damselfly Nymph

Scud

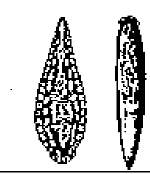


Dragon Fly Nymph

Tolerant Taxa – Pollution tolerant organisms that may be found in any quality water.



Blackfly Larva



Leech

Midge Fly Larva

Aquatic Worm

Pouch & Pond Snail

Appendix VI

Regional Curves

BANKFULL HYDRAULIC GEOMETRY RELATIONSHIPS FOR NORTH CAROLINA STREAMS

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ABSTRACT

Bankfull hydraulic geometry relationships, also called regional curves, relate bankfull stream channel dimensions to watershed drainage area. This paper describes results of bankfull hydraulic geometry relationships developed for North Carolina Piedmont streams. Gage stations were selected with a minimum of 10 years of continuous or peak discharge measurements, no major impoundments, no significant change in land use over the past 10 years, and less than 20% impervious cover in the watershed. To supplement data collected in gaged watersheds, stable reference reaches in un-gaged watersheds were also included in the study. Cross-sectional and longitudinal surveys were measured at each study reach to determine channel dimension, pattern, and profile information. Log-Pearson Type III distributions were used to analyze annual peak discharge data for USGS gage station sites. Power function relationships were developed using regression analyses for bankfull discharge, channel cross-sectional area, mean depth, and width as functions of watershed drainage area. The bankfull return interval for the gaged watersheds ranged from 1.1 to 1.8, with a mean of 1.4 years. Continuing work will expand this database for the North Carolina Mountains, Piedmont, and Coastal Plain physiographic provinces.
Key Words: Hydraulic Geometry, Regional Curve, Bankfull, Flood Frequency Analyses

INTRODUCTION

Stream channel hydraulic geometry theory developed by Leopold and Maddock (1953) describes the interrelations between dependent variables such as width, depth and area as functions of independent variables such as watershed area or discharge. These relationships can be developed at a single cross section (at-a-station) or across many stations along a reach (Merigliano, 1997). Hydraulic geometry relationships are empirically derived and can be developed for a specific river or watershed in the same physiographic region with similar rainfall/runoff relationships (FISRWG, 1998).

Hydraulic geometry relationships are often used to predict channel morphology features and their corresponding dimensions. This paper describes the process used in North Carolina to develop hydraulic geometry relationships at the bankfull stage. Results for the rural Piedmont physiographic region are presented. Bankfull hydraulic geometry relationships, also called regional curves, were first developed by Dunne and Leopold (1978) and related bankfull channel dimensions to drainage area. Gage station

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analyses throughout the United States has shown that the bankfull discharge has an average return interval of 1.5 years or 66.7% annual exceedence probability (Dunne and Leopold, 1978; Leopold, 1994). A primary purpose for developing regional curves is to aid in identifying bankfull stage and dimension in un-gaged watersheds and to help estimate the bankfull dimension and discharge for natural channel designs (Rosgen, 1994).

FIELD INDICATORS OF BANKFULL STAGE

The correct identification of the bankfull stage in the field can be difficult and subjective (Williams, 1978; Knighton, 1984; and Johnson and Heil, 1996). Numerous definitions exist of bankfull stage and methods for its identification in the field (Wolman and Leopold, 1957; Nixon, 1959; Schumm, 1960; Kilpatrick and Barnes, 1964; and Williams 1978). The identification of bankfull stage in the humid Southeast is especially difficult because of dense understory vegetation and long history of channel modification and subsequent adjustment in channel morphology. It is generally accepted that bankfull stage corresponds with the discharge that fills a channel to the elevation of the active floodplain. The bankfull discharge is considered to be the channel forming agent that maintains channel dimension and transports the bulk of sediment over time. Field indicators include the back of point bars, significant breaks in slope, changes in vegetation, the highest scour line, or the top of the bank (Leopold, 1994). The most consistent bankfull indicators for streams in the rural Piedmont of North Carolina are the highest scour line and the back of the point bar. It is rarely the top of the bank or the lowest scour or bench.

STUDY AREA

North Carolina contains three major physiographic provinces: Mountains, Piedmont, and Coastal Plain. Because rainfall/runoff relationships vary by province and land cover, separate bankfull hydraulic geometry relationships are being developed for rural, suburban, and urban areas for each physiographic region (total of 9 regional curves). It may be necessary to further stratify the data for unique areas such as high rainfall areas in the Mountains and the Sandhills bordering the Piedmont and Coastal Plain. To date, data collection efforts have focused on the rural Piedmont and Mountains.

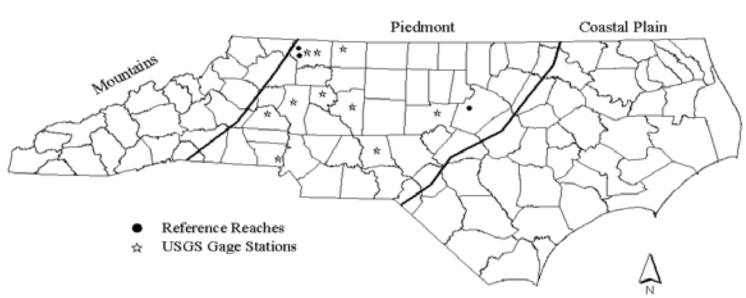

Figure 1: North Carolina map showing physiographic provinces with gaged and un-gaged study reaches.

USGS gage stations were identified with at least 10 years of continuous or peak discharge measurements, no major impoundments, no significant change in land use over the past 10 years, and less than 20% impervious cover over the watershed area. To supplement data collected in gaged watersheds, stable reference reaches in un-gaged watersheds were also selected for data collection using the same criteria. Figure 1 shows the relative locations of gaged and un-gaged study reaches.

METHODOLOGY

Data Collection

The following gage station records were obtained from the United States Geological Survey: 9-207 forms, stage/discharge rating tables, annual peak discharges, and established reference marks. At the gage, bankfull stage was flagged upstream and downstream of the gage station using the field indicators listed above. Once a consistent indicator was found, a cross-sectional survey was completed at a riffle or run near the gage plate. Temporary pins were installed in the left and right banks, looking downstream. The elevations from the survey were related to the elevation of a gage station reference mark. Each cross section survey started at or beyond the top of the left bank. Moving left to right, morphological features were surveyed including top of bank, bankfull stage, lower bench or scour, edge of water, thalweg, and channel bottom (Harrelson et al., 1994; U.S. Geological Survey, 1969). From the survey data, at-a-station bankfull hydraulic geometry was calculated.

For each reach, a longitudinal survey was completed over a stream length equal to at least 20 bankfull widths (Leopold, 1994). Longitudinal stations were established at each bed feature (heads of riffles and pools, maximum pool depth, scour holes, etc.). The following channel features were surveyed at each station: thalweg, water surface, low bench or scour, bankfull stage, and top of bank. The slope of a line fitted through the bankfull stage indicators was compared to a line of best fit through the water surface points. Leopold (1994) used this technique to verify the feature as bankfull if the two fitted lines were parallel and consistent over a long reach. The longitudinal survey was carried through the gage plate to obtain the bankfull stage. Using the current rating table and bankfull stage, the bankfull discharge was determined. The stream was classified using the Rosgen (1994) method.

Data Analyses

Log-Pearson Type III distributions were used to analyze annual peak discharge data for the USGS gage station sites. Procedures outlined in USGS Bulletin #17B Guidelines for Determining Flood Flow Frequency were followed (U.S. Geological Survey, 1982). USGS recommends Log-Pearson distributions because the log transformation removes positive skew from the data. Generalized skew coefficients and corresponding mean square errors for the Blue Ridge/Piedmont and Coastal Plain are 0.195 and 0.038, respectively (Pope, 1999). For this study, a range of exceedence probabilities from 0.9950 to 0.0100 was chosen. This range represents recurrence intervals between 1.005 and 100 years, with focus between the 1 and 2-year recurrence interval. The annual exceedence probability was calculated as the inverse of the recurrence interval. Exceedence probabilities were plotted as functions of corresponding calculated discharge measurements on log-probability paper, and a regression line was fit to the data. The bankfull discharge recurrence interval was then estimated from the graph.

Ungaged stream reaches were also surveyed to provide points in watersheds with relatively small drainage areas. To obtain a bankfull discharge (Q) estimate, at the stable ungaged watersheds, Manning's equation was used as:

$$Q = 1.4865\ AR^{2/3}\ S^{1/2} / n \qquad (1)$$

where R = hydraulic radius, A = cross sectional area, S = average channel slope or energy slope, and n = roughness coefficient estimated using the bankfull mean depth and channel bed materials. Flood frequency analyses was not completed on ungaged streams.

RESULTS AND DISCUSSION

The at-a-station hydraulic geometry relationships for bankfull discharge, cross-sectional area, width, and mean depth as functions of watershed area for the rural Piedmont of North Carolina are shown in Figures 3a-d. These relationships represent 10 USGS gage stations and 3 un-gaged reaches ranging in watershed area from 0.2 to 128 mi^2. The best-fit regression equations and upper and lower 95% confidence limits are shown for each relationship. The power function regression equations and corresponding coefficients of determination are:

$$Q_{bkf} = 66.57\ A_w^{0.89}\ ;\ (R^2 = 0.97) \qquad (2)$$

$$A_{bkf} = 21.43\ A_w^{0.68}\ ;\ (R^2 = 0.95) \qquad (3)$$

$$W_{bkf} = 11.89\ A_w^{0.43}\ ;\ (R^2 = 0.81) \qquad (4)$$

$$D_{bkf} = 1.50\ A_w^{0.32}\ ;\ (R^2 = 0.88) \qquad (5)$$

where, Q_{bkf} = bankfull discharge (cfs), A_w = watershed drainage area (mi$^{2)}$, A_{bkf} = bankfull cross sectional area (ft^2), W_{bkf} = bankfull width(ft), and D_{bkf} = bankfull mean depth (ft). Table 1 summarizes field measurements, hydraulic geometry, gage station analyses, and flood frequency analyses. The high coefficients of determination indicate good agreement between the measured data and the best-fit relationships. However, the wide range of the values included within the 95% confidence limits indicates the need for caution when using these relationships. For example, the bankfull cross-sectional area for a 10-mi^2 watershed ranges from approximately 60 to 180 ft^2 with a predicted value of 103 ft^2. The range of variability increases with increasing watershed area. This natural variability results from variations in average annual runoff, stream type (Rosgen, 1994), land use, and the natural variability of stream hydrology (Leopold, 1994). The bankfull return interval ranged from 1.09 to 1.80, with an average of 1.4 years. Dunne and Leopold (1978) reported a bankfull return interval of 1.5 years from a national study.

The relationships described in equations 2-5 represent data collected only in rural Piedmont streams in North Carolina. Ongoing work is being done in urbanized Piedmont watersheds and in streams throughout the Mountain and Coastal Plain provinces to compare with the existing relationships. Continuing data collection will ultimately result in a set of relationships for each physiographic province and sub-region, stratified by rainfall/runoff relationships.

CONCLUSION

Bankfull hydraulic geometry relationships are valuable to engineers, hydrologists, geomorphologists, and biologists involved in stream restoration and protection. They can be used to assist in field identification of bankfull stage and dimension in un-gaged watersheds. They can also be used to help evaluate the relative stability of a stream channel. Results of this study indicate good fit for regression equations of hydraulic geometry relationships in the rural Piedmont of North Carolina. However, users must be careful to consider the natural variability represented by the 95% confidence limits for these relationships. Further work is necessary to develop reliable relationships for other regions and rainfall/runoff conditions.

ACKNOWLEDGEMENTS

The NC Interagency Stream Restoration Task Force is developing bankfull hydraulic geometry relationships for all three physiographic regions in North Carolina. Special thanks go to task force members, Dani Wise, Ben Pope, Ray Riley, Sherman Biggerstaff, Jean Spooner, Carolyn Mojonnier, Rachel Smith, Mark Cantrell, Alan Walker, and Neil Woerner. The authors acknowledge the AWRA reviewers for their thorough review of this manuscript.

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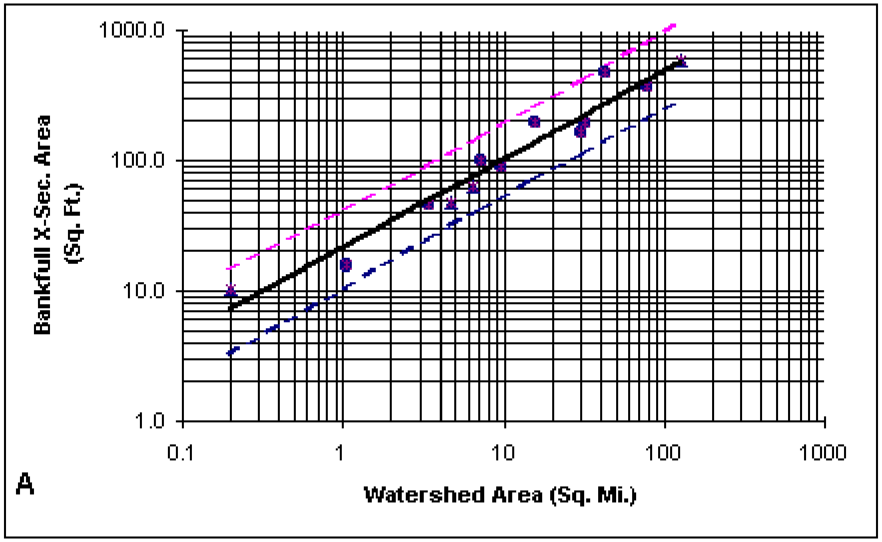
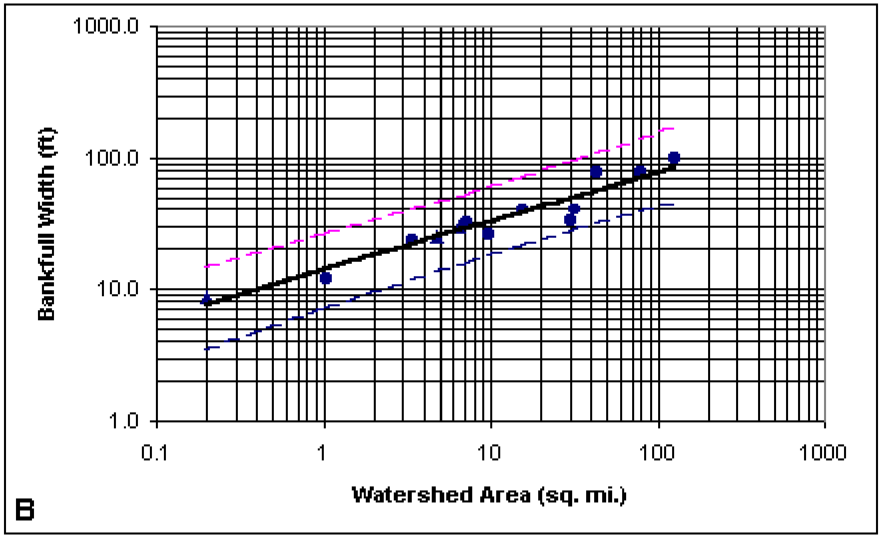
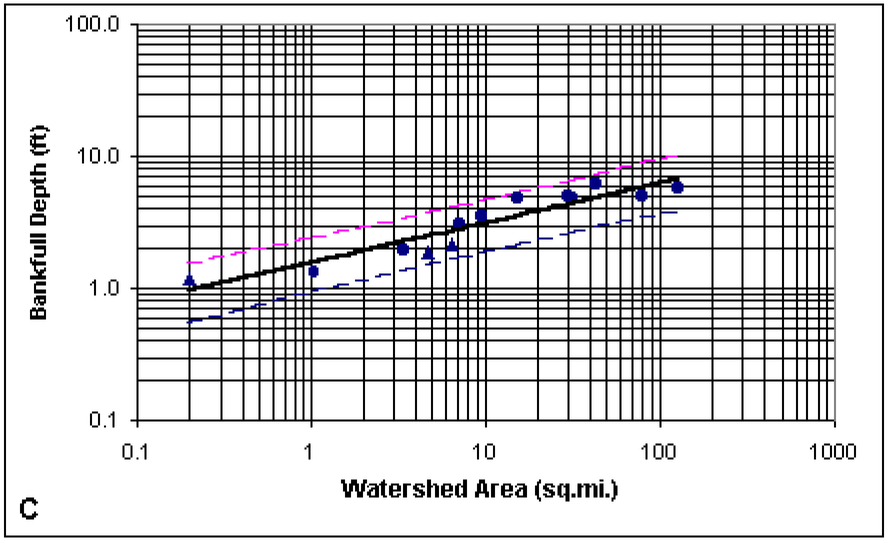
Stream Name	Gage Station ID	Drainage Area (mi^2)	Stream Type (Rosgen)	Bankfull Discharge (cfs)	Bankfull Xsec Area (ft^2)	Bankfull Width (ft)	Bankfull Mean Depth (ft)	Water Surface Slope (ft/ft)	Return Interval (Years)
Sal's Branch	Reference Reach	0.2	E4	55.4	10.4	8.7	1.2	0.0109	n/a
Humpy Creek	02117030	1.05	E5	83.0	15.8	12.0	1.3	0.0060	1.7
Dutchmans	02123567	3.44	C5	85.1	45.6	23.5	1.9	0.0170	1
Mill Creek	Reference Reach	4.7	E4	277	46.7	24.5	1.9	0.0080	n/a
Upper Mitchell River	Reference Reach	6.5	B4c	356	62.5	29.2	2.1	0.0095	n/a
Norwood Creek	0214253830	7.18	E5	253.7	98.8	32.0	3.1	0.0008	1.1
North Pott's Creek	02121180	9.6	E5	507.2	89.6	25.4	3.5	0.0012	1.7
Tick Creek	02101800	15.5	E	655.3	194	40.5	4.8	0.0005	1.3
Moon Creek	02075160	29.9	E5	708.8	162	33.0	4.9	0.0015	1.8
Long Creek	02144000	31.8	E5	1041	195	40.0	4.9	0.0010	1.4
Little Yadkin River	02114450	42.8	G5	2236	469	77.5	6.1	0.0018	1.4
Mitchell River	02112360	78.8	C	2681	377	77.0	4.9	0.0030	1.6
Fisher River	02113000	128	C3	3687	578	101	5.7	0.0023	1.4

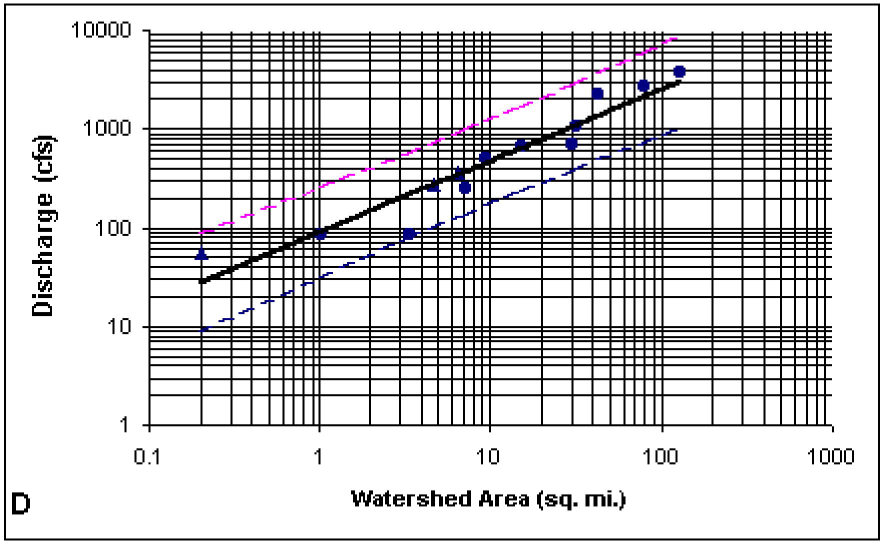
Table 1: Hydraulic geometry, survey summary, and flood frequency analyses for gaged and ungaged stream reaches.

Bankfull hydraulic geometry relationships for rural Piedmont North Carolina Streams. The four graphs represent: a) cross sectional area, b) width, c) depth, and d) discharge. The circles represent gage stations and the triangles represent ungaged streams. The outside dashed lines are the 95% confidence intervals for all the data points.






100.0
10.0
1.0
0.1
Bankfull Depth (ft)
0.1
1
10
100
1000
Watershed Area (sq.mi.)
C


10000
1000
100
10
1
Discharge (cfs)
0.1
1
10
100
1000
Watershed Area (sq. mi.)
D

BANKFULL REGIONAL CURVES FOR NORTH CAROLINA MOUNTAIN STREAMS

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ABSTRACT: Bankfull hydraulic geometry relationships, also called regional curves, relate bankfull stream channel dimensions and discharge to watershed drainage area. This paper describes preliminary results of bankfull regional curve relationships developed for North Carolina Mountain streams. Gage stations were selected with a minimum of 10 years of continuous or peak discharge measurements, no major impoundments, no significant change in land use over the past 10 years, and impervious cover ranges of <20%. To supplement data collected in gaged watersheds, stable reference reaches in un-gaged watersheds were also included in the study. Cross-sectional and longitudinal surveys were measured at each study reach to determine channel dimension, pattern, and profile information. Log-Pearson Type III distributions were used to analyze annual peak discharge data for USGS gage station sites. Power function relationships were developed using regression analyses for bankfull discharge, channel cross-sectional area, mean depth, and width as functions of watershed drainage area. The bankfull return interval for the rural mountain gaged watersheds ranged from 1.1 to 1.7 years, with a mean of 1.3 years. The mean bankfull return interval for rural North Carolina Piedmont gage stations was 1.4 years. Continuing work will expand this database for the North Carolina Mountain Physiographic Region.
KEY TERMS: Hydraulic Geometry, Regional Curve, Bankfull, Flood Frequency Analyses, Mountains

INTRODUCTION

Stream channel hydraulic geometry theory developed by Leopold and Maddock (1953) describes the interrelations between dependent variables such as width, depth and area as functions of independent variables such as discharge. Hydraulic geometry relationships are empirically derived and can be developed for streams in the same physiographic region with similar rainfall/runoff relationships (FISRWG, 1998). Bankfull hydraulic geometry relationships, also called regional curves, relate bankfull channel dimensions to drainage area (Dunne and Leopold, 1978). Gage station analyses throughout the United States have shown that the bankfull discharge has an average return interval of 1.5 years or 67% annual exceedence probability (Dunne and Leopold, 1978; Leopold, 1994). A primary purpose for developing regional curves is to aid in identifying bankfull stage and dimension in un-gaged watersheds and to help estimate the bankfull dimension and discharge for natural channel designs (Rosgen, 1994). This paper describes the process used in North Carolina to develop hydraulic geometry relationships at the bankfull stage. Preliminary results for rural watersheds in the Blue Ridge Mountain physiographic region are presented.

NORTH CAROLINA MOUNTAIN STUDY AREAS

North Carolina contains three major physiographic provinces: the Mountains, Piedmont, and Coastal Plain. The highest (100 inches) and the lowest (40 inches) mean annual precipitation in the Eastern U.S. is recorded in the North Carolina Mountains, both within the project study area and within 50 miles of each other. The steep mountain topography is also a factor in stream morphology, with the

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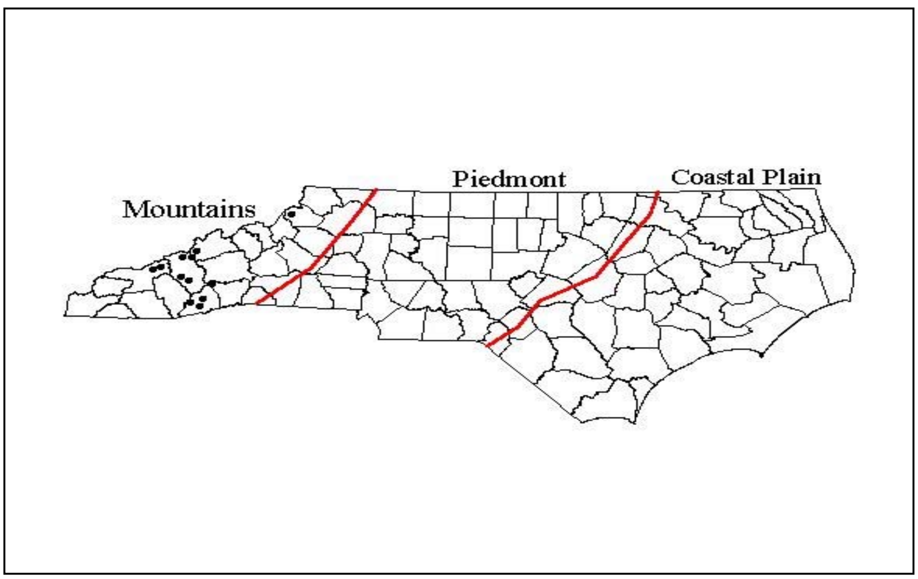
highest peak east of the Rocky Mountains at Mt. Mitchell (6,684 feet). In general, watersheds are more than 50% forested. Land cover dominated by human influences is locally high, but is less than 40% overall. Because rainfall/runoff relationships vary by province and land cover, separate bankfull hydraulic geometry relationships are being developed for rural and urban areas for each physiographic province. It may be necessary to further stratify the data for unique areas such as high rainfall areas in the Mountains and the Sandhills bordering the Piedmont and Coastal Plain.

USGS gage stations were identified with at least 10 years of continuous or peak discharge measurements, no major impoundments, no significant change in land use over the past 10 years, and impervious cover ranges of <20%. A geographic information system was used to analyze Thematic Mapper (TM) 1996 data to select watersheds with less than 20% impervious cover. To supplement data collected in gaged watersheds and provide points in smaller drainage areas, stable reference reaches in un-gaged watersheds were also selected using the same criteria. Project study sites are shown in Figure 1.

METHODOLOGY

Figure 1: North Carolina map showing physiographic provinces with Mountain study sites shown has dots.



Field Identification of Bankfull

Accurate identification of the bankfull stage in the field can be difficult and subjective (Williams, 1978; Knighton, 1984; and Johnson and Heil, 1996). Numerous definitions exist of bankfull stage and methods for its identification in the field (Wolman and Leopold, 1957; Nixon, 1959; Schumm, 1960; Kilpatrick and Barnes, 1964; and Williams 1978). The identification of bankfull stage in the humid Southeast is especially difficult because of dense understory vegetation and long history of channel modification and subsequent adjustment in channel morphology. It is generally accepted that bankfull stage corresponds with the discharge that fills a channel to the elevation of the active floodplain. The bankfull discharge is considered to be the channel-forming agent that maintains channel dimension and transports the bulk of sediment over time. Field indicators include the back of point bars, other significant breaks in slope, changes in vegetation type, the highest scour line, or the top of the bank (Leopold, 1994). The most consistent bankfull indicators for streams in North Carolina are the highest scour line and the back of the point bar. It is rarely the top of the bank or the lowest scour or bench.

DATA COLLECTION AND ANALYSES

The following gage station records were obtained from the United States Geological Survey: 9-207 forms, stage/discharge rating tables, annual peak discharges, and established reference marks. Bankfull stage was flagged upstream and downstream of the gage station using the field indicators listed above. Once a consistent indicator was found, a cross-sectional survey was completed at a riffle or run near the gage plate. Temporary pins were installed in the left and right banks, looking downstream. The elevations from the survey were related to the elevation of a gage station reference mark. Each cross section survey started at or beyond the top of the left bank. Moving left to right, morphological features were surveyed including top of bank, bankfull stage, lower bench or scour, edge of water, thalweg, and channel bottom (Harrelson et al., 1994). From the survey data, bankfull hydraulic geometry was calculated.

For each reach, a longitudinal survey was completed over a stream length approximately equal to 20 bankfull widths (Leopold, 1994). Longitudinal stations were established at each bed feature (heads of riffles and pools, maximum pool depth, scour holes, etc.). The following channel features were surveyed at each station: thalweg, water surface, low bench or scour, bankfull stage, and top of the low bank. The longitudinal survey was carried through the gage plate to obtain the bankfull stage. Using the current rating table and bankfull stage, the bankfull discharge was determined. Log-Pearson Type III distributions were used to analyze annual peak discharge data for the USGS gage station sites (Harman et al., 1999). Procedures outlined in USGS Bulletin #17B Guidelines for Determining Flood Flow Frequency were followed (U.S. Geological Survey, 1982). The bankfull discharge recurrence interval was then calculated from the flood frequency analyses. The stream was classified using the Rosgen (1994) method.

Ungaged, stable streams were also surveyed to provide points in watersheds with relatively small drainage areas. A stability analyses was completed before the stream was surveyed which included a bank erosion assessment, channel incision measurements, floodplain assessments, and review of historical maps and aerial photographs. To obtain a bankfull discharge (Q) estimate, at the stable ungaged watersheds, Manning's equation was used as:

$$Q = 1.4865\ AR^{2/3}\ S^{1/2} / n \qquad (1)$$

Where, R = hydraulic radius (ft), A = cross sectional area(ft^2), S = average channel slope or energy slope (ft/ft), and n = roughness coefficient estimated using the bankfull mean depth and channel bed materials. Flood frequency analyses was not completed on ungaged streams.

RESULTS AND DISCUSSION

The regional curves for the rural Mountains of North Carolina are shown in Figures 2a, b, c, and d. These relationships represent 9 USGS gage stations and 3 un-gaged reaches ranging in watershed area from 2.0 to 126 mi^2. The power function regression equations and corresponding coefficients of determination for bankfull discharge, cross sectional area, width, and mean depth are shown in Table 1.

Table 1: Power function regression equations for bankfull discharge and dimensions, where Q_{bkf} = bankfull discharge (cfs), A_w = watershed drainage area (mi^2), A_{bkf} = bankfull cross sectional area (ft^2), W_{bkf} = bankfull width(ft), and D_{bkf} = bankfull mean depth (ft).

Parameter	Power Function Equation	Coefficient of Determination R^2
Bankfull Discharge	$Q_{bkf} = 115.7A_w^{0.73}$	0.88
Bankfull Area	$A_{bkf} = 22.1A_w^{0.67}$	0.88
Bankfull Width	$W_{bkf} = 19.9A_w^{0.36}$	0.81
Bankfull Depth	$D_{bkf} = 1.1A_w^{0.31}$	0.79

Table 2 summarizes field measurements and hydraulic geometry. Table 3 summarizes bankfull discharge, flood frequency, and mean annual rainfall analyses. The moderately high coefficients of determination indicate good agreement between the measured data and the best-fit relationships. The vast range in mean annual precipitation (42 inches to 98 inches) explains the large degree of variability. Other sources of variability include the age of the forest, topography, land cover, soil type, runoff patterns, stream type and the natural variability of stream hydrology (Leopold, 1994). The bankfull return interval ranged from 1.1 to 1.9 years, with an average of 1.5 years. The mean bankfull return interval for rural North Carolina Piedmont gage stations was 1.4 years (Harman et al., 1999). Dunne and Leoplod (1978) reported a bankfull return interval of 1.5 years from a national study.

CONCLUSION

Bankfull hydraulic geometry relationships are valuable to engineers, hydrologists, geomorphologists, and biologists involved in stream restoration and protection. They can be used to assist in field identification of bankfull stage and dimension in un-gaged watersheds. They can also be used to help evaluate the relative stability of a stream channel. Results of this study indicate good fit for regression equations of hydraulic geometry relationships in the rural Mountains of North Carolina. Further work is necessary to develop additional data points to further explain the variability.

ACKNOWLEDGEMENTS

The NC Stream Restoration Institute is developing bankfull hydraulic geometry relationships for all three physiographic regions in North Carolina. Special thanks go to Angela Jessup, Richard Everhart, Ben Pope, Ray Riley, Sherman Biggerstaff, Kevin Tweedy, Jean Spooner, Carolyn Buckner, Barbara Doll, Rachel Smith, Louise Slate, and Brent Burgess. The authors acknowledge the AWRA reviewers for their thorough review of this manuscript.

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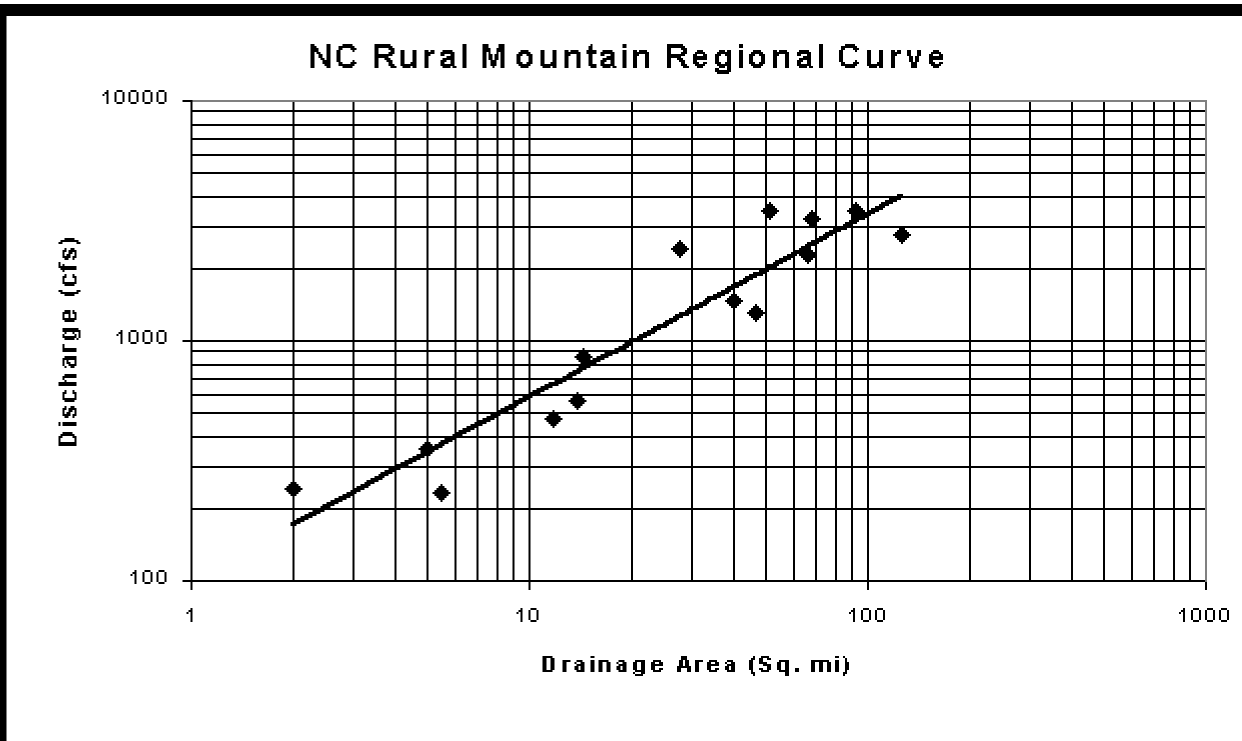
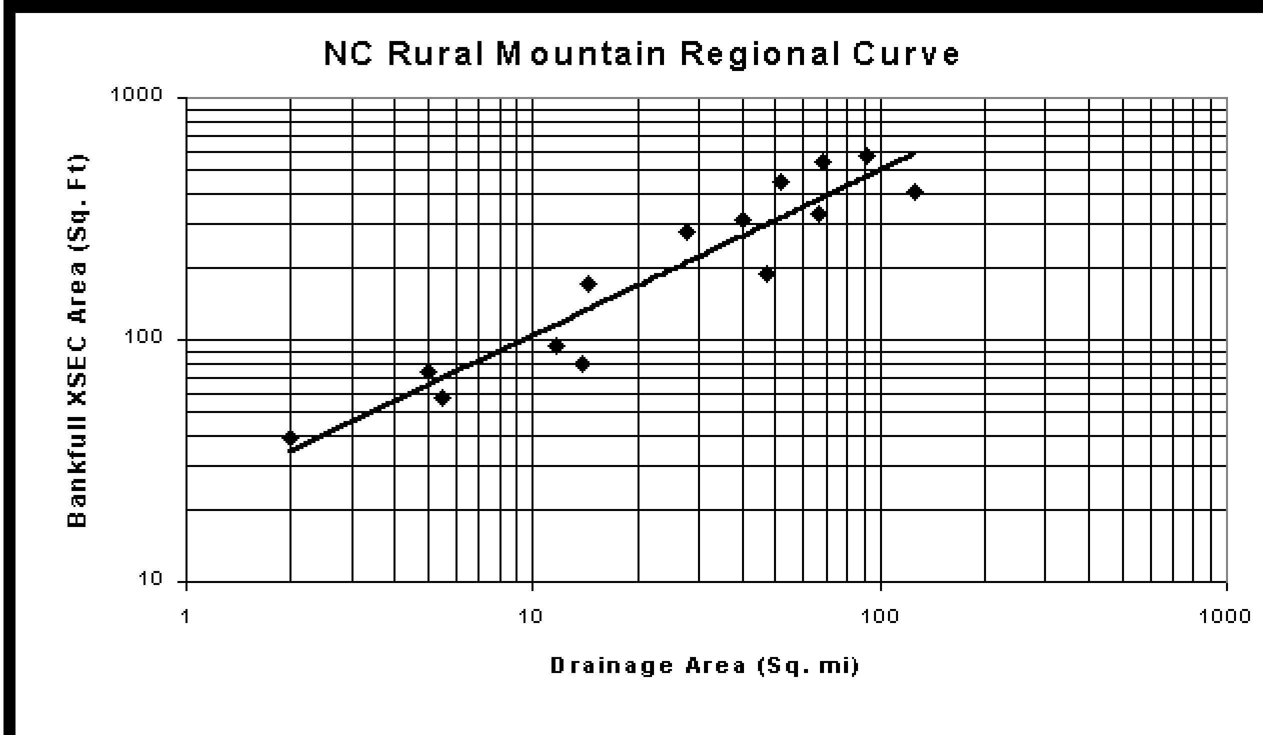
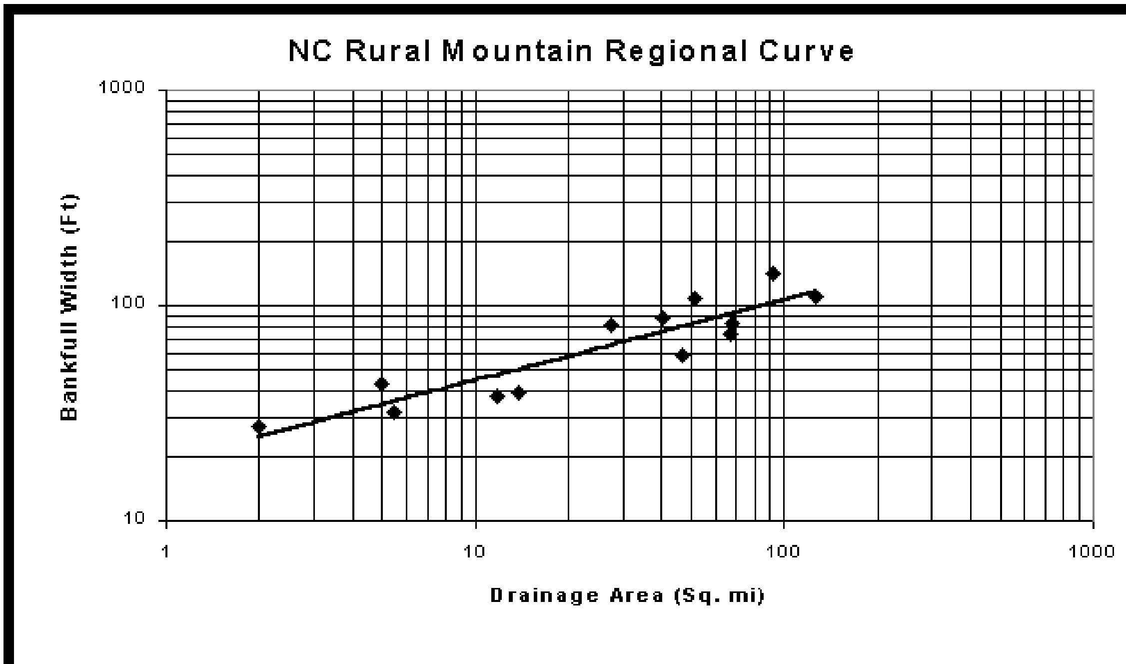
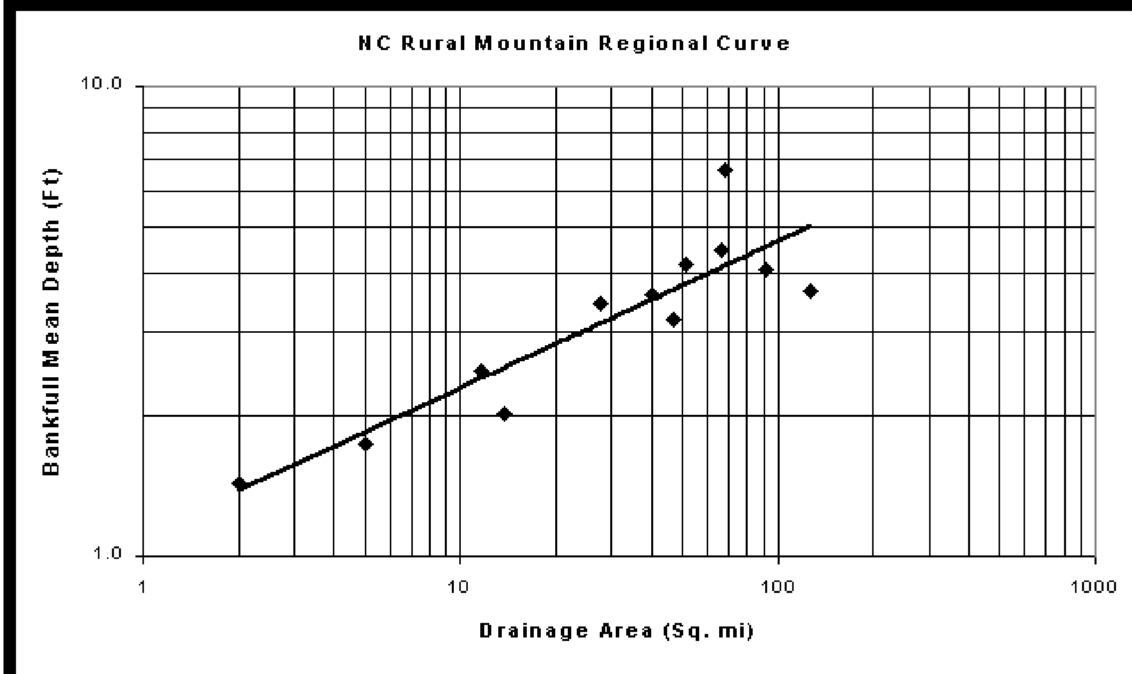
Stream Name	Gage Station ID	Stream Type (Rosgen)	Drainage Area (mi2)	Bankfull Discharge (cfs)	Bankfull Xsec Area (ft2)	Bankfull Width (ft)	Bankfull Mean Depth (ft)	Return Interval (Years)
French Broad at Rosman	3439000	E4	67.9	3226	544.9	82.4	6.6	1.3
Mills River	3446000	C4	66.7	2263	333	74.3	4.5	1.9
Davidson River	3441000	B4c	40.4	1457	316	87.6	3.6	1.1
Catheys Creek near Brevard	344000	B4c	11.7	470	94.2	38	2.5	1.67
West Fork of the Pigeon	3455500	B3c	27.6	2433	277.9	80.6	3.4	1.10
East Fork Pigeon River	3456500	B	51.5	3450	446.3	107	4.2	1.59
Watauga River	3479000	B4c	92.1	3492	572	140.3	4.1	1.25
Big Laurel	3454000	B4	126	2763	406	110.8	3.7	1.59
East Fork Hickey Fork Creek	n/a	B3a	2.0	242	39.3	27.4	1.4	n/a
Cold Spring Creek	n/a	B4	5.0	352	74.4	42.9	1.7	n/a
Caldwell Fork	n/a	B	13.8	560	79.3	39.4	2.0	n/a
Cataloochee	3460000	B4c	46.9	1320	186.9	58.7	3.2	1.60
Bee Tree	3450000	B3	5.46	231.5	56	32.1	1.7	1.85
North Fork Swannanoa	344894205	C3	14.5	855.7	170.6	69.3	2.5	


NC Rural Mountain Regional Curve
10000
1000
100
Discharge (cfs)
1
10
100
1000
Drainage Area (Sq. mi)


NC Rural Mountain Regional Curve
1000
100
10
Bankfull XSEC Area (Sq. Ft)
1
10
100
1000
Drainage Area (Sq. mi)



NC Rural Mountain Regional Curve
Bankfull Width (Ft)
1000
100
10
1
10
100
1000
Drainage Area (Sq. mi)



NC Rural Mountain Regional Curve
Bankfull Mean Depth (Ft)
10.0
1.0
1
10
100
1000
Drainage Area (Sq. mi)

Hydraulic Geometry Relationships for Urban Streams throughout the Piedmont of North Carolina

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William A. Harman[11], Rachel E. Smith[12] and Jean Spooner[2]

ABSTRACT: Hydraulic geometry relationships, or regional curves, relate bankfull stream channel dimensions to watershed drainage area. Hydraulic geometry relationships for streams throughout North Carolina vary with hydrology, soils, and extent of development within a watershed. This urban curve shows the bankfull features of streams in urban and suburban watersheds throughout the North Carolina Piedmont. Seventeen streams were surveyed in watersheds that had ten-percent or greater impervious cover. The watersheds had been developed long enough for the streams to redevelop bankfull features and had no major impoundments. The drainage areas for the streams ranged from 0.4 to 110.3 square kilometers. Cross-sectional and longitudinal surveys were conducted to determine the channel dimension, pattern and profile of each stream and power functions were fitted to the data. Comparisons were made with regional curves developed by Harman, et al. (1999) for the rural piedmont and enlargement ratios were produced. These enlargement ratios indicated a substantial increase in the hydraulic geometry for the urban streams in comparison to the rural streams. The study data was collected by NC State University, the University of North Carolina at Charlotte and Charlotte Storm Water Services. Urban regional curves are useful tools for applying natural channel design in developed watersheds. They do not, however, replace the need for field calibration and verification of bankfull stream channel dimensions.

KEY TERMS: Hydraulic Geometry, Regional Curve, Bankfull, Flood Frequency Analyses, Urbanization, Urban Water Management

INTRODUCTION

Decades of urban sprawl have degraded large numbers of streams throughout the country. For example, channelization, loss of riparian vegetation, floodplain restrictions and changes in hydrology have altered the dimension, pattern, and profile, and thereby the function, and habitat of many urban streams. As little as ten-percent impervious cover has been linked to stream degradation, with degradation becoming more severe as impervious cover increases (Schueler, 1995). Hammer (1973) found that the average annual flood, which equaled the 1.78-year storm, was doubled by an increase in population density of 5,500-6,000 persons per square mile from a rural condition. In addition, large contiguous impervious areas can significantly increase the size of a stream channel (Hammer 1972).

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Hammer (1972) developed stream channel enlargement ratios from a comparison of 50 urban and 28 rural watersheds in the Piedmont of Pennsylvania. His study showed an enlargement ratio for the cross-section of urbanized streams ranged from 0.7 to 3.8 for drainage areas ranging from 2.6 to 15.5 square kilometers in size.

A common sequence of physical adjustments has been observed in many streams following disturbance. This adjustment process is often referred to as channel evolution. Disturbance can result from channelization, increase in runoff, removal of streamside vegetation, as well as other changes that negatively affect stream stability. All of these disturbances are common in the urban environment. Several models have been used to describe this process of physical adjustment for a stream. Two models (Schumm et al. 1984, Simon 1989, and Simon an Downs 1995) have gained wide acceptance as being generally applicable for channels with cohesive banks (FISRWG 1998). Simons characterizes evolution in six steps, including 1) sinuous, premodified, 2) channelized, 3) degradation, 4) degradation and widening, 5) aggradation and widening, and 6) quasi equilibrium.

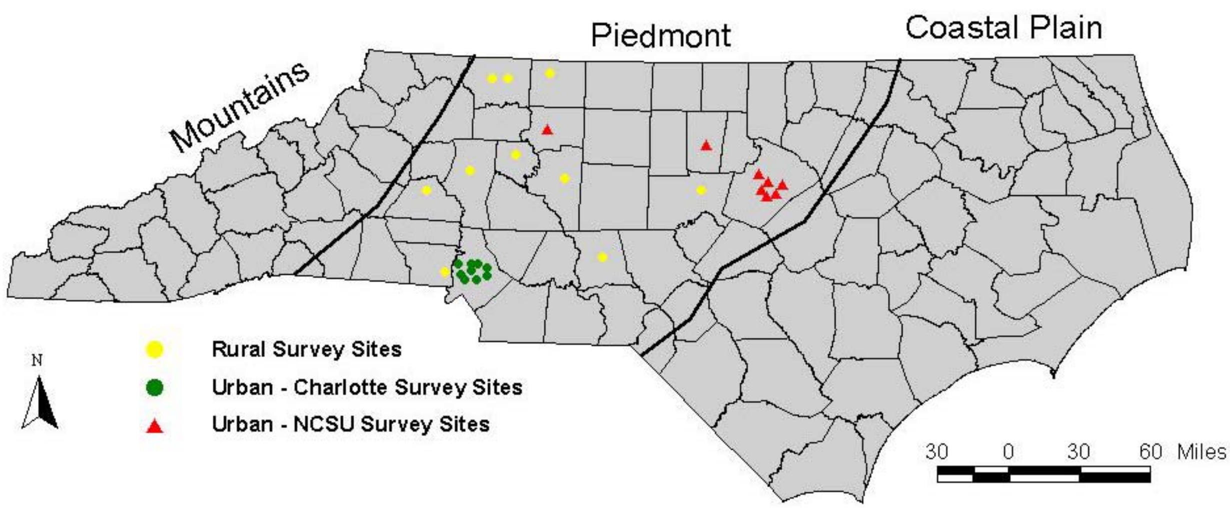
The channel evolution process is initiated once a stable, well-vegetated stream that frequently interacts with its floodplain is disturbed. Disturbance commonly results in an increase in stream power that causes degradation, often referred to as channel incision. Incision eventually leads to over-steepening of banks, and when critical bank heights are exceeded, the banks begin to fail and mass wasting of soil and rock leads to channel widening. Incision and widening continue moving upstream, commonly know as a head-cut. Eventually the mass wasting slows and the stream begins to aggrade. A new low-flow channel begins to form in the sediment deposits. By the end of the evolutionary process, a stable stream with dimension, pattern, and profile similar to those of undisturbed channels forms in the deposited alluvium. The new channel is at a lower elevation than its original form with a new floodplain constructed of alluvial material. The old floodplain remains a dry terrace (FISRWG. 1998). Most urban streams are at some stage of this evolutionary process. The time period required to reach a state of quasi equilibrium is highly variable and has not yet been determined.

Channelization and channel incision in addition can result in a loss of the water quality filtration and denitrifying function for the riparian buffers along many stream corridors. This is due to the lowering of the water table and the increase in the ratio of bank height to bankfull height associated with channelization and/or incision. In North Carolina, it was found that nitrogen removal capacity is lost as much of the groundwater flow to the stream passes beneath the buffer root system in these deeply incised stream systems (Kunickis, 2000).

Restoration and stabilization of urban streams is a priority focus for many federal, state and local government agencies and nonprofit groups. Many restoration practitioners strive to restore stability to disturbed streams by rebuilding natural stream characteristics, including a properly sized bankfull channel, adequate floodplain width, meanders, riffles, and pools. Stability is achieved when the stream has developed a stable dimension, pattern, and profile such that, over time, channel features are maintained and the stream system neither aggrades nor degrades (Rosgen, 1996). This restoration approach relies on the accurate identification of the bankfull channel dimension and discharge. Hydraulic geometry relationships that relate bankfull stream channel dimensions and discharge to watershed drainage area are therefore useful tools for stream restoration design. Because hydraulic geometry relationships for streams vary with hydrology, soils, and extent of development within a watershed, it is necessary to develop curves for various levels of development in each hydrophysiographic region. There are three primary physiographic regions in North Carolina: the Mountains, Piedmont, and Coastal Plain. The Piedmont is located between the Mountains and Coastal Plain and is characterized by rolling hills and wide alluvial valleys. The average annual precipitation is approximately 45 inches. Most Piedmont streams have moderate slopes that are controlled by bedrock outcrops (Horton et al., 1991). Hydraulic geometry data has already been developed for rural Piedmont North Carolina streams (Harman et al., 1999). This study focuses on identifying and comparing bankfull dimension and discharge of streams with urban watersheds to those with rural watersheds in the Piedmont.

Seventeen streams were surveyed in North Carolina Piedmont watersheds that had greater than ten-percent impervious cover. The watersheds had been developed long enough for the streams to redevelop bankfull features and had no major impoundments. The majority of the streams included in the study were in the process of recovering from past disturbances, including channelization or incision resulting from changes in hydrology due to urbanization. The reaches selected for survey were in or approaching quasi equilibrium. The drainage areas for the streams ranged from 0.4 to 110.3 square kilometers. The study includes data collected by NC State University, and by the University of North Carolina at Charlotte and the Charlotte Storm Water Services (Wilkerson, S.D., Master of Science thesis, Civil Engineering Department, UNC Charlotte). Streams are located in Chapel Hill, Raleigh, Durham, Winston-Salem and Charlotte. The locations of the survey sites are displayed on the map in Figure 1.

Figure 1. Survey Sites in North Carolina



This paper develops hydraulic geometry relationships for urban streams that have reached or are approaching quasi equilibrium in the channel evolution process. Urban curves for the Piedmont of North Carolina area were developed that compare bankfull cross-sectional area, discharge, width, and depth with drainage area. These relationships are compared to rural curves developed by Harman et al. (1999). Enlargement ratios comparing urban to rural curves are calculated to compare the magnitude of increases in the hydraulic geometry associated with urban impacts.

MATERIALS AND METHODS

U.S. Geological Survey (USGS) gaged urban streams were identified. Of the urban gaged streams, only those that met the study criteria were surveyed. The study criteria included: Piedmont streams with at least 10 percent impervious surface in their drainage area, no major impoundments, exhibiting bankfull indicators and having a stable riffle or run cross-section. Additional urban streams were identified through map analysis, local agency contacts and field reconnaissance. A consistent bankfull indicator was identified along each stream survey reach. Bankfull stage in general corresponds to the discharge that fills a channel to the elevation of the active floodplain. The bankfull discharge is considered to be the channel-forming flow, maintaining channel dimension and transporting the bulk of sediment over time (Leopold, 1994). Field indicators of bankfull stage include the back of point bars, significant breaks in slope, changes in vegetation, the highest scour line, or the top of the bank (Leopold, 1994). The most consistent bankfull indicators for Piedmont North Carolina streams are the highest scour line and the back of the point bar. The top of the bank or the lowest scour or bench is rarely an indicator of bankfull (Harman et al., 1999).

Cross-sectional and longitudinal surveys were conducted to determine the channel dimension, pattern and profile for each stream. Cross-sections were surveyed at a representative stable riffle or run that was not suffering from severe active erosion. Moving left to right looking downstream, morphological features were surveyed including top of bank, bankfull stage, lower bench or scour, edge of water, thalweg, and channel bottom (Harrelson et al., 1994; U.S. Geological Survey, 1969). Bankfull hydraulic geometry was calculated from the survey data at each riffle cross-section.

For each reach, a longitudinal survey was completed over a stream length equal to at least 20 bankfull widths (Leopold, 1994). Longitudinal stations were established at each bed feature (heads of riffles and pools, maximum pool depth, scour holes, etc.). The following channel features were surveyed at each station: thalweg, water surface, low bench or scour, bankfull stage, and top of bank. The slope of a line fitted through the bankfull stage indicators was compared to a line of best fit through the water surface points. Leopold (1994) used this technique to verify the feature as bankfull if the two lines were parallel and consistent over a long reach. At gaged stream sites, the longitudinal survey was carried through the gage plate to obtain the bankfull stage. The stream was classified using the Rosgen method (1994).

For gaged streams, the bankfull discharge and return period were determined using the USGS stage-discharge rating table and flood-frequency analysis, respectively. At least ten years of USGS gage discharge data, including annual peak flows, was necessary to develop flood frequency relationships. Log-Pearson Type III distributions were used to analyze the annual peak discharge data (U.S. Geological Survey, 1982). The generalized skew coefficient presented in the USGS Bulletin 17B was used for the flood frequency analysis (U.S. Geological Survey, 1982). The annual exceedence probability was calculated as the inverse of the recurrence interval. Exceedence probabilities were plotted as functions of corresponding calculated discharge measurements. From these flood frequency relationships a specific discharge can then be related to a return interval. In the case of Pigeon House Creek, Bushy Branch and Marsh Creek at Millbrook, the return interval was provided by a USGS flood frequency study of 32 small urban basins in North Carolina (U.S. Geological Survey, 1996). For this study, concurrent records of rainfall and runoff data collected in small urban basins were used to calibrate rainfall-runoff models. Historic rainfall records were used with the calibrated models to synthesize a long-term record of annual peak discharges. The synthesized record of annual peak discharges was then used in a statistical analysis to determine flood-frequency distribution. The study reported the discharges for the 2-, 5-, 10-, 25-, 50- and 100-year recurrence intervals. USGS provided the 1.11- and 1.25-year discharges for the three streams included in this study (Pope, B. F., Personal Communication, February 15, 2000, U.S. Geological Survey, Raleigh, N.C.).

For non-gaged streams, bankfull discharge was calculated using Manning’s equation (Chow, 1959). Cross-sectional area and hydraulic radius were calculated using the cross-section survey data and a roughness coefficient was estimated according to Chow (1959). A sensitivity analysis comparing the discharge calculated using Manning’s equation to the discharge produced by the gage data was conducted to validate the discharge method selected. The results of the sensitivity analysis are presented in Table 1.

Table 1: Discharge Sensitivity Analysis

Stream Name	Manning's Discharge (cms)	Gage Discharge (cms)	% Error
Pigeon House Branch	3	3	0.3
McMullen Creek @ Sharon View Road	34	28	19.6
Long Creek @ Oakdale	34	29	17.2
Irwin Creek near Billy Graham Pkwy	73	69	5.0
McAlpine @ Sardis Road	68	74	-8.4
Little Sugar Creek @ Archdale Road	130	124	4.5

For the streams surveyed by NC State University, existing EPA land use data was then used to estimate the impervious percentage for each stream's watershed. The EPA land use data is categorized by level two in the Anderson Land Use Classification System (Anderson et al., 1976) which includes residential, commercial, industrial, several vegetation types, pasture, cropland, industrial, and others (EPA, 1998). Natural Resource Conservation Service guidelines were used to assign an impervious cover percentage to each land use (NRCS, 1986). In the case of the Charlotte streams, Mecklenburg County's land use data was used to determine the impervious percentage. Distinct land use polygons were identified within each study watershed. Each land use area was assigned a land use code and each land use code was then assigned an average impervious surface percentage using the Natural Resource Conservation Service guidelines (NRCS, 1986).

For each stream, the bankfull cross-sectional area, discharge, width, and depth were plotted versus drainage area for the urban data. These relationships were found to be linear on a log scale, e.g., a power function was utilized. Confidence intervals (95%) on the individual observations and the regression relationships were also calculated. The same regression relationships and confidence intervals were also developed for the rural data presented by Harman et al. (1999). The urban curves were then compared to the rural data (Harman et al., 1999). A statistical regression test (Analysis of Covariance) using the PROC GLM procedure in SAS® was performed to test for homogeneity of slopes. That is, to test if there is statistical evidence that the slope was different for the urban as compared to the rural curves. If there was no evidence of slope differences, a pooled slope was assumed and parallel regression lines with different intercepts were calculated. Confidence intervals (95%) on the regression relations were also calculated. If there was evidence of different slopes, the error estimate around the regression lines was pooled and each line was allowed to have a different slope as well as intercept.

From a comparison of the urban and rural regional curves, it is possible to quantify the effect of urbanization by examining different enlargement ratios of a specific drainage area and x dimension, Ex, where: Ex = xu/xr, and xu =bankfull dimension of depth (Dbkf), width (Wbkf), cross-section (Abkf) or discharge (Qbkf) at a specific drainage area in urban areas, and xr= the same bankfull dimensions at a specific drainage area in rural areas. These enlargement ratios are based on comparing the dimensions obtained from the power functions (regional curves) fitted to the data and not comparison of the specific data. Relating the urban and rural region curves by plotting the enlargement ratios as a function of drainage area gives yet another power function.

RESULTS AND DISCUSSION

Table 2 summarizes field measurements and hydraulic geometry data for the urban streams. The rural regional curve data from Harman et al. (1999) are also included in Table 2. The relationships for bankfull discharge, cross-sectional area, width, and mean depth as functions of watershed area for the urban Piedmont of North Carolina are shown in Figures 2. The resulting 95% confidence intervals for both the individual observations and the regression relationship are also shown on Figure 2. In comparison the same hydraulic geometry relationships and associated confidence intervals for the rural Piedmont relationships from Harman et al. (1999) are shown in Figure 3. The urban relationships shown in Figure 2 represent nine USGS gage stations and eight un-gaged reaches ranging in watershed area from 0.4 to 110.3 square kilometers. The power functions regression equations and corresponding coefficients of determination for the urban curves are:

$$A_{bkf} = 3.02\ A_w^{\ 0.65} \qquad r^2=0.95 \qquad (1)$$

$$Q_{bkf} = 4.77\ A_w^{\ 0.63} \qquad r^2=0.94 \qquad (2)$$

$$W_{bkf} = 5.43\ A_w^{\ 0.33} \qquad r^2=0.88. \qquad (3)$$

$$D_{bkf} = 0.54\ A_{w.}^{\ 0.33} \qquad r^2=0.87 \qquad (4)$$

where, Q_{bkf} = bankfull discharge in cubic meters per second (cms), A_w = watershed drainage area in square kilometers (sq. km.), A_{bkf} = bankfull cross sectional area in square meters (sq. m.), W_{bkf} = bankfull width in meters (m), and D_{bkf} = bankfull mean depth in meters (m). The high coefficients of determination indicate good agreement between the measured data and the best-fit relationships. However, variability results from natural variations in average annual runoff, stream type (Rosgen, 1994), land use, and stream hydrology (Leopold and Maddock, 1953, Leopold, 1994). The bankfull return interval ranged from 1.1 to 1.5 for the gaged stream stations, with both the average and the median return interval at 1.3. Dunne and Leopold (1978) reported a bankfull return interval of 1.5 years from a national study.

The comparison of the urban data to the rural data to test for slope differences and to determine enlargement is shown on Figure 4. For each of the geometric relationships, there was no statistical evidence that the slopes for the urban and rural curves were different. Therefore, these regression relationships were calculated with the same slopes and different intercepts. In each relationship, there was a statistically significant difference between the intercepts; therefore, indicating significant shift, or enlargement, with the urban streams for similar drainage areas. The best-fit regression equations for the pooled data are shown for each urban and rural relationship (Figure 4). The resulting enlargement ratios are as follows:

$$E_{Abkf} = 2.65 \times (A_w)^{0.0} \qquad (5)$$

$$E_{Qbkf} = 2.91 \times (A_w)^{0.\ 0} \qquad (6)$$

$$E_{Wbkf} = 1.66 \times (A_w)^{0.0} \qquad (7)$$

$$E_{Dbkf} = 1.57 \times (A_w)^{0.0} \qquad (8)$$

It can be seen from these functions that the urban streams display a substantial increase in hydraulic geometry as compared to the rural counterparts. Since all the streams evaluated in this study were located in the same physiographic region, the Piedmont, it can be assumed that these enlargement ratios are a good representation of the flux in channel size, which can be expected as a rural watershed is developed. The drainage areas of the streams ranged from 0.4 to 110.3 square kilometers. There was no evidence that the enlargement ratios varied with watershed size (determined from the Analysis of Covariance which showed no evidence for different slopes on the log scale between the urban and rural curves.) Therefore, the exponent is estimated to be zero.

CONCLUSION

As expected, this study found enlarged bankfull dimension and discharge for urban streams versus rural streams with the same watershed area in the Piedmont region of North Carolina (see Figure 4). The increase in bankfull cross-sectional area between rural and urban streams is comparable to the increase calculated using Hammer's channel enlargement ratios. This study shows an enlargement ratio of the cross-section of urbanized streams of 2.6, which is comparable to Hammer's (1972) enlargement range of 0.7 to 3.8 found in similar sized watersheds. The enlargement ratio falls in the upper end of the range found by Hammer and show much less variability. The study also shows an increase in bankfull average depth with an increase in urbanization. This depth increase however does not represent an increase in pools. Rather, the streams surveyed were dominated by riffle and run and lacking good pool habitat. The increase in depth is merely a function of a larger channel that is carrying larger discharges.

Bankfull hydraulic geometry relationships are valuable to engineers, hydrologists, geomorphologists, and biologists involved in stream restoration and protection. They can be used to assist in field identification of bankfull stage and dimension in un-gaged watersheds. They do not, however, replace the need for field calibration and verification of bankfull stream channel dimensions. Results of this study indicate good fit for regression equations of hydraulic geometry relationships in the urban Piedmont of North Carolina.

Further work is necessary to develop reliable relationships for other regions and rainfall/runoff conditions. Additional data are being collected for the urban and suburban curves in Piedmont North Carolina in order to capture a broader range of stream types, drainage area impervious cover percentages and drainage area sizes throughout Piedmont North Carolina. Additional stratification of the data according to impervious percentage may be necessary. The current logarithmic scale used for presenting the data does not reveal significant variation between 17-80 percent impervious surface area.

Figure 2: Hydraulic geometry relationships of (a) bankfull cross-sectional area, (b) discharge, (c) width, and (d) depth compared to watershed area for urban streams in the North Carolina Piedmont.

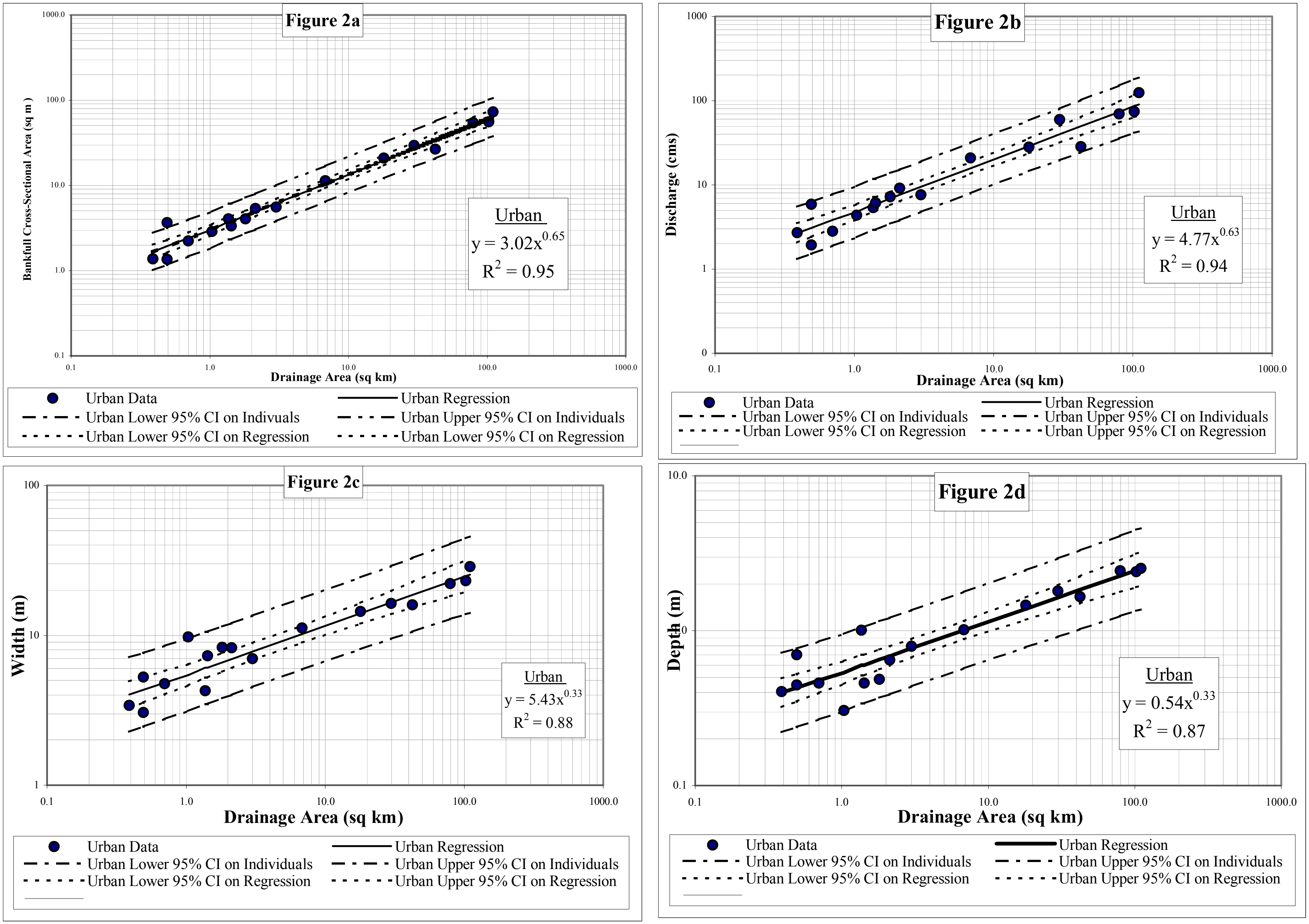


Figure 3: Hydraulic geometry relationships of (a) bankfull cross-sectional area, (b) discharge, (c) width, and (d) depth compared to watershed area for rural streams in the North Carolina Piedmont from Harman et al. (1999).

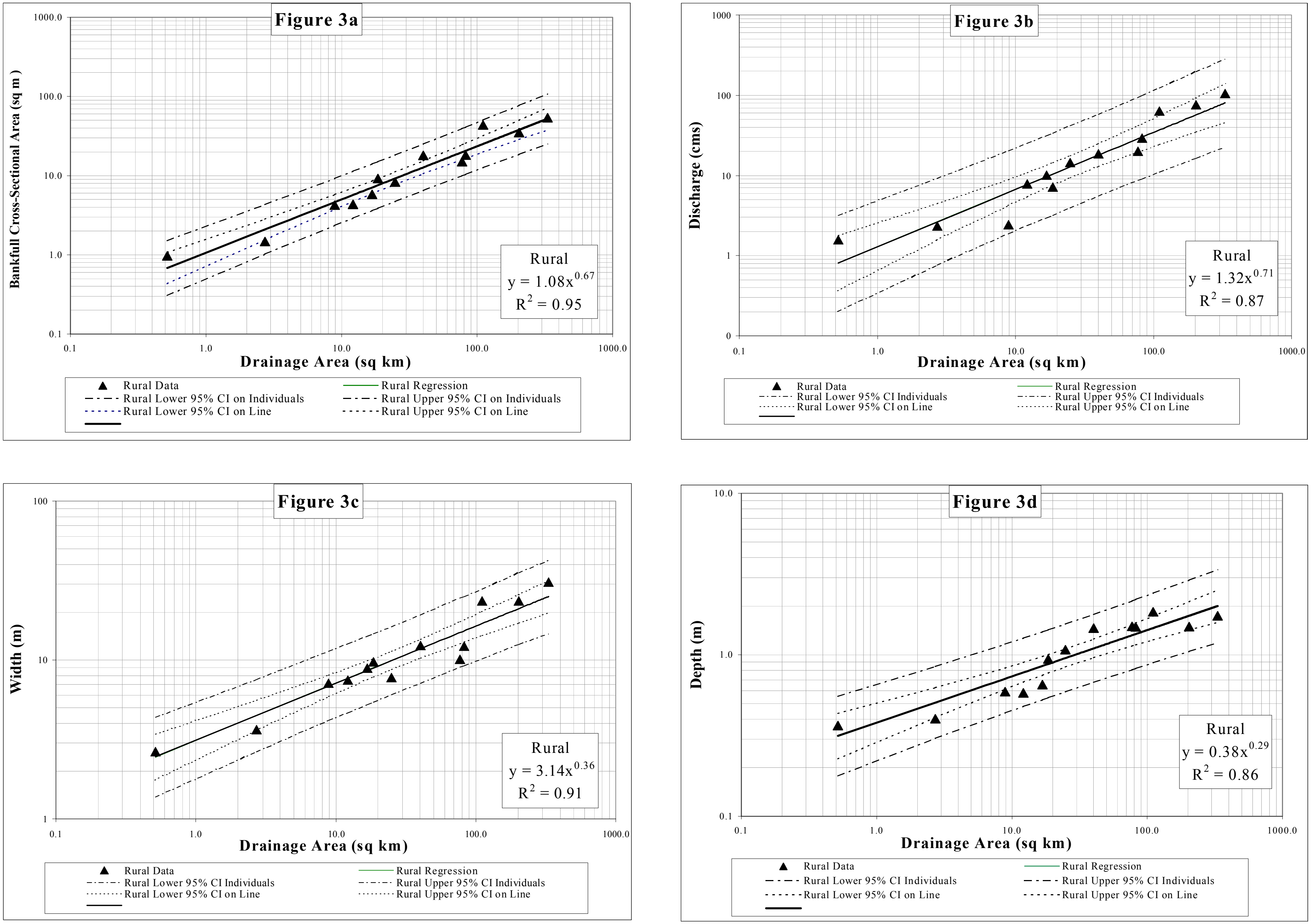


Figure 4: Comparison of urban versus rural regional hydraulic geometry relationships of (a) bankfull cross-sectional area, (b) discharge, (c) width, and (d) depth compared to watershed area for streams in the North Carolina Piedmont.

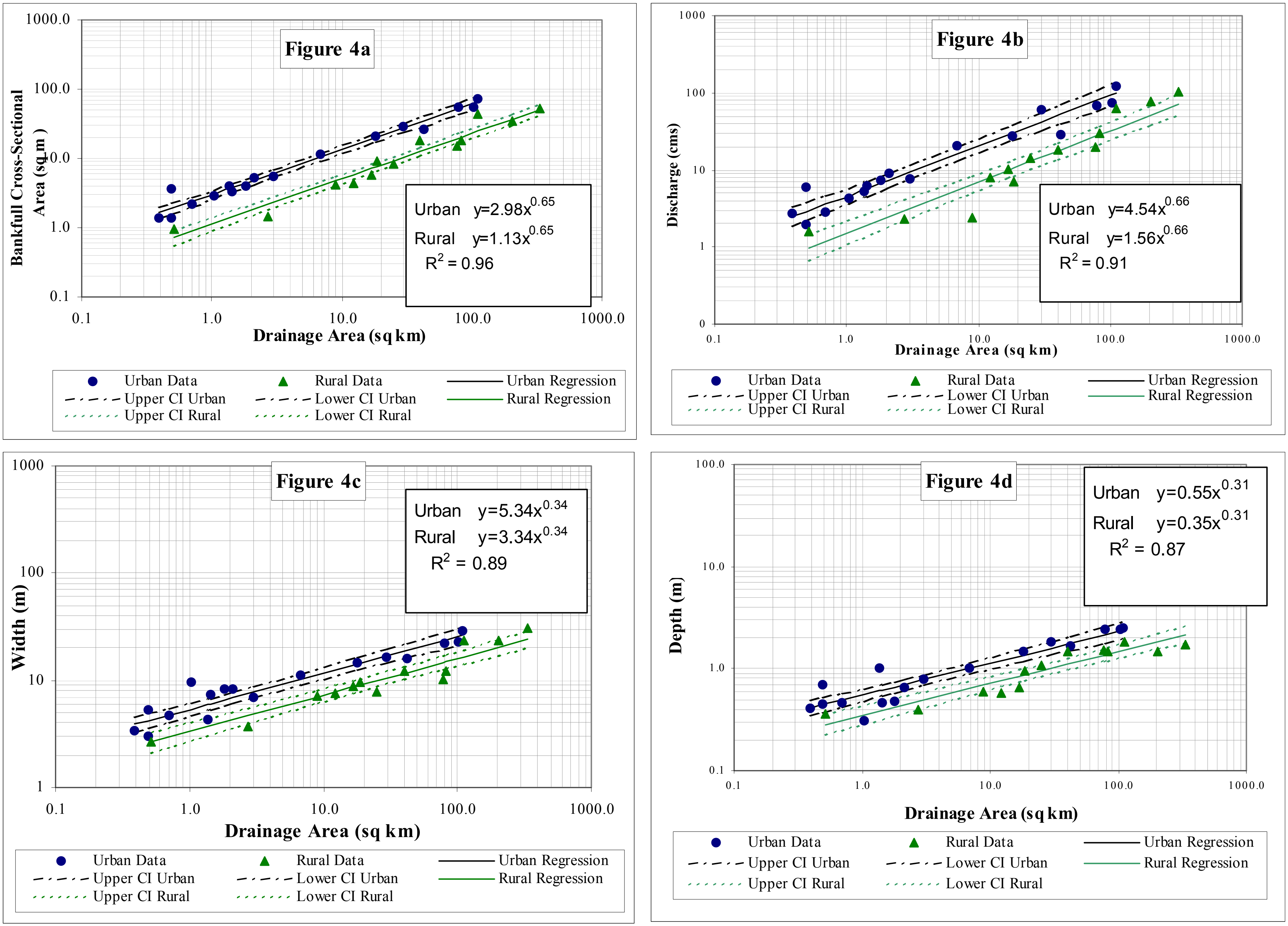


Table 2. Hydraulic geometry and survey summary for gaged and ungaged urban and rural stream reaches.

Survey Team *	Stream Name	Gaged Site	D.A. (sq.km.)	Bkfl X-sect. Area (sq. m.)	Discharge (cms)	Width (m)	Mean Depth (m)	Return Interval	Stream Type (Rosgen)	Impervious Surface Percentage
NCSU	Bushy Branch @ Schaub Dr.	No ***	0.5	1.4	2	3	0.4	1.5	E	20
NCSU	Bolin Creek Tributary	No	0.4	1.4	3	3	0.4		Eb	36
NCSU	Marsh Creek @ Millbrook	No ***	0.5	3.7	6	5	0.7	1.1	E	25
NCSU	Pigeon House Branch	Yes	0.7	2.2	3	5	0.5	1.1	E	47
NCSU	Rocky Branch 1	Yes **	1.0	2.9	4	10	0.3		F	80
C	Plaza-Midwood Creek at Masonic Dr.	No	1.4	4.1	5	4	1.0		E	26
NCSU	Brushy Fork Trib #2 (WS)	No	1.4	3.4	6	7	0.5		C	66
NCSU	Rocky Branch 2	Yes **	1.8	4.0	7	8	0.5		F	80
NCSU	Kentwood Park	No	2.1	5.4	9	8	0.6		Bc	54
C	Little Hope Creek @ Woodlawn	No	3.0	5.6	8	7	0.8		E	38
C	Little Hope Creek @ Seneca Place	Yes	6.8	11.3	21	11	1.0	1.4	E	41
C	McMullen Creek @ Sharon View Rd.	Yes	18.0	21.0	28	14	1.5	1.5	E	33
C	McMullen Creek @ Quail Hollow Rd.	No	29.8	29.5	59	16	1.8		E	32
C	Long Creek @ Oakdale	Yes	42.5	26.5	29	16	1.7	1.4	E	17
C	Irwin Creek near Billy Graham Pkwy	Yes	79.5	54.0	69	22	2.4	1.2	E	32
C	McAlpine @ Sardis Rd.	Yes	102.6	55.4	74	23	2.4	1.3	E	24
C	Little Sugar Creek @ Archdale Rd.	Yes	110.3	72.7	124	29	2.5	1.2	E	39
Rural	Sal's Branch	No	0.5	1.0	2	3	0.4		E4	<10
Rural	Humpy Creek	Yes	2.7	1.5	2	4	0.4	1.7	E5	<10
Rural	Dutchmans	Yes	8.9	4.2	2	7	0.6	1	C5	<10
Rural	Mill Creek	No	12.2	4.3	8	7	0.6		E4	<10
Rural	Upper Mitchell River	No	16.8	5.8	10	9	0.7		B4c	<10
Rural	Norwood Creek	Yes	18.6	9.2	7	10	0.9	1.1	E5	<10
Rural	North Pott's Creek	Yes	24.9	8.3	14	8	1.1	1.7	E5	<10
Rural	Tick Creek	Yes	40.1	18.0	19	12	1.5	1.3	E	<10
Rural	Moon Creek	Yes	77.4	15.1	20	10	1.5	1.8	E5	<10
Rural	Long Creek	Yes	82.4	18.1	29	12	1.5	1.4	E5	<10
Rural	Little Yadkin River	Yes	110.9	43.6	63	24	1.8	1.4	G5	<10
Rural	Mitchell River	Yes	204.1	35.0	76	23	1.5	1.6	C	<10
Rural	Fisher River	Yes	331.5	53.7	104	31	1.7	1.4	C3	<10

*C=UNC Charlotte and Charlotte Storm Water Services; NCSU = NC State University; Rural = from Harman et al., 1999.
** Ten years of gage data not available for flood frequency analysis.
*** Gage no longer in place. Discharge calculated using Manning's equation.

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Fact Sheet Number 2

River Course

Application of the **Rosgen Stream Classification System** to North Carolina

River Course is a fact sheet series developed to provide information and technologies related to the use of natural channel design in restoring impaired streams.

nc stream restoration institute

Restoration of impaired streams begins with an understanding of the watershed's current condition and stream potential. Stream classification offers a way to categorize streams based on channel morphology. This fact sheet focuses on a classification system popular with hydrologists, engineers, and biologists—the Rosgen stream classification system.

Stream Classification

The classification of natural streams is not new. Over the past 100 years, there have been about 20 published stream classification systems. The first recognized classification was by Davis in 1899. Davis classified streams in terms of age (youthful, mature, and old age). The classification systems devised between 1899 and1970 were largely qualitative descriptions of stream features and landforms and were difficult to apply universally. In 1994, Rosgen published *A Classification of Natural Rivers*. Because of its usefulness in stream restoration, this classification system has become popular among hydrologists, engineers, geomorphologists, and biologists working to restore the biological function and stability of degraded streams.

Rosgen Stream Classification System

The Rosgen stream classification system categorizes streams based on channel morphology so that consistent, reproducible, and quantitative descriptions can be made. Through field measurements, variations in stream processes are grouped into distinct stream types. Rosgen lists the specific objectives of stream classification as follows:

1. Predict a river's behavior from its appearance.
2. Develop specific hydraulic and sediment relationships for a given stream type.
3. Provide a mechanism to extrapolate site-specific data to stream reaches having similar characteristics.
4. Provide a consistent frame of reference for communicating stream morphology and condition among a variety of disciplines and interested parties.

The Rosgen stream classification consists of four levels of detail ranging from broad qualitative descriptions to detailed quantitative assessments. Figure 1 shows the hierarchy (Levels I through IV) of the Rosgen classification inventory and assessment. Level I is a geomorphic characterization that categorizes streams as "A," "B," "C," "D," "DA," "E," "F," or "G." Level II is called the morphological description and requires field measurements. Level II assigns a number (1 through 6) to each stream type describing the dominant bed material. Level III is an evaluation of the stream condition and it's stability. This requires an assessment and prediction of channel erosion, riparian condition, channel modification, and other characteristics. Level IV is verification of predictions made in Level III and consists of sediment transport, stream flow, and stability measurements.

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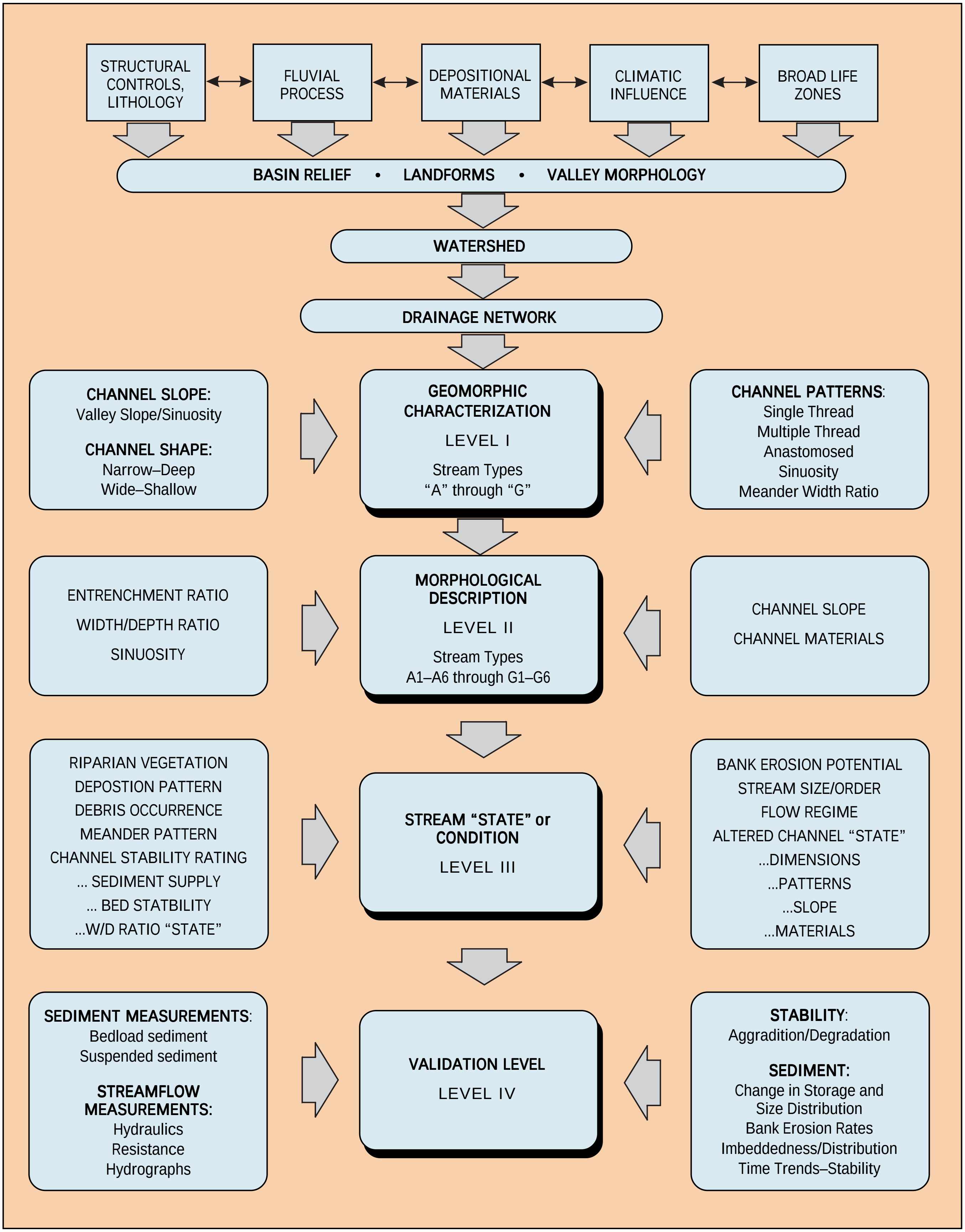
Figure 1. Rosgen Stream Classification Levels.



Bankfull Stage

The width/depth and entrenchment ratios used in the classification are measured at the bankfull stage. By definition, bankfull stage is the elevation of the floodplain adjacent to the active channel. If the stream is entrenched, bankfull stage is identified as a scour line, bench, or top of the point bar. If the stream is not entrenched, then bankfull is near or at the top of the bank. Relationships of bankfull cross sectional area as a function of watershed size help identify bankfull stage in the field. Bankfull stage and natural stream process terminology are further discussed in *River Course 1: Natural Stream Processes*, AG-590-1. Field techniques for identifying bankfull stage are provided in *River Course 3,* AG-590-3.

Application of the Rosgen Stream Classification System

A hierarchical key to the Rosgen stream classification system is shown in Figure 3 on page 4. The criteria and measurements used to classify the stream are discussed below.

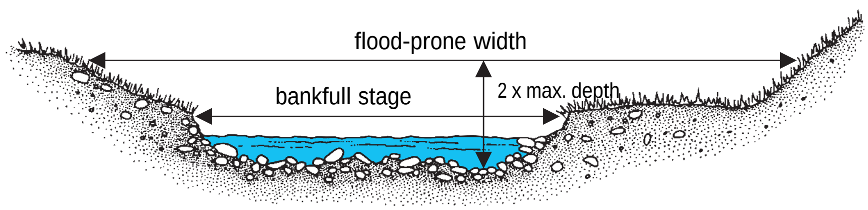


Figure 2. The entrenchment ratio measures the degree of channel incision as the flood-prone width divided by the bankfull width.

Single or Braided Channel Determination — A braided channel consists of three or more distinct channels. Anything less is considered a single channel. The only stream types for braided channels are "D" and "DA." Single or braided channel determination can be made from aerial photograph or field observation.

Entrenchment Ratio —The entrenchment ratio is a field measurement of channel incision. Specifically, it is the flood-prone width divided by the bankfull width. The flood-prone width is measured at the elevation of twice the maximum depth at bankfull. Lower entrenchment ratios indicate channel inclusion. Large entrenchment ratios mean that there is a well-developed floodplain. An example of this measurement is shown in Figure 2. The following stream types are entrenched: "A," "F," and "G."

Width to Depth Ratio —The width to depth ratio is a field measurement of the bankfull width divided by the mean bankfull depth. The break between single channel classifications is 12, meaning that the bankfull width is 12 times greater than the mean bankfull depth. Stream types with width/depth ratios greater than 12 are "B," "C," and "F." Stream types less than 12 are "A," "E," and "G." The "D" stream types have a width/depth ratio greater than 40 and the "DA" stream types are less than 40.

Sinuosity —Sinuosity is a measure of a stream's "crookedness." Specifically, it is the channel length divided by a straight-line valley length. The greater the number, the higher the sinuosity. Sinuosity is related to slope. Natural streams with steep slopes have low sinuosities, and streams with low slopes typically have high sinuosities. Sinuosity can be measured from large scale aerial photographs but should not be measured from 1:24,000 or smaller scale topographic maps.

Water Surface Slope — The water surface slope is a field measurement from the top of a riffle to the top of another riffle at least 20 bankfull widths downstream. This is considered the average slope. "A" and "B" stream types have the steepest slopes and "E" and "DA" stream types have the lowest. However, slope varies greatly among stream types.

Median Size of the Bed Material — A pebble count procedure is used to determine the D50 of the bed material. The D50 is the median particle size, meaning that 50 percent of the material is smaller and 50 percent is larger. A stream reach of 20 bankfull widths is sampled. The reach is divided into pool and riffle sub-reaches. One hundred samples are taken from pools and riffles according to their percentage of the total length. For example, if 60 percent of the reach is a riffle and 40 percent is a pool, then 60 samples will be taken from the riffles and 40 from the pools. A cumulative frequency plot of the particle size distribution will provide the D50.

The D50 will provide the following "level II" classification.

	Size Range (mm)
Bedrock = 1	>2,048
Boulder = 2	256-2,048
Cobble = 3	64-256
Gravel = 4	2-64
Sand = 5	0.062-2
Silt/Clay = 6	<0.062

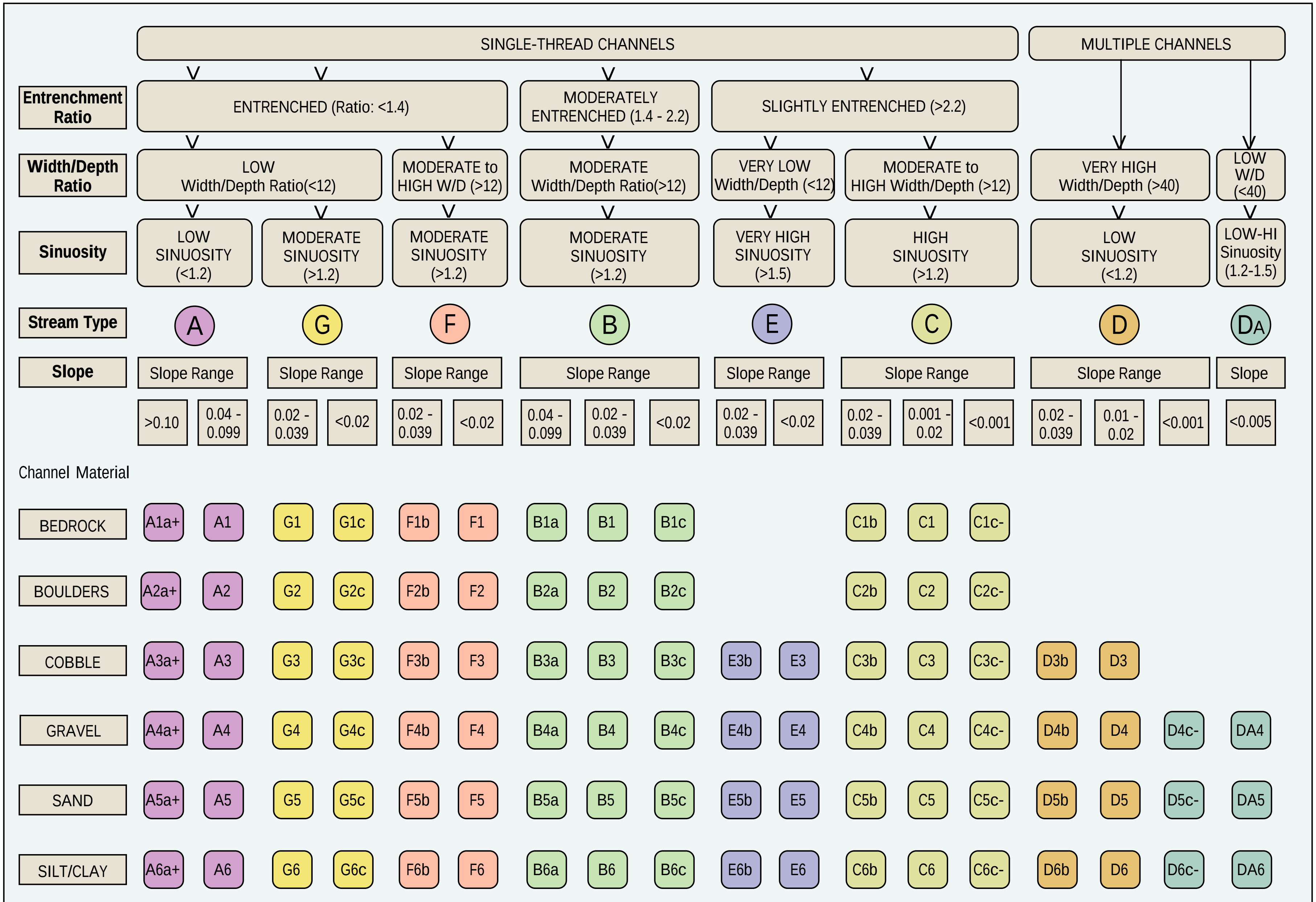


Figure 3. Key to the Rosgen Classification of Natural Rivers. As a function of the "continuum of physical variables" within stream reaches, values of *entrenchment* and *sinuosity* ratios can vary by +/– 0.2 units; while values for width/depth ratios can vary by +/– 2.0 units.

DESCRIPTION OF NORTH CAROLINA STREAM TYPES

Stream Type "A"

Type "A" streams are single thread channels with a width/depth ratio less than 12, meaning they are narrow and moderately deep. They are entrenched, high gradient streams with step/pool bed features. "A" streams with a channel slope greater than 10 percent are classified as "Aa+." "A" streams flow through steep V-shaped valleys, do not have a well-developed floodplain, and are fairly straight.

Basin: Yadkin

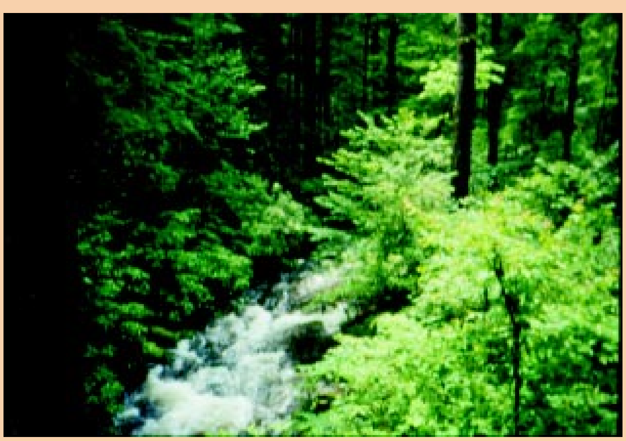
Stream Type: A1

Basin: Yadkin

Stream Type: A1a+

Stream Type "B"

Type "B" streams are wider than "A" streams and have a broader valley but not a well-developed flood plain. These single thread streams are moderately entrenched with moderate to steep slopes. Type "B" streams are often rapid dominated streams with step/pool sequences. Bank heights are typically low. The high width/depth ratios and moderate entrenchment ratios make this stream type quite resilient to moderate watershed changes.



Basin: Little Tennessee

Stream Type: B3

Basin: Catawba

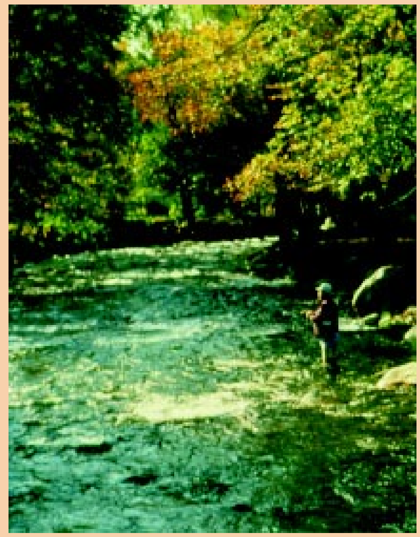
Stream Type: B4c

DESCRIPTION OF NORTH CAROLINA STREAM TYPES (*continued*)

Stream Type "C"

Type "C" streams are riffle/pool streams with a well-developed floodplain, meanders, and point bars. These streams are wide with a width/depth ratio greater than 12. Type "C" streams are moderately entrenched, and therefore, use their floodplain during large storms.

Basin: French Broad
Stream Type: C5



Basin: French Broad
Stream Type: C4

Stream Types "D" and "DA"

Type "D" streams are multi-channel (3 or more) streams. These braided streams are found in well-defined alluvial valleys. Braided channels are characterized by moderate to high bank erosion rates, depositional features such as transverse bars, and frequent shifts in bed forms. The channels are typically on the same gradient as their valley. There are few "D" streams in North Carolina.

The "DA" stream type is a stable braided stream with a low but highly variable width/depth ratio (for braided channels) and low slope (less than 0.5 percent). The DA stream types are found in wide alluvial valleys or deltas exhibiting interconnected channels and an abundance of wetlands. This stream type is often found in the coastal plain of North Carolina.

Basin: Chowan
Stream Type: DA6

Basin: Neuse
Stream Type: DA6

DESCRIPTION OF NORTH CAROLINA STREAM TYPES (*continued*)

Stream Type "E"

For the single thread channels, the "E" stream types are the evolutionary end point for stream morphology and equilibrium. The "E" stream type is slightly entrenched with low width/depth ratios, and moderate to high sinuosities. The bedform features are consistent riffle/pool sequences. Analyses of North Carolina streams determined that many "E" stream types in wide floodplains have been relocated to the edge of the floodplain and straightened. This has resulted in moderate entrenchment ratios and lower sinuosities. Dense vegetation has helped these streams remain as "E" stream types, but they do not function at their biological potential because of disruptions in the riffle/pool sequence. "E" stream types are generally found in wide alluvial valleys, ranging from mountain meadows to the coastal plain.

Basin: Holston (Virginia)
Stream Type: E4

Basin: Neuse
Stream Type: E4

Stream Type "F"

The "F' stream types are deeply entrenched, often meandering streams with a high width/depth ratio (greater than 12). These stream types are typically working to create a new floodplain at a lower elevation and will often evolve into "C" and then "E" stream types. This evolutionary process leads to very high levels of bank erosion, bar development, and sediment transport. The "F" stream types are found in low-relief valleys and gorges.

Basin: Watauga
Stream Type: F4

Basin: Watauga
Stream Type: F4

DESCRIPTION OF NORTH CAROLINA STREAM TYPES (*continued*)

Stream Type "G"

The "G" or gully stream types are similar to the "F" types but with low width/depth ratios. With few exceptions, "G" stream types possess high rates of bank erosion as they try to widen into an "F." "G" stream types are found in a variety of landforms, including meadows, urban areas, and new channels within relic channels.

Basin: Catawba
Stream Type: G5

Basin: Cape Fear
Stream Type: G6

References

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Fact Sheet Number 2

River Course

River Course is a fact sheet series developed to provide information and technologies related to the use of natural channel design in restoring impaired streams.

Application of the **Rosgen Stream Classification System** to North Carolina

nc stream restoration institute

Restoration of impaired streams begins with an understanding of the watershed's current condition and stream potential. Stream classification offers a way to categorize streams based on channel morphology. This fact sheet focuses on a classification system popular with hydrologists, engineers, and biologists—the Rosgen stream classification system.

Stream Classification

The classification of natural streams is not new. Over the past 100 years, there have been about 20 published stream classification systems. The first recognized classification was by Davis in 1899. Davis classified streams in terms of age (youthful, mature, and old age). The classification systems devised between 1899 and1970 were largely qualitative descriptions of stream features and landforms and were difficult to apply universally. In 1994, Rosgen published *A Classification of Natural Rivers*. Because of its usefulness in stream restoration, this classification system has become popular among hydrologists, engineers, geomorphologists, and biologists working to restore the biological function and stability of degraded streams.

Rosgen Stream Classification System

The Rosgen stream classification system categorizes streams based on channel morphology so that consistent, reproducible, and quantitative descriptions can be made. Through field measurements, variations in stream processes are grouped into distinct stream types. Rosgen lists the specific objectives of stream classification as follows:

1. Predict a river's behavior from its appearance.
2. Develop specific hydraulic and sediment relationships for a given stream type.
3. Provide a mechanism to extrapolate site-specific data to stream reaches having similar characteristics.
4. Provide a consistent frame of reference for communicating stream morphology and condition among a variety of disciplines and interested parties.

The Rosgen stream classification consists of four levels of detail ranging from broad qualitative descriptions to detailed quantitative assessments. Figure 1 shows the hierarchy (Levels I through IV) of the Rosgen classification inventory and assessment. Level I is a geomorphic characterization that categorizes streams as "A," "B," "C," "D," "DA," "E," "F," or "G." Level II is called the morphological description and requires field measurements. Level II assigns a number (1 through 6) to each stream type describing the dominant bed material. Level III is an evaluation of the stream condition and it's stability. This requires an assessment and prediction of channel erosion, riparian condition, channel modification, and other characteristics. Level IV is verification of predictions made in Level III and consists of sediment transport, stream flow, and stability measurements.

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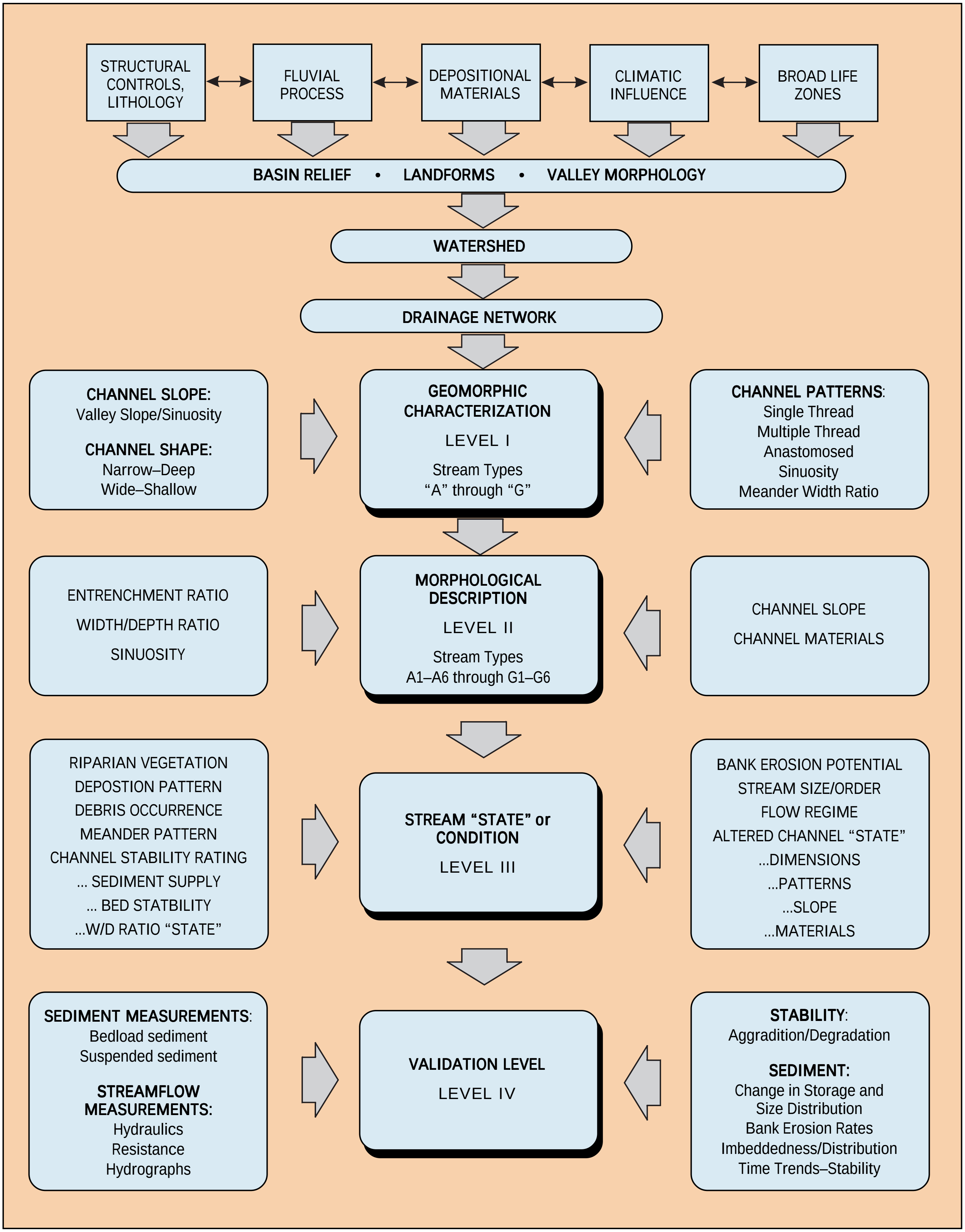
Figure 1. Rosgen Stream Classification Levels.



Bankfull Stage

The width/depth and entrenchment ratios used in the classification are measured at the bankfull stage. By definition, bankfull stage is the elevation of the floodplain adjacent to the active channel. If the stream is entrenched, bankfull stage is identified as a scour line, bench, or top of the point bar. If the stream is not entrenched, then bankfull is near or at the top of the bank. Relationships of bankfull cross sectional area as a function of watershed size help identify bankfull stage in the field. Bankfull stage and natural stream process terminology are further discussed in *River Course 1: Natural Stream Processes*, AG-590-1. Field techniques for identifying bankfull stage are provided in *River Course 3,* AG-590-3.

Application of the Rosgen Stream Classification System

A hierarchical key to the Rosgen stream classification system is shown in Figure 3 on page 4. The criteria and measurements used to classify the stream are discussed below.

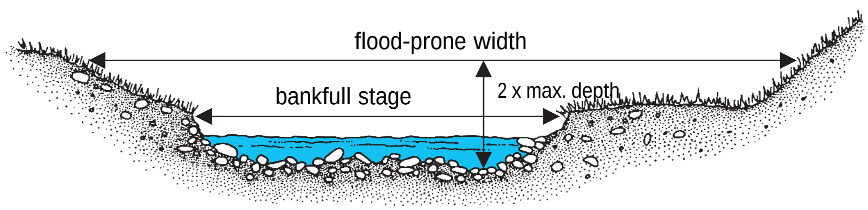


Figure 2. The entrenchment ratio measures the degree of channel incision as the flood-prone width divided by the bankfull width.

Single or Braided Channel Determination — A braided channel consists of three or more distinct channels. Anything less is considered a single channel. The only stream types for braided channels are "D" and "DA." Single or braided channel determination can be made from aerial photograph or field observation.

Entrenchment Ratio —The entrenchment ratio is a field measurement of channel incision. Specifically, it is the flood-prone width divided by the bankfull width. The flood-prone width is measured at the elevation of twice the maximum depth at bankfull. Lower entrenchment ratios indicate channel inclusion. Large entrenchment ratios mean that there is a well-developed floodplain. An example of this measurement is shown in Figure 2. The following stream types are entrenched: "A," "F," and "G."

Width to Depth Ratio —The width to depth ratio is a field measurement of the bankfull width divided by the mean bankfull depth. The break between single channel classifications is 12, meaning that the bankfull width is 12 times greater than the mean bankfull depth. Stream types with width/depth ratios greater than 12 are "B," "C," and "F." Stream types less than 12 are "A," "E," and "G." The "D" stream types have a width/depth ratio greater than 40 and the "DA" stream types are less than 40.

Sinuosity —Sinuosity is a measure of a stream's "crookedness." Specifically, it is the channel length divided by a straight-line valley length. The greater the number, the higher the sinuosity. Sinuosity is related to slope. Natural streams with steep slopes have low sinuosities, and streams with low slopes typically have high sinuosities. Sinuosity can be measured from large scale aerial photographs but should not be measured from 1:24,000 or smaller scale topographic maps.

Water Surface Slope — The water surface slope is a field measurement from the top of a riffle to the top of another riffle at least 20 bankfull widths downstream. This is considered the average slope. "A" and "B" stream types have the steepest slopes and "E" and "DA" stream types have the lowest. However, slope varies greatly among stream types.

Median Size of the Bed Material — A pebble count procedure is used to determine the D50 of the bed material. The D50 is the median particle size, meaning that 50 percent of the material is smaller and 50 percent is larger. A stream reach of 20 bankfull widths is sampled. The reach is divided into pool and riffle sub-reaches. One hundred samples are taken from pools and riffles according to their percentage of the total length. For example, if 60 percent of the reach is a riffle and 40 percent is a pool, then 60 samples will be taken from the riffles and 40 from the pools. A cumulative frequency plot of the particle size distribution will provide the D50.

The D50 will provide the following "level II" classification.

	Size Range (mm)
Bedrock = 1	>2,048
Boulder = 2	256-2,048
Cobble = 3	64-256
Gravel = 4	2-64
Sand = 5	0.062-2
Silt/Clay = 6	<0.062

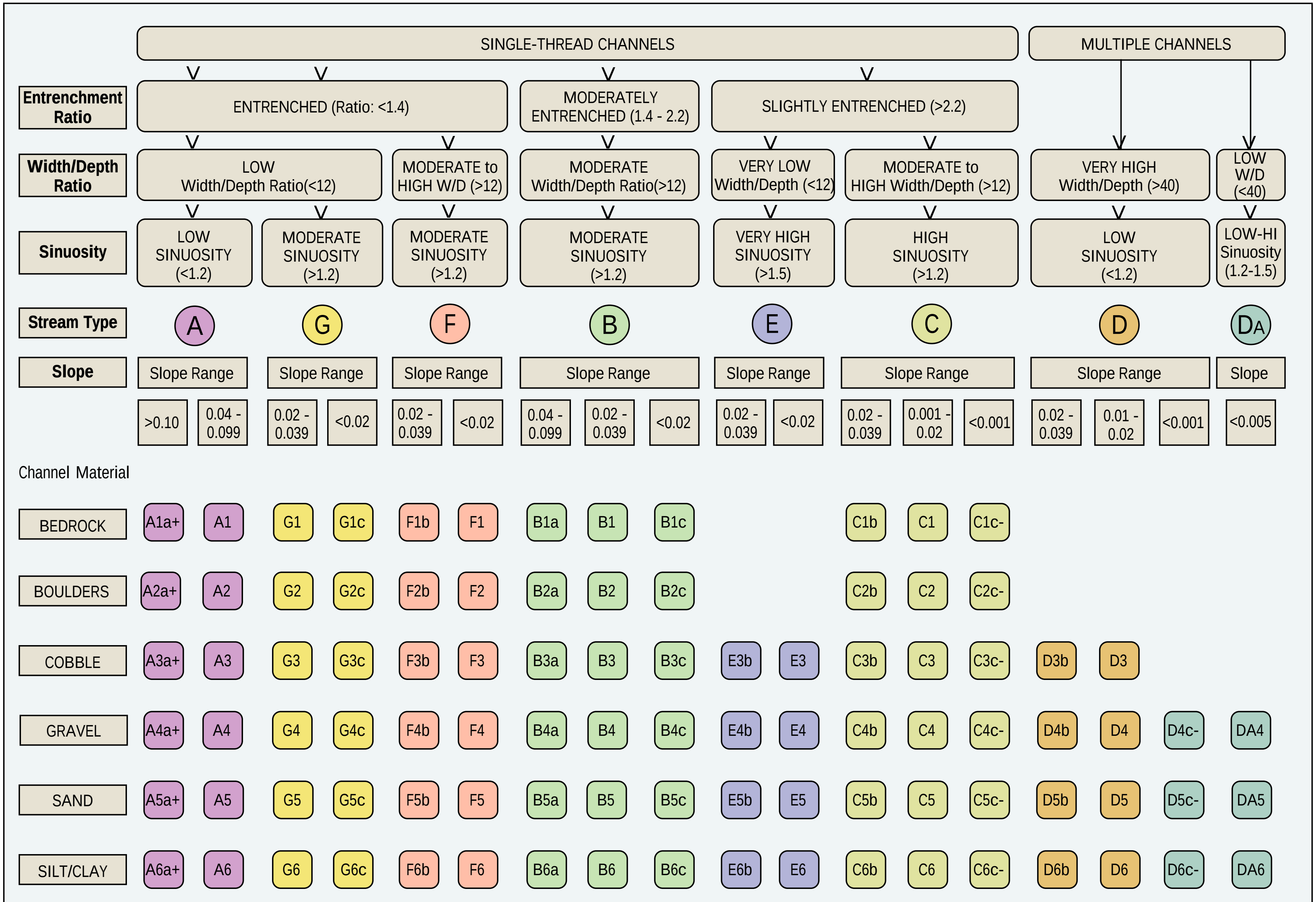


Figure 3. Key to the Rosgen Classification of Natural Rivers. As a function of the "continuum of physical variables" within stream reaches, values of *entrenchment* and *sinuosity* ratios can vary by +/– 0.2 units; while values for width/depth ratios can vary by +/– 2.0 units.

DESCRIPTION OF NORTH CAROLINA STREAM TYPES

Stream Type "A"

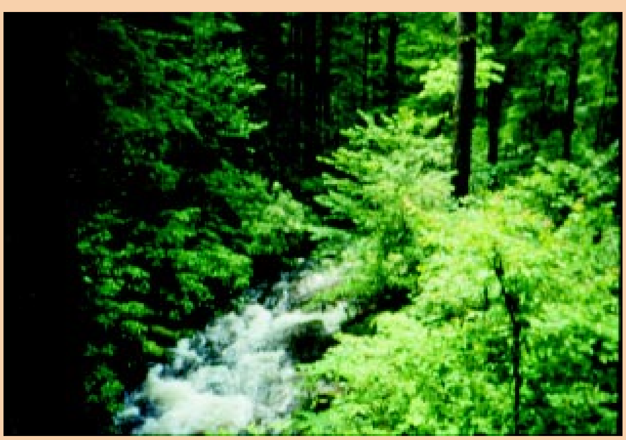
Type "A" streams are single thread channels with a width/depth ratio less than 12, meaning they are narrow and moderately deep. They are entrenched, high gradient streams with step/pool bed features. "A" streams with a channel slope greater than 10 percent are classified as "Aa+." "A" streams flow through steep V-shaped valleys, do not have a well-developed floodplain, and are fairly straight.

Basin: Yadkin
Stream Type: A1

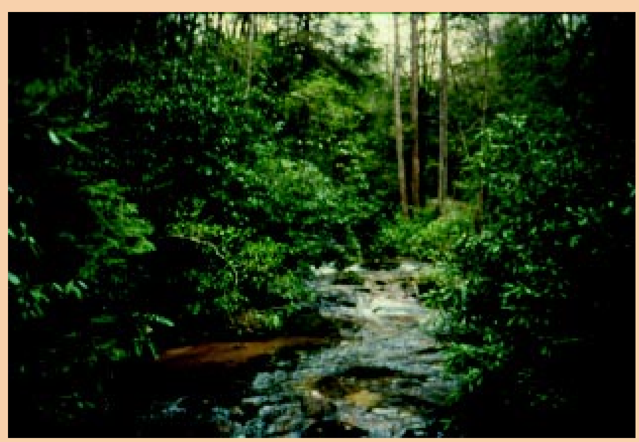
Basin: Yadkin
Stream Type: A1a+

Stream Type "B"

Type "B" streams are wider than "A" streams and have a broader valley but not a well-developed flood plain. These single thread streams are moderately entrenched with moderate to steep slopes. Type "B" streams are often rapid dominated streams with step/pool sequences. Bank heights are typically low. The high width/depth ratios and moderate entrenchment ratios make this stream type quite resilient to moderate watershed changes.



Basin: Little Tennessee
Stream Type: B3



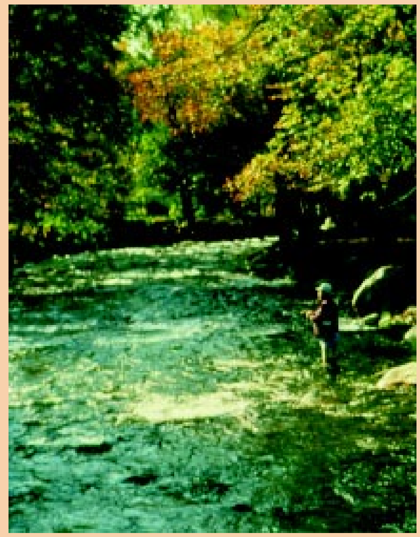
Basin: Catawba
Stream Type: B4c

DESCRIPTION OF NORTH CAROLINA STREAM TYPES (*continued*)

Stream Type "C"

Type "C" streams are riffle/pool streams with a well-developed floodplain, meanders, and point bars. These streams are wide with a width/depth ratio greater than 12. Type "C" streams are moderately entrenched, and therefore, use their floodplain during large storms.

Basin: French Broad
Stream Type: C5



Basin: French Broad
Stream Type: C4

Stream Types "D" and "DA"

Type "D" streams are multi-channel (3 or more) streams. These braided streams are found in well-defined alluvial valleys. Braided channels are characterized by moderate to high bank erosion rates, depositional features such as transverse bars, and frequent shifts in bed forms. The channels are typically on the same gradient as their valley. There are few "D" streams in North Carolina.

The **"DA" stream** type is a stable braided stream with a low but highly variable width/depth ratio (for braided channels) and low slope (less than 0.5 percent). The DA stream types are found in wide alluvial valleys or deltas exhibiting interconnected channels and an abundance of wetlands. This stream type is often found in the coastal plain of North Carolina.

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Stream Type: DA6

Basin: Neuse
Stream Type: DA6

DESCRIPTION OF NORTH CAROLINA STREAM TYPES (*continued*)

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For the single thread channels, the "E" stream types are the evolutionary end point for stream morphology and equilibrium. The "E" stream type is slightly entrenched with low width/depth ratios, and moderate to high sinuosities. The bedform features are consistent riffle/pool sequences. Analyses of North Carolina streams determined that many "E" stream types in wide floodplains have been relocated to the edge of the floodplain and straightened. This has resulted in moderate entrenchment ratios and lower sinuosities. Dense vegetation has helped these streams remain as "E" stream types, but they do not function at their biological potential because of disruptions in the riffle/pool sequence. "E" stream types are generally found in wide alluvial valleys, ranging from mountain meadows to the coastal plain.

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Stream Type: E4

Basin: Neuse

Stream Type: E4

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Basin: Watauga

Stream Type: F4

Basin: Watauga

Stream Type: F4

DESCRIPTION OF NORTH CAROLINA STREAM TYPES (*continued*)

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Basin: Catawba
Stream Type: G5

Basin: Cape Fear
Stream Type: G6

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