NCDOT Guidelines for Drainage Studies and Hydraulic Design

Contents

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1 INTRODUCTION

The 2016 version of the *Guidelines for Drainage Studies and Hydraulic Design,* hereinafter referred to as the "*Guidelines",* is the result of consolidation of the 1999 version of the *Guidelines* and the 1973 *Handbook of Design for Highway Drainage.* It provides design engineers (in-house and consultants) with new guidance to meet emerging environmental, regulatory and design challenges. It includes design policies, procedures, methods, forms, and tools needed to develop the hydrologic and hydraulic designs for NCDOT projects.

This document includes major changes and additions below:

- Legal Aspects, Policies, and Practices in Highway Drainage (revised)
- Preliminary Hydraulic Studies for Planning Document (new)
- Hydrology (revised)
- Stormwater Management (revised)
- Bridge Scour (new)
- Permit Drawings (revised)
- Floodplain Management (new)
- Table of Contents and References (revised)
- Electronic version (single PDF) with internal and external links (new)

It is the responsibility of the design engineer to verify survey and engineering data that are provided by others before using these data in developing the hydraulic design. The responsible engineer is required to affix his or her professional engineering seal to the following documents and reports:

- Construction Plans
- Bridge Survey and Hydraulic Design Report
- Culvert Survey and Hydraulic Design Report
- Hydraulic Design Documentation Summary (Appendix A)
- FEMA documentation:
    - No-rise Certification
    - MT-2 Form
    - As-built Plans Certification Form

Commented [JS1]: Since As-built Plans can be certified by PLS, should not include in list for PE seal required. Since As-Built Certification form requires engineer to certify As-Built plans, they must be sealed by PE or CLS.

This document is not intended to be comprehensive on the practice of hydraulic engineering. The design engineer may reference other materials and should exercise sound engineering judgment in its application to ensure that the design is complete and appropriate. The design engineer is recommended to reference the AASHTO 2007 *Highway Drainage Guidelines* (1) and 2014 *Drainage Manual* (2) for the practice of hydraulic engineering.

The design engineer should follow all policies, specified methods, procedures and tools outlined in this document in developing the drainage plans. However, the design engineer may request approval for variance from the State Hydraulics Engineer for alternative designs.

This document is being published in both hardcopy and electronic (PDF) formats. The electronic version of this document can be accessed and downloaded from the Hydraulics Unit website. The hardcopy version is available for purchase from NCDOT Publications. (See information at https://connect.ncdot.gov/letting/pages/order-publications.aspx.)

A supplementary errata section will be included at the beginning of the electronic version of this document to track minor error corrections, new rules, changes to forms, addenda, etc. which will be rectified in future editions of this publication. To maintain consistency between the hardcopy and electronic versions, no actual changes will be made to the electronic version of the document until such time as a new edition is published. Any updates to forms, appendix items, or addenda will be referenced in the errata section and posted on the Hydraulics Unit website until they are incorporated into a new edition. New editions incorporating full review, update, and incorporation of all revisions and addenda will be issued on a five year cycle and will be coordinated through the FHWA Division Office by the State Hydraulics Engineer.

2 LEGAL ASPECTS, POLICIES, AND PRACTICES IN HIGHWAY DRAINAGE

2.1 Introduction

The purpose of this chapter is twofold:

1. Summarize the relevant federal and state laws which govern NCDOT highway drainage design.
2. Discuss general NCDOT policies and practices pertinent to typical highway drainage designs.

2.2 Federal Laws

2.2.1 Clean Water Act

In 1977, the U. S. Congress amended the Federal Water Pollution Control Act (FWPCA) to regulate the discharge of pollution into waters of the U.S. and it was officially designated the *Clean Water Act*, 33 USC 1344 (CWA) (33). It serves as the cornerstone of federal law for all water quality programs. It directs the Environmental Protection Agency (EPA) and other regulatory agencies to establish standards of water quality for states to follow.

Section 401 of the CWA states that no federal permit or license can be issued that may result in a discharge to waters of the United States unless the State certifies that the discharge is consistent with standards and other water quality goals, or waives certification.

Section 404 of the CWA prohibits the unauthorized discharge of dredged or fill material into waters of the United States, including navigable waters. Such discharges require a permit. The United States Army Corps of Engineers (USACE) has granted Nationwide General Permits for several categories of certain minor activities involving discharge of fill material. Under the provisions of 33 CFR 330.5(a)(15), fill associated with construction of bridges across navigable waters of the United States, including cofferdams, abutments, foundation seals, piers, temporary construction, and access fills, are authorized under the Nationwide Section 404 Permit. Section 404 also requires any federal permit applicant to obtain a Section 401 water quality certification from the appropriate state regulatory agency if the proposed activity may affect the quality of waters of the United States (2).

2.2.2 National Pollutant Discharge Elimination System

In 1987, Congress passed an amendment to the Clean Water Act which added stormwater permits to the National Pollutant Discharge Elimination System (NPDES) program under Section 402. Section 319, which addresses nonpoint source pollution, requires each state to better integrate the Coastal Nonpoint Program and the Statewide Nonpoint Program. In 1997, the NC Legislature passed House Bill 515, which initiated development of a statewide stormwater permit under the National Pollutant Discharge Elimination System (NPDES).

NCDOT was the first statewide agency in the nation to be issued an individual statewide transportation NPDES Stormwater Permit (NCS000250) on June 8, 1998 by the United States Environmental Protection Agency (EPA) through NC Department of Environment and Natural Resources (DENR), which is now NC Department of Environmental Quality (DEQ). This permit is jointly managed by the Hydraulics and Roadside Environmental Units. Requirements contained in the permit address a broad range of NCDOT activities, including the following programs:

- Illicit Discharge Detection and Elimination
- Stormwater System Inventory and Prioritization
- Best Management Practices (BMP) Retrofit
- BMP Toolbox for Post-Construction Runoff
- BMP Inspection and Maintenance
- Post-Construction Runoff Control
- Vegetation Management
- Construction
- Industrial Activities
- Education and Involvement
- Research
- Total Maximum Daily Load (TMDL)

For more details, please see discussion in Chapter 13.

2.2.3 National Environmental Policy Act

The National Environmental Policy Act of 1969 (NEPA) (42 U.S.C. 4321–4347) Section 102 requires that all Federal agencies shall ensure that environmental amenities and value be given appropriate consideration in decision making, along with economic and technical considerations (1).

For Federal Aid projects, NCDOT is required to comply with Federal Highway Administration (FHWA) regulations, which are tailored for linear transportation projects and are consistent with NEPA implementation. NCDOT signed an Interagency Agreement in 1977 with the FHWA and the U.S. Army Corps of Engineers (USACE), which integrated Section 404 permit requirements with the NEPA process, constituting the original Merger Process for transportation projects in North Carolina (37). This process, modified most recently in a 2012 Memorandum of Understanding, serves to streamline the project development and permitting processes (67). More information on the Merger Process is provided in Chapter 3, Section 3.3. FHWA guidance on NEPA implementation is provided at https://www.environment.fhwa.dot.gov/projdev/pd2implement.asp.

2.2.4 Executive Order 13653

Executive Order 13653, issued November 1, 2013, requires federal agencies to prepare the nation for the impacts of climate change by promoting (1) engaged and strong partnerships as well as information sharing at all levels of government, (2) risk-informed decision making, (3) adaptive learning, and (4) preparedness planning. Subsequently, FHWA issued Order 5520 on December 15, 2014, to establish policy on preparedness and resilience to climate change and extreme weather events. In this directive, climate change refers to any significant change in the measures of climate, such as temperature, precipitation, wind patterns, etc. lasting for an extended period of time. Changes in climate may manifest as a rise in sea level, as well as increase the frequency and magnitude of extreme weather events (75).

2.2.5 National Flood Insurance Program

The National Flood Insurance Program (NFIP) was established by the National Flood Insurance Act of 1968 (36). NFIP requirements could impose restrictions on the construction of highways in floodplains and floodways in communities that have qualified for flood insurance. It is possible to comply with the federal requirements regarding the encroachment of a highway on a floodplain and still be faced with future legal liabilities because of the impact of the highway on the floodplain and the stream (1). Hydraulics engineers should review the potential for these future liabilities to ensure that they are properly addressed in the development of the proposed hydraulic design. Regulations pertaining to federal flood insurance are contained in 44 CFR 59-80, National Flood Insurance Policy (29).

For information on floodplain management, see Chapter 15.

2.2.5.1 Executive Order 11988

Executive Order 11988, issued in 1977, requires federal agencies to avoid to the extent possible the long and short-term adverse impacts associated with the occupancy and modification of floodplains and to avoid direct and indirect support of floodplain development wherever there is a practicable alternative (31, 32).

2.2.5.2 Executive Order 13690

Executive Order 13690, issued January 30, 2015 amends Executive Order 11988 by establishing a Federal Flood Risk Management Standard, a flexible framework to increase resilience against flooding and help preserve the natural value of floodplains, as part of a national policy on resilience and risk reduction consistent with President Barack Obama's *Climate Action Plan*. (73, 74)

2.2.5.3 Guidance from FHWA

In June 1982, the Federal Highway Administration (FHWA) and the Federal Emergency Management Agency (FEMA) established a Memorandum of Understanding regarding a procedural document entitled "Procedures for Coordinating Highway Encroachments on Floodplains with the Federal Emergency Management Agency". This and additional documentation has subsequently been formally issued in Non-regulatory Supplements 1-3 for Part 650, Subpart A of Title 23 CFR in the Federal Aid Policy Guide (FAPG) (8). These supplements discuss, among other things, recommendations regarding state agencies' and municipalities' responsibility for proposed storm drain installations, design standards for floodplain encroachments, and coordinating proposed highway encroachments on floodplains with FEMA to ensure regulatory compliance. It should be emphasized that Federal Aid projects are required to be in compliance with FHWA regulations or orders, while being consistent with FEMA requirements (including Executive Orders). FHWA regulation applies to all Federal Aid actions in a base floodplain (not just FEMA-regulated floodplains). Detailed guidance on FEMA National Flood Insurance Program compliance as it pertains to specific NCDOT drainage practices is provided in Chapter 15 of these *Guidelines* and in other chapters, as applicable (30).

2.2.5.4 FEMA Hazard Mitigation Grant Program Properties Impacts

Another important FEMA issue of concern relative to highway projects is impact to Hazard Mitigation Grant Program (HMGP) properties (a.k.a. FEMA buyout properties), which may exist pursuant to acquisition under authorization of Section 404 of the Robert T. Stafford Disaster Relief and Emergency Assistance Act, as amended (the Stafford Act), Title 42, United States Code (U.S.C.) 5170c. The Stafford Act requires that such property acquisitions comply with 44 CFR Part 80 FEMA Property Acquisition and Relocation for Open Space. As such, ownership of the acquired property is transferred to the local community government or eligible conservation organization to be maintained for open space purposes in perpetuity in order to restore and/or conserve the natural floodplain functions. Deed restrictions are placed on the property, which prohibit, among other things:

- Addition of any new pavement for roads, highways, bridges and paved parking areas (including asphalt, concrete, oil-treated soil, or other material that inhibits floodplain functions).
- Placement of fill, except where necessary to avoid affecting onsite archeological resources.

Reuse of existing paved surfaces for recreational uses on the acquired property consistent with allowable uses is generally acceptable.

In the development of design alternatives for consideration for a given highway project, it is therefore imperative that HMGP properties be identified early in the planning stage so that every effort can be made to avoid impacts. Identification of HMGP properties and determination of the applicable restrictions associated with them should be coordinated through the NC Department of Public Safety, Division of Emergency Management, Hazard Mitigation Section. Further details regarding HMGP properties are discussed in the FEMA publication *Hazard Mitigation Assistance Guidance; Hazard Mitigation Grant Program, Pre-Disaster Mitigation Program, and Flood Mitigation Assistance Program* (February 27, 2015) (46).

2.3 State Laws and Programs

2.3.1 State Environmental Policy Act

Under the State Environmental Policy Act of 1971 (SEPA) [G.S. 113A, Article 1], State agencies are required to review and report on a proposed project's environmental effect in the form of either an Environmental Assessment (EA) or an Environmental Impact Statement (EIS) document unless the project is covered by minimum criteria. These documents are meant to disclose the direct, secondary, cumulative, long-range, and short-term impacts of the proposed project. An EA is prepared if the project is not anticipated to produce significant adverse environmental impacts, if the impacts can be mitigated to a non-significant level, or if the magnitude of impacts is uncertain. If the project's impacts will be significant or not able to be fully mitigated, an EIS should be prepared. An EIS will provide a more extensive evaluation of the advantages and disadvantages of project alternatives and is written in greater detail than an EA (38).

2.3.2 Coastal Area Management Act

In 1974, the General Assembly passed the Coastal Area Management Act (CAMA) [G.S. 113A, Article 7] to balance economic development and environmental protection in North Carolina’s twenty coastal counties. These counties are subject to the rules and policies of the Coastal Resources Commission (CRC), which administers CAMA regulatory compliance. The Division of Coastal Management (DCM), a division of NCDEQ (formerly NCDENR), serves as staff to the CRC and works to protect, conserve and manage North Carolina's coastal resources through an integrated program of planning, permitting, education and research pursuant to CRC rules and policies.

Areas of Environmental Concern (AEC) are the foundation of the CRC's permitting program for coastal development. An AEC is an area of natural importance: It may be easily destroyed by erosion or flooding; or it may have environmental, social, economic or aesthetic values that make it valuable to our state (39).

The CRC classifies areas as AECs to protect them from uncontrolled development, which may cause irreversible damage to property, public health or the environment. AECs cover almost all coastal waters and about 3 percent of the land in the 20 coastal counties.

The CRC has established four categories of AECs:

- The Estuarine and Ocean System
- The Ocean Hazard System
- Public Water Supplies
- Natural and Cultural Resource Areas.

2.3.3 NC Water Supply Watershed Protection Act

In 1989, the Water Supply Watershed Protection Act was passed by the State Legislature (G.S. 143-214.5) to protect drinking water supplies. It directed the Environmental Management Commission (EMC) to adopt minimum statewide water supply protection standards and implement water quality protection programs (40). It also required classification of the waters of the State based on their quality and significance to the municipalities (41).

2.3.4 Stormwater Management Rules

State highway (NCDOT) development projects are permitted based on a case by case evaluation of each individual project, which are considered to be covered under 15A NCAC 02H .1003, subparagraph (d)(3)(C) "Other Projects", which states: *"otherwise meets the provisions of this Section and has water dependent structures, public roads and public bridges which minimize built-upon surfaces, divert stormwater away from surface waters as much as possible and employ other best management practices to minimize water quality impacts."* Notable among these are the criteria that have been established for determining locations where hazardous spill protection measures must be provided to protect critical water supply watershed areas (see Appendix O). Furthermore, NCDOT is regulated under a separate NPDES Stormwater Permit (see 2.2.2), which covers all NCDOT activities statewide.

2.3.5 Riparian Buffer Rules

Beginning in 1999, EMC adopted Riparian Buffer Rules (G.S. 143-214.20-26; 15A NCAC 02B) to protect existing riparian buffers on nutrient sensitive waters (NSW) and certain water supply watersheds (42). See Chapter 13 Stormwater Management for additional discussion.

2.3.6 State Sedimentation Pollution Control Act

The State Sedimentation Pollution Control Act was adopted in 1973. This promulgated rules and regulations to control accelerated erosion and sedimentation resulting from land disturbing activities. The Department of Transportation has been delegated the authority to administer an erosion and sedimentation control program within the Department. NCDOT's Roadside Environmental Unit is primarily responsible for development of the erosion and sedimentation control plans for state highway projects. Guidance regarding culvert construction phasing considerations with respect to hydraulic design is provided in Chapter 12 of these guidelines.

2.3.7 State Floodplain Management Policy

Governor James G. Martin issued State Executive Order 123 in July 1990 requiring all state agencies to follow a uniform floodplain management policy and providing guidance for compliance with federal regulations (59). Section 3 of the EO states:

> *The Department of Administration shall administer a Uniform Floodplain Management Policy for State Agencies. By agreement between the Department of Transportation and the Department of Administration, the Department of Transportation shall work directly with the Federal Department of Transportation and the Federal Emergency Management Agency to apply appropriate standards and management to comply with the Floodplain Management Policy relevant to highway construction within floodplains.*

This Executive Order provides the legal basis for NCDOT to enter into a Memorandum of Agreement with the NC Floodplain Mapping Program, as discussed in Chapter 15 (58).

2.3.8 Reasonable Use Rule

North Carolina long adhered to the Civil Law Rule in regard to surface water drainage. This rule obligates owners of lower land to receive the natural flow of surface water from higher lands. It subjects a landowner to liability whenever he or she interferes with the natural flow of surface waters to the detriment of another in the use and enjoyment of his or her land. Since almost any use of land involves some change in drainage and water flow, a strict application of the civil law principles was impracticable in a developing society. Thus, a more moderate application of this rule to allow a landowner reasonable use of his or her property evolved.

In 1977, the North Carolina Supreme Court formally adopted the Rule of Reasonable Use with respect to surface water drainage and abandoned the Civil Law Rule (Pendergrast v. Aiken, 236 S.E.2d 787, 293 N.C. 201). The adopted Reasonable Use Rule allows each landowner to make reasonable use of his or her land even though by doing so, he or she alters in some way the flow of surface water thereby harming other landowners, with liability being incurred only when this harmful interference is found to be unreasonable and causing substantial damage. There are still some unanswered questions in the application of the adopted Reasonable Use Rule to specific areas of state agency activities. However, this rule is more compatible with and adaptable to the realities of modern life and will provide just, fair and consistent treatment. Therefore, NCDOT general drainage policies and practices follow this rule.

The Reasonable Use Rule places responsibility on the landowner to make reasonable use of his or her land. While "reasonable use" is open for interpretation on a case by case basis, the implication for highway drainage is that provisions for, and treatments of, surface waters on properties are to be made in accordance with sound, reasonable, and acceptable engineering practices. Therefore, it is incumbent on engineers to evaluate the potential effects of surface water activities on both upstream and downstream properties and to include provisions in their design to hold these effects to reasonable levels.

2.4 General Drainage Policies and Practices

2.4.1 Augmentation or Acceleration of Peak Rate of Flow

Development of property can cause an increase in the quantity and peak rate of flow by increasing impervious areas and providing more hydraulically efficient channels and overland flow. It is NCDOT policy to develop and make reasonable use of its lands and rights-of-way through sound, reasonable and acceptable engineering practices and to deny responsibility for effects of augmented or accelerated flow caused by its improvements unless determined to cause unreasonable and substantial damages. Likewise, it is NCDOT policy to expect the same practice and acceptance of responsibility of owners and developers of properties adjacent to state highways.

2.4.2 Diversions

Diversions are defined as the act of altering the path of surface waters from one drainage outlet to another. It is NCDOT policy to design and maintain its road systems, so that no diversions are created thereby, insofar as is practicable from sound engineering practice. Anyone desiring to create a diversion into any highway rights-of-way shall not be allowed to do so unless written permission is obtained from the State Hydraulics Engineer. Permission will be granted only after it has been determined that:

- the additional flow can be properly accommodated without causing damage to the highway,
- the cost for any required adjustments to the highway system will be borne by the requester, and
- appropriate consideration and measures have been taken to indemnify and save harmless NCDOT from potential downstream damage claims.

It is NCDOT policy not to become a party to diversions unless refusal would create a considerable and real hardship to the requesting party.

2.4.3 Improvements and Maintenance of Drainage within the Right-of-Way

Drainage structures and ditches shall be maintained such that they do not present an unreasonable level of damage potential for the highway or adjacent properties.

Where the elevation of the flow line of an existing culvert under a highway is not low enough to adequately provide for natural drainage, NCDOT will assume full responsibility for lowering the culvert or otherwise providing needed improvement.

Where a requested culvert invert adjustment is a result of a property owner lowering the flow line of the inlet and outlet ditch in order to improve drainage of his or her property, the following considerations shall be given to the action taken:

- The lowered culvert must have a reasonable expectancy of being functional and maintainable.
- NCDOT participation (up to full cost) must be based on benefit gained by the roadway drainage system as a result of the lowering.
- Where the new installation is of doubtful, or no benefit to highway drainage, the requesting party must bear the entire cost of installation.

Where the size of an existing highway culvert is inadequate as a result of a general overall development of the watershed, it is NCDOT's responsibility to replace the structure or otherwise take appropriate action.

Where such a culvert's inadequacy is the result of a single action or development, it is considered "unreasonable and substantially damaging" under the State's adopted drainage ruling (see 2.3.8). Therefore, the party responsible for the action or development should bear the cost of replacement.

Where a new culvert crossing is requested, if the culvert is required for proper highway drainage or sufficient benefits to the highway drainage system would occur, the full cost will be borne by NCDOT providing there is no diversion of flow involved. Where the new installation is of doubtful or no benefit to highway drainage, the property owner will bear the entire cost. When both parties receive benefit, a joint effort may be negotiated.

Established culvert crossings will be maintained. Requests to eliminate any culvert will require approval of the State Hydraulics Engineer.

When new private drives for single-family residential property are constructed entering the highway, the property owner can furnish, delivered to the site, the amount, type and size pipe designated by NCDOT, to be installed by maintenance forces. This is not applicable for commercial property. For additional guidance on this matter, refer to NCDOT's *Policy on Street and Driveway Access to North Carolina Highways* (60).

No alteration, attachment, extension, nor addition of appurtenance to any culvert shall be allowed on highway rights-of-way without written permission from the State Hydraulics Engineer.

2.4.4 Improvements and Maintenance of Drainage outside the Right-of-Way

While it is the responsibility of NCDOT to provide adequate drainage for constructing and maintaining the State Highway System, it is not its policy nor responsibility to provide improved drainage for the general area traversed by such roads, unless incidental to the drainage of the road or highway itself. Drainage involvement outside the highway rights-of-way is limited to two general areas of justification:

- Sufficient benefit could be gained by such action to warrant the cost. These benefits would be in such areas as reduction in roadway flood frequency or extent, facilitation of maintenance, or a reduction in potential damages.
- Work is required to correct a problem or condition created by some action of NCDOT.

It is not the responsibility of NCDOT to eliminate flooding on private property that is not attributable to acts of the agency or its representative.

In general, outlet ditches will be maintained for a sufficient distance downstream to provide adequate drainage for the highway facility. On large outlets serving considerable areas outside the right-of-way, the maintenance should be done on a cooperative basis, with the benefited properties bearing their proportionate share. Shares will, in general, be based on proportioning of runoff from the areas served by the outlet.

It is not the policy of NCDOT to pipe inlet or outlet drains, natural or artificial, outside the right-of-way, which existed as open drains prior to existence of the highway. Where the property owner wishes to enclose an inlet or outlet, NCDOT may install the pipe adjacent to the right-of-way if justified by reason of reduced maintenance, safety or aesthetics if the pipe is furnished at the site by the property owner. This does not apply to the development of commercial property.

2.4.5 Obstructions

It is the policy of NCDOT that when a drain is blocked downstream of the highway, which is detrimental to highway drainage, if from natural causes, NCDOT will take necessary measures to remove the blockage or obstruction. Where the blockage is caused by wrongful acts of others, it is the policy of NCDOT to take whatever recourse deemed advisable and necessary to cause the party responsible to remove the blockage. Where a blockage occurs downstream of a highway, whether natural or artificial, and is of no consequence to NCDOT, it is the policy to remain neutral in causing its removal.

State Statute (G. S. 136-92) provides that anyone obstructing any drains along or leading from any public road is guilty of a misdemeanor.

2.4.6 Drainage Easements

It is generally preferable that any structural feature such as a drop inlet, catch basin, or pipe end be contained within a permanent easement. Where runoff is discharged from the right-of-way at a point where there is no natural drain or existing ditch, a permanent drainage easement is required to allow construction of a ditch or channel to convey the discharge to an acceptable natural outlet. Where permanent easements are required, sufficient information will be obtained, so that the limits, grade, and cross section may be determined. The easement shall be of sufficient size to contain the spoil and provide working room for equipment.

When the discharge is into a natural drain or existing ditch and the increase in flow would exceed the capacity or otherwise create a problem, a temporary drainage easement can be obtained to allow enlarging or otherwise improving the drain to a point where the increased discharge will not cause damage.

Where diversion of water is made to a natural drain or existing ditch which could increase the discharge considerably above its capacity, an easement is required to enlarge and improve the drain to a point where the increased discharge can be released without causing damage.

Where improvement to an existing drain is required for proper drainage and not covered in the paragraph above, a permanent drainage easement is not required. Even though the drain may be enlarged and deepened, if the property owner is informed of what is to be done and agrees in writing to allow entry onto his or her property for this work, it is all that is required. This should not be construed to mean that in all cases of this nature that only a permit of entry should be obtained. There will be instances where a permanent easement is desirable.

2.4.7 Dams and Impoundments

It is the policy of NCDOT to discourage the location of roadways on dams due to the increase in potential for long term maintenance and replacement cost. In those instances where a defined advantage may be gained or a substantial savings in funds may be realized, the use of a dam for a roadway may be considered.

Where it is determined that a dam will be utilized as a roadway the following criteria must be met:

- It must have approval certification from NCDEQ (formerly NCDENR) pursuant to the State Dam Safety Law of 1967 (G.S. 143-215.23-37), when applicable.
- All pertinent data regarding the design of the embankment and impoundment structure must be presented to NCDOT for review.
- Top section of the dam must be equal to the approach roadway section width (shoulder to shoulder) plus a minimum of 4 feet.
- At a minimum, guardrail will be required on the impoundment side of the roadway.
- The spillway will be designed to provide a minimum freeboard at the roadway shoulder of 2 feet for a 50-year impoundment level.
- Means of draining the lake completely will be provided.

Design acceptance or approval by NCDOT is limited to the use of the dam as a roadway only, and is in no way intended as approval of the embankment as an impoundment structure.

When a section of roadway that also serves as a dam is accepted, responsibility incurred by NCDOT is limited to maintenance of the roadway for highway purposes from shoulder to shoulder only. Responsibility for the impoundment, any damage that may result therefrom, and maintenance of the embankment or appurtenances as may be required to preserve its integrity as an impoundment structure shall remain with the owner of the impoundment. Any maintenance work will be subject to the provisions of G.S. 136-93.

Impoundment of water on highway rights-of-way may be allowed under the following criteria:

- The impoundment does not adversely affect the rights-of-way for highway purposes.
- Adjustments as required (e.g. flattening slopes, rip rap slope protection, structure modifications, etc.) shall be the responsibility of the encroaching party.
- Provision shall be made for draining the impoundment to facilitate highway maintenance.

2.4.8Subdivision Streets

When roads and streets built by others are accepted onto the State Highway System for maintenance, responsibility for the drainage system, discharge pattern and outlet locations is to maintain them as they exist at the time of acceptance and is limited to the rights-of-way. In general, stormwater treatment facilities should be located outside of the dedicated rights-of-way.

Information on design, review and approval requirements is provided in the NCDOT publication *Subdivision Roads Minimum Construction Standards* (3).

When accepting streets for maintenance, where drainage review is required by Hydraulics Unit, the following information should be furnished for the review:

- Street layout and grades, and if applicable, include proposed catch basins, manholes, stormwater treatment facilities, etc. along with grades (top and invert elevations) of the storm drain system
- Typical Section

- Contour map (if available)
- Pipe sizes and grades
- Drainage areas at each pipe or inlet
- Inlet computations showing gutter spread and bypass for curb and gutter systems.
- Proposed easements
- Vicinity map

The above information should be submitted prior to the beginning of construction of the subdivision, so that if any changes are recommended, these could be incorporated in the original construction, rather than having to make post-construction adjustments.

Where storm drain systems are used, the minimum design for the collector system should be for the 10-year storm frequency; however, for cross-drainage, design for the appropriate storm frequency for the functional classification of the highway facility (usually 25-year or 50-year) should be achieved.

Where roads and streets built by others now exist on the system, NCDOT's responsibility for the drainage system installed by the developer does not extend beyond the right-of-way or easement limits accepted by NCDOT. The acceptance of the streets onto the State Highway System does not include drainage easements outside the right-of-way unless specifically stated that those easements so designated by NCDOT are included in the acceptance.

Where requests for additions to the system arise on roads and streets built by others, the requests shall not be granted until the drainage installations have been inspected and approved by a representative of NCDOT. The representative shall be the Division Engineer or appointed delegate. If desired, or if special treatment is needed, a review by the Hydraulics Unit should be requested. If structures other than pipe installations are included, they shall be approved by the State Hydraulics Engineer.

2.4.9 Adjustments to Pipe Culverts

No alteration, extension nor addition of appurtenance to any pipe culvert shall be allowed on highway right-of-way without the written consent of the Division Engineer or his or her authorized representative.

All requests for alteration, extension or addition of appurtenance to any pipe culvert shall be made in writing to the Division Engineer. Prints shall be furnished showing the location and detail of the proposed work. The print shall include arrows indicating the direction of flow, and approximate acreage drained by the pipe and size and type of the existing pipe. If appurtenances are involved, the type of construction shall be shown. The approximate depth from inlet rim to invert shall be shown when catch basins or drop inlets are proposed. Where only minor drainage alterations are involved, the Division Engineer will have authority to approve the encroachment. If other than minor drainage alterations are involved, the Division Engineer shall provide a drawing and recommendations to the Hydraulics Unit for review and approval. Upon approval by the State Hydraulics Engineer, the request shall be returned to the Division Engineer for preparation and execution of the Encroachment Contract. Any request for alteration to pipe culverts may be submitted to the State Hydraulics Engineer, if the Division Engineer deems it appropriate.

2.4.10 Adjustments to Box Culverts

No alterations of, nor additions to any box culvert on the highway system shall be allowed without written permission from the State Hydraulics Engineer.

All requests for alteration of, or additions to, box culverts shall be made in writing to the Division Engineer. Prints shall be furnished showing in detail the location and nature of the proposed work. The prints shall show sufficient detail such that they may be used as construction drawings. The proposed alteration shall be accomplished within the parameters of good engineering construction and hydraulic design. The Division Engineer shall forward one of these drawings to the State Hydraulics Engineer, with his or her recommendations. After any required revisions and upon approval of the plans by the State Hydraulics Engineer, the request shall be returned to the Division Engineer for preparation and execution of the Encroachment Contract.

2.4.11 Highway Drainage within the Railroad Right-of-Way

When a highway project involves drainage work at a railroad crossing within or adjacent to a railroad right-of-way, every effort should be made to avoid adverse impacts to the railroad, its drainage facilities, and right-of-way. If the impacts to a railroad are unavoidable, any activity within the railroad right-of-way must be coordinated with the owner of the railroad. Resources within NCDOT which may be consulted regarding railroad coordination include the Rail Division and the local Highway Division offices. Railroad companies CSX Transportation and Norfolk Southern Corporation, provide specific guidance regarding their requirements for activities involving culverts and pipelines within their rights-of-way. This guidance is available online for viewing and downloading (see refs. 51 & 52). For new highway bridges over railroads, deck drains should not discharge directly over the railroad tracks.

2.4.12 Stormwater BMP Facilities within NCDOT Rights-of-Way

The following must be observed with respect to stormwater best management practices (BMP) facilities within NCDOT rights-of-way:

- No private stormwater BMP facilities are allowed within NCDOT rights-of-way.
- No private stormwater pipes or other drainage conveyances are allowed to connect to NCDOT BMP facilities.
- Encroachments that impact NCDOT BMP facilities (e.g. construction of a driveway that would reduce a length of an established length of grass swale treatment) should be appropriately accounted for in NCDOT's Stormwater Controls Management System (SCMS).

3 PRELIMINARY HYDRAULIC STUDIES FOR PLANNING DOCUMENT

3.1 Overview

The work performed during the project development (planning) phase is intended to provide needed information required for the selected alternatives in the preparation of the planning document. In the subsequent design phase, much of the data gathered in the earlier phase may need to be verified, updated, and refined. Additional details may be needed prior to the final hydraulic design that were not required in the project development phase.

3.2 Project Development (Planning) Phase

In the planning phase of project development, the design engineer performs preliminary studies and makes recommendations to facilitate and guide decisions made in the project development process. During this planning phase, a Preliminary Design Report (PDR), Appendix D Item 1 should be completed for each major stream crossing (as defined below in Section 3.3).

For bridge replacement projects, the PDR is typically completed prior to the scheduled Field Scoping Meeting (FSM). The preliminary bridge replacement design recommendations are determined at the FSM by a consensus of the multi-disciplinary team of participants. Issues covered at the FSM typically include hydraulic design, geotechnical concerns, roadway design, project development, environmental analysis, traffic safety, structure design, constructability, maintenance access, and local Division concerns. Appendix D Item 2 is a listing of some of the hydraulic design concerns which may need to be discussed at the FSM.

For State Transportation Improvement Program (STIP) projects other than bridge replacement projects, a preliminary field review should be conducted as part of the preliminary hydraulics study, and it would be helpful to complete the PDR for each major stream crossing prior to the preliminary field review. Consult the Natural Resources Technical Report (NRTR), if one has been completed, for consideration of avoidance and minimization of impacts to high quality environmental resources. A checklist is also provided in Appendix D Item 3 of items which should be reviewed during preliminary field reconnaissance. At this time, local highway maintenance personnel should be contacted for input on flood history, problem areas and other pertinent drainage information.

Using data collected in the PDR and preliminary field review, the preliminary hydraulic recommendations for STIP projects are to be developed for every major stream crossing site. The primary purpose of the preliminary hydraulic recommendation is to determine the hydraulic conveyance of the drainage structure that will be needed in order to develop preliminary project cost and estimate of environmental impacts for comparing the project's study alternatives. Existing structures should be evaluated for hydraulic adequacy and structural integrity, and a determination should be made regarding whether they need replacement or can be retained and feasibly modified to accommodate the proposed highway improvements. Any supplemental information regarding the preliminary hydraulic recommendation may be documented in the notes section of the PDR. In the event more space is needed for additional notes, additional pages may be attached. For NCDOT roadway projects, the PDR form is intended to serve as the necessary documentation of the preliminary hydraulic recommendations for use in preparation of the project's planning document. Instructions and an example are included in Appendix D to assist in preparing the PDR form.

3.3 Determination of Major Stream Crossing

For preliminary drainage studies, it is neither practicable nor necessary to study small stream crossings involved with a project; only major stream crossings need be studied. A major stream crossing is defined as one which would require a waterway opening providing hydraulic conveyance greater than that of a single 72-inch diameter pipe (i.e. waterway opening of 30 square feet or more). Any existing crossing with a structure size which may be below, but close to this size and potentially may be undersized, should be included in the preliminary drainage study. Preliminary hydraulic recommendations for major stream crossings should be documented on the form in Appendix D Item 4. It should be noted that overflow drainage structures in the floodplain adjacent to a stream, while not technically conveying a stream, should be considered part of a system of structures comprising a major stream crossing, where applicable, and should thus be accounted for in the hydraulic analyses and documentation.

For NCDOT roadway projects which require concurrence of federal and state agencies through the NEPA 404 Merger Process, the design engineer is responsible for providing preliminary hydraulic recommendations (37, 67). During Concurrence Point 2 (Detailed Study Alternatives Carried Forward), the design engineer offers input regarding any proposed study alternatives which may be problematic for FEMA compliance or difficult for facilitation of drainage. During Concurrence Point 2A (Bridging Decision and Alignment Review), the hydraulic engineer should provide preliminary hydraulic recommendations for the drainage structures required to provide adequate hydraulic conveyance to accommodate the major stream crossings under study for the project, including possibly accompanying the Merger team during a field review of the project area. Appendix D Item 4 form should be used for Concurrence Point 2A documentation.

3.4 Determination of Minimum Length Bridge (for Preliminary Estimates)

Preliminary recommendations for bridge replacements or new location bridges are often based on NCDOT's definition of a minimum length bridge, which is illustrated in Appendix E Item 6. This criterion generally provides for a minimum ten foot wide offset from anywhere along the stream bank to the below-ground projection of the roadway embankment slope (typically 1.5:1 normal to the end bent). This does not necessarily preclude specification of a vertical abutment bridge in the final design stage, which could further reduce bridge length, provided it would meet project requirements. While this is a general rule for preliminary bridge sizing, there also may be unique site constraints which may otherwise affect the recommendation.

3.5 Project Commitments Regarding FEMA Coordination

Planning documents for NCDOT projects usually include formal project commitments (a.k.a. "green sheets"). When a FEMA-regulated stream is involved, the Hydraulics Unit requires that project commitment statements such as the following be included to address FEMA compliance coordination:

Hydraulics Unit commitment:

The Hydraulics Unit will coordinate with the NC Floodplain Mapping Program (FMP) to determine status of project with regard to applicability of NCDOT's Memorandum of Agreement, or approval of a Conditional Letter of Map Revision (CLOMR) and subsequent final Letter of Map Revision (LOMR).*

* If project is in Mecklenburg County, CLOMR submittals should be coordinated with Charlotte-Mecklenburg Storm Water Services.

Highway Division commitment:

This project involves construction activities on or adjacent to FEMA-regulated stream(s). Therefore, the Division shall submit sealed As-built construction plans to the Hydraulics Unit upon completion of structure construction, certifying that the drainage structure(s) and roadway embankment that are located within the 100-year floodplain were built as shown in the construction plans, both horizontally and vertically.

3.6 Project Commitment Regarding Climate Change and Extreme Weather Events

Planning documents for NCDOT projects that may be vulnerable to extreme weather and flooding, such as sea level rise, should also include the following commitment statement in the green sheets:

Hydraulics Unit and Roadway Design Unit commitment:

NCDOT will follow FHWA's policy as set forth in in FHWA Order 5520, "Transportation System Preparedness and Resilience to Climate Change and Extreme Weather Events" and guidance as set forth in FHWA's publications "Highways in the River Environment-Floodplains, Extreme Events, Risk, and Resilience" June 2016, (FHWA-HIF-16-018) and "Highways in Coastal Environment: Assessing Extreme Events" October 2014, (FHWA-NHI-14-006) to minimize climate and extreme weather risks and protect transportation infrastructure.

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4 PRELIMINARY ROADWAY PLANS REVIEW AND PRE-DESIGN STUDY

4.1 Preliminary Roadway Plans Review

For transportation improvement projects, NCDOT hydraulic design staff initially receive a set of preliminary roadway plans for review from the Roadway Design Unit. The purpose of the preliminary review is to allow the design engineer to determine any potential drainage problems with the design and to provide comment on changes which may be needed. Items which should be evaluated include, but are not limited to, the following:

- overtopping elevation (relative to 100-yr and design event elevations, as applicable)
- effects to floodplain (e.g. lateral floodway encroachment, fill in floodway, etc.)
- project commitments made in planning / project development phase
- potential problems with spread/hydroplaning
- locations of high undercut areas where berm ditches are needed
- superelevation: at rollover locations, on bridge deck(s), at intersections, at sags and crests
- roadway grades, intersection grades
- alignment review for avoidance/minimization efforts
- drainage outlet locations
- effects to existing drainage systems/outlets
- potential diversions
- sag (low point) on bridge or in cut section(s) with no relief
- minimum cover over culverts
- existing level of service for the transportation facility
- physical condition and hydraulic adequacy of existing drainage structures
- preliminary bridge superstructure grade and span arrangement
- typical roadway sections
- embankment slope in wetland areas
- navigational channel requirements
- under-clearance requirement for greenway/animal crossing
- access/vertical clearance under bridge for inspection/maintenance
- sidewalks, bike lanes, multi-use paths

4.2 Pre-Design Study

Prior to commencing detailed final design and associated final field reconnaissance, the project should be reviewed to familiarize the design engineer with the project requirements. Archived field survey records, including Bridge and Culvert Survey and Hydraulic Design Reports (BSRs and CSRs, Appendix E), and office data, including any previous drainage complaints, should be collected and reviewed to determine what additional information is required during the final field reconnaissance and survey stage. As with the project development phase, local highway maintenance personnel should be contacted again prior to commencing final design to update and confirm information on flood history, problem areas and other pertinent drainage information. Specific design methods, procedures and criteria are also addressed at this stage. Design engineers should complete this phase by having a Pre-design Review meeting with the appropriate NCDOT hydraulic design staff. The design engineer is to prepare a list of topics and information, including hydraulic design assumptions, for discussion at the meeting. Any actions and decisions agreed to at the review meeting should be summarized in meeting minutes and included in the final project documentation. Also review project commitments ("green sheets") made in the project development stage to ensure they can be implemented. The first page of Appendix B should be completed and approved by the appropriate NCDOT hydraulic design staff prior to field reconnaissance.

5 FIELD RECONNAISSANCE AND SURVEY

5.1 Overview

The Location and Surveys Unit, in conjunction with the Photogrammetry Unit, provides survey data that are required for the development of hydraulic design plans. The type and presentation format of these data are provided in the Location and Surveys Unit's document *NCDOT Field Surveys for Hydrographic Data* (25).

Typical survey data required for hydrologic and hydraulic studies include:

- existing bridge superstructure and substructure locations and elevations
- existing culvert dimensions (including invert elevations, top slab depth, multi-barrel web thickness, condition, etc.)
- pipe sizes and condition, invert elevations
- existing drainage channels (including, size, slope, stability, etc.)
- drainage structure invert elevations
- streams and ponds (location, geometry, hydraulic characteristics, etc.)
- storm drain system components, etc.
- curb and gutter locations
- topographic features (e.g. paved areas, buildings, wooded areas, etc.)
- digital terrain model (DTM) and LiDAR

Wetlands and jurisdictional streams are delineated by the Natural Environment Section (NES) and verified by the US Army Corps of Engineers (USACE) and/or the NC Department of Environmental Quality (NCDEQ) staff. Survey data for transportation improvement projects are compiled and stored in a single Final Survey Microstation file. For specialty or unusual survey needs, such as bathymetric surveys in sounds, large rivers, ponds or lakes, the Location Engineer may need to coordinate with the design engineer to define the survey coverage area and data requirements during the initial stage of the survey.

It is the primary design engineer's responsibility to verify and supplement the survey data in the field prior to commencing detailed design to ensure that these survey data are accurate for use in developing the hydraulic model analyses, Bridge and Culvert Survey and Hydraulic Design Reports, and drainage plans. The design engineer should consider the level of data needed for the hydrologic and hydraulic analyses to be performed. This should be compared with the survey data provided by Location and Surveys and Photogrammetry Units to determine what additional data must be obtained, such as stream bed slope, channel geometry (at locations where detailed stream cross sections may be needed), etc. If the accuracy of the survey data is in question or if additional field surveys are warranted, assistance from Location and Surveys staff may be requested. Appendix D, Item 4 includes a list of field information that should be collected in the preliminary design phase of the project (which may later be supplemented with more detailed survey information in the final design stage).

5.2 Purpose of a Drainage Survey

The purpose of a drainage survey is to determine how to best convey stormwater runoff, associated with the roadway, to a natural drainage outlet safely, efficiently, aesthetically, and with environmental stewardship. Opportunities to observe live storm runoff events are seldom available. Therefore, the design engineer must rely on expertise, experience and judgment in evaluating site conditions and making appropriate recommendations.

5.3 High Water Marks

Moving water usually leaves marks along the watercourse. Anyone will notice the effects of a great storm on a large stream if it is seen before cleanup operations have been completed and marks removed. But it takes a trained eye to perceive the marks caused by the smaller storms, which leave no visible evidence of damage, but which, nevertheless, might wash out a roadway fill or flood the road.

Indications of the flow of water could include:

- drift (fences are good collectors of drift)
- erosion, such as:
    - cultivated field scoured down to bare clay or gravel in the low areas
    - eroded stream banks
    - scour hole at the outlet of a drainage structure
    - roadway shoulder eroded below the pavement with all the fines washed out
- deposition of streaks of sand and gravel in a field or on pavement
- presence of excessive sediment deposits in a channel
- high water marks on trees and structures
- flow patterns in matted grass

Additionally, it is important to obtain local flood history information from the local Division maintenance personnel and local residents or service personnel (mail carrier, school bus drivers, etc.) who may be familiar with the project site. When conditions are found which indicate potential damage to the road, these should be addressed in the development of the final design recommendations on how to safely convey storm runoff. Reliable high water mark elevations should be recorded on Bridge and Culvert Survey and Hydraulic Design Reports (BSRs and CSRs, Appendix E).

5.4 Drainage Field Reconnaissance

When conducting a field survey for a roadway drainage structure such as a bridge or culvert, it is important to remember that the highway drainage structure must be designed to satisfy the following constraints for the duration of its structural life:

- must safely convey the design flow so as to prevent inundation of the travel way without creating excessive flooding on upstream or downstream properties

- must not create flow velocities causing excessive scour erosion in the outlet channel or on the roadway fill at the inlet
- must structurally support the roadway and traffic loading
- must provide adequate means for terrestrial and aquatic passage

The challenge for the design engineer is to design the most economical structure which will satisfy all of these constraints. More detailed guidance on these topics is provided in Chapters 8 and 9. However, with respect to allowable backwater and scour velocities, certain field data must be collected to establish these parameters. Elevation data on upstream development in the vicinity should be obtained to determine if structures are near the observed or known high water elevation. In order to estimate scouring velocities in a channel, it is necessary to describe the type of material in the stream bed and determine whether scour occurs in the natural channel.

In addition to the above, the field reconnaissance should serve to:

- visually acquaint the design engineer with conditions and constraints of the site (such as obtaining overtopping elevation to determine existing level of service, assessing potential impacts of grade adjustments, etc.)
- identify topographic features missed in prior surveys
- verify data obtained from other sources, such as base mapping or other survey data
- identify ponds, lakes, reservoirs and other stormwater retention areas which may affect discharge rates
- review existing drainage features and obtain information on performance
- review potential outlet facilities and downstream conveyances for performance, adequacy, stability, and condition
- identify sediment-sensitive areas such as lakes, ponds, and channels
- review contributing watershed characteristics (e.g. pasture, wooded, industrial, residential, etc.)
- identify new or planned construction or proposed development
- locate and/or verify wetlands and other environmentally sensitive areas (to note any obvious discrepancies which may need review by the Natural Environment Section)
- obtain by survey or verify from structure inspection reports or Location and Surveys data details of size, location, length, material type and condition of existing drainage structures
  - for existing box culverts to be extended: top slab and vertical interior wall thickness
  - for existing bridges: pier widths, footers, abutments, mud sills
- assess existing structure's condition, and if it is in question (e.g. cracks, perched, spalling, etc.), note to follow up by contacting the Structures Management Unit and/or Materials and Tests Unit, as applicable, to obtain a structural integrity evaluation
- obtain channel data (see Chapter 11)
- obtain historical flood and other stream flow information such as:
  - maximum and other large flood levels at, upstream, and downstream of the study site
  - dates of these occurrences and frequency
  - more frequent flooding levels (examples: annual, 2 year, 5 year)
- note any channel scour and migration
- note drift potential, debris size and quantity
- obtain descriptive photographs of site (e.g. upstream and downstream view from road, face of structure upstream and downstream, evidence of scour, floodplain characteristics, structures in floodplain, etc.), noting location and direction of view

5.5 Drainage Data Collection

Examples of additional drainage survey data and supplemental topographical information which should be collected:

- elevations of flooding (high water marks, historical flood levels)
- elevation of upstream and downstream features which could control the design, such as buildings, roads, yards, fields, and other drainage structures
- stream bed elevations a sufficient distance upstream and downstream to establish the normal stream gradient
- floodplain and channel cross-sections for backwater analysis and channel realignments
- structure geometry and related data needed for hydraulic model analysis (e.g. rail height, pier widths, guardrail, sediment accumulation, etc.)
- development and land cover in floodplain for determination of flow resistance and distribution (e.g. roughness coefficients for hydraulic model analysis)
- general description of stream bed and bank materials (clay, silt, sand, gravel, cobble, rock, etc.)
- depth to rock - if extensive rock is visible, explore extent by probing bed on culvert size streams for possible footing depth. (If warranted, Geotechnical Unit should be contacted for more detailed investigation.)
- locations of high undercut areas where berm ditches are needed.
- locations of top of bank along upstream and downstream channel for sufficient distance to establish riparian buffer limits for assessment of impacts in buffer zones
- location of springs, seeps, or noticeable high water tables
- potential locations for hazardous spill basins (if required)
- verification of wetlands and jurisdictional streams shown in base mapping on Roadway plans, to ensure accuracy for permit application (Coordinate with NES as soon as possible if any significant discrepancies are encountered.)

Additionally in urban areas, where curb and gutter roadway typical section is proposed:

- Locate and obtain elevations of driveways and low areas behind proposed curb where drainage inlets may be needed.
- Locate and obtain elevations of offsite drainage system behind proposed curb
- Locate small inflow systems such as roof and basement drains.

Review and obtain the following information for use in bridge scour analysis:

- Description of floodplain
- Channel bed material (e.g. sand, silt, etc.) and gradation (e.g. fine, medium, coarse)
- Evidence of scour at existing structure, particularly at the abutments and interior bents
- Channel cross-sections at bridge face and at locations of the upstream and downstream toe of the embankment
- Photos to support the selection of roughness coefficient values, hydraulic control features, etc.
- Elevation and location of deepest point in channel (thalweg – not necessarily at center of stream)
- If visible, note type and condition of existing foundation
- Note any visible repairs / bank stabilization.

All pertinent data gathered through this field reconnaissance and survey should be recorded on work plans, field notes, and filed with project documentation. Important hardcopy project documentation should also be preserved in a digital format, such as a MicroStation CADD file or scanned PDF file. Pages 2-4 of Appendix B should be completed while conducting the field study.

5.6 Field Safety

All personnel performing field reconnaissance work for NCDOT must follow the policies and guidance in NCDOT's Safety Policy and Procedure (SPP) Manual (53) and Workplace Safety (Operations Procedures – SOP) Manual (54).

There is no specific published guidance or policy pertaining exclusively to NCDOT roadside work by field survey crews. Roadway Standard Drawings (16) Division 11 contains NCDOT standards for work zone traffic control, which may be consulted as a reference for general information and guidance on such things as flagging traffic and placement of roadside warning signs, cones, and other traffic control devices, as may be applicable. It should be noted that NCDOT requires personnel trained and certified by an approved source to perform traffic flagging, so if required, coordination with the local Division office may be warranted to ensure that appropriate personnel are assigned to serve in this capacity.

If surveys are needed within a railroad right-of-way, a permit of entry must be arranged through coordination with the Location and Surveys Unit and the Rail Division. This work may likely be outsourced to qualified and certified contractors approved by the railroad owners. Under no circumstance should a hydraulic survey field crew enter a railroad right-of-way without an authorized permit of entry.

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6 DRAINAGE PLANS DEVELOPMENT

6.1 Overview of Development Process

Using the preliminary roadway plans as a base, the development of the drainage plans should be done in the MicroStation Drainage (DRN) file, and generally proceeds as follows:

1. Verify and supplement as necessary all existing drainage features (structure type, size, elevations). Contact the Location and Surveys Unit for clarification or revision if major discrepancies or errors are discovered in the field, or if significant supplemental surveys are needed beyond typical scope of a Hydraulics field review.

2. Note all existing drainage divides, flow directions, ditches, channels, etc. (Important notes on hardcopy plans should be transferred to the digital MicroStation plan drawings on the appropriate information levels, such as notes about existing pipe conditions, erosion problems, etc.)

3. Verify and supplement information addressing utilities that may affect drainage features.

4. Sketch any special ditches or other topographical features identified during field surveys and not included on the preliminary plans.

5. Make notes of design controls identified during data collection and field survey stage, such as elevation of lowest adjacent grade of buildings in floodplain, which could potentially be adversely affected.

6. Determine and evaluate the patterns of surface flow as affected and developed by the project construction. (Note flow direction and areas of flow concentration as may be needed for clarity.)

7. Develop a schematic layout of drainage features (bridges, box culverts, pipes, storm drain systems, ditches, channels, etc.) to properly convey surface flow within and adjacent to the project. Note these features on the plans.

8. Perform the design studies required to detail each drainage feature (type, size, location, material, etc.) and document the design detail of each individual feature as directed in the related section of these *Guidelines*.

9. Upon completion of hydraulic design, a final set Redline Drainage Plans (electronic PDF and CADD versions) are to be prepared, and should include, as a minimum, the following items:

    - Drainage areas (label size and show boundary depictions)
    - Existing drainage patterns (see item 6 above)
    - Storm drain system inlets, pipes, etc. with top and invert elevations, structure numbers
    - Ditches and outlet channels (with details, plan/profile views, and computations, as appropriate)

- Topological contours (and flow arrows where needed for clarity)
- Important design notes, including information from field investigation, utility conflicts, commitments, retaining or removing items, etc.
- Sag and crest locations on roadway with flow direction arrows
- Stream tops of banks
- Quantities of excavation, rip rap, geotextile fabric, etc.
- Culvert and cross-pipe hydraulic data
- Permanent and temporary drainage easements
- Limits of shoulder berm gutter at bridges

10. The Checklist for Drainage Study and Hydraulic Design (Appendix B) must also be finished and included with the project documentation upon completion of design.

6.2 Sealing of Drainage Plans and Design Reports by Professional Engineer

Once right-of-way plans are completed by the Roadway Design Unit, they are submitted for review by the Contract Standards and Development Unit, which checks the plans and identifies any corrections needed. After the plans are corrected, the final plans are then signed and sealed by the responsible North Carolina professional engineers who performed or supervised the engineering work. Procedures for electronically sealed plans have recently been implemented within NCDOT. Typically, the design engineer will need to seal the title sheet, any special detail sheets with drainage-related details, and all plan and profile sheets. If Bridge or Culvert Survey and Hydraulic Design Reports (BSRs or CSRs, Appendix E) are included with the project, the design engineer must also certify that the information in these reports and the plans are accurate, as they also are to be signed and sealed by a licensed North Carolina Professional Engineer as part of the official legal design documentation for the project. Additionally, as noted in Chapter 1 Introduction, the Hydraulic Design Documentation Summary (Appendix A), corresponding to the project's documentation package, must be individually sealed by the responsible engineer.

7 HYDROLOGY

7.1 Introduction

The hydrologic analysis phase involves the determination of discharge rates and volumes of runoff that drainage facilities will be required to convey. Acceptable hydrologic methods for highway drainage studies and applicable criteria for their use are discussed in this chapter. When the project site involves a FEMA-regulated stream, discharge methods and values provided in the effective published Flood Insurance Study (FIS) report should be used for determining compliance with National Flood Insurance Program (NFIP) regulations (29). (This may result in the need for additional hydraulic modeling to meet NCDOT design criteria, so there may be both a model for NFIP compliance as well as a design model for the NCDOT project.) The results from any hydrological procedure should be calibrated with historical site information. The design engineer should also consider potential future land use changes within a watershed over the life of a roadway structure and include this effect when estimating design discharges.

7.2 Drainage Area Determination

There are a variety of sources for obtaining drainage area data, including USGS topographic contour maps, published lists of drainage areas from study reports (such as FEMA Flood Insurance Studies and USGS water data reports), archived NCDOT Bridge and Culvert Survey and Hydraulic Design Reports (BSR, CSR; Appendix E), digital elevation data (such as Light Detection and Ranging, or LiDAR, data), and the relatively new USGS StreamStats web-based GIS application for North Carolina, which utilizes Digital Elevation Models (DEMs) based on LiDAR data and a combination of local resolution stream data and National Hydrography Datasets (NHD) for automated computation of drainage areas (and other basin characteristics). Drainage areas should be verified during project field review. The design engineer of record is responsible for verifying the accuracy of the drainage area regardless of the method used to obtain it.

7.2.1 USGS StreamStats

StreamStats is a web-based GIS application (http://water.usgs.gov/osw/streamstats/north_carolina.html) that was released by USGS in 2012. It allows users to easily obtain streamflow statistics, basin characteristics, etc., for USGS gage data collection stations and for user-selected ungaged locations. The application will delineate the drainage area at user-selected stream locations. The website includes comprehensive instructions and associated help files (including *Getting Started* and *Quick Tour* links). Users are advised to review and familiarize themselves with this information before attempting to use the application.

7.2.2 USGS Quadrangle Maps

USGS topographic mapping is available through the *National Map Viewer* website http://nationalmap.gov. Additionally, a GIS web map service (WMS) called USA_Topo_Maps provides a base map of national coverage of USGS topographic contour mapping.

7.2.3 Digital Elevation Data

Several sources of digital elevation data are available. The primary and most current, accurate, and readily available data is in the MicroStation TIN (triangular irregular network) file (supplied by NCDOT Location & Surveys and Photogrammetry Units) for the specific project area. However, this coverage is often inadequate for hydrologic studies, so it may need to be supplemented with other digital elevation data sources, such as LiDAR coverage or USGS Digital Elevation Models. Further details on each of these are discussed below.

7.2.3.1 MicroStation TIN Files

NCDOT's Location and Surveys Unit and Photogrammetry Unit collaborate to produce the final survey files for NCDOT projects, including planimetric mapping, digital terrain models (DTMs), and associated TIN files. The DTM file is first generated from processing the raw survey data; then, the DTM file is used to generate a TIN file to represent the existing ground surface. Often, the original TIN files provided for a project do not provide adequate geographical coverage for hydrologic analyses (e.g. offsite drainage), so supplemental digital elevation data may be used to generate additional TIN file coverage that can be merged with the original TIN.

7.2.3.2 LiDAR Data

One supplemental source of digital elevation data available in North Carolina is the statewide Light Detection and Ranging (LiDAR) coverage that was developed for the NC Floodplain Mapping Program (FMP). The entire state has been mapped using LiDAR techniques to collect digital elevation data. These data and corresponding metadata are available for download, and can be accessed from FMP's website (http://www.ncfloodmaps.com).

7.2.3.3 USGS Digital Elevation Models and Local Government Topographic Data

Digital elevation model (DEM) data are available from the USGS National Elevation Dataset (NED). Procedures on how these data can be downloaded are provided on the *National Map Viewer* website (see 7.2.2). These DEMs may prove most useful for areas in bordering states; however, within the state, NC FMP's LiDAR coverage will likely be more current, higher resolution, and accurate than that available from the NED. Additionally, large municipalities and some counties have developed topographic and elevation data which may be publically available for use in drainage area determination.

7.2.4 Archived NCDOT Bridge and Culvert Survey and Hydraulic Design Reports

There are thousands of bridge and culvert design reports archived at the Hydraulics Unit (hardcopies and PDF electronic copies). They provide valuable hydrologic and hydraulic information, such as drainage area size, as well as discharge rates and associated computed water surface elevations, methods used for computations, flood history records, etc. Information provided on these reports are only as accurate as methods and technology available as of the date of the report. It is the design engineer's responsibility to verify the information on the report before relying on it.

7.2.5 FEMA Flood Insurance Studies

FEMA Flood Insurance Study (FIS) reports' Summary of Discharges Tables are a good source for drainage areas and associated computed discharges for the FEMA hydraulic models. (See Section 7.4.1 for more information.)

7.3 Peak Discharge Design Frequency

Design frequency for NCDOT drainage structures is determined based on the roadway classification, traffic volume, level of service, flooding potential to properties, maintenance cost, etc. A summary of design frequencies that are typically used for NCDOT roadway drainage facilities is provided in Table 7-1. Consideration for site-specific conditions, such as upstream or downstream potential property impacts, existing level of service provided, length of time a temporary detour will be in place, etc. may warrant exceptions to these and should be discussed and agreed upon, preferably during the pre-design review.

	FREQUENCY (years)			
ROADWAY CLASSIFICATION	Bridges, Culverts and Cross Pipes	Storm Drain System: On Grade	Storm Drain System: At Sags (without relief)	Ditches
Major Arterials (e.g. Interstates, US, NC Routes)	50	10	50	10
Minor Arterials, Collectors, and Local Roads	25	10	25	10
Temporary/Detours	10	-	-	10

Table 7-1 Design Frequency

7.4 Peak Discharge Estimates

The design engineer should select from a number of acceptable peak discharge methods, depending upon the site's watershed characteristics. Table 7-2 lists peak discharge methods which are acceptable for NCDOT hydrologic studies. It also references the NCDOT Highway Hydrologic Charts (digitally corrected reproduction of the 1973 State Highway Commission Charts), which are applicable for limited use as discussed in Section 7.4.4 and Appendix C. It is the hydraulic engineer's responsibility to apply sound engineering judgment and to provide documented justification of methods used. Reported discharges should be expressed to two significant figures for 0.1 cfs to 10,000 cfs, and if higher, to three significant figures (examples: round 135.22 to 140; round 13,522 to 13,500), unless specifying discharges cited identically from a published FEMA Flood Insurance Study report.

Hydrologic Methods / Feature	FIS (for NFIP compliance)	USGS Methods	Rational Method (up to 20 ac)	NCDOT Hwy. Hydrologic Charts	NRCS Method (for routing)
Bridges	X	X			X
Culverts	X	X			X
Storm Drain Systems			X	X	X
Cross Pipes (≤ 72 in. dia.)	X	X	X	X	X
Gutter Spread			X		
Ditches and Channels	X	X	X	X	
BMP Devices			X		X
Natural Stream Design	X	X	X		X
Storage Facilities					X
Floodplain Impacts	X	X			X

Table 7-2 Peak Discharge Method Selection

7.4.1 FEMA Flood Insurance Study

If a project study site is on a FEMA-regulated stream that is included in a published effective FEMA FIS, then the discharges specified in the FIS Summary of Discharges table should be used in the hydraulic model to demonstrate FEMA regulatory compliance. Those streams which were studied by detailed methods will typically list computed discharges for the 10- , 50 - , 100-, and 500-year recurrence intervals. Streams studied by limited detailed methods will only list the 100-year discharge.

Copies of effective FIS reports can be viewed and downloaded online from NC Floodplain Mapping Program's (NC FMP) website (http://www.ncfloodmaps.com).

7.4.2 USGS Stream Gage Analysis

Precedence should be given to analysis of the published stream gage data records when a USGS gage exists at or near the study site. Published North Carolina flood frequency statistics from continuous record USGS gages are available from the Flood-Frequency Statistics USGS Gaged Sites web link (http://nc.water.usgs.gov/flood/floodstats/gaged/index.html) on the NCDOT Hydraulics Unit website (https://connect.ncdot.gov/resources/hydro/pages/default.aspx).

7.4.2.1 Peak Discharge Estimation at Gaged Site

The above USGS website provides three types of statistical peak discharge estimates. The first is computed by fitting the recorded annual regulated peak flows to the log-Pearson Type III distribution using a localized computed sample skew. A second estimate that is provided is computed from the appropriate regionalized regression equation developed for the hydrologic area of the gage station location. The third, and presumably most accurate and reliable estimate provided combines the results of the first two into a weighted estimate for that gage station. Details on how these estimates are computed are discussed in USGS report SIR 2009-5158 (4). This report also discusses how flood-frequency peak discharge estimates at gaged sites can be adjusted (by transposition) to ungaged sites, as summarized in the following guidance.

7.4.2.2 Peak Discharge Estimation at Ungaged Site near Gaged Site

If the study site is not located at the location of a reference stream gage station on the same stream, and the drainage area at the study location is within fifty percent (50%) of that of the reference gage station, it is acceptable to adjust (or transposition) the discharge from the gage station to compute discharge estimates at the study location. The recommended method for peak discharge transposition is detailed in USGS report SIR 2009-5158 (4). This method is not recommended if the difference in drainage areas between the two locations is greater than fifty percent (50%). If the ungaged site is located between two gaged stations on the same stream, two peak discharge estimates can be made using the above procedure and hydrologic judgment applied to determine which is the more appropriate of the two.

7.4.2.3 Peak Discharge Estimation at Ungaged Site

In 2012, USGS launched the North Carolina StreamStats application website. In addition to the recommended use of this application for its automated drainage area delineation capabilities (see 7.2.1), this application is also recommended for use in computing discharges from USGS regression equations at ungaged sites. Rural discharge estimates are computed from the rural regional regression equations presented in SIR 2009-5158 (4). Urban and small rural basin discharge estimates are computed from the regression equations presented in reports SIR 2014-5030 (62), WRI 96-4084 (5), or USGS Fact Sheet 007-00 (63), as applicable. In the event that the StreamStats website is unavailable, refer to guidance in the referenced reports.

7.4.3 Rational Method

The Rational Method estimates the peak discharge (Q) in cubic feet per second (cfs) as a function of drainage area (A) in acres, mean rainfall intensity (I) in inches per hour (for a duration equal to the time of concentration, t_c), and a dimensionless runoff coefficient (C). The Rational Formula is Q = CIA.

NRCS methods (49) for calculating t_c should be used. Minimum value for t_c should be 10 minutes. An upper limit of 20 acres drainage area is recommended for applicability of this method.

7.4.3.1 Rational Runoff Coefficient

The value of the runoff coefficient (C) increases with the imperviousness of the surface cover. Table 7-3 provides some commonly used values for various surface types (7). The higher values in the ranges shown should be used when the terrain slope is steep. Less permeable soils warrant higher range C values. Likewise, areas such as grassed medians and berms behind curb and gutter may also warrant higher C value because of reduced permeability due to soil compaction performed during construction.

TYPE OF SURFACE	C
Pavement	0.7 - 0.9
Gravel surfaces	0.4 - 0.6
Industrial areas	0.5 - 0.9
Residential (Single-family)	0.3 - 0.5
Residential (Apartments, etc.)	0.5 - 0.7
Grassed, steep slopes	0.3 - 0.4
Grassed, flat slopes	0.2 - 0.3
Woods / Forest	0.1 - 0.2

Table 7-3 Typical Rational Runoff Coefficients

7.4.3.2 Rainfall Intensity

Rainfall intensity (I) data can be obtained from the NOAA Atlas 14 published report (47) and corresponding Precipitation Frequency Data Server (PFDS) website, where “I” values are tabulated for a range of durations and storm event frequencies at user-selected locations. In the PFDS table, the duration which is closest to the computed time of concentration (t_c) value will be used to obtain the corresponding “I” value to use in the Rational Formula. A minimum t_c of ten (10) minutes should be used.

The website to access the PFDS is: http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html
See Appendix Q for an example of how to use the PFDS to find rainfall intensity values for a given project location.

Intensity values in GEOPAK Drainage (68) are hard coded into the Drainage Library and may not exactly match the NOAA Atlas 14 values for a given location, but should be relatively close. For routine storm drain system design, use the intensity values generated within GEOPAK Drainage.

7.4.4 NCDOT Highway Hydrologic Charts

The NCDOT Highway Hydrologic Charts, corrected and digitally reproduced from the 1973 State Highway Commission charts, are provided in Appendix C. They should primarily be used for sizing of small pipes.

7.4.5 NRCS Method – Storage Routing

Natural Resources Conservation Service (NRCS, formerly Soil Conservation Service) methods, presented in TR-55 (49) and TR-20 (48), are recommended for hydrographic storage routing. The TR-55 manual presents simplified hydrologic procedures for estimating flood hydrographs and peak discharges in small watersheds. The model begins with a rainfall uniformly imposed on the watershed over a specified time. Mass rainfall is then converted to mass runoff by using a runoff curve number (CN) which is based on soil type, land cover, impervious area, surface storage, infiltration rate, etc. Runoff is then converted to a hydrograph to develop peak discharges applying hydrograph routing procedures, runoff travel time, etc. TR-20 provides computer-aided hydrologic analyses for estimating flood hydrograph peak discharges in both small and large watersheds. For current soils data, the NRCS Web Soil Survey website is recommended (http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm). Public domain software programs available from the Army Corps of Engineers Hydraulic Engineering Center (HEC) or NRCS are acceptable to perform hydrograph calculations and routing. Other hydrograph methods supported by FHWA and AASHTO (1,2,7) may be used with approval of the State Hydraulics Engineer.

7.5 Accuracy of Hydrologic Estimates

The USGS scientists used various statistical methods to perform hydrologic analysis to develop regression equations for estimating peak discharges for both gaged and ungaged sites. It takes into account the complex geomorphic system of precipitation, evaporation, evapotranspiration, infiltration, overland flow, impoundments, channel flow, etc. The hydrologic analysis is not an exact science. The accuracy of the estimated discharges may vary significantly depending on location and other contributing factors. For example, the average standard error for the 10-year peak discharge in the Piedmont region is 25%; whereas, it is 73% for the 500-year peak discharge in the Sand Hills region (62).

It can be argued that some hydrologic methods are more accurate than others; however, estimated discharges should be calibrated to locally observed or measured events. Methods should be applied within their limits of applicability and with understanding of the underlying assumptions and hydrologic principles supporting them. While detailed hydrologic analysis is not practicable and would be beyond the scope expected in normal NCDOT hydraulic engineering practice, the design engineer is encouraged to calibrate the results from any hydrologic procedure to historical data. For bridge hydraulic analysis (see Chapter 8), these NCDOT *Guidelines* recommend that comparison be made to at least one historical occurrence.

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8 BRIDGES

8.1 Overview

The primary goal of hydraulic design for a bridge is to provide sufficient hydraulic conveyance to safely and efficiently convey the floodwater without adversely affecting channel stability, the floodplain, the roadway facility, or adjoining properties. The design engineer is recommended to reference Chapter 7 (Hydraulic Analysis for the Location and Design of Bridges) of the *AASHTO - Highway Drainage Guidelines* (1), NCDOT *Bridge Policy* (44), FHWA *Hydraulic Design of Safe Bridges* (27), the FHWA floodplain policy statement in *Federal Aid Policy Guide, 23 CFR 650A* (8), and FHWA *Additional Guidance on 23 CFR 650A* (30).

The design of a bridge at a stream crossing requires a comprehensive engineering approach that involves data collection and documentation, hydrologic analysis, hydraulic analysis, scour evaluation, environmental impact evaluation, economic consideration, and documentation of the final design. The design procedures presented herein will ensure a systematic process that will adequately address most bridge crossing situations.

8.2 Priority for Consideration of Hydraulic Structure Type Recommendation

The recommended hydraulic structure type should be considered in the following priority order:

1. Pipe culvert, circular or arch
2. Box culvert, conventional four-sided reinforced concrete walls or aluminum box
3. Bottomless (three-sided) culvert, founded on scour-resistant rock
4. Bridge

8.3 Data Collection and Documentation

Information gathered during the pre-design study and field survey is to be assembled for the study site.

This process will include:

(a) Review of the Preliminary Design Report (Appendix D), as well as available survey information.

(b) Development of the Bridge Survey and Hydraulic Design Report (BSR, Appendix E). Prior to development of the final design, the following information and guidance should be followed:

   1. The drawing scales are normally set at 1 in. = 50 ft. horizontal, 1 in. = 10 ft. vertical. The hardcopy BSR is a standard letter size document (typically 25.5 in. by 11 in. tri-folded). If a larger sheet exceeding the typical BSR size is required, it may be trimmed and folded to the standard letter size. Hardcopy original reports, signed and sealed by the responsible professional engineer, are maintained in the Hydraulics Unit files, in addition to a digital archive of scanned copies of the reports.

2. Information to be shown on the profile view includes, but is not limited to, the following:
   - Centerline station, skew, structure (existing and proposed), span arrangement, lowest low chord, and natural ground (upstream and downstream) to accurately depict the floodplain and channel. In event of dual parallel bridges, separate profiles for each bridge may be needed. Inclusion of a typical section detail relating design grade point to centerline elevation is recommended.
   - Design and 100-year water surface elevations.
   - Historical floods data, such as the high water mark (elevation) and date of flood, etc.
   - Existing and proposed features, such as utilities, road grades, drainage structures, bridge superstructure, bent locations, riprap armoring, etc. (Existing bridge and piers should be shown with black dashed lines.)
   - Adjacent structure elevation(s), such as the lowest adjacent grade and finished floor elevation of buildings, etc.
   - Water surface elevation at date of survey and normal water surface (vegetation line – a.k.a. ordinary high water) elevation
   - Theoretical scour depths
   - Design scour depths (added later from Geotechnical report when received)
   - Elevation of rock line (if applicable) from geotechnical subsurface investigation
   - For coastal tidally influenced bridges, also show MHW (mean high water), MTL (mean tide level), and MLW (mean low water) elevations. Tidal datum information can be obtained from the National Oceanic and Atmospheric Administration (NOAA) website: www.noaa.gov.
   - Excavation in floodplain (note elevations), if applicable
   - Sufficient vertical clearance under bridge for maintenance and inspection activities

3. Information to be shown on plan view includes, but is not limited to, the following:
   - Natural features, such as stream channel showing water's edge and top of bank, the existing land use and type(s) of vegetative cover in floodplain, jurisdictional streams, wetland limits, and riparian buffers.
   - Survey benchmark
   - Man-made features in floodplain, such as buildings, houses, roads, utilities, levees, etc.
   - Existing bridge in black dashed lines
   - Roadway superelevation
   - Limits of riprap for spill-through end bents
   - For riverine flow, show direction of flow and stream name
   - In coastal tidal areas, show direction of flood tide (landward/rising) and ebb tide (oceanward/falling)
   - North arrow, stationing and alignment
   - Floodway Boundaries (for FEMA Detailed Study streams only)
   - Pertinent finished floor elevations on adjacent properties

8.4 Hydrologic Analysis

This phase involves the development of a number of discharges on which the performance of alternate designs will be evaluated. While the guidance in this chapter is intended to be specifically related to bridge design, much of the hydrologic analysis information presented here may be applicable to culvert design as well.

The hydrologic analysis for bridge and culvert designs should entail:

(a) Determination of a drainage area, land use, hydrologic region, etc. for the site.
(b) Developing flood discharges for a range of flood events. (See Chapter 7 Hydrology.)
(c) For the stream crossing that is in a FEMA Flood Insurance Study (FIS), the design engineer shall use the FIS discharges to evaluate compliance with FEMA regulations. The design engineer should determine whether the FEMA discharges may be used for developing the hydraulic design. If there is considerable disparity between the FEMA study data and results from hydrological procedures presented in these *Guidelines*, the design engineer should determine the more appropriate method to use for developing the hydraulic design, and document the justification for it on the BSR.

8.5 Hydraulic Analysis

This phase involves hydraulic analysis for review and selection of one or more alternatives. The bridge hydraulic design is typically based on a one-dimensional flow riverine step backwater analysis. HEC-RAS is the most commonly used and widely accepted hydraulic modeling software (22-24) to perform this type of analysis and is therefore the preferred software for most NCDOT bridge hydraulic design applications.

The design engineer should develop the HEC-RAS model with consideration of the following:

- The cross section configuration, as shown in Figure 5-1 of the HEC-RAS *Hydraulic Reference Manual* (23) should be utilized.
- A known starting water surface elevation is preferred to be used as the downstream boundary condition for a subcritical run. Slope conveyance may be used if there is not a known starting water surface elevation.
- The beginning downstream section of the model should be located an adequate distance from the fully expanded flow section (Section 1, exit) to allow the step-backwater computations to converge to a correct water surface elevation before reaching Section 1.
- Intermittent sections may be added to the model to ensure model stability.
- All HEC-RAS hydraulic models should be analyzed as subcritical flow regardless of the channel gradient, unless use of alternate analysis method (e.g. supercritical flow or mixed flow) is approved by the State Hydraulics Engineer.
- Reliable historical flood data, if available, should be used to calibrate the model.

- Publications FHWA TS-84-204 (9) and USGS WSP 1849 (66) are good references for selecting Manning's roughness coefficient (n) values.

- Utilize the HEC-RAS project file system to document all geometric, flow, and hydraulic design data configurations (plans) analyzed, including all water surface profiles, cross section plots, structures, and various output tables. HEC-RAS files submitted for approval should follow established naming and content conventions as specified on the Hydraulics Unit website. Final design recommendations and supporting data from HEC-RAS should be appropriately documented on the BSR.

Bridges in hydrodynamic, complex flow environments or tidally influenced areas may warrant utilization of unsteady or two-dimensional flow analyses methods, which are not discussed here. The design engineer is advised to reference FHWA (27) for guidance and to obtain approval from the State Hydraulics Engineer before commencing design and analysis work using these methods.

8.5.1 General Design Criteria

The selection of an optimal final design alternative is accomplished by evaluating the study results with respect to acceptable design constraints, which are prescribed by both general and specific criteria.

- Avoid creating adverse impact of increased floodwater depth on properties upstream and downstream.
- Flow velocities through the hydraulic structure(s) should not result in channel instability or flood damage to the highway facility or adjacent property.
- Existing channel and floodplain flow patterns are maintained to the extent practicable.
- To the extent practicable, the level of traffic service provided should be consistent with the functional classification of the highway and projected traffic volumes unless a design variance is warranted.
- Project should result in minimal disruption of ecosystems and values unique to the floodplain and stream.
- Assess the floodplain impacts to properties during project construction, such as utilization of temporary causeway, temporary on-site detour and staging areas.
- Pier and abutment location, spacing, and orientation are designed to minimize flow disruption, debris collection and scour potential.
- Ensure compliance with National Flood Insurance Program regulations.

8.5.1.1 Sub Regional Tier Design

In 2008, NCDOT and FHWA approved guidelines establishing controlling design elements for new and reconstructed bridges on the state roads designated as minor collectors, local and secondary roads, which were published in the NCDOT document *Sub Regional Tier Design Guidelines for Bridge Projects* (57). If a bridge project is designed to the standards set forth in that document, no formal design exception approval is required. The design engineer should read and become familiarized with these sub regional tier guidelines to ensure that an appropriate design process is followed.

8.5.2 Specific Design Criteria

8.5.2.1 Climate Change and Extreme Weather Events

Transportation infrastructure is designed to handle impacts of a changing climate, such as sea level rise, increased frequency and magnitude of heavy precipitation and tropical storms, etc. Preparing for extreme weather events is critical to protecting the integrity of transportation and ecological (floodplain and wetland) systems and prudent investment of taxpayer dollars. The NCDOT staff will seek to follow FHWA's policy and guidance to develop cost-effective strategies to minimize climate and extreme weather risks and protect transportation infrastructure. For example, the design engineer will follow the FHWA publication *Highways in the River Environment – Floodplains, Extreme Events, Risk, and Resilience,* HEC-17 (FHWA-HIF-16-018), June 2016 (26).

8.5.2.2 Design Flood Frequency

This is the specific return period (frequency) flood that has been established as being an acceptable level for roadway overtopping, or when roadway overtopping is not involved, it will be the level of flood used for establishment of freeboard and/or backwater limitations. Overtopping is generally considered to be the point at which the computed water surface elevation overtops the minimum weir flow elevation; however, for bridge scour computations using HEC-RAS, weir flow begins to be computed when the energy grade line elevation exceeds the minimum weir flow elevation. When the energy grade line elevation is used as the basis for determination of when overtopping occurs, this should be noted in the BSR and in the modeling narrative, if applicable. See Table 7-1 for desirable design discharge standards based on accepted inundation levels relative to roadway functional classification. Variation from these or other specific standard values must be justified by an assessment process which reflects consideration for risk of damage to the roadway facility and other properties, traffic interruption, cost, environmental impacts and hazard to the public.

8.5.2.3 Backwater

Backwater is defined as the difference in the upstream water surface elevations between the non-encroached and encroached condition imposed upon the floodplain by the highway embankment and proposed structure. It is measured at the upstream toe of the roadway embankment. Backwater for the 100-year event should be limited to no more than 1.0 foot. If an existing structure already creates a 100-year backwater in excess of 1.0 foot, the design engineer may seek to replace it with a structure that reduces the backwater, provided it will not result in adverse impacts to the receiving channel and downstream properties. The backwater for the design year flood event for the proposed bridge should not exceed that of the existing bridge.

For National Flood Insurance Program (NFIP) regulated floodplains where no regulatory floodway has been established, the cumulative effect of the proposed highway encroachment combined with all other existing and anticipated development shall not result in backwater in excess of 1.0 foot above the established 100-year elevation shown on the effective FEMA Flood Insurance Rate Map (FIRM). It is the policy of NCDOT to compensate the adjoining property owners for the loss of their property value as the result of the proposed transportation facility. For example, an increase in floodway width would reduce a property owner's developable land value. To clarify, "compensate" means to purchase or relocate the property, purchase floodplain (drainage) easement on the property, etc. NCDOT follows the guidance provided in the 1982 Federal Highway Administration (FHWA) Memorandum of Understanding with the Federal Emergency Management Agency entitled "Procedures for Coordinating Highway Encroachments on Floodplains within the Federal Emergency Management Agency (FEMA)", and the September 1992 FHWA NS 23 CFR Part 650A, Transmittal 5 (30). When a detailed flood study area is involved and its regulatory floodway is established, typically no increase in backwater is allowed for the proposed conditions unless a Conditional Letter of Map Revision (CLOMR) proposal is developed and submitted to the community and FEMA for approval. A CLOMR proposal involves a revision in the floodway boundaries to accommodate the proposed transportation facilities without increasing the 100-year flood elevation above the established floodway elevation. All potential CLOMR submittals for NCDOT projects must be reviewed by the State Hydraulics Engineer before submittal will be allowed to the respective regulatory agencies for approval. See Chapter 15 for guidance concerning FEMA NFIP compliance.

8.5.2.4 Minimum Length Bridge

For a bridge with spill-through abutments, the ends of the bridge should typically be located such that, anywhere along the abutment, a linear projection of the spill-through slope face normal to the direction of flow would provide a minimum of ten feet setback from any point on the channel bank or bed. The minimum length bridge is graphically depicted in Appendix E Item 6. Greater setback may be required due to the potential channel migration and scour prediction or other factors, such as greenway or animal passage accommodation. This does not necessarily preclude specification of a vertical abutment bridge, which could further reduce bridge length (which would eliminate the spill-through slope distance, but would still require the ten foot setback).

8.5.2.5 Bridge End Bent Cap

Generally, 4 ft. end bent cap depths are used on new bridge designs; however, 2 ft. 6 in. depth end bent caps may be a viable design option where warranted by site conditions, such as low roadway fill height. Two diagrams are included in Appendix E Item 5 which depict the dimensions for bridge waterway opening for both end bent cap depths. These diagrams should also be utilized to correctly specify the bridge waterway opening and minimum bridge rail (and guardrail) flow obstruction in a HEC-RAS hydraulic model and the associated bridge profile drawing in the BSR.

8.5.2.6 Modeling Bridge Rail and Appurtenances

The design engineer should exercise judgment when coding in the bridge rail, guardrail, and any other appurtenances that may obstruct conveyance of flow (such as attached storm drain system or utilities). The following guidance is typically followed by convention for NCDOT projects, but may not be applicable to every situation. The design engineer should document decisions to justify use of different methods or criteria than these in the modeling narrative:

- Model existing bridge rail based on height and length, and show as blocked.
- Model proposed bridge rail based on height and bridge length, and show as blocked.

- Model, at minimum, the first 12 ft. of guardrail anchor unit at each end of the bridge and show as blocked (see Roadway Standard Drawings 862.03) (16).
- Model other appurtenances, such as an attached storm drain system or utility which may hang below the low chord of the bridge, thus reducing the waterway opening, using the bottom of the obstruction as the effective low chord. Note this clearly in the modeling narrative to specify the adjustments made to the low chord elevations to account for the obstruction.

8.5.2.7 Substructure and Superstructure Determination

The bridge substructure components (drilled piers, piles, spread footings) are determined by the Geotechnical and Structures Management Units based on several factors such as subsurface soil data, loading requirements, navigational clearance, environmental constraints, etc. Early coordination with the Structures Management Unit is recommended at the beginning of the hydraulic design phase on decisions pertaining to the proposed bridge, such as superstructure type and depth, span arrangement, skew angle, longitudinal and cross slopes of deck, deck drainage, etc. Consideration should be given to the roadway overtopping flood level, freeboard, and potential impacts of raising the roadway grade. Piers should generally be aligned in the direction of flood flow. Span lengths and piers should be designed to minimize flow disturbance and drift traps as is consistent to good design and construction principles. Prior to finalizing the design of a bridge, a draft copy of the BSR should be submitted to Structures Management Unit's staff for comment.

8.5.2.8 Freeboard

Standard freeboard design for bridges shall be as follows:

- New location: Provide two (2) feet minimum vertical clearance for bridge superstructure (low chord elevation) above the design flood elevation for primary route structures or secondary route crossings over major rivers. Provide one (1) foot minimum vertical clearance for all other new location bridges (including temporary detour bridges).
- Existing location replacement: If practicable, provide freeboard as stated above for new location crossings. Otherwise, as a minimum, maintain the freeboard provided by the existing bridge.

Greater freeboard may be needed for unique issues, such as heavy debris, climate change consideration, extreme weather (wind, storm surge), navigational clearance, etc. If the bridge deck is in superelevation, the freeboard is measured at the low side of the low chord. Furthermore, it is preferable, where practicable, that the low side of the superelevated bridge deck be set on the upstream side of the bridge. Variance from the freeboard requirement must be approved by the State Hydraulics Engineer prior to completion of the design.

8.5.2.9 Slope Protection

As a minimum, Class II rip rap should be placed on the spill-through abutment slopes through the waterway opening, extending beyond the bridge end bents along the roadway embankment 20 feet and 10 feet on the upstream and downstream sides, respectively. Along the roadway embankment, the top elevation of the rip rap should be placed either one foot above that of the design flood or up to the shoulder point elevation if the road is submerged during the design flood event, whichever is lower. For a lake crossing, the elevation of the rip rap should be at least two feet above the normal pool elevation of the lake, or higher, if so indicated by a wave run-up analysis. At the toe of fill, the rip rap protection should be keyed-in to a depth at least three and a half feet (3.5 ft.) below the ground surface. Additionally, existing and potential stream bank erosion or instability should be considered, and riprap armoring should be provided as needed.

8.5.2.10 Bridge Deck Drainage

A minimum longitudinal gradient of 0.3% is recommended to facilitate adequate drainage of the bridge deck. Standard practice for structural design has typically been to specify six-inch (diameter) deck drains at twelve-foot centers on all girder-type bridges. For cored slab and box beam bridges, flow is discharged horizontally through the bridge rail via rectangular deck drains. The standard dimensions of these deck drain hydraulic openings are 8 in. wide by 4 in. high for cored slabs and 5 in. wide by 4 in. high for box beams. (The actual drain opening is 6 in. high, but will be obstructed by 2 in. pavement overlay.) These deck drains cannot be placed any closer than 5 ft. (measured to center of the opening) from each end of the bridge or from either side of an interior bent and must have a minimum spacing of 3 ft. (center to center). If the bridge is on a heavy skew, a minimum offset of 6 ft. from the ends or interior bents of the bridge may be required. Structures Management Unit staff should also be consulted as early as possible in the design process regarding proposed deck drainage accommodations to verify constructability. Examples of structural concerns which may affect deck drainage could include, but are not limited to, the following:

- deck drains are required for an entire span
- raised median on the bridge
- sidewalk
- barrier rail for protected bicycle/pedestrian lane included on bridge
- particular bridge rail type may affect deck drain locations

If no deck drains are allowed over water, collection of surface runoff from the downgrade end of a bridge is required, and a grated drop inlet should be utilized. If there is inadequate depth for a grated drop inlet, a concrete flume may be used, extending to the toe of fill into a riprap pad.

To the maximum extent practicable, bridge deck drains should not be placed directly over the stream. The additional guidance provided below is recommended:

- <u>Bridges over streams with riparian buffers:</u> Bridges that are located within the promulgated riparian buffer watersheds, such as Randleman Lake, Neuse River, Tar-Pamlico, etc. for which regulatory riparian buffers have been established, shall not have deck drains which discharge directly into the surface water, open channel or buffer zone (typically measured 50 feet from the top of channel banks). Measures such as riprap pads may be provided if needed to ensure that stormwater discharged from bridge deck drains will be released as diffused flow into the buffer. In the event that safety concerns may warrant placement of deck drains within the buffer area, the bridge design will be subject to individual review and approval by the regulatory agencies on a project by project basis.

- Bridges in CAMA Counties: In the 20 coastal counties subject to the jurisdiction of the Coastal Area Management Act (CAMA), bridges shall not have deck drains which discharge directly into surface water. Any direct discharge outside the main stream channel shall also be avoided to the maximum extent practicable (MEP), unless otherwise approved by the regulatory agencies. For bridges over sounds or the Intracoastal Waterway, the volume of stormwater runoff from bridge deck drains is miniscule relative to these immense water bodies, and there typically are no practical locations in which to provide effective treatment. Bridges in these areas may be allowed to discharge directly into the surface waters, unless otherwise advised by the regulatory agencies. Most of these bridges also provide navigational clearance for boating and shipping traffic, so the effects of the high rise and coastal winds would help to diffuse and diminish any detrimental impact of stormwater from bridge decks.
- Bridges over Outstanding Resource Waters and Water Supply Waters: Stream crossings may pose an increased risk of hazardous material spills into sensitive waters. For this reason, bridges over Outstanding Resource Waters (ORW) and Water Supply (WS) waters WS-I, WS-II, WS-III, and WS-IV may be subject to hazardous spill basin requirements. Hazardous Spill Basins (HSBs) are structural stormwater controls designed to temporarily store hazardous materials from accidental spills. If an HSB is required for a stream crossing, the bridge drainage system should route all bridge runoff through the HSB prior to discharging into the receiving water. More information about the application and design of HSBs is available in Appendix O of these Guidelines and in Chapter 8 of the NCDOT *Stormwater Best Management Practices Toolbox* (34).
- Enclosed drain system for a bridge deck: If a closed drainage system is designed for a bridge deck, its outlet should be placed as far away as practicable from the protected surface water. A preformed scour hole is recommended at the outlet to help diffuse and infiltrate the stormwater, unless other BMP devices are used. Closed drainage systems are only specified for pre-stressed girder type bridges and will typically be comprised of 6-inch diameter PVC deck drains installed vertically through the deck connected to a longitudinal drainage system (typically an 8-inch diameter UVL-proof PVC pipe) beneath the deck. To ensure positive drainage, a minimum 0.3% slope is desirable for the drainage system. Such closed systems are not desirable and should only be considered as a last resort if no other practicable alternatives are available.
- Grade separation structures: Bridges over roadways or railways shall not have deck drains which discharge directly over travel lanes, sidewalks, or railroad tracks. The gutter spread along the structure must be evaluated for issues affecting the safety of the traveling public, such as hydroplaning. This acceptable spread is dependent on shoulder or additional width provided on a structure, but generally should not extend into the through-travel lane (see Chapter 10, Section 10.3). Considering the potentially significant quantity of flow from the deck, it is very important to check the adequacy of the end drains and provide recommendations for additional measures when warranted.

The above guidelines must also be balanced with the safety need to limit the spread of storm runoff to minimize hazards such as hydroplaning and ice accumulation. (See guidance in Chapter 10, Section 10.3 and Table 10-1). Provision must be made at the down grade end of all bridges to adequately convey any storm runoff not intercepted by deck drains to a storm drain system or outlet. Further detailed guidance on bridge deck drainage design is provided in HEC-21 (10).

8.5.2.11 Channel Relocation

The alignment of the proposed bridge and its piers should be designed to accommodate the existing channel. Prudent design consideration should be given to bridge crossings over unstable channels susceptible to high levels of bank erosion and channel migration. Repairing an unstable channel may be warranted to determine the proposed bridge length and location of end and interior bents. A major channel modification or relocation in and around a bridge crossing requires a thorough environmental assessment review, sound engineering design, cost analysis, and approval by the State Hydraulics Engineer.

8.5.2.12 Detour Structures

The design for a detour structure is site-specific. In general, the detour bridge and roadway grade are designed to convey flood water during a ten-year flood event. These temporary structures may be lower and shorter than their permanent counterparts. They may result in potential risks, such as traffic interruption, flood damages to the roads and adjoining properties, etc. Generally the detour bridges sit on two end bents that are supported by steel piles. The minimum length of a detour bridge is the width of the main channel plus a minimum of five-foot setback from each bank. On a site by site basis, the five-foot setback may be adjusted to ensure the integrity of channel banks and need of construction access. The bottom of the detour bridge deck (low chord) should allow at least one foot clearance over the flood elevation during the10-year flood event. The theoretical scour analysis for the detour bridges may be limited only to the contraction scour during a ten-year flood event. For detour structures on FEMA-regulated streams, see additional guidance in Chapter 15, Section 15.6. When developing the detour bridge design, the Division Bridge Construction Engineer should be consulted regarding the potential type of temporary detour bridge structure anticipated to be utilized for the project.

Detour Survey and Hydraulic Design Report (Appendix E, Item 3) should be used to document design criteria used for detour bridges. Sketch proposed structure(s) and roadway grade in plan and profile showing roadway grade elevation, minimum low chord elevation, structure location and size, limits and elevations of any required scour protection (if applicable), and any channel modifications. These should be scanned and compiled into a single document to be distributed and filed appropriately.

8.5.2.13 Multiple Bridge Openings

Roadways over streams or rivers with wide floodplains may warrant multiple openings in the floodplain to provide better conveyance through the embankment. Where it is evident that multiple openings may be required, the design engineer should develop hydraulic models to assess the location and performance of each hydraulic opening structure. The results of the modeling and performance of these structures should be documented in the BSR. The guidance outlined in the *HEC-RAS Hydraulic Reference Manual* (23) should be utilized.

8.6 Bridge Scour Evaluation

An estimate of potential scour depth is required for all new bridge designs. FHWA has issued a set of three Hydraulic Engineering Circulars (HECs) to provide guidance for bridge scour and stream stability analyses:

- HEC-18 *Evaluating Scour at Bridges* (11)
- HEC-20 *Stream Stability at Highway Structures* (13)
- HEC-23 *Bridge Scour and Stream Instability Countermeasures* (43)

Bridge scour evaluation requires a multidisciplinary analysis that involves input from the design engineer, the Geotechnical Engineering Unit and the Structures Management Unit. The design engineer's role in evaluating scour involves the following three steps:

1. Stream stability and geomorphic assessment
2. Scour analysis
3. Bridge scour and stream instability countermeasures

8.6.1 Stream Stability and Geomorphic Assessment

The design engineer should evaluate the stream stability and make a geomorphic assessment of the stream crossing. This part of the process includes office data collection, a site visit evaluation and an overall assessment of the stream stability.   This information must be documented and will be used in the overall scour evaluation.

Office data collection specific to the scour evaluation includes but is not limited to:

- Bridge Routine Inspection Reports
- Historical Bridge Survey Reports
- FHWA Scour Program reports
- Aerial photography
- Old structure plans
- Available Geotechnical information

Information collected specific to the scour evaluation during the site visit includes but is not limited to:

- Stream characteristics - straight, meandering, braided, anastomosed, engineered
- Floodplain characteristics – natural, agricultural, urban, suburban, rural, industrial etc. and susceptibility to change

- Overall stream stability:
  - Lateral stream stability (plan form) - bank material, bank slope, bank vegetation, bank erosion, leaning trees, debris potential, floodplain material. Any past or possible channel migration should be noted.
  - Vertical stream stability (profile) - bed material, degrading, aggrading, stable, scour holes, pools, riffles, etc.
  - Stream response - stable or subject to change.
- Debris potential - leaning or undercut trees along banks, size and quantity.
- Scour at existing bridge to be replaced (if applicable) - observed conditions around existing piers and spill-through slopes, indication of previous scour, depth etc., foundation type – is footing visible?

Based on the above evaluations, the design engineer should make an overall assessment of the stream stability. In particular, the design engineer should note the potential for lateral shifting (migration) of the channel when evaluating scour of piers and or abutments close to the channel banks. Potential for lateral shifting (migration) of the channel should be considered in the layout of the bridge (location of piers and or ends of bridge). See following guidance for calculating pier scour and abutment scour. A statement addressing the overall assessment of the stream stability and its determination in the scour evaluation should be noted on the BSR with the scour computations.

8.6.2 Scour Analysis

Evaluate scour design flood frequency as follows:

Regional Tier and Statewide Tier Projects

1. If the overtopping flood is less than the 100 year flood, analyze scour for the overtopping flood only. Show and plot overtopping scour calculations on the Bridge Survey Report.
2. If the overtopping flood is greater than the 100 year flood but less than the 500 year flood, analyze scour for the 100 year and overtopping floods. Show and plot both scour calculations on the Bridge Survey Report.
3. If the roadway is not overtopped by the 500 year flood, analyze scour for both the 100 year and 500 year floods. Show and plot both scour calculations on the Bridge Survey Report.

Sub Regional Tier Projects

1. If the overtopping flood is less than the 100 year flood, analyze scour for the overtopping flood only. Show and plot overtopping scour calculations on the Bridge Survey Report.
2. If the overtopping flood is greater than the 100 year flood, analyze scour for the 100 year flood only. Show and plot 100 year scour calculations on the Bridge Survey Report.

8.6.2.1 Contraction Scour

The design engineer should evaluate contraction scour for all bridges. Normally, NCDOT bridge length provides a minimum 10 ft. setback from any point on the channel bank or bed, as described in Chapter 3, Section 3.5. Standard practice is to use spill-through sloped abutments lined with Class II rip rap keyed into the overbank area under the bridge a minimum depth of 3.5 ft. This is described as contraction scour Case 1c in HEC-18. Contraction scour typically should only be computed for the main channel and not the overbank areas between the main channel and the abutments; however, computing overbank contraction scour may be appropriate for a bridge spanning a very wide floodplain.

Live-bed contraction scour occurs at a stream when there is transport of bed material from the upstream reach into the bridge cross section. With live bed contraction scour, the area of the contracted section increases until a state of equilibrium occurs, at which the transport of sediment out of the contracted section equals the sediment transported in (11).

Clear-water contraction scour occurs when (a) there is no bed material transport from the upstream reach into the downstream reach, or (b) the material transported in the upstream reach is transported through the downstream reach mostly in suspension and at less than capacity of flow. With clear-water contraction scour, the area of the contracted section increases until, in the limit, the velocity of flow or the shear stress on the bed is equal to the critical velocity or the critical shear stress of a certain particle size in the bed material (11).

Design guidance for calculating contraction scour is as follows:

Determine if the scour design flood frequency water surface elevation results in non-pressure flow scour conditions (water surface elevation is below the low chord elevation of the bridge) or pressure flow scour conditions (water surface elevation is above the low chord elevation of the bridge).

For non-pressure flow scour conditions, calculate contraction scour using the live bed contraction scour equation 6.2 in Chapter 6 of HEC-18 with a k_1 exponent of 0.69. The equation is:

$$y_2 / y_1 = (Q_2 / Q_1)^{6/7} (W_1 / W_2)^{k_1}$$

$$y_s = y_2 - y_0 = \text{(average contraction scour depth)}$$

Where:

y_1 = Hydraulic depth in the upstream main channel, ft.

y_2 = Hydraulic depth in the contracted section channel, ft. (this is computed by the equation)

y_0 = Hydraulic depth in the contracted section channel before scour (Use the upstream internal bridge section in HEC-RAS), ft.

Q_1 = Flow in upstream main channel, ft^3/s

Q_2 = Flow in contracted channel (use the upstream internal bridge section in HEC-RAS), ft^3/s

W_1 = Top width of upstream main channel, ft. (See note 4 in HEC-18 Section 6.3)

W_2 = Top width of main channel in contracted section (use the upstream internal bridge section in HEC-RAS), ft.

k_1 = 0.69 (for worst case scenario)

To ensure accuracy of bridge contraction scour computations, the values of y_1, Q_1 and W_1 of the upstream main channel to be used in the contraction scour equations should be taken at the upstream approach section (fully effective unconstricted section). The approach section must be properly located and the channel geometry correctly verified by field surveys. The approach section should be located at a point upstream of the bridge just before the flow begins to contract due to the bridge opening. This may require adding another upstream section in developing the Corrected Effective HEC-RAS model, especially in the case of Limited Detailed Study models, which may have been created with an upstream approach section that is not within a reasonable distance upstream to correctly represent the location at which flow contraction begins. It also may have only an approximated channel configuration not based on field surveys. In some instances, the channel width and floodplain geometry at the approach section may be considerably different than the channel nearer the bridge, in which case it would not be appropriate to use the approach section geometry for the contraction scour calculation. If this is the case, then the values of y_1, Q_1 and W_1 may be taken from the upstream toe section of the natural conditions model at the bridge location.

The design engineer should also carefully identify the channel section through the internal bridge opening. The top of bank stations should accurately define the channel through the bridge opening in the HEC-RAS model.

Non-pressure flow contraction scour conditions for overflow bridges should be calculated using clear water contraction scour equation 6.4 in chapter 6 of HEC-18. The equation is:

$$y_2 = [(K_u\, Q^2) / (D_m^{\ 2/3}\, W^2)]^{3/7}$$

$$y_s = y_2 - y_0 = \text{(average contraction scour depth)}$$

Where:

y_2 = Average equilibrium depth in the contracted section after scour, ft.

Q = Discharge through the bridge associated with the width W, ft^3/s

D_m = Diameter of the smallest non-transportable particle in the bed material ($1.25D_{50}$) in the contracted section, ft.

D_{50} = Median diameter of bed material, ft.

W = Top width of the contracted section less pier widths, ft.

y_0 = Hydraulic depth in the contracted section channel before scour (use the upstream internal bridge section in HEC-RAS), ft.

K_u = 0.0077 for English Units

If the D_{50} bed material for the overflow bridge is not known, use D_{50} for very coarse sand (.007ft.). If the overflow bridge is part of a braided river system then the design engineer should use the live bed contraction scour equation.

Pressure flow scour conditions should be calculated as outlined in section 6.10 of chapter 6 of HEC 18. NCDOT practice is to only compute pressure flow scour conditions up to the point of roadway overtopping. Therefore Q_{ue} (effective channel discharge for live bed conditions and overtopping flow) is not required to be computed. The pressure flow scour equations should be used with the live bed contraction scour equation and/or the clear water contraction scour (for overflow bridges) as noted above.

The pressure flow scour equations are as follows:

$y_s = y_2 - h_b$

Where:

y_s = pressure flow scour depth, ft

y_2 = average depth in the contracted section as determined from the live bed contraction scour equation or contraction scour equation noted above, ft.

h_b = vertical height of bridge opening (bed to low chord) prior to scour, ft.

Contraction scour at bottomless culverts ("three-sided") is not required since NCDOT requires that these be founded on scour resistant rock.

8.6.2.2 Pier Scour

Evaluate pier scour for all internal piers. The design engineer should reference Equation 7.3 of HEC-18 to compute the pier scour as shown below:

$y_s / a = 2 K_1 K_2 K_3 (y_1/a)^{0.35} Fr_1^{0.43}$

Where:

y_s = Scour depth, ft.

y_1 = Flow depth directly upstream of the pier, ft (use the upstream toe section in HEC-RAS).

K_1 = Correction factor for pier nose shape from figure 7.3 and table 7.1 in HEC-18

K_2 = Correction factor for angle of attack of flow from table 7.2 or equation 7.4 in HEC-18

K_3 = Correction factor for bed condition from table 7.3 in HEC-18

a = Pier width, ft

L = Length of pier, ft

Fr_1 = Froude Number directly upstream of the pier=$V_1/(gy_1)^{1/2}$

V_1 =Mean velocity of flow directly upstream of pier, ft/s.

g = Acceleration of gravity (32.2 ft/s^2)

For complex pier foundations, the design engineer should use the procedures outlined in HEC-18. An Excel spread sheet developed for Florida DOT (FDOT) is also available for use in calculating complex pier foundations. It can be downloaded from FDOT's website (http://www.dot.state.fl.us/rddesign/Drainage/Bridge-Scour-Policy-Guidance.shtm).

Based on the stream stability and geomorphic assessment of the bridge site, a note is to be added on the BSR with the pier scour calculations stating whether or not the local pier scour was calculated based on potential channel migration or no channel migration. If there is potential for channel migration such that the channel could migrate to the pier location, then the pier scour should be calculated based on the depth of flow from the channel bottom prior to scour. If there is no potential for channel migration, then the pier scour should be calculated based on the depth of flow at the pier location prior to scour.

8.6.2.3 Abutment Scour

Evaluate abutment scour for all vertical abutment bridges or spill-through abutment bridges that have less than the minimum 10 ft. setback from any point on the channel bank or bed as noted above in 8.6.2.1. Abutment scour evaluation is not required for spill through bridges that are designed based on the minimum bridge length or greater unless it is determined through the overall assessment of the stream stability that abutment scour may be a concern.

The NCHRP 24-20 *Estimation of Scour Depth at Bridge Abutments* (69) method outlined in Chapter 8 of HEC-18 should be used. It should be noted that the NCHRP 24-20 method calculates both abutment and contraction scour. The equations and procedure are as follows:

$$y_{max} = \alpha_A y_c$$

$$y_c = y_1(q_2/q_1)^{6/7}$$

$y_s = y_{max} - y_0$

where:

y_{max} = Maximum flow depth resulting from abutment scour, ft.

y_c = Flow depth including live bed contraction scour, ft.

$\propto_A$ = Amplification factor for live bed conditions.

y_1 = Hydraulic depth in the upstream (approach) main channel, ft.

q_1 = Upstream unit discharge, ft^2/s. Estimate by dividing the upstream channel discharge by the upstream channel top width.

q_2 = Unit discharge in the constricted opening accounting for non-uniform flow distribution, ft^2/s. Estimate by dividing the total bridge opening discharge by the total bridge opening width.

y_s = Abutment scour depth, ft.

y_0 = Flow depth prior to scour, ft.

After calculating q_2/q_1, the design engineer should use Figures 8.9 and 8.10 of HEC-18 to compute $\propto_A$. The values of y_c, y_{max} and y_s may then be calculated based on the equations above.

Froehlich's Abutment Scour Equation or the HIRE Abutment Scour Equation as outlined in HEC-18 may be used if determined to be more applicable and approved by the reviewing engineer.

8.6.3 Plotting Scour

The cone of influence (scour hole side slopes) for total scour to be shown on the bridge profile view of the BSR should be at least 1.4 H: 1 V; however, HEC-18 suggests using 2 H: 1 V (ref. 11, Section 7.8). If only contraction scour is calculated, the design engineer may plot scour depth from channel bottom prior to scour. The width of the bottom of the contraction scour should match the channel bottom width. If there is an existing scour hole under the existing bridge, do not add the calculated scour depth to the existing scour depth, unless the existing scour depth was used in the y_2 calculation of scour and in the bridge hydraulic analysis. Show the depth of calculated scour relative to the projected natural stream bed; an example is illustrated in Appendix R.

Based on the location of piers, the theoretical scour may be plotted as follows:

- Pier is in main channel

  Add contraction and pier scours as the maximum scour and plot it below the thalweg elevation at the pier location. Depth of flow and velocity for pier scour should be based on channel bottom elevation prior to scour. The width of the bottom of the pier scour should be the width of the pier. Plot both the side slopes of the pier and the contraction scours at 1.4:1.

- Pier is not in main channel, but may be later due to channel migration

  Add contraction and pier scours as the maximum scour at the pier location and plot it from the thalweg elevation. Depth of flow and velocity for pier scour should be based on channel bottom prior to scour. The width of the bottom of the pier scour should be the width of the pier. Plot both the side slopes of the pier and the contraction scour at 1.4:1.

- Pier is not in main channel with little potential for migration

  Plot contraction scour as noted above. Plot pier scour based on depth of flow at pier location prior to scour. If cone of influence of contraction scour intersects pier location below natural ground at pier, plot pier scour from this point. The width of the bottom of the pier scour should be the width of the pier. Plot both the side slopes of the pier and the contraction scours at 1.4:1.

- Abutment scour

  Use NCHRP 24-20 Method to plot the abutment scour. Begin the plot of the scour at the lowest point in the stream bed out to the ends of the bridge end bents. Note that the NCHRP 24-20 Method computes both contraction and abutment scour. If Froehlich's or Hire Abutment scour equations are used, plot abutment scour from ground elevation at abutment.

8.6.4 Documentation of Scour on the BSR

The design engineer should include the following information in the "Additional Information and Computations" section of the BSR:

- The overall assessment of the stream stability and its determination in the scour evaluation
- If pier is subjected to potential channel migration.
- Appropriate scour computations during each flood event
- Evidence of existing scours in and around the main channel, interior and end bents

The design engineer calculates the theoretical scour based on the guidelines outlined in this section. This information must be documented on the BSR, which is provided to the Geotechnical Engineering Unit for their use in developing the Design Scour Elevations. Based on the Geotechnical Engineering Unit's Subsurface Investigation Report, the Design Scour Elevation may be adjusted from the Theoretical Scour Elevation on the BSR. The Geotechnical Engineering Unit and/or the Structures Management Unit may consult with the Hydraulics Engineer throughout the scour evaluation process as necessary. (76)

8.6.5 Scour for Coastal/Tidal Bridges

The scour equations developed for inland rivers are also recommended for use in estimating and evaluating scour for tidal flows and storm surge (HEC-18, Chapter 9). The design engineer should reference section 8.9 of this chapter for guidance in modeling coastal/tidal bridges.

Generally the tide-influenced rivers are characterized by river flows, tidal fluctuations, waves and storm surges. If a structure is affected by both riverine flooding and tidal/storm surge flooding, the design engineer should determine if the worst case conditions of discharge, depths and velocities occur due to tides and storm surge or by inland floods. FEMA, USGS, NOAA and USACE records, maintenance records and local interviews are good source of flood records, such as precipitations, flood discharge, durations, depths and velocities, etc. In some instances it may be necessary to evaluate scour based on the flooding that would occur from storm surge backwater runoff and the scour that would occur due to riverine flooding conditions and use the worst case. There may be other cases where the hydrodynamic force is mainly driven by tide, wind and storm surge. An example is the design of transportation facilities along the coast over tidal inlets and estuaries that warrant the use of more detailed hydraulic models.

If the specific variables required for the scour analysis are available from the hydraulic model used in the design of the bridge, then the design engineer should use these.

The design engineer may use one of the following two methods for the scour calculation due to storm surge - Simplified Storm Surge or Level III Wave Vulnerability Study Method:

<u>Simplified Storm Surge Method</u>

1. Compute the volume of storm surge by multiplying the design basin area by the average depth of storage, i.e. the difference of the ground and design flood elevations or overtopping elevation, whichever is lower.
2. Determine the flood discharge which is the volume of storage divided by the duration of surge; available from nearby rain gage sites, or a minimum of 6 hours.

$$Q = A \times d \times 43{,}560 / (t \times 3600)$$

Where:

Q = discharge, cubic feet per second

A = drainage area, acres

d = average depth of storage, ft

t = duration of surge, hrs.

3 Determine average flow velocity through the bridge opening by dividing the discharge by the bridge opening area (for the design scour flood frequency depth).

4. Determine discharge in the upstream channel section using the depth of flow (for the design scour flood frequency depth), channel geometry, channel slope and Manning's n values. This will require the use of a single section hydraulic analysis of the upstream channel section.
5. Calculate scour using the applicable scour equations for contraction, pier, and abutment scour outlined in the previous sections, as applicable.

Level III Wave Vulnerability Study Method

In July 2013 NCDOT entered into a contract with Dr. Max Sheppard, Ph.D., P.E. of Ocean Engineering Associates to develop the *NCDOT Bridge Superstructure Level III Wave Vulnerability Study* (56). This study provides Level III storm surge and wave analyses for use by structure design engineers to compute design water levels and wave parameters, which are needed to analyze the forces and moments which act against the dead weight of the bridge members. The study includes hindcasting 62 of the most severe storms in the state over the last 160 years; developing extreme value analyses on water elevations, wave heights, and depth averaged current velocities in the state's coastal areas. A complete list of these design parameters is available on the Hydraulics Unit website. The design engineers should use them in the development of a BSR, unless a site-specific flood model is deemed more appropriate. The design engineer should develop the following tidal scour design parameters based on data available from the Wave Study:

- Velocity of flow and depth of flow (for the design scour flood frequency) at the bridge crossing.
- Discharge through the bridge opening based on the area of the bridge opening (for the design scour flood frequency depth) multiplied by the velocity of flow.
- Discharge in the upstream channel section using the depth of flow (for the design scour flood frequency depth), channel geometry, channel slope and manning's n values. This may require the use of a single section hydraulic analysis of the upstream channel section.

The Hydraulics Unit should be contacted to obtain the site-specific GIS data associated with this study, which includes the 5-, 10-, 25-, 50-, and 100-year return intervals. (If bridge overtops below 5-year interval, use 5-year data as minimum for scour analysis.)

Computation of scour can then be performed using the applicable scour equations for contraction, pier, and abutment scour outlined in the previous sections, as applicable.

8.7 Economic Consideration

When more than one alternate will satisfy all control factors for a site, the evaluation and selection of an optimal alternate should include a cost analysis to ensure that the selected alternate will be the most cost effective over the structure's life cycle.

8.8 Documentation of Design

All information pertinent to the selection of the optimal final design alternate shall be documented in a manner suitable for review and retention, including:

- Complete the BSR (Appendix E). In addition to the information already included at the beginning of the BSR preparation, also show the proposed structure(s) and roadway grade in plan and profile, including crown grade elevation, superstructure, low chord, bent locations, limits of shoulder berm gutter (if applicable), riparian buffer zone (outer limit only, where applicable), specification of deck drainage accommodations, limits and elevations of rip rap and any channel modifications, typical bridge section, and any necessary details. In the bridge profile drawing, it is also important to show water surface elevations for Q_{design}, and Q_{100}. All water surface elevations should be expressed to nearest tenth of a foot (0.1 ft.).
- Provide (in the interior gridded area of the BSR) a performance table of the natural, existing (if applicable) and proposed conditions water surface elevations at the upstream toe section for the following discharges: Q_{10}, Q_{design}, Q_{100}, and Q_{500} (or $Q_{overtopping}$, if less). The distance upstream of the bridge face at which the proposed conditions water surface elevations are referenced should be specified.
- Include scour analysis computations on the BSR. Plot estimated scour depths on the profile view for both the 100-year and 500-year return intervals (or for the overtopping discharge, if less, respectively).
- If applicable, the following note should be included in the Additional Information and Computations section of the BSR: "No upstream or downstream structures that were in place at the time this project was designed will be adversely impacted by this bridge project."
- Provide digital scan of sealed and approved BSR for digital archive record.
- Provide copies of hydraulic computer model data files, with complete input and output, supporting (and consistent with) corresponding design documentation.

8.9 Coastal / Tidal Bridges

Design and analysis of stream crossings in the coastal region that are subject to the effects of tidal flows and storm surge follow a similar procedure to that outlined for riverine crossings. However, there are major differences in the hydrologic and hydraulic analysis phases. The design engineer is referred to the basic Tidal Prism procedure discussed in HEC-18 (11), as well as more information on this and other more detailed one and two dimensional tidal crossing modeling guidance presented in HEC-25 (12, 72). Crossings of tidal inlets, bays and estuaries present special design challenges, and hydraulic design of such bridges should be closely coordinated with the State Hydraulics Engineer. A map showing approximate coastal limits of tidal influence is provided in Appendix K (61). Tidal influence should also be confirmed by field evidence and reports from local residents familiar with the project site. For information on calculating bridge scour for coastal / tidal bridges, refer to section 8.6.5.

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9 CULVERTS

9.1 Overview

A culvert in this chapter is defined as a hydraulic conduit that conveys flow through a roadway embankment. The most commonly used culvert shapes are circular, rectangular, elliptical, and arches. They range in size from large multiple barrel culverts to a single 18-inch diameter pipe, which is the minimum size for cross-drainage. The design process for culverts is similar to that for bridge crossings in that it involves: design documentation, data collection, hydrologic analysis, hydraulic analysis and design, and economic consideration.

9.2 Design Documentation

Development of a Culvert Survey and Hydraulic Design Report (CSR, Appendix E), is required for any structure that is on a FEMA regulated stream, or has a hydraulically effective total waterway opening of thirty (30) square feet or more, excluding any area of the culvert that is buried below the streambed. For culverts with a waterway opening of less than 30 square feet, design data should be summarized on the Pipe Data Sheet (Appendix G). All design data in the CSR or Pipe Data Sheet should be based on either HEC-RAS (22-24) hydraulic models or HDS-5/HY-8 (55) results, as applicable.

Documentation on the CSR should include, but is not limited to, the following:

(a) Plot and label the proposed structure in plan and two profile views: along roadway alignment and along the structure alignment. Note roadway centerline station, skew, and grade point elevation. Box culvert dimensions are typically specified in terms of the number of barrels at a given span dimension by rise dimension (e.g. 2 @ 10 ft. x 6 ft. RCBC). The drawing scales in the CSR are typically 1 inch = 50 feet horizontal and 1 inch = 10 feet vertical. Information should be limited to that which is pertinent to the structure sizing and location.

(b) Show centerline invert elevation (or top of footing elevation for "bottomless" culvert) and slope. Note: Precise length and end invert elevations are determined by Structures Management Unit.

(c) Show normal, design and 100-yr. water surface elevations on all views.

(d) Enter all required data for selected structure as completely as possible on the CSR. It is helpful to enter "N/A" in data fields which are not applicable. Use the Additional Information and Computations section to document pertinent important design information not covered elsewhere in the CSR.

(e) Note software and versions used for computations. Supporting computer data files (e.g. HEC-RAS, HY-8, HDS-5) and summaries must be included in project documentation.

(f) Complete the performance table for the proposed structure with a comparison to the natural and existing conditions (if applicable) stage-discharge relations.

9.3 Culvert Data Collection

Information gathered during the pre-design study (see Chapter 3) and field survey (see Chapter 5) relative to each particular crossing or all crossings in general is to be assembled. Prior to development of the final design, the following information and guidance should be followed to begin preparing the appropriate documentation.

9.3.1 Culvert Data – Profiles Views

There are two profiles that are included in the CSR. One is the longitudinal profile of the roadway showing the floodplain section and the roadway vertical alignment grades for both the existing and proposed conditions. On this profile, conventionally, the culvert opening and natural ground are depicted at the upstream face; if different convention is used, label for clarification. The other profile is along the centerline of the structure, depicting the layout of the culvert relative to the stream.

(1) The longitudinal profile along the roadway alignment:

The longitudinal profile should include: natural ground lines upstream (and downstream also, if significantly different), channel base and banks, roadway grade for both the existing and proposed conditions, existing and proposed culverts, water surface elevations (as of date of survey, and normal - if different), 100-year floodplain limits, historical flood elevations (including dates of occurrence, and estimated frequency), utility elevations, controlling backwater feature elevations (buildings -finished floor elevations and lowest adjacent grade, roadways, driveways, other drainage structures, overtopping controls, etc.), and general classification of stream bed and bank materials (clay, sand, gravel, etc.). The low point of the roadway profile is the point at which roadway overtopping will occur. It is prudent to note this location and elevation on the profile.

(2) The centerline profile of the structure:

This profile should include: stream bed, top of banks, existing and proposed roadway cross-sections, existing and proposed culverts, normal water surface (vegetation line – a.k.a. ordinary high water) profile, historical flood levels, controlling feature elevations properly positioned along the profile, and rock line, if identified. The purpose of the centerline profile is to establish the length and inverts of the proposed culvert by superimposing the culvert barrel on the roadway cross section and stream bed profile. If an existing culvert is to be retained and extended, its type, condition, top slab and interior web thickness, slope, and opening, should also be noted.

Any additional stream details utilized for design or needed for channel realignments are to be plotted on the CSR. Note: These also need to be included on details sheets in the roadway plans to ensure they will be followed and utilized during construction.

9.3.2 Culvert Data – Plan View

Information to be provided on the plan view includes, but is not limited to:

(1) Natural features – stream/water edges, banks, ground cover, wetland boundary, buffers
(2) Manmade features - buildings, houses, roads, driveways, existing drainage, utilities, etc.
(3) Proposed roadway and fill slope limits, retaining walls, easements, right-of-way
(4) Proposed drainage structure(s), channels, rip-rap, etc.
(5) Floodway Boundaries designated and regulated by FEMA
(6) Other information, such as flow direction, north arrow, survey line and stations, land cover, etc.

9.3.3 Cross Pipe Data

For any culvert with total waterway opening of less than 30 square feet and on a stream that is not regulated by FEMA, its design data can be summarized on the Pipe Data Sheet (Appendix G). The design engineer will also need to reference the drainage plans for topographical and proposed layout information.

Note that driveway pipes in roadside ditches should be sized to convey the same discharge as that for which the ditch is designed (see Chapter 11 Roadside Ditches and Channels). Generally, for driveway pipes, design documentation on Pipe Data Sheets is not required; however, the design engineer may elect to do so for those which are 48 inches in diameter or larger.

9.4 Hydrologic Analysis

The hydrologic analysis for a culvert differs from that for bridges primarily due to the smaller drainage areas involved; however, they may be similar for larger culverts. For more guidance regarding hydrologic analysis, please refer to Chapter 7 Hydrology.

The hydrologic analysis for culvert design entails:

(a) Determination of the drainage area for the site.
(b) Developing flood discharges:
    1. Q_d - design discharge, as listed in Table 7-1
    2. Q_{10} - 10 year discharge
    3. Q_{100} – 100 year discharge
    4. Q_{ot} – overtopping discharge, if less than Q_{500}
    5. Q_{500} – 500 year discharge, if less than Q_{ot}

If the stream crossing is in a FEMA Flood Insurance Study (FIS), the Base Flood discharge in the FIS shall be used to assess the flood impact and compliance with FEMA's NFIP. If an error is found in the FEMA hydrologic analysis, an alternate analysis method may be warranted. The design engineer may request a review from NCFMP and/or the State Hydraulics Engineer for guidance and approval of an alternative for determining the discharge rates.

(c) Record pertinent hydrologic analysis data on the CSR, such as land use change, stream gage, physical changes (dam, impoundment, etc.).
(d) Provide a performance table of the natural, existing (if applicable), and proposed conditions flood elevations at the upstream toe section for the following discharges: Q_{10}, Q_d , Q_{100}, and Q_{500} (or Q_{ot}, if less). The location of the flood elevations that are compared should be clearly identified (for example: "at section 1001, 15 ft. upstream of culvert inlet").
(e) Include details and typical cross sections inside and outside the culvert that depict the design features necessary to mimic the natural channel, such as back fill of native bed materials, benches, sills and baffles, energy dissipators, etc.

9.5 Hydraulic Analysis and Design

9.5.1 Design Criteria

The first step in developing a CSR is to establish the applicable design criteria and constraints prior to commencing actual structural sizing and location. To the maximum extent practicable, every effort should be made to avoid or minimize adverse impacts to the natural and human environments. A sound culvert design should include consideration for proper location and alignment, adequate opening, safety of the traveling public, debris loading, channel stability, sediment transport, post-construction maintenance, outlet channel protection, life cycle of material, etc. The design engineer may reference Appendix F Item 3 – Culvert Avoidance and Minimization Design for guidance.

9.5.1.1 Material Selection

The selection of a culvert may vary depending on its location, subsurface materials, and constructability. The most commonly used structures are reinforced concrete box culverts (RCBC), reinforced concrete pipes (RCP), corrugated steel pipes (CSP), and corrugated aluminum alloy pipes (CAAP). Of those structures, the most common shapes are rectangular, circular and arch. Depending on the site constraints as well as the size and type of structure that are needed, the design engineer should follow the applicable guidance below:

Pipe culverts:

Material selection, associated fill-height limitations, and pipe installation methods should follow the applicable guidance prescribed in the NCDOT Pipe Material Selection Guide (Appendix H), Chapter 5 of the NCDOT Roadway Design Manual (15), and Standard No. 300.01 "Method of Pipe Installation", NCDOT Roadway Standard Drawings (16).

Box culverts:

Box culverts are typically comprised of reinforced concrete, either precast or cast in place. There are also large metal structures, arches and box shapes, with and without bottom plates that can be considered for sites requiring large opening and/or spans. However, unless site constraints dictate other culvert type, the design of the culvert should be developed based on a four-sided, cast-in-place reinforced concrete box culvert. Any culvert design alternates to the approved CSR proposed by the contractors during construction should be reviewed and approved by the State Hydraulics Engineer. Maximum fill height tables for some standard size metal arch structures are provided in Appendix H.

9.5.1.2 End Treatment

Headwalls are generally used on the inlet end of a 36-inch diameter pipe culvert or larger. Maximum height of headwalls shall be one foot above the pipe structure. Neither Mechanically Stabilized Earth (MSE) nor Modular Block walls are considered appropriate for culvert headwall application. If the culvert is 150 feet or more in length and functions in inlet control, an improved inlet design may be considered. The outlet end of a pipe does not require an endwall, unless an exception is warranted, such as limited right-of-way, buoyancy on metal pipes, eroded channel, pipe-disjoint potential, etc. For guidance on end treatment of parallel pipes, reference section 5-20, of the *Roadway Design Manual* (15).

9.5.1.3 Allowable Headwater

The allowable headwater elevation is established based on an evaluation of flood elevation, freeboard, upstream structures, and proposed roadway elevations. The headwater depth is measured from the design flood elevation to the invert of the inlet of the culvert and generally should not exceed the lowest upstream shoulder (overtopping) point elevation of the roadway or an elevation about twenty percent higher than the height of the culvert, whichever is lower. For routes functionally classified as Major Arterials (Interstates and primary routes), a minimum freeboard of 1.5 feet is recommended. Other factors to consider include impacts to adjacent properties, potential damage to the culvert and roadway, level of service, cost, safety, channel stability, floodplain regulations, available detour routes, etc.

For a culvert replacement, the headwater of the proposed culvert should not exceed that of the existing culvert during the design flood and 100-year events. An exception may be allowed when it is located in a rural area with no appreciable flood damage impact to the floodplain or adjoined properties. For a road project on new location, the new culvert should not result in more than one (1) foot of backwater over the natural condition. Also refer to guidance regarding backwater in Chapter 8, Section 8.5.2.2.

If the replacement or new culvert is on a FEMA regulated stream, FEMA's base flood elevation (BFE) should be used as the allowable headwater elevation to size the culvert. If the proposed design would result in a change in BFE, the design engineer should obtain a Conditional Letter of Map Revision (CLOMR) or Memorandum of Agreement (MOA) approval.

9.5.1.4 Multiple Barrels

Often, multiple barrels may need to be considered such as when roadway embankment is low in height or the channel is shallow and wide. The recommended minimum barrel dimension for a box culvert is five (5) feet in both width and height. A multiple barrel box culvert is more economical than a single barrel of the same hydraulic conveyance, due to its structural requirements for the top slab member. When the total width of the multiple barrels is larger than that of the channel, a review should be made to evaluate the need for barrels to be set at different elevations to minimize head cut, channel instability, and aggradation.

9.5.1.5 Sills and Baffles

Sills are vertical walls attached to the culvert bottom, placed at both the inlet and outlet of the culvert to mimic the natural channel opening. Baffles are vertical walls attached to the culvert bottom placed at designed intervals inside the culvert to maintain a low flow channel for aquatic organism passage. In general, one barrel passes normal flow and the others collect sediment and debris. Normally all multiple barrels are built on the same elevation. The low-flow barrel(s) is (are) buried one foot below the streambed and aligned with the natural channel; other barrels are installed with engineered sills to mimic the existing channel width.

The force of the high floods may result in a natural flushing of sediment and debris out of the barrels, depending on the available headwater, vegetation growth, backwater from the receiving stream, etc. If there is heavy accumulation of sediment in the barrels of an existing culvert, the cause and source of the sediment accumulation should be investigated, and mechanical removal of sediment should be considered. If site conditions clearly indicate that excess sediment inside the barrel would be flushed out of the barrel in high water events, the design engineer may perform the hydraulic analysis on the basis of the total clear width and height of the barrel (excluding the buried portion) being available for flow conveyance. Conversely, if a culvert is in an aggregated channel and no stream restoration is planned, the total clear width and height should not be assumed effective for flow conveyance in the design. Sills are normally placed in each barrel of multiple barreled culverts to retain the native material in the culvert as well as to minimize head cutting.

Normally, native material is preferred to be used for backfilling culverts. Refer to guidance provided in Appendix F Item 1 for design details for sills and baffles. For additional information and guidance regarding accommodations to facilitate aquatic organism passage and habitat, see Appendix N Stream Crossing Guidelines for Anadromous Fish Passage and FHWA *Culvert Design for Aquatic Organism Passage* HEC-26 (35). Appendix N also includes a reference guide which shows the distribution of potential anadromous fish habitat streams in North Carolina.

9.5.1.6 Length and Alignment

Culverts must generally be long enough to accommodate the proposed roadway section with a 2:1 fill slope, or flatter, from shoulder point to the top of pipe or top of roof slab of box (not headwall). To the extent practicable, a culvert should be aligned with the natural channel with minimum transitions made between the opening ends of the culvert and natural channel. When significant channel realignment (other than minor alignment adjustments at the inlet and outlet) is required, a natural channel design may be utilized (see Chapter 11). In general, pipes and box culverts should be aligned with the existing channel. The skew that is referenced in the CSR is defined as the angle measured clockwise from the centerline roadway alignment in the direction of progressing stations (i.e. “line ahead”) to the centerline of the culvert. The culvert should be skewed to align with the direction of flow. If a culvert extension requires a bend to better align with the stream, the existing culvert should be extended a minimum of five feet along the existing structure alignment before applying the bend. Note that an added bend in the culvert will incur an energy loss which must be accounted for in the hydraulic computations. Bends in culverts should be avoided if the potential for debris to become lodged is apparent.

9.5.1.7 Slope and Sediment

Pipe or box culverts should be constructed on slopes that are consistent with the existing channel to minimize channel aggradation or degradation. Most culverts are constructed on slopes that are less than ten percent (10%). For concrete pipes on steep slopes, a junction box and/or an end wall is recommended at the outlet. Culverts on steep slopes may result in major maintenance issues, such as deformation from negative pressure, seepage, joint separation, outlet scour hole, sink hole, etc.

Normally the inverts of a culvert should be set at an appropriate depth below the natural bed to ensure the passage of aquatic organisms. This depth may range from a few inches for small pipes to one (1) foot for large culverts (refer to Appendix H, Pipe Bury Depths table). All box culvert inverts should be set a minimum of one (1) foot below the natural bed (unless extending an existing culvert that is not buried). If shallow, non-erosive bedrock is found three (3) feet or less below the streambed, proposal of a bottomless (“three-sided”) culvert may be considered. Confirmation from the Geotechnical Unit on the depth of the rock line along the length of the proposed culvert is required.

Most culverts do not encounter sedimentation or head cut problems if they conform to and are aligned with the natural channel. A stable channel is expected to balance erosion and deposition of sediment, achieving equilibrium over time. If a culvert is in a degrading channel, it may result in upstream head cutting and scour holes downstream. Examples are entrenched downstream channel, urbanized channelization, channel straightening, etc. If a culvert is in an aggrading channel, it may accumulate sedimentation inside and outside the barrel, which may require periodic channel and culvert cleanout to maintain design conveyance. Examples are erosion from development in the watershed, flow blockage, ponding downstream, etc. If the culvert and/or channel are heavily silted, the design engineer should account for the resulting reduction in hydraulic conveyance, unless the excessive sediment is proposed to be removed from both the channel and the culvert and measures provided to prevent recurrence of the heavy siltation. The design engineer may use HEC-RAS to perform sediment transport and mobile bed computations to determine the available hydraulic conveyance of the culvert during the flood event of interest.

9.5.1.8 Tailwater

The computed normal water depth for each discharge level being evaluated generally establishes the tailwater depth. For culverts which are not on FEMA-regulated streams, tailwater depth may be determined by a simple single section normal depth calculation, such as that provided in HY-8 (55). For those on FEMA-regulated streams, tailwater should be determined using HEC-RAS (discussed below). Effects of downstream controls and constrictions must also be considered. Tailwater calculations should be documented in the Additional Information and Computations section of the CSR or on the Pipe Data Sheet, as applicable.

9.5.2 Culvert Design

Culverts which are not on FEMA regulated streams may be analyzed using the FHWA's *Hydraulic Design of Highway Culverts, Hydraulic Design Series No. 5* (HDS-5) (14) methodology or by HEC-RAS (22-24), as appropriate. HEC-RAS should be used if proposing to replace a bridge with a culvert or in situations where a more detailed step backwater analysis is needed.

Special design situations that may affect the load bearing of the structure should be coordinated with the Structures Management Unit as early as possible in the design process. Examples are pipe connecting to the culvert, traverse utility lines inside or adjacent to the culvert, "Y" culvert junction, bend in culvert, etc.

9.5.2.1 HEC-RAS

HEC-RAS should typically be used when any of the following apply:

- Stream is in a regulated FEMA flood zone
- Need to assess flood impact by the proposed crossing to structures on adjoining properties
- Establish water surface elevations (by step backwater analysis) for a culvert design
- Determine backwater caused by a bridge for the existing and proposed conditions

9.5.2.1.1 General Modeling Guidance

The culvert hydraulic analysis routine in HEC-RAS is similar to that for bridge hydraulics, except that the equations for inlet control in FHWA's HDS-5 (14) are used where applicable to compute the energy losses. HEC-RAS can model many different culvert shapes. However, it does not include a shape corresponding to that of a corrugated aluminum box culvert, which is commonly used in North Carolina. The design engineer may refer to Appendix F Item 4 for modeling guidance for a corrugated aluminum box culvert. Bottomless ("three-sided") culvert structures typically have either a flat top or arched top waterway opening. (An arched-top structure may be modeled as a flat-top structure, ignoring flow area in the arched-top portion of the opening in HEC-RAS runs.)

As a one-dimensional flow modeling tool in culvert analysis, HEC-RAS computes the energy grade elevation with the initial assumption that all flow is going through the culvert. The culvert will typically be flowing full and will be submerged, before the flow overtops the road. If the computed energy grade elevation is greater than the weir (overtopping) elevation, then weir flow occurs, and HEC-RAS performs an iterative procedure to balance weir and culvert flows to determine the water surface elevation. However, the weir (overtopping) flow may not occur at the roadway location directly above the culvert. The design engineer should review the roadway profile and floodplain to determine where the minimum elevation for weir flow (overtopping) will occur. For example, a culvert may not be flowing full due to a low lying bank that allows the water move away from the culvert, through a ditch and across the road.

9.5.2.2 Debris Consideration

The culvert opening should be reasonably sized to provide for debris passage. The general limitation of design headwater depth to not exceed the culvert opening height by more than about twenty percent has proven to limit debris problems to acceptable levels. Where experience or physical evidence indicates the watercourse will transport excessive debris, special debris controls (e.g. deflectors) may need to be developed or the estimated capacity of the structure reduced to reflect the potential for debris blockage.

9.5.2.3 Evaluation of Outlet Velocity

All stormwater outlets must be in compliance with NC Statute 15A NCAC 04B.0109 regarding stormwater outlet protection. After a given culvert size has been determined to be adequate for conveyance of the design discharge, it is important to evaluate the ten-year outlet velocity to ensure the culvert will not result in an adverse effect downstream. If the partial flow outlet velocity for the ten-year discharge (Q_{10}) exceeds the scour velocity for the receiving stream, placement of rip rap or other acceptable outlet protection is required. Refer to the ditch stability charts (Appendix J) to determine acceptable flow velocity. Use the greater of tailwater depth or normal flow depth in the culvert to determine the partial flow outlet velocity. In HEC-RAS, use the downstream culvert velocity (Culv Vel DS) for this evaluation. Chapter 11 Roadside Ditches and Channels provides more detailed guidance regarding ditch and channel analysis and design criteria.

9.6 Economic Consideration

When more than one alternate will satisfy all control factors for a site, the evaluation and selection of an optimal alternate should include a cost analysis to ensure that the selected alternate will be the most cost effective over the structure's life cycle.

9.7 Construction Sequence

See Chapter 12 Erosion and Sedimentation Control, Section 12.3 regarding the culvert construction sequence plan.

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10 STORM DRAIN SYSTEM

10.1 Overview

The purpose of a storm drain system is to prevent adverse impacts to the existing drainage and to remove water from the roadway surface, subgrade, and embankment. It consists of pavement drainage, inlet structures, storm drain pipes, junctions, manholes, stormwater storage facilities, hazardous spill basins, and outfalls. The design process for storm drain systems usually follows the basic steps of planning/data collection, hydrologic/hydraulic design, and outlet analysis. The pavement and inlet design may be accomplished by a computer program which follows the procedures of HEC-22 (6). GEOPAK Drainage (68) is an acceptable software application for storm drain system design. GEOPAK Drainage is the current hydraulic design application that runs within the MicroStation environment. In the event it is replaced by the manufacturer, refer to the Hydraulics Unit web page for any updates.

10.2 Determination of Design Constraints

Information gathered from the planning document and/or early project coordination during the pre-design study and field surveys relevant to the storm drain system should be assembled for design reference, and design constraints identified, including the following:

10.2.1 Drainage of Adjacent Properties

The roadway storm drain system may involve or affect adjacent properties along the roadway. Sometimes improvement of an existing storm drain system may be warranted to alleviate an existing drainage problem. For example adding storage basins or augmenting cross drain conveyance may be needed to facilitate conveyance of increased runoff from offsite drainage. Additional improvements for public health and safety must also be considered, such as providing trash racks, fencing, and warning signage on storage basins or large cross drains where there may be potential drowning or other safety hazards.

10.2.2 Design Frequency and Rainfall Intensity

Roadway inlet locations, capacities, gutter spread, and storm drain pipe system should be analyzed and designed using a ten-year discharge (Q_{10}) with a minimum time of concentration of 10 minutes. An intensity of 4 inches/hour should be used for calculating spread and determination of appropriate locations for inlet placement to collect roadway pavement runoff. For the overall storm drain system and non-roadway inlets (such as yard inlets and drop inlets collecting offsite runoff) design should be developed using the rainfall intensity guidance provided in Chapter 7 Section 7.4.3.2. In sag areas where relief by curb overflow is not provided, the roadway design discharge level (Table 7-1, Ch. 7) should be used for analysis to ensure level of service for anticipated traffic volume is maintained.

10.2.3 Gutter Grade and Pipe Slopes

A minimum gutter gradient of 0.2 percent (0.3 percent desirable) should be utilized. When a lesser gradient is encountered, the gutter must be warped to provide the minimum gradient required for positive drainage. This minimum slope criteria may also be considered to be applicable to pipe slopes in the storm drain system. HEC-22 (6) recommends using the minimum slope required to maintain a minimum full-flow pipe velocity of 3 ft/sec in order to promote self-cleaning. An alternative inlet system, such as a slotted or trench drain, or elongated throat catch basin may be considered for use in sag or low gradient gutter sections. Refer to NCDOT Standard 846.01 for standard gutters used on NCDOT roadways (16).

10.2.4 Inlet types

The standard inlet for typical 2 ft. – 6 in. curb and gutter is a combination grate and curb opening (commonly referred to as a "catch basin" or "CB"), std. no. 840.01 of Roadway Standard Drawings (16). Use of other than standard inlet types for curb sections requires project specific approval. Otherwise, standard grated drop inlets (DIs, 2GIs, etc.) are to be used in shoulder sections, roadway and median ditches, and other appropriate locations. Angled vane grates are recommended for gradients exceeding three percent. Grates with two-inch or less opening width shall be used in areas subject to pedestrian traffic. Traffic bearing inlets and grates (e.g. TB 2GI, TB DI) are to be specified for drop inlets which are placed in or within four feet of a permanent or temporary travel lane. This does not apply to Catch Basins (CBs), which are considered to be traffic bearing. A useful summary of NCDOT standard inlet types with box depths for various pipe sizes is posted on the Hydraulics Unit website in the GEOPAK Applications section. Consideration should also be given to the potential likelihood of a paved shoulder being utilized as a temporary travel lane in deciding whether to call for a traffic-bearing structure. Additional guidance is provided in Section 5-13 of the NCDOT Roadway Design Manual (15).

10.3 Inlet Analysis and Design Criteria

The following specific criteria apply to inlet analysis and design:

- On grades, the curb opening can be ignored in determining inlet capacity. The grate efficiency may be assumed to equal that of a parallel bar grate.
- Inlet capacity at sags should allow for debris blockage by providing twice the required computed opening (i.e. assume 50% blockage). Use design frequency from Table 7-1.
- Inlet spacing shall be sufficient to limit spread as required for safe vehicle maneuverability. Acceptable design spread criteria are specified in Table 10-1. Allowable spread into the travel lane during temporary conditions (detours, phased construction, etc.) should be evaluated based on factors such as traffic volume, road classification, posted speed limit, and lane width, etc. For curb and gutter sections (with no side parking or bike lanes, etc.) the width of the gutter pan is considered the "shoulder" width in Table 10-1.

Roadway Classification	Design speed (on grade) or Sag (low point)*	Design Frequency (yr)	Intensity (in/hr)	Allowable Spread (ft)
Major Arterials	≤ 45 mph	10	4	Shoulder * + 3
(e.g. Interstate,	> 45 mph	10	4	Shoulder *
US, NC routes)	Sag (low point)†	50	4	Shoulder * + 3
Minor Arterials, Collectors, and Local Streets	≤ 45 mph	10	4	½ travel lane
	> 45 mph	10	4	Shoulder *
	Sag (low point)†	25	4	½ travel lane

*Applies to shoulder width 6 ft or greater; for narrower shoulder widths, design spread should not exceed 6 ft. † Sag (low point) criteria is applicable where there is no overland relief.

Table 10-1 Design Frequency and Spread Criteria for Inlet Placement

- On bridges or when the typical roadway section includes a full shoulder (six feet or wider), bike lane, or parking lane, any spread into the travel lane should be avoided. For spread on bridges on urban curb and gutter section roadways, spread may be allowed into the travel lane consistent with that allowed along the approaches to the bridge.
- In evaluating spread for maximum efficiency and safety, remember to consider the height of curb, as flow should not be allowed to exceed the curb height. For standard 6-inch high curb, it is preferable that the design flow depth not exceed 5 inches.
- While there is generally no maximum spacing requirement for inlets, no trunk line pipe should extend more than 500 feet without access on a curb and gutter typical section. For median and side ditch systems in shoulder sections, 700 feet is an acceptable upper limit.
- Longitudinal runs of pipe beneath roadway travel lanes should be avoided.
- A minimum vertical clearance of 0.5 foot from the hydraulic grade line to top of inlet grate or junction is recommended.
- It is desirable that inlets be designed for 100% interception of runoff; however, minor bypass discharge to a downstream inlet is acceptable, provided it is accounted for in design computations.
- Bypass discharge at a superelevation rollover should not exceed 0.1 cfs.
- False sumps should be used downstream of median ditch inlets to provide 100% interception of runoff, analyzed as a low point (sag) inlet.
- Review preliminary design plans for low point (sag) locations in roadway cut sections, which should be avoided if practicable, as they are usually difficult to drain and easily clogged.
- For high volume multilane arterial routes (such as interstates) with more than three lanes sloped in one direction, it may be necessary to break the superelevation to eliminate potential hydroplaning hazard. This should be coordinated with Roadway Design Unit as early as possible.

- On high volume arterial and collector routes with raised median, it may be useful to call for a 2 ft. – 9 in. curb and gutter (requires special detail – not NCDOT standard) in areas where the pavement is sloped toward the high side of the median, with inlets placed to limit spread to no more than 3ft. into the adjacent travel lane.
- Standard Drawings 560.01 and 560.02 (16) should be referred to in evaluating median drainage, as the direction of pavement drainage will differ depending on whether the width of the median paved shoulder is greater or less than 10 ft.

10.4 Pipe System Analysis and Design Criteria

- Storm drain pipes should typically be concrete unless a site limitation, such as grade, corrosive condition, or other reasonable justification can be made to support use of an alternate material. Refer to Appendix H, Item 1 regarding criteria for acceptability of alternate pipe material specification.
- The minimum pipe size to serve a single inlet is 12 inch diameter. For pipes connecting to more than one inlet, pipe under pavement, side drains (driveway pipes), or pipes having a length of more than 100 feet, a 15 inch diameter is the minimum size which should be used. (Minimum size for an open-ended cross pipe functioning as a culvert is 18 inches, excluding driveway pipes). Use of 12 inch or smaller diameter pipe (other than to serve a single inlet or driveway) should be approved by the Hydraulics Unit.
- When differing size pipes enter and exit a junction the desired practice is to match the crown elevations of the pipes when practicable.
- Pipe systems shall not decrease in size in the downstream direction.
- See additional guidance on pipe material selection in Section 10.6.
- Due consideration must be given to method of pipe installation (Standard 300.01) (16) and fill height requirements (Appendix H), as may be warranted.
- Driveway pipes must comply with NCDOT's *Policy on Street and Driveway Access to North Carolina Highways* (60).
- Avoid placement of storm drain systems where it would disturb contaminated soils (identified on the plans) for which the contamination is to be managed by containment rather than removal. If unavoidable, as a minimum, specify a sealed (watertight) system through the contaminated area, which would warrant an exception to the standard Pipe Material Selection Guide (Appendix H). Consult the Geotechnical Unit for guidance concerning any additional measures needed.

10.5 Hydrologic and Hydraulic Design

Storm drain system design is a two phase process involving first a selection of the required surface inlets, followed by the design of a subsurface pipe system to serve the surface inlets. GEOPAK Drainage is an acceptable software application for storm drain system design, which is consistent with the following general design procedure based on HEC-22 (6) guidance:

10.5.1 Inlet Selection and Placement Procedure

1. Prior to commencing the hydrologic/hydraulic analysis of the surface system, a layout of locations requiring inlets should be developed on a set of plans. This would include sag points, upstream of intersections, upgrade of superelevation rollovers, and at locations requiring junction back-of-curb inlets. On curved alignments, it may be necessary to add intermediate inlets to avoid having to construct pipes on a curve, and coordination with the Division is recommended regarding this.
2. With the above noted locations determined, the next step is to analyze the runoff and gutter spread along the roadway to establish additional required inlet locations to meet spread and depth criteria. The hydrologic method used will typically be the Rational Method and follows the guidance in Chapter 7 (Hydrology). The general procedure, as outlined in Chapter 6 (Drainage Plans), should be used to confirm drainage boundaries, flow paths, outlet conditions and other project special design features.
3. The design is to be documented on a form similar to Appendix I Item 1. The inlets, junctions, and outlets or other features (as applicable) should be numbered in a logically ascending order and their location referenced to a project station. If the storm drain system numbering changes by time plans are let for construction, the revised construction numbers should be documented on the design forms for future reference. Some computer programs (such as GEOPAK Drainage) (68) may also require the outlet of a storm drain system, as well as pipe elbows, pipe collars, etc. to be assigned a structure number. Further guidance regarding structure numbering for NCDOT projects is posted on the Hydraulics Unit website in the GEOPAK Applications section.

10.5.2 Storm Drain Design Procedure

1. Following the above inlet selection and location procedure, lay out the pipe system to provide a connecting route of flow from the inlet(s) to the proper outlet point(s).
2. Once initial system layout is completed, the next step is to size the individual pipes.
3. The storm drain design computation form (Appendix I Item 2 – see Section 10.5.2.1 below) follows a systematic design process of developing the pipe network from upstream to downstream. Selection of pipe sizes is accomplished utilizing Manning's flow capacity equation, with the limitations on maximum pipe capacity presented in Appendix I Item 6. Sizing of most systems by this procedure is generally sufficient, and may be automated by a software application (e.g. GEOPAK Drainage).
4. The procedure for hydraulic grade line development is outlined below in Section 10.5.2.2. A check of the system by development of hydraulic grade line is recommended, and can be checked relatively quickly if using software to perform the computations. However, calculating hydraulic grade line manually can be very time consuming. Therefore, if hand computations are being used, the design engineer should consider whether the time and effort needed to perform a hydraulic grade line check of a system is warranted. Conditions that may warrant undertaking this additional design analysis are:
    - Systems with outlets that are subject to high tailwater conditions.
    - Systems that transition from a steep to flat gradient.
    - Systems on a flat gradient, especially if they have substantial junction or bend losses.

10.5.2.1 Storm Drain Design Computations Procedure

Reference Appendix I Item 2, for storm drain system design documentation, as outlined below in order of columns from left to right:

1. Inlet number at upstream end of pipe, corresponding to inlet computation sheet (design number/construction number).
2. Inlet numbers at downstream end of pipe, corresponding to inlet computation sheet.
3. Total cumulative drainage area served by the section of pipe.
4. Cumulative sum of the incremental product of the incremental drainage area multiplied by the corresponding runoff coefficient (Sum CA) for each inlet contributing flow to that location.
5. Length of the pipe between study points.
6. Time of concentration for contributing drainage area to inlet at upstream end of pipe.
7. Flow time for first pipe equals inlet time. Flow time for subsequent sections is a sum of the time of concentration of the previous reach (minimum t_c = 10 minutes) plus time of flow in subject pipe.
8. Enter larger value from items 6 and 7 as the design time. Use 10 minutes as minimum value. For design time greater than 30 minutes, a flood hydrograph or other routing procedure is recommended.
9. Design storm rainfall intensity for duration equal to design time.
10. Design discharge for pipe reach. (Rational method: multiply Sum CA by design intensity.)
11. Invert elevation of pipe inlet.
12. Invert elevation of pipe outlet.
13. Invert slope of pipe.
14. Diameter of pipe. This size is to be selected based on pipe flow capacity (item 16)
15. Pipe material (e.g. M – metal, C – concrete).
16. Capacity is computed using Manning's full flow capacity equation: $Q = (0.46/n)(D^{2.67})(S_o^{0.5})$. A nomograph solution for this equation is provided in Appendix I, Item 3. The capacity utilized for design cannot exceed the values contained in Appendix I, Item 6. Manning's roughness coefficient (n) corresponds to the pipe material specified in item 15.
17. Velocity based on design discharge and selected pipe size (can use charts Appendix I, Item 4 or calculate with Manning Equation and Continuity Equation, Q=VA).
18. Upstream box depth.
19. Remarks – Use to document unusual design conditions, restrictions, allowable pipe material, etc.

10.5.2.2 Hydraulic Grade Line Development Procedure

A hydraulic grade line will provide the potential elevation, under design conditions, to which water will rise in the various inlets and junctions. This can serve as a check for potential unacceptable outflow or pressure problem areas within the system dictating a change in the system design.

Reference Appendix I, Item 7 for hydraulic grade line computations, as outlined below in order of columns from left to right:

1. The inlet or junction number immediately upstream of the outlet (design number / construction number).
2. Water surface elevation at outlet, or 0.8 (D_o) + invert elevation of the outflow pipe, whichever is greater.
3. Diameter (D_o) of outflow pipe.
4. Design discharge (Q_o) for the outflow pipe.
5. The length (L_o) of the outflow pipe.
6. Friction loss (H_f) for full pipe flow. Loss due to flow in the pipe can be computed by multiplying pipe length (L_o) by friction slope (S_f). Friction slope can be determined from pipe flow charts or by using the formula: $S_f = (Q/K)^2$, where $K = (1.486/n)(A)(R^{0.67})$. Sheet 4 - Appendix I, sheet 5 provides values of (K) for various pipe sizes.
7. Contraction loss (H_c). Loss due to contraction of flow at inlet of outflow pipe. Computed by the formula: $H_c = 0.25 (V_o^2/2g)$, where: V_o = flow velocity in outlet pipe (full flow); g = 32.2 ft/sec^2 (gravitational acceleration constant).
8. Expansion loss (H_e). Loss due to expansion of flow into the junction. Use expansion loss from primary inflow line, given by $He = 0.35 (V_i^2/2g)$, where: V_i = flow velocity in inlet pipe (full flow)
9. Bend loss (H_b) loss due to change in direction of flow. Use change in angle of primary flow line. Bend loss is given by $H_b = K (V_i^2/2g)$, where K is the bend loss coefficient from the following list:

90 º K = 0.70	40 º K = 0.38
80 º K = 0.66	30 º K = 0.28
70 º K = 0.61	25 º K = 0.22
60 º K = 0.55	20 º K = 0.16
50 º K = 0.47	15 º K = 0.10

10. Total losses (H_t), sum of friction, contraction, expansion, and bend losses.
11. Inlet water surface elevation. This is the potential water surface elevation within the inlet or junction. (Outlet water surface elevation plus total losses.)
12. Inlet rim elevation or top of junction. It is desirable for the water surface elevation to be a minimum of 0.5 feet below this elevation. If not, the pipe size should be increased or other measures taken as practicable to lower the water level.
13. Remarks.

Repeat the procedure for the upstream junction and plot the potential water surface elevation if above the crown elevation of the outlet pipe.

10.5.3 Storm Drain System Outlet Analysis

The storm drain system design must include an evaluation to determine that the downstream receiving channel and property (including its associated drainage features) will not be adversely affected by increased discharge or erosion from the upstream runoff and is in compliance with NC Statute 15A NCAC 04B.0109 regarding Stormwater Outlet Protection. The design engineer should bear in mind that the intent of this statute, as it relates to NCDOT actions, is to ensure, to the maximum extent practicable, every effort is made to avoid or minimize adverse impact to the downstream channel and the adjacent downstream property as a result of stormwater runoff exiting from NCDOT's right-of-way.

This evaluation should address:

- Potential effects on the receiving stream when identified as an environmentally sensitive stream (reference Chapters 11 and 13).
- Potential effects on the highway facility due to downstream outlet inadequacies.
- Potential effects to other properties due to outlet inadequacies.
- Effect of the highway improvements on the downstream facility. (Percent increase in quantity, velocity, depth, etc.) Typically the two-year, five-year, and ten-year event discharges are evaluated for this analysis.
- Potential corrective measures (with estimate of associated cost).
- Recommended actions.

10.6 Pipe Material Selection

In 2009, NCDOT developed requirements and guidance to foster competition with respect to the specification of alternate types of culvert and storm drain system pipes. These were intended to be commensurate with similar competitive requirements for other construction materials, in compliance with federal law. Current guidance is outlined in Appendix H in a table labeled "NCDOT Pipe Material Selection Guide". This table is also posted on the Hydraulics Unit website. If the hydraulic engineer requires a specific pipe material and class for a given pipe, this should be clearly specified on the design plans. Supplemental tables in Appendix H are provided for reference; however, the "NCDOT Pipe Material Selection Guide" should take precedence if information in the supplemental tables differ.

10.7 Drainage Summary Sheet

The Drainage Summary Sheet in the roadway design plans contains a detailed listing of all the quantities for various pay items associated with the drainage design for the project. This sheet is generally prepared by Roadway Design Unit and checked by the design engineer. To facilitate production, a program has been developed to generate automated quantities from data stored in GEOPAK Drainage (68). Documentation for this is posted on the Hydraulics website in the GEOPAK Applications section.

10.8 Treatment of Existing Pipes

When existing pipe is to be removed, or removed and replaced, this should be noted in the drainage plans. Pipe removal is warranted when the existing pipe is deteriorated and unusable or if it is being replaced in the same location. If the existing pipe is no longer needed for flow conveyance, but it is deemed advantageous to leave in place under the pavement, the design engineer may call for pipe plugs (NCDOT Standard 840.71) (16) at both ends of the pipe. If the structural integrity of the abandoned pipe is a concern with respect to support of the overlying fill material (e.g. a corroded metal pipe), the design engineer may alternatively call for filling the pipe with flowable material. If an existing pipe within the project construction limits is deemed to be in good condition and is recommended to be retained, this also should be called out on the drainage plans.

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11 ROADSIDE DITCHES AND CHANNELS

11.1 Overview

A channel is a conveyance in which water flows with a free surface and may be natural or manmade. A roadside ditch is a man-made channel generally paralleling the roadway surface and distinguished by a regular geometric shape. The design process and analysis requirements for roadside ditches and channels differ. Roadside ditches are roadside and median drainage conveyances that carry surface stormwater off away from the roads and their subgrade drains. For the purpose of this chapter, "channel" shall refer to all open conveyance facilities not classified as roadside ditches or requiring more than a two foot wide base. Although the design procedure presented is general, the guidance provided is intended to address specific criteria and analysis requirements. The design engineer should reference FHWA's HEC-11, (17), HEC-14 (28), HEC-15 (18), Chapter 6 of the *AASHTO Highway Drainage Guidelines* (1), and Chapter 10 of the *AASHTO Drainage Manual* (2) for more detailed design guidance.

11.2 Roadside Ditches

11.2.1 Establishment of Ditch Plan

Establish a ditch plan which shows the proposed ditch locations and flow patterns. This ditch plan is a part of the drainage plan (Chapter 6, Section 6.1 – item 7).

11.2.2 Determination of Typical Ditch Cross Section

Determine the standard or typical ditch cross sections for the project. This is provided by the roadway plans typical sections. When a ditch is required along the construction limits and is not shown in the roadway typical section, the following criteria should be followed in establishing a typical section:

- A standard berm ditch section should be specified at the top of a cut section where required as depicted in Roadway Standard Drawing 240.01 (16). In the event it is necessary to bring water down cut slopes into the highway drainage system when the roadway grade is at a lower elevation than the natural drain which it crosses, it may be necessary to intercept runoff from the berm ditch into a berm drainage outlet, as depicted in Roadway Standard Drawing 850.10-11 (16), to convey the runoff from the top of the cut slope to a storm drain inlet located in the typical roadway cut ditch. Safety bars over the pipe opening may be warranted in neighborhoods where safety of small children is a concern.
- Toe of fill ditches adjacent to shallow fills and flat slopes (4:1 or flatter) should be formed by continuation of the fill slope to a desired ditch depth, provision of a base width, if required, then a stable back slope (2:1 minimum).
- Toe of fill ditches adjacent to high steep slopes should be constructed with a minimum two (2) foot berm. A wider berm is desirable for very high fills to prevent embankment from filling the ditch and for maintenance if access is limited from opposite the roadway side.

11.2.3 Determination of Ditch Gradient

Determine the gradient to be used on all proposed ditches. Roadside ditches included in the typical roadway section should have a grade corresponding to the roadway profile. When the roadway profile grade is less than 0.3%, special roadway ditch grades may be established and noted on the plans. Ditches along the toe of fill will generally parallel the grade of the natural ground at an established acceptable depth. Ditch grades are to be established and plotted on the roadway plans in the profile view.

11.2.4 Investigation of Capacity of Ditch

Roadside ditches are to be designed to contain, as a minimum, the Q_{10} discharge (including temporary detour ditches). The typical roadside ditch section should be established with sufficient depth to drain the pavement subbase and provide flat side slopes for safe vehicle maneuverability. This generally provides very generous capacity for the design flow requirements. Therefore, actual capacity determination can be evaluated on a selective basis at sites on common project grades to verify adequacy and establish limitations on the length of ditch run. If there is a likelihood of future pavement widening toward the median, this should be accounted for in the median ditch drainage analysis and design. Driveway pipes in ditches should typically be sized to convey the same design discharge as that for which the ditch is designed.

The size requirements of the project special side ditches along the toes-of-fill will be established based on an analysis of the design flood. This ditch capacity analysis will be performed using Manning's equation: $Q = (1.49/n)\ A(R^{2/3})\ (S^{1/2})$, where Q is discharge in cubic feet per second (cfs), A is flow area in square feet, S is slope (feet of fall per feet of length), and R is the hydraulic radius in feet.

Discharge determination shall follow the requirements of Chapter 7 - Hydrology. The roadway section including shoulders and slopes shall be considered an urban watershed. This capacity analysis is usually worked in conjunction with the next step of lining evaluation.

11.2.5 Evaluation of Ditch Lining for Stability

The stability of vegetative ditch linings is to be analyzed by use of Charts 1 and 2 in Appendix J. These charts are based on the commonly used 'V' and base ditch sections. However, a procedure and example are included for evaluating other channel configurations. The stability limitation is based on an established acceptable velocity. When applying the chart, if conditions at a particular site are such that the resulting chart value is located to the left of the stability line (velocity under 4.5 ft/sec), a vegetative cover would not be expected to erode. Conversely, if it is to the right of the line, the ditch would be expected to be unstable and erode when subjected to the design flow; therefore, some type of armoring (such as rip rap) should be used.

Charts 3 and 4 in Appendix J are provided to analyze the stability of rip rap ditch linings (Types A, B, and Class I rip rap). They are used in the same manner as Charts 1 and 2 to determine the stability of stone lining under differing ditch shape and flow conditions.

The Appendix J ditch stability design charts were developed in accordance with the procedures in HEC-15 (18) which determine the acceptability of given lining type by comparing the maximum shear stress of the flow to the permissible shear stress of the lining.

The maximum shear stress of the flow in a ditch can be established by the following equation:

$\tau_d = \gamma d S_o$

Where,

- τ_d is the maximum shear stress of the flow (lb/ft^2).
- is the unit weight of water (lb/ft^3). (Typically 62.4 lb/ft^3)
- d is the depth of flow (ft)
- S_o is the channel longitudinal slope (ft/ft)

As the Appendix J charts demonstrate, grass-lined ditches tend to become unstable when flow velocity approaches 4.5 ft/sec or greater. Table 11-1 lists permissible shear stress values for typical non-vegetative ditch liners used by NCDOT:

Liner	d_{50} (in)	τ_p (lb/ft^2)
Class A riprap	4	1.6
Class B riprap	8	3.2
Class I riprap	10	4.0
Class II riprap	12	4.8

Table 11-1 Permissible Shear Stress (τ_p)

Another channel liner used by NCDOT is Permanent Soil Reinforcement Matting (PSRM), which is a synthetic geotextile product typically used for permanent erosion control or in conjunction with certain stormwater control devices, as specified in the Stormwater Best Management Practices Toolbox (34). PSRM should not typically be specified as the primary liner for a roadside ditch or channel; however it may be specified as an alternative liner where Type A rip-rap may not be acceptable, such as within the clear recovery zone or in a homeowner’s front yard. PSRM has a permissible shear stress of 3 lb/ft^2.

Type and dimensions of ditch liner are to be specified in the ditch details shown in the plans. Roadway Standard Drawings 876.01-04 (16) depict standards for riprap placement in channels, drainage ditches, and at pipe outlets. For concrete ditch behind a retaining wall, note that Geotechnical Unit has established standard cells and details which must be included, as applicable, in the design plans. (https://connect.ncdot.gov/resources/Geological/Pages/Geotech_Forms_Details.aspx)

11.2.6 Analysis of Ditch Outlet

Determine any special measures that may be required to mitigate or avoid scour or degradation at or downstream of the ditch outlet. A check should be made of the transition of flow from a ditch to the receiving outlet.

Factors to be considered are:

(a) Is there provision for a smooth transition of flow from the ditch to the outlet?
(b) Will the outlet adequately handle the quantity of flow? Is improvement required?
(c) Is the velocity of flow at the outlet too high for the condition of the receiving channel? Is riprap or other means of energy dissipation justified? (Refer to Chapter 10, Section 10.5.3.)
(d) When the receiving outlet is sheet overland flow, is concentration of flow by the ditch a potential problem? Is some form of flow diffusion required?
(e) Is access to the outlet provided for inspection and maintenance?

11.3 Channels

Channel analysis differs from roadway ditch analysis in that it involves establishing a channel configuration to meet specific site hydrologic, and geomorphic requirements. The requirements for analysis can range from simple sizing of small ditches constructed adjacent to the roadway fill for interception and conveyance of discharge to acceptable outlets, to complex studies of extensive natural stream and river relocation. In addition to the guidance provided in this document, the design engineer should follow FHWA's Hydraulic Engineering Circular No. 15 (18) and Chapters 10 and 16 of the AASHTO *Drainage Manual* (2), for further guidance for small ditch and channel analysis. For larger stream involvement, FHWA's *Highways in the River Environment* (19), *Applied River Morphology* (20), NC Wildlife Resources Commission's *Guidelines for Mountain Stream Relocation and Restoration in North Carolina* (21), NCDEQ (formerly NCDENR) *Stream Mitigation Guidelines* (45), and *Stream Restoration, A Natural Channel Design Handbook* (50) are suggested references. It should also be noted that individual NCDOT Division offices may have established criteria for ditch and channel design which are applicable to construction practices within their own Division; therefore the design engineer should consult with the division to ensure that appropriate and acceptable ditch and channel designs are specified and constructed.

11.3.1 Channel Lining for Stabilization

Rip rap lining may be needed to control erosion. A supplemental geotextile liner may be specified underneath the standard riprap liner where warranted and should be shown and quantified in the ditch details and quantity estimates provided on the roadway plans. For channel capacity and stability analysis, follow the same guidance used for ditch design provided in Sections 11.2.4 and 11.2.5, utilizing the design charts provided in Appendix J.

11.3.2 Realignment of Natural Channels

Realignment of natural streams should be designed and configured to match as near as practicable to the natural channel in alignment and gradient. Minimum disturbance to the natural flow is always the aim of good hydraulic design, except in areas where natural flow is unstable or detrimental, requiring restoration or mitigation measures, which can be incorporated in the highway drainage design.

For minor stream realignment at the inlet and outlet of structures (less than 100 feet total, approximately 50 feet each end), the design engineer should follow guidance provided in "Stream Relocation Guidelines" developed jointly by representatives of the NCDOT and the NC Wildlife Resources Commission in 1993 (Appendix M).

11.3.2.1 Morphological Stream Classification

If relocation of a stream channel is unavoidable, the design of the replacement channel should provide dimension, pattern and profile that affords natural stability. A process of stream classification developed by Dave Rosgen, detailed in *Applied River Morphology* (20), has been widely used and accepted for effective analysis of natural streams and rivers. The objective of classifying streams on the basis of channel morphology is to set categories of discrete stream types, so that consistent, reproducible descriptions and assessments of conditions and potential can be developed.

Some specific objectives of a classification system are:

- Provide methodology for predicting a stream's behavior from its appearance (classification).
- Guide development of specific hydraulic and sediment transport relationships for stream type and state.
- Provide mechanism for comparison of data for stream reaches having similar characteristics.
- Provide a consistent frame of reference for communicating stream conditions and morphology across disciplines.

The general guidance provided in the following sections should be followed in analysis of natural channels.

11.3.2.2 Data Collection for Stream Studies

Data collection includes office study as well as a field survey. Much of the information needed for initial classification can be obtained from topographic mapping and aerial photography. The field survey provides more detailed information for refinement of the initial classification as well as the analysis and design process. It should include as a minimum the collection of the following data:

11.3.2.2.1 Data Needed for Stream Classification

- channel width (bankfull)
- channel depth (section mean)
- maximum depth (at bankfull)
- bankfull cross section area
- slope (average for at least 20-30 channel width reach)
- stream length (20-30 bankfull channel widths in length)
- valley length (20-30 bankfull channel widths in length)
- bed material (type, size [D_{50}])
- bank material (type, size [D_{50}])
- width of flood-prone area

11.3.2.2.2 Data Needed for Stream Analysis and Design

- Channel Dimension
    - pool depth
    - pool width
    - pool area
    - riffle depth
    - riffle area
    - maximum pool depth
- Channel Pattern
    - meander length
    - amplitude
    - radius of curvature
    - belt width
- Channel Profile
    - valley slope
    - riffle slope
    - average water surface slope
    - pool slope
    - pool to pool spacing
    - pool length

11.3.2.3 Establishment of Stream Type Classification

With the above data collected and further determination of stream features such as entrenchment ratio, width/depth ratio, and sinuosity, a stream type classification can be established following the procedure discussed in Chapter 3 of *Applied River Morphology* (20).

11.3.2.4 Evaluation of Existing Conditions

It is important to assess the existing condition of the stream as it relates to stability, state, and causes of changes, potential future impacts, and hydrologic and hydraulic requirements. This assessment process should address:

- the watershed,
- flow regime,
- riparian vegetation,
- bank stability,
- bed stability,
- meander patterns,
- sediment supply and transport,
- debris,
- aggradation/degradation,
- aquatic and terrestrial habitat,
- discharge levels and conveyance requirements
- evolutionary trend.

Stream conditions gathered through the assessment process apply only to the reach of the stream studied, and may vary considerably upstream and downstream as the character of the valley changes. Some stream study reaches may be at such an altered state that existing conditions data are of little value in developing recommendations for a relocated or restored channel. In such a case, a reference stream of similar classification and morphological characteristics can be used as a guide for developing study proposals.

11.3.2.5 Development and Documentation of Proposed Channel Design

The above evaluation process should provide the design engineer with sufficient information and knowledge necessary to develop a recommended channel relocation or restoration proposal that meets hydrological and ecological requirements and provides a natural, stable system. A wildlife resource specialist should be consulted for input during the design process. All information pertinent to the channel design should be documented in an appropriate design report format.

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12 EROSION AND SEDIMENT CONTROL

12.1 Overview

NCDOT was first delegated an erosion and sediment control program by the North Carolina Sedimentation Control Commission in 1974. Controlling accelerated erosion and sedimentation is critical for the protection of water quality in streams and water bodies receiving drainage from NCDOT projects. This chapter addresses erosion and sediment control on NCDOT projects and compliance with applicable state and federal regulations.

12.1.1 Effects of Accelerated Erosion and Sedimentation

Erosion and sedimentation can cause or contribute to a number of water quality related problems including:

- Elevated turbidity
- Increased water temperature
- Decreased dissolved oxygen
- Increased algae growth
- Loss of aquatic habitat
- Reduction in stream conveyance
- Increased flooding
- Reduced storage volume in reservoirs
- Increased filtration costs for municipal water supplies

12.1.2 Erosion and Sediment Control Requirements

- The North Carolina Sedimentation Pollution Control Act of 1973 and Administrative Rules are enforced by the Division of Energy, Minerals and Land Resources - Land Quality Section in the NC Department of Environmental Quality (NCDEQ, formerly NCDENR). The Act applies to land-disturbing activities for public or private development and highway construction and maintenance. Because of the magnitude of land-disturbance conducted by the NCDOT, the Sedimentation Control Commission within NCDEQ delegated authority to the Division of Highways to implement an erosion and sediment control program with periodic project inspections and an annual audit by the Land Quality Section. The NCDOT has responsibility to comply with all statutory and administrative rules and all requirements stipulated in the program delegation.

- The Federal Clean Water Act (CWA) and the National Pollutant Discharge Elimination System (NPDES) require that construction activities control the discharge of pollutants in stormwater runoff including sediment. They are enforced by the United States Environmental Protection

Agency (USEPA) and by the Division of Energy, Minerals and Land Resources (DEMLR) and the Division of Water Resources (DWR) within the NCDEQ (formerly NCDENR) through delegation of authority from the USEPA. An NPDES permit is required in order to discharge stormwater, and in North Carolina, construction activities are covered under NPDES General Permit – NCG 010000. The permit incorporates compliance with State erosion and sediment control requirements along with other stormwater pollution prevention requirements. NCDOT must comply with a specific NPDES stormwater permit (NCS000250), which incorporates the requirements NCG 010000, and state nutrient management strategy rules. Both are discussed in Chapter 13.

12.2 NCDOT Erosion and Sediment Control Program

The Roadside Environmental Unit (REU) within the Division of Highways has primary responsibility for implementing the delegated NCDOT erosion and sediment control program. The REU prepares erosion control plans, develops and maintains erosion and sediment control standards, details, specifications, develops project special provisions, produces training materials for erosion and sediment control and monitors active work-sites for compliance with the Sedimentation Pollution Control Act and NCG 010000.

12.2.1 Erosion and Sediment Control Plans

Within the REU, the Soil and Water Engineering Section is responsible for designing and approving erosion and sediment control plans for land-disturbing activities of one or more contiguous acres associated with NCDOT highway construction. Plan designs consider a number of factors including construction sequencing, existing topography, proposed land grades, soil type, hydrology, design storm, required trapping efficiency for certain devices, classification of receiving waters, critical habitat areas, and other identified environmental concerns.

More information regarding the NCDOT erosion and sediment control program including design requirements for devices used on highway construction projects can be found at:

http://www.ncdot.gov/doh/operations/dp_chief_eng/roadside/soil_water/

12.2.2 Riparian Buffer Rules

At present, riparian buffer rules have been adopted by the NC Environmental Management Commission (EMC) in the Neuse River Basin, the Randleman Lake Water Supply Watershed, the Tar-Pamlico River Basin, along the Catawba River main stem, the Goose Creek Water Supply Watershed and the Jordan Lake Water Supply Watershed. Highway construction projects are subject to these rules and must preserve vegetated riparian buffer zones along streams and rivers. These regulatory buffers provide for only certain types of minimally invasive encroachments. More extensive encroachments must be permitted by the NC Division of Environmental Quality (NCDEQ, formerly NCDENR) DWR. The rules that are currently in effect can be found in 15A NCAC 02B.0233, 15A NCAC 02B.0250, 15A NCAC 02B.0259, 15A NCAC 02B.0243, 15A NCAC 02B.0607, 15A NCAC 02B.0267 respectively. As new buffer rules are adopted or existing rules are modified by the EMC, these regulatory codes will be updated accordingly.

12.2.3 Erosion and Sediment Control Inspections

NCDOT Project Inspectors and the REU Field Operations Sections perform inspections of highway construction activities to ensure compliance with all erosion and sediment control requirements. Plan implementation as well as installation, maintenance and effectiveness of devices are evaluated. A report is generated for all inspections noting corrective actions if needed.

Project Inspectors perform inspections at least weekly and more often after periods of rainfall. Findings are recorded in the inspector's daily report. A list of all needed corrections is given to the contractor with a copy provided the Resident Engineer or the District Engineer for maintenance projects.

REU Field Operations staff inspect monthly. If significant problems or potential violations are observed, an Immediate Corrective Action (ICA) is issued to the Resident or District Engineer. Corrective actions must begin within 24 hours, and grading operations can be suspended until are problems are resolved. Field Operations staff will revisit the site within five (5) working days or seven (7) calendar days (whichever is shorter). Serious violations can result in the issuance of a Notice of Violation (NOV) by the NCDEQ (formerly NCDENR) Land Quality Section and possible enforcement actions.

12.3 Culvert Construction Sequence

The design engineer should provide a culvert construction sequence plan for each culvert that provides a total waterway opening of thirty (30) square feet or greater. These plans are provided to Structures Management, Roadside Environmental, and Traffic Management Units to assist with culvert construction. The construction sequence plan is comprised of a construction sequence narrative and figure, which provide a description of the phases required to construct the culvert to manage water conveyance and erosion control. The construction sequence plan is intended to serve as a reasonable and acceptable method to accomplish construction; however, there may be other methods that are found to be more appropriate and acceptable. Construction sequencing should be discussed and agreed upon during the field inspection. The final construction sequence plan will be developed by the REU and included in the project's erosion control plans.

The design engineer is responsible for the calculations required for the construction sequence plan, including stream diversion flows, pipe and diversion channel sizing for stream flows, volumes for sediment basin and sediment bags, and excavation quantities for diversion channels.

Temporary stream diversions and pipes are to be sized for the mean daily flow, which should be computed based on the normal water surface elevation (vegetation line – a.k.a. ordinary high water) in the channel as determined from field review.

Volume needed for temporary basins or sediment bags for treatment of dewatering effluent from construction areas are calculated using the following formula:

$$V_b = [L \times W \times (NWS+1)]/27$$

Where:

V_b = Volume needed for temporary basin or sediment bags (yd^3)

L= Length of culvert plus required construction access (ft)

W = Width of culvert plus required construction access (ft)

NWS = Normal Water Surface depth (ft)

Note that 1 ft depth is added to the NWS depth to account for base excavation.

Basin volume (V_b) and trapezoidal basin dimensions for a temporary stilling basin per Standard Drawing 1630.04 (16) necessary to provide the target volume can be calculated using the Temporary Stilling Basin Dimensions and Volume Calculator shown in Appendix F Item 5, which can be downloaded from the Hydraulics Unit website.

Required excavation volumes for temporary diversion channels should be estimated by taking the largest excavation cross-section area and multiplying by the length of the diversion channel.

An example of a culvert construction sequence plan is provided in Appendix F Item 6.

The culvert construction sequence plan should include:

1. Narrative describing culvert construction phasing and other noteworthy information
2. A figure depicting the following:
    - culvert construction phases
    - diversion channels or pipes with sizing calculations
    - drainage ditch excavation volume
    - sediment basin or bags with location and temporary drainage easement
    - temporary dikes
    - roadway drainage and roadway features as shown on plans

13 STORMWATER MANAGEMENT

13.1 Highway Stormwater Program

Stormwater runoff is a cause of water pollution in North Carolina and is regulated federally by the Clean Water Act (CWA) and also by state regulations. NCDOT has a delegated stormwater program from the NC Department of Environmental Quality (NCDEQ), formerly the NC Department of Environment and Natural Resources, which covers the requirements of both state and federal regulations. The Department's Highway Stormwater Program (HSP), managed by the Hydraulics Unit, is responsible for maintaining stormwater compliance for the Department. The design engineer is responsible for complying with all state and federal stormwater regulations during project delivery.

13.2 National Pollutant Discharge Elimination System Permit and Stormwater Regulations

The Department's National Pollutant Discharge Elimination System (NPDES) Stormwater Permit (NCS000250) and associated state laws and administrative codes define the requirements for NCDOT stormwater management. NCDOT was the first in the nation to receive a statewide transportation NPDES Stormwater permit on June 8, 1998. This permit is renewed by NCDEQ, NC Division of Energy, Mineral, and Land Resources (NCDEMLR) every five years. The current permit covers from October 1, 2015 to September 30, 2020. The permit allows discharge of stormwater from NCDOT facilities both in the construction and post-construction periods.

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The NCDEQ regulates specific pollutants of concern that impair waters of the state, and it also regulates practices that protect water quality or endangered species. Nutrient Sensitive Waters (NSW) have been identified in the state, which include the Neuse and Tar Pamlico River Basins and associated special watershed programs for Falls Lake and Jordan Lake. Riparian Buffer Rules have been promulgated, which provide both Nutrient Management Strategies and water quality protection strategies throughout the state. There are currently six (6) watersheds or river basins for which Riparian Buffer Rules have been established:

- Neuse River Basin (includes Falls Lake)
- Tar-Pamlico River Basin
- Catawba River Basin
- Jordan Lake Water Supply Watershed
- Randleman Lake Water Supply Watershed
- Goose Creek Watershed

NCDOT also protects water quality through hazardous spill prevention with the installation of Hazardous Spill Basins along designated road facilities in certain water classification areas. Guidance on Hazardous Spill Basins is provided in Appendix O.

13.3 Post-Construction Stormwater Program – Compliance for Transportation Projects

Stormwater management occurs during construction and post-construction activities. Construction stormwater runoff is regulated by the State Sedimentation Control Act and the Federal NPDES stormwater permit. The Roadside Environmental Unit manages erosion and sedimentation control requirements on NCDOT projects. More information about the erosion and sedimentation control plans and requirements may be found on the Roadside Environmental Unit, Soil and Water Section website and in Chapter 12 of these *Guidelines.*

Stormwater runoff after construction is known as post-construction runoff. Since the post-construction period exists perpetually, the importance of implementing effective controls is imperative. NCDOT manages post-construction stormwater through the Post-Construction Stormwater Program (PCSP).

Stormwater is required to be managed to the "maximum extent practicable" (MEP)* for NCDOT projects as directed by the document titled Post-Construction Stormwater Controls for Roadway and Non-Roadway Projects (64). This policy document has been approved by NCDEQ for NCDOT projects and guides the design engineer in compliance requirements. The NCDOT Best Management Practices Toolbox (BMP Toolbox) (34) is used with the PCSP to provide guidance on stormwater control design requirements. Regulatory interaction and coordination is imperative to achieve the MEP standard.

> * The Federal Register, Volume 64, page 68754, December 8, 1999, states: "Maximum extent practicable (MEP) is the statutory standard that establishes the level of pollutant reductions that operators of regulated MS4s [TS4s in NCDOT's case] must achieve. The CWA requires that NPDES permits for discharges from MS4s 'shall require controls to reduce the discharge of pollutants to the maximum extent practicable, including management practices, control techniques and system, design and engineering methods.' CWA Section 402 (p) (3) (B) (iii)."

MEP for transportation projects considers the following:

- right-of-way costs
- existing mature trees and buffers that provide water quality and ecological benefits
- topography limitations such as steep slopes, cut sections, etc.
- geological limitations such as rock, high ground water table, etc.
- environmental justice
- utility conflicts
- costs of construction and maintenance of a control device
- applicability and effectiveness of non-structural controls

Stormwater compliance is required for all NCDOT development and re-development projects that add new built upon area (BUA). BUA is generally defined as impervious surface or partially impervious surface that does not allow water to infiltrate through the surface into the subsoil. A more specific definition is available in the PCSP document. The PCSP document identifies the workflows for stormwater management compliance and applicability to a project.

Stormwater management decisions are made during the planning and design phases of a project. Decisions during these two phases are documented in the Stormwater Management Plan (SMP), which demonstrates the Department's stormwater compliance to MEP. After the project contract let date, the construction of stormwater Best Management Practices (BMP) devices may require the oversight of the design engineer. Following construction, the Hydraulics Unit, in cooperation with the Roadside Environmental Unit and the Division, coordinates inspection and maintenance of BMPs (65).

13.4 Roadway Projects vs. Non-Roadway Projects

In general, transportation projects are classified as either roadway or non-roadway projects. Projects that are incorporated into the Department's right-of-way (ROW) are considered roadway projects. Those that are off the ROW, such as industrial facilities and Division offices, are considered non-roadway projects. Information about Roadway Projects and Non-Roadway Projects are discussed separately below.

13.4.1 Roadway Projects

13.4.1.1 Planning

Considerations for stormwater management begin in the planning phase of a roadway project while it is being scoped and the planning document is being completed. Section 2.2 of the PCSP document identifies minimum planning measures to be considered for all projects. During this phase, when alignment alternatives are being discussed and environmental features are being identified for avoidance and mitigation, the design engineer should identify the watershed, any associated regulations along with the water quality classification, and impairment status of any potentially impacted water resources (70, 71). In addition, information about the new BUA to be added should be noted along with type of facility and whether the project typical section is shoulder or curb and gutter. As part of the preliminary hydraulic study, the design engineer should identify any existing stormwater controls from previous NCDOT project permits or those which may be owned by others.

13.4.1.2 Design: Stormwater Management Plan

Stormwater management requirements and the MEP standard may differ depending on the project type. Bridge, safety, widening, or new location projects may have different requirements with respect to the stormwater controls. Minimum measures for the drainage design phase as outlined in Section 2.3 of the PCSP document should be considered for every project. These include adequate ground cover, stabilizing embankments and slopes, providing adequate energy dissipation, utilizing natural features and drainage pathways, maximizing vegetative conveyance, encouraging diffuse flow, and avoiding directly connected impervious areas. These measures should be included in the design regardless of whether a Stormwater Management Plan (SMP) is required. If a SMP is required, the measures employed should be identified in the narrative.

Most projects will require a SMP since new BUA is being added. The SMP is the NPDES compliance document of record for the MEP standard. SMPs must be completed and submitted to the Hydraulics Unit prior to the contract let date.

Once the design engineer receives the Roadway Preliminary Plans and the drainage design is started, stormwater controls should be considered an integral component of the design. As stated above, MEP is context sensitive and varies with project type and location. Decisions on project stormwater controls should be made in cooperation with the resource agencies and Department staff around the 30% design phase or the 4B Concurrence Point if the project is following the Merger Process. If project constraints are limiting BMPs, especially if the project is not following Merger, the design engineer may coordinate with the resource agencies to achieve MEP. All determinations should be recorded in the SMP. While design of vegetative slopes, swales, and other conveyance controls are practical in the majority of conditions along roadway shoulder sections, more structurally based controls may be needed when there is a high concentration of impervious areas, curb and gutter systems are used, or high quality resource waters are present. Stormwater controls should be considered as mitigation measures for outlets that are determined to be critical to downstream receiving areas as discussed in the outlet analysis section in Chapter 10 (Section 10.5.3). Coordination with the Geotechnical Unit, Right-of-Way Unit, and Plans and Standards Management Unit or other units may be needed to complete stormwater control designs without delaying project delivery.

The design of all stormwater controls, identification of adequate ROW requirements for maintenance access and constructability, and any details and associated special provisions needed shall be completed by the design engineer prior to the combined field inspection (CFI) or the final design field inspection (FDFI). Following the CFI or FDFI, the design engineer should begin to develop the SMP for the project. The design engineer should use the latest version of the SMP formatted for Microsoft Excel. The Excel version of the SMP includes guidance on content to include in the plan to ensure consistency across projects. For projects which include one or more structural stormwater BMPs, worksheets (tabs) are provided in the Excel version of the SMP which allow the design engineer to enter the pertinent design information specific to each BMP type. Commonly used structural BMP types are swales, filter strips, level spreaders, preformed scour holes, and detention or retention basins. The BMP worksheets are integrated with the latest version of the BMP Toolbox. If a BMP design deviates from the criteria in the BMP Toolbox, the design engineer should document the justification for the design deviation, such as any project constraints or other considerations.

Completed SMPs shall be submitted via email (NCDOT_Hydraulics_SMP@ncdot.gov) to the Hydraulics Unit for the NPDES compliance report and archiving purposes. This email submittal is separate from the SMP submittal required for stream and wetlands and riparian buffers permit packages. SMPs and their associated revisions are required to be submitted at least three (3) months prior to the contract let date. Additional information on SMPs is available in chapter 4 of the PCSP document.

13.4.1.3 Construction

When a project design requires stormwater controls that include outlet control structures, media filters, wetlands, or other non-routine construction techniques handled by roadway contractors, coordination with the Division Construction Engineer and Resident Engineer is recommended. As stated above, coordination during the CFI or FDFI regarding constructability should be discussed. The design engineer should participate in the pre-construction meeting and be available to offer guidance during construction.

13.4.1.4 Maintenance

Upon completion of a project, the stormwater BMPs are recorded in the Departments Stormwater Control Management System (SCMS). SCMS provides information about the inspection and maintenance of the BMPs.

13.4.2 Non-Roadway Projects

Non-roadway projects can originate from a number of different sources within NCDOT's organization, such as one of the 14 highway Divisions, Facilities Management Division, Rail Division, Ferry Division, or Bicycle and Pedestrian Division. They also may constitute or be part of a scheduled STIP project (e.g., rest area or weigh station). Regardless of the source of the non-roadway project's origination, all design engineers shall follow the same process for compliance with the PCSP.

The PCSP Manual guides the hydraulics engineer through the more prescriptive requirements of non-roadway projects as outlined in Chapter 3 of the PCSP Manual (64). Coordination with the resource agencies similar to that identified for roadway projects is also required for non-roadway projects. Non-roadway projects should be coordinated with the DWR Transportation Permitting Branch.

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14 PERMIT DRAWINGS

14.1 Overview

The drainage study and hydraulic design process includes the development of permit drawings and completion of pertinent application forms for State and Federal environmental permits. These drawings and accompanying information show the anticipated impacts to natural resources associated with the proposed project design.

14.2 General Procedure

The procedure for development of the drawings and application should generally be as follows:

14.2.1 Review of Planning Document and Field Verification of Impacts

Review the planning document and associated Natural Resources Technical Report (NRTR), which lists and identifies wetland areas and jurisdictional streams likely to be impacted by the project and provides preliminary estimates of impact quantities. The planning document includes delineation of wetland area limits and estimated lengths of impacts to jurisdictional streams; however the information presented in the planning document is not sufficiently accurate for the final permit application.

The impacts must be verified and updated during the final hydraulic design stage in accordance with the protocol specified in Appendix P (See Section 14.2.3 below).

14.2.2 Compilation of Environmental Impacts Data

Through the final design phase, environmental data collected from field review and office analysis is to be compiled and organized to be presented in the permit application documentation, including:

- Location, quantity, and classification of wetlands and streams impacted
- Topography and elevation data at impact sites
- Drainage structure and/or channel design data
- Contributing watershed areas
- Flow data (e.g. average, low, bankfull)

14.2.3 Preparation of Permit Drawings

When the permit application is being prepared, considerable time may have elapsed since the time the drainage design and hydraulic recommendations were completed. It is important that the permit drawings be consistent with the project's final roadway plans and drainage design. Appendix P provides specific procedural guidance regarding permit drawing preparation, consistency review, and subsequent electronic delivery protocol for final submittal. NCDOT posts copies of recently issued permits online, and a link to this site is provided on the Hydraulics Unit webpage for reference.

14.2.4 Completion of Forms to Include with Permit Drawing

Documentation associated with each permit application will vary depending on the requirements of the specific project, its location, and the particular natural environmental resources which may be impacted. Therefore, not all of the forms listed below will be required for every project; however, all applicable forms should be fully completed and checked for accuracy and consistency with the associated permit drawings. Permit forms which may be required are listed below, and reference copies are provided in Appendix L.

The needed forms should be downloaded from the Hydraulics Unit website:

- Wetland and Surface Water Impacts Summary
- Riparian Buffer Impacts Summary
- Stormwater Management Plan (SMP)
- CAMA Major Permit Application (multiple forms)

15 FLOODPLAIN MANAGEMENT

15.1 Overview

Any NCDOT road and/or structure that crosses a Federal Emergency Management Agency (FEMA) regulated Special Flood Hazard Area (SFHA), as shown on the effective Flood Insurance Rate Maps (FIRMs) and/or the Flood Risk Information System (FRIS) website (http://rfris.nc.gov/fris/), will require coordination and approval from FEMA, or its designees in North Carolina, which are the North Carolina Division of Emergency Management Floodplain Mapping Program (NCFMP) and Charlotte-Mecklenburg Storm Water Services (CMSWS). NCFMP is authorized to issue the Flood Insurance Rate Maps statewide, except for CMSWS, which issues its own. Furthermore, it should be emphasized that Federal Aid projects are required to be in compliance with FHWA regulations or orders, while being consistent with FEMA requirements (including Executive Orders). FHWA regulation applies to all Federal Aid actions in a base floodplain (not just FEMA-regulated floodplains).

Approximately 85% of the streams across the state are designated as having SFHAs. There are three types of flood studies performed and promulgated in North Carolina: Detailed Study (DS), Redelineated Detailed Study (RDS) and Limited Detailed Study (LDS). It is the policy of NCDOT to abide by federal and state floodplain management regulations and rules. These include:

- FEMA's National Flood Insurance Program (NFIP) (29)
- FHWA's *Federal Aid Policy Guide, Location and Hydraulic Design of Encroachments on Flood Plains* (23 CFR 650 Subpart A) (8)
- Memorandum of Understanding by FHWA and FEMA (June 1982) (30),
- Presidential Executive Order 11988 (32)
- Presidential Executive Order 13690 (73),
- North Carolina Governor's Executive Order 123 (July 1990) (59)

To streamline the coordination with the two FEMA-delegated agencies (NCFMP and CMSWS), NCDOT and NCFMP entered into a Memorandum of Agreement (MOA) in 2008, which was subsequently modified in 2009, 2013, 2015 and 2016 (58).

It is the policy of NCDOT to encourage a broad and unified effort to:

1. Employ a practical and reasonable approach to the design of transportation facilities located within floodplains.
2. Avoid lateral encroachments into floodplains to the extent practicable.
3. Minimize and mitigate unavoidable adverse impacts on adjoining properties in floodplains.

4. Restore and preserve natural floodplain value and function to the extent practicable.
5. Avoid rise in Base Flood Elevation (BFE) greater than one (1) foot in the floodplain of a FEMA regulated stream, unless a variance is granted by the State Hydraulics Engineer to proceed with regulatory agencies' approval for a Conditional Letter of Map Revision (CLOMR).

When a bridge or a culvert crosses a regulated SFHA, the design engineer shall use FEMA's hydrologic data and hydraulic models to assess the impact by the proposed project to the floodplain in accordance with NFIP regulations. The design engineer shall develop optimal roadway encroachment, structure types, and hydraulic openings in a floodplain that are cost effective and least damaging to the human and natural environments.

15.2 Design Data Documentation

To develop the optimal floodplain management, the design engineer shall follow 44 CFR 60.1 through 77.2 (29) of the NFIP, FHWA *Location and Hydraulic Design of Encroachments on Flood Plains 23CFR 650A* (8, 36) and NCDOT's MOA with NCFMP (58). The design engineer should document pertinent floodplain design data in the Bridge Survey and Hydraulic Design Report (BSR) and Culvert Survey and Hydraulic Design Report (CSR) and in the hydraulic modeling narrative included in the submittal package.

These design data include, but are not limited to:

- Geometry, orientation, and hydraulic conveyance of existing and proposed structures
- Profile of the floodplain
- Hydrologic methodology
- Hydraulic model version used
- Corrections made to the effective FEMA models
- Methods used in computing the hydraulic losses through structures
- Roughness coefficients of channel and overbanks
- Limits of the floodway or non-encroachment width
- Location of adversely affected structures and the elevation of the lowest floor (including basement) and lowest adjacent grade to the structure
- Drainage structure's hydraulic performance with respect to any change in the Base Flood Elevation (BFE), which is defined as the elevation of the flood having a one-percent chance of being equaled or exceeded in any given year

15.3 Coordination With Regulatory Agencies

Depending on the nature and the magnitude of the changes in BFE between the proposed and existing structures, the design engineer shall follow the guidance below:

1. FEMA Consultation in Planning Stage: During the project planning stage, the design engineer may consult with FEMA, NCFMP, or CMSWS, as applicable, on NCDOT's planning documents, such as the Draft Environmental Impact Statement (DEIS) or Environmental Assessment (EA). If a determination by FEMA, NCFMP, or CMSWS may affect the selection of the Least Environmentally Damaging Practical Alternative (LEDPA), a written statement regarding such determination should be obtained from them prior to the completion of the final EIS or Finding of No Significant Impact (FONSI). An example of this would be a proposed roadway alignment that would result in a longitudinal encroachment of a FEMA regulated floodway, thus causing potential flood damage to insurable structures. For projects that are processed with a Categorical Exclusion, this coordination may not be warranted, or it may be carried out during the design stage.
2. MOA Types 1, 2a or 2b: If the proposed structure results in either no change or a decrease in BFE, the design engineer shall coordinate with NCFMP in accordance with the MOA. This applies to all the streams that are in a DS, RDS or LDS statewide. The State Hydraulics Engineer approves the MOA Types 1 and 2a projects; the NCFMP approves Type 2b projects.
3. MOA Type 2c: If the input data for the effective FEMA hydraulic models are unavailable, incomplete, illegible, or have erroneous hydrologic and/or topographic data, etc., an approximation of the effective model may be developed. The design engineer shall coordinate with NCFMP in accordance with the MOA. This applies to all streams that are in a DS or RDS statewide, provided the proposed structure does not result in an increase in BFE over the existing conditions. If NCFMP concurs with pursuing as a Type 2c MOA candidate, documentation of this pre-consultation concurrence by NCFMP must be included with the MOA submittal packet.
4. MOA Types 2d or 2e: If the proposed structure is over an LDS stream and results in an increase in BFE, the design engineer shall coordinate with NCFMP in accordance with the MOA. This applies to all the streams that are in an LDS statewide. The State Hydraulics Engineer and NCFMP approve the MOA Type 2d and 2e, respectively.
5. MOA Type 2f: If the proposed structure is over an LDS stream and results in a BFE increase of greater than one foot in the area that is within the Department's rights-of-way, the design engineer may request approval from the State Hydraulics Engineer and NCFMP for the project to be processed as an MOA Type 2f candidate. The design engineer shall assess flood risk impacts to properties and to the traveling public. This application is only limited to projects where no practical alternatives exist to meet backwater limitations as outlined in the NFIP regulations. As an MOA Type 2f candidate, such a project requires special approval from both the State Hydraulics Engineer and the NCFMP Director. This approval needs to be documented in the hydraulic modeling narrative included in the MOA submittal packet.

6. MOA Type 2g: The State Hydraulics Engineer and NCFMP may approve projects that result in a rise in BFE and/or increase and modification to the regulatory floodway caused by a proposed structure over a FEMA regulated stream at or near the bridge deck or culvert face, provided these changes are contained solely within the Department's rights-of-way. The design engineer shall assess flood risk impacts to properties and to the traveling public. This application is only limited to projects where no practical alternatives exist to meet backwater limitations as outlined in the NFIP regulations. As an MOA Type 2g candidate, such a project requires special approval from both the State Hydraulics Engineer and the NCFMP Director. This approval needs to be documented in the hydraulic modeling narrative included in the MOA submittal packet.
7. MOA Types 3a and 3b: For approved CLOMR projects, within six (6) months after project completion, NCDOT shall submit the associated certified As-built plans to NCFMP for inclusion for future DFIRM mapping updates. MOA Type 3a applies to streams for which DFIRM mapping is still current after issuance of the CLOMR approval. MOA Type 3b applies to streams for which the hydrologic and hydraulic models were restudied and DFIRM mapping modified since the issuance of the CLOMR approval.
8. MOA Type 3c: For clarification and guidance on the hydrologic analysis and hydraulic models associated with the effective flood study, the design engineer may request a pre-design consultation with NCFMP in accordance with the MOA. For example, the design engineer may request an approval from NCFMP to use alternative engineering methods or applications that are more appropriate and may result in more scientifically and technically correct estimates of flood elevations of the regulated streams. The design engineer should provide appropriate documentation in the BSR, CSR, or pipe design report, as applicable, and in the hydraulic modeling narrative included with the MOA submittal packet. If NCFMP concurs with pursuing as a Type 3c MOA candidate, documentation of this pre-consultation concurrence by NCFMP must also be included with the MOA submittal packet.
9. As-built Plans Review and Final MOA Submittal: Within the six (6) months of completion of a structure over a FEMA regulated stream, the Hydraulics Unit staff should coordinate with the Division Operations staff in obtaining the sealed As-built plans. An engineering review is required to determine whether the surveyed structure geometry data on its As-built plans match what is specified on the BSR or CSR. Upon certification of the As-built Plans, final submittal is made to NCFMP for all MOA types.
10. MOA Type 4a: If the As-built plans do not match the model, BSR/CSR and MOA packet must be revised accordingly. If the revision results in a BFE change, a flood damage assessment to the adjacent properties is required, and appropriate mitigation measures shall be determined. Submittal of a LOMR may be required. The Hydraulics Unit may

coordinate with NCFMP for consultation and to apply for an MOA Type 4a candidate. This As-built plans submittal requirement applies to all CLOMR and MOA projects that were reviewed and approved by FEMA, CMSWS, NCFMP and the State Hydraulics Engineer, as applicable.

11. CLOMR Submittals: If a proposed structure is over a DS or RDS stream and results in an increase in BFE greater than 0.1 ft., the design engineer shall coordinate through Hydraulics Unit with the respective regulatory agencies and apply for a Conditional Letter of Map Revision (CLOMR) approval. If the structure is located within Mecklenburg County, its CLOMR packet shall be sent to CMSWS. For the other 99 counties of the state, the CLOMR packet will be submitted to NCFMP. CLOMR approval will be issued by FEMA after all review comments are satisfactorily addressed. All projects anticipated to require a CLOMR must be reviewed by the State Hydraulics Engineer before submittal will be allowed to the respective regulatory agencies for approval.

15.4 Avoidance of FEMA Buyout Properties

Any construction or alteration of the transportation facilities (roadway embankment, side walk, stormwater BMPs, roadside ditches, etc.) on the FEMA buyout properties shall be avoided to the extent practicable. A FEMA buyout property is defined as any land that was purchased by FEMA under its Hazard Mitigation Grant Program or Flood Mitigation Assistance Program and title-transferred to the local government for the restoration and preservation of the floodplain (46). If encroachment by the proposed transportation facility cannot be avoided, the design engineer shall coordinate with FEMA, through NCFMP, for consultation, coordination, and approval prior to the project letting. For additional information, see Chapter 2, Section 2.2.5.4.

15.5 Encroachment in Floodplain and Regulatory Floodway or Non-Encroachment Area

No road or structure including its members, is allowed to be constructed within the designated regulatory floodway or non-encroachment area without a regulatory review and approval. A longitudinal encroachment, such as a roadway that is constructed parallel to a stream, encroaching into the stream's floodplain, does not require a regulatory review or approval as long as the encroachment is not within the designated regulated floodway or non-encroachment area. However, the design engineer should consider performing a hydraulic study and flood damage assessment to the adjoining properties that are located in the floodplain to protect the Department from lawsuits or liability claims.

15.6 Temporary Encroachment in Regulatory Floodway

Temporary roads for construction activities and on-site detour traffic that last longer than one year and encroach into the floodway must be reviewed and coordinated with NCFMP and the community's floodplain administrators. The design engineer should perform hydraulic analysis and work with Division Operations staff to include a provision in the project's contract to stipulate the following, as applicable:

1. Boundary of the regulatory floodway
2. Duration of construction within the floodway
3. Installation of on-site stream gages
4. Installation of a flood warning system
5. Designated staging areas for equipment that are at least one (1) foot above the BFE
6. Notification of the affected property owners of the potential risk of flooding from the temporary encroachment
7. Department commitment assuming liability for any flood damages resulting from the temporary encroachment

No CLOMR or LOMR approvals will be required for the temporary encroachment into the FEMA regulated floodway.

15.7 Rest Area Buildings in Floodplain

Rest area buildings and related water and wastewater treatment facilities shall be located outside the base floodplain where practicable. Rest area buildings which are located in the base floodplain shall be floodproofed or constructed two (2) feet above the BFE.

15.8 Replacement of Emergency Flood-Damaged Structures

If the Department's drainage structures are damaged by flooding due to extreme weather events, Department personnel should follow the protocol below:

Emergency Replacement of Drainage Structures:

1. Pipe Replacement:
    - Pipe can either be concrete pipe or metal of any shape (circular, arch, elliptical, etc.)
    - Guiding documents are MOA and NCDOT *Guidelines for Drainage Studies and Hydraulic Design*.
    - The State Hydraulics Engineer approves the design and/or NFIP compliance.

- NCDOT submits design information to FMP for the inclusion of future NFIP flood maps. No hydraulic (HEC-RAS) model or formal MOA submittal is required.

2. Reinforced Concrete Box Culvert or Bridge Replacement:

    - RCBC can be either precast or cast-in-place box culvert.
    - Guiding documents are MOA and NCDOT *Guidelines for Drainage Studies and Hydraulic Design*.
    - The State Hydraulics Engineer approves the design and notifies Division for construction.
    - For structures that are on FEMA regulated streams, the Hydraulics Unit staff follows MOA to submit design reports to FMP for compliance review during or post construction. FMP Director or the State Hydraulics Engineer approves the design reports per MOA.
    - For structures that are not on FEMA regulated streams, the State Hydraulics Engineer or his staff approves the design reports.

15.9 Acceptable Level of Precision for Base Flood Elevations

In the BSR, CSR, and pipe design report, the design engineer should follow the specific rules of rounding guidance below to document the design flood elevations:

1. All flood elevations are to be rounded to the nearest one tenth of a foot (0.1 ft.).
2. If the first digit to be dropped (i.e. in the hundredth decimal place) is less than 5, the last digit retained is not changed. For example, a BFE of 100.14 ft. is rounded to 100.1 ft.
3. If the first digit to be dropped (i.e. in the hundredth decimal place) is greater than or equal to 5, the last digit retained is increased by 1 (or "rounded up"). For example, a BFE of 100.15 ft. is rounded to 100.2 ft.

The rounded flood elevations are then compared to determine the applicability for MOA candidates. If the difference in BFE between the proposed and existing NCDOT structure is 0.1 ft. or less, it is considered as no change, or no rise in BFE. For example, if the HEC-RAS model for a bridge that is over a FEMA regulated stream has a Corrected Effective BFE of 100.25 ft., rounded to 100.3 ft., and has a Revised BFE of 100.44 ft., rounded to 100.4 ft., the difference of these two rounded BFEs is 0.1 ft.; therefore, it qualifies for an MOA Type 1 candidate. This applies to all streams in the state regardless of types of the flood study (DS, RDS or LDS).

All proposed floodway and non-encroachment width dimensions should be rounded to the nearest foot. Likewise, a similar rounding rule applies to the floodway width. Examples: If the proposed floodway width from a HEC-RAS output is 300.49 ft., it is rounded to 300 ft.; if the floodway width is 301.58 ft., it is rounded to 302 ft.

15.10 Documentation for FEMA Submittals

The following information is primarily related to the specific project documentation required for NCDOT projects involving bridges (or culverts) on FEMA-regulated streams:

15.10.1 NCFMP-NCDOT Memorandum of Agreement (MOA) Projects

Most of the bridge replacement projects will require a regulatory approval via the MOA process. The MOA and associated documentation requirements for project submittals to NCFMP are maintained and updated on the Hydraulics Unit website in the FEMA/FMP Coordination section. Also posted on the website is the current checklist of Common MOA HEC-RAS Issues, which should be utilized to facilitate timely MOA project approvals. (58)

15.10.2 FEMA Conditional Letter of Map Revision (CLOMR) Projects

For projects which will result in an increase in the 100-year base flood elevation (BFE), requiring a floodway revision and corresponding approval of a CLOMR, the additional required documentation will include (but is not limited to) the following:

- Completion of the applicable CLOMR application (MT-2) forms (The latest version of these forms are available on the FEMA.gov website).
- Hydraulic analyses (computer models - input and output) which duplicate the hydraulic analyses (Duplicate Effective model) used for the effective Flood Insurance Study (FIS) for the following frequency floods (as applicable): 10-, 50-, 100- and 500-year floods and the 100-year floodway.
- New/revised hydraulic analyses (computer models - input and output) for existing conditions (Corrected Effective model) for the following frequency floods (as applicable): 10-, 50-, 100-, and 500-year floods and floodway. (This involves adding cross sections for the crossing site without the proposed structure and for any changes in the floodplain.)
- New/revised hydraulic analyses (computer models - input and output) for proposed conditions (revised model) for the following frequency floods: 10-, 50-, 100-, and 500-year floods and floodway. (This involves the addition of the crossing features and any proposed floodway changes.)
- Certified topographic work map (sealed by professional engineer) with existing and proposed topography and contours (maximum 5 ft. contour interval), showing revised

existing and/or proposed 100- and 500-year flood boundaries, 100-year floodway, base flood (100-yr) elevations, cross sections, stream alignment, road alignment, etc.

- Annotated Flood Insurance Rate Map (FIRM) showing revised existing and/or proposed 100- and 500-year flood boundaries, 100-year floodway, corporate limits, etc.
- Annotated Flood Insurance Study (FIS) flood profile(s) showing revised existing and/or proposed 10-, 50-, 100-, and 500-year flood profiles (as applicable).
- Annotated FIS Floodway Data Table(s) showing corrected existing and/or proposed floodway data.
- Documentation demonstrating compliance with Sections 9 and 10 of the Endangered Species Act. This documentation needs to be attached to the Riverine Hydrology and Hydraulics Form (MT-2 Form 1) of the CLOMR packet.
- List of the affected property owners (including their mailing addresses and the proposed changes in BFE and floodway widths). The affected property owners will be notified by the community of these changes. If development that has occurred in the existing flood fringe area since the adoption of the community's floodway ordinance will now be located within the revised floodway area, NCDOT will ensure that adversely affected adjacent property owners are compensated for the loss.
- Sample letter of property owner notifications.
- Within six (6) months of completion of construction of a drainage structure for which a CLOMR was approved, the above documentation must be updated, as applicable, and submitted along with As-built plans and the corresponding hydraulic model for approval of the final Letter of Map Revision (LOMR) by FEMA.

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16 REFERENCES

1. AASHTO. *Highway Drainage Guidelines, Fourth Edition*. Task Force on Hydrology and Hydraulics, American Association of State Highway and Transportation Officials, Washington, DC, 2007.

2. AASHTO. *Drainage Manual*. Technical Committee on Hydrology and Hydraulics, Highway Subcommittee on Design, American Association of State Highway and Transportation Officials, Washington, DC, 2014.

3. NCDOT. *Subdivision Roads Minimum Construction Standards,* North Carolina Department of Transportation, Raleigh, NC, 2010 (rev. 2016); web: < https://connect.ncdot.gov/resources/Asset-Management/StateMaintOpsDocs/Subdivision Manual Jan 2010 Revised May 2016.pdf > Retrieved November 9, 2016.

4. USGS. *Magnitude and Frequency of Rural Floods in the Southeastern United States, through 2006: Volume 2, North Carolina, Scientific Investigations Report 2009-5158*; J.C. Weaver, T.D. Feaster, A.J. Gotvald (authors), United States Geological Survey, United States Department of the Interior, Reston, VA, 2009.

5. USGS. *Estimation of Flood-Frequency Characteristics of Small Urban Streams in North Carolina, Water-Resources Investigations Report 96-4084;* J.C. Robbins, B.F. Pope (authors), United States Geological Survey, United States Department of the Interior, Raleigh, NC, 1996.

6. FHWA. *Urban Drainage Design Manual, Third Edition, Hydraulic Engineering Circular 22* (HEC-22)*;* S.A. Brown, J.D. Schall, J.L. Morris, C.L. Doherty, S.M. Stein, J.C. Warner (authors), Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 2009

7. FHWA. *Highway Hydrology, Second Edition, Hydraulic Design Series Number 2* (HDS-2)*;* R.H. McCuen, P.A. Johnson, R.M. Ragan (authors); Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 2002.

8. FHWA. *Federal Aid Policy Guide, Location and Hydraulic Design of Encroachments on Flood Plains, Title 23 Code of Federal Regulations (CFR) 650, Subpart A.*, Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 1969.

9. FHWA/USGS. *Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains, FHWA-TS-84-204 / USGS Water Supply Paper 2339*; G.J. Arcement, Jr., V.R. Schneider (authors, USGS), Federal Highway Administration, U.S. Department of Transportation, Washington, DC, and United States Geological Survey, United States Department of the Interior, April 1984.

10. FHWA. *Design of Bridge Deck Drainage, Highway Engineering Circular 21*(HEC-21)*;* G.K. Young, S.E. Walker, F. Chang (authors), Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 1993.

11. FHWA. *Evaluating Scour at Bridges, Fifth Edition, Hydraulic Engineering Circular 18* (HEC-18)*;* L.A. Arneson, L.W. Zevenbergen, P.F. Lagasse, P.E. Clopper (authors), Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 2012.

12. FHWA. *Highways in the Coastal Environment, Second Edition, Hydraulic Engineering Circular 25* (HEC-25)*;* S. L. Douglass, J. Krolak (authors), Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 2008.

13. FHWA. *Stream Stability at Highway Structures, Fourth Edition, Hydraulic Engineering Circular 20* (HEC-20)*;* P.F. Lagasse, L.W. Zevenbergen, W.J. Spitz, L.A. Arneson (authors), Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 2012.

14. FHWA. *Hydraulic Design of Highway Culverts, Third Edition, Hydraulic Design Series Number 5* (HDS-5)*;* J.D. Schall, P.L. Thompson, S.M. Zerges, R.T. Kilgore, J.L. Morris (authors), Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 2012.

15. NCDOT. *Roadway Design Manual;* North Carolina Department of Transportation, 2012; web: <https://connect.ncdot.gov/projects/Roadway/Pages/Roadway-Design-Manual.aspx> Retrieved June 22, 2016.

16. NCDOT. *Roadway Standard Drawings;* North Carolina Department of Transportation, 2012; web: < https://connect.ncdot.gov/resources/Specifications/Pages/2012-Roadway-Drawings.aspx> Retrieved June 22, 2016.

17. FHWA. *Design of Riprap Revetment, Hydraulic Engineering Circular 11* (HEC-11)*;* S.A. Brown, E.S. Clyde (authors), Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 1989.

18. FHWA. *Design of Roadside Channels with Flexible Linings, Third Edition, Hydraulic Engineering Circular 15* (HEC-15)*;* R.T. Kilgore, G.K. Cotton (authors); Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 2005.

19. FHWA. *River Engineering for Highway Encroachments – Highways in the River Environment, Hydraulic Design Series No. 6* (HDS-6)*;* E.V. Richardson, D.B. Simons, P.F. Lagasse (authors); Office of Bridge Technology, Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 2001.

20. Rosgen, Dave. *Applied River Morphology*. Wildland Hydrology Publication, Fort Collins, CO, 1996.

21. NCWRC. *Guidelines for Mountain Stream Relocations in North Carolina, Technical Report Number 1;* P.J. Wingate, W.R. Bonner, R.J. Brown, B.M. Buff, J.H. Davies, J.H. Mickey, H.M. Ratledge (authors), Division of Inland Fisheries, North Carolina Wildlife Resources Commission, Raleigh, NC, 1979.

22. USACE. *HEC-RAS River Analysis System User's Manual, Version 4.1;* Gary W. Brunner, CEIWR-HEC (author); Institute for Water Resources, Hydrologic Engineering Center (HEC), US Army Corps of Engineers, Davis, CA, 2010.

23. USACE. *HEC-RAS River Analysis System Hydraulic Reference Manual, Version 4.1;* Gary W. Brunner, CEIWR-HEC (author); Institute for Water Resources, Hydrologic Engineering Center (HEC), US Army Corps of Engineers, Davis, CA, 2010.

24. USACE. *HEC-RAS River Analysis System Applications Guide, Version 4.1;* Gary W. Brunner, CEIWR-HEC (author); Institute for Water Resources, Hydrologic Engineering Center (HEC), US Army Corps of Engineers, Davis, CA, 2010.

25. NCDOT. *Field Surveys for Hydrographic Data, Version 2.2;* Location & Surveys Unit, North Carolina Department of Transportation, Raleigh, NC, 2007 (rev. 2010); web: < https://connect.ncdot.gov/resources/Location/Manual Documents/Location Hydro Manual 2010.pdf > Retrieved November 9, 2016.

26. FHWA. *Highways in the River Environment – Floodplains, Extreme Events, Risk, and Resilience; Hydraulic Engineering Circular 17, 2nd Edition* (HEC-17, FHWA-HIF-16-018)*;* R.T. Kilgore, G.R. Herrmann, W.O. Thomas, Jr., D. B. Thompson (authors); Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 2016.

27. FHWA. *Hydraulic Design of Safe Bridges – Hydraulic Design Series Number 7* (HDS-7)*;* L.W. Zevenbergen, L.A. Arneson, J.H. Hunt, A.C. Miller (authors), Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 2012.

28. FHWA. *Hydraulic Design of Energy Dissipators for Culverts and Channels, Third Edition, Hydraulic Engineering Circular 14* (HEC-14), P.L. Thompson, R.T. Kilgore (authors), Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 2006.

29. FEMA. *Emergency Management and Assistance, Subchapter B - Insurance and Hazard Mitigation; Title 44, Code of Federal Regulations*; Federal Emergency Management Agency, U.S. Department of Homeland Security, Washington, DC, 2013. web: < http://www.gpo.gov/fdsys/pkg/CFR-2013-title44-vol1/pdf/CFR-2013-title44-vol1.pdf > Retrieved June 22, 2016.

30. FHWA. *Additional Guidance on 23 CFR 650A;* J. Krolak, Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 2011, web: < http://www.fhwa.dot.gov/engineering/hydraulics/policymemo/0650asu1.cfm > Retrieved June 22, 2016. Note: Formerly referred to as FHWA-FEMA MOU June 1982 and NS23 CFR 650A.

31. U.S. Water Resources Council, *Floodplain Management Guidelines for Implementing Executive Order 11988; Title 43 Federal Register (FR) 6030*, February 10, 1978.

32. "Floodplain Management", Executive Order 11988, *Federal Register,* 42 FR 26971, 3 CFR, 1977 Comp., p. 117.

33. "Federal Water Pollution Control Act", Title 33 U.S. Code, Sec. 1251 et seq., 1987 ed.

34. NCDOT. *Stormwater Best Management Practices Toolbox, Version 2,* NCDOT Highway Stormwater Program, Hydraulics Unit, North Carolina Department of Transportation, Raleigh, NC, 2014; web: < https://connect.ncdot.gov/resources/hydro/Stormwater%20Resources/NCDOT__BMP_Toolbox_2014_April.pdf > Retrieved June 22, 2016.

35. FHWA. *Culvert Design for Aquatic Organism Passage, Hydraulic Engineering Circular 26* (HEC-26)*;* R.T. Kilgore, B.S. Bergendahl, R.H. Hotchkiss (authors), Central Federal Lands

Highway Division, Federal Highway Administration, U.S. Department of Transportation, Lakewood, CO, 2010.

36. FEMA. *The National Flood Insurance Act of 1968, as Amended, and The Flood Disaster Protection Act of 1973, as Amended, 42 U.S.C. 4001 et seq.;* Federal Emergency Management Agency, Department of Homeland Security, Washington, DC, 1997.

37. NCDOT. Merger Process Guide. *Connect NCDOT – Business Partner Resources*. North Carolina Department of Transportation (n.d.) . Retrieved June 22, 2016, from: https://connect.ncdot.gov/resources/Environmental/Pages/Merger-Process-Guide.aspx

38. NCDEQ. State Environmental Policy Act (SEPA). *NC Environmental Quality, Permits & Rules*, North Carolina Department of Environmental Quality, (n.d.). Retrieved July 30, 2016 from: http://deq.nc.gov/permits-regulations/sepa

39. NCDEQ. CAMA Handbook for Development. *NC Environmental Quality, Coastal Management*, North Carolina Department of Environmental Quality, (n.d.). Retrieved July 30, 2016 from: http://ncdenr.s3.amazonaws.com/s3fs-public/Coastal Management/documents/PDF/handbook printable.pdf

40. NCDEQ. Environmental Management Commission. *NC Environmental Quality, Divisions, Water Resources, Water Resources Commissions*, North Carolina Department of Environmental Quality, (n.d.). Retrieved July 30, 2016 from: http://deq.nc.gov/about/divisions/water-resources/water-resources-commissions/environmental-management-commission

41. NCDEQ. Water Supply Watershed Protection Program. *NC Environmental Quality, Divisions, Energy, Mineral, and Land Resources, Stormwater, Stormwater Program*, North Carolina Department of Environmental Quality, (n.d.). Retrieved July 30, 2016 from: http://deq.nc.gov/about/divisions/energy-mineral-land-resources/water-supply-watershed-protection-program

42. NCDEQ. Riparian Buffers Protection Program. *NC Environmental Quality,* North Carolina Department of Environmental Quality, (n.d.). Retrieved July 30, 2016 from: http://deq.nc.gov/about/divisions/water-resources/water-resources-permits/wastewater-branch/401-wetlands-buffer-permitting/riparian-buffers-protection

43. FHWA. *Bridge Scour and Stream Instability Countermeasures, Hydraulic Engineering Circular 23, Third Edition, Volumes 1 and 2* (HEC-23)*;* P.F. Lagasse, P.E. Clopper, J.E. Pagán-Ortiz, L.W. Zevenbergen, L.A. Arneson, J.D. Schall, L.G. Girard (authors), Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 2009

44. NCDOT. *Bridge Policy,* NCDOT Roadway Design Unit, North Carolina Department of Transportation, Raleigh, NC (n.d.); web: < https://connect.ncdot.gov/projects/Roadway/RoadwayDesignAdministrativeDocuments/Bridge%20Policy.pdf > Retrieved June 22, 2016.

45. NCDEQ. *Stream Mitigation Guidelines*, North Carolina Department of Environmental Quality, Division of Water Resources (with USACE, EPA, NCWRC), Raleigh, NC, April 2003, web: < http://portal.ncdenr.org/c/document_library/get_file?uuid=ab4ccad4-5cbe-45f3-979f-ab3fe35d21a1&groupId=61581 > Retrieved June 22, 2016.

46. FEMA. *Hazard Mitigation Assistance Guidance; Hazard Mitigation Grant Program, Pre-Disaster Mitigation Program, and Flood Mitigation Assistance Program*; Federal Emergency Management Agency, U.S. Department of Homeland Security, Washington, D.C., 2015.

47. NOAA. *Atlas 14, Precipitation-Frequency Atlas of the United States, Volume 2, Version 3.0;* G.M. Bonnin, D. Martin, B. Lin, T. Parzbok, M. Yetka, D. Riley (authors); U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service; Silver Spring, MD, 2006.

48. NRCS. *Technical Release TR-20 Computer Program for Project Formulation Hydrology*; U.S. Department of Agriculture, Soil Conservation Service (now Natural Resources Conservation Service), Washington, DC; 1992.

49. NRCS. *Technical Release TR-55 Urban Hydrology for Small Watersheds*; U.S. Department of Agriculture, Natural Resources Conservation Service, Conservation Engineering Division, Washington, DC; 1986.

50. NCSU. *Stream Restoration, A Natural Channel Design Handbook;* B.A. Doll, G. L. Grabow, K.R. Hall, J. Halley, W. A. Harman, G.D. Jennings, D.E. Wise (authors); N.C. State University, N.C. Stream Restoration Institute and North Carolina Sea Grant (EPA 319 Grant Program); Raleigh, NC; 2003. Retrieved online June 22, 2016 from: http://www.bae.ncsu.edu/programs/extension/wqg/srp/sr_guidebook.pdf and appendices from: http://www.bae.ncsu.edu/programs/extension/wqg/srp/guidebook_appendices.pdf

51. *Norfolk Southern Corporation Guidelines for Under Track Culverts;* (rev. 1/17/1991). Norfolk Southern Corporation, Norfolk, VA. Retrieved June 22, 2016 from: < http://www.nscorp.com/nscorphtml/pdf/Customers/SEC3_MISC2.pdf >

52. *CSX Transportation Design & Construction Standard Specifications – Pipeline Occupancies* (9/15/2003, rev. 2/24/2010), Office of Chief Engineer – Design (n.d.) Construction, CSX Transportation, Jacksonville, FL. Retrieved June 22, 2016 from: < http://www.csx.com/share/wwwcsx_mura/assets/File/Customers/Non-freight_Services/Property_Real_Estate/Pipeline_-_Design_Construction_Standards.pdf >

53. NCDOT. *Safety Policy and Procedure Manual*; North Carolina Department of Transportation, 1997. web: < https://connect.ncdot.gov/resources/Documents/Safety Policy and Procedure Manual.pdf > Retrieved June 22, 2016.

54. NCDOT. *Workplace Safety Manual*; North Carolina Department of Transportation, 2004. web: < https://connect.ncdot.gov/resources/documents/workplace safety manual.pdf > Retrieved June 22, 2016.

55. FHWA. *HY-8 Culvert Hydraulic Analysis Program, version 7.3; Federal Highway* Administration, 2012. web: < http://www.fhwa.dot.gov/engineering/hydraulics/software/hy8/index.cfm > Retrieved June 22, 2016.

56. NCDOT. *NCDOT Bridge Superstructure Level III Wave Vulnerability Study (FHWA/NC/2010-06);* D. Max Sheppard, Ph.D. and Philip E. Dompe, P.E. (authors); North Carolina Department of Transportation, Raleigh, NC, 2012.

web: <https://connect.ncdot.gov/resources/hydro/Hydraulics Memos Guidelines/NCDOT Wave Loading Draft Final Report 10-27-2013.pdf > Retrieved November 9, 2016.

57. NCDOT. *Sub Regional Tier Design Guidelines for Bridge Projects*; North Carolina Department of Transportation, 2008. web: < https://connect.ncdot.gov/resources/hydro/Hydraulics Memos Guidelines/Sub Regional Tier Guidelines.pdf > Retrieved November 9, 2016.

58. NCDOT. *NCDOT–NCFMP Memorandum of Agreement*; North Carolina Department of Transportation and North Carolina Floodplain Mapping Program, Raleigh, NC, 2016. web: < https://connect.ncdot.gov/resources/hydro/FEMA and Interagency Design/MOA_mod_20160812_(AID_6686).pdf > Retrieved November 9, 2016.

59. North Carolina Executive Order 123 *Uniform Floodplain Management Policy*, Governor James G. Martin, Raleigh, NC, 24 July 1990.

60. NCDOT. *Policy on Street and Driveway Access to North Carolina Highways*, North Carolina Department of Transportation, 2003. web: https://connect.ncdot.gov/resources/safety/Teppl/TEPPL All Documents Library/Policy on Access Manual.pdf

61. USGS. *Hydrology of Major Estuaries and Sounds of North Carolina, Water-Supply Paper 2221*; G.L. Giese, H. B. Wilder, and G.G. Parker, Jr. (authors); United States Geological Survey, United States Department of the Interior, Alexandria, VA, 1985.

62. USGS. *Methods for estimating the magnitude and frequency of floods for urban and small, rural streams in Georgia, South Carolina, and North Carolina, 2011*; *Scientific Investigations Report 2014-5030, Version1.1*; T.D. Feaster, A.J. Gotvald, and J.C. Weaver (authors), United States Geological Survey, United States Department of the Interior, Reston, VA, 2014.

63. USGS. *The national flood-frequency program—Methods for estimating flood magnitude and frequency in rural and urban areas of North Carolina, 2001: U.S. Geological Survey Fact Sheet 007–00*; R.R. Mason, Jr., L.A. Fuste, J.N. King, and W.O. Thomas, Jr. (authors); United States Geological Survey, United States Department of the Interior, Reston, VA, 2002.

64. NCDOT. *Post-Construction Stormwater Program – Post-Construction Stormwater Controls for Roadway and Non-Roadway Projects*, NCDOT Highway Stormwater Program, Hydraulics Unit, North Carolina Department of Transportation, Raleigh, NC, 2014, web: < https://connect.ncdot.gov/resources/hydro/Stormwater%20Resources/PCSP_Guidance_Document_Final_April2014.pdf >

65. NCDOT. *Stormwater Control Inspection and Maintenance Manual*, NCDOT Highway Stormwater Program, Hydraulics Unit, North Carolina Department of Transportation, Raleigh, NC, 2014, web: < http://www.ncdot.gov/programs/environment/stormwater/download/SWControlInspectionMaintJan2010.pdf >

66. USGS. *Roughness Characteristics of Natural Channels, Water Supply Paper 1849;* Harry M. Barnes, Jr. (author); United States Geological Survey, United States Department of the Interior, Washington, D.C., 1967.

67. NCDOT. *Memorandum of Understanding – Section 404 of the Clean Water Act and National Environmental Policy Act – Integration Process for Surface Transportation Projects in North Carolina (Rev. 5/16/2012)*; Raleigh, NC, 2012. web: < https://connect.ncdot.gov/resources/Environmental/Compliance Guides and Procedures/Memorandum of Understanding.pdf >

68. Bentley Systems, Inc. *GEOPAK V8i (Select Series 2) for MicroStation V8i* [Computer software]; Exton, PA, 2010.

69. NCHRP, *Estimation of Scour Depth at Bridge Abutments NCHRP Project 24-20, Draft Final Report;* R. Ettema, T. Nakato, M. Muste (authors); National Cooperative Highway Research Program, Transportation Research Board, National Academy of Science, Washington, DC, 2010.

70. NCDEQ, Surface Water Classification & Standards, North Carolina Department of Environmental Quality,, Division of Water Resources (DWR) (n.d.). Retrieved April 4, 2016 from web: < https://deq.nc.gov/about/divisions/water-resources/planning/classification-standards/classifications >

71. NCDEQ, 2014 Integrated Report, North Carolina Department of Environment and Natural Resources, Division of Water Resources (DWR) (n.d.). Retrieved April 4, 2016 from web: < http://ncdenr.maps.arcgis.com/apps/webappviewer/index.html?id=dcb44280272e4ac49d9a86b999939fec >

72. FHWA. *Highways in the Coastal Environment: Assessing Extreme Events, Hydraulic Engineering Circular 25, Volume 2* (HEC-25 Vol. 2)*;* S. L. Douglass, B.M. Webb, R. Kilgore (authors), Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 2014.

73. "Establishing a Federal Flood Risk Management Standard and a Process for Further Soliciting and Considering Stakeholder Input," Executive Order 13690, *Federal Register*, 80 FR 6425, 2015.

74. *The President's Climate Action Plan,* President Barack Obama, Executive Office of the President, Washington, DC, 2013. Retrieved August 11, 2016 from web: < https://www.whitehouse.gov/sites/default/files/image/president27sclimateactionplan.pdf >

75. "Preparing the United States for the Impacts of Climate Change," Executive Order 13653, *Federal Register*, 78 FR 66819, 2013.

76. NCDOT. *Geotechnical Investigations and Recommendations Manual*, NCDOT Geotechnical Engineering Unit, North Carolina Department of Transportation, Raleigh, NC, 2016; web: < https://connect.ncdot.gov/resources/Geological/Documents/16-03-29_Geotechnical Investigation and Recommendations Manual.pdf >

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17 APPENDICES

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