North Carolina
Department of
Transportation

Guidelines for Drainage Studies and Hydraulic Design

Hydraulics Unit
February 22, 2022

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It's been said that drainage design is as much art form and skill as it is pure engineering. For highway drainage, this is particularly true. While analyzing drainage inside the right of way is crucial, most highway drainage problems occur outside the highway right of way. Any drainage approaching the right of way must also leave the right of way, and that simple fact begins to define the art of highway drainage design. It's not always a straightforward process. Gathering background data, understanding ever-changing local conditions, and determining the best solution with respect to all stakeholders are not easy tasks. Drainage engineers must possess a good mix of detective skills, technical expertise, and creativity. They routinely find themselves working through problems that don't always have an easy answer, realizing the laws of nature and uncertainty are the only things that are certain.

For many years drainage engineers have relied on a statistically stable climate to predict rainfall runoff, or discharge rates. These discharge rates are then used to make hydraulic recommendations for a project. However, there appears to be ever growing certainty that the climate we have understood to be relatively constant is in fact changing. Climate scientist have attributed these changes to conditions in the atmosphere brought about by greenhouse gas emissions. Finding ways to mitigate such changes will require skilled problem solvers. Skilled hydrologists and hydraulic engineers will be in demand. The *North Carolina Climate Science Report* (2020) reports these conclusions:

- it is **very likely** that extreme precipitation frequency and intensity in North Carolina will increase due to increases in atmospheric water vapor content, and
- it is **virtually certain** that sea level along the North Carolina coast will continue to rise due to expansion of ocean water from warming and melting of ice on land, such as the Greenland and Antarctic ice sheets

The 2022 release of the *Guidelines for Drainage Studies and Hydraulic Design (Guidelines)* begins to address these concerns by introducing more planning-level discussions around risk and resilience and establishing performance standards early in the project development process. Some of these standards may exceed or otherwise deviate from current design standards but are intended to be project and site specific, while also meeting the standards established for the project corridor or the project region. This is just one example of a change from the traditional, prescriptive approach to project development and is better aligned with the current Integrated Project Delivery model at NCDOT. It also aligns with the risk- based approach to planning and design embraced by FHWA, realizing not all risks can be eliminated, but they can be mitigated. This new method will also require more input from stakeholders and coordination with the project team. To assist the project team with this new project delivery approach, many tools have been developed, or are in stages of development to facilitate earlier and better-informed decision-making.

The 2022 release of the *Guidelines* is also the beginning of a newly adopted process to update the Guidelines on a more frequent basis. This is a direct result of the Strategic Guidance Update Plan (SGUP) developed by KCI Associates of NC in 2021. A key recommendation of the SGUP is to revise the Guidelines to a portable, living document format, which will more readily accommodate frequent updates to those portions of the guidance for which technology or industry best practice are more rapidly evolving. This process will be most successful with user feedback and suggestions for improvement. All *Guideline* users are encouraged to participate in this new process.

The most up to date information regarding these *Guidelines* and any other news from the Hydraulics Unit will be sent by announcements from the Hydraulics Unit. So be sure to “Stay in the Flow” and sign up for announcements on the Unit’s webpage at [Hydraulics (ncdot.gov)].

Acknowledgement

The 2022 Guidelines are the culmination of many hours of content writing, reviewing, and editing by dedicated Hydraulics Unit staff members and dedicated engineering firm professionals over the course of many weeks and many meetings. Without this dedication and expertise, these updates would not be possible.

Thank you

The 2022 Guidelines are dedicated to the memory of Jerry Snead.

Jerry Michael Snead

JULY 10, 1963 – SEPTEMBER 12, 2021

North Carolina Department of Transportation

Chapter 1 Introduction

Hydraulics Unit

February 22, 2022

Revisions Sheet			
Page	**Old Section**	**New Section**	**Description**
-	-	-	• Entire Chapter revised to new format and minor grammatical changes made throughout • All references and links have been updated throughout Chapter
1	1	1.1	• 1st paragraph revised • Deleted 2nd paragraph and bullets • Deleted 6th & 7th paragraphs • Added new 6th paragraph
2	-	1.2	Added new section - References

Table of Contents: Chapter 1, Introduction

1.1 Introduction

The 2022 version of the *Guidelines for Drainage Studies and Hydraulic Design,* hereinafter referred to as the "*Guidelines",* is a five-year update to the previous 2016 *Guidelines*. It includes design policies, procedures, methods, forms, and tools needed to develop the hydrologic and hydraulic designs for NCDOT projects.

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 Planning Report (HPR)
- FEMA documentation
- no-rise certification
- MT-2 form
- as-built plans certification form

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 should reference the AASHTO 2007 *Highway Drainage Guidelines* (AASHTO, 2007) and 2014 *Drainage Manual* (AASHTO, 2014) 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.

For this 2022 update, the format has been changed from a published printed manual with an identical PDF version to a new completely web-based format. This is a first step toward creating a new living document, which can be updated more readily on an as-needed basis rather than on a long-term schedule (such as a five-year update). This new format will ultimately align the *Guidelines* with the Department's new Integrated Project Delivery (IPD) initiative and the associated Project Delivery Networks (PDN) that are being developed. The user is encouraged to review the information provided on the Department's IPD website.

1.2 References

AASHTO. (2007). *Highway Drainage Guidelines, Fourth Edition.* Washington DC: American Association of State Highway and Transportation Officials.

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

North Carolina
Department of
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Chapter 2 Legal Aspects, Policies and Practices in Highway Drainage

Hydraulics Unit
February 22, 2022

Revisions Sheet			
Page	**Old Section**	**New Section**	**Description**
-	-	-	• Entire Chapter revised to new format and minor grammatical changes made throughout • All references and links have been updated throughout Chapter
2	2.2.3	2.2.3	2nd paragraph, 2nd sentence – Revised year to 1997
4	2.2.5.4	2.2.5.4	4th paragraph revised
6	2.3.4	2.3.4	Last sentence revised; Removed reference to Appendix O
7	2.3.6	2.3.6	Removed extra text from bottom of section
8	-	2.3.9	Added new section – Executive Order 80
9	-	2.4.1.1	Added new section – Discharge vs. Conveyance
12	-	2.4.5.1	Added new section – Obstructed Outlets Protocol
13	2.4.7	2.4.7	4th paragraph revised
16	2.4.12	2.4.12	3rd bullet revised
16	-	2.4.13	Added new section – Emergency Replacement of Drainage Structures
18	-	2.5	Added new section - References
21	-	2.6	Added new section – Additional Documentation

Table of Contents: Chapter 2, Legal Aspects, Policies and Practices in Highway Drainage

2.1 Introduction

This chapter has two purposes:

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, Congress amended the Federal Water Pollution Control Act (FWPCA) to regulate the discharge of pollution into U.S. waters, which was officially designated the *Clean Water Act*, 33 USC 1344 (CWA) (U.S. Code, 2011). 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) (NCDOT, 2021), 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 (AASHTO, 2014).

2.2.2 National Pollutant Discharge Elimination System

In 1987, Congress passed an amendment to the Clean Water Act to add 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 NPDES.

On June 9, 1998, NCDOT was the first statewide agency in the nation to be issued an individual statewide transportation NPDES Stormwater Permit (NCS000250) by the EPA through the NC Department of Environment and Natural Resources (DENR), which is now the 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, see also 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 ensure that environmental amenities and value be given appropriate consideration in decision making, along with economic and technical considerations (AASHTO, 2007).

NCDOT must comply with Federal Highway Administration (FHWA) regulations for all Federal aid projects, which are tailored for linear transportation projects and are consistent with NEPA implementation. NCDOT signed an Interagency Agreement in 1997 with the FHWA and the U.S. Army Corps of Engineers (USACE) to integrate Section 404 permit requirements with the NEPA process, constituting the original merger process for transportation projects in North Carolina (NCDOT, 2021). This process was recently modified in a 2012 Memorandum of Understanding and streamlines the project development and permitting processes (NCDOT, 2012). 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:

- engaged and strong partnerships and information sharing at all levels of government
- risk-informed decision making
- adaptive learning
- preparedness planning

FHWA subsequently 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. Changes in climate may manifest as a rise in sea level, as well as increase the frequency and magnitude of extreme weather events (Federal Register, 2013).

2.2.5 National Flood Insurance Program

The National Flood Insurance Act of 1968 (FEMA, 1997) established the National Flood Insurance Program (NFIP), which 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 due to the impact of the highway on the floodplain and the stream (AASHTO, 2007). 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 (FEMA, 2016).

See Chapter 15 for information on floodplain management.

2.2.5.1 Executive Order 11988

This Order was issued in 1977 and 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 (U.S Water Resources Council, 1978), (Federal Register, 1977).

2.2.5.2 Executive Order 13690

Executive Order 13690 was issued on January 30, 2005 and amends Executive Order 11988. This order establishes a Federal Flood Risk Management Standard as a flexible framework to increase resilience against flooding and helps 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* (Federal Register, 2015), (Obama, 2013).

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 has 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) (FHWA, 1969).

These supplements discuss recommendations regarding state agencies and municipalities' responsibility for:

- proposed storm drain installations
- design standards for floodplain encroachments
- coordinating proposed highway encroachments on floodplains with FEMA to ensure regulatory compliance

Federal Aid projects must comply 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 (FHWA, 1992).

2.2.5.4 FEMA Hazard Mitigation Grant Program Properties Impacts

Another important area of concern is the impact on Hazard Mitigation Grant Program (HMGP) properties (e.g., 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 (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 to restore and/or conserve the natural floodplain functions. Deed restrictions are placed on the property which prohibit:

- adding any new pavement for roads, highways, bridges, and paved parking areas (including asphalt, concrete, oil-treated soil, or other material that inhibits floodplain functions)
- Placing 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.

HMGP properties must be identified early in the planning stage so every effort can be made to avoid impacts while developing design alternatives for consideration for a given highway project. Identifying HMGP properties, and determining 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) (FEMA, 2015).

2.3 State Laws and Programs

2.3.1 State Environmental Policy Act

The State Environmental Policy Act of 1971 (SEPA) [G.S. 113A, Article 1] requires State agencies 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
- impacts can be mitigated to a non-significant level
- magnitude of impacts is uncertain

An EIS should be prepared if the project's impacts will be significant or not able to be fully mitigated. 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 (NCDEQ, n.d.).

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 20 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 CRC staff 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
- may be easily destroyed by erosion or flooding
- may have environmental, social, economic, or aesthetic values that make it valuable to our state (NCDEQ, 2021)

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 three percent of the land in the 20 coastal counties.

The CRC has established four categories of AECs:

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

2.3.3 NC Water Supply Watershed Protection Act

In 1989, State Legislature (G.S. 143-214.5) passed the Water Supply Watershed Protection Act to protect drinking water supplies. The Act directed the Environmental Management Commission (EMC) to adopt minimum statewide water supply protection standards and implement water quality protection programs (NCDEQ, 2021). It also required classification of State's waters, based on their quality and significance to the municipalities (NCDEQ, 2021).

2.3.4 Stormwater Management Rules

State Highway (NCDOT) development projects are permit-based, with each individual project evaluated on a case by case, which are covered under 15A NCAC 02H .1003, subparagraph (d)(3)(C) "Other Projects". The rule 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 BMP must be provided to protect critical water supply watershed areas.

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 (NCDEQ, 2021).

See Chapter 13 Stormwater Management for additional information.

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 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.

2.3.7 State Floodplain Management Policy

In 1990, Governor James G. Martin issued State Executive Order 123, which requires all State agencies to follow a uniform floodplain management policy and providing guidance for compliance with Federal regulations (Martin, 1990).

Section 3 of the Executive Order 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 (NCDOT, 2008 and as amended).

2.3.8 Reasonable Use Rule

Prior to the adoption of the Reasonable Use Rule, North Carolina adhered to the civil law rule regarding surface water drainage. This civil law rule obligated owners of lower land to receive the natural flow of surface water from higher lands and subjected a landowner to liability whenever he or she interfered 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 not practical. As such, 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, which 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 if 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. As such, 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, engineers should 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.

2.3.9 Executive Order 80

In October 2018, Governor Cooper issued executive Order 80: North Carolina's Commitment to address Climate Change and Transition to a Clean Energy Economy. Among other things, it directed Cabinet agencies to "evaluate the impacts of climate change on their programs and operations and integrate climate change mitigation and adaptation policies into their programs and operations." (Section 2, (Cooper, 2018))

Climate change mitigation and adaptation policies for drainage studies can be found in Chapter 6: Resilience.

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.

2.4.1.1 Discharge vs. Conveyance

Discharge is the release of stormwater that has accumulated on NCDOT right-of-way to areas outside of the right-of-way. Conveyance is the transfer of stormwater or floodwaters across, or through, the NCDOT right-of-way that originate outside of NCDOT right-of-way. It is the policy of NCDOT to discharge stormwater from its facilities in a manner that does not violate water quality standards or erosion control standards per the NPDES permit, and to convey stormwater and floodwaters in a manner that does not violate the reasonable use rule and any other applicable laws and rules, such as the National Flood Insurance Program (Reference Chapters 13 and 15).

NCDOT reserves the right to alter or remove discharge or conveyance structures within its rights-of-way and accepts no liability for such action when following applicable laws, rules, and standards.

2.4.2 Diversions

Diversions are defined as the act of altering the path of surface waters from one drainage outlet to another. NCDOT's policy is to design and maintain its road systems, so that no diversions are created thereby. 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
- appropriate consideration and measures have been taken to indemnify and hold NCDOT harmless 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 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 because 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.

It is NCDOT's responsibility to replace the structure or otherwise take appropriate action wherever the size of an existing highway culvert is inadequate because of a general overall development of the watershed.

When 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). The party responsible for the action or development should bear the cost of replacement.

When a new culvert crossing is requested, and if the culvert is required for proper highway drainage or sufficient benefits to the highway drainage system would occur, NCDOT will bear the full cost, providing there is no diversion of flow involved. When 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 and deliver 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* (NCDOT, 2003).

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.

HEC-RAS models analyze one-dimensional flow from downstream to upstream and do not account for any flow attenuation (other than a very few exceptions) due to undersized structures.

While new culverts may allow more water to flow downstream during high water events, using engineering hydraulic judgement based on hydraulic analysis, the Department's policy above, as well as being compliant with all federal and state regulations, there should be no adverse impacts on structures or buildings in the immediate downstream vicinity of these culverts.

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

It is NCDOT's responsibility 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 NCDOT's responsibility 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. Maintenance should be done on a cooperative basis, with the benefited properties bearing their proportionate share, on large outlets serving considerable areas outside the right-of-way. In general, shares will be based on proportioning of runoff from the areas served by the outlet.

It is not NCDOT's policy 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

If a drain is blocked downstream of the highway and detrimental to highway drainage and from natural causes, NCDOT will take necessary measures to remove the blockage or obstruction. Where the blockage is caused by wrongful acts of others, NCDOT will 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, NCDOT will 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.

2.4.5.1 Obstructed Outlets Protocol

Protocol for addressing obstructed outlets, pursuant to G.S. 136-92, as discussed in Section 2.4.5:

- Division staff should advise property owner of unacceptable nature of the action. Allow reasonable time (1 to 2 weeks) for removal.
- If no satisfactory action taken, division staff will request review by Hydraulics Unit.
- Upon receiving review report from Hydraulics Unit, division staff will advise the property owner in writing by registered mail to take appropriate action by a specified reasonable deadline, informing the property owner that if satisfactory action is not taken by that date, the matter will be turned over to the Attorney General's office for legal action.
- Where there is roadway flooding or impending danger to the motoring public, NCDOT Maintenance forces may go off right-of-way for removal of the obstruction without the property owner's permission. However, this type of action may result in litigation for illegal entry of private property. In such cases, we would allow for the court to rule whether NCDOT acted in a prudent and responsible manner.
- Division staff will take photographs to illustrate and provide evidence of the potential danger imposed by the obstruction. It is advisable to also have the Sheriff's Deputy present to witness the danger.

2.4.6 Drainage Easements

It is preferred 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

NCDOT discourages 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 four 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 two feet for a 50-year impoundment level;
- A means of draining the lake completely will be provided.

NCDOT's design acceptance or approval is limited to the use of the dam as a roadway only. It is in no way intended as approval of the embankment as an impoundment structure.

When a dam that also serves as a section of roadway 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:

- 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.

2.4.8 Subdivision Streets

Responsibility for the drainage system, discharge pattern and outlet locations to maintain them as they exist at the time of acceptance and is limited to the rights-of-way whenever roads and streets that have been built by others are accepted into the State Highway System for maintenance. 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* (NCDOT, rev 2020).

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

This information should be submitted prior to the beginning of construction of the subdivision to enable any recommended changes to be incorporated into 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. 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.

Requests for additions to the system that arise by roads and streets built by others 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. A Hydraulics Unit review is available upon request if desired or if special treatment is needed. 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 and will include the following:

- location and detail of the proposed work
- arrows indicating the direction of flow
- approximate acreage drained by the pipe
- size and type of the existing pipe

The type of construction must be shown whenever appurtenances are involved. 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 the 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.

CSX Transportation and Norfolk Southern Corporation, two railroad companies, 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 (Norfolk Southern Corporation, 2015), (CSX Transportation, 2018). For new highway bridges over railroads, deck drains should not discharge directly over the railroad tracks.

2.4.12 Stormwater BMP Facilities within NCDOT Right-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 non-swale BMP facilities should be considered on a case-by-case basis to ensure compliance with applicable regulations and permits (e.g., 404/401). Any authorized impacts to existing non-swale BMP facilities should be appropriately accounted for in NCDOT's Stormwater Controls Management System (SCMS).

2.4.13 Emergency Replacement of Drainage Structures

Emergency replacements requiring federal reimbursement should follow the protocol below:

- Recommendations should follow guidance set by the NCDOT Guidelines for Drainage Studies and Hydraulic Design Chapters 8 and 9.
- When a structure is located on a FEMA regulatory stream, NCDOT coordinates with FMP as defined in Chapter 15
- For reinforced concrete box culverts and bridges, NCDOT submits the appropriate Bridge or Culvert Design Documentation to State Maintenance Office.

- For culverts (excluding RCBC) NCDOT submits a Hydrologic and Hydraulic (H&H) to State Maintenance Office. Information on the report requirements is provided in the H&H Report Guide for Federal Reimbursement

Design and estimates should be submitted to the Division for Federal reimbursement documentation.

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2.6 Additional Documentation

H&H Report Guide for Federal Reimbursement

North Carolina
Department of
Transportation

Chapter 3 Preliminary Hydraulic Studies for Planning Document

Hydraulics Unit

February 22, 2022

Revisions Sheet			
Page	**Old Section**	**New Section**	**Description**
-	-	-	• Entire Chapter revised to new format and minor grammatical changes made throughout • All references and links have been updated throughout Chapter
1	3.1	3.1	• Revised heading to "Introduction" • Revised paragraph
1	3.2	3.2	Entire section revised
2	-	3.2.1	Added new section – Level of Service Determination and Risk Analysis
2	-	3.3	Added new section – Hydraulic Planning Report; renumbered subsequent sections
6	3.3	3.4	Entire section revised
9	Appendix E – Item 6	3.5	Added Figure 1 and updated reference
-	3.6	6.1.1	Section moved to Chapter 6
10	-	3.7	Added new section – Completion of the Preliminary Stormwater Management Plan
11	-	3.8	Added new section – References
12	-	3.9	Added new section – Additional Documentation
12	Appendix D – Item 1	3.9	Replaced with Hydraulic Planning Report Template (link)
13	Appendix D – Item 2	3.9.1	Added new section – Items to Consider Discussing During the Field Scoping Meeting (FSM)
15	Appendix D – Item 3	3.9.2	Added new section – Preliminary Hydraulic Field Visit Checklist

Table of Contents: Chapter 3, Preliminary Hydraulic Studies for Planning Document

3.1 Introduction

The project development and planning phase provides the needed information required to inform subsequent design and permitting decisions. This information will inform:

- environmental impacts included in the planning document
- project cost estimates by providing major hydraulic structure recommendations
- the hydraulic scope of work for later phases of the project
- hydraulic risk and resilience decisions

During the subsequent design phase, much of the earlier data gathered 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 project development planning phase, the Design Engineer performs preliminary studies and makes recommendations to facilitate and guide decisions. During this planning phase, a Hydraulic Planning Report (HPR) should include each major drainage structure (as defined below in Section 3.4).

For bridge replacement projects, the HPR is typically completed prior to the scheduled Field Scoping Meeting (FSM).At the FSM, a multidisciplinary team will work together to determine the preliminary bridge replacement design recommendations. Issues covered at the FSM typically include hydraulic design, geotechnical concerns, roadway design, project development, environmental analysis, traffic safety, structure design, constructability, maintenance access, utility relocations, right of way needs, and local Division concerns. Section 3.3 lists 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. Prior to the preliminary field review, research available data for each major drainage structure crossing. Consult the Natural Resources Technical Report (NRTR), if available, to consider avoidance and minimization of impacts to high quality environmental resources. Section 3.9.2 provides a checklist to review during preliminary field reconnaissance. During the field reconnaissance, contact the local highway maintenance personnel for input on flood history, problem areas, and other pertinent drainage information. The Drainage Design Field Investigation Checklist (Section 3.9.2) is a good resource to collect the appropriate field data necessary for good drainage design.

Develop preliminary hydraulic recommendations using data collected in the office data research and preliminary field review for every major drainage structure site. Evaluate existing structures for hydraulic adequacy and structural integrity, and determine the feasibility of replacement or retention. Document any supplemental information regarding the preliminary hydraulic recommendation in the Design Concerns section of the HPR template. Attach more pages if more space is needed for additional notes. The HPR template serves as necessary documentation of the preliminary hydraulic recommendations for use in the preparation of the project's planning document for NCDOT roadway projects.

3.2.1 Level of Service Determination and Risk Analysis

Chapter 7 – Table 1 should be considered the acceptable Level of Service criteria for most projects. Consider a higher Level of Service for important transportation corridors such as the Strategic Transportation Corridor, evacuation routes, interstates, and other major roadways. The Hydraulics Planning Report should include discussion and analysis of:

- inundation probability and duration that may exceed the design standards in Chapter 7 – Table 1
- the criticality of the corridor for commodity and first responder access during disasters
- susceptibility to changes of level of service associated with climate change
- potential impact to inter-state and intra-state mobility and commerce
- access to key critical infrastructure.
- roadway within the project limits for inundation from sources other than cross drainage, such as lateral river floodplains, to ensure no portion of the roadway will be inundated during the specified design storm event

For major crossings that could benefit from a lower Level of Service than noted in Chapter 7 – Table 1, the Hydraulic Planning Report should include discussion and analysis of the criticality of the corridor for commodity and first responder access during disasters, susceptibility to changes of level of service associated with climate change, potential impact to inter-state and intra-state mobility and commerce, and access to key critical infrastructure.

3.3 Hydraulic Planning Report

The Hydraulic Planning Report provides preliminary hydraulic structure project recommendations and must include information required to prepare the Planning Document. During the subsequent design phase, the report must include identifying hydraulic-related issues that may pose significant risk of cost or delay to the project development.

The report will identify existing and/or proposed crossings for all major drainage structures and determine the proposed project impacts on each structure. Hydrologic and hydraulic analyses will be performed to determine the hydraulic performance for existing and future conditions. A recommendation will be made for the retention and/or extension of the structure, supplementation of the structure to provide additional conveyance or total replacement of the structure. The preliminary hydraulic recommendations will be used in the planning phase to help determine costs and the extent of natural and human environmental impacts of the project. If public involvement is required for the project, the major crossings will be plotted on public meeting maps. During Hydraulic Planning Report Scoping, care should be exercised to determine the risk to cost and environmental impacts based on the project type. For example, if an existing structure is hydraulically inadequate, it can significantly impact cost and schedule to rectify. This is especially true for high traffic and high fill situations. High utility impacts also affect cost and schedule significantly. Such information is critical to good project planning. The report should be comprehensive enough to discuss and include design aspects that can significantly affect cost and environmental impacts. It should not be an excessive exercise that contains project or programmatic information that is repetitive and redundant.

If there are no major drainage structures, those items specific to major drainage structures may be omitted, and the scope of work adjusted and agreed upon by the designer and reviewer. However, there are items that will need to be included for all widening and new location projects; for example, these may include mapping of project limits, permit requirements, analysis of anticipated levels of future urbanization, and site-specific items such as current/potential flooding or drainage issues, documentation of and recommendations for minimizing impacts to existing stormwater treatment devices, FEMA floodplain involvement, etc. A field review is required for all projects to identify and verify site-specific items. A preliminary Stormwater Management Plan (pSMP) (as a separate PDF) is also required for all projects.

3.3.1 Procedure

The Hydraulic Engineer will prepare a Hydraulic Planning Report for the project based on the tasks listed below, as applicable:

Task 1: Research / Data Collection

1. Review the NRTR, if available.
2. Develop a list of blue line streams for all major stream crossings. A major stream crossing is one requiring a major drainage structure, defined as requiring a waterway opening of 30 square feet or more.
3. Review existing reports and data for existing structures and upstream and downstream structures (Routine Bridge Inspection Reports/CSR/BSR/Scour Reports).
4. Determine if there are accounts of scour at the existing structures.
5. Determine FEMA involvement at all streams by reviewing community FIS and FIRM maps.

- If applicable, determine if effective hydraulic model from FRIS is available. If not, contact NCDOT Highway Floodplain Program to request the FEMA model. Use the Flood Insurance Study Data Request Form on the Hydraulics website.

6. Determine if stream gages are located near any crossing.
7. Contact appropriate NCDOT maintenance personnel to determine flood history and past performance of structures (historical high water, roadway overtopping, and debris potential).

Task 2: Hydraulics Field Review

1. Obtain data as noted in items 1, 2 and 3 of the Preliminary Hydraulic Field Visit Checklist (Section 3.9.2).
2. Record any reliable information on flooding or overtopping events obtained from local residents and other local individuals familiar with the area.
3. Document any design concerns or site constraints that should be considered during project development, such as presence of existing permitted stormwater basins, utility concerns, right of way concerns, etc.

Task 3: Preliminary Design Calculations and Structure Sizing

1. Compute Hydrologic Calculations.
   - Determine appropriate hydrologic method for anticipated watershed land use and compute discharges.
   - If in detailed FIS, compare FEMA discharges to computed discharges and evaluate appropriate discharges to use for design.
   - Evaluate appropriate level of future urbanization to apply in hydrology (even if no major drainage structures).
2. Determine Structure Size.
   - Assess hydraulic adequacy of existing structures.
   - Determine preliminary structure size recommendation for each stream crossing studied.
   - Determine stream stability by such means as reviewing historical plan and profile data.

Task 4: Assimilate Data and Prepare the Hydraulic Planning Report

1. Complete the HPR Template, including:
   - Cover page
   - General page, completed for the entire project (not per site, although site-specific detail can be provided as appropriate).
     - Use Miscellaneous Project Information for any relevant information not contained elsewhere in the HPR, particularly information not associated with a major drainage structure.
     - Green Sheet Commitments identifies which (if any) of the standard Hydraulics-related commitments that apply.
     - Risk Identification identifies project risks noted by the Hydraulics Engineer. Consider including these items in the project's Risk Assessment Worksheet.

  - Avoidance and Minimization identifies potential areas of revision to alignment, typical section, etc. that could reduce significant impact of the hydraulic design on construction, maintenance, environmental impacts, etc. These items may be considered for inclusion in the Avoidance and Minimization Tracker.
- Preliminary Hydraulic Recommendations for Major Crossings table.
  - Mark "N/A" for Site No. if there are no major drainage structures.
- Site data and recommendations for each site.
  - Data on the existing structure including condition and flooding history
  - Data on the existing channel upstream and downstream
  - Data on the upstream and downstream hydraulic structures. For comparison purposes, these should be those on the State-maintained system. Design storm for private or municipal structures may not be comparable.
  - Summary of site hydrology including assessment of future land use/ development and design discharges.
  - Data on FEMA involvement, including the impact that the proposed structure could have on the adjacent floodplain and upstream properties, with description and number of structures (buildings) and their locations relative to the site. Identify if an MOA or CLOMR submittal is anticipated.
  - If an on-site detour structure is required for an existing site, recommend size, location, and approximate roadway grade relative to main roadway.
  - Site-specific design concerns as applicable. This could include adequacy of the existing and proposed roadway alignment (horizontal and vertical), especially as it may relate to hydraulic design concerns, such as streams and wetlands, floodplain impacts, or hydroplaning, or any other issues that would require extra coordination with other design disciplines. Recommendations for site-specific mitigation measures should be included as well as how the recommended structure provides mitigation, if applicable.
  - Recommend proposed hydraulic structure at each site. Recommend location for replacement structure, if warranted. If bridge, ensure that superstructure type is appropriate for route type and ADT.

2. Roadway alignment and site map, showing all stream crossing sites and overall project limits, placed in the report PDF after the cover page. Provide the digital mapping files as a separate attachment.
3. Plan view sketch to scale, showing existing site data, including existing/proposed alignments, adjacent development and land use, channel with water's edge and top of banks, scour or other issues noted in the field, and recommended structure. If recommended structure is a bridge, include assumed superstructure size/type and recommended span arrangement. Note the locations of existing utility lines (e.g. sewer, telephone, power, etc.) that could affect the hydraulic recommendations or selection of alternatives.
4. Profile view sketch to scale, showing existing (if applicable) and proposed road grades, channel with adjacent floodplain, existing structure (if applicable), and recommended structure. If recommended structure is a bridge, include assumed superstructure size/type and recommended span arrangement.

5. FEMA mapping with site marked, even those without FEMA involvement.
6. Photographs of crossing site and any relevant field conditions.
7. Identify other design concerns and site constraints that may affect project delivery, but do not necessarily occur at a stream crossing. This could include known existing drainage/flooding issues, inadequacy of existing drainage outlets, existing stormwater BMPs or flood control structures which may be impacted by the project.
8. Preliminary Hydroplaning Assessment as needed. Refer to Chapter 4 – Section 4.3 for applicability.
9. Supplemental Data, as applicable from the Deliverables tab in the HPR Template, to be submitted with the HPR but not included in the report PDF itself.

Task 5: Prepare a Preliminary Stormwater Management Plan (pSMP)

1. Prepare a preliminary Stormwater Management Plan (pSMP) to assess environmental considerations such as stream classification and permit requirements (Buffer, CAMA, NPDES Permit etc.). Review the NCDOT's NPDES Post- Construction Stormwater Program (PCSP) and summarize measures needed for compliance.
   - General Project Information
   - Water Body Information

Deliverables (See Deliverables Tab in the HPR Template)

Provide one electronic copy of each of the following to NCDOT for review. Include additional electronic copy(ies) as needed after addressing all NCDOT comments:

- Hydraulic Planning Report (PDF, each page formatted to print on either 8½ x11" or 11x17" paper)
- Preliminary Stormwater Management Plan (PDF and Excel)
- Supplemental Data (PDF and other formats as dictated by data type, submitted in a single folder)

3.4 Determination of a Major Stream Crossing

For preliminary drainage studies, it is usually neither practicable nor necessary to study every stream crossing involved with a project. Smaller stream crossings are generally considered part of the roadway drainage and usually do not involve a significant risk or cost to the project, so only major stream crossings are generally studied in the preliminary drainage studies phase. A major stream crossing is one which would require a major drainage structure, which is defined as requiring an effective waterway opening of 30 square feet or more (hydraulic conveyance greater than a single 72-inch diameter pipe). 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 if the replacement structure will likely fit this definition. Preliminary hydraulic recommendations for major stream crossings should be documented on the Preliminary Hydraulic Recommendations for Major Crossings table in the HPR Template. Overflow dra inage 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 be accounted for in the hydraulic analyses and documentation.

3.4.1 Inclusion of FEMA Studied Streams and Other Areas of Risk in Preliminary Studies

Include any crossing of a stream that is within a mapped FEMA-designated Special Flood Hazard Area (SFHA) in preliminary drainage studies. Consider including any other stream crossings or drainage features which are deemed high risk, potentially high risk, or have a requirement for regulatory compliance.

3.4.2 Preliminary Input Required for NEPA/404 Merger Projects

The Design Engineer is responsible for providing preliminary hydraulic recommendations for NCDOT roadway projects which require concurrence of Federal and State agencies through the NEPA/404 Merger Process ((NCDOT 2012), (NCDOT 2012)).

- During Concurrence Point 2 (Detailed Study Alternatives Carried Forward), the Hydraulic 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. The Hydraulic Engineer should also accompany the Merger team during a Concurrence Point 2A field review of the project area if one is held. Refer to Guidance for Merger Concurrence Point 2A Meeting for additional information.

3.5 Determination of the 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 Figure 1. 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 specifying 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 gene ral rule for preliminary bridge sizing, there also may be unique site constraints which may otherwise affect the recommendation.

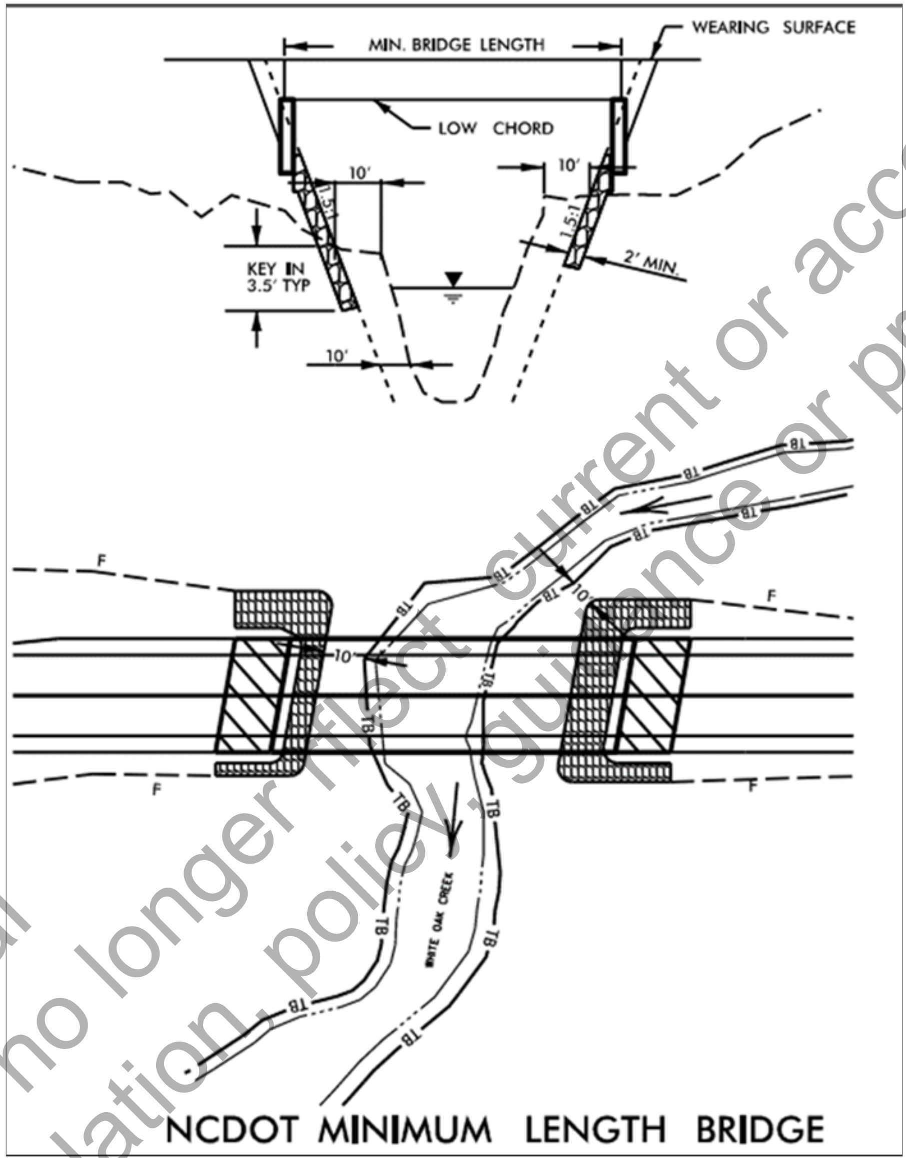

Figure 1. NCDOT Minimum Length of Bridge

3.6 Project Commitments Regarding FEMA Coordination

Planning documents for NCDOT projects usually include formal project commitments, also known as "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 regarding 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, coordinate CLOMR submittals 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.

3.7 Completing the Preliminary Stormwater Management Plan (pSMP)

Complete a preliminary Stormwater Management Plan (pSMP) in accordance with guidance in Chapter 13 during the planning phase for all projects requiring a Stormwater Management Plan. The pSMP is used in conjunction with the NC-SELDM Catalog to establish stormwater treatment goals for the project at each waterbody crossing. Document these preliminary Best Management Practice determinations in the pSMP. As the project progresses, document a final determination of the need and feasibility of Best Management Practices in the SMP.

3.8 References

NCDOT. 2007 (rev. 2010). "Field Surveys for Hydrographic Data, Version 2.2." *Location & Surveys Unit, North Carolina Department of Transportation.* https://connect.ncdot.gov/resources/Location/Manual%20Documents/Location%20Hydro%20Manual%202010.pdf.

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—. 2012. *Merger Process.* Accessed December 2021. https://connect.ncdot.gov/resources/Environmental/EPU/Merger/Pages/default.aspx.

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—. n.d. "Safe Operating Procedures and Workplace Safety Manual." *Safety & Risk Management SOPs.* Accessed November 2021.

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3.9 Additional Documentation

Post-Construction Stormwater Program Manual

Flood Risk Information System (FRIS)

Environmental Sensitivity Map

USGS StreamStats

Flood Insurance Study Data Request Form

Hydraulic Planning Report Template

Guidance for Merger Concurrence Point 2A Meeting

3.9.1 Items to Consider Discussing During the Field Scoping Meeting (FSM)

STRUCTURE

- Bridge replacement with culvert (or vice versa)
- Culvert sills, baffles, bottomless (3-sided) structure, native bed material
- Precast or cast-in-place (CIP)
- Existing bents, abutments – offsets for new bent locations, removal or not?
- Vertical abutments proposed?
- Alternate structure recommendations
- Box beam, cored slab, concrete girder, steel girder, etc.
- Fill height
- Bridge rail height and type
- 10 ft. offset – provided or waived?
- Drilled shafts or piles
- Is Geotechnical information available? Does it affect design?
- Bed to crown height
- Superstructure depth
- Step-caps vs. consistent depth superstructure spans
- Low chord adjustments vs. raising grade
- Freeboard considerations
- Vertical clearance needed under bridge for maintenance / inspection access
- End bent caps depths – 4’ or 2’-6”
- Skew considerations, flow direction, bent alignment and location (in water?)

FEMA

- FEMA permit required?
- Will MOA apply? CLOMR anticipated?
- Status of effective hydraulic model (Redelineated study?)
- In FEMA Special Flood Hazard Area (SHA), does 100-year overtop road?
- Lowest adjacent grade on potentially affected properties

SCOUR

- Unusual scour potential? Protection needed?
- Are banks stable? Protection needed?
- Debris potential
- Riprap on excavated bench and/or stream banks

STREAM

- Design event (frequency), level of service, (low-water bridge?)
- Normal water surface depth

- High water information (if available)
- Stream channel width, banks, slope, flow velocity, etc.
- Jurisdictional environmental features (wetlands, tributaries, etc.)

OTHER

- Sidewalk, bike lanes, raised median
- Deck drains, 2GI or concrete flume, limits of shoulder berm gutter, guardrail
- Potential driveway relocations
- Allowable spread
- Temporary causeway needed? Related issues
- Construction staging issues
- Temporary onsite detour needed? If so, what alignment and elevation?
- Greenway, pedestrian, bike, farming access accommodation

3.9.2 Preliminary Hydraulic Field Visit Checklist

1. MEASUREMENTS OF BRIDGE/CULVERT, WATERWAY, APPROACHES
   - Soundings for bridge opening, incl. bridge seats, low chord, toe of abutment, natural ground, tops of banks, water's edge, water surface elevation
   - Measure/locate each span
   - Measure size of culvert opening(s) (width x height)
   - Measure cover over pipe/culvert
   - Measure skew of structure
   - Plot location of channel and tops of banks relative to structure
   - Note abutment type and condition
   - Note any evidence of scour/erosion/bank instability; for culverts, also note the following:
     - Scour hole at outlet (depth, length, width)
     - Is invert perched? If so, measure how much
   - Note bed material and condition
   - Review existing land use for determination of Manning roughness coefficient values
   - Determine approximate location/elevation for roadway overtopping
   - Note any identifiable migration of stream
   - Identify and sketch potential stream relocations
   - Note condition of existing bridge/box culvert (cracks, spalling, etc.)
   - Measure normal depth of water (beyond influence of existing structure), recent high water, Ordinary High Water (OHW – mud or vegetation line)
   - Note signs of high water and elevation
   - Note if flow is confined to a single barrel (if culvert is multi-barrel)
   - Measure width of channel (base, water's edge to water's edge, top of bank to top of bank) and plot channel alignment/skew relative to structure (at approximate crossing location if new location)
   - Note debris potential
   - Note and locate as appropriate anything that may affect proposed structure (remnant piers, etc.)
   - Note whether USGS stream gage is attached to or near bridge
   - Note utilities concerns (overhead, attached to structure, adjacent to roadway, etc.)

2. NEARBY PROPERTY, STRUCTURES, ETC. AFFECTED
   - Note any structures upstream that may be in the floodplain
   - Note nearby utilities
   - Note potential environmentally sensitive areas (including wetlands, parks, ponds, lakes, reservoirs)
   - Note Right-of-Way acquisition concerns (especially for recommended alignment)
   - Measurements of building offsets, driveway location, etc. if directly adjacent to bridge/culvert

- Describe floodplain characteristics upstream and downstream

3. PHOTOGRAPHICAL INFORMATION
   - Upstream channel and banks
   - Downstream channel and banks
   - Bridge face showing approaches
   - Left and right approach alignments
   - Abutments and typical interior bent
   - Any special conditions that warrant a photograph
   - Document/label photos taken in field notes for identification purposes

4. FIELD NOTES/DELIVERABLES
   - Date and note personnel on field notes
   - Plan view sketch at 1"=50' scale (or other convenient scale)
     - Plan view sketch should include ex. structure/bents (incl. remnant piles, if applicable), channel alignment with water's edge and tops of banks, and include road, and any pertinent adjacent features (building, drive, woods line, utilities, ditch, pipe etc.), North arrow and flow direction. After field visit, proposed structure should be added at appropriate skew and include preliminary span arrangement.
   - Profile view at 1"=10' scale (or other convenient scale).
     - Profile view should include ex. structure/bents, WE & TB, etc. After the field visit, prop. structure should be added and include preliminary superstructure and span arrangement.
   - Record of historical flooding information from locals (w/name, address, phone no., years in residence): ever overtopped, highest level reached, flooding frequency etc.
   - Show recommendation for replacement or for new structure
   - Note any advantages or disadvantages with respect to various alternatives
   - Note recommendation for proposed structure/road alignment, and temp. on-site detour
   - Record of photographical information

Obtained from Routine Inspection Report:
- Superstructure type and depth (top of deck to low chord)
- Substructure type
- Year built
- Clear roadway width
- Overall (out to out) bridge deck width
- Note bridge sounding data for historical migration of streambed or developing scour
- Review photos and notes about debris
- Note any maintenance performed due to scour

North Carolina Department of Transportation

Chapter 4 Preliminary Roadway Plans Review and Pre-Design Study

Hydraulics Unit

February 22, 2022

Revisions Sheet			
Page	Old Section	New Section	Description
-	-	-	• Entire Chapter revised to new format and minor grammatical changes made throughout • All references and links have been updated throughout Chapter
1-16	-	-	Entire Chapter Revised
16	Appendix B	4.7	• Pre-Design Checklist link has been added • Drainage Design Field Investigation Checklist link has been added

Table of Contents: Chapter 4, Preliminary Roadway Plans Review and Pre-design Study

4.1 Introduction

The review of the Design Recommendations Plan Set provides the Design Engineer an opportunity to review the design plans and recommend any design plan changes necessary to mitigate potential drainage problems found during this review. Any preliminary drainage recommendations and commitments made during planning should also be reviewed for consistency and assurance of implementation during the subsequent final design phase.

The Hydraulics Pre-design Meeting provides an opportunity for the hydraulic designer and hydraulic reviewer to discuss quality assurance elements such as procedures, criteria, and methods, and to reach concurrence before final hydraulic design begins. This meeting should occur prior to commencing detailed drainage design. The meeting is important to prevent schedule delays and limit re-work.

4.2 Review of Roadway Preliminary Plans (Design Recommendations Plan Set)

The hydraulic designer usually receives preliminary roadway plans for review from the roadway designer. While some communication may have occurred between the roadway designer and hydraulic designer during the preliminary roadway plan development, further review and communication is usually necessary to modify some of the elements of the design prior to final hydraulic design. Items that should be evaluated include:

Grade

- Review roadway grades and intersection grades for concerns such as long curves that result in excessive lengths of roadway at less than minimum slopes, and creation of sags or flat areas where alignments intersect
- Review existing level of service for the transportation facility
- Verify grade provides adequate freeboard/cover for bridges, culverts, and cross-pipes
  - Review Hydraulic Planning Report (HPR), if available, for preliminary major drainage structure sizes and grade recommendations, and estimate pipe sizes for larger cross-pipes not included in the HPR.
  - Review vertical bridge clearance for inspections and maintenance
- Verify grade changes that reduce roadway overtopping won't create unacceptable increases in water surface elevations.
- Verify any required clearances for bridges over waterways with anticipated girder size/type
  - navigational clearance
  - greenway/multiuse path clearance
- Verify adequate grade for drainage systems

- Some typical problem areas include existing shoulder section changing to curb and gutter (C&G), or 2-lane going to 4-lane divided with depressed median.
- Verify that new drainage systems can maintain positive drainage to existing drainage outlets.

- Review sag locations
  - Avoid sags in cut where possible or verify positive drainage can reasonably occur. This includes areas adjacent to walls and barrier rail.
  - Verify sags will not be located on bridges, and that sags are a sufficient distance from approach slabs to allow the placement of a drainage structure.
- Review grades for potential diversion concerns
- Review grades to verify an appropriate level of service against overtopping is being met

Typical Sections

- Review typical sections for potential drainage concerns
- Review raised median curb type
  - Will the curbing result in issues with excessive inlets to combat excessive spread? Consider requesting 2'-9" C&G on low side of superelevation (particularly if the typical section calls for 1'-6" C&G).
  - Will underdrains likely be required? Examples include raised grassed medians
- Review for other issues with typical section; for example, should a steeper cross-slope be requested to reduce spread concerns?
- Monolithic islands should be at least four feet wide to place inlets in them
  - Recommend pavement cross-slopes be graded away from islands that are narrower than four feet or request a wider island
- Check spread on bridges and overpasses to verify adequate shoulder width
  - Request change to bridge typical section to provide minimum required shoulder width for spread. Preference is to contain spread in the shoulder, particularly in regions susceptible to freezing. The exception is in areas where the driver is accustomed to experiencing that amount of spread in the roadway, such as in areas with extensive C&G prior to the bridge (Chapter 8, section 8.7.2.9).

Complete a Hydroplaning Assessment if required per section 4.3 below.

Miscellaneous

- Review plans for site-specific issues, such as encroachment on existing stormwater basins (is there room to enlarge basin to make up for lost area?), lateral encroachment on streams, etc.
- Look for areas with encroachment into FEMA floodplains that may be problematic, particularly those with buildings in the floodway
  - check for lateral floodway encroachment, fill in floodway, etc.
- Review drainage-related project commitments made in planning/project development phase to ensure they can be met, such as previously agreed-to bridge length requirements and under-clearance requirements for greenway/animal crossings
- Review drainage outlet locations and effects to existing drainage systems/outlets

- Review preliminary bridge superstructure grade and span arrangement
- Look for potential problems with superelevation such as at rollover locations, at or near vertical sags and crests, at intersections, or on bridge decks
- Look for long lengths of flat shoulder sections such as on the high side of a full supered section
- Review alignment for environmental impact avoidance/minimization efforts or potential for improvement, such as:
  - maximum allowed fill slopes used in wetlands where appropriate to minimize impacts
  - widening away from jurisdictional features, when possible
- Review for any other issues not listed above that could present a problem for hydraulic design

4.3 Hydroplaning

4.3.1 Overview

Dynamic hydroplaning can occur on wide sections of roadways with multiple lanes sloped transversely in one direction. Dynamic hydroplaning occurs when a vehicle's tire encounters a greater water film thickness on the pavement than can be pushed away by the tire, lifting the tire from the pavement and making the vehicle unstable as illustrated below:

Figure 1. Simplified illustration of dynamic hydroplaning (FDOT. Hyung S. Lee and Dinesh Ayyala (authors) 2020)

Note: This section does not address pavement rutting, vehicle skidding, or spread accumulating against a barrier such as a curb or barrier wall.

4.3.2 Assessment of Hydroplaning Potential on Tangent Sections

A hydroplaning assessment is required for highways with a design speed of 60 mph or greater and when one or both conditions occur at any point along the project:

- Tangent section with 36 ft or greater sloped in one direction.

- Superelevated sections of 36 ft or greater, accounting for contributing directly connected impervious areas such as shoulders and gore areas.

Identifying possible hydroplaning concerns should occur at two different stages early in project development, as discussed below:

Preliminary Hydroplaning Assessment

This assessment is completed when developing the Hydraulic Planning Report and examines the preliminary roadway typical sections. If the roadway profile is not yet determined, use a longitudinal slope of 5% to maximize the predicted water film thickness. By performing the preliminary assessment early in the project, additional time becomes available in the planning process to adjust the typical section(s) and/or accommodate mitigation strategies, if needed.

Final Hydroplaning Assessment

This assessment should occur while reviewing and developing comments on the Design Recommendations Plan Set(s) and examines the proposed roadway typical section(s) and areas of concern. The Hydraulic Design Engineer should coordinate closely with the Roadway Design Engineer during the development of the Design Recommendations Plan Set to incorporate geometric mitigation strategies, if needed.

To perform the above two hydroplaning assessments on the project, use the guidance and the NCDOT Hydroplaning Assessment Tool provided, with the assumptions discussed below in this section.

4.3.2.1 Predicted Drivers' Speed and Rainfall Intensity

Research shows that drivers slow down during heavier rainfall events. Evaluate hydroplaning potential using the predicted drivers' speed reductions shown below:

Table 1. Predicted Driver Speed Reductions in Response to Rainfall (FDOT. Claude Villiers, Dahai Guo, and Bertho Augustin (authors) 2012)

Rainfall Intensity (in/hr)	Predicted Driver Speed (mph)
0.1	Design Speed - 0
0.25	Design Speed - 0
0.5	Design Speed - 6
1	Design Speed - 8
2	Design Speed - 12
3	45 mph
4	

Experience in evaluating hydroplaning potential has shown that 2 in/hr is the critical rainfall intensity when determining the predicted driver's speed. At 3 and 4 in/hr rainfall intensities, drivers typically lower driving speeds to less than 45 mph, at which speed hydroplaning is not expected to occur. As such, **use the 2 in/hr rainfall intensity for the hydroplaning assessment.**

4.3.2.2 Pavement Characteristics

Pavement characteristics play a large part in determining hydroplaning speed. Mean Profile Depth (MPD) and Mean Texture Depth (MTD) are measures of the average water storage depth in pavements, as illustrated below:

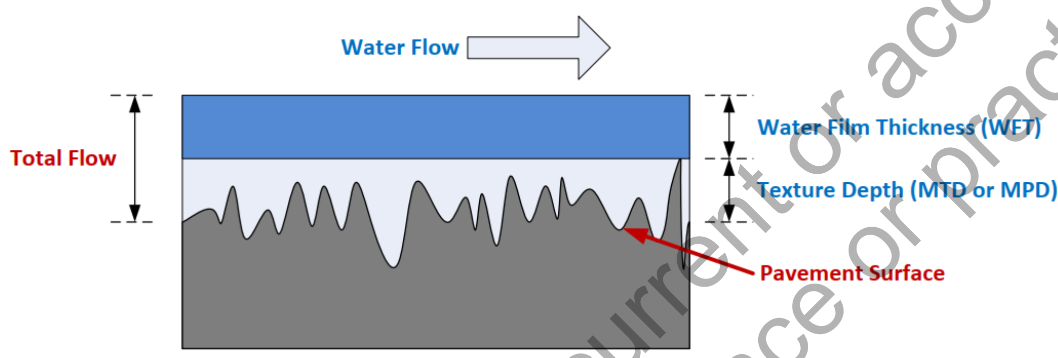

Figure 2. Illustration of water film thickness and texture depth definitions (FDOT. Hyung S. Lee and Dinesh Ayyala (authors) 2020)

When conducting a hydroplaning assessment, use the MTDs listed in Table 2, set the permeability to zero, and pavement temperature set to 32° F.

Table 2. MTDs to be used for analysis of hydroplaning potential

Pavement Type	MTD (in)/(mm)	MPD (in)/(mm)
Dense Graded Asphalt	0.027 / 0.7	0.024 / 0.6
Open Graded Friction Course	0.067 / 1.7	0.050 / 1.3
Concrete Pavement	0.035 / 0.9	0.033 / 0.8

4.3.2.3 Water Film Thickness (WFT)

NCDOT methodology uses the average of four different WFT equations:

- Gallaway Eq.,
- British Road Research Laboratory (RRL),
- NZ modified Manning's Eq., and
- PAVDRN (SI) Eq.

The procedure in Section 4.3.5 and in the Hydroplaning Assessment Tool provide procedure and computational assistance on calculating WFT.

4.3.2.4 Hydroplaning Speed using PAVDRN

As discussed in the procedure of the Hydroplaning Assessment Tool, for determining hydroplaning speeds, use the PAVDRN Equation shown below:

$$HPS = \begin{cases} 26.04 \cdot WFT^{-0.259} & \text{if } WFT < 0.094\,\text{in.} \\ 3.09 \cdot Max\left(\dfrac{10.409}{WFT^{0.06}} + 3.507, \left[\dfrac{28.952}{WFT^{0.06}} - 7.817\right] \cdot MTD^{0.14}\right) & \text{if } WFT \geq 0.094\,\text{in.} \end{cases}$$

Equation 1. PAVDRN Equation for Predicting Hydroplaning Speed (FDOT. Hyung S. Lee and Dinesh Ayyala (authors) 2020)

where,

HPS	=	hydroplaning predicted speed (mph)
WFT	=	water film thickness (in)
MTD	=	mean texture depth (in)

4.3.2.5 Adjustment for Modern Tire Pressure and Tire Tread

The PAVDRN hydroplaning speed equation was developed with physical data from the late 1970s that used a 24 psi standard tire inflation pressure and tires without tread patterns. Since 2008, modern cars are federally required to monitor tire pressure and most modern cars use a recommended tire pressure between 32 and 35 psi, though a few are lower. No data is readily available on the warning tire inflation targets used on modern cars. From the research of Fwa and Ong (Ong 2007), moving the tire pressure from the 24 psi, used in developing the PAVDRN Equation, to 29 psi results in a 5 mph increase in hydroplaning speed.

For the range of typical WFTs expected for 2 in/hr rainfall events on NCDOT highways, the PAVDRN equation is based on data for smooth tires. Fwa and Ong (Ong 2007) predict a modest 1.2 mph increase in hydroplaning speed for the standard ASTM E-501 tire with longitudinal ribs, but modern tire tread patterns are far better at shedding pavement water and are expected to result in increased hydroplaning speed predictions beyond the 1.2 mph.

Therefore, to adjust for this gap between modern tire conditions – both tire pressure and tread patterns - and the tire conditions upon which the PAVDRN hydroplaning speed equation was developed, **the predicted hydroplaning speed of the PAVDRN equation should be conservatively** increased by 5 mph.

4.3.3 General Hydroplaning Mitigation Strategies

Hydroplaning mitigation strategies can assist the hydraulic design engineer with incorporating the best strategy to reduce hydroplaning potential. Depending on the mitigation strategy selected, this is likely to be an iterative process across different transportation disciplines and requires ongoing collaboration.

4.3.3.1 Optimization of Geometric Design

When considering a geometric strategy to mitigate a potential hydroplaning problem, the hydraulic engineer should work closely with the roadway design engineer to determine longitudinal slopes to reduce hydroplaning concerns. Geometric elements that may also be considered in design include the following:

Contributing Pavement: Reduce the effective contributing pavement width of the cross section:

- Break high-side shoulders away from the travel lanes.
- Barrier-separate and capture runoff from designated lanes (e.g., auxiliary, high occupancy, express, etc.) from general use lanes.
- Break the inside lanes toward the median.
- Reduce buffer widths

Longitudinal Slope: Employ flatter grades to make sheet flow more perpendicular to the road, which reduces the runoff flow path length and resultant water film thickness. This concept is illustrated in Figure 3, below. Recognize that a flatter longitudinal slope may cause spread concerns in areas having barrier wall or other constraints to block the flow of runoff.

$$L = W\sqrt{1+\left(\frac{S_G}{S_C}\right)^2}$$

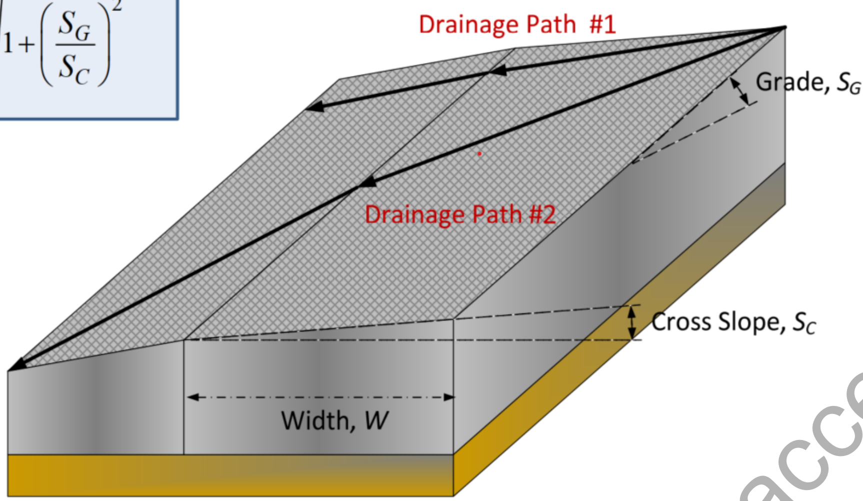

Figure 3. Runoff Flow Path Length on a Tangent Roadway Section (FDOT. Hyung S. Lee and Dinesh Ayyala (authors) 2020)

Cross-slope: Increase the cross-slope steepness to provide faster and more efficient removal of water from the pavement. In tangent sections, increase the cross slope of each successive pair of lanes outward from the first two lanes from the crown line with the lowest lane not exceeding 3.5%; AASHTO recommends breaking the cross slope every two lanes and prohibits cross slopes greater than 3.5% on high-speed facilities.

4.3.3.2 Pavement Surface Improvements

The hydraulic engineer should consult the State Pavement Design Engineer when considering a pavement surface mitigation strategy to a hydroplaning problem. Examples of pavement surface treatments for mitigating hydroplaning potential include the following:

- Open Graded Friction Course (OGFC)
- High Friction Surface Treatment (HFST)
- Ultra-Thin Bonded Wearing Course (UTBWC)
- Milling and Resurfacing
- Diamond grinding
- Diamond Grooving
- Shot Blasting

Note: When proposing treatments other than OGFC, provide MTD, MPD, raw test data and documentation to the Hydraulics and Materials & Tests Units.

4.3.4 Hydroplaning Mitigation Strategies for Superelevation Transitions

4.3.4.1 Geometric Design Mitigation Strategies

Pay special attention to the geometric design at superelevation transition locations. The most critical sections of the superelevation, where the water film depths are maximized, are typically near the zero-cross-sloped sections where the tangent-superelevation transition occurs. Several mitigation strategies to minimize hydroplaning are noted below.

- Flatten longitudinal slopes as much as practical in superelevation transitions to reduce the area of maximum water film thickness (WFT) (TXDOT. Randall J. Charbeneau (author) 2008). Recognize that a flatter longitudinal slope may cause spread concerns in areas having barrier wall and other constraints to block the flow of runoff.

- Stagger the superelevation transitions by lane to reduce the overall WFT on lanes as they transition through a zero cross slope, as shown in Figure 4, below:

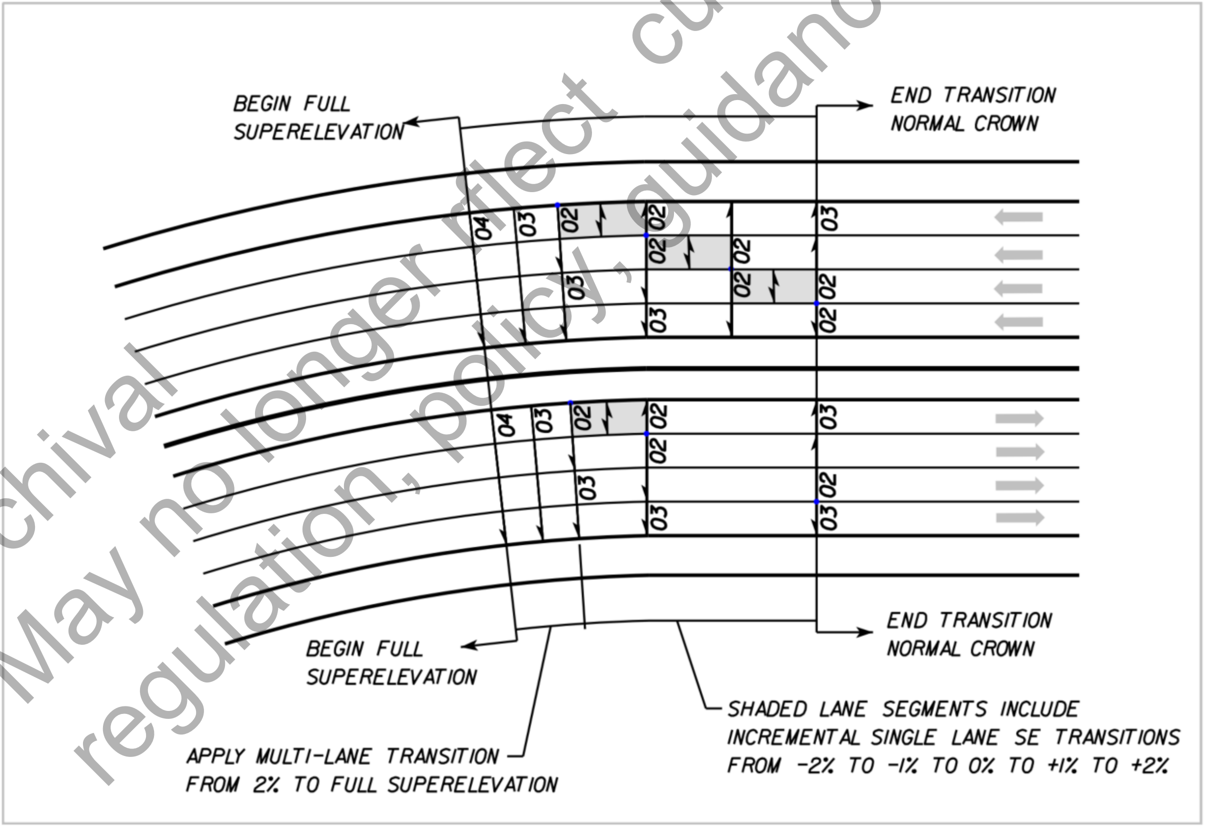

Figure 4. Staggered Superelevation Transition (Concept from FTE) (Florida's Turnpike Enterprise (FTE). Al-Ahad Ekram and Steven Kane (authors) 2018)

- AASHTO's, *A Policy on Geometric Design of Highways and Streets, 7th Edition*, Chapter 3, Section 3.3.8.9 (AASHTO 2018), recommends two grade criteria to increase drainage in these flat cross slope transition areas:
    - Maintain minimum profile grade of 0.5 percent through the transition section.
    - Maintain minimum edge-of-pavement longitudinal grade of 0.2 percent through the transition section.

4.3.4.2 Driver Behavior and Mitigation Strategies

Because weather events can be severe and unpredictable, it is impossible to effectively remove all risk from the roadways. In addition, hydroplaning risk depends on many factors which are beyond the control of the designer and is heavily dependent on the condition and maintenance of the vehicle and the decisions of the driver. The following are four examples of some identified risks:

- Speed: Driving at posted speed limits greater than 50 miles per hour under heavy rainfall places drivers in danger of dynamic hydroplaning. Traveling speeds should be less than 50 miles per hour during heavy rainfall to lower the potential for hydroplaning. Driving at a "speed unsafe for conditions" or "failure to control speed" may incur a citation.

- Driving: Sudden braking, use of cruise control, oversteering and understeering when running into water on the pavement surface, can increase the chance of dynamic hydroplaning due to the friction capacity being significantly reduced.

- Tire Pressure: Tire pressures should be in accordance with the manufacturer's specifications and maintained on a regular basis. The National Highway Traffic Safety Administration (NHTSA) states to check the pressure on all tires, including the spare, once a month (https://www.nhtsa.gov/equipment/tires).

- Tire Maintenance: To reduce the risk of hydroplaning, the minimum tire tread depth should be no less than 1.59 mm (2/32 in.). Tire tread wear should be maintained by the driver on a regular basis by having their tires regularly rotated and balanced properly.

Mitigation strategies also include measures focusing on increasing driver awareness and responsibility. Below are two non-engineering related strategies that the hydraulic engineer may consult the State Traffic Operations Department.

- Signage: Explore the installation of temporary or permanent signage that alert drivers to reduce speed or that the pavement is slippery when wet. The use of variable speed limits based on changing weather conditions may also be appropriate.

- Public Education: Use variable messaging boards, as needed, to advise drivers of significant rainfall intensities and excessive vehicle speeds; appropriate tire inflation and tread depth may be included or published independently to educate driver responsibility.

4.3.5 Procedure

A step-by-step procedure for computations is included in the Hydroplaning Assessment Tool on the **Procedure** tab worksheet.

Evaluate the following areas for hydroplaning risk:

Typical Sections

- Typical sections with a travel lane width of 36 ft. or greater and with a design speed of 60 mph or greater:
  - For a Preliminary Hydroplaning Assessment, use a 5% longitudinal slope
  - For a Final Hydroplaning Assessment, use the steepest longitudinal slope, positive or negative, within the limits of each qualifying typical section.

Areas of Concern

- Superelevations at the 0.02 cross slope across all lanes, sloping in one direction, with a total lane width of 36 ft. or greater, and with a design speed of 60 mph or greater.

  Note: In cases where superelevated sections have sufficient superelevation to cause the high shoulder to rotate to zero cross slope, assume that half the shoulder is draining across the travel lanes.

- Travel lanes with a design speed of 60 mph or greater, that receive runoff from gore areas, auxiliary lanes, or ramps resulting in a total contributing pavement width of 36ft or greater.

- Adjacent ramps and auxiliary lanes when the total width of through lanes plus ramps and/or auxiliary lanes is 36 ft. or greater with a mainline design speed of 60 mph or greater.

- Roadway cross slopes that transition to meet bridge cross slopes flatter than the roadway cross slopes.

4.4 Hydraulics Pre-design Meeting

4.4.1 Applicability

The Hydraulics Pre-design Meeting is recommended for all projects that require drainage design. This meeting will not be required for simple bridge replacement projects and projects with very minor drainage design, or if the Hydraulic Design Engineer, NCDOT Hydraulics Reviewer, and the NCDOT Project Manager agree that the meeting is not needed. If a formal Pre-design Meeting is not held, it is the responsibility of the Hydraulic Design Engineer to communicate and coordinate with the appropriate NCDOT personnel regarding any design assumptions, concerns, or issues in a timely manner to avoid impacts to the project schedule.

4.4.2 Scheduling

The Hydraulics Pre-design Meeting should be held after approval of the Design Recommendation Plan Set and prior to commencing detailed drainage design. The Hydraulic Design Engineer should schedule the meeting with the NCDOT Hydraulic Reviewer.

4.4.3 Attendees

The following should be invited to the meeting:

- Hydraulic Design Lead: attendance required
- Hydraulic Designer(s)
- NCDOT Hydraulic Reviewer (GESC with QA expertise or Hydraulics Unit internal staff): attendance required
- NCDOT Hydraulic Supervisor or their designee (required invitees for all projects is managed by the NCDOT Project Management Unit and other projects that will be reviewed by the Hydraulics Unit)
- NCDOT Project Manager (PMU, Division, Design-Build, etc.)

4.4.4 Discussion Items

- Design criteria (hydraulic design assumptions)
- Required deliverables
- Scope changes if any
- Project-specific questions
- Pre-Design Checklist for Drainage Study and Hydraulic Design
- Submittal schedule to meet overall project schedule

4.4.4.1 Design Criteria (Hydraulic Design Assumptions)

The Hydraulic Designer should prepare a document prior to the meeting to categorize and list all applicable design assumptions to be used, such as variables, methodologies, equations, standards, etc. This facilitates a discussion and agreement between the Hydraulic Designer and NCDOT Hydraulic Reviewer prior to design. Many designers find it convenient to prepare and maintain a standard list of design assumptions for use on any project, and then tailor it as needed for the project in question.

The following topics should be included, as applicable:

- Hydrology
  - hydrologic methodology, including expectations for future urbanization values
  - Rational Method 'c' values
  - design frequencies for different facility types
- Pipes
  - allowable HW/D values
  - use of trenchless installation methods (requires consultation with Project Manager and Division)
  - alternate pipe material usage
- Pipe and Storm Drain System Design
  - inlet spacing, maximum allowable spread, allowable bypass
  - retention/replacement of existing drainage systems/pipes
  - drainage box/frame and grate types (in medians, narrow slot, traffic bearing, etc.)
  - spread requirements for temporary travel lanes, if applicable
- Ditch Design
  - ditch minimum allowable grade
  - usage of ditch liners - rip rap and Permanent Soil Reinforcement Matting (PSRM)
  - Manning's 'n' values
  - berm requirements for lateral ditches
  - use of ditches in C&G sections
- Structures
  - existing and preliminary proposed structure sizes for bridges and culverts
  - bridge deck drain type, location, spacing
  - pipe and culvert burial
- Other
  - outlet analyses, whether at all outlets or certain ones
  - maximum side slopes (cut or fill) and any other Geotechnical recommendations
  - use of Shoulder Berm Gutter (SBG)

4.4.4.2 Project-specific Questions

The Hydraulic Designer should review the plans and be ready to discuss any foreseeable design issues. This will help obtain agreement on the general approach to drainage design in unique situations or areas where standard practice may not fit. The review should include any known drainage problems identified in the Hydraulic Planning Report (HPR), or by Hydraulics Unit or Division personnel. Performing a field visit prior to the meeting can help identify potential issues for discussion, especially for larger and more complex projects. Potential topics include:

- undersized existing systems, particularly when draining to them

- adequacy of existing outlets
- unavoidable diversions
- relocating ditches in wetlands
- ditch cleanouts, particularly if anticipated to be extensive or in jurisdictional areas
- encroachment on existing private Stormwater Control Measures (SCMs)
- impacts to ponds, whether to drain or fill
- any challenges or risks for the Department

These topics are generally resolved between the Hydraulic Designer and the NCDOT Hydraulic Reviewer, but some may need input or action from the Project Manager, such as those that may require coordination with other disciplines, municipalities, etc.

4.4.4.3 Additional Topics for Discussion

Consider the following additional topics for discussion:
- What are the Post-Construction Stormwater Program (PCSP) requirements?
- Are there any proposed stormwater basins?
    - Is subsurface investigation needed from geotechnical studies?
- What additional surveys or pipe inspections are needed?
- Green Sheet commitments
- Permitting requirements
    - Wetland and Surface Waters
    - Buffers
    - CAMA
    - FERC
    - Section 7 issues that impact design
    - Railroad
- NEPA/404 Merger Process (Anticipated meeting dates, plan requirements, submittal dates)
- What items should be included on redline submittals?
    - Hard copy/pdf, phased submittals, use of Preconstruction SharePoint Site, ProjectWise, etc.)

For Design-Build projects, the Request for Proposal (RFP) is the controlling document. It may have specific requirements above, or in addition to, normal design practices and guidelines, and should be followed.

Note: It is helpful if the Hydraulic Designer submits criteria and questions to the NCDOT Hydraulic Reviewer in advance of meeting.

4.4.5 Other Tasks to be completed during the Meeting

- Hydraulic Designer is responsible for recording and submitting meeting minutes.
- NCDOT Hydraulic Reviewer reviews and signs the completed Pre-design Checklist for Drainage Study and Hydraulic Design.

4.4.6 Post-Meeting Follow Up

The Hydraulic Designer should provide draft meeting minutes to all invitees and attendees, with meeting minutes documenting any required follow up agreed to during the meeting. Final minutes should be posted on the Preconstruction SharePoint site for the project.

4.5 Merger Concurrence Point 4B Meeting

For those projects following the 404/NEPA Merger Process, a Concurrence Point 4B (CP4B) meeting is held to review the preliminary drainage design to gather any input that may need to be considered when completing the final hydraulic design. For additional guidance, refer to Guidance for Merger Concurrence Point 4B Meetings and Plans.

4.6 References

AASHTO. 2018. *Policy on Geometric Design of Highways and Streets - 7th Edition.*

FDOT. Claude Villiers, Dahai Guo, and Bertho Augustin (authors). 2012. *Evaluation of Driver Behavior to Hydroplaning in the State of Florida Using Driver Simulation.* FDOT Contract Number: BDQ22 977-01.

FDOT. Hyung S. Lee and Dinesh Ayyala (authors). 2020. *Enhanced Hydroloplaning Prediction Tool.* FDOT Contract Number: BE570. .

FDOT. M. Gunaratne et al (authors). 2012. *Hydroplaning on Multi Lane Facilities.* FDOT Contract Number: BDK84 977-14.

Florida's Turnpike Enterprise (FTE). Al-Ahad Ekram and Steven Kane (authors). 2018. "Hydroplaning Crash Study and Mitigation Strategies Phase II." *Florida's Turnpike Enterprise.* October. Accessed December 2021. http://floridasturnpike.com/wp-content/uploads/2020/07/FTE-Hydroplaning-Study-Phase-II-Tech-Memo.pdf.

Mounce, J.M. and R.T. Bartoskewitz. 1993. *In Transportation Research Record 1401 - Hydroplaning and Roadway Tort Liability.* Washington DC: Transportation Research Board - National Research Council.

Ong, G.P and Fwa, T.F. 2007. *Prediction of Wet-Pavement Skid Resistance and Hydrolplaning Potential - Transportation Research Record: Journal of the Transportation Research Board, No. 2005.* Transportation Research Board of the National Academies.

TXDOT. Randall J. Charbeneau (author). 2008. *Highway Drainage at Superelevation Transitions (FHWA/TX-08/0-4875-1).* Texas Department of Transportation / Federal Highway Administration (FHWA).

4.7 Additional Documentation

Drainage Design Field Investigation Checklist

NCDOT Hydroplaning Assessment Tool

Example Hydroplaning Assessment

Pre-Design Checklist for Drainage Study and Hydraulic Design

Guidance for Merger Concurrence Point 4B Meeting and Plans

North Carolina
Department of
Transportation

Chapter 5 Drainage Plans Development

Hydraulics Unit

February 22, 2022

Revisions Sheet			
Page	**Old Section**	**New Section**	**Description**
-	-	-	• Entire Chapter revised to new format and minor grammatical changes made throughout • All references and links have been updated throughout Chapter
1	-	5.1	Added new section – Introduction; Subsequent sections renumbered
2	5.1	5.2	Last paragraph – Removed reference to Appendix D, Item 4. Now references HPR
-	5.2	-	Section deleted
5	5.3	5.2.2	Section moved to be included under 1st bullet
5	5.3	5.2.2	Last Paragraph – Removed reference to Appendix E; revised links
4	5.5	5.2.2	12th bullet – Removed hazardous spill basins; replaced with Stormwater Control Measures (SCMs)
5	5.5	5.2.2	Last paragraph – Removed reference to Appendix B; revised links
6	6.1	5.3.1	Added 2nd bullet – Subsequent bullets renumbered
6	6.1	5.3.1	10th Bullet – Removed references to Appendix T; refers to Section 5.4
7	6.1	5.3.1	11th Bullet – Removed references to Appendix B; revised links
7	-	5.4	Added new section – Items to Include on Redline Drainage Plans
8	-	5.5	Added new section – Completing 3D Series Hydraulic Summary Plan Sheets (Including Drainage Summary Sheets and Stormwater Control Summary Sheets)
10	6.2	5.6	• Removed references to Appendices; revised links • Last sentence revised
12	-	5.7	Added new section – References
13	-	5.8	Added new section – Additional Documentation
13	Appendix B	5.8	Drainage Design Field Investigation Checklist link added

	Appendix D – Item 4	5.8	Replaced with the Hydraulic Planning Report Template (link)

Table of Contents: Chapter 5, Drainage Plans Developement

5.1 Introduction

The purpose of a drainage study 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. Field investigations, data collection, observation, and computations are part of the drainage study. A report is generated for the study, the format of which is dependent on the project. This chapter discusses drainage plan development for a typical roadway project.

5.2 Field Reconnaissance and Survey

The Location and Surveys Unit, in conjunction with the Photogrammetry Unit, provides the survey data 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* (NCDOT 2007 (rev. 2010)).

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.
- condition of drainage structure and invert elevations
- storm drain system components
- curb and gutter locations
- streams and ponds (location, geometry, hydraulic characteristics, stability, outlet structure etc.)
- topographic features (e.g., paved areas, buildings, wooded areas, etc.)
- digital terrain model (DTM) and LiDAR

Wetlands and jurisdictional streams are delineated by the Environmental Analysis Unit (EAU) 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 the Location and Surveys and Photogrammetry Units to determine what additional data must be obtained, such as stream bed slope, and channel geometry (at locations where detailed stream cross sections may be needed). If the accuracy of the survey data is in question or if additional field surveys are warranted, request assistance from the Location and Surveys Unit staff. The Hydraulic Planning Report (HPR) includes a list of field information to 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.

5.2.1 Drainage Field Reconnaissance

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

- safely conveys the design flow to prevent inundation of the travel way without creating excessive flooding on upstream or downstream properties
- does not create flow velocities causing excessive scour erosion in the outlet channel or on the roadway fill at the inlet
- structurally supports the roadway and traffic loading
- provides adequate means for terrestrial and aquatic passage

The Design Engineer's challenge is to design the most economical structure which will satisfy all these constraints. More detailed guidance on these topics is provided in Chapters 8 and 9. With respect to allowable backwater and scour velocities, certain field data must be collected to establish these parameters. Obtain elevation data on upstream development in the vicinity to determine if structures are near the observed or known high water elevation. 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, or assessing potential impacts of grade adjustments
- 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)

- 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 Environmental Analysis Unit)
- 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 retained or extended:
        - top slab and vertical interior web (wall) thicknesses
        - inlet bevel, if present
    - for existing bridges:
        - pier widths, footers, abutments, mud sills
- assess existing structure's condition
    - if in question (e.g., cracks, perched, spalling), follow up by contacting the Structures Management Unit and/or the 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 (e.g., annual, two-year, five-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), noting location and direction of view

5.2.2 Drainage Data Collection

Additional drainage survey data and supplemental topographical information which should be collected include:

- elevations of flooding (high water marks, historical flood levels)
    - 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

    - Obtain local flood history information from the local Division maintenance personnel and residents or service personnel (mail carrier, school bus drivers, etc.) who may be familiar with the project site. Conditions found to indicate potential damage to the road 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).
- elevation of upstream and downstream features which could control the design, such as buildings, roads, yards, fields, and other drainage structures
- stream bed elevations for 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)
- 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
- locations of springs, seeps, or noticeable high-water tables
- potential locations for Stormwater Control Measures (SCMs), if required
- evaluation of wetlands and jurisdictional streams shown in base mapping on roadway plans to ensure accuracy for permit application
    - coordinate with EAU 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) 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)
- type and condition of existing foundation, if visible
- any repairs/bank stabilization, if visible

All pertinent data gathered through this field reconnaissance and survey should be recorded on work plans, field notes, and filed with project documentation. Important project documentation should also be preserved in a digital format, such as a MicroStation CADD file or scanned PDF file. The Drainage Design Field Investigation Checklist should be completed while conducting the field study.

5.2.3 Field Safety

All personnel performing field reconnaissance who work for NCDOT must follow the policies and guidance in NCDOT's Safety Policy and Procedure (SPP) Manual (NCDOT 1995) and Workplace Safety (Operations Procedures – SOP) Manual (NCDOT n.d.).

There is no specific published guidance or policy pertaining exclusively to NCDOT roadside work by field survey crews. Roadway Standard Drawings (NCDOT 2012) 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. If required, coordinate with the local Division office to ensure that appropriate personnel are assigned to serve in this capacity.

If surveys are needed within a railroad right-of-way, arrange a permit of entry by coordinating 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.

5.3 Drainage Plans

5.3.1 Development Process

Using the preliminary roadway plans as a base, develop the drainage plans in the MicroStation Drainage (DRN) file, and proceed as follows:

1. As necessary, verify and supplement all existing drainage features (structure type, size, elevations).
2. 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.
3. Note all existing drainage divides, flow directions, ditches, channels, etc. Transfer important notes on hardcopy plans to the digital MicroStation plan drawings on the appropriate information levels, such as notes about existing pipe conditions, erosion problems, etc.
4. Verify and supplement information addressing utilities that may affect drainage features.
5. Sketch any special ditches or other topographical features identified during field surveys and not included on the preliminary plans.
6. Make notes of design controls identified during data collection and field survey stage, such as elevation of lowest adjacent grade (LAG) of buildings in floodplain, which could potentially be adversely affected.
7. Determine and evaluate the patterns of surface flow as affected and developed by the project construction. Note flow direction and areas of flow concentration for clarity, as needed
8. 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
9. 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*.
10. Upon completion of hydraulic design, prepare a final set of redline drainage plans, in electronic PDF and CADD versions. These should include the following items as a minimum (see Section 5.4 for additional items to consider):
    - drainage areas (label size and show boundary depictions)
    - existing drainage patterns (see Section 5.4.1)
    - storm drain system inlets, pipes, etc., with top and invert elevations and structure numbers
    - ditches and outlet channels, with details, plan/profile views and computations, as appropriate
    - topographical contours, including flow areas 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

11. The Checklist for Drainage Study and Hydraulic Design must also be finished and included with the project documentation upon completion of design.

5.4 Items to Include on Redline Drainage Plans

5.4.1 Field Reconnaissance Items

- Clearly show existing drainage patterns. This is important not only for review, but also as a record of pre-project conditions.
- Show existing contours with readable elevations at a contour interval appropriate for the terrain.
- Mark existing ditches (and labeled if not clear), with a continuous series of arrows for the extent of the ditch.
- Mark general overland flow patterns (non-ditch) with arrows as needed in addition to contours.
    - Pay particular attention to areas where contours are indistinct or difficult to discern, or where contours alone are not adequate (such as areas adjacent to the slope stakes that are not well reflected in the contours). Do not use the same arrow symbology for overland flow as for existing ditches to avoid confusing the two.
- Note existing pipe condition (especially if retaining or plugging), any erosion/problem notes, etc.
- Provide descriptions for all existing ditches (other than roadside ditches that appear in the cross sections) to show existing channel geometry dimensions. Ditch descriptions should include water depth (if applicable) and type of cover/condition for outfall ditches.
- Note the condition of existing ponds/spillways within the project area. Note spillway/outlet locations and any draw down pipe sizes.
- Show top of banks for major drainage structures.

5.4.2 Hydraulic Design Items

- Mark proposed grade sag/crest locations on plan sheets. Indicate direction of grade (with an arrow pointing in the downgrade direction) for any alignment that does not have a sag/crest marked on that sheet.
- Mark tops/inverts marked on the redline set, including cross pipes and equalizer pipes.
- Show all required TDE/PDE on plans for review.
- Label proposed ditches (plan view) and alignment/stationing filled in for ditch

details. Include ditch labels with base width dimension for base ditches.

- Set minimum depth on ditch details to contain the design flow plus freeboard and specify to the whole or half-foot (one foot or greater).
- Show drainage area boundaries for all ditches/inlets/pipes. If drainage area extends off sheet, provide readable contour map at an appropriate scale that shows full delineation of drainage area.
- Show Q10/V10 for all ditches entering (or discharging adjacent to) wetlands, and include all variables used in analysis on redline set.
- Draft buffer zones (BZ1 & BZ2). Be careful about drafting around acute angles. Do not just Copy Parallel.
- Document design notes on redlines as needed, to explain design decisions and document other issues not readily apparent.
- Do not turn off any levels/reference files that are required for R/W plans, such as property owners.
- Show cross pipes and design data block from Pipe Data Sheet on the profiles.
- Include all variables on ditch comps (including Manning's 'n'/side slopes).
- All features requiring grading, including but not limited to special ditches, stormwater BMPs etc., shall have a grading plan including, at minimum, slope stake lines. Inclusion of proposed contours is preferred.
    - Contours are required for stormwater BMPs with a basin component proposed
- Details shall have clear dimensioning including, but not limited to, side slopes, base widths, berm widths, depths, etc.

Items preferred to be on redline set plan sheets, but not required if provided separately:

- ditch computations
- outlet (pre/post) analysis summary
- overpass spread computations

5.5 Completing 3D Series Hydraulic Summary Plan Sheets (Including Drainage Summary Sheets and Stormwater Control Measure Summary Sheets)

Construction plan sheets include 3D Series drainage summary sheets. Traditionally, these sheets have included the summary of pipe and drainage structure types. With the implementation of Project Delivery Network (PDN) version 2.0, the 3D series sheets will now also include stormwater control measure summaries for projects where stormwater controls are included. Not all projects will include stormwater control measures; these sheets should be the last sheets within the 3D series.

5.5.1 Drainage Summary Sheets

Drainage summary sheets should be completed per guidance in the Drainage Summary Sheet – Steps for Hydraulic Users

Once the traditional drainage summary sheets have been completed, the user should add the stormwater control summary sheets starting with the next available consecutive sheet number.

5.5.2 Stormwater Control Measure Summary Sheets

The Highway Stormwater Program (HSP) has amended the Stormwater Management Plan (SMP) template to automate the creation of the Stormwater Control Measure Summary Sheet. Hydraulic Design Engineers are required to complete an SMP for all projects and should always use the latest SMP template version.

Users should complete the SMP per the instructions included in that document. Users should complete the “general project information” and “waterbody information” tabs along with any applicable stormwater control measure tabs (swales, filter strip, PSHs and energy dissipators, level spreader and HSB, other toolbox BMPs, other non-toolbox BMPs). These tabs are illustrated in Figure 1.

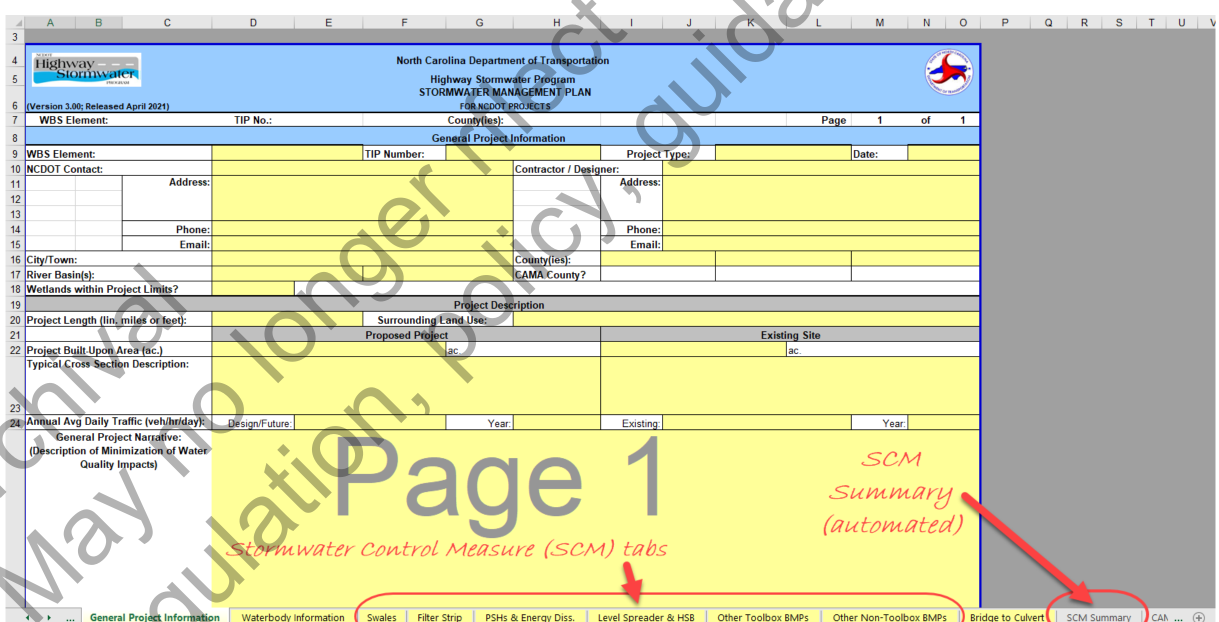

Figure 1. Stormwater Management Plan Template

As a user completes the SCM tabs on the SMP:

1. the SCM summary tab will be auto-populated and sorted by plan sheet number, alignment (L, Y1, etc.), and station
2. after completion of the SCM tabs, click on the SCM summary tab
    a. table should be complete and sorted
3. complete the computed by and checked by with dates box in the upper left corner of the first sheet, cells D7, D8, F7, and F8 (see Figure 2)
4. complete the next consecutive 3D series plan sheet number in the upper right corner of the first sheet, cell Z8

Any additional sheets will be automatically numbered. All other cells within the worksheet should be locked and non-editable. The worksheet print area is preset to include only the first sheet. If additional sheets are needed, expand the print area manually to include those sheets. Once the print area is set appropriately, print the sheets to PDFs at the ANSI D size (22"x34", full-size plan sheet).

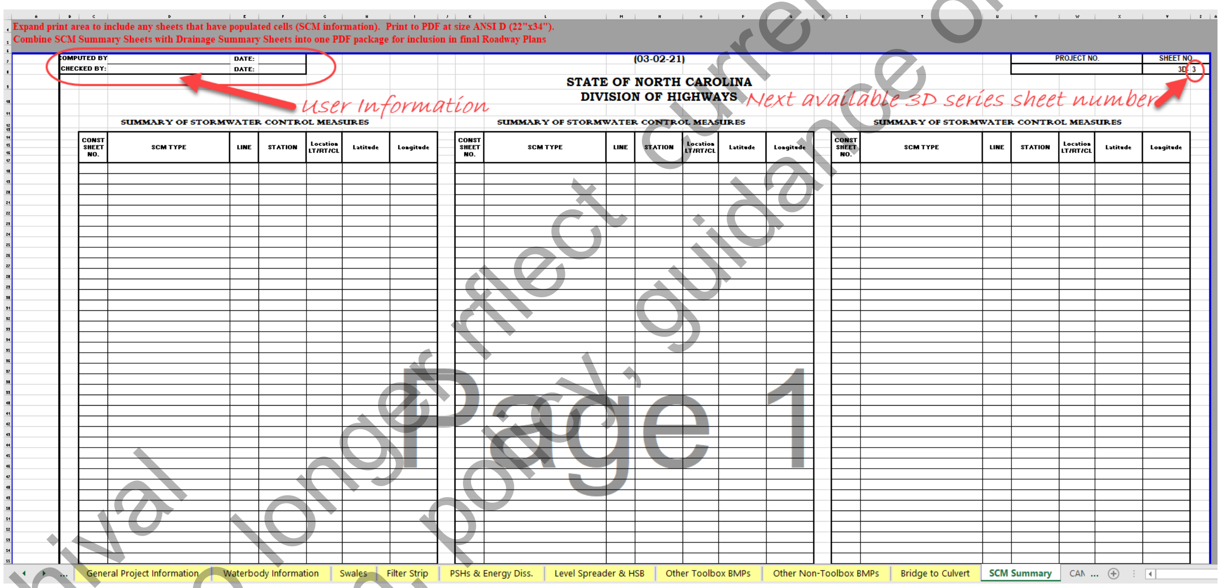

Figure 2. Stormwater Control Measure Summary Sheet

5.5.3 Deliverables

The printed PDF should be combined with the drainage summary sheets to create one consolidated PDF file. The total 3D series sheets PDF file should then be sent to the project Roadway Design Engineer to be incorporated into the final plan set. The final SMP should be uploaded to the Preconstruction Connect site via the ATLAS workbench.

5.6 Sealing of Drainage Plans and Design Reports by Professional Engineer

The final plans are signed and sealed by the responsible North Carolina Professional Engineers who performed or supervised the engineering work. Procedures for electronically sealed plans have been implemented within NCDOT. Typically, the hydraulic 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) are included with the project, the hydraulic design engineer must also certify that the information in these reports and the plans is 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, documentation corresponding to the project's Project Delivery Network (PDN) package must be individually sealed by the responsible engineer.

5.7 References

NCDOT. (1995, December). *Safety Policy and Procedure Manual.* Retrieved November 2021, from Safety & Risk Management SPPs: https://connect.ncdot.gov/business/safety/Pages/SPP.aspx

NCDOT. (2007 (rev. 2010)). *Field Surveys for Hydrographic Data, Version 2.2.* Retrieved from Location & Surveys Unit, North Carolina Department of Transportation: https://connect.ncdot.gov/resources/Location/Manual%20Documents/Location%20Hydro%20Manual%202010.pdf

NCDOT. (2012). *Roadway Standard Drawings*. (North Carolina Department of Transportation - Roadway Unit) Retrieved November 2021, from https://connect.ncdot.gov/resources/Specifications/Pages/2012-Roadway-Drawings.aspx

NCDOT. (n.d.). *Safe Operating Procedures and Workplace Safety Manual.* Retrieved November 2021, from Safety & Risk Management SOPs.

5.8 Additional Documentation

Hydraulic Planning Report (HPR)

Drainage Design Field Investigation Checklist

Bridge Survey and Hydraulic Design Report (BSR) Key

Culvert Survey and Hydraulic Design Report (CSR) Key

Drainage Summary Sheet for Hydraulics Users Guide

Stormwater Control Measure Summary Sheets

North Carolina
Department of
Transportation

Chapter 6 Resilience

Hydraulics Unit

February 22, 2022

Revisions Sheet			
Page	**Old Section**	**New Section**	**Description**
-	-	-	• Entire Chapter revised to new format • Previous version of Chapter 6 has been combined with Chapter 5. This Chapter will be a new chapter and is reserved for future updates.
1	8.5.2.1	6.1	This section was moved from Chapter 8
1	3.6	6.1.1	This section was moved from Chapter 3

Table of Contents: Chapter 6, Resilience

6.1. Introduction

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.

NCDOT is currently developing policies to address climate change and extreme weather events. 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* (FHWA, R.T. Kilgore, G.R. Herrmann, W.O. Thomas, Jr., D.B. Thompson (authors) 2016) as necessary, *Highways in Coastal Environment – Third Edition (FHWA-HIF-19-059)* (FHWA, Scott L. Douglass, Bret M. Webb (authors) 2020)

6.1.1. Project Commitment Regarding Climate Change and Extreme Weather Events

When necessary, project commitments may need to include language to address climate change and extreme weather mitigation measures and design strategies. The language below is an example of a commitment statement that may be used:

Hydraulics Unit and Roadway Design Unit commitment:

NCDOT will follow FHWA's policy as set forth 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, R.T. Kilgore, G.R. Herrmann, W.O. Thomas, Jr., D.B. Thompson (authors) 2016) *and Highways in Coastal Environment – Third Edition (FHWA-HIF-19-059)* (FHWA, Scott L. Douglass, Bret M. Webb (authors) 2020) *to minimize climate and extreme weather risks and protect transportation infrastructure.*

6.2. Reserved

This section is reserved for future updates

6.3. References

FHWA, R.T. Kilgore, G.R. Herrmann, W.O. Thomas, Jr., D.B. Thompson (authors). 2016. "Highways in the River Environment - Floodplains, Extreme Events, Risk and Resilience; Hydraulic Engineering Circular 17, 2nd Edition (HEC-17)." *Federal Highway Administration, U.S. Department of Transportation.* June. https://www.fhwa.dot.gov/engineering/hydraulics/pubs/hif16018.pdf.

FHWA, Scott L. Douglass, Bret M. Webb (authors). 2020. *Highways in the Coastal Environment (HEC-25) - Third Edition.* Federal Highway Administration, U.S. Department of Transportation. January. Accessed November 2021. https://www.fhwa.dot.gov/engineering/hydraulics/pubs/hif19059.pdf.

North Carolina Department of Transportation

Chapter 7 Hydrology

Hydraulics Unit

February 22, 2022

Revisions Sheet			
Page	**Old Section**	**New Section**	**Description**
-	-	-	• Entire Chapter revised to new format and minor grammatical changes made throughout • All references and links have been updated throughout Chapter
1	7.1	7.1	Last sentence revised.
1	7.2	7.2	1st sentence – Removed "relatively new" from USGS StreamStats, Removed reference to Appendix E and Updated links
1	7.2.1	7.2.1	Revised link
2	7.2.3.2	7.2.3.2	Last sentence added
3	7.2.4	7.2.4	Link added
3	7.3	7.3	• Revised 3rd sentence • Last sentence added
3	-	7.3.1	Added new section – Level of Service Determination
4	7.4	7.4	Removed 3rd sentence
5	7.4	7.4	Table 2 – Revised Rational Method up to 100 acres; Removed "(for routing" from NRCS Method; Added asterisk and footnote for NCDOT Hwy Hydrologic Charts
7	7.4.2.3	7.4.2.3	Entire section revised
7	7.4.3	7.4.3	Last sentence – Revised upper limit to 100 acres
8	7.4.3.2	7.4.3.2	Removed 3rd paragraph
8	7.4.4	7.4.4	Entire section revised
10	-	7.6	Added new section - References
12	-	7.7	Added new section – Additional Documentation
12-17	Appendix C	7.7	Added NCDOT Charts

Table of Contents: Chapter 7, Hydrology

7.1 Introduction

The hydrologic analysis phase involves determining the discharge rates and volumes of runoff that drainage facilities are required to convey. This chapter discusses the acceptable hydrologic methods for highway drainage studies and applicable criteria for their use. 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 (FEMA 2016). 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 land use changes over the life of a project and non-stationarity in future climate projections, and include these effects when estimating design discharges. (See Chapter 6 for more guidance regarding project resilience.)

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)
- digital elevation data (such as Light Detection and Ranging, or LiDAR, data)
- 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 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 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 should review 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. MicroStation Triangular Irregular Network (TIN) files provide the primary and most current, accurate, and readily available data file, and is supplied by NCDOT Location and Surveys and Photogrammetry Units for the specific project area. Since this coverage is often inadequate for hydrologic studies, 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. The DTM file is then used to generate a TIN file to represent the existing ground surface. The original TIN files provided for a project do not always 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). Additional information regarding availability and quality of LiDAR data can be found on NCDOT Photogrammetry Unit's website.

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. Within the state, NC FMP's LiDAR coverage will likely be more current, higher resolution, and accurate than that available from the NED. Additionally, larg e municipalities and some counties have developed topographic and elevation data which may be publicly available for use in drainage area determination.

7.2.4 Archived NCDOT Bridge and Culvert Survey and Hydraulic Design Reports

The Hydraulics Unit archives thousands of bridge and culvert design reports, in both hard copy and PDF formats. (https://connect.ncdot.gov/sites/hydro/Reservoir/Pages/default.aspx)

These reports provide valuable hydrologic and hydraulic information, such as drainage area size, discharge rates and associated computed water surface elevations, methods used for computations, flood history records, etc. The Design Engineer should verify the information on the report before relying on it, since the information provided on these reports is only as accurate as the methods and technology available as of the date of the report.

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 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 during the planning phase and agreed upon during the pre-design review. See Chapter 12, Section 12.3 for the criteria to specify the design frequency for temporary pipes or diversion channels for culvert construction sequencing.

7.3.1 Level of Service Determination

The hydraulic level of service is a performance standard for NCDOT highways. It is based on defined design storm to subsequently set minimum hydraulic design standards for the project. Table 1 provides the standard minimum design frequencies for various hydraulic elements based upon roadway classification.

Table 1. Design Frequency

Roadway Classification	FREQUENCY (years)			
	Bridges, Culverts and Cross Pipes	Storm Drain System		Ditches
		On Grade	At Sags (without relief)	
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

*While it is not practicable to design an entire highway system so that damage or closure due to extreme flood events will never occur, it is possible to reduce the risk of occurrence by implementing an increased level of service where warranted. For example, it would be considered reasonable and prudent that higher hydraulic performance standards for the Strategic Transportation Corridor network, major arterials, evacuation routes, and other important roadways should be carefully considered during planning and design to include, among other things, risk to commerce, accessibility, and evacuation due to road closure caused by inundation, including non-stationarity in future climate models.

Some roads may warrant a lesser hydraulic design frequency. In these instances, discussion and analysis of inundation probability and duration that are less than the design storms listed in Table 1 should be documented. The documentation should include criticality of the roadway and access concerns.

See Chapter 3 for more information regarding hydraulic planning-level studies.

7.4 Peak Discharge Estimates

The Design Engineer should select from several acceptable peak discharge methods, depending upon the site's watershed characteristics. Table 2 lists peak discharge methods which are acceptable for NCDOT hydrologic studies. 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.

Table 2. Peak Discharge Method Selection

Hydrologic Methods	FIS (for NFIP compliance)	USGS Methods	Rational Method (up to 100 ac)	NRCS Method	NCDOT Hwy. Hydrologic Charts*
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	

*Use NCDOT Charts only in Region 2 (mountain regions)

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, the discharges specified in the FIS Summary of Discharges table should be used in the hydraulic model to demonstrate FEMA regulatory compliance. Streams 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.

View and download copies of effective FIS reports 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)

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.
- The second is computed from the appropriate regionalized regression equation developed for the hydrologic area of the gage station location.
- The third combines the results of the first two into a weighted estimate for that gage station. This is presumably the most accurate and reliable estimate.

Details on how these estimates are computed are discussed in USGS report SIR 2009-5158 (USGS. J.C. Weaver, T.D. Feaster, A.J. Gotvald (authors) 2009 (rev. 2015)). 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 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 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 (USGS. J.C. Weaver, T.D. Feaster, A.J. Gotvald (authors) 2009 (rev. 2015)). This method is not recommended if the difference in drainage areas between the two locations is greater than fifty percent. If the ungaged site is located between two gaged stati ons on the same stream, two peak discharge estimates can be made using the above procedure. Hydrologic judgment can be 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. The Design Engineer is responsible for reviewing the validity of equations and variables, and for being familiar with the limitations of any equations used by StreamStats. The Design Engineer should also note the IA percent used in calculating discharges and adjust as needed to account for changes in IA or for future development. SIR 2014-5030 (USGS. T.D. Feaster, A.J. Gotvald, and J.C. Weaver (authors) 2014) should be used whenever applicable. For rural basins within the applicable ranges of SIR 2014-5030, with a drainage area (DA) greater than 1 sq. mi. and IA less than 10%, the Design Engineer should compare the discharge values given by the 2014 equations with the SIR 2009-5158 equations. Engineering judgement should be used to determine the most appropriate value. For rural basins outside of applicability of 2014-5030, use the rural regional regression equations presented in SIR 2009-5158 (USGS. J.C. Weaver, T.D. Feaster, A.J. Gotvald (authors) 2009 (rev. 2015)).

For urban basins outside of applicability of SIR 2014-5030, such as Region 2, use WRI 96-4084 (USGS. J.C. Robbins, B.F. Pope (authors) 1996), or USGS Fact Sheet 007-00 (USGS. R.R. Mason, Jr., L.A. Fuste, J.N. King, and W.O. Thomas, Jr. (authors) 2002), as applicable. There may still be some situations where the basin characteristics are outside of the limits of all the USGS publications and the Design Engineer should use judgement in determining the most applicable method. If 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, as presented in TR-55 (NRCS 1986) and TR-20 (NRCS 2015) should be used for calculating t_c. Minimum value for t_c should be 10 minutes. An upper limit of 100 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 3 provides commonly used values for various surface types (FHWA. R.H. McCuen, P.A. Johnson, R.M. Ragan (authors) 2002). The higher values in the ranges shown sho uld 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.

Table 3. Typical Rational Runoff Coefficients

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

7.4.3.2 Rainfall Intensity

Obtain rainfall intensity (I) data from the NOAA Atlas 14 published report (NOAA. G.M. Bonnin, D. Martin, B. Lin, T. Parzbok, M. Yetka, D. Riley (authors) 2006) 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. Use a minimum of ten minutes.

Access the PFDS: https://hdsc.nws.noaa.gov/hdsc/pfds/

Intensity values in GEOPAK Drainage (Bentley Systems, Inc. 2010) 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 previous 2016 version of the Guidelines included the NCDOT Highway Hydrologic Charts, corrected and digitally reproduced from the 1973 State Highway Commission charts, which were provided in Appendix C of that version of Guidelines. They formerly were primarily used for sizing of small pipes. Due to more state-of-the-art hydrologic methods their usage is becoming obsolete, but the charts may still be used for small mountainous watersheds (Region 2) on a case-by-case basis. The charts have been provided in Section 7.7 for reference.

7.4.5 NRCS Methods – Storage Routing

Natural Resources Conservation Service (NRCS, formerly Soil Conservation Service) methods, presented in TR-55 (NRCS 1986) and TR-20 (NRCS 2015), 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, visit the NRCS Web Soil Survey website:

(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 ((AASHTO 2007), (AASHTO 2014), (FHWA. R.H. McCuen, P.A. Johnson, R.M. Ragan (authors) 2002)) 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 contemplates 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 ten-year peak discharge in the Piedmont region is 25%; it is 73% for the 500-year peak discharge in the Sand Hills region (USGS. T.D. Feaster, A.J. Gotvald, and J.C. Weaver (authors) 2014).

It can be argued that some hydrologic methods are more accurate than others. 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 should 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.

7.6 References

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

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

USGS. R.R. Mason, Jr., L.A. Fuste, J.N. King, and W.O. Thomas, Jr. (authors). 2002. *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.* Reston, VA: United States Geological Survey, United States Department of the Interior.

USGS. T.D. Feaster, A.J. Gotvald, and J.C. Weaver (authors). 2014. *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.* Reston, VA: United States Geological Survey, United States Department of the Interior.

7.7 Additional Documentation

NCDOT Hydrologic Charts

(Revised and digitally reproduced from 1973 State Highway Commission charts)

List of Charts:

Chart number	Description
C200.1	Hydrologic Contour (HC) Map
C200.2	Rural Runoff
C200.3	Urban Runoff
C200.4	Rural Drainage Area (DA) Shape Correction
C200.5	Rural Drainage Area (DA) Land Cover Correction

Procedure for rural watersheds:

1. Verify DA < 1 sq. mi.; otherwise, SHC charts not applicable.
2. Determine HC from C200.1 to nearest 0.5 interval. In highly channelized areas, particularly in coastal areas, a value of 1.0 above that shown in C200.1 should be used. Thus, it is unlikely that a value less than 4.0 would ever be used.
3. In C200.2, determine 50-yr discharge (Q_{50}) for the given HC and DA values. For other frequencies, apply the appropriate frequency factor listed. These values may need to be adjusted further for DA shape and land cover, as outlined in following steps 4 and 5.
4. Determine shape parameter W/L. From this and the DA, the shape correction factor can be determined in C200.4.
5. With the DA and percentage forest cover, use C200.5 to determine the land cover correction factor. Do not use this factor to reduce discharge unless future development in the watershed is not anticipated, such as in certain mountainous, wetland, or designated preservation areas.
6. Acceptable values for the multiple of shape and land cover correction factors are limited to the range of 0.7 to 1.5. Apply the adjustment factors to the discharge values determined from step 3.

Procedure for urban watersheds:

1. If DA < 20 acres, verify whether Rational Method would be more appropriate to use instead of the SHC charts. Also, if DA > 100 acres, C200.3 is not applicable. If uncertain whether watershed is urban, calculate discharges for both urban and rural conditions, then apply appropriate engineering judgment and document which results are deemed appropriate for study site.
2. Determine HC from C200.1.
3. Determine type and relative density of development to determine the appropriate development density adjustment factor.
   a. Residential – high type: lot sizes > 0.5 acres
   b. Average Development: small lots < 0.5 acres, or mixed residential / small business
   c. Large area – full business: DA >75 acres
   d. Small area – full business: DA < 75 acres
4. In C200.3, use HC and DA to obtain 10 yr. discharge (Q_{10}). Apply appropriate adjustment factor for other frequency events and development density adjustment from step 3.

10/13/2016

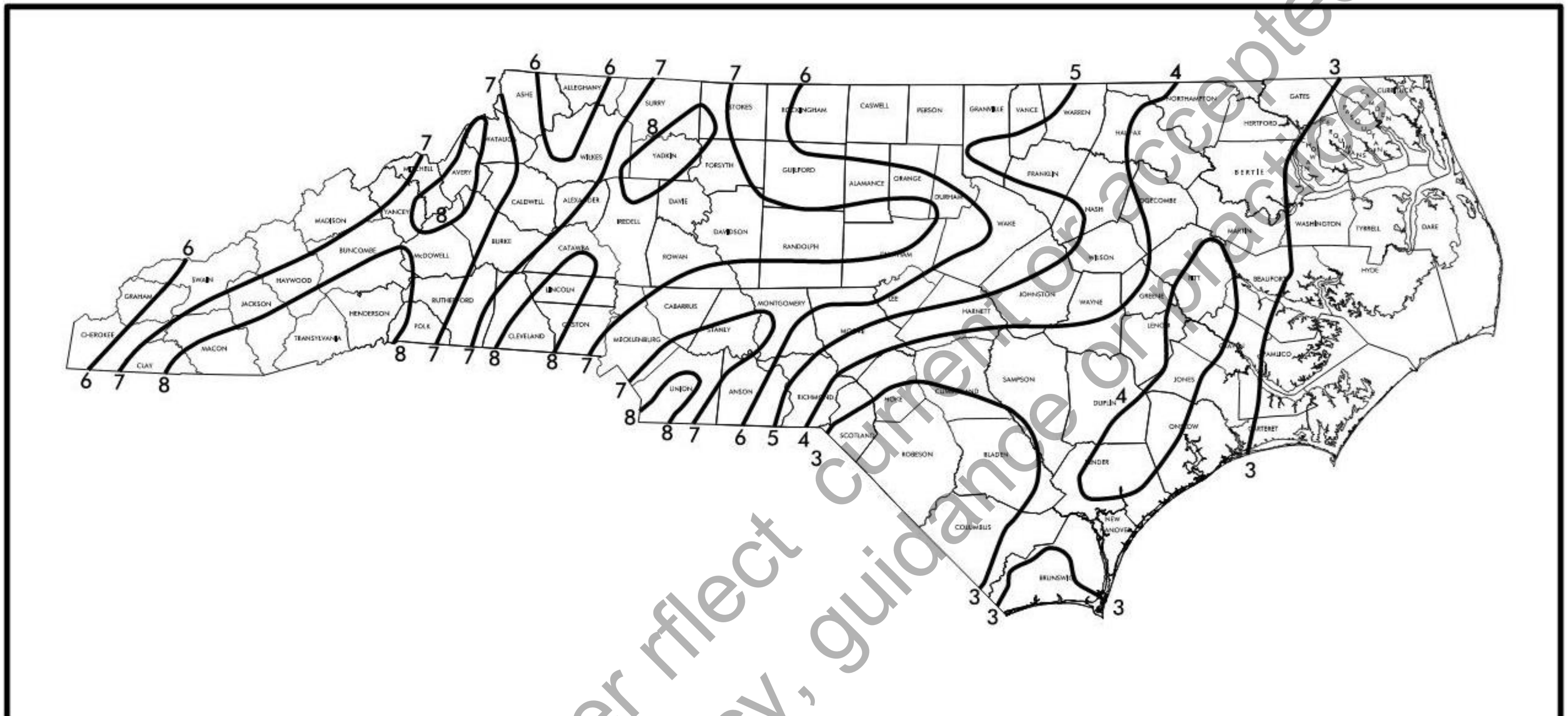
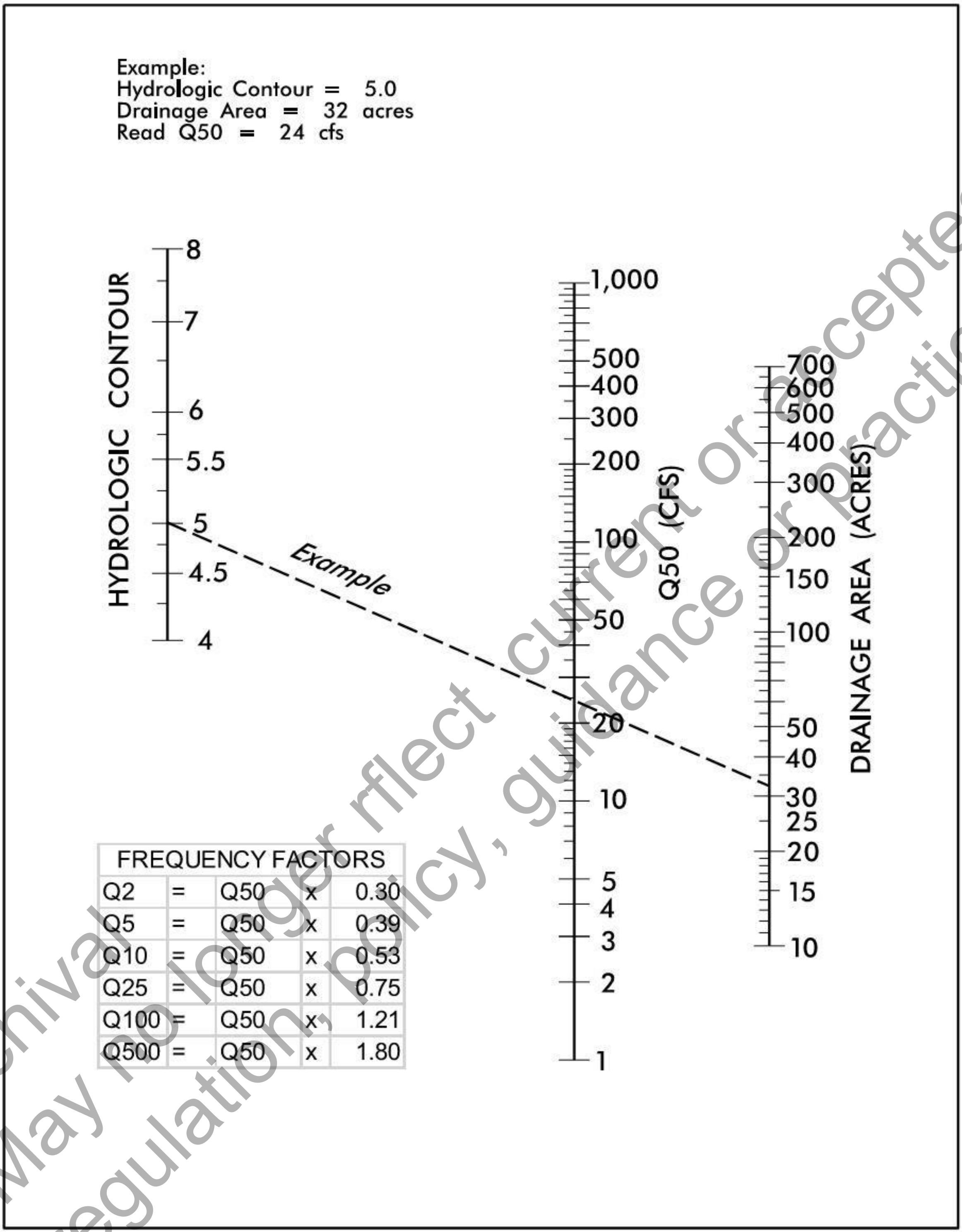


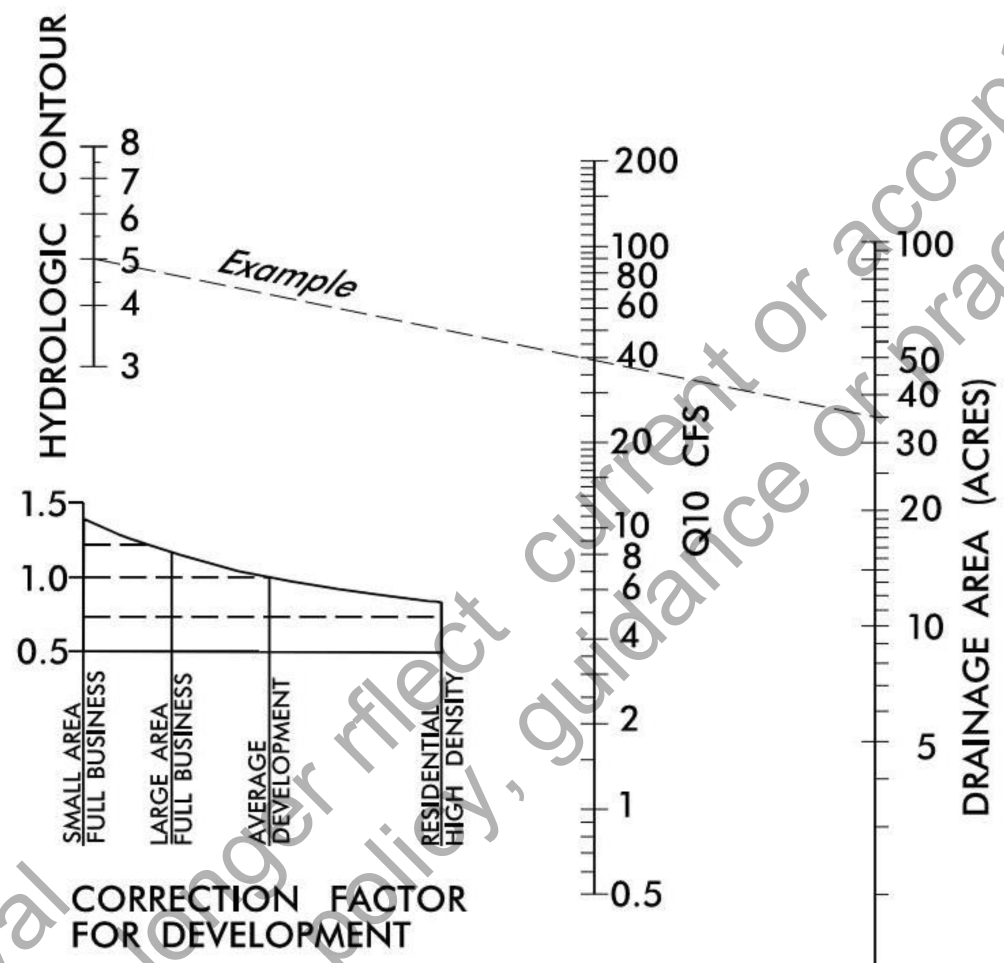
Chart C200.1 NC Hydrologic Contours



FREQUENCY FACTORS				
Q2	=	Q50	x	0.30
Q5	=	Q50	x	0.39
Q10	=	Q50	x	0.53
Q25	=	Q50	x	0.75
Q100	=	Q50	x	1.21
Q500	=	Q50	x	1.80

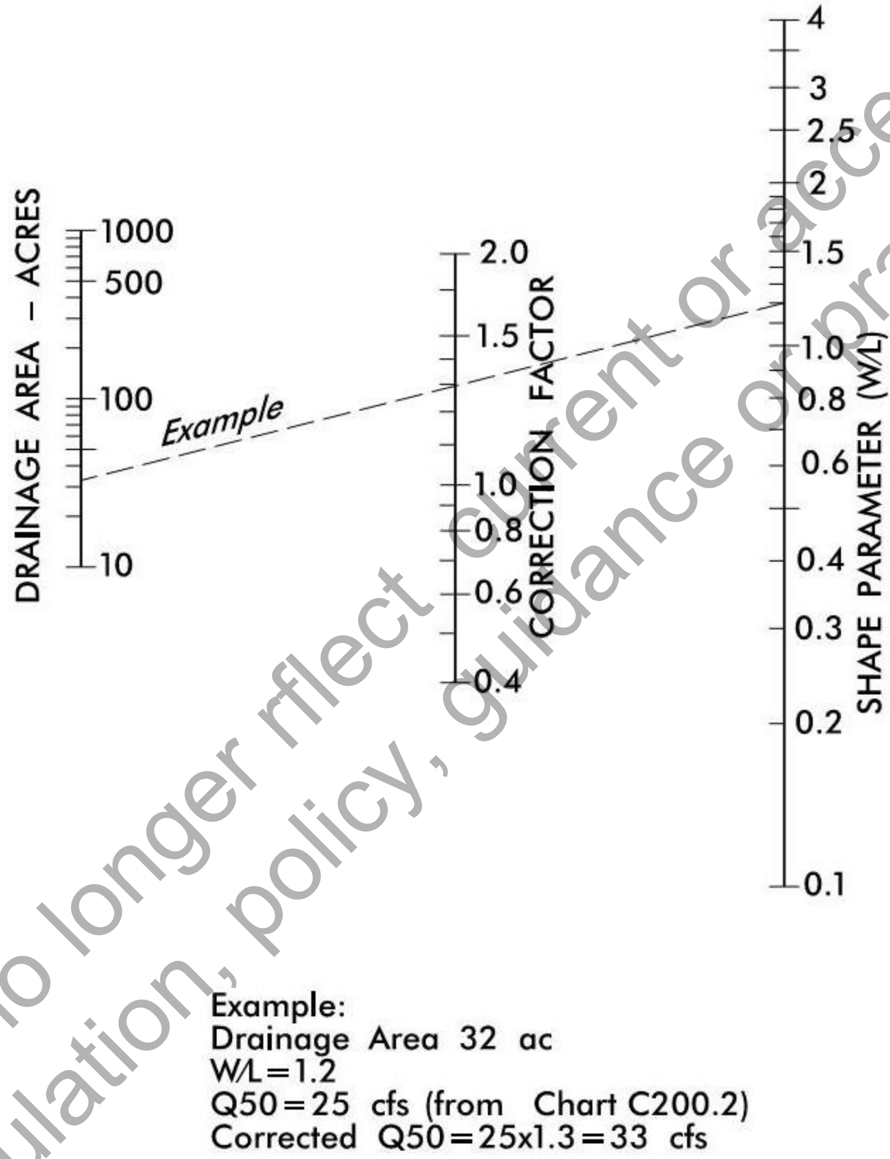
C200.2 RURAL RUNOFF CHART (REVISED)

Example:
Hydrologic Contour 5.0
Drainage Area 35 ac
Small Area – Full Business
Q10=39x1.4=55 cfs



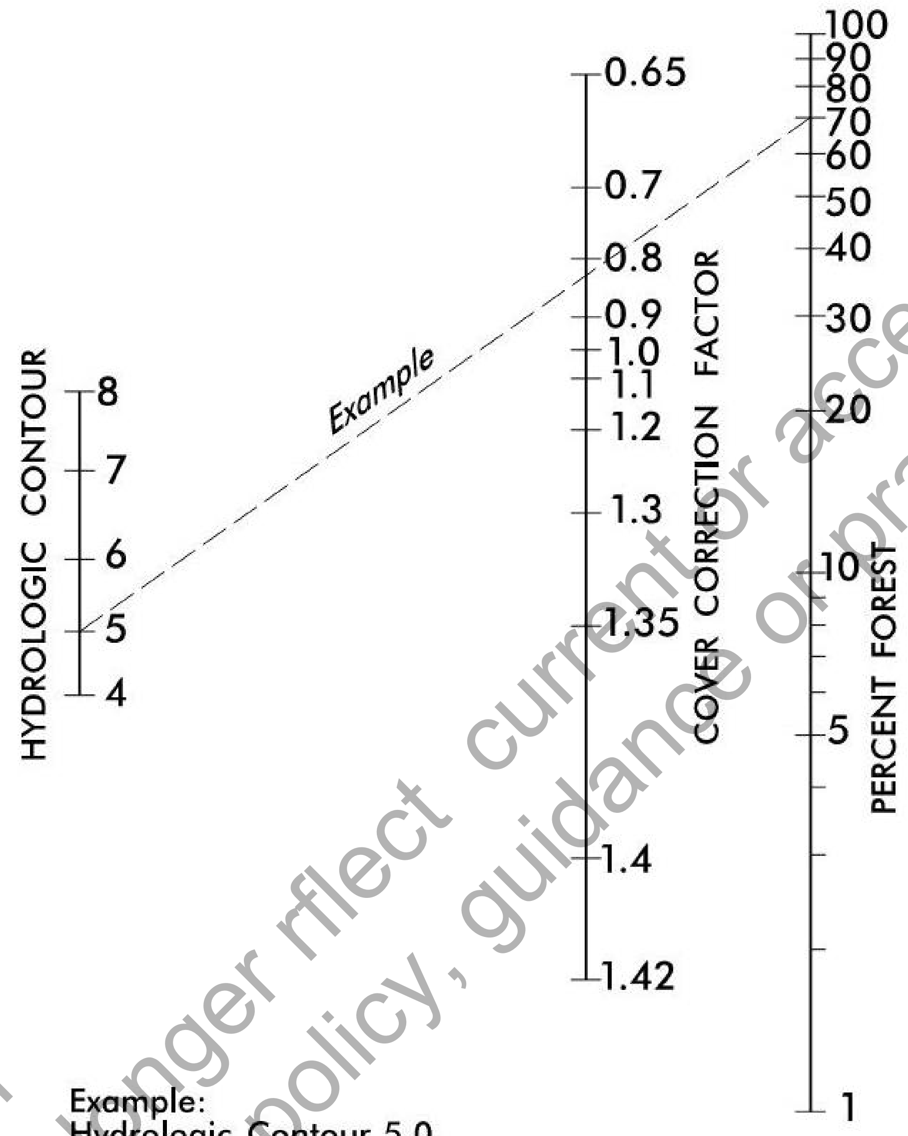
FREQUENCY FACTORS				
Q2	=	Q10	x	0.50
Q5	=	Q10	x	0.75
Q25	=	Q10	x	1.35
Q50	=	Q10	x	1.85
Q100	=	Q10	x	2.15
Q500	=	Q10	x	3.10

C200.3 URBAN RUNOFF CHART (REVISED)



DRAINAGE AREA SHAPE PARAMETER CORRECTION FACTORS

C200.4



Example:
Hydrologic Contour 5.0
Drainage Area 35 ac
70% forest cover
Q50=25 cfs (from C200.2)
Corrected Q50=25x0.84=21 cfs

DRAINAGE AREA COVER PARAMETER CORRECTION FACTORS

C200.5

North Carolina Department of Transportation

Chapter 8 Bridges

Hydraulics Unit

February 22, 2022

Revisions Sheet			
Page	**Old Section**	**New Section**	**Description**
-	-	-	• Entire Chapter revised to new format and minor grammatical changes made throughout • All references and links have been updated throughout Chapter
1	8.1	8.1	• Revised heading • 1st paragraph – revised wording
1	8.2	8.2	Entire section revised
1	8.7	8.3	Moved section; subsequent sections renumbered
2	8.3	8.4	Entire section revised
2	8.8	8.5	Moved section; subsequent sections renumbered; Entire section revised
5	8.5	8.7	4th bullet – revised to "Intermediate sections"
-	8.5.2.1	6.1	Moved to Chapter 6 - Resilience
6	8.5.2.2	8.7.2.1	Added last sentence
8	8.5.2.4	8.7.2.3	Last 2 sentences added
9	8.5.2.4	8.7.2.3	Figure 1 added (previously Appendix E – Item 6)
10	8.5.2.5	8.7.2.4	• Last sentence added • Added References to Figures 3 & 4 (previously Appendix E – Item 6)
10	8.5.2.6	8.7.2.5	Last bullet added
11	8.5.2.10	8.7.2.9	Entire section revised
14	8.5.2.12	8.7.2.11	Last sentence - removed "scanned and"
14	8.5.2.13	8.7.2.12	3rd sentence added - "Two-dimensional (2D) models are recommended for multiple opening analysis."
22	8.6.3	8.8.3	Added Figure 2 (previously Appendix R)
24	-	8.8.5	Added new section – Observed Scour Assessment Procedures
-	8.9	16.6	Moved to Chapter 16 – Coastal Hydraulic Design
-	8.6.5	16.6.1	Moved to Chapter 16 – Coastal Hydraulic Design

25	-	8.9	Added new section – References
28	-	8.10	Added new section – Additional Documentation
29	Appendix E – Item 5	8.10	Added Figure 3
30	Appendix E – Item 5	8.10	Added Figure 4

Table of Contents: Chapter 8, Bridges

8.1 Introduction

The primary goal of a bridge's hydraulic design is to set the bridge geometric constraints to convey floodwaters safely and efficiently without adversely affecting channel stability, the floodplain, the roadway facility, or adjoining properties. All Design Engineers should reference:

- Chapter 7 (Hydraulic Analysis for the Location and Design of Bridges) of the *AASHTO - Highway Drainage Guidelines* (AASHTO 2007)
- NCDOT *Bridge Policy* (NCDOT n.d.)
- FHWA *Hydraulic Design of Safe Bridges* (FHWA, L.W. Zevenbergen, L.A. Arneson, J.H. Hunt, A.C. Miller (authors) 2012)
- FHWA floodplain policy statement in *Federal Aid Policy Guide, 23 CFR 650A* (FHWA 1969)
- FHWA *Additional Guidance on 23 CFR 650A* (FHWA, J. Krolak 2011)

A bridge's design 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 in this chapter will help 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 based on performance, cost, maintenance, and constructability.

8.3 Economic Consideration

When more than one alternative can 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.

8.4 Data Collection and Documentation

Information gathered during the pre-design study and field survey must be assembled for the study site. This process will include:

- Review of the Hydraulic Planning Report (Refer to Chapter 3), as well as available survey information
- Prepare preliminary bridge layouts sketches as appropriate and review with Division staff and the Structural Engineer.
- Prior to developing the final design, the following information should be gathered:
    - 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.
    - 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, also known as ordinary high water) elevation
    - elevation of rock line from geotechnical subsurface investigation, if applicable
    - for coastal tidally influenced bridges, also show Mean High Water (MHW), Mean Tide Level (MTL), and Mean Low Water (MLW) elevations.
        - tidal datum information can be obtained from the National Oceanic and Atmospheric Administration (NOAA) website: www.noaa.gov
    - sufficient vertical clearance under bridge for maintenance and inspection activities
    - 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
    - manmade features in floodplain, such as buildings, houses, roads, utilities, levees, etc.

8.5 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:

- completion of the BSR (follow BSR key for additional guidance)

- 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 foot).
- in the BSR's interior gridded area, provide a performance table of the natural, existing (if applicable) and proposed conditions water surface elevations at the upstream toe section for the Q_{10}, Q_{design}, Q_{100}, and Q_{500} (or $Q_{overtopping}$, if less) discharges
    - specify the bridge face's distance upstream where the proposed conditions water surface elevations are referenced
- scour analysis computations on the BSR
- survey benchmark
- the following notation in the Additional Information and Computations section of the BSR, if applicable:
    - "No upstream or downstream structures that were in place at the time this project was designed will be adversely impacted by this bridge project."
- digital scan of sealed and approved BSR for digital archive record

copies of hydraulic computer model data files, with complete input and output, supporting (and consistent with) corresponding design documentation

- Information 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
    - existing bridge and piers should be shown with black dashed lines
    - 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
- excavation in floodplain (note elevations), if applicable
- theoretical scour depths
- design scour depths (added later from geotechnical report when received)

  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)

Information shown on plan view includes, but is not limited to, the following:

- proposed structure

- existing structure in black dashed lines
- roadway superelevation
- limits of riprap for spill-through end bents
- for riverine flow, direction of flow and stream name
- in coastal tidal areas, 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

8.6 Hydrologic Analysis

This phase involves the development of several 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 also applicable to culvert design.

The hydrologic analysis for bridge and culvert designs should include:

- determining a drainage area, land use, hydrologic region, etc. for the site
- developing flood discharges for a range of flood events (See Chapter 7 Hydrology)
- using Flood Insurance Study (FIS) discharges to evaluate compliance with FEMA regulations for a stream crossing that is in a FEMA FIS
- determining 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.

8.7 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 (USACE 2021), (USACE 2021), (USACE 2021), (USACE 2021) to perform this type of analysis, and is the preferred software for most NCDOT bridge hydraulic design applications.

The Design Engineer should develop the HEC-RAS model with consideration of the following:

- utilize the cross-section configuration, as shown in Figure 5-1 of the HEC-RAS *Hydraulic Reference Manual* (USACE 2021).
- use a known starting water surface elevation the preferred downstream boundary condition for a subcritical run. Slope conveyance may be used if there is not a known starting water surface elevation.
- locate the beginning downstream section of the model at 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.
- add intermediate sections to the model to ensure model stability.
- analyze all HEC-RAS hydraulic models 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.
- use reliable historical flood data, if available, to calibrate the model.
    - publications FHWA TS-84-204 (USGS, G.J. Arcement, Jr., V.R. Schneider (authors) 1984) and USGS WSP 1849 (USGS, Harry M. Barnes Jr. (author) 1967) are good references for selecting Manning's roughness coefficient (n) values
    - use 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 should reference FHWA (FHWA, L.W. Zevenbergen, L.A. Arneson, J.H. Hunt, A.C. Miller (authors) 2012) for guidance and to obtain approval from the State Hydraulics Engineer before commencing design and analysis work using these methods.

8.7.1 General Design Criteria

Selecting 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.
- Maintain existing channel and floodplain flow patterns to the extent practicable.
- Provide a level of traffic service that is consistent with the functional classification of the highway and projected traffic volumes to the extent practicable, 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.
- Design pier and abutment location, spacing, and orientation to minimize flow disruption, debris collection and scour potential.
- Ensure compliance with National Flood Insurance Program regulations.

8.7.1.1 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* (NCDOT 2008). 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.

8.7.2 General Design Criteria

8.7.2.1 Design Flood Frequency

This is the specific return period (frequency) flood that has been established as being an acceptable level for roadway overtopping. 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. For bridge scour computations using HEC-RAS, begin computing weir flow when the energy grade line elevation exceeds the minimum weir flow elevation. Note when the energy grade line elevation is used as the basis for determination of when overtopping occurs in the BSR and in the modeling narrative, if applicable. See Chapter 7,Table 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. Generally, the design flood frequency should follow the Hydraulic Planning Report (HPR), unless otherwise approved by the Hydraulics Unit.

8.7.2.2 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 one foot. If an existing structure already creates a 100-year backwater in excess of one 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 one foot above the established 100-year elevation shown on the effective FEMA Flood Insurance Rate Map (FIRM).

NCDOT's policy is 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.

- Compensate, defined: 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 (FHWA, J. Krolak 2011). 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.

8.7.2.3 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 Figure 1. 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). Variances from the minimum setback are sometimes warranted, such instances should be discussed with the Hydraulics Unit. The final bridge length is determined by an appropriate hydraulic model during final design.

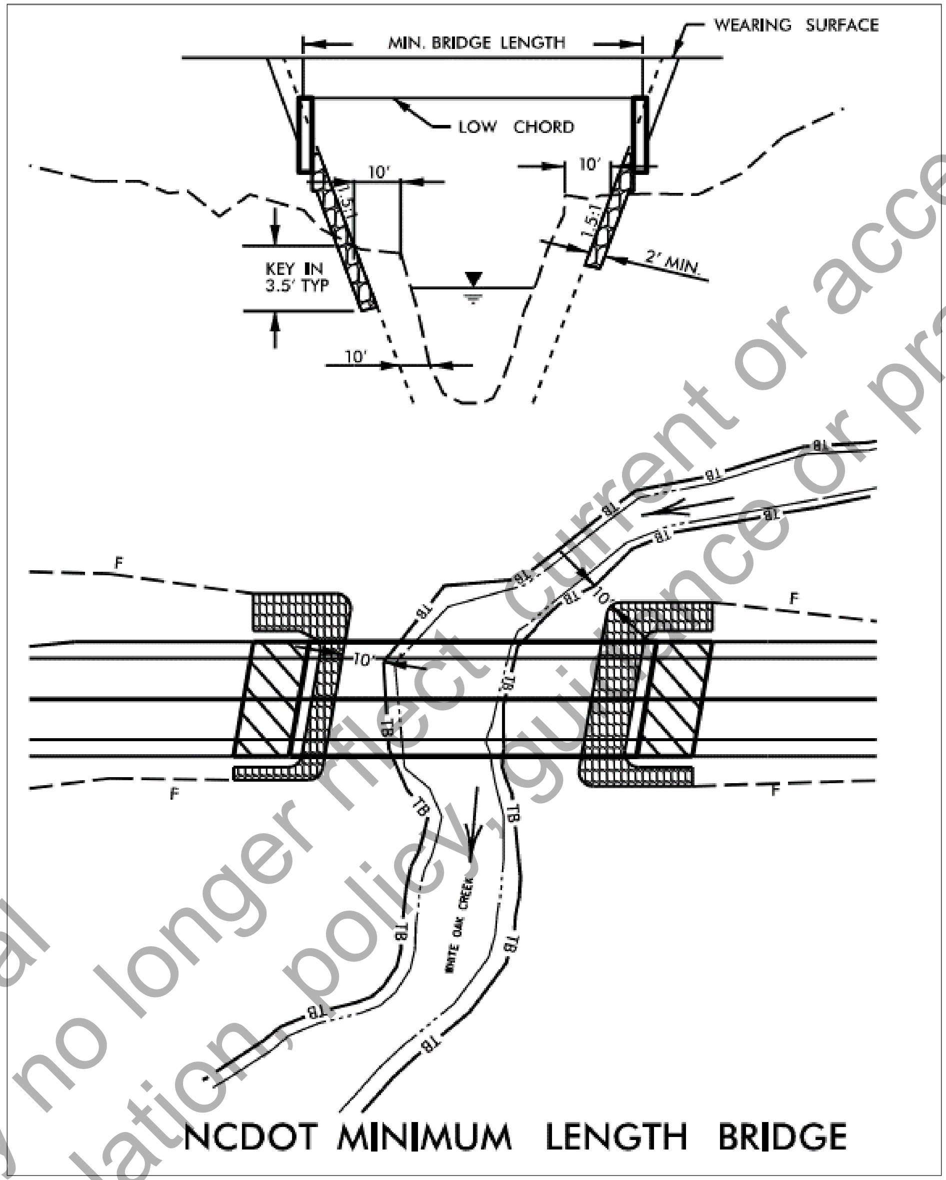


Figure 1. NCDOT Minimum Length of Bridge

8.7.2.4 Bridge End Bent Cap

Generally, 4 feet end bent cap depths are used on new bridge designs. However, two feet, six-inch depth end bent caps may be a viable design option where warranted by site conditions, such as low roadway fill height. Figure 3 and Figure 4 shows two diagrams, 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. The Bridge Engineer should be consulted to verify the final bridge end bent cap dimension.

8.7.2.5 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
- Proposed bridge rail based on height and bridge length, and show as blocked
- At minimum, the first 12 feet of guardrail anchor unit at each end of the bridge and show as blocked (see Roadway Standard Drawings 862.03) (NCDOT 2012)
- 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
- Reference the MOA CCP document for further hydraulic modeling guidance

8.7.2.6 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, submit a draft copy of the BSR to the Structures Management Unit for comment.

8.7.2.7 Freeboard

Standard freeboard design for bridges shall be as follows:

- New location:
  - provide two 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-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, measure the freeboard at the low side of the low chord. It is also 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.

8.7.2.8 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 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 below the ground surface. Additionally, existing and potential stream bank erosion or instability should be considered, and riprap armoring should be provided as needed.

8.7.2.9 Bridge Deck Drainage

A minimum longitudinal gradient of 0.3% is recommended to facilitate adequate drainage of the bridge deck. For wide bridge decks and areas subject to debris buildup, a minimum 0.5% grade is recommended. When deck drains are needed, the typical design is:

- For girder-type bridges: 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
  - eight inches wide by four inches high for cored slabs
  - five inches wide by four inches high for box beams
  - The actual drain opening is six inches high but will be obstructed by two inches of pavement overlay. These deck drains cannot be placed any closer than five feet (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 three feet (center to center).
- If the bridge is on a heavy skew, a minimum offset of six feet from the ends or interior bents of the bridge may be required. Deck drain capacity (and resulting spread calculations) should be evaluated assuming 30% blockage.

Consult the Structures Management Unit staff as early as possible in the design process regarding proposed deck drainage accommodations to verify constructability.

Examples of characteristics which may affect deck drainage could include, but are not limited to, the following:

- bridge type (girder, box beam, cored slab)
- 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

Collection of surface water at the end of the bridge could be needed regardless of usage of deck drains. When collection of surface runoff from the downgrade end of a bridge is needed, 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 rip rap pad.

To the maximum extent practicable, bridge deck drains should not be placed directly over the stream. This is especially true for small streams and relatively short bridge lengths. For bridge spans requiring deck drains, the guidance in Chapter 13 should be followed regarding bridge crossings.

Further best practices regarding deck drains:

- avoid deck drains over spill-through rip rap abutments to reduce embankment erosion concerns
- provide rip rap pads beneath deck drains in highly erosive soil conditions. An armored shallow swale may be required in some instances to reduce erosion.
- enclose the 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 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 (FHWA, G.K. Young, S.E. Walker, F. Chang (authors) 1993).

8.7.2.10 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.

8.7.2.11 Detour Structures

The design for a detour structure is site-specific. In general, the detour bridge and roadway grade should be 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 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 compiled into a single document to be distributed and filed appropriately.

8.7.2.12 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. Whenever multiple openings are required, the design engineer should develop hydraulic models to assess the location and performance of each hydraulic opening structure. Two-dimensional (2D) models are recommended for multiple opening analysis. 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 and the HEC-RAS Two-Dimensional Modeling User's Manual* (USACE 2021) (USACE 2021) should be utilized.

8.8 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* (FHWA, L.A. Arneson, L.W. Zevenbergen, P.F. Lagasse, P.E. Clopper (authors) 2012)
- HEC-20 *Stream Stability at Highway Structures* (FHWA, P.F. Lagasse, L.W. Zevenbergen, W.J. Spitz, L.A. Arneson (authors) 2012)
- HEC-23 *Bridge Scour and Stream Instability Countermeasures* (FHWA, P.F. Lagasse, P.E. Clopper, J.E. Pagán-Ortiz, L.W. Zevenbergen, L.A. Arneson, J.D. Schall, L.G. Girard (authors) 2009)

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

8.8.1 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.

8.8.2 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.

8.8.2.1 Contraction Scour

The Design Engineer should evaluate contraction scour for all bridges. Normally, NCDOT bridge length provides a minimum ten foot 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 feet. 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 (FHWA, L.A. Arneson, L.W. Zevenbergen, P.F. Lagasse, P.E. Clopper (authors) 2012).

Clear-water contraction scour occurs when:

- there is no bed material transport from the upstream reach into the downstream reach, or
- 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 (FHWA, L.A. Arneson, L.W. Zevenbergen, P.F. Lagasse, P.E. Clopper (authors) 2012).

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:

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

$y_s = y_2 – y_0$ = (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:

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

$y_s = y_2 - y_0$ = (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, 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.

8.8.2.2 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.

Based on the stream stability and geomorphic assessment of the bridge site, a note should 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.

8.8.2.3 Abutment Scour

Evaluate abutment scour for all vertical abutment bridges or spill-through abutment bridges that have less than the minimum ten-foot setback from any point on the channel bank or bed as noted above in 0. 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* (NCHRP, R. Ettema, T. Nakato, M. Muste (authors) 2010) 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:

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

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

$$y_s = y_{max} - y_0$$

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.

8.8.3 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, Section 7.8 of HEC-18 suggests using 2 H: 1 V (FHWA, L.A. Arneson, L.W. Zevenbergen, P.F. Lagasse, P.E. Clopper (authors) 2012). 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 Figure 2.

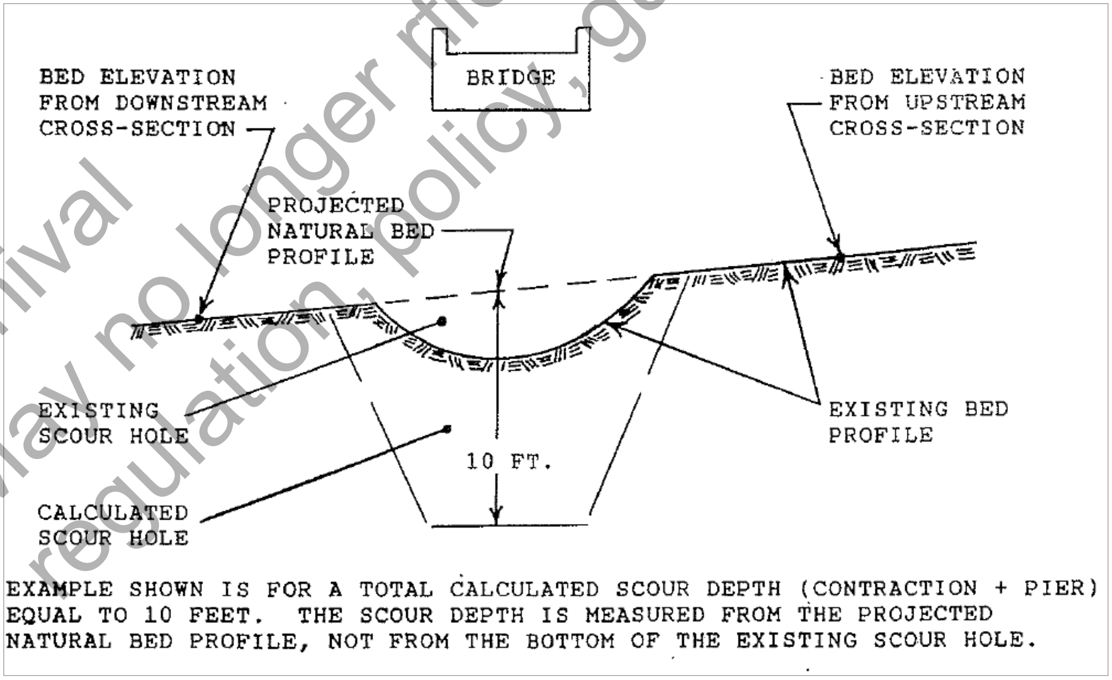


Figure 2. Diagram of Bridge Scour Depth Relative to Projected Natural Stream Bed

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

- if 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
  - 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
- if 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
  - 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
- if 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
  - 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

8.8.4 Documentation of Scour on the BSR

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

- 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 (NCDOT 2021).

8.8.5 Observed Scour Assessment Procedures

Follow the following procedures:

1. Observed scour issues will be reported in an email stating the structure number and a description of field observations (include pictures or a copy of the inspection report) to the Scour Team at ScourNotify@ncdot.gov.
2. The Hydraulics Unit develops a response to the reported scour issue through a review of all available documents and data related to the structure. The Hydraulics Unit will also suggest if the NBIS Item 113 Scour Code needs to be updated to reflect the current scour conditions. The response will be provided on a Scour Evaluation Form which details the scour issue, corresponding POA, and proposed item 113 code.
3. The Hydraulics Unit emails the Scour Evaluation Form to the representatives on the Scour Committee (includes members from Geotechnical, Hydraulics and Structure Management Units).
    - If there is a suggested change to NBIS item 113 or additional input is needed from Geotechnical and or Structures Management, the representatives on the Scour Committee provide feedback and concurrence.
    - If there is no suggested change to NBIS item 113 and additional input is not required, the representatives on the Scour Committee can provide comments if needed.
4. Once the Scour Evaluation Form has been finalized, the Hydraulics Unit will email the final report to the representatives on the Scour Committee, Inspectors, SIA, and other interested parties.

The completed version of this document will be stored in the structure file via WIGINS for record keeping.

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8.10 Additional Documentation

Bridge Survey & Hydraulic Design Report (BSR) Key

Detour Structure Survey & Hydraulic Design Report

MOA CCP document

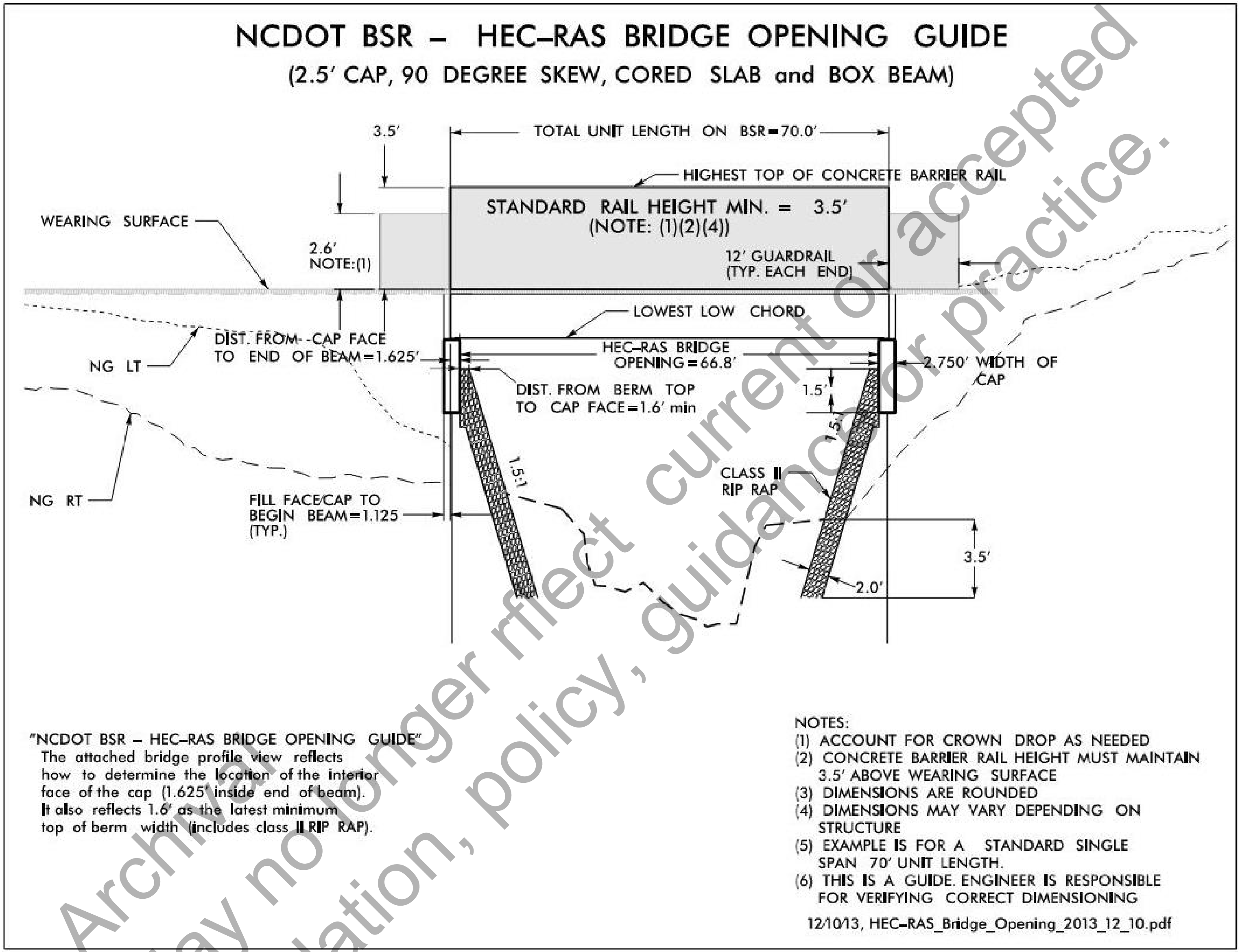

Figure 3. HEC-RAS Bridge Opening Guide (2.5' Cap)

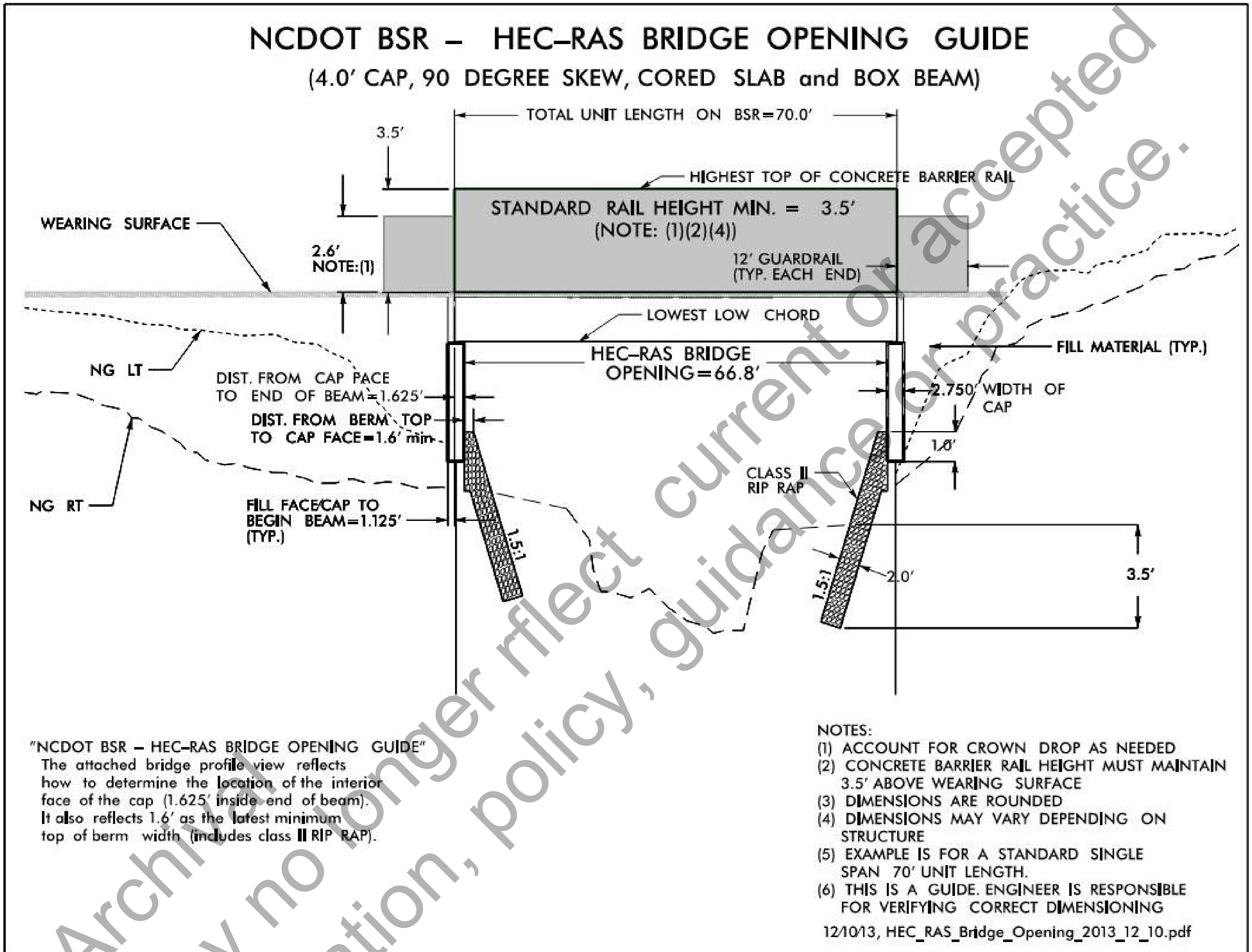

Figure 4. HEC-RAS Bridge Opening Guide (4.0' Cap)

North Carolina
Department of
Transportation

Chapter 9 Culverts

Hydraulics Unit

February 22, 2022

Revisions Sheet			
Page	**Old Section**	**New Section**	**Description**
-	-	-	• Entire Chapter revised to new format and minor grammatical changes made throughout • All references and links have been updated throughout Chapter
1	9.6	9.2	Moved Section – Economic Consideration; Re-numbered sections throughout
4	9.5.1	9.6.1	Removed last sentence
5	Appendix F – Item 3	9.6.1.1	Added new section – Culvert Avoidance and Minimization Design
6	9.5.1.3	9.6.1.4	• 2nd paragraph, 3rd sentence – added "for the 100-year event" to end • 2nd paragraph, 4th sentence – revised reference to "Chapter 8, Section 8.7.2.2" • Last paragraph revised
6	9.5.1.4	9.6.1.5	Revised entire section
7-12	Appendix F – Item 1	9.6.1.6.1	Added new section – Guidance for When to Use Sills/Baffles in Box Culverts
12-13	Appendix F – Item 2	9.6.1.6.2	• Added new section – Native Material Specification • 1st paragraph – revised to state that Native Material is preferred to be used for backfilling culverts
13-15	Appendix N	9.6.1.7	• Added new section – Anadromous Fish Passage • Technical Guidelines, 1st bullet – added US forest Service FishXing reference
16-17	Appendix H – Item 4	9.6.1.9	Added Tables 1 - 3
19	Appendix F – Item 4	9.6.2.1.2	Added new section – Aluminum Box Culvert (ABC) HEC-RAS Modeling Guidance
20	9.5.2.3	9.6.2.3	Entire section revised
21	-	9.7	Added new section – Pipe Liner Rehabilitation; Re-numbered sections
22	-	9.9	Added new section - References
24	-	9.10	Added new section – Additional Documentation

24	Appendix E – Item 2	9.10	Added link - Culvert Survey & Hydraulic Design Report
24	Appendix E – Item 3	9.10	Added link – Detour Structure Survey & Hydraulic Design Report
24	Appendix G	9.10	Added link – Pipe Data Sheet
24	Appendix H – Item 1	9.10	Added link – Pipe Material Selection Guide
24	Appendix V – Item 1	9.10	Added link – NCDOT Pipe Liner Manual
24	Appendix V – Item 2	9.10	Added link – NCDOT Pipe Liner Special Provision
24	Appendix V – Item 3	9.10	Added link – Grouting Host Pipe Special Provision
24	Appendix V – Item 4	9.10	Added link – Invert Paving Special Provision
25-28	Appendix H – Item 3	9.10	Added table – Table 210 Engineering Field Handbook Minimum and Maximum Fill Heights over Pipes

Table of Contents: Chapter 9, Culverts

9.1 Introduction

In this chapter, a culvert is defined as a hydraulic conduit that conveys flow through a roadway embankment. The most used culvert shapes are circular, rectangular, elliptical, and arch. 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 involves economic consideration, design documentation, data collection, hydrologic analysis, hydraulic analysis and design.

9.2 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.

9.3 Design Documentation

A Culvert Survey and Hydraulic Design Report (CSR) is required for any structure that is on a FEMA-regulated stream or has a hydraulically effective total waterway opening of thirty 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, summarize the design data on the Pipe Data Sheet. All design data in the CSR or Pipe Data Sheet should be based on either HEC-RAS ((USACE 2021) (USACE 2021) (USACE 2021) (USACE 2021)) hydraulic models or HDS-5/HY-8 ((FHWA, J.D.Schall, P.L. Thompson, S.M. Zerges, R.T. Kilgore, J.L. Morris (authors) 2012), (FHWA 2021)) results, as applicable.

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

1. Plot and label the proposed structure in plan and two profile views -- along roadway alignment and along the structure alignment. Note the roadway centerline station, skew, and grade point elevation. Specify the box culvert dimensions in terms of the number of barrels at a given span dimension by rise dimension (e.g., two at ten feet by six feet RCBC). The drawing scales in the CSR are typically 1 inch = 50 feet horizontal and 1 inch = 10 feet vertical. Limit information to that which is pertinent to the structure sizing and location.
2. Show centerline invert elevation (or top of footing elevation for "bottomless" culvert) and slope. Note: determine precise length and end invert elevations by Structures Management Unit.
3. Show normal, design and 100-year water surface elevations on all views.
4. Enter all required data for selected structure as completely as possible on the CSR. 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.

5. Note software and versions used for computations. Include supporting computer data files (e.g., HEC-RAS, HY-8, HDS-5) and summaries in all project documentation.
6. Complete the performance table for the proposed structure with a comparison to the natural and existing conditions (if applicable) stage-discharge relations.

9.4 Data Collection

Assemble 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. Prior developing the final design, follow the following guidance to begin preparing the appropriate documentation.

9.4.1 Culvert Data – Profiles Views

There are two profiles that are included in the CSR: 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, the culvert opening and natural ground are typically depicted at the upstream face. Label for clarification if a different convention is used. 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 should include:
   - natural ground lines upstream, and downstream, 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.
   - 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 should include:
   - stream bed
   - top of banks

- existing and proposed roadway cross-sections
- existing and proposed culverts
- normal water surface (vegetation line, also known as ordinary high water) profile
- historical flood levels
- controlling feature elevations properly positioned along the profile
- rock line, if identified

The centerline profile's purpose 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. Note if an existing culvert is to be retained and extended, and include its type, condition, top slab and interior web thickness, slope, and opening.

Plot any additional stream details utilized for design or needed for channel realignments 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.

9.4.2 Culvert Data – Plan View

Include the following information on the plan view:

- natural features: stream/water edges, banks, ground cover, wetland boundary, buffers
- manmade features: buildings, houses, roads, driveways, existing drainage, utilities, etc.
- proposed roadway and fill slope limits, retaining walls, easements, right-of-way
- proposed drainage structures, channels, rip rap, etc.
- Floodway Boundaries designated and regulated by FEMA
- other information, such as flow direction, north arrow, survey line and stations, land cover, etc.

9.4.3 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, summarize the design data on the Pipe Data Sheet. The Design Engineer must also reference the drainage plans for topographical and proposed layout information.

Size driveway pipes in roadside ditches 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.

9.5 Hydrologic Analysis

The hydrologic analysis for a culvert differs from that for bridges primarily due to the smaller drainage areas involved. However, the analysis may be similar for larger culverts. Refer to Chapter 7 Hydrology for more guidance regarding hydrologic analysis.

The hydrologic analysis for culvert design entails:

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

Use the Base Flood discharge if the stream crossing is in a FEMA Flood Insurance Study (FIS) to assess the flood impact and compliance with FEMA's NFIP. An alternate analysis may be warranted if an error is found in the FEMA hydrologic analysis. 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.

1. Record pertinent hydrologic analysis data on the CSR, such as land use change, stream gage, physical changes (dam, impoundment, etc.).
2. 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). Clearly identify the location of the flood elevations that are compared
    - For example, "at section 1001, 15 feet upstream of culvert inlet"
3. 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.

9.6 Hydraulic Analysis and Design

9.6.1 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. Avoid or minimize adverse impacts to the natural and human environments to the maximum extent possible. 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.

9.6.1.1 Avoidance and Minimization Measures

When designing a culvert, ensure that the following avoidance and minimization design criteria have been evaluated and implemented as much as possible:

- Proposed culvert slope is consistent with the existing stream slope. Proposed low flow dimensions through the culvert are consistent with the existing low flow channel dimensions in the stream. Alternating low flow sills/baffles may be required to achieve this.
- Proposed low flow velocities through the culvert are consistent with the existing low flow velocities in the stream.
- Proposed culvert is appropriately buried such that the bed material will be retained throughout the culvert length. The use of alternating low flow sills/baffles should be evaluated based on culvert slope, bed material and stream stability.
- The dimension and profile of the stream above and below the culvert should not be modified by widening the stream channel or by reducing the depth of the stream in the vicinity of the culvert. Establishing a low flow floodplain bench should be evaluated at the inlet and outlet of multiple barrel culverts.
- Minimize culvert length as much as possible.
- Culvert alignment avoids sharp bends at the inlet and outlet to avoid bank erosion at the inlet and outlet. Stream realignment and/or armoring may be needed to improve culvert alignment and/or to mitigate potential stream bank erosion. Minimize the amount of stream work to be done up and down stream.

9.6.1.2 Material Selection

The selection of a culvert may vary depending on its location, subsurface materials, and constructability. The most 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, follow the applicable guidance below:

- Pipe culverts:
  Follow the guidance prescribed in the NCDOT Pipe Material Selection Guide, Chapter 5 of the NCDOT Roadway Design Manual (NCDOT 2021), and Standard No. 300.01 "Method of Pipe Installation", NCDOT Roadway Standard Drawings (NCDOT 2012) for material selection, associated fill-height limitations, and pipe installation methods.

- 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. Develop the culvert design based on a four-sided, cast-in-place reinforced concrete box design unless site constraints dictate other culvert type. The State

Hydraulics Engineer should review and approve any culvert design alternates to the approved CSR proposed by the contractors during construction. NCDOT Pipe Material Selection Guide and Section 9.10 provides the maximum fill height tables.

9.6.1.3 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, consider an improved inlet design. 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, refer to Section 5-20 of the *Roadway Design Manual* (NCDOT 2021).

9.6.1.4 Allowable Headwater

The allowable headwater elevation is established based on an evaluation of flood elevation, freeboard, upstream structures, and proposed roadway elevations. Measure the headwater depth from the design flood elevation to the invert of the inlet of the culvert, generally not exceeding 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 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 foot of backwater over the natural condition for the 100-yr event. Also refer to guidance regarding backwater in Chapter 8, Section 8.7.2.2.

FEMA's Base Flood Elevation (BFE) should be used as the allowable headwater elevation to size the culvert if the replacement or new culvert is on a FEMA-regulated stream. If the proposed design would result in a change in BFE, the Design Engineer should obtain a Conditional Letter of Map Revision (CLOMR) or State Floodplain Compliance (SFC) approval. See Chapter 15 for additional guidance.

9.6.1.5 Multiple Barrels

Multiple barrels often 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 new box culvert is six feet span (width) by seven feet rise (height). This allows for six feet of vertical clearance inside a box culvert for inspection and maintenance, presuming the floor is buried one foot below the stream bed. Exceptions to this minimum size specification should be approved by Hydraulics Unit. An existing culvert with smaller dimensions does not necessarily warrant replacement of the culvert. 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, evaluate the need for barrels to be set at different elevations to minimize head cut, channel instability, and aggradation.

9.6.1.6 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.

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 barrels 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. Investigate the cause and source of sediment accumulation if a heavy accumulation of sediment is found in the barrels of an existing culvert and consider mechanically removing the sediment. If site conditions clearly indicate that excess sediment inside the barrel would be flushed out of the barrel in high water events, perform the hydraulic analysis based on 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, do not assume the total clear width and height to be 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.

9.6.1.6.1 Guidance for When to Use Sills / Baffles in Box Culverts

This guidance is intended primarily for reinforced concrete box culverts but may also be applicable to larger aluminum box culverts, corrugated steel pipes and corrugated steel pipe arches. Refer to Section 9.6.1 for criteria to evaluate in culvert design. Refer to Section 9.6.1.6.2 for material to be used to backfill sills/baffles.

Sills are vertical extensions attached to the culvert bottom placed at the inlet and outlet of the culvert. Baffles are vertical extensions attached to the culvert bottom placed at designed intervals inside the culvert beyond the sills located at the inlet and outlet. Sills can be used to retain the native material in the culvert as well as to help prevent head cutting. Sills may be used at the inlet and outlet of the higher flow barrels of multiple barreled culverts to help maintain the natural stream width and depth through one or more of the barrels. Baffles and sills can be used together to help:

- retain native material in culverts on steeper slopes
- slow velocities in very steep culverts
- create a low flow channel in the culvert by varying the dimensions (height and width) of the sills/baffles.

See Figure 1 below for example of sill/baffle detail:

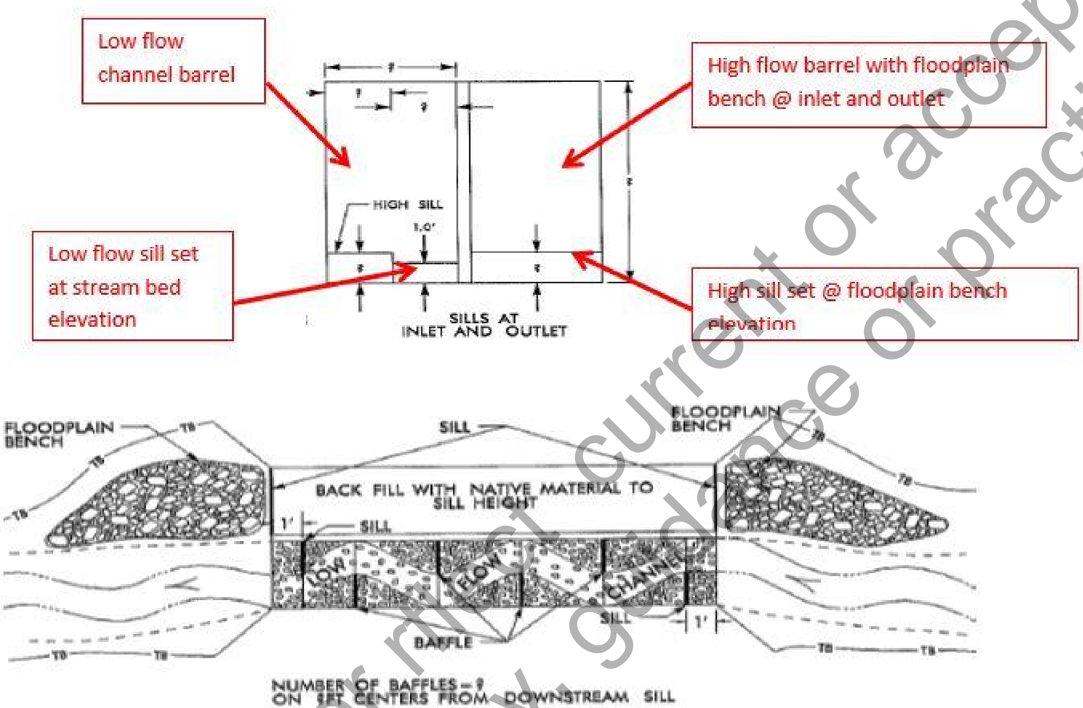

Figure 1. Sill/Baffle Detail

Baffles and sills do not have to be alternating as shown in the above detail. Evaluate each stream crossing to determine the appropriate design and evaluate the need for using sills and baffles based on factors such as culvert width, stream width, culvert slope, stream slope, culvert length, stream stability, bed material, propensity to head cut and the need for floodplain benches. The following criteria may be used as a guide in determining when to use sills/baffles in box culverts.

Evaluate Culvert Width vs. Stream Width

If possible, design the culvert barrel width to match the stream's low flow width. For new multi-barrel culverts, only one barrel should convey the stream at low flow conditions. Look up and down stream of an existing structure to determine the stream's low flow width, since the width of the stream close to the existing structure is in many cases wider. If the culvert barrel width when compared to the existing streams low flow width is such that the stream's low flow width and depth cannot be maintained through the culvert, sills and baffles will be required to establish a continuous low flow channel through the culvert barrel. The height of the sills and baffles should vary across the width of the culvert barrel to provide a continuous low flow channel through the culvert similar to the natural stream's low flow (thalweg) width and depth. See Figure 2 for reference. The sills and baffles should be spaced throughout the length of the culvert to hold the bed material and maintain adequate flow depth during low flow conditions. The culvert should be buried a minimum of one foot and backfilled with native material. The top of the low flow sills/baffles should match the stream bed elevation in the low flow channel.

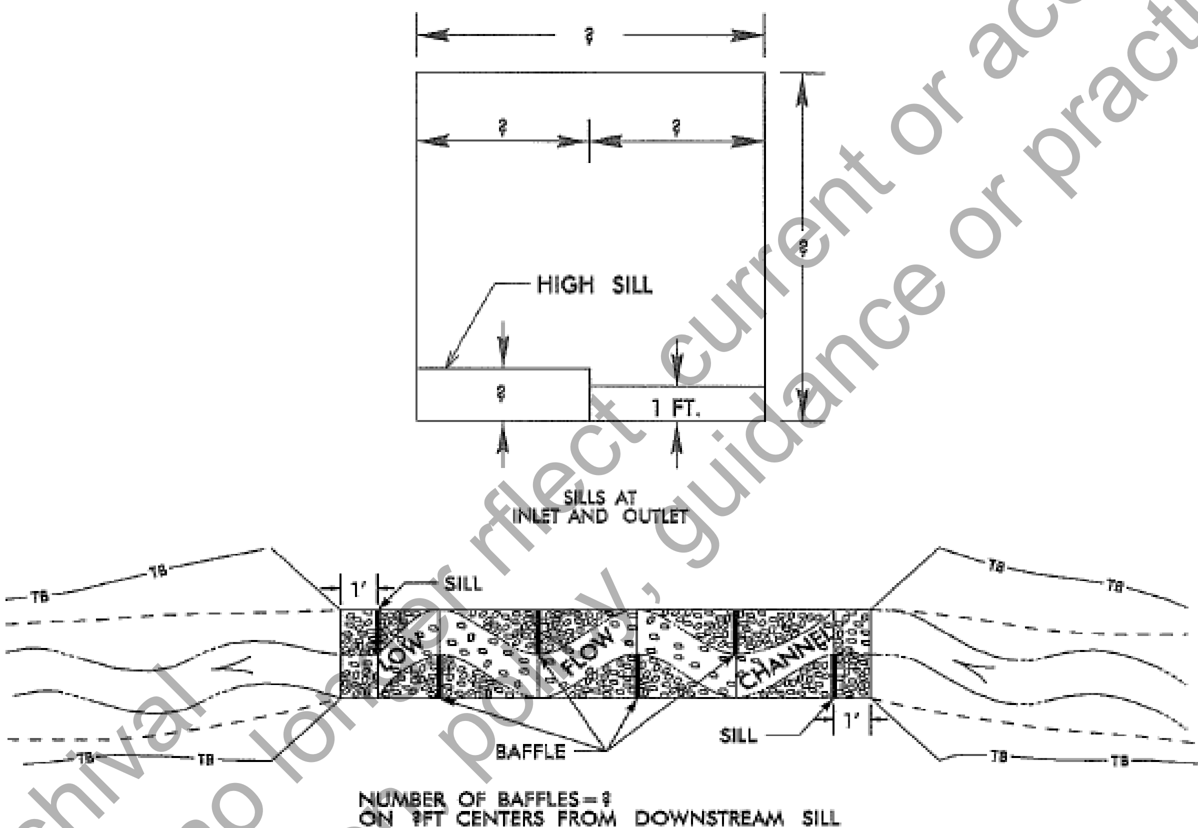

Figure 2. Sills and Baffles Used to Create a Low Flow Channel Through Culvert

Evaluate Culvert Slope vs. Stream Slope

Evaluate the culvert slope/stream slope if the culvert barrel dimensions are such that the stream's low flow width and depth can be maintained through the culvert, to determine if sills and or baffles are required to help retain the bed material in the culvert. In this case, the dimensions of the sills/baffles do not need to vary since the width and slope of the culvert will maintain the stream's low flow width and depth. The purpose of the sills and baffles is to retain bed material in the culvert, provide an approximate low-flow stream shape to assist in aquatic organism passage, and to help prevent head-cutting when culverts inverts are buried below the stream bed. The following general guidance may be used when determining the need for sills and baffles based on culvert slope/stream slope (stream stability and bed material should be considered also as noted below):

- Sills and baffles are generally not required if the culvert slope/stream slope is less than 1%. Bury the culvert a minimum of one foot below the stream bed and allow it to fill in on its own. If the stream is very unstable and the stream slope varies up and downstream of the culvert, evaluate if sills and baffles should be used. Typically, unstable streams with less coarse bed materials (sand and silt) may require the use of sills and baffles at slopes less than 1%.
- Sills and baffles are generally required if the culvert slope/stream slope is between 1% and 2%, to help retain the native material in the culvert barrel. The culvert should be buried a minimum of one foot below the stream bed with sills and baffles. The sill and baffle height should match the burial depth and they should be backfilled with native material. If the stream is very stable and if the stream slope is constant throughout the length of the culvert as well as up and downstream of the culvert, sills and baffles may not be required. Typically, stable streams with coarser bed materials (gravel, cobbles and boulders) would be more likely to not require sills and baffles until slopes above 2% are reached.
- Sills and baffles are required if the culvert slope/stream slope is greater than 2%, to help retain the native material in the culvert barrel. The culvert should be buried a minimum of one foot below the stream bed with sills and baffles. The sill and baffle height should match the burial depth and they should be backfilled with native material.

Floodplain Benches

Figure 3. Culvert with Floodplain Bench

Sills should be used for multiple barrel culverts where high flow barrels are required with floodplain benches at the inlet and outlet. Place the sills at the inlet and outlet of the high flow barrel(s) and backfill the barrel(s) to the sill height with native material. The sill height at the inlet and outlet of the high flow barrel should be above the low flow normal water surface elevation. See Figure 4 for reference. Figure 4 shows a multi barrel culvert with one barrel that matches the low flow stream width and the other barrel with sills and floodplain benches at the inlet and outlet. The low flow barrel for this detail matches the streams low flow width and does not require sills to retai**Error! Reference source not found.** is a picture of a multiple barrel culvert with floodplain bench.

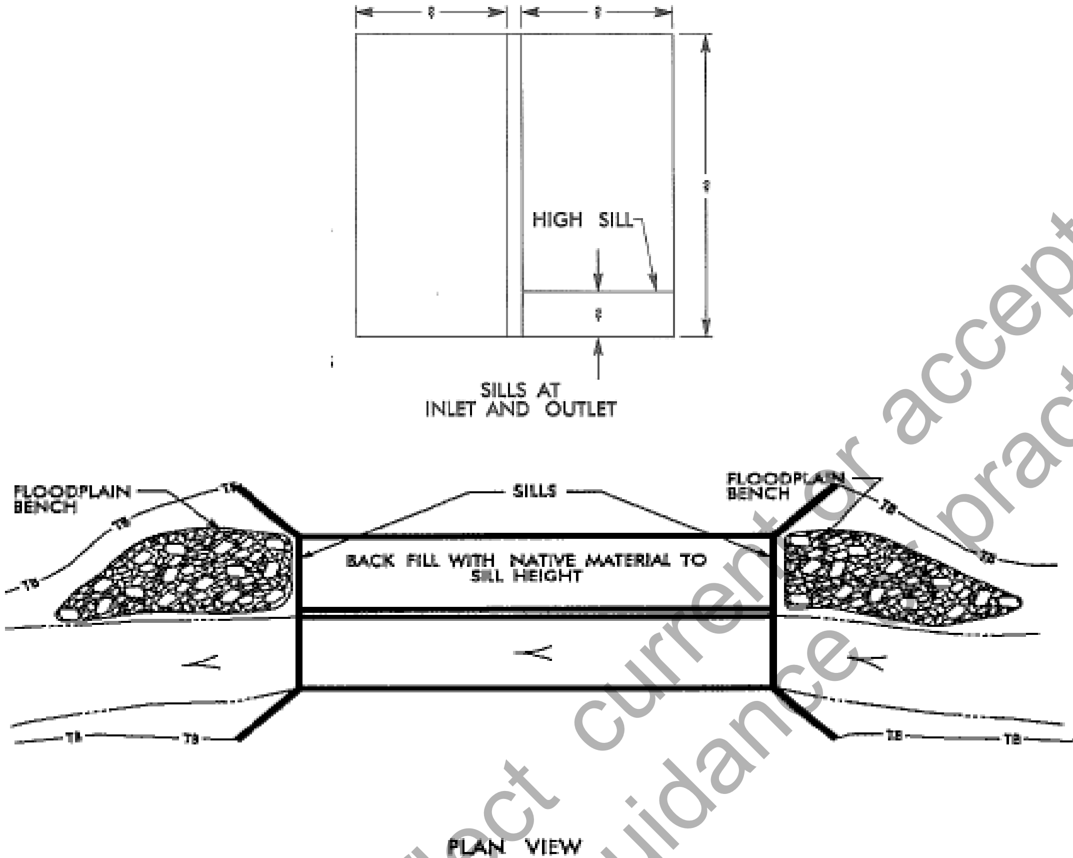

Figure 4. Sills in High Flow Barrel with Floodplain Bench

Wide single span culverts, such as aluminum box culverts, may require floodplain benches at the inlet and outlet to maintain the natural stream width up and downstream of the culvert. The sills for these types of structures should be detailed to provide a low flow notch to match the stream's low flow width. See Figure 5 below for example detail:

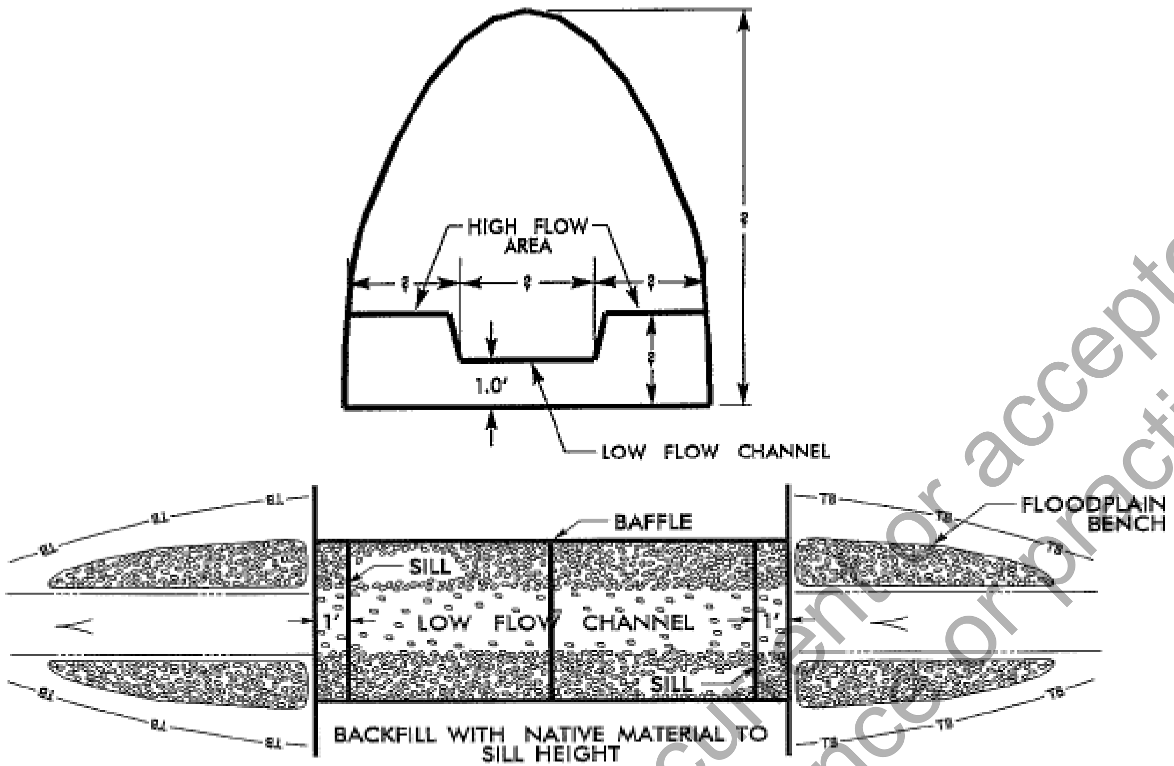

Figure 5. Sill with Notch on Wide Single Span Culvert with Floodplain Bench

Sill Spacing

Sills/baffles in culverts are typically spaced at approximately 25-foot intervals. On slopes steeper than 2%, the spacing may be shortened to an interval length equal to 0.5 feet divided by the slope of the culvert or as deemed appropriate. Ten feet is typically the minimum spacing used. Space the sills to hold the bed material and maintain adequate flow during low flow conditions.

Detail the dimensions, locations and spacing of the sills/baffles on the CSR (or on a detail to be included with the CSR) and note which culvert barrels should be backfilled with native material.

9.6.1.6.2 Native Material Specification for Backfilling

Native Material consists of material that is excavated from the stream bed or floodplain at the project site during culvert construction. Normally, native material is preferred to be used for backfilling culverts. Pay for native material as incidental to the culvert construction. Additional rip rap, if needed, will be paid at the contract price of rip rap or negotiated price, if not already in the contract. Detail the dimensions, locations and spacing of the sills/baffles on the CSR (or on a detail to be included with the CSR) and note which culvert barrels should be backfilled with native material.

The following note should be added to the CSR when backfilling the culvert with Native Materials between sills and/or baffles:

- Native Material consists of material that is excavated from the stream bed or floodplain at the project site during culvert construction. Only material that is excavated from the stream bed may be used to line the low flow culvert barrel. Rip rap may be used to supplement the Native Material in the high flow culvert barrels. If using rip rap to line the high flow culvert barrels, place Native Material on top to fill voids and provide a flat surface for animal passage. Native Material is subject to approval by the engineer and may be subject to permit conditions.

The above note may be modified as follows if there is no high flow culvert barrel:

- Native Material consists of material that is excavated from the stream bed at the project site during culvert construction. Native Material is subject to approval by the engineer and may be subject to permit conditions.

The above note may be modified as follows if native material is only required in the high flow culvert barrel

- Native Material consists of material that is excavated from the stream bed or floodplain at the project site during culvert construction. Rip rap may be used to supplement the Native Material in the high flow culvert barrels. If using rip rap to line the high flow culvert barrels, place Native Material on top to fill voids and provide a flat surface for animal passage. Native Material is subject to approval by the engineer and may be subject to permit conditions.

Provide the following backfill note on the CSR:

"The Engineer, in consultation with DEO staff, shall review all material to be used as backfill prior to conducting the backfill activity. Backfill shall consist of native material only unless the Engineer, in consultation with DEO staff, determines that (1) the native material is unsuitable, or (2) additional material is required to supplement the native material. The chosen backfill material shall not have adverse effects to aquatic life, aquatic life passage, or water quality. Native material consists of material that is excavated from the stream bed or floodplain at the project site during culvert construction."

9.6.1.7 Anadromous Fish Passage

Anadromous Fish are a valuable resource, and their migration must not be adversely impacted. This document provides guidance to NCDOT to ensure that replacing existing and new highway stream crossing structures will not impede the movement of Anadromous Fish.

Applicable when:

- project is in the Coastal Plain region. Refer to NCDOT Project Atlas Site (NCDOT 2021) for physiographic boundary region
- perennial and intermittent streams are delineated on most recent USGS 7.5-minute quadrangle maps

General Guidelines:

- Project design and scheduling should avoid the necessity of instream activities during the Spring migration period, which defined as the time between February 15 and June 15. In areas where the shortnose sturgeon may be present, the Cape Fear, Brunswick and Waccamaw Rivers, Spring is defined as February 1 to June 15.
- Bridges and other channel spanning structures are preferred where practical.

Technical Guidelines:

- In all cases, the width, height and gradient of the proposed opening shall be such as to pass the average historical spring flow without adversely altering flow velocity. Spring flow should be determined from gage data if available. In the absence of this data, bankfull flow can be used as a comparative level. For fish swimming limitations use US Forest Service FishXing swim speed table (USDA Forest Service 2012) or USACE's *Fisheries Handbook of Engineering Requirements and Biological Criteria* (USACE. Bell, Milo C. (author) 1986)
- The invert of box culverts must be at least one foot below the natural stream bed. For smaller pipes, follow the burial tables shown in Table 1 or Table 2, contingent upon the project being located in a CAMA County.
- Crossings of perennial streams serving watersheds greater than one square mile shall provide a minimum of four feet of additional opening width, measured at spring flow elevation, to allow for terrestrial wildlife passage.
- In stream footings for bridges will be set one foot below the natural stream bed when practical.

At a minimum, provide the following information to facilitate resource agency review for crossing sites:

- plan and profile views showing the existing and proposed crossing structures in relation to the stream bank and bed
- average historical spring flow (or bankfull flow) for the site
- how the proposed structure affects the velocity and stage of the spring flow (bankfull)
- justifying any variance from the guideline recommendations

For additional information and guidance regarding accommodations to facilitate aquatic organism passage and habitat, refer to FHWA *Culvert Design for Aquatic Organism Passage* HEC-26 (FHWA. R.T. Kilgore, B.S. Bergendahl and R.H. Hotchkiss (authors) 201

0). The NCDOT Project ATLAS website (NCDOT 2021) also includes the distribution of potential anadromous fish habitat streams in North Carolina.

9.6.1.8 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). Align the culvert with the natural channel with minimum transitions made between the opening ends of the culvert and natural channel to the extent possible. When significant channel realignment is required other than minor alignment adjustments at the inlet and outlet, utilize a natural channel design (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. Skew the culvert 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. Avoid bends in culverts if the potential for debris to become lodged is apparent.

9.6.1.9 Slope and Sediment

Construct pipe or box culverts 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. 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.

Set the inverts of a culvert 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 foot for large culverts. All box culvert inverts should be set a minimum of one foot below the natural bed, unless extending an existing culvert that is not buried. If shallow, non-erosive bedrock is found three feet or less below the streambed, consider proposing a bottomless ("three-sided") culvert. Confirmation from the Geotechnical Unit on the depth of the rock line along the length of the proposed culvert is required. Refer to the tables below for specific burial depth guidance.

Table 1. Pipe Burial Depths - Non-CAMA Counties

Jurisdictional Streams				Non-Jurisdictional Streams			
Pipe Diameter (in)	Burial Depth (in)	Burial Depth (ft)	% Burial	Pipe Diameter (in)	Burial Depth (in)	Burial Depth (ft)	% Burial
18	3.6	0.3	20	18	Not Req'd	-	-
24	4.8	0.4	20	24	Not Req'd	-	-
30	6.0	0.5	20	30	Not Req'd	-	-
36	7.2	0.6	20	36	Not Req'd	-	-
42	8.4	0.7	20	42	Not Req'd	-	-
48	9.6	0.8	20	48	Not Req'd	-	-
54	12.0	1.0	-	54	Not Req'd	-	-
60	12.0	1.0	-	60	Not Req'd	-	-
66	12.0	1.0	-	66	12.0	1.0	-
72	12.0	1.0	-	72	12.0	1.0	-

Table 2. Pipe Burial Depths - CAMA Counties

Jurisdictional Streams			Non-Jurisdictional Streams		
Pipe Diameter (in)*	Burial Depth (in)	Burial Depth (ft)	Pipe Diameter (in)	Burial Depth (in)	Burial Depth (ft)
18	-	-	18	Not Req'd	-
24	-	-	24	Not Req'd	-
30	-	-	30	Not Req'd	-
36	12.0	1.0	36	Not Req'd	-
42	12.0	1.0	42	Not Req'd	-
48	12.0	1.0	48	Not Req'd	-
54	12.0	1.0	54	Not Req'd	-
60	12.0	1.0	60	12.0	1.0
66	12.0	1.0	66	12.0	1.0
72	12.0	1.0	72	12.0	1.0

*Since the minimum bury depth is 12", a 36" diameter pipe is considered the smallest practical pipe to use.

Table 3. Minimum Equivalent Pipe Diameter

Buried Pipe Diameter (in)	Equivalent Inlet Ctrl. Pipe Diameter (in)	Equivalent Outlet Ctrl. Pipe Diameter (in)
18	15	12
24	18	15
30	24	18
36	30	24
42	36	30
48	42	36
54	48	42
60	54	48
66	60	54
72	66	60

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, 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. 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.

9.6.1.10 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, determine tailwater depth by a simple single section normal depth calculation, such as that provided in HY-8 (FHWA 2021). For those on FEMA-regulated streams, determine tailwater using HEC-RAS (discussed below). Effects of downstream controls and constrictions must also be considered. Document tailwater calculations in the Additional Information and Computations section of the CSR or on the Pipe Data Sheet, as applicable.

9.6.2 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) (FHWA, J.D.Schall, P.L. Thompson, S.M. Zerges, R.T. Kilgore, J.L. Morris (authors) 2012) methodology or by HEC-RAS ((USACE 2021) (USACE 2021) (USACE 2021) (USACE 2021)), 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.

9.6.2.1 HEC-RAS

Use HEC-RAS when any of the following apply:

- stream is in a regulated FEMA flood zone
- there is a need to assess flood impact by the proposed crossing to structures on adjoining properties
- establishing water surface elevations (by step backwater analysis) for a culvert design

- determining backwater caused by a bridge for the existing and proposed conditions

9.6.2.1.1 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 (FHWA, J.D.Schall, P.L. Thompson, S.M. Zerges, R.T. Kilgore, J.L. Morris (authors) 2012) 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. Refer to Section 9.6.2.1.2 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. 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 to move away from the culvert, through a ditch and across the road.

9.6.2.1.2 Aluminium Box Culvert (ABC) HEC-RAS Modeling Guidance

Since the Corrugated Metal Box Culvert shape in HEC-RAS does not match the actual area of the ABC when the span and rise of the ABC is placed into the HEC-RAS model, the following methodology should be used to model the ABC:

- ABC's span should be reduced while maintaining the rise until the effective area of the ABC is approximated in the HEC-RAS model. Although this is not considered to be an exact methodology, it should provide a more conservative answer for most situations.
- ABCs should be modeled in HEC-RAS as Corrugated Metal Box Culverts using the Culvert Data Editor as follows:
    - Select Culvert Shape as "Box". Reduce the span as necessary, by trial and error, to provide a culvert area opening that is reflective of the effective open area of the culvert. Use the manufacturer's size chart to determine the actual area of the ABC.
    - If the culvert is buried or altered by other means such as sills/baffles, low flow floodplain benches, etc., determine the effective open area by subtracting out the blockage from the ABC's actual area.

- The rise should be the actual rise of the proposed ABC and should not be adjusted.
- Compare the computed open area of the culvert to the effective open area of the ABC. Chart # should be 16, 17, 18 or 19 depending on the rise/span ratio noted in HDS-5 (FHWA, J.D.Schall, P.L. Thompson, S.M. Zerges, R.T. Kilgore, J.L. Morris (authors) 2012) for the chart.
- Base the rise/span ratio on the actual dimensions of the ABC. Do not use the reduced span length. Scale #1 should be used, based on a 90-degree headwall.
- Complete all other information based on the proposed culvert.

Example:

15'-9" X 8'-0" ABC, buried one foot below the stream bed

Actual culvert area from manufacturer's chart = 111.8 ft^2, rise/span ratio = 0.5079; use Chart #19, 90-degree headwall, use Scale #1

Effective open area of culvert = Actual Culvert area – blockage

15.75' bottom span X 1 foot (bury depth) = 15.72 ft^2 blockage

Effective open area = 111.8 ft^2 – 15.72 ft^2 = 96.05 ft^2 , say 96 ft^2

Computed open area in HEC-RAS is modeled as a 15'-9" X 8'-0" Corrugated Metal Box Culvert buried one foot (one foot blocked in Culvert Data Editor) = 110.25 ft^2 (Note effective open area of culvert overestimated by 14 ft^2)

Adjust span length by trial and error to reach effective open area of culvert = 96 ft^2

Use span length = 13.72', Computed open area in HEC-RAS = 96.04 ft^2 , say 96 ft^2

Therefore, model in HEC-RAS as a 13.72' X 8' Corrugated Metal Box Culvert buried 1 foot.

9.6.2.2 Debris Consideration

Reasonably size the culvert opening to provide for debris passage. The general limitation of design headwater depth to not exceed the culvert opening height by more than about 20% 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.

9.6.2.3 Evaluation of Outlet Velocity

After a given culvert size has been determined to be adequate for conveyance of the design discharge, it is important to evaluate effects from the outlet velocity and recommend any mitigation measures such as armoring. Use the ten-year (V_{10}) outlet velocity for this comparison. If the partial flow outlet velocity for the ten-year discharge (Q_{10}) exceeds the scour velocity for the receiving stream, placing rip rap or other acceptable outlet protection is required. FHWA HEC-15 (FHWA. R.T. Kilgore and G.K. Cotton (authors) 2005) procedures should be used 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.

9.7 Pipe Liner Rehabilitation

The design calculations shall support the acceptability of the proposed rehabilitation system to provide the necessary hydraulic capacity and structural strength to support the anticipated total load and hydrology at the site of rehabilitation, as determined from a review that has been signed and sealed by a Professional Engineer holding a valid license to practice engineering in the State of North Carolina (unless an exception is noted below). Such certification shall cover all design data, supporting calculations, installation plan, and planned rehabilitation materials. The calculations shall indicate that the liner design is for a full structural replacement of a fully deteriorated host pipe.

Refer to NCDOT Pipe Liner Manual on the Hydraulics site for more guidance.

9.8 Construction Sequence

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

9.9 References

FHWA. 2021. *HY-8 Culvert Hydraulic Analysis Program, version 7.70.* December. Accessed December 2021. https://www.fhwa.dot.gov/engineering/hydraulics/software/hy8/index.cfm.

FHWA, J.D.Schall, P.L. Thompson, S.M. Zerges, R.T. Kilgore, J.L. Morris (authors). 2012. "Hydraulic Design of Highway Culverts, Third Edition, Hydraulic Design Series Number 5 (HDS-5)." *Federal Highway Administation, U.S. Department of Transportation.* April. https://www.fhwa.dot.gov/engineering/hydraulics/pubs/12026/hif12026.pdf.

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USACE. 2021. *HEC-RAS River Analysis System 2D Modeling User's Manual, Version 6.0.* ary W. Brunner, CEIWR-HEC (author); Institute for Water Resources, Hydrologic Engineering Center (HEC), US Army Corps of Engineers. May. Accessed November 2021. https://www.hec.usace.army.mil/software/hec-ras/documentation/HEC-RAS_6.0_2D_Modeling_Users_Manual.pdf.

—. 2021. *HEC-RAS River Analysis System Applications Guide, Version 6.0.* Gary W. Brunner, John C. Warner, Brent C. Wolfe, Steven S. Piper, and Landon Marston.

May. Accessed November 2021. https://www.hec.usace.army.mil/software/hec-ras/documentation/HEC-RAS_6.0_Applications_Guide.pdf.

—. 2021. *HEC-RAS River Analysis System Hydraulic Reference Manual, Version 6.0.* Gary W. Brunner, CEIWR-HEC (author); Institute for Water Resources, Hydrologic Engineering Center (HEC), US Army Corps of Engineers. May. Accessed November 2021. https://www.hec.usace.army.mil/software/hec-ras/documentation/HEC-RAS_6.0_Reference_Manual.pdf.

—. 2021. *HEC-RAS River Analysis System User's Manual, Version 6.0.* Brunner, Gary W. CEIWR-HEC (author); Institute for Water Resources, Hydrologic Engineering Center (HEC), US Army Corps of Engineers. May. Accessed November 2021. https://www.hec.usace.army.mil/software/hec-ras/documentation/HEC-RAS_6.0_Users_Manual.pdf.

USACE. Bell, Milo C. (author). 1986. "Fisheries Handbook of Engineering Requirements and Biological Criteria." *US Army Corps of Engineers - Fish Passage Development and Evaluation Program.* Accessed December 2021. http://www.seattle.gov/light/skagit/relicensing/cs/groups/secure/@scl.skagit.team/documents/document/cm9k/ntcw/~edisp/prod570976.pdf.

USDA Forest Service. 2012. "FishXing: Software and Learning Systems for Fish Passage through Culvert (2012-11) version 3." *US Department of Agriculture - Forest Service.* November 08. Accessed December 2021. http://www.fsl.orst.edu/geowater/FX3/help/SwimData/Swim_Speed_Table.htm.

9.10 Additional Documentation

Culvert Survey & Hydraulic Design Report (CSR) Key

Detour Structure Survey & Hydraulic Design Report

Pipe Data Sheet

NCDOT Pipe Liner Manual

NCDOT Pipe Material Selection Guide

NCDOT Pipe Liner Special Provision

Grouting Host Pipe Special Provision

Invert Paving Special Provision

SAPL Structural Design for Liner Thickness Worksheet

D. Minimum and Maximum Fill Over Pipes

The following tables provide acceptable minimum and maximum earthfill heights over the pipe for several different types of pipe materials.

Table 1. Minimum Gauge for Corrugated Metal Pipe (CMP) *(Reference 1)*

Diameter, in.	Acceptable Fill Height, ft		Minimum Gauge CMP			
	Minimum	Maximum	Steel (corrugations)		Aluminum (corrugations)	
			2 2/3 x ½ in.	3 x 1 in.	2 2/3 x ½ in.	3 x 1 in.
≤18	2	25	16	16	16	16
21	2	25	16	16	16	16
24	2	23	16	16	16	16
	>23	25	16	16	12	16
30	2	18	16	16	14	16
	>18	25	16	16	12	16
36	2	15	16	16	14	16
	>15	25	16	16	12	16
42	2	22	16	16	12	16
	>22	23	16	16	10	16
	>23	24	16	16	---	16
	>24	25	14	16	---	14
48	2	19	16	16	12	16
	>19	20	16	16	10	16
	>20	21	16	16	---	16
	>21	23	14	16	---	14
	>23	25	12	16	---	14
54	2	17	14	16	12	16
	>17	18	14	16	10	16
	>18	20	14	16	---	14
	>20	23	12	16	---	14
	>23	25	12	16	---	12
60	2	16	12	16	10	16
	>16	20	12	16	---	14
	>20	23	12	16	---	12
	>23	25	10	16	---	12
66	2	15	10	16	---	16
	>15	19	10	16	---	14
	>19	22	10	16	---	12
	>22	25	---	16	---	12

Title 210 – Engineering Field Handbook

Table 1. Minimum Gauge for Corrugated Metal Pipe (CMP) *(Reference 1)*

Diameter, in.	Acceptable Fill Height, ft		Minimum Gauge CMP			
			Steel (corrugations)		Aluminum (corrugations)	
	Minimum	Maximum	2 2/3 x ½ in.	3 x 1 in.	2 2/3 x ½ in.	3 x 1 in.
72	2	13	10	16	---	16
	>13	17	10	16	---	14
	>17	20	10	16	---	12
	>20	24	---	16	---	10
	>24	25	---	14	---	10
78	2	16	---	16	---	14
	>16	22	---	16	---	12
	>22	25	---	14	---	10

Table 2. Minimum Thickness for Welded Steel Pipe *(Reference 1)*

Pipe Diameter, in	Acceptable Fill Height, ft		Minimum Pipe Wall Thickness, in
	Minimum	Maximum	
≤10	2	30	0.187
12	2	25	0.187
14, 16	2	30	0.25
18	2	23	0.25
	>23	25	0.375
20	2	18	0.25
	>18	25	0.375
24	2	12	0.25
	>12	25	0.375
30	2	8	0.25
	>8	18	0.375
	>18	25	0.5
36	2	6	0.25
	>6	12	0.375
	>12	23	0.5
42	2	5	0.25
	>5	9	0.375
	>9	16	0.5
48	2	4	0.25
	>4	7	0.375
	>7	12	0.5

Table 3. Minimum Acceptable PVC Pipe *(Reference 1)*

Nominal Pipe Diameter, in	Acceptable Fill Height, ft		Minimum Acceptable PVC Type[1]	
	Minimum	Maximum	Schedule	Standard Dimension Ratio (SDR)
4	2	10	40	26
	>10	16	40	21
	>16	21	40	---
	>21	25	80	---
6	2	10	40	26
	>10	12	40	21
	>12	16	80	21
	>16	25	80	---
8	2	10	40	26
	>10	16	80	21
	>16	25	80	---
10	2	8	40	21
	>8	16	80	21
	>16	24	80	---
12 -14	2	7	40	26
	>7	10	80	26
	>10	16	80	21
	>16	22	80	---
16	2	7	40	26
	>7	10	80	26
	>10	16	80	21
	>16	21	80	---
18	2	7	40	26
	>7	10	80	26
	>10	16	80	21
	>16	20	80	---
20	2	6	40	26
	>6	10	80	26
	>10	16	80	21
	>16	20	80	---

Table 3. Minimum Acceptable PVC Pipe *(Reference 1)*

Nominal Pipe Diameter, in	Acceptable Fill Height, ft		Minimum Acceptable PVC Type[1]	
	Minimum	Maximum	Schedule	Standard Dimension Ratio (SDR)
24	2	<3	---	26
	3	6	40	26
	>6	10	80	26
	>10	16	80	21
	>16	19	80	---
30 - 36	2	10	---	26
	>10	16	---	21

[1] Polyvinyl Chloride Pipe, PVC 1120 or PVC 1220, conforming to ASTM D-1785 or ASTM D-2241.

Table 4. Corrugated Plastic Tubing[2] (CPT) *(References 1,2,3)*

Trench Width, in	Max Fill Height, ft	Maximum Diameter CPT (in) per Installation Type	
		Tile Machine	Open Trench
12	any	8"	6"
16	8.4	12"	10"
20	6.8	15"	12"
24	6.0	18"	18"
28	5.6	24"	18"
32	5.3	24"	24"

[2] Single wall corrugated polyethylene (PE) pipe conforming to ASTM F405 or F667

References:

1. USDA-NRCS, National Engineering Handbook, Part 636, Chapter 52, Structural Design of Flexible Conduits.

2. American Society of Agricultural and Biological Engineers. 2008. Standard ASAE EP480. Design of Subsurface Drains in Humid Areas.

3. Spangler, M.G. and R.L. Handy. 1982. Soil Engineering. 4th Edition.

North Carolina
Department of
Transportation

Chapter 10 Storm Drain System

Hydraulics Unit

February 22, 2022

Revisions Sheet			
Page	Old Section	New Section	Description
-	-	-	• Entire Chapter revised to new format and minor grammatical changes made throughout • All references and links have been updated throughout Chapter
1	10.1	10.1	Entire section revised
1	10.2.1	10.2.1	Entire section revised
1	10.2.2	10.2.2	1st and 2nd sentences revised
2	10.2.3	10.2.3	Removed 5th sentence
2	10.2.4	10.2.4	9th through 12th sentences were added
4	10.3	10.3	• Bullet 13 – Added reference to Chapter 4 – hydroplaning guidelines; Removed last sentence • Bullet 14 – reworded for clarification
4-7	10.4	10.4	• Bullet 1 revised • Bullet 6 – Removed Appendix H reference and provided link • Added Bullets 7 & 8
7	10.5	10.5	Revised to include OpenRoads; Added last sentence
8	10.5.1	10.5.1	Revised Bullet 3
8	10.5.2	10.5.2	Bullet 3 – Removed Appendix I reference and provided link
9	10.5.2.1	10.5.2.1	• Removed Appendix I reference; Added reference links • Revised Bullets 16 and 17
10	10.5.2.2	10.5.2.2	• 2nd paragraph – Removed Appendix I reference; provided link • Bullet 6 revised
11	10.5.3	10.5.3	Entire section revised
12	10.6	10.6	Removed Appendix H reference; Provided link
12	10.7	10.7	• Revised 2nd sentence

			• Last sentence added for reference to Chapter 5 and Drainage Summary Sheet – Steps for Hydraulic Users
12	10.8	10.8	Entire section revised
12-19	-	10.9	Added new section – Soil Type Determination Guidance
20	-	10.10	Added new section - References
21-30	-	10.11	Added new section – Additional Documentation
21	Appendix H, Item 1	10.11	Added link – Pipe Material Selection Guide
-	Appendix H, Item 2	-	Removed
22-25	Appendix H, Item 3	10.11.1	Added table – Table 210 Engineering Field Handbook Minimum and Maximum Fill Heights over Pipes
5-6	Appendix H, Item 4	10.4	Added Tables 2, 3, and 4
28	Appendix I, Item 1	10.11.4	Added form – Inlet Computation Sheet
29	Appendix I, Item 2	10.11.5	Added form – Storm Drain Design Computations
-	Appendix I, Item 3 and 4	-	Removed
26	Appendix I, Item 5	10.11.2	Added Table – Hydraulic Properties – Circular Pipes
27	Appendix I, Item 6	10.11.3	Added Table – Storm Drain Pipe Maximum Capacity Table
30	Appendix I, Item 7	10.11.6	Added form – Hydraulic Grade Line Computation Sheet
7	Appendix I, Item 8	10.4	Added Table 5

Table of Contents: Chapter 10, Storm Drain System

10.1 Introduction

A storm drain system consists of the various inlet structures, storm drain pipes, junctions, manholes and other minor structures that are used to convey stormwater runoff away from the surface of the roadway. Storm drain system design usually follows the basic steps of planning/data collection, field reconnaissance, hydrologic/hydraulic design, and outlet analysis. A computer program following the HEC-22 procedures (FHWA. S.A. Brown, J.D. Schall, et al. (Authors). 2009) will accomplish the pavement and inlet design. OpenRoads Designer (Bentley Systems, Inc. 2021) or GEOPAK Drainage (Bentley Systems, Inc. n.d.) are acceptable software applications to use for all hydraulic design projects. Refer to the Hydraulics Unit web page for any updates to the most current software.

10.2 Determination of Design Constraints

For design reference, assemble all information and design constraints from the planning document and/or early project coordination during the pre-design study and field surveys relevant to the storm drain system, 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. When this occurs, follow guidance in Chapter 2, Section 2.4. Be sure to address any existing drainage issues that have been identified in the Hydraulic Planning Report (HPR).

10.2.2 Design Frequency and Rainfall Intensity

For pavement inlets, such as with curb and gutter section roadways, use an intensity of four inches per hour to calculate gutter spread and determine appropriate locations for inlet placement to collect roadway pavement runoff. For all other inlets, and to analyze and design storm drain pipe systems, use a ten-year discharge (Q_{10}) with a minimum time of concentration of ten minutes. For the overall storm drain system and non-roadway inlets (such as yard inlets and drop inlets collecting offsite runoff), develop the design by using the rainfall intensity guidance provided in Chapter 7 Section 7.4.3.2. In sag areas where there is no relief by curb overflow, use the roadway design discharge level (Chapter 7, Table 1) to maintain the level of service for anticipated traffic volume.

10.2.3 Gutter Grade and Pipe Slopes

Utilize a minimum gutter gradient of 0.2 percent (0.3 percent desirable). When encountering a lesser gradient, warp the gutter to provide the minimum gradient required for positive drainage. This minimum slope criteria may also be considered to apply to pipe slopes in the storm drain system. HEC-22 (FHWA. S.A. Brown, J.D. Schall, et al. (Authors). 2009) recommends using the minimum slope required to maintain a minimum full-flow pipe velocity of 3 feet per second 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 when other methods are not practical. Refer to NCDOT Standard 846.01 for standard gutters used on NCDOT roadways (NCDOT 2018).

10.2.4 Inlet types

The standard inlet for a typical 2'-6" curb and gutter is a combination grate and curb opening (commonly referred to as a "catch basin" or "CB"), standard number 840.01 of Roadway Standard Drawings (NCDOT 2018). Using other than standard inlet types for curb sections will require project specific approval. Otherwise, standard grated drop inlets (DIs, 2GIs, etc.) must 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 opening widths of two inches or less must be used in areas subject to pedestrian traffic. Specify traffic bearing inlets and grates (e.g., TB 2GI, TB DI) for drop inlets 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. Also consider the potential likelihood of a paved shoulder being utilized as a temporary travel lane when deciding to call for a traffic-bearing structure. Steel and cast iron are two types of traffic-bearing grates, and the engineer should specify which material should be used. The steel grates can be anchored to the inlet frame but cast iron cannot. Steel grates are preferred in locations subject to heavy truck traffic, as they can withstand the heavier loading better than cast iron grates. Additional guidance is provided in Part II Section 3.7.2.1 of the NCDOT Roadway Design Manual (NCDOT 2021).

10.3 Inlet Analysis and Design Criteria

The following specific criteria apply to inlet analysis and design:

- On grades, ignore the curb opening when 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 Chapter 7, Table 1.
- Inlet spacing shall be sufficient to limit spread as required for safe vehicle maneuverability. Table 1 below specifies acceptable design spread criteria. Allowable spread into the travel lane during temporary conditions (detours, phased construction, etc.) should be 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 1.

Table 1. Design Frequency and Spread Criteria for Inlet Placement

Roadway Classification	Design speed (on grade) or Sag (low point)*	Storm Drain Design Frequency (year)	Spread computation Intensity (inches/hour)	Allowable^ Spread (feet)
Major Arterials (e.g., Interstates, US, NC Routes)	≤ 45 mph	10	4	Shoulder * + 3
	> 45 mph	10	4	Shoulder *
	Sag (low point)†	50	4	Shoulder * + 3
Minor Arterials, Collectors, and Local Roads	≤ 45 mph	10	4	½ travel lane
	> 45 mph	10	4	Shoulder *
	Sag (low point)†	25	4	½ travel lane

*Applies to shoulder width six feet or greater; for narrower shoulder widths, design spread should not exceed six feet.

† Sag (low point) criteria is applicable where there is no overland relief.

^ In no case should total allowable spread exceed a 10’ width or 5” depth at the gutterline, except through consultation with the Hydraulics Unit or Highway Division, as applicable.

- Avoid any spread into the travel lane on bridges or when the typical roadway section includes a full shoulder (six feet or wider), bike lane, or parking lane. 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.
- Consider the height of curb when evaluating spread for maximum efficiency and safety, since flow should not be allowed to exceed the curb height. The design flow depth should not exceed five inches for a standard six-inch high curb.
- While there is generally no maximum spacing requirement for inlets, do not extend trunk line pipe 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.

- Avoid longitudinal runs of pipe beneath roadway travel lanes.
- A minimum vertical clearance of one-half 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.
- Use false sumps 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 since they are usually difficult to drain and can easily clog.
- For high volume multilane arterial routes (such as interstates) with three or more lanes sloped in one direction, it may be necessary to break the superelevation to eliminate potential hydroplaning hazard. Refer to the Chapter 4 hydroplaning guidelines for further guidance.
- On high volume arterial and collector routes with raised median, where the pavement is sloped toward median, call for a 2'-9" curb and gutter on the high side of the median, with inlets placed to limit spread to no more than three feet into the adjacent travel lane. This requires special detail and is not NCDOT standard.
- Refer to Standard Drawings 560.01 and 560.02 (NCDOT 2018) when evaluating median drainage, since the direction of pavement drainage will differ depending on whether the width of the median paved shoulder is greater or less than ten feet.

10.4 Pipe System Analysis and Design Criteria

- Storm drain pipes should follow the NCDOT Pipe Material Selection Guide
- 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, use a minimum size of 15-inch diameter. The 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 the method of pipe installation (Standard 300.01) (NCDOT 2018) and fill height requirements, as may be warranted. Refer to

the NCDOT Pipe Material Selection Guide to find the fill height requirements, or in Section 10.11, Table 210 *Engineering Field Handbook Minimum and Maximum Fill Heights over Pipes* for pipes not listed in the selection guide. Refer to manufacturer's recommended fill height tables for any non-standard pipes/culverts.

- In jurisdictional stream crossings, set pipe inverts at an appropriate depth below the natural bed to ensure the passage of aquatic organisms. Refer to the tables below for specific burial depth guidance

Table 2. Pipe Burial Depths - Non-CAMA Counties

Jurisdictional Streams					Non-Jurisdictional Streams			
Pipe Diameter (in)	Burial Depth (in)	Burial Depth (ft)	% Burial		Pipe Diameter (in)	Burial Depth (in)	Burial Depth (ft)	% Burial
18	3.6	0.3	20		18	Not Req'd	-	-
24	4.8	0.4	20		24	Not Req'd	-	-
30	6.0	0.5	20		30	Not Req'd	-	-
36	7.2	0.6	20		36	Not Req'd	-	-
42	8.4	0.7	20		42	Not Req'd	-	-
48	9.6	0.8	20		48	Not Req'd	-	-
54	12.0	1.0	-		54	Not Req'd	-	-
60	12.0	1.0	-		60	Not Req'd	-	-
66	12.0	1.0	-		66	12.0	1.0	-
72	12.0	1.0	-		72	12.0	1.0	-

Table 3. Pipe Burial Depths - CAMA Counties

Jurisdictional Streams			Non-Jurisdictional Streams		
Pipe Diameter (in)*	Burial Depth (in)	Burial Depth (ft)	Pipe Diameter (in)	Burial Depth (in)	Burial Depth (ft)
18	-	-	18	Not Req'd	-
24	-	-	24	Not Req'd	-
30	-	-	30	Not Req'd	-
36	12.0	1.0	36	Not Req'd	-
42	12.0	1.0	42	Not Req'd	-
48	12.0	1.0	48	Not Req'd	-
54	12.0	1.0	54	Not Req'd	-
60	12.0	1.0	60	12.0	1.0
66	12.0	1.0	66	12.0	1.0
72	12.0	1.0	72	12.0	1.0

*Since the minimum bury depth is 12", a 36" diameter pipe is considered the smallest practical pipe to use.

Table 4. Minimum Equivalent Pipe Diameter

Buried Pipe Diameter (in)	Equivalent Inlet Control Pipe Diameter (in)	Equivalent Outlet Control Pipe Diameter (in)
18	15	12
24	18	15
30	24	18
36	30	24
42	36	30
48	42	36
54	48	42
60	54	48
66	60	54
72	66	60

- Consider the pipe's thickness in each pipe's design. Refer to Table 5 for the thickness of reinforced concrete pipes (RCP).

Table 5. Reinforced Concrete Pipes (RCP) Wall "B" Thickness

Diameter (inches)	Thickness (inches)
12	2.00
15	2.25
18	2.50
24	3.00
30	3.50
36	4.00
42	4.50
48	5.00
54	5.50
60	6.00
66	6.50
72	7.00
78	7.50
84	8.00
90	8.50
96	9.00
102	9.50
108	10.00

- Driveway pipes must comply with NCDOT's *Policy on Street and Driveway Access to North Carolina Highways* (NCDOT 2003).
- Avoid placement of a storm drain system where it disturbs contaminated soils (identified on the plans) for which the contamination is to be managed by containment rather than removal. If unavoidable, specify a sealed (watertight) system through the contaminated area at minimum. This requires an exception to the standard NCDOT Pipe Material Selection Guide. 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 that first selects the required surface inlets and then designs the subsurface pipe system to serve the surface inlets. OpenRoads Designer (Bentley Systems, Inc. 2021) or GEOPAK Drainage (Bentley Systems, Inc. n.d.) are acceptable software applications for storm drain system design, which is consistent with the following general design procedure based on HEC-22 (FHWA. S.A. Brown, J.D. Schall, et al. (Authors). 2009) guidance. Refer to the Hydraulics Unit web page for any updates to the most current software.

10.5.1 Inlet Selection and Placement Procedure

1. Develop a layout of locations requiring inlets on a set of plans prior to commencing the hydrologic/hydraulic analysis of the surface system. The layout should include sag points, upstream of intersections, upgrade of superelevation rollovers, and 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; coordination with the Division is recommended in this instance.
2. With the above-noted locations determined, 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). Use the procedure as outlined in Chapter 5 (Drainage Plans) to confirm drainage boundaries, flow paths, outlet conditions and other project special design features.
3. Document the design on a form similar to the Inlet Computation Sheet shown in Section 10.11.4 or on the "Inlet" tab of the Storm Drain Design Computations Form . Number the inlets, junctions, and outlets or other features as applicable in a logically ascending order, with their locations referenced to a project station. Structure numbers should have the roadway plan sheet number, then the structure number (example 0401 for the 1st structure on Plan Sheet 04). Only renumber structures if plan sheet numbers change. Some computer programs, such as GEOPAK Drainage (Bentley Systems, Inc. n.d.) or OpenRoads Designer (Bentley Systems, Inc. 2021), 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, size the individual pipes.
3. The Storm Drain Design Computation Form (Section 10.11.5 – see Section 10.5.2.1 below) follows a systematic design process of developing the pipe network from upstream to downstream. Use Manning's flow capacity equation to select pipe sizes, with the limitations on maximum pipe capacity as calculated in the hydraulic toolbox. See Section 10.11.3 - Storm Drain Pipe Maximum Capacity Table for further reference. Sizing of most systems by this procedure is generally sufficient, and may be automated by a software application (e.g. GEOPAK Drainage or OpenRoads Designer Drainage and Utilities) (Bentley Systems, Inc. n.d.) (Bentley Systems, Inc. 2021).
4. The procedure for the hydraulic grade line development is outlined in Section 10.5.2.2. A check of the system by development of the hydraulic grade line is recommended, which 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 appropriate locations to perform a hydraulic grade line check. Conditions that warrant a hydraulic grade line check are:

- systems with outlets subject to high tailwater conditions, including backwater from undersized downstream drainage systems
- systems that transition from a steep to flat gradient
- systems on a flat gradient, especially with substantial junction or bend losses
- Any change in conveyance that may induce an outlet control condition (slope, material roughness, size)

10.5.2.1 Storm Drain Design Computations Procedure

Document storm drain system design on the Storm Drain Design Computations Form. Refer to Section 10.11.5 or the "Storm" tab of the Storm Drain Design Computations Form for the form, and refer below for the procedure which corresponds 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 ten 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. Compute capacity using Manning's full flow capacity equation: $Q = (0.46/n)(D^{2.67})(S_o^{0.5})$. The capacity utilized for design cannot exceed the values contained in Section 10.11.3. 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 calculate with Manning Equation and Continuity Equation, Q=VA).
18. Upstream box depth.
19. Use "remarks" 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. The hydraulic gradeline is a useful check for unacceptableflow conditions within the drainage system that may dictate a necessary change to an element of the drainage system. Document hydraulic grade line computations on the Hydraulic Grade Line Computations form. Refer to Section 10.11.6 or the "HGL" tab of the Storm Drain Design Computations Form for the form, and refer below for the procedure which corresponds 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 $0.8D_o$ + 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 $K = (1.486/n)(A)(R^{0.67})$.
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:

90º K = 0.70	40º K = 0.38
80º K = 0.66	30º K = 0.28
70º K = 0.61	25º K = 0.22
60º K = 0.55	20º K = 0.16
50º K = 0.47	15º 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 administrative code 15A NCAC 04B.0109 regarding Stormwater Outlet Protection. The intent of this rule, as it relates to NCDOT actions, is to ensure that 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.

The NCDOT Hydraulics Unit has developed a Compliance Documentation Workflow to assist with maintaining compliance with rule 15A NCAC 04B .0109. One of the steps in the workflow is to determine the maximum Permissible Velocity (V_{perm}) of stormwater discharges leaving the site. Based on the rule, the V_{perm} is dependent upon the type of soils/material in and near the discharge point. Guidance for identifying the site's soil material and V_{perm} is provided in Section 10.9. Investigate impacts from velocity and/or quantity of the stormwater runoff, as these can impact receiving channel water quality. Follow the guidelines and processes outlined in the Post-Construction Stormwater Controls for Roadway and Non-Roadway Projects (PCSP manual) (NCDOT 2014).

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 a table labeled "NCDOT Pipe Material Selection Guide". Requirements for a specific pipe material and class for a given pipe must be clearly specified on the design plans. Supplemental tables in Section 10.4 and Section 10.11 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 completed by the Hydraulic Design Engineer. To facilitate production, a program has been developed to generate automated quantities from data stored in GEOPAK Drainage (Bentley Systems, Inc. n.d.) or in OpenRoads Designer (Bentley Systems, Inc. 2021). Refer to Chapter 5 – Section 5.5 and Drainage Summary Sheet – Steps for Hydraulic Users for guidance on completing the Drainage Summary Sheet.

10.8 Treatment of Existing Pipes

Note when existing pipe is to be removed, or removed and replaced 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 is deemed advantageous to leave in place, the Hydraulic Design Engineer may call for pipe plugs (NCDOT Standard 840.71) (NCDOT 2018) at both ends of the pipe. If the current or future structural integrity of the abandoned pipe is a concern with respect to support of the overlying fill material (e.g., a metal pipe), or is under pavement, the Design Engineer should 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, note this also on the drainage plans.

10.9 Soil Determination Guidance

This section provides four options to determine the soil type at the discharge point. Options 1 through 3 are remote determinations and consist of three different ways to find and determine the soil series that has been mapped by the USDA/NRCS at that location and to obtain the soil description for that soil series. Option 4 provides guidance for visiting the site and either evaluating the soils or collecting soils for evaluation later.

10.9.1 Remote Determinations

Option 1: Web Soil Survey

A key advantage of using the Web Soil Survey (WSS) is that a Custom Soils Report (the output from Step 7 below) can be downloaded that will document the mapping and the soil series. Place the Custom Soils Report in the project files for reference and documentation of the mapped soil series. The aerial photographs used for the soil mapping are the most recent typically available, making it is easy to locate a project area on the aerial photography.

The main disadvantage of using the WSS is that several soil maps/reports must be produced when a large number of discharge points are located over a long project.

1. Visit the Web Soil Survey (WSS) website Web Soil Survey - Home (usda.gov). Click on the green button in the upper portion of the home page labeled "START WSS".
2. The starting point is the Area of Interest (AOI) tab. An aerial map of the country appears with search options is on the left side of the page. If a shapefile for the project and/or discharge points is available, upload the shapefile by selecting "Import AOI" and upload the requested files or a zip file with those files. Once uploaded, click the "Set AOI" at which point the shapefile becomes the AOI. Search by State, County and/or address and zoom in to find the project site area. Once the search is complete, an AOI Interactive Map will appear if searching by State, County and/or address. Use the navigation tools in the upper right of the AOI Interactive Map navigate to the project site. Create an AOI by clicking on one of the two AOI tabs on the right side of the toolbar at the top of the map. This will create a rectangle/square or a polygon for the AOI that contains the project site/discharge point.
3. The map will show that area cross-hatched, at which point navigate to the soil map by selecting the Soil Map tab at the top of the webpage once the AOI is created. This will bring up a new map showing the soil series boundaries within the AOI.
4. Identify the soil series where the stormwater discharge point is located.
5. Obtain a soil profile description for the identified soil series from the following website USDA-NRCS Official Soil Series Description (OSD) View by List. A link to this website is located on the WSS home page on the left side. When using this website, select the first option (View OSD by Series Name) under the heading Official Soil Series Descriptions. Type in the soil series name and a typical profile description for that soil series with soil horizon depths will appear.

6. Determine the depth of the stormwater discharge pipe and correspond that to the similar depth within the soil profile description. Use engineering judgment to determine an appropriate reference (e.g., natural ground or other feature) for estimating depth. Document the soil texture(s) for that soil horizon(s). Match the soil texture(s) in the OSD with the type of material identified in Table 1 below. If the depth of the discharge pipe is lower than the depth of the soil profile description, use the texture for the deepest horizon.
7. Create a Custom Soils Report to preserve and document mapping. Select the Shopping Cart tab at the top of the WSS webpage. Under Report Properties along the left side of the page, edit or add information to generate a title for the report. Click on the checkout button in the top right corner and "OK" to produce a PDF of the report. A PDF will open in a new tab, which can then be saved to the project folder.

Option 2: Google Earth kmz soil file

Although Options 1 and 2 draw upon the same base data for soils information, a key advantage of this option is its ease of navigation and the ability to find discharge points if there are numerous discharge points to evaluate once the SoilWeb kmz and the project kmz are loaded into Google Earth. If project changes occur and discharge points are moved it is easy to go back and redo the evaluation. Obtaining and loading the SoilWeb kmz into Google Earth is a onetime step which can then be used for other projects.

Google Earth and the SoilWeb kmz can be used without the project alignment. However, for larger projects with numerous discharge points, uploading the project kmz can make finding the discharge points easier. Obtaining a kmz of the project may take some time and may be dependent upon help from a CAD or GIS Specialist.

1. Obtain the SoilWeb.kmz file from http://casoilresource.lawr.ucdavis.edu/soil_web/kml/SoilWeb.kmz.
2. Load the SoilWeb.kmz into Google Earth by performing the following:
   - Copy the SoilWeb.kmz onto your desktop.
   - Open Google Earth and drag the SoilWeb.kmz from the desktop into My Places on the left side of Google Earth. Turn SoilWeb.kmz on or off by checking the box next to the kmz.
3. Obtain and load a kmz of the project alignment, into Google Earth.
4. Zoom into the project site and/or discharge points to obtain the soil series where the project or discharge point is located.
5. Click on the discharge point to see the soil series for that point. Click on the series description towards the top of the pop-up window. At the top of the next page under Map Unit Composition, select the soil type with the greatest area percentage (usually at the top of the list) to see a description of the soil type. Under Soil

Taxonomy – Soil Series select - Link to OSD - which link to the soil profile description at the USDA-NRCS website.

6. Determine the depth of the stormwater discharge pipe and match that to the similar depth within the soil profile description. Document the soil texture(s) for the soil horizon(s). Match the soil texture(s) in the OSD with the type of material identified in the soil texture table. If the depth of the discharge pipe is lower than the depth of the soil profile description, use the texture for the deepest horizon regarding permissible velocity guidance.

Option 3: Using USDA-NRCS printed soil surveys

This is a good option if the project is in a river basin with stream buffer regulations (such as the Neuse River Basin, Tar-Pamlico River Basin, and Jordan Lake Basin), since the most recent copy of the printed soil survey is used to determine if a stream is buffered. This is also the best option for individuals who are less familiar with navigating the internet or importing and exporting files.

One of the main disadvantages of this option is its difficulty in locating the precise discharge point on the soil mapping. The soil maps are typically at a 1:15840 scale and are often based on aerial photographs from the 1970's or 1980's. There has also been significant land use changes since the maps were published, making it difficult to locate the discharge points.

1. Obtain the most recent printed copy of the appropriate county soil survey from that county's USDA – NRCS office or visit https://www.nrcs.usda.gov/wps/portal/nrcs/surveylist/soils/survey/state/?stateId=NC. Select an actual year instead of the "most recent" to view the online Web Soil Survey (Option 1 above). Select the County and year, and navigate to the root file to locate the map index and maps. Deleting the year and file type extension from the end of the URL. For example, to get to the root file for Alamance County (https://www.nrcs.usda.gov/Internet/FSE_MANUSCRIPTS/north_carolina/alamanceNC1960/text.pdf), delete the /text.pdf from the end of the URL and to see the root file for the Alamance County soil survey from 1960. There are links to the map index and multiple map sheets. Use the map index to determine the location of the map sheet. Use the existing features that were present at the time of publication of the soil survey which may be between 1960 to 1980 to locate the site on these soil surveys.
2. Locate the project site on the printed soil survey or website-provided map and identify the soil series where the stormwater discharge point is located.
3. Obtain a soil profile description for the identified soil series from the following website USDA-NRCS Official Soil Series Description View by List. Select the first option [View OSD by Series Name] under the heading Official Soil Series Descriptions. Type in the soil series name to find a typical profile description for that soil series with soil horizon depths.
4. Determine the depth of the stormwater discharge pipe and match it to the similar depth within the soil profile description. Document the soil texture(s) for that soil

horizon(s). Match the soil texture(s) in the OSD with the type of material identified in the soil texture table below. If the depth of the discharge pipe is lower than the depth of the soil profile description, use the texture for the deepest horizon.

10.9.2 Onsite Determinations

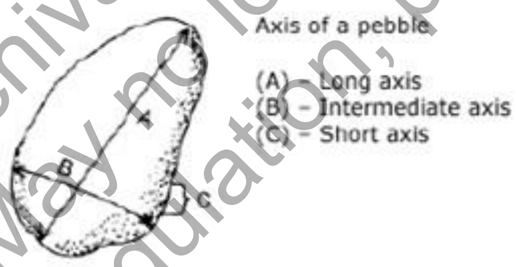
If an onsite determination is preferred or if conditions observed vary considerably from the above mapping references, an onsite determination of soil texture can be made using the following steps:

1. Determine the depth/elevation of the stormwater discharge pipe.
2. Advance hand auger borings to those depths at the discharge point.
3. Use the Guide to Texture by Feel method published by USDA-NRCS which can be found at https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/edu/?cid=nrcs142p2_054311 and at the end of this guidance to determine the soil texture at the depth of the pipe.
4. Match the soil texture(s) derived from the Guide to Texture by Feel with the type of material identified in the soil texture table below.

Table 6. Soil Texture Table Material for Rule 15A NCAC 04B .0109

15A NCAC 04B.0109 Soil Material Description	OSD/USDA Textures[1, 2]	Max. Permissible Velocity for the 10-Year Peak Flow Runoff (fps)
Fine Sand (noncolloidal)	Coarse sand, sand, fine sand, loamy sand	2.5
Sandy Loam (noncolloidal)	Sandy loam	2.5
Silt Loam (noncolloidal)	Silt loam	3.0
Ordinary Firm Loam	Loam, clay loam, silty clay loam, sandy clay loam	3.5
Alluvial Silts	Silt	3.5
Fine Gravel	2 – 5 mm in size	5.0
Stiff Clay (very colloidal)	Sandy clay, silty clay, clay, weathered bedrock	5.0
Graded, Loam to Cobbles (noncolloidal)	Cobbles are 76 to 250 mm in size	5.0
Alluvial Silts (colloidal)3	NA[3]	5.0
Graded Silt to Cobbles (colloidal)	Cobbles are up to 250 mm in size	5.5
Cobbles and Shingles	Cobbles are 76 to 250 mm in size	5.5
Coarse Gravel	20 – 76 mm in size	6.0
Shales and Hard Pans	NA[4]	6.0

1 – To determine a particle size (gravel or cobble) measure along the intermediate axis. If a variety of sizes are present count 100 particles and use the predominant size



2 – Source for textures is US Department of Agriculture Handbook 18, Soil Survey Manual. March 2017

3–A grain size analysis can be used to differentiate between colloidal and non-colloidal materials with those being less than one micrometer being considered colloidal. In the absence of any laboratory analysis the more restrictive velocity should be used.

4 – Shale is a Sedimentary rock that formed by the hardening of a deposit of clay, silty clay, or silty clay loam and that tends to split into thin layers. A Hardpan is a hardened or cemented soil horizon, or layer. The soil material is sandy, loamy, or clayey and is cemented by iron oxide, silica, calcium carbonate, or other substance.

10.9.3 Guide to Texture by Feel

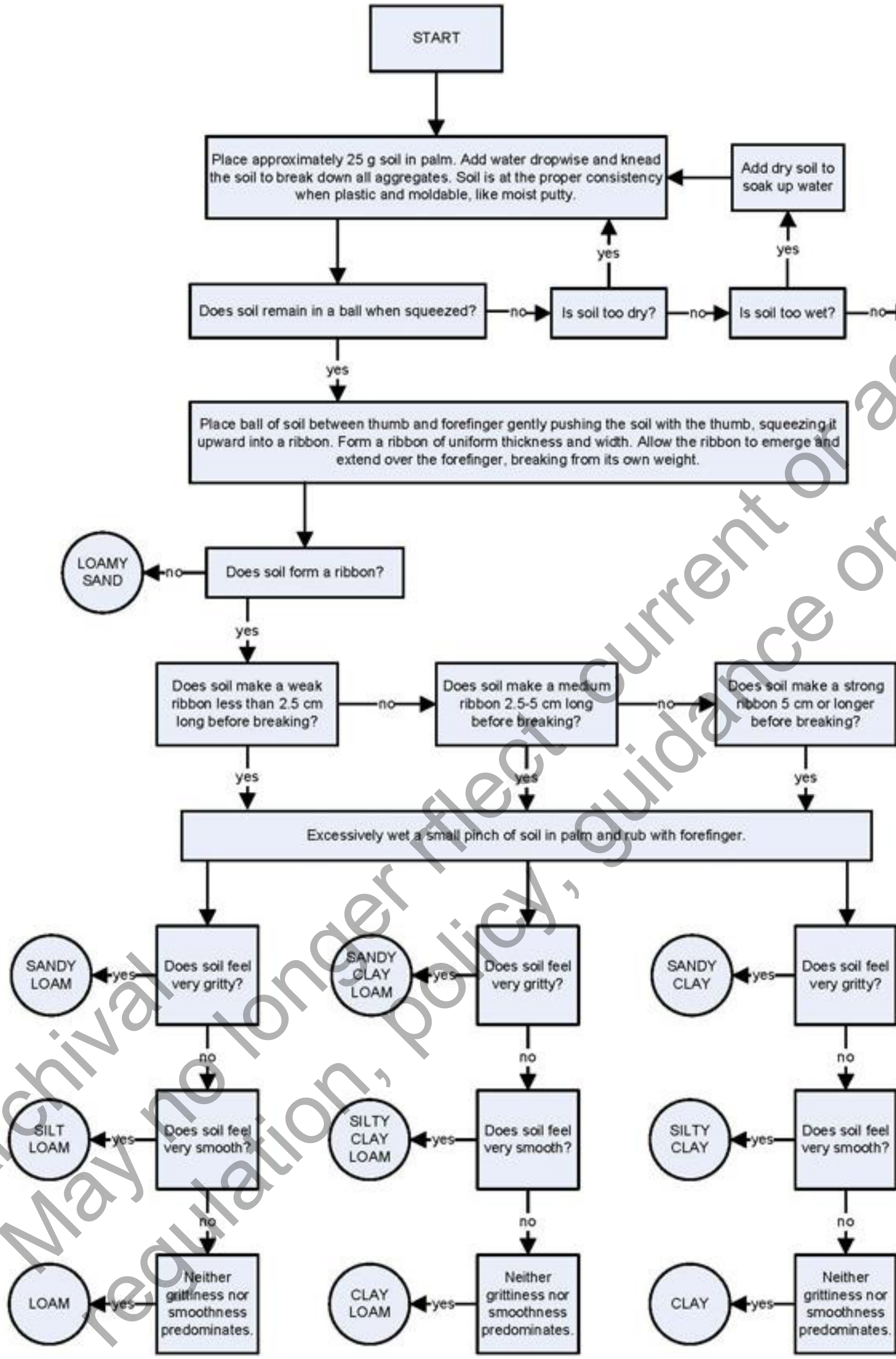


Figure 1. Flow diagram for teaching texture by feel analysis (NRCS (modified from S.J. Thien) 1979)

10.9.4 Additional Resources

The newly updated Soil Survey Manual, USDA Handbook No. 18 (NRCS. C. Ditzler, K. Scheffe, and H.C. Monger (eds.) 2017), provides the major principles and practices needed for making and using soil surveys and for assembling and using related data. The Manual serves as a guiding document for activities of the National Cooperative Soil Survey (NCSS). Previously published in 1937, 1951, and 1993, the Soil Survey Manual is one of the defining documents for soil survey in the world. For additional resources and links, refer to Section 10.11.

10.10 References

Bentley Systems, Inc. . n.d. *Geopak Version 08.08.02.81 or Higher.* Exton, PA.

Bentley Systems, Inc. 2021. *OpenRoads Designer version 10.10 or higher.* Exton, PA.

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—. 2018. *Roadway Standard Drawings.* Accessed December 2021. https://connect.ncdot.gov/resources/Specifications/Pages/2018-Roadway-Standard-Drawings.aspx.

NRCS (modified from S.J. Thien). 1979. "Guide to Texture by Feel." *US Department of Agriculture - Natural Resources Conservation Service.* Accessed December 2021. https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/home/?cid=nrcs142p2_054311.

NRCS. C. Ditzler, K. Scheffe, and H.C. Monger (eds.). 2017. "Soil Survey Manual - USDA Handbook 18." *US Department of Agriculture - Natural Resources Conversation Service.* March. Accessed December 2021. https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/soils/ref/?cid=nrcs142p2_054262.

10.11 Additional Documentation

NCDOT Pipe Material Selection Guide
NCDOT Hydraulics Unit Forms and Checklists

- Please see Storm Drain Design Computation Forms

NC Statute 15A NCAC 04B.0109

NCDOT Compliance Documentation Workflow for Rule 15A NCAC 04B .0109

NCDOT PCSP Manual

Drainage Summary Sheet – Steps for Hydraulic Users

The following is a link to the NRCS Soil Survey online manual.

https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/soils/ref/?cid=nrcs142p2_054262

Videos

- USDA - Locating a printed soil survey

https://www.youtube.com/watch?v=oIPKw3ey6ec&list=PLKyiLObeuDlo_nzll8g0sOWz3IujRzVck&index=4

- USDA - Using the Web Soil Survey (3 Videos)

https://www.youtube.com/watch?v=vxSW49ZK8vM&list=PLKyiLObeuDlo_nzll8g0sOWz3IujRzVck&index=1

https://www.youtube.com/watch?v=bcilQrk3bjs&list=PLKyiLObeuDlo_nzll8g0sOWz3IujRzVck&index=2

https://www.youtube.com/watch?v=thWicmr1tp0&list=PLKyiLObeuDlo_nzll8g0sOWz3IujRzVck&index=3

- Determining Soil Texture by Feel

https://www.youtube.com/watch?v=GWZwbVJCNec

https://www.youtube.com/watch?v=MXnDc0WQhMQ

- This one is from Australia but has some helpful hints

https://www.youtube.com/watch?v=fufeaLBLGlk

- CEEN 341 - Lab 11 - Visual Classification of Soil

https://www.youtube.com/watch?v=j85hdjoqtvE

- CEEN 341 - Lecture 5 - Soil Classification

https://www.youtube.com/watch?v=Ng7kza18K48

10.11.1 Engineer Field Handbook – Maximum and Minimum Fill Height Tables

Title 210 – Engineering Field Handbook

D. Minimum and Maximum Fill Over Pipes

The following tables provide acceptable minimum and maximum earthfill heights over the pipe for several different types of pipe materials.

Table 1. Minimum Gauge for Corrugated Metal Pipe (CMP) *(Reference 1)*

Diameter, in.	Acceptable Fill Height, ft		Minimum Gauge CMP			
			Steel (corrugations)		Aluminum (corrugations)	
	Minimum	Maximum	2 2/3 x ½ in.	3 x 1 in.	2 2/3 x ½ in.	3 x 1 in.
≤18	2	25	16	16	16	16
21	2	25	16	16	16	16
24	2	23	16	16	16	16
	>23	25	16	16	12	16
30	2	18	16	16	14	16
	>18	25	16	16	12	16
36	2	15	16	16	14	16
	>15	25	16	16	12	16
42	2	22	16	16	12	16
	>22	23	16	16	10	16
	>23	24	16	16	---	16
	>24	25	14	16	---	14
48	2	19	16	16	12	16
	>19	20	16	16	10	16
	>20	21	16	16	---	16
	>21	23	14	16	---	14
	>23	25	12	16	---	14
54	2	17	14	16	12	16
	>17	18	14	16	10	16
	>18	20	14	16	---	14
	>20	23	12	16	---	14
	>23	25	12	16	---	12
60	2	16	12	16	10	16
	>16	20	12	16	---	14
	>20	23	12	16	---	12
	>23	25	10	16	---	12
66	2	15	10	16	---	16
	>15	19	10	16	---	14
	>19	22	10	16	---	12
	>22	25	---	16	---	12

(210-650-H, Amend. IL66, August 2013)

IL17.D-1

Table 1. Minimum Gauge for Corrugated Metal Pipe (CMP) *(Reference 1)*

Diameter, in.	Acceptable Fill Height, ft		Minimum Gauge CMP			
			Steel (corrugations)		Aluminum (corrugations)	
	Minimum	Maximum	2 2/3 x ½ in.	3 x 1 in.	2 2/3 x ½ in.	3 x 1 in.
72	2	13	10	16	---	16
	>13	17	10	16	---	14
	>17	20	10	16	---	12
	>20	24	---	16	---	10
	>24	25	---	14	---	10
78	2	16	---	16	---	14
	>16	22	---	16	---	12
	>22	25	---	14	---	10

Table 2. Minimum Thickness for Welded Steel Pipe *(Reference 1)*

Pipe Diameter, in	Acceptable Fill Height, ft		Minimum Pipe Wall Thickness, in
	Minimum	Maximum	
≤10	2	30	0.187
12	2	25	0.187
14, 16	2	30	0.25
18	2	23	0.25
	>23	25	0.375
20	2	18	0.25
	>18	25	0.375
24	2	12	0.25
	>12	25	0.375
30	2	8	0.25
	>8	18	0.375
	>18	25	0.5
36	2	6	0.25
	>6	12	0.375
	>12	23	0.5
42	2	5	0.25
	>5	9	0.375
	>9	16	0.5
48	2	4	0.25
	>4	7	0.375
	>7	12	0.5

Table 3. Minimum Acceptable PVC Pipe *(Reference 1)*

Nominal Pipe Diameter, in	Acceptable Fill Height, ft		Minimum Acceptable PVC Type[1]	
	Minimum	Maximum	Schedule	Standard Dimension Ratio (SDR)
4	2	10	40	26
	>10	16	40	21
	>16	21	40	---
	>21	25	80	---
6	2	10	40	26
	>10	12	40	21
	>12	16	80	21
	>16	25	80	---
8	2	10	40	26
	>10	16	80	21
	>16	25	80	---
10	2	8	40	21
	>8	16	80	21
	>16	24	80	---
12 -14	2	7	40	26
	>7	10	80	26
	>10	16	80	21
	>16	22	80	---
16	2	7	40	26
	>7	10	80	26
	>10	16	80	21
	>16	21	80	---
18	2	7	40	26
	>7	10	80	26
	>10	16	80	21
	>16	20	80	---
20	2	6	40	26
	>6	10	80	26
	>10	16	80	21
	>16	20	80	---

Table 3. Minimum Acceptable PVC Pipe *(Reference 1)*

Nominal Pipe Diameter, in	Acceptable Fill Height, ft		Minimum Acceptable PVC Type[1]	
	Minimum	Maximum	Schedule	Standard Dimension Ratio (SDR)
24	2	<3	---	26
	3	6	40	26
	>6	10	80	26
	>10	16	80	21
	>16	19	80	---
30 - 36	2	10	---	26
	>10	16	---	21

[1] Polyvinyl Chloride Pipe, PVC 1120 or PVC 1220, conforming to ASTM D-1785 or ASTM D-2241.

Table 4. Corrugated Plastic Tubing[2] (CPT) *(References 1,2,3)*

Trench Width, in	Max Fill Height, ft	Maximum Diameter CPT (in) per Installation Type	
		Tile Machine	Open Trench
12	any	8"	6"
16	8.4	12"	10"
20	6.8	15"	12"
24	6.0	18"	18"
28	5.6	24"	18"
32	5.3	24"	24"

[2] Single wall corrugated polyethylene (PE) pipe conforming to ASTM F405 or F667

References:

1. USDA-NRCS, National Engineering Handbook, Part 636, Chapter 52, Structural Design of Flexible Conduits.

2. American Society of Agricultural and Biological Engineers. 2008. Standard ASAE EP480. Design of Subsurface Drains in Humid Areas.

3. Spangler, M.G. and R.L. Handy. 1982. Soil Engineering. 4th Edition.

10.11.2 Hydraulic Properties – Circular Pipes

HYDRAULIC PROPERTIES - CIRCULAR PIPES

Pipe Diam. (Inch)	A Pipe Area (sq. ft.)	R Hydraulic Radius (feet)	Value of K = 1.486/n x A x R $^{2/3}$ (n = 0.012)	Value of K = 1.486/n x A x R $^{2/3}$ (n = 0.024)
8	0.349	0.167	13.1	6.5
10	0.545	0.208	23.7	11.9
12	0.785	0.250	38.6	19.3
15	1.227	0.313	70.0	35.0
18	1.767	0.375	113.8	56.9
21	2.405	0.438	171.7	85.8
24	3.142	0.500	245.1	122.5
27	3.976	0.563	335.5	167.8
30	4.909	0.625	444.4	222.2
33	5.940	0.688	572.9	286.5
36	7.069	0.750	722.6	361.3
42	9.621	0.875	1090	545.0
48	12.566	1.000	1556	778.1
54	15.904	1.125	2130	1065
60	19.635	1.250	2821	1411
66	23.758	1.375	3638	1819
72	28.274	1.500	4588	2294
78	33.183	1.625	5680	2840
84	38.485	1.750	6921	3460
90	44.179	1.875	8319	4159
96	50.265	2.000	9881	4940
102	56.745	2.125	11615	5807
108	63.617	2.250	13527	6763
114	70.882	2.375	15625	7812
120	78.540	2.500	17915	8958
126	86.590	2.625	20404	10202
132	95.033	2.750	23099	11550
138	103.869	2.875	26006	13003
144	113.097	3.000	29132	14566

10.11.3 Storm Drain Pipe Maximum Capacity Table

STORM DRAIN PIPE

MAXIMUM CAPACITY TABLE

(1) PIPE SIZE	(2) MAXIMUM CAPACITY
12"	6
15"	9
18"	13
24"	25
30"	43
36"	64
42"	90
48"	120
54"	160
60"	200
66"	250

(1) CONCRETE PIPE

(2) CAPACITY (c.f.s.) BASED ON INLET CONTROL FOR MAXIMUM DEPTH IN STANDARD CATCH BASIN

6/90

10.11.4 Inlet Computation Sheet

INLET COMPUTATION SHEET

DATE: ______ SHEET ___ OF ___
I.D. NO. ______ PROJ. NO.: ________ COUNTY: ____________ DESIGNED BY: ________
DESCRIPTION: ____________________ REACH: ____________ CHECKED BY: ________

LOCATION			ROADWAY		RUNOFF							INLET			
INLET NO. DES./ CONST.	STATION	ELEVATION	GRADE	CROSS SLOPE	DRAINAGE AREA D.A.	RUNOFF COEFF. C	TIME OF CONC. T_C	RAINFALL INTENSITY I	DISCHARGE FROM D.A. $Q_{D.A.}$	DISCHARGE CARRYOVER Q_C	TOTAL DISCHARGE $Q_T = Q_{D.A.} + Q_C$	SPREAD	INTERCEPT Q_I	BYPASS Q_B	REMARKS

This form can be downloaded from the Hydraulics Unit website.

10.11.5 Storm Drain Design Computation Sheet

STORM DRAIN DESIGN COMPUTATIONS

[SEE ALSO HYDRAULIC GRADE LINE SHEETS]

DATE:

SHEET ___ OF ___

I.D. NO. ____________ PROJ. NO. ________________ COUNTY: __________________ DESIGNED BY: ____________

DESCRIPTION: ____ CHECKED BY: ____________

LOCATION		RUNOFF								PIPE DESIGN								
FROM	TO				TIME OF CONCENTRATION min.					INLET ELEV.	OUTLET ELEV.							
DES./ CONST.	DES./ CONST.	CUM. D.A. ac	SUM CA	PIPE L (ft)	INLET TIME	FLOW TIME	DESIGN TIME	INT I (in/hr)	DISCH. Q (cfs)	INV	INV	SLOPE ft/ft	DIA. in	MATERIAL	CAP. cfs	VEL. ft/s	UPSTREAM BOX DEPTH	REMARKS

This form can be downloaded from the Hydraulics Unit website.

10.11.6 Hydraulic Grade Line Computation Sheet

HYDRAULIC GRADE LINE

SHEET ____ OF ____

DATE: ______________

ID NO. ______________ PROJECT: ______________________________ COUNTY: ____________________ DESIGNED BY: ____________________

DESCRIPTION: ____ CHECKED BY: ____________________

INLET OR JUNCT. NO. DES. / CONST.	OUTLET W.S. ELEV.	D_O	Q_O	L_O	HEAD LOSSES					INLET W.S. ELEV.	RIM ELEV.	REMARKS
					H_f	H_c	H_e	H_b	H_t			

This form can be downloaded from the Hydraulics Unit website.

North Carolina
Department of
Transportation

Chapter 11
Roadside Ditches and Channels

Hydraulics Unit

February 22, 2022

Revisions Sheet			
Page	**Old Section**	**New Section**	**Description**
-	-	-	• Entire Chapter revised to new format and minor grammatical changes made throughout • All references and links have been updated throughout Chapter
1	11.1	11.1	Revised section heading to Introduction
3	11.2.5	11.2.5	• 1st paragraph revised • Removed 2nd and 3rd paragraphs • 3rd and 5th paragraphs revised
4	11.3	11.3	4th sentence revised to change document title of "Guidelines for Mountain Stream Relocation in North Carolina."
4 - 5	11.3	11.3	4th sentence replaced NCDEQ Stream Mitigation Guidelines and Stream Restoration, A Natural Channel Design Handbook with updated documents.
5	11.3.1	11.3.1	Last sentence revised: Replaced reference to Appendix J with FHWA HEC-15
9	-	11.4	Added new section - References
11	-	11.5	Added new section – Additional Documentation
11	Appendix M	11.5	Added Stream Relocation Guidelines

Table of Contents: Chapter 11, Roadside Ditches and Channels

11.1 Introduction

A channel is a conveyance in which water flows with a free surface. It may be natural or manmade. A roadside ditch is a manmade channel that parallels the roadway surface and is distinguished by a regular geometric shape. The design process and analysis requirements differ for roadside ditches and channels. Roadside ditches are roadside and median drainage conveyances that carry surface stormwater away from roads and subgrade drains.

This chapter defines a channel as any open conveyance facility not classified as a roadside ditch or requiring more than a two-foot-wide base. This chapter addresses specific criteria and analysis requirements, with general design procedures presented. For more detailed design guidance, refer to FHWA's HEC-23 (FHWA 2009), HEC-14 (FHWA, P.L. Thompson, R.T. Kilgore (Authors) 2006), HEC-15 (FHWA, R.T. Kilgore, G.K. Cotton (Authors) 2005), Chapter 6 of the *AASHTO Highway Drainage Guidelines* (AASHTO 2007), and Chapter 10 of the *AASHTO Drainage Manual* (AASHTO 2014).

11.2 Roadside Ditches

11.2.1 Establishment of Ditch Plan

Establish a ditch plan to show the proposed ditch locations and flow patterns. This ditch plan is a part of the drainage plan (Chapter 5, Section 5.3.1 – Item 8).

11.2.2 Determination of Typical Ditch Cross Section

Determine the standard or typical ditch cross sections for the project, which are 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:

- Specify a standard berm ditch section at the top of a cut section where required, as depicted in Roadway Standard Drawing 240.01 (NCDOT 2018). If 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 (NCDOT 2018), 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 for the safety of small children.

- Form toe of fill ditches adjacent to shallow fills and flat slopes (4:1 or flatter) by continuing the fill slope to a desired ditch depth, providing a base width, if required, then a stable back slope (2:1 minimum).
- Construct toe of fill ditches adjacent to high steep slopes with at least a two-foot berm (five-foot preferred). 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 gradients to be used on all proposed ditches. Roadside ditches included in the typical roadway section will have a grade corresponding to the roadway profile. When the roadway profile grade is less than 0.3%, establish special roadway ditch grades and note them on the plans. Ditches along the toe of fill will generally parallel the grade of the natural ground at an established acceptable depth. Establish and plot ditch grades on the roadway plans in the profile view.

11.2.4 Investigation of Ditch Capacity

Design roadside ditches, including temporary detour ditches, to contain the Q_{10} discharge at a minimum. Establish the typical roadside ditch section 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. Evaluate actual capacity determination on a selective basis at sites on common project grades to verify adequacy and establish limitations on the length of ditch run. Account for any likelihood of future pavement widening toward the median in the median ditch drainage analysis and design. Size driveway pipes in ditches to convey the same design discharge as that for which the ditch is designed.

Establish the size requirements of the project special side ditches along the toes of fill based on an analysis of the design flood. Perform this ditch capacity 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. Consider the roadway section including shoulders and slopes to be an urban watershed. This capacity analysis is usually completed in conjunction with the next step of lining evaluation.

11.2.5 Evaluation of Ditch Lining for Stability

Analyze the stability of vegetative ditch linings by using FHWA HEC-15 (FHWA, R.T. Kilgore, G.K. Cotton (Authors) 2005) procedures, 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).
- γ 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)

Grass-lined ditches tend to become unstable when flow velocity approaches 4.5 ft/sec or greater, requiring a non-vegetative liner to maintain stability.

Table 1 lists permissible shear stress values for typical non-vegetative ditch liners used by NCDOT:

Table 1. Permissible Shear Stress

Liner	d50 (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

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 (NCDOT 2014). 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 riprap may not be acceptable, such as within the clear recovery zone or in a homeowner's front yard. Its use should be clearly detailed to show that the matting serves as a reinforcement for the root system, and not on the surface with the vegetation trying to grow up through it. PSRM has a permissible shear stress of 3 lb/ft^2.

Specify type and dimensions of ditch liner in the ditch details shown in the plans. Roadway Standard Drawings 876.01-04 (NCDOT 2018) depict standards for rip rap placement in channels, drainage ditches, and at pipe outlets. For concrete ditch behind a retaining wall, note that the 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. Check the transition of flow from a ditch to the receiving outlet.

Factors to be considered:

- Is there provision for a smooth transition of flow from the ditch to the outlet?
- Will the outlet adequately handle the quantity of flow? Is improvement required?
- Is the velocity of flow at the outlet too high for the condition of the receiving channel? Is rip rap or other means of energy dissipation justified? (Refer to Chapter 10, Section 10.5.3.)
- 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?
- 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, follow FHWA's Hydraulic Engineering Circular No. 15 (FHWA, R.T. Kilgore, G.K. Cotton (Authors) 2005) and Chapters 10 and 16 of the AASHTO *Drainage Manual* (AASHTO 2014), for further guidance for small ditch and channel analysis. For larger stream involvement, FHWA's *Highways in the River Environment* (FHWA, E.V. Richardson, D.B. Simons, P.F. Lagasse (Authors) 2001), *Applied River Morphology* (Rosgen 1996), NC Wildlife Resources Commission's *Guidelines for Mountain Stream Relocation in North Carolina* (NCWRC, P.J. Wingate, W.R. Bonner, R. J. Brown, B.M. Buff, J.H. Davies, J.H. Mickey, H.M. Ratledge (Authors) 1979), USACE's *Wilmington District Stream and Wetland Compensatory Mitigation Update* (USACE 2016), USACE's *Bank and ILF Establishment for All USACE Districts* (USACE n.d.), and USDA NRCS's *Stream Restoration Design (National Engineering Handbook*

654) (USDA NRCS 2007). Individual NCDOT Division offices may have established criteria for ditch and channel design which are applicable to construction practices within their own Divisions. 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 rip rap 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, using the design procedures in FHWA HEC-15 (FHWA, R.T. Kilgore, G.K. Cotton (Authors) 2005).

11.3.2 Realignment of Natural Channels

Design and configure the realignment of natural streams 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), follow guidance provided in "Stream Relocation Guidelines" developed jointly by representatives of the NCDOT and the NC Wildlife Resources Commission in 1993 (See Section 11.5.1).

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* (Rosgen 1996), 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 include:

- providing a methodology for predicting a stream's behavior from its appearance (classification)
- guiding development of specific hydraulic and sediment transport relationships for stream type and state
- comparing data for stream reaches having similar characteristics

- providing a consistent frame of reference for communicating stream conditions and morphology across disciplines

Follow the general guidance provided in the following sections when analyzing 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 refining the initial classification as well as the analysis and design process.

At minimum, collect 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, establish the stream type classification by following the procedure discussed in Chapter 3 of *Applied River Morphology* (Rosgen 1996).

11.3.2.4 Evaluation of Existing Conditions

Assess the existing stream condition 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. When this occurs, use a reference stream of similar classification and morphological characteristics as a guide to develop study proposals.

11.3.2.5 Developing and Documenting Proposed Channel Design

The above evaluation process should provide the Hydraulic 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. Consult a wildlife resource specialist for input during the design process. Document all information pertinent to the channel design in an appropriate design report format.

11.4 References

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11.5 Additional Documentation

11.5.1 Minor Stream Relocation Guidance

Stream Relocation Guidelines

NOTE: These guidelines are for the piedmont and coastal regions. While these guidelines are similar to the trout county requirements, they do not replace the existing process for trout counties. This guidance is to be followed prior to the permit process to facilitate that process and to minimize impacts

"Minor Relocations"

Applicable when:
- Less than 100 feet of total relocation is required at a given crossing (from the end of the structure, inluding headwalls), and no more than 50 feet is relocated on any one side (upstream or downstream)

Technical guidelines:
-Relocation should be similar to original channel in
    Width
    Depth
    Gradient
    Substrate
-Bank vegetation should be re-established, but no specific planting regime is required

Co-ordination with WRC field staff:
-No coordination is required unless in High Quality Waters(HQW), critical habitat(as mapped by WRC), or at locations involving Federal/State listed species. Treat these cases as "Standard Relocations".
Note: WRC coordination will be welcomed even on "Minor"projects.

"Standard Relocations"

Applicable when:
- Greater than 100 feet of total relocation is required at a given crossing (from the end of the structure inlcuding headwalls), Or more than 50 feet is relocated on any one side (upstream or downstream)

Technical guidelines:
-Relocation should be similar to original channel in
    Width
    Depth
    Gradient
    Substrate

For the following items, site specific requirements will be determined through coordination with the WRC field staff. These items will follow WRC's established guidelines and will incorporate any highway specific guidance jointly developed between WRC, Hydraulics, and Roadside Environmental:
- Re-etablishment of bank vegetation with planting regime required
- Meanders and habitat structures (root wads, wing deflectors, etc.) approximating the original stream

Co-ordination with WRC field staff:
-Coordinate the relocation with the appropriate WRC district fisheries biologist

General Guidance: Minimize instream activities during peak spawning periods (April-June)
- Schedule instream activities during periods of low flow as much as possible
- Use vegetation to stabilize streambank vs. riprap to the maximum extent practicable
- Minimize use of fertilizer adjacent to stream
- Use native woody/shrub like species with small basal width within 25-50 ft. of the structure to reducd clogging. Beyond that distance use native tree species.
- It is preferred that bank vegetation be re-established prior to introducing flow into the channel.
- For reference utilize NC Wildlife Res. Comm. document "NC Stream Protection and Improvement Guidelines"

NOTE: Coordination with WRC on projects covered by nationwide permits (outside the 25 trout counties) is voluntary. This is a proactive effort by NCDOT and WRC minimize habitat impacts from highway projects and to facilitate communication and understanding at the field level.

North Carolina
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Chapter 12
Erosion and Sediment Control

Hydraulics Unit
February 22, 2022

Revisions Sheet			
Page	**Old Section**	**New Section**	**Description**
-	-	-	• Entire Chapter revised to new format • All references and links have been updated throughout Chapter
2	12.1.3	12.1.3	2nd bullet, 5th sentence - removed "a specific" and replaced with "the Department's"
4	12.3	12.3	A sentence was added to the end of the 3rd paragraph
6		12.4	Added new section - References
7		12.5	Added new section – Additional Documentation
7	Appendix F	12.5	Added Stilling Basin Dimensions and Volume drawing and Culvert Construction Sequence drawing.

Table of Contents: Chapter 12 Erosion and Sediment Control

12.1 Introduction

The North Carolina Sedimentation Control Commission first delegated an erosion and sediment control program to NCDOT 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 many water quality related problems, including:

- elevated turbidity
- increased water temperature
- decreased dissolved oxygen
- increased algae growth
- loss of aquatic habitat
- reduced 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 Division of Energy, Minerals and Land Resources - Land Quality Section in the North Carolina Department of Environmental Quality (NCDEQ, formerly NCDENR) enforces the North Carolina Sedimentation Pollution Control Act of 1973 and Administrative Rules. This 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 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. NCDOT is responsible for complying 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. Each is 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 through delegation of authority from the USEPA. An NPDES permit is required to discharge stormwater. In North Carolina, NPDES General Permit – NCG 010000 covers construction activities. The permit complies with State erosion and sediment control requirements along with other stormwater pollution prevention requirements. NCDOT must comply with the Department's 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, and specifications; develops project special provisions; produces training materials for erosion and sediment control; and monitors active worksites 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 several factors, including construction sequencing, existing topography, proposed land grades, soil type, hydrology, design storm, required trapping efficiency for certain devices, classifying receiving waters, critical habitat areas, and other identified environmental concerns.

Refer to the website below for information regarding the NCDOT erosion and sediment control program including design requirements for devices used on highway construction projects.

https://connect.ncdot.gov/resources/roadside/Pages/Soil-Water.aspx

12.2.2 Riparian Buffer Rules

The North Carolina Environmental Management Commission (EMC) has presently adopted riparian buffer rules 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 and evaluate plan implementation as well as installation, maintenance, and effectiveness of devices. 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, with Inspectors recording their findings in a daily report. The Inspector gives a list of all needed corrections to the contractor, with a copy provided the Resident Engineer or the District Engineer for maintenance projects.

REU Field Operations staff perform inspections 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 all problems are resolved. Field Operations staff will revisit the site within five working days or seven calendar days, whichever is shorter. Serious violations can result in the issuance of a Notice of Violation (NOV) by the NCDEQ Land Quality Section and possible enforcement actions.

12.3. Culvert Construction Sequence

Provide a culvert construction sequence plan for each culvert that provides a total waterway opening of 30 square feet or greater, and deliver these plans to Structures Management, Roadside Environmental, and Traffic Management Units to assist with culvert construction. The construction sequence plan includes a construction sequence narrative and figure(s), which provide a description of the phases required to construct the culvert to manage water conveyance and erosion control. The construction sequence plan serves as a reasonable and acceptable method to accomplish construction; however, there may be other methods that are more appropriate and acceptable. Construction sequencing should be discussed and agreed upon during the field inspection. The REU will develop the final construction sequence plan and include it in the project's erosion control plans.

The Hydraulic 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.

Size temporary stream diversions and pipes for the mean daily flow, which should be computed based on the normal water surface elevation (vegetation line, also known as ordinary high water) in the channel as determined from field review. Using this flow depth, determine the mean daily flow by the Manning and Continuity equations.

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 foot 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 (NCDOT, 2018) necessary to provide the target volume can be calculated using the Temporary Stilling Basin Dimensions and Volume Calculator shown in Section 12.5, which can be downloaded from the Hydraulics Unit website.

Estimate the required excavation volumes for temporary diversion channels 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 Section 12.5.

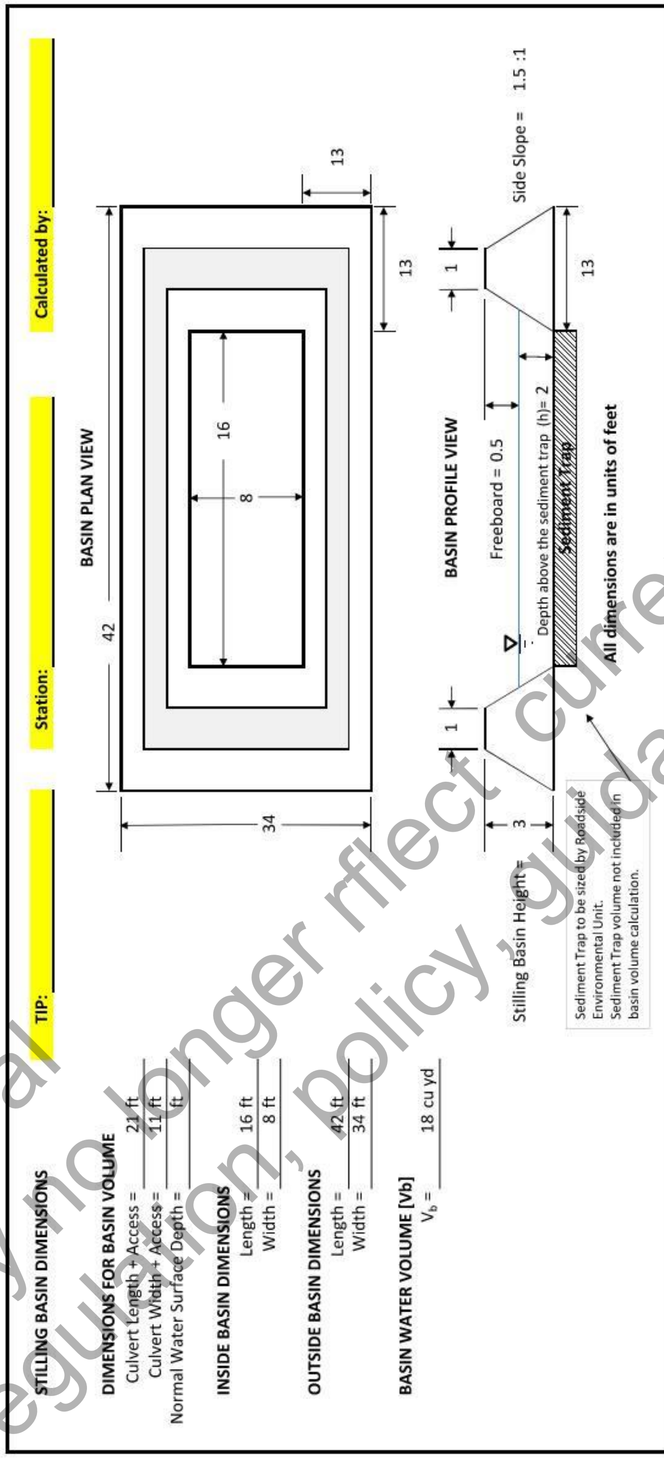
The culvert construction sequence plan should include:

1. Narrative describing culvert construction phasing and other noteworthy information
2. Figure(s) 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

12.4. References

NCDOT. (2018). *Roadway Standard Drawings*. Retrieved December 2021, from https://connect.ncdot.gov/resources/Specifications/Pages/2018-Roadway-Standard-Drawings.aspx

12.5. Additional Documents



STILLING BASIN DIMENSIONS AND VOLUME

TIP: Station: Calculated by:

STILLING BASIN DIMENSIONS

DIMENSIONS FOR BASIN VOLUME

Culvert Length + Access = 21 ft

Culvert Width + Access = 11 ft

Normal Water Surface Depth = ft

INSIDE BASIN DIMENSIONS

Length = 16 ft

Width = 8 ft

OUTSIDE BASIN DIMENSIONS

Length = 42 ft

Width = 34 ft

BASIN WATER VOLUME [Vb]

V_b = 18 cu yd

This form can be downloaded from the Hydraulics Unit website.

Figure 1. Temporary Stilling Basin Calculator

GAP CREEK
CULVERT CONSTRUCTION SEQUENCE
–RPC– STA. 9+99 –LPC– STA. 9+89

PROJECT REFERENCE NO.	SHEET NO.
R-2915A	
RW SHEET NO.	
ROADWAY DESIGN ENGINEER	HYDRAULICS ENGINEER

1. CONSTRUCT STILLING BASIN PER NCDOT STANDARD DRAWING 1630.04 TO SIZE SPECIFIED AND AT LOCATION SHOWN.
2. CONSTRUCT IMPERVIOUS DIKES AND TEMPORARY DIVERSION CHANNEL AS SHOWN.
3. DIVERT CHANNEL FLOW THROUGH TEMPORARY DIVERSION CHANNEL.
4. CONSTRUCT PROPOSED CULVERT AND CHANNEL IMPROVEMENTS.
5. REMOVE IMPERVIOUS DIKES AND ALLOW FLOW THROUGH RCBC.
6. REMOVE STILLING BASIN AND FILL TEMPORARY DIVERSION CHANNEL.
7. COMPLETE PROPOSED ROADWAY CONSTRUCTION.

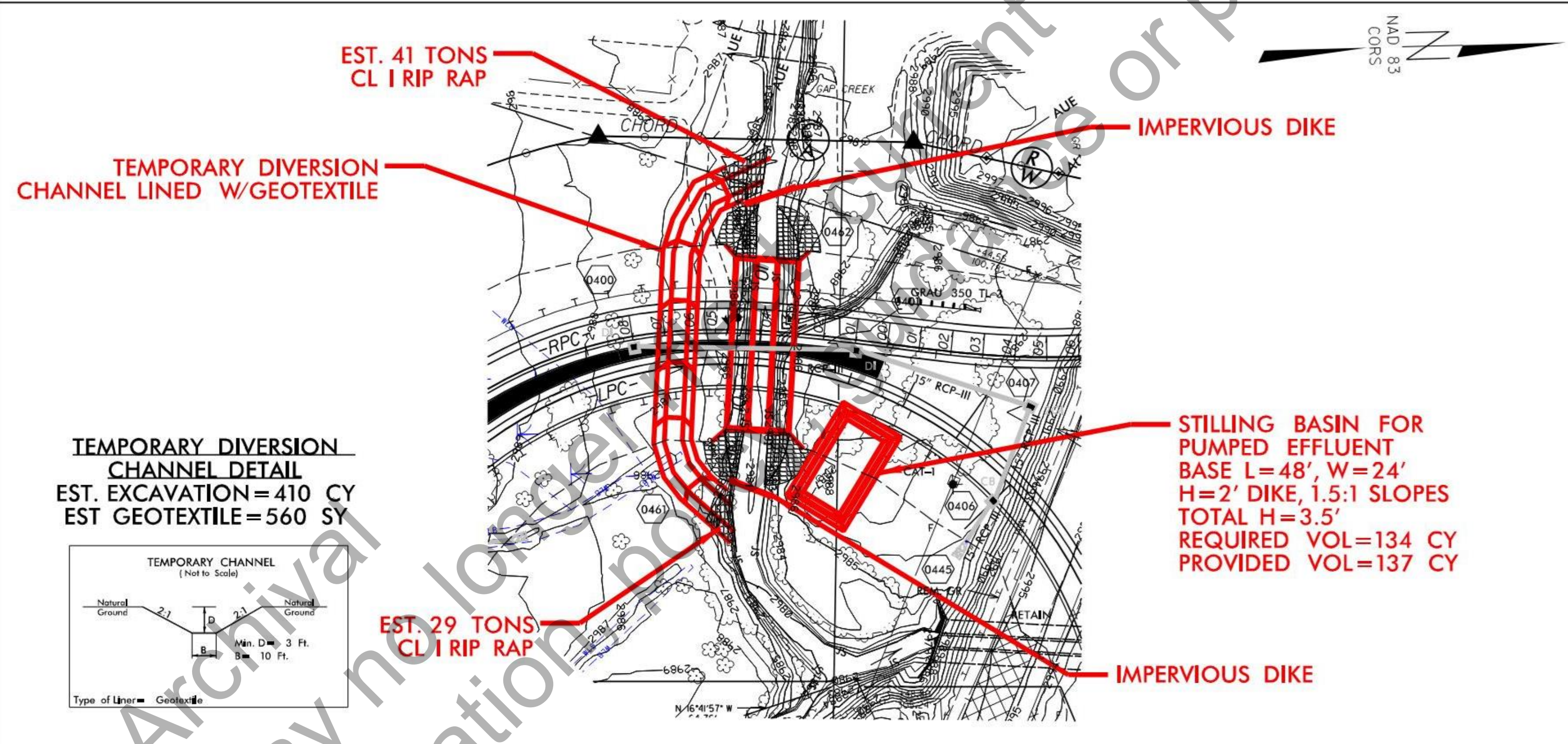


Figure 2. Culvert Construction Sequence Plan Example

North Carolina
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Chapter 13 Stormwater Management

Hydraulics Unit

February 22, 2022

Revisions Sheet			
Page	Old Section	New Section	Description
-	-	-	• Entire Chapter revised • All references and links have been updated throughout Chapter

Table of Contents: Chapter 13, Stormwater Management

Acronyms

BMP	Best Management Practices
BUA	Built Upon Area
EMC	Environmental Management Commission
GREEN	Guided Reduction of Excess Environmental Nutrients
HPR	Hydraulic Planning Report
HSP	NCDOT Highway Stormwater Program
MEP	Maximum Extent Practicable
NCDEQ	NC Department of Environmental Quality
NCDOT-JLSLAT	NCDOT Jordan / Falls Lake Stormwater Load Accounting Tool
NCDWR	NC Division of Water Resources
NC-SELDM	North Carolina SELDM Catalog
NPDES	National Pollutant Discharge Elimination System
OAH	Office of Administrative Hearings
PCSP	Post-Construction Stormwater Program
PDN	Project Delivery Network
ROW	Right-of-way
pSMP	Preliminary Stormwater Management Plan
SELDM	USGS' Stochastic Empirical Loading and Dilution Model
SMP	Stormwater Management Plan
TMDL	Total Maximum Daily Load
Toolbox	NCDOT BMP Toolbox
TS4	Transportation Separate Storm Sewer Systems

13.1 Introduction

Stormwater runoff may convey pollutant constituents to a receiving body of water, potentially causing water pollution. The Clean Water Act regulates stormwater runoff at the federal level, and various state and municipal governments regulate runoff at the local level. Stormwater regulations primarily relate to construction-related discharges and post-construction discharges.

This Chapter provides an overview of water quality regulations associated with post-construction stormwater discharges and the approaches to be considered during hydraulic design. The Hydraulic Design Engineer is responsible for following all state and federal stormwater regulations for post-construction stormwater discharges. The construction and maintenance activities that occur in later project stages to protect water quality should also be considered during all phases of the project's lifespan throughout the project, including planning and design.

The State Sedimentation Control Act regulates stormwater runoff and the National Pollutant Discharge Elimination System (NPDES) stormwater permit authorizes post-construction discharges. The Roadside Environmental Unit manages erosion and sedimentation control requirements on NCDOT projects during the construction phase. Refer to the Roadside Environmental Unit, Soil and Water Section website and Chapter 12 for more information about erosion and sedimentation control plans and requirements.

13.2 Highway Stormwater Program

NCDOT operates one of the nation's largest permitted transportation separate storm sewer systems (TS4), with a unique combination of statewide NPDES permit coverage and a large primary and secondary road system. State and federal stormwater management regulations also apply to discharges from NCDOT's industrial, operations, rail, and ferry transportation systems.

In 1998, NCDOT implemented its Highway Stormwater Program (HSP) as a department-wide initiative to protect and improve water quality while fulfilling NCDOT's mission to provide and support a safe and integrated transportation system.

The HSP has developed tools and guidance to implement the permit requirements. The Hydraulics and Roadside Environmental Units jointly manage the HSP and develop tools and resources while providing technical support to Hydraulic Design Engineers, business partners, and others. It also coordinates compliance with federal and state stormwater regulations, including federal NPDES, state nutrient management strategy rules and other water-related environmental programs. HSP maintains tools that are relevant to post-construction stormwater compliance, including the Post-Construction Stormwater Controls for Roadway and Non-Roadway Projects (PCSP manual) (NCDOT

2014), and the Stormwater Best Management Practices Toolbox (BMP Toolbox) (NCDOT 2014). Additional tools include the BMP Decision Support Matrix, preliminary Stormwater Management Plan (pSMP), Stormwater Management Plan (SMP), and the North Carolina Stochastic Empirical Loading and Dilution Model Catalog (NC-SELDM Catalog) (USGS. J.C. Weaver, C.c. Stillwell, et (authors) 2021). Each of these considered the linear environment and are discussed in more detail below.

13.3 Stormwater Regulations

There are several regulations to consider during the design process. Most stormwater requirements applicable to NCDOT projects have been integrated into the NPDES Post-Construction Stormwater Program (PCSP). The NPDES Post-Construction Stormwater Program focuses on the quality of stormwater runoff, but additional state regulations require evaluating runoff quantity to ensure non-erosive discharges to receiving channels (15A NCAC 04B .0109). Consult the PCSP manual for the workflows necessary to comply with stormwater regulations.

Several watersheds across the state have been designated as Nutrient Sensitive Waters and may have special stormwater requirements specifically intended to reduce nitrogen and/or phosphorus loads in runoff. Consult the PCSP manual for more information.

NCDOT is no longer required to apply for state stormwater permits. Some existing state stormwater permits have expired and their requirements have combined with the NPDES permit programs. Other existing state stormwater permits remain active and must be followed until the permit is rescinded.

Since most NCDOT projects receive automatic coverage under the statewide NPDES stormwater permit, North Carolina's general statutes exclude most projects from local government stormwater ordinances.

13.3.1 Overview of NCDOT's NPDES Permit

Federal and state regulations require managing stormwater discharges from NCDOT's roadway and non-roadway facilities to minimize the impacts on water quality, and the NPDES permit primarily implements these requirements. All NCDOT roadway and non-roadway projects which increase net built upon area must comply with the NPDES requirements outlined in the PCSP.

NCDOT received its first statewide NPDES stormwater permit on June 8, 1998. NCDEQ's Division of Energy, Mineral, and Land Resources (NCDEMLR) renews this permit approximately every five years, and NCDOT must apply for renewed permit coverage no later than 180 days prior to the current permit's expiration date. The renewed permit commonly retains most of the requirements but may have some modifications and/or contain new requirements. New NCDOT facilities, including roadways, railways, buildings, and industrial/operational facilities, automatically receive coverage under the permit.

The NPDES permit is very broad in both its scope and coverage. The permit authorizes NCDOT to discharge construction-related and post-construction stormwater from general roadway and railway drainage, non-roadway facility drainage, and industrial/operational facility drainage. The permit also allows borrowing pit wastewater in accordance with the limitations and conditions specified in the permit. The NPDES stormwater permit automatically covers locally administered NCDOT projects.

The permit is legally binding and NCDOT must comply with all conditions specified. Any permit noncompliance may constitute a violation of the Clean Water Act (CWA) and may be grounds for enforcement action. The Hydraulic Design Engineer must work with NCDOT to comply with all requirements associated with post-construction stormwater discharges.

NCDOT's NPDES permit mandates many programs and management actions that minimize NCDOT's discharge pollutants and protect water quality standards. Refer to the PCSP requirements (See Section 13.4 below) and the Erosion and Sediment Control Program, managed by the Hydraulics Unit and Roadside Environmental Unit.

13.3.2 Nutrient Sensitive Watersheds and Buffer Rules – GREEN Programs

The North Carolina Environmental Management Commission (EMC) adopts rules to protect the State's air and water resources or endangered species. Select estuaries and reservoirs have experienced excessive levels of algal growth, resulting in reduced dissolved oxygen levels and potential harm to fish and other aquatic life. This phenomenon, known as eutrophication, is typically caused by elevated loads of nitrogen and phosphorus from the watershed. In response, the EMC has adopted comprehensive sets of rules, collectively known as nutrient management strategies, which focus on reducing nutrient loading within these watersheds. Each set of rules is customized to a given watershed and the strategy's requirements vary somewhat as they relate to stormwater management, agricultural best management practices, wastewater treatment, and riparian buffer protection. Refer to 15A NCAC 02B rules for a description of the EMC's nutrient management strategies. The table below summarizes the components of nutrient management strategies currently in place or under development. Watershed classifications, including nutrient sensitive waters, can be identified using NCDEQ's Surface Water Classification interactive map.

Table 1. Watersheds with Nutrient Management Strategies

Watershed	Riparian Buffer Rules	Other Water Quality Regulations
Neuse River Basin	X	Nutrient Management Strategy
Tar-Pamlico River Basin	X	Nutrient Management Strategy
Jordan Lake Water Supply Watershed	X	Nutrient Management Strategy
Falls Lake Watershed	X (as part of Neuse River Basin Rules)	Nutrient Management Strategy
Catawba River Basin	X	
Randleman Lake Water Supply Watershed	X	
Goose Creek Watershed	X	Site Specific Water Quality Management Plan
High Rock Lake Watershed	Under development	Under development

Jordan Lake and Falls Lake rules were the first nutrient management strategies that required NCDOT to prepare a stormwater management program specific to those watersheds. The EMC approved NCDOT's programs for the Jordan Lake and Falls Lake watersheds on November 8, 2012 and January 9, 2014, respectively, representing the effective start dates of those programs within the two watersheds. The NCDOT Jordan/Falls Lake Stormwater Accounting Load tool (NCDOT-JLSLAT) assesses the effectiveness of BMPs added under the Jordan Lake and Falls Lake programs, known as Guided Reduction of Excess Environmental Nutrients (GREEN), which is discussed in greater detail in the GREEN program documents for each watershed. The HSP coordinates annual compliance reporting and provides technical assistance to the various NCDOT business units implementing these programs.

13.3.3 State Stormwater Regulations

On August 1, 2013, NCDEQ streamlined stormwater permitting policy for projects. It no longer requires NCDOT to submit applications for state stormwater permits in High Quality Waters (HQW) watersheds, Outstanding Resource Waters (ORW) watersheds, and the 20 Coastal Area Management Act (CAMA) Counties promulgated in 15A NCAC

02H .1001. Instead, any NCDOT roadway and non-roadway projects proposing a new built upon area must follow the requirements outlined in the PCSP manual. Additionally, all previously issued High Density state stormwater permits can expire as scheduled, and the NPDES BMP Inspection and Maintenance Program will cover the BMP operation and maintenance requirements. Projects permitted under a Linear Roadway Project state stormwater permit without an expiration date remain subject to the permit until such time as the permit is rescinded. All project issues remain subject to state stormwater permit conditions and should be handled individually.

13.3.4 Local Government Stormwater Regulations

Per North Carolina general statues § 160D-925 and § 153A-454, state government projects are exempt from complying with local government stormwater control ordinances if the project is covered by an NPDES permit. Since NCDOT's NPDES permit is statewide and covers a wide range of transportation related activities, nearly all of NCDOT's projects are exempt from local government stormwater ordinances. NCDOT's NPDES permit also covers locally administered NCDOT projects and are also exempt from the local government's ordinances.

13.3.5 Outlet Protection Regulations

The velocity and/or quantity of stormwater discharges from the right-of-way can impact the water quality of a receiving channel. **Stormwater discharges from outlets must be designed to minimize impacts to the downstream channel and adjacent downstream properties and be in compliance with rule 15A NCAC 04B .0109 regarding stormwater outlet protection.** Minimizing such impacts should be a component of drainage design and documented within the SMP. See Chapters 9 and 10 of these Guidelines for more information.

13.4 NPDES Post-Construction Stormwater Program

13.4.1 Introduction to the Post-Construction Stormwater Program and Stormwater Management Plan

NCDOT's NPDES permit requires implementing a Post-Construction Stormwater Program (PCSP) to manage runoff from new built upon area (BUA) on roadway and non-roadway projects. Post-construction stormwater controls refer to long-term best management practices that treat stormwater runoff after project construction. Post-construction BMPs should be evaluated and selected during the planning and design phases, as these controls remain effective throughout the life of the project. Two examples of a post-construction BMP are grass swales and dry detention ponds.

The primary goal of construction stormwater management is to minimize erosion and sediment loss with temporary BMPs which are often removed once the project site is stabilized. An example of a temporary BMP used during construction is silt fence.

The NPDES permit implements the Clean Water Act, which requires that stormwater to be managed to the "maximum extent practicable" (MEP)[1]. The approach to establishing the MEP for NCDOT projects is in the Post-Construction Stormwater Controls for Roadway and Non- Roadway Projects (PCSP manual) (NCDOT 2014) and is summarized with the following:

1. Establish project-specific stormwater treatment goals and document these objectives in the preliminary Stormwater Management Plan (pSMP). The Hydraulics Unit, in partnership with USGS, developed the NC-SELDM Catalog tool to help identify stormwater treatment goals at crossings.
2. Design the project to achieve the stormwater treatment goals.
3. Identify and document site constraints that could impact achievement of the stormwater treatment goals.
4. Design the feasible best management practices, given any site constraints.
5. Document the feasible best management practices in the final stormwater management plan.

NCDEQ has approved the PCSP manual for NCDOT projects. It defines how the BMP Toolbox is implemented on each project, and when BMPs are required. This manual explains the compliance requirements and contains clearly defined processes and treatment objectives for roadway and non-roadway projects. The Hydraulic Design Engineer should make every effort to follow the processes outlined in the PCSP when designing the drainage system for the project. The NCDOT Stormwater Best Management Practices Toolbox (BMP Toolbox) (NCDOT 2014) are used with the PCSP to provide guidance on stormwater control design requirements.

BMPs that constitute the MEP outcome must be determined on a site-by-site basis to address water quality concerns and can include non-structural controls and structural controls. Structural controls may include BMPs from the BMP Toolbox or standard design practices known to minimize impacts to water quality and are defined as

[1] 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).

minimum measures in the PCSP manual. Stormwater management requirements and the MEP standard may differ depending on the project type and location. Bridge, safety, widening, or new location projects may have different requirements with respect to the stormwater controls.

Stormwater management decisions made during the planning and design phases of a project are documented in three deliverables prepared by the Hydraulic Design Engineer:

- Hydraulic Planning Report (HPR)
  - identifies design parameters, risks, assumptions, avoidance and minimization measures, and existing stormwater treatment devices; and provides preliminary hydraulic recommendations for major crossings, including size and type (such as bridge or culvert) on a project.
- Preliminary Stormwater Management Plan (pSMP)
  - documents impacted waterbody characteristics
  - establishes project stormwater treatment goals to help inform subsequent drainage design decisions
  - establishes reasonable expectations for Hydraulic Design Engineers and regulatory approvers
- Final Stormwater Management Plan (SMP)
  - documents project stormwater management decisions to comply with the NPDES permit and other stormwater regulations.
  - is necessary to document compliance with the PCSP.
  - establishes the MEP outcome for the project.
  - helps to communicate with engineers and scientists preparing any applicable permits.
  -

- See Chapter 3 for more information on the HPR.

13.4.2 Applying the Post-Construction Stormwater Program

- Post-Construction Stormwater Program requirements apply to all NCDOT development and re-development projects that add new built upon area (BUA). The PCSP manual has separate compliance workflows for roadway and non-roadway projects.
-
- Stormwater treatment goals for each receiving water, including appropriate minimum measures, are established early in the hydraulic design process and are documented in the preliminary Stormwater Management Plan (pSMP). Use the NC-SELDM Catalog tool to assist in identifying stormwater treatment goals. Consult the

BMP Decision Support Matrix to assist in the selection of the appropriate stormwater control measures for the project.

- The final Stormwater Management Plan should document the stormwater best management practices selected for the project to comply with the PCSP as well as outlet protection rule 15A NCAC 04B .0109. Use the final SMP to document stormwater treatment goals in the pSMP that were not attained due to site constraints.
- The maximum extent practicable compliance standard can be achieved by:
- establishing stormwater treatment goals
- designing to achieve treatment goals
- identifying site constraints
- designing feasible BMPs

The PCSP defines how to implement the BMP Toolbox for each project. PCSP compliance is required for all NCDOT development and re-development projects that add new built upon area (BUA), which is defined as an impervious surface or partially impervious surface that does not allow water to infiltrate through the surface into the subsoil. The PCSP manual identifies the workflows to select the applicable stormwater management approach, and directs the Hydraulic Design Engineer through stormwater management compliance, implementation of the BMP Toolbox for each project and selection of structural and non-structural best management practices. Compliance with NCDOT's NPDES permit compliance results when location-specific water quality needs are identified and applied to the project design to the maximum extent practicable (MEP) by using the PCSP manual, the BMP Toolbox, and other tools.

Follow the guidance in the PCSP manual and related tools to identify applicable BMPs, including:

- Using the NC-SELDM Catalog to establish stormwater treatment goals for each surface water impacted by the project.
- Documenting the classification(s) of surface water bodies that will be impacted by a project's footprint and the stormwater treatment goals for each surface water in the preliminary Stormwater Management Plan (pSMP).
- Referring to the BMP Toolbox manual for detailed guidance on design requirements for BMPs.
- Review the BMP Decision Support Matrix to determine which device from the BMP Toolbox may address site-specific conditions
- Document the stormwater control measures in the SMP which, when finalized, establishes the project's compliance with the MEP standard.

13.4.2.1 Central Guidance for Compliance with Post-Construction Stormwater Regulations

The PCSP manual is a key reference for post-construction stormwater regulation compliance. It integrates stormwater management requirement workflows from across the State applicable to NCDOT projects, including:

- 404/401 water quality certifications
- State stormwater permitting
- local government ordinances and permitting
- various nutrient management strategy requirements, enabling the PCSP to avoid overlapping or conflicting with other stormwater regulations.

13.4.2.2 Roadway and Non-Roadway Workflows

The PCSP manual specifies different stormwater management requirement workflows for roadway versus non-roadway NCDOT projects due to the different pollutant-loading characteristics between linear transportation projects (e.g., roads) and parcel-based development. The PCSP defines a new roadway project as any new roadway construction or other roadway-related activity occurring within the NCDOT right-of-way (ROW) or easement.

Non-roadway projects are defined as any new NCDOT facility or any modification to an existing facility that does not otherwise qualify as new road development. New non-roadway projects are generally not located within the linear ROW.

Refer to the PCSP manual for more discussion on roadway and non-roadway projects.

13.4.2.3 Planning and Design Minimum Measures

Minimum measures are non-structural best management practices applicable to the planning and design phases of a project which help to minimize impact to instream water quality post-construction. The PCSP manual describes a variety of minimum measures for project team consideration. As noted in the PCSP workflows for both roadway and non-roadway projects, minimum measures should be evaluated for their applicability on all projects, and their implementation documented in the SMP.

13.4.2.4 BMP Toolbox and BMP Decision Support Matrix

Stormwater control measures are sometimes needed to provide additional treatment in addition to the minimum measures described in the previous section. The NC-SELDM Catalog may recommend that stormwater control measures from the BMP Toolbox be included for specific roadway/stream crossings. In this case, refer to the BMP Decision Support Matrix, a table-style reference that provides guidance to select structural BMPs for targeted parameters of concern while addressing various site constraints.

After identifying potential BMP types, consult the BMP Toolbox for additional design guidance, including:

- General information on pollutant removal mechanisms
  - useful when targeting treatment of a particular pollutant of concern (e.g., projects near impaired waters).
- BMP feasibility and selection guidance
  - the BMP Toolbox helps determine which stormwater control measures are most suitable for the project.
  - intended to supplement the engineer's sound judgment, which always takes precedence in BMP selection decisions.
- Technical design guidance
  - the BMP Toolbox provides design criteria guidance to be used in conjunction with the policy and requirements outlined in the PCSP.
- Safety considerations
  - evaluate safety to ensure the best choice of BMP within the context of the project.
  - evaluate the human environment in the vicinity of the proposed BMP to ensure the device will not pose any safety hazards, especially when selecting BMPs which temporarily or permanently pond water.
- Maintenance considerations
  - all structural BMPs require ongoing inspection and maintenance as required by the NPDES permit.
  - refer to the BMP Toolbox for information to consider to facilitate future maintenance operations.
  - NCDOT's Stormwater Control Inspection & Maintenance Manual (NCDOT 2010) provides additional details on inspection and maintenance requirements for each BMP type.

13.4.2.5 Preliminary Stormwater Management Plan (pSMP)

The preliminary Stormwater Management Plan (pSMP) should be developed concurrently with the Hydraulic Planning Report (HPR). The Post-Construction Stormwater Program (PCSP) workflows and the NC-SELDM Catalog are used to establish stormwater treatment goals for the project at each receiving water. These preliminary stormwater treatment goals are documented in the pSMP as part of an activity in NCDOT's Project Delivery Network (PDN). Document the final determination of the need and feasibility of BMPs as the project design process proceeds in the SMP.

The PCSP, BMP Toolbox, pSMP and SMP work together to ensure the protection of water quality standards for surface waters receiving runoff from new built upon area.

The pSMP establishes stormwater treatment goals early in the hydraulic design process to help subsequent drainage design decisions, as well as decisions by other disciplines such as Right-of-Way, Utility Coordination and Design, Geotechnical, etc. Per the PCSP guidance, complete a pSMP every time a SMP is needed. Refer to the “Overview” and “Guidance” tabs of the SMP for instructions to prepare the pSMP. The pSMP consists of the tabs “General Project Information” and “Waterbody Information” of the SMP form.

The pSMP is used to document characteristics of waterbodies in the project area, and record the determination of need for stormwater BMPs as established by the PCSP workflows and the NC-SELDM Catalog. Once the “General Project Information” and “Waterbody Information” tabs are complete, the pSMP establishes the stormwater treatment goals for the project, which helps inform subsequent drainage design decisions and establish reasonable expectations for Hydraulic Design Engineers and regulatory approvers.

13.4.2.6 NC-SELDM Catalog

Completing the pSMP includes a preliminary determination if structural stormwater controls are needed for each of the receiving waters, based on guidance from the PCSP manual. The Hydraulic Design Engineer must evaluate each jurisdictional stream crossing shown on the StreamStats application, which may differ from the major stream crossings reported in the HPR.

NCDOT collaborated with the US Geological Survey (USGS) to develop a North Carolina version of USGS’ Stochastic Empirical Loading and Dilution Model (SELDM) using stream data from NC waterbodies to help with preliminary BMP selection. This model evaluated the potential risk to water quality from post-construction roadway runoff by modeling over 70,000 roadway projects and receiving stream characteristics to develop a streamlined NC-SELDM Catalog. Using data from StreamStats and preliminary design plans, the NC-SELDM Catalog determines which one of the following applies:

- A direct discharge may be acceptable
- Minimum measures are sufficient, or
- A BMP Toolbox control measure may be necessary

Document the NC-SELDM determination for each crossing under the “General Project Narrative” section of the “General Project Information” tab in the pSMP. The NC-SEDLM Catalog includes a “Detailed Instructions” tab for guidance on its use.

The NC-SELDM Catalog assessment at each project stream crossing results in one of three output responses:

1. The NC-SELDM Catalog output of **DirectDischarge** indicates a low likelihood that runoff from the transportation facility will degrade water quality in the receiving stream.
   - Useful when evaluating the suitability for a distributed direct discharge from a

long bridge. Even if stormwater discharges are not predicted to impact water quality, the Hydraulic Design Engineer is expected to implement minimum measures where feasible. Select a Toolbox BMP if site specific considerations not factored into the NC-SELDM Catalog analysis, (e.g. channel instability) warrant such an approach.

2. The NC-SELDM Catalog output of **MinimumMeasures** indicates a possibility that runoff from the transportation facility could degrade water quality but minimum measures as described in the PCSP manual are expected to be sufficient to mitigate the risk.
   - Useful when the Hydraulic Design Engineer is uncertain as to the level of treatment needed at the crossing. An output of MinimumMeasures does not prevent the Hydraulic Design Engineer from selecting a practice from the BMP Toolbox manual if site specific conditions warrant such an approach.
3. The NC-SELDM Catalog output of **BMPtoolbox** indicates a possibility that runoff from the transportation facility could degrade water quality and one or more practices from the BMP Toolbox manual should be considered for the crossing.
   - Useful in the early stages of hydraulic design for planning right-of-way or permanent drainage easement needs to facilitate long term maintenance. This information helps in additional field data collection, such as seasonal high-water table, infiltration rates, or other design parameters. Consult the BMP Decision Support Matrix to identify potential BMP types to address parameter(s) of concern that are identified from the waterbody's classification or its impairment. This information is also documented in the pSMP's "Waterbody Information" tab. Consult the BMP Decision Support Matrix for preliminary guidance on BMP suitability to siting constraints and other implementation considerations.

Through the use of the NC-SELDM Catalog, the pSMP establishes the stormwater quality treatment goals for the project at each crossing to assist in planning for the hydraulic design. However, the NC-SELDM catalog output does not factor in certain site-specific parameters, such as the susceptibility of the receiving channel to erosive flows, which may significantly affect stormwater management decisions. As such, consider the pSMP as a planning tool and not the final determination for compliance with the NPDES permit, 401 certification, or rule 15A NCAC 04B .0109.

13.4.2.7 Stormwater Management Plan

Use the pSMP as a resource when progressing to the final drainage design. As part of completing final drainage design, a final SMP should be prepared for NCDOT projects across the State that add built upon area or involve the replacement of an existing bridge with a culvert. The SMP includes a "Bridge to Culvert" worksheet (tab) to document information typically important for project permitting such as avoidance and minimization efforts, aquatic life passage, culvert alignment, and outlet velocities. For projects including one or more structural stormwater BMPs, the SMP provides worksheets (tabs) that allow Hydraulic Design Engineer to enter the pertinent design information specific to each BMP.

When the results of the NC-SELDM Catalog indicate minimum measures or practices from the BMP Toolbox are recommended for any specific highway-stream crossing, the Hydraulic Design Engineer must evaluate the application of these controls while developing the preliminary drainage design.

The SMP is the NPDES permit compliance document of record for the MEP standard. Implementing project commitments and the PCSP constitutes achieving the MEP standard for reducing the discharge of pollutants from NCDOT projects.

- Any deviation from the results of the pSMP or design guidelines in the PCSP manual or BMP Toolbox must be documented in the final SMP form upon completion of design.
- Document the reasons for not following the pSMP recommendations, in detail in the SMP.
- If a BMP design deviates from the criteria in the BMP Toolbox, justify the design deviation, including any project constraints or other considerations, in the SMP.
- Record any determinations made with the resource agencies in the SMP.

In addition to the stormwater controls recommended through the pSMP, consider additional controls 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 Roadway Design, Geotechnical, Right-of-Way, Utility Coordination and Design and other disciplines may be needed to complete stormwater control designs without delaying project delivery. These controls should also be documented in the SMP.

See the “Overview” tab of the SMP form for instructions on submitting the SMP. Maintain the pSMP and the final SMP as two separate documents in the project files.

13.5 Construction Considerations for Post-Construction Stormwater Discharges

After the project contract let date, the construction of stormwater BMP devices may require the Hydraulic Design Engineer’s oversight to ensure that the BMP device is constructed to meet the pollution controls intended in the design, and continue to meet the maximum extent practicable concept discussed in Section 13.4. Coordinate with the Division Construction Engineer and Resident Engineer 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, and discuss coordination during the field inspection regarding constructability. The Hydraulic Design

Engineer should participate in the pre-construction meeting and be available to offer guidance during construction.

13.6 Maintenance Considerations for Post-Construction Stormwater Discharges

Upon completion of the drainage design, the summary sheet of stormwater control measures from the SMP is included in the construction plan set. The Roadside Environmental Field Operations Engineer uses this summary to verify that the BMP was constructed at the end of the construction period. The Field Operations Engineer enters the BMP into NCDOT's Stormwater Control Management System (SCMS) for subsequent inspection and maintenance as required in the Department's NPDES permit and the Stormwater Control Inspection and Maintenance Manual (NCDOT 2010).

13.7 Water Quality Standards Regulations and Additional Water Quality Considerations

13.7.1 Water Quality Standards

Surface water quality standards are state regulations that protect surface waterbodies, (e.g. streams, rivers, lakes, and estuaries) from pollution, including pollutants conveyed by stormwater runoff. Water Quality Standards (WQS) are the foundation of all water quality protection programs and play an important role in drainage studies and hydraulic design. The Engineer is responsible for protecting the environment by adequately managing stormwater runoff as well as protecting public safety and welfare by providing adequate drainage on projects. WQS are published in the North Carolina administrative code under Title 15A Chapter 02 Subchapter B (abbreviated NCAC 15A 02B). The North Carolina Office of Administrative Hearings (OAH) functions as the State's codifier and publisher of all administrative rules and are available online on OAH's website. Under the federal Clean Water Act, each state must complete a Triennial Review, where they review their WQS every three years and make any modifications necessary to ensure the protection of the State's waters. Since WQS change periodically, consult the most up to date environmental reference materials for their project area.

Regulations governing Water Quality Standards include three main parts:

1. Beneficial use designations (classifications) apply to a waterbody and define the best uses to be protected.
   - Examples of best uses include aquatic life protection, body contact recreation such as swimming, fishing intended for human consumption, and drinking water supply.
   - There are two types of classifications
     - Primary classifications which define the overall best use of the waterbody

- Supplemental classifications, which are sometimes added to the primary classification to define special uses. For example, Class C waterbodies are fresh surface waters whose best use designation is aquatic life support. A Class C waterbody with the supplemental Tr classification indicates that the waterbody has characteristics which support the survival and propagation of trout on a year round basis. An interactive map to find stream classifications is hosted by NCDEQ.

The NC Division of Water Resources (DWR) maintains the State's Schedule of Classifications which includes

- entries identifying the surface waterbody or a segment of the waterbody by name (typically adopted from the USGS 7.5 minute topographic maps), the river basin containing the waterbody, and the waterbody's classification.
- a brief description locating the portion of the waterbody to which the classification applies.
- the effective date of the classification and the waterbody's index number. The index number is DWR's assignment of a unique hyphenated identification number for the waterbody's entry in the Schedule of Classifications. The index number is important for identifying waterbodies because streams sometimes share names, such as the New River located in the northwest portion of the state and the New River located along NC's southeastern coast.

All waterbodies are not listed in the Schedule of Classifications. However, with few exceptions all surface waters of the state do carry a classification by rule. If the Schedule of Classifications does not list a waterbody, as is often the case with unnamed tributaries, the waterbody is assigned the same classification as the nearest receiving waterbody listed in the Schedule of Classifications. (The Hydraulic Design Engineer should note that waters of the State, defined in § 143-212(6), differ from waters of the United States, defined in 40 CFR 120.2.)

Below is an example entry in the NC Schedule of Classifications which is available online at DWR's website. The Schedule of Classifications will list the name of the waterbody, a description, the classification, the classification date, and the index number.

Norris Branch	From the Appalachian State University Raw Water Holding Reservoir Dam to Howard Creek	C;Tr:+	02/01/93	10-1-9-7-(2)

For a given waterbody, the Schedule of Classifications may also include a special designation (+, @, #, *). These special designations typically indicate that additional rules or a special management strategy applies to the waterbody. The additional requirements can vary depending on the river basin where the waterbody is located. When a waterbody of interest is marked with a special designation character, the

Hydraulic Design Engineer should identify any additional requirements which may affect the project. Typically, any additional requirements are specified in a rule which will be cited in the Schedule of Classifications.

It is important to recognize that various state agencies, other than the NC Division of Water Resources (NCDWR), may assign surface water designations to waterbodies. For example, the NC Wildlife Resources Commission has a designation system for trout waters which serves a different purpose than the Tr supplemental classification. While these surface water designations are not the same as a WQS classification, some designations are associated with regulations that can affect NCDOT projects. Information about additional surface water designations from other agencies can be found on NCDEQ's website and includes:

Table 2. Additional Surface Water Designations Determined by Agencies Other Than NCDWR

Regulation	Governing Agency
State Natural and Scenic Rivers General Statute (GS) 143B-135.140 through §§ 135.172	NC Division of Parks and Recreation
Wild and Scenic Rivers Act of 1968 (map) 16 U.S.C. §§1271	Managed by a consortium of federal agencies.
Designated Public Mountain Trout Waters (list) 15A NCAC 10C .0205	NC Wildlife Resources Commission
Areas of Environmental Concern 15A NCAC Chapter 7	NC Division of Coastal Management
Designated Shellfish Harvesting Areas (map) 15A NCAC 03K .0100	NC Division of Marine Fisheries
Primary Nursery Areas (map) 15A NCAC 03N .0104	NC Marine Fisheries Commission

2. Numeric and narrative criteria are intended to be protective of the use designation. These criteria can differ based on the waterbody classification. For example, the

numeric criterion for dissolved oxygen is ‘not less than 5 mg/L’ for Class C waters and ‘not less than 6 mg/L’ for Class C Tr (trout) waters. When reviewing water quality criteria, review the narrative criteria since these statements include legally enforceable components of the water quality standard.

3. Procedures for applying numeric and narrative criteria may be included in certain WQS regulations. These procedures may apply to a variety of regulated entities, including NCDOT, such as NCDOT projects that are site-specific management strategies for the protection of threatened or endangered species found in NCAC 15A 02B. The Goose Creek Watershed Site Specific Water Quality Management Plan is an example of such a strategy which includes riparian buffer protection requirements unique to the watershed, as well as special wastewater and stormwater treatment requirements.

13.7.2 Integrated Report and 303(d) List of Impaired Waters

All surface waterbodies have been assigned classification(s), which defines its best intended use as well as numeric and narrative criteria designed to protect those uses. Section 305(b) of the federal Clean Water Act (CWA) requires that states periodically report to EPA and the public on whether waterbodies are supporting their specific designated uses. EPA summarizes these reports and provides Congress with an assessment of the health of the nation’s waters.

Section 303(d) of the CWA requires states to provide the EPA on even numbered years a list of waters not attaining WQS. These waters are labeled as impaired, indicating that one or more intended uses are not being supported. The impairment implies that the existing pollution controls applicable to the waterbody have not been adequate to attain or maintain the WQS. As a result, additional management action is needed, and the CWA requires states to develop a Total Maximum Daily Load (TMDL) for the impaired waterbody. A TMDL is a calculation of the maximum amount of a pollutant that a waterbody can receive and still safely meet WQS, and an allocation of that load among the various sources of the pollutant (see Section 13.7.5 for more discussion of TMDLs).

In 2006, EPA updated its reporting guidance and encouraged states to combine its section 305(b) and 303(d) reporting requirements into a single document commonly known as the Integrated Report. On even numbered years, the Division of Water Resources publishes North Carolina’s Integrated Report which includes all waterbodies listed in the Schedule of Classifications, which determines whether the waterbodies in the project vicinity are supporting their intended uses, or what pollutant is causing the impairment. If a pollutant of concern is identified in the Integrated Report, refer to the BMP Decision Support Matrix to select a BMP which provides treatment for the specific pollutant of concern.

NC's Integrated Report is separated into five categories. Categories 1, 2, and 3 include waters which are supporting at least one intended use or are not otherwise known to be impaired. Waters listed in Category 4 are all considered impaired but either already have a TMDL calculation approved by EPA or have some other pollution control strategy which is believed adequate to restore the intended uses once fully implemented. Category 5 includes waters which are impaired and slated to have a TMDL calculation developed sometime in the future. The list of waters in Category 5 is the 303(d) List. Recognize that the 303(d) List is not a complete accounting of all impaired waters in North Carolina, but rather an accounting of impaired waters awaiting a TMDL calculation. To determine if a waterbody of interest is impaired, the Hydraulic Design Engineer must reference both the list of waters in Category 4 and the list of waters in Category 5.

13.7.3 Pollutants of Concern

The Clean Water Act has a specific definition of the term pollutant, but there are many others. A pollutant is any constituent (substance) discharged into waters of the state that adversely affects water quality and the designated uses of the waterbody. Stormwater (rainwater) runoff in and of itself is not a pollutant, but any biological or chemical constituent dissolved or otherwise entrained within the runoff may be considered the pollutant upon its discharge into a waterbody. Typically, these biological or chemical constituents become dissolved or entrained within stormwater as the runoff flows over land, especially land covered by impervious surfaces. Since the engineer generally has little control over the "source" or deposition of constituents onto land surfaces, the engineer's design objective is to manage the conveyance and maximize the capture of these constituents.

13.7.4 Point Sources of Pollutants and Outfalls

CWA categorizes sources of stormwater pollutants as either Point Sources (PS) or Nonpoint Sources (NPS).

13.7.4.1 Point Sources vs. Nonpoint Source

Point source is any discernible, confined, and discrete conveyance such as a pipe, ditch, or channel. Point sources of pollutants are transported to a waterbody via a confined and discrete conveyance.

Nonpoint source refers to the absence of a discernible, confined, and discrete stormwater conveyance. A nonpoint source of pollution is any source of pollution that enters a waterbody through some means other than a discrete conveyance. For example, diffuse overland flow, such as the discharge from a properly functioning level spreader or preformed scour hole. There is no outfall associated with a nonpoint source.

13.7.4.2 Outfall vs. Outlet

Outfall Versus Outlet

Outfall refers to the point where stormwater from a conveyance system discharges into waters of the United States, such as a jurisdictional stream. Outfall is defined in the CWA and has specific regulatory meaning in the context of NPDES permits.

Outlet is a more flexible user defined term. In the context of NCDOT projects, it typically refers to the point where stormwater discharges from a drainage structure into another conveyance or onto the landscape without a continuing conveyance. It can also be used to refer to the downstream end of a pipe or culvert.

Examples of outlets can include but are not limited to:

- The point where a pipe discharges into an engineered or natural ephemeral open channel.
- The point where a conveyance system exists the right-of-way boundary and continues to be conveyed across third party property.
- The downstream end of a culvert which conveys waters of the United States underneath a roadway.

The point at which the point source discharges into waters of the United States is called an **outfall**. Since the term outfall has specific regulatory meaning under the CWA and NPDES, be sure to accurately use the term in Stormwater Management Plans. An example of a NCDOT outfall would be the point at which a roadside ditch, located within the ROW, discharges into a perennial stream. The term **outfall** should be exclusively used to describe the point at which the stormwater conveyance terminates at waters of the United States and should not be used in Stormwater Management Plans to describe the point where a roadside ditch is "turned out" into adjacent property where an overland stormwater conveyance continues outside the ROW.

The term **outlet** should be used to describe the point where stormwater discharges exit a drainage structure (e.g., a pipe, culvert, or open channel) but are not discharging to waters of the United States. Use **outlet** (rather than outfall) to describe the downstream opening of a culvert or pipe which conveys waters of the United States from one side of the road crossing to another. If a Grated Inlet (GI) is positioned over and directing stormwater runoff into a culvert, the GI would be considered an outfall. Bridge deck drains which directly discharge stormwater into the waterbody below are also considered outfalls.

13.7.5 Consideration of TMDLs and Impaired Waterbodies

Prior to design, identify any known pollutants of concern and whether the project is in the vicinity of and drains to an impaired waterbody or a waterbody subject to an EPA approved Total Maximum Daily Load (TMDL). If the project is near and drains to an impaired waterbody, including waterbodies subject to an approved TMDL, the minimum design goal is to avoid any further deterioration in water quality. The Highway

Stormwater Program (HSP) coordinates NCDOT's compliance with TMDLs through various NPDES and state rule compliance programs, as well as other watershed-based initiatives. The HSP uses project SMP data to calculate the Department's progress towards compliance with the TMDL wasteload allocation if required by the NPDES permit. Additional information can be found on NCDOT's TMDL website.

13.8 References

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13.9 Additional Documentation

BMP Decision Support Matrix

BMP Toolbox

Guided Reduction of Excess Environmental Nutrients (GREEN)

NCAC 15A 02B

NCDEQ Surface Water Classification

NCDOT TMDL website

NCDOT-JLSLAT

NC-SELDM Catalog

PCSP manual

Preliminary Stormwater Master Plan (pSMP)

Roadside Environmental Unit, Soil and Water Section

Stormwater Master Plan (SMP)

USGS StreamStats

North Carolina
Department of
Transportation

Chapter 14 Permit Drawings

Hydraulics Unit

February 22, 2022

Revisions Sheet			
Page	**Old Section**	**New Section**	**Description**
-	-	-	• Entire Chapter revised to new format and minor grammatical changes made throughout • All references and links have been updated throughout Chapter
1	14.2.1	14.2.1	Last sentence – Removed reference to Appendix P, Added link for Permit Drawing Guidelines
1	14.2.3	14.2.3	3rd sentence – Removed reference to Appendix P, Added link for Permit Drawing Guidelines
2	14.2.4	14.2.4	Last sentence – Removed reference to Appendix L; Added links for forms and website
3	-	14.3	Added new section – References
4	-	14.4	Added new section – Additional Documentation
-	Appendix P	Permit Drawing Guidelines	Removed Appendix P; New companion document for Chapter 14; Links provided within Chapter

Table of Contents: Chapter 14, Permit Drawings

14.1 Introduction

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 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 Permit Drawing Guidelines (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 must 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

Considerable time may have elapsed between the preparation of the permit application and the completion of the drainage design and hydraulic recommendations. Permit drawings must be consistent with the project's final roadway plans and drainage design. The Permit Drawing Guidelines provide specific procedural guidance regarding permit dra wing preparation and consistency review for final submittal. NCDOT posts copies of recently issued permits online.

14.2.4 Completion of Forms to Include with Permit Drawings

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. Not all 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 that may be required may be downloaded from the links below:

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

14.3 Merger Concurrence Point 4C Meeting

For those projects following the 404/NEPA Merger Process, a Concurrence Point 4C (CP4C) meeting is held to review the completed permit drawings to resolve any potential issues prior to applications for the permit(s). For additional guidance, refer to Guidance for Merger Concurrence Point 4C Meetings and Plans.

14.4 References

Section reserved for future updates

14.5 Additional Documentation

Permit Drawing Guidelines

Wetland and Surface Water Impacts Summary

Riparian Buffer Impacts Summary

Stormwater Management Plan (SMP)

Guidance for Merger Concurrence Point 4C Meetings and Plans

North Carolina
Department of
Transportation

Chapter 15 Floodplain Management

Hydraulics Unit

February 22, 2022

Revisions Sheet			
Page	**Old Section**	**New Section**	**Description**
-	-	-	• Entire Chapter has been revised for content • All references and links have been updated throughout Chapter

Table of Contents: Chapter 15, Floodplain Management

15.1 Introduction

No road or structure including its members, shall be constructed, improved, or removed within a designated regulatory floodway or non-encroachment area without a regulatory review and approval. Federal Emergency Management Agency (FEMA) designates these areas as a 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://fris.nc.gov/fris/).

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 if the encroachment is not within the designated regulated floodway or non-encroachment area. This does not relieve the engineer from risk or potential liability associated with adverse effects to adjoining properties because of such action. As such, the Design Engineer should evaluate the risk and consider performing a hydraulic study and flood damage assessment to the adjoining properties that are in the floodplain.

15.1.1. Coordination with Regulatory Agencies

Any such work as noted in Section 15.1 requires 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 Flood Insurance Rate Maps statewide. The NCDOT Highway Floodplain Program (HFP) has been established as a delegated authority through a Memorandum of Agreement (MOA) with NCFMP to facilitate coordination and approvals for project impacts within SFHAs.

Federal Aid projects must comply 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.

15.1.2. Guiding Regulations, Rules and Policies

Most streams have designated 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 follow Federal and State floodplain management regulations and rules. These include:

- FEMA's National Flood Insurance Program (NFIP) (FEMA, 2016)
- FHWA's *Federal Aid Policy Guide, Location and Hydraulic Design of Encroachments on Flood Plains* (23 CFR 650 Subpart A) (FHWA, 1969)
- Memorandum of Understanding by FHWA and FEMA (June 1982) (FHWA, J. Krolak, 2011),
- Presidential Executive Order 11988 (Federal Register, 1977)

- Presidential Executive Order 13690 (Federal Register, 2015),
- North Carolina Governor's Executive Order 123 (July 1990) (Martin, 1990)

NCDOT's policy encourages encourage a broad and unified effort to:

- employ a practical and reasonable approach to the design of transportation facilities located within floodplains
- avoid encroachments into floodplains to the extent practicable
- minimize and mitigate unavoidable adverse impacts on adjoining properties in floodplains
- restore and preserve natural floodplain value and function to the extent practicable

15.2 Project Coordination

During project planning and development, the Hydraulic Design Engineer shall evaluate impacts to SFHAs and determine appropriate mitigation strategies. Such mitigation strategies and evaluations may require coordination with NCDOT HFP, FEMA, NCFMP, or CMSWS.

15.2.1. Planning Stage Coordination

For projects requiring anEnvironmental Impact Statement (EIS), determine if the selection of the Least Environmentally Damaging Practical Alternative (LEDPA) would require impacts to floodplains. If necessary, obtain a written statement regarding such determination from FEMA, NCFMP, or CMSWS prior to the completion of the final EIS or Finding of No Significant Impact (FONSI). An example of this is a proposed roadway alignment that results in a longitudinal encroachment of a FEMA regulated floodway that causes potential flood damage to insurable structures.

For projects that are processed with a Categorical Exclusion and would potentially impact a FEMA regulated floodway, confirm with NCDOT HFP to determine if additional coordination is warranted. In most cases, additional coordination is only necessary during the design stage.

Endangered Species Act (ESA) compliance is required for projects that require a Conditional Letter of Map Revision (CLOMR). Refer to the guidance for CLOMRs at FEMA's website.

15.2.2. Final Design Stage Coordination

State Floodplain Compliance (SFC) approval in final design stage is achieved by following the currently applicable technical guidance posted on the Hydraulics Unit website (CCP).

Conditional Letter of Map Revision (CLOMR) approval in final design stage is achieved for projects which cause base flood elevation increases above those permitted under subparagraphs (c)(10) or (d)(3) of the US Code of Federal Regulations 44 CFR 60.3 (FEMA, 2016). Any which result in an increase in the 100-year Base Flood Elevation (BFE) will require a floodway revision and corresponding approval of a CLOMR.

15.2.3. Post-Construction Coordination

As-built Plans Review and Final Submittal is required within six months of a structure's completion on a FEMA-regulated stream. Follow the currently applicable technical guidance posted on the Hydraulics Unit website (CCP).

15.3 Maintenance Activities in FEMA Regulatory Area

The Department evaluates the impacts to SFHAs for maintenance activities to determine appropriate mitigation strategies. These mitigation strategies and evaluations may require coordination with NCDOT HFP and be in accordance with the currently applicable technical guidance posted on the Hydraulics Unit website (CCP).

Maintenance activities include:

- resurfacing
- roadway cross-section modification(s)
- shoulder widening
- addition of guardrail, sidewalk or curb and gutter systems
- culvert modification(s) of any kind

15.3.1. Maintenance Culvert Replacements on a FEMA Regulatory Stream

A review process was established between NCFMP and NCDOT to help streamline review of the Department's maintenance culvert replacements. The agreement is based on NCDOT maintenance culvert replacements only and was established with consideration given to the minimal nature of the work. The process applies only for NCDOT County/Bridge Maintenance culvert-to-culvert replacements (excluding RCBCs) with no adjustments to road grades. RCBC, Bridge replacements and road grade changes do not qualify for this review process and require review through the SFC process. Follow the currently applicable technical guidance posted on the Hydraulics Unit website (CCP).

15.4 Acceptable Level of Precision

For floodplain compliance reports, all reported water surface elevations, including the Base Flood Elevation (BFE), should be specified to the nearest one hundredth of a foot (0.01 foot).

The reported BFE proposed conditions and existing conditions elevations are compared to determine the applicability for SFC approval. 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 specified to the nearest foot.

15.5 Avoidance of FEMA Buyout Properties

Any construction or alteration of the transportation facilities (roadway embankment, sidewalk, 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 a local government and reimbursed by FEMA under its Hazard Mitigation Grant Program (HMGP) or Flood Mitigation Assistance Program (FMA) for the restoration and preservation of the floodplain (FEMA, 2015). 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 2.2.5.3.

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 NCDOT HFP. The Design Engineer should assess risk for such activities, perform hydraulic analysis and work with Division staff to include a provision in the project's contract to stipulate the following, as applicable:

- duration of construction within the floodway
- installation of on-site stream gages
- installation of a flood warning system
- designated staging areas for equipment that are at least one foot above the BFE
- notification of the affected property owners of the potential risk of flooding from the temporary encroachment
- department commitment assuming liability for any flood damages resulting from the temporary encroachment

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

15.7 Emergency Replacement of Drainage Structures

Emergency replacements requiring federal reimbursement should follow the protocol below:

- recommendations should follow Guidance set by the CCP and NCDOT *Guidelines for Drainage Studies and Hydraulic Design*
- when a structure is located on a FEMA regulatory stream, NCDOT coordinates with FMP as defined in section 15.3.1
- culvert (excluding RCBC): NCDOT submits a Hydrologic and Hydraulic (H&H) Report to State Maintenance Office for Federal reimbursement. See Section 15.7.1 for more information about H&H reports.
- Reinforced Concrete Box Culvert and Bridge: NCDOT submits the appropriate Bridge or Culvert Design Documentation to State Maintenance Office for Federal reimbursement. (Chapters 8 and 9)

Design and estimates should be submitted to the Division for federal reimbursement documentation.

15.7.1. Hydrologic & Hydraulic (H&H) Reports Needed for Federal Reimbursement

A Hydrologic and Hydraulic (H&H) report is required to obtain Federal reimbursement for damages due to extreme weather events. The H&H report falls under FEMA's Public Assistance Program and Policy Guide (PAPPG) under that document's Appendix J: Cost-Effective Hazard Mitigation Measures. A report is required before a replacement can be made to ensure that the facility's LOS is maintained or improved, there are no adverse impacts to adjacent properties, and it follows the regulations of the NFIP. The H&H report consists of the following information (an example can be found on the Hydraulics Website):

- geographical information
- County
- road number and name
- latitude and longitude
- nearby crossing (road location)
- topographical map
- presence of any downstream structures
- hydrological information
- river basin
- drainage area
- hydrology for discharge determination

- FEMA study type
- hydraulic calculations using the charts from FHWA's Hydraulic Design of Highway Culverts – Series 5 (HDS-5) (FHWA, J.D.Schall, P.L. Thompson, S.M. Zerges, R.T. Kilgore, J.L. Morris (authors), 2012)
- existing and proposed inlet and outlet calculations
- existing and proposed inlet and outlet velocities
- existing and proposed inlet and outlet elevations
- package signed and sealed by a Professional Engineer (PE)
- package addressed to the Division Maintenance Engineer
- copy sent to the Division County or Bridge Maintenance Engineer

15.8 References

Federal Register. (1977, May). *Floodplain Management, Executive Order 11988*. Retrieved November 2021, from 42 FR 26971, 3 CFR, 1977 Comp. p. 117: https://www.archives.gov/federal-register/codification/executive-order/11988.html

Federal Register. (2015). *Establishing a Federal Flood Risk Management Standard and a Process for Further Soliciting and Considering Stakeholder Input*. Retrieved November 2021, from Executive Order 13690, Federal Register, 80 FR 6425: https://www.federalregister.gov/documents/2015/02/04/2015-02379/establishing-a-federal-flood-risk-management-standard-and-a-process-for-further-soliciting-and

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

FEMA. (2016, June 22). *Emergency Management and Assistance, Subchapter B - Insurance and Hazard Mitigation; Title 44, Code of Federal Regulations*. Retrieved November 2021, from https://www.govinfo.gov/content/pkg/CFR-2013-title44-vol1/pdf/CFR-2013-title44-vol1.pdf

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

FHWA, J. Krolak. (2011). *Additional Guidance on 23 CFR 650A.* Retrieved November 2021, from Federal Highway Administration, U.S. Department of Transportation: https://www.fhwa.dot.gov/engineering/hydraulics/policymemo/0650asu1.cfm

FHWA, J.D.Schall, P.L. Thompson, S.M. Zerges, R.T. Kilgore, J.L. Morris (authors). (2012, April). *Hydraulic Design of Highway Culverts, Third Edition, Hydraulic Design Series Number 5 (HDS-5).* Retrieved from Federal Highway Administation, U.S. Department of Transportation: https://www.fhwa.dot.gov/engineering/hydraulics/pubs/12026/hif12026.pdf

Martin, G. J. (1990). *North Carolina Executive Order 123 Uniform Floodplain Management Policy.* Raleigh, NC.

NCDOT. (2016). *NCDOT - NCFMP Memorandum of Agreement (Mod. 8/12/2016).* https://connect.ncdot.gov/resources/hydro/FEMA%20and%20Interagency%20Design/MOA_mod_20160812_(AID_6686).pdf: North Carolina Department of Transportation and North Carolina Floodplain Mapping Program.

15.9 Additional Documentation

NCDOT MOA Coordination & Compliance Plan (CCP)

North Carolina
Department of
Transportation

Chapter 16
Coastal Hydraulic Design

Hydraulics Unit

February 22, 2022

Revisions Sheet			
Page	**Old Section**	**New Section**	**Description**
-	-	Chapter 16	• Entire Chapter revised to new format • Previous version of Chapter 16 has been included in individual chapters. This chapter will be a new chapter and is reserved for future updates.

Table of Contents: Chapter 16, Coastal Hydraulic Design

16.1. Introduction

The coastal environment presents many unique challenges to consider when successfully planning, designing, constructing, and maintaining roadway facilities. These unique challenges often require specialized education and experience beyond that gained from practice in the riparian environment, and consequently have historically received less attention. It is important to consider and evaluate these challenges of the coastal environment at all stages in project development, including resiliency to sea level rise in the planning stage, unique erosional and scour mechanisms in the design stage, and effective repair and prevention after severe storm events in the maintenance stage. Refer to HEC-25 (FHWA. S.L. Douglass, B.M. Webb (Authors) 2020) for further reading on natural coastal processes and coastal science/engineering principles as they apply to highways.

16.2. Coastal Hydraulics Expertise

While with proper guidance, some coastal engineering design functions may be performed by those with limited coastal engineering training, many require the specialized education and experience of a qualified coastal engineer. It is important to have an understanding of what the qualifications are of a coastal engineer, and when one is required.

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16.2.1. Conditions Requiring a Coastal Engineer

Conditions that typically require direct attention by a coastal engineer include (AASHTO 2008):

- Hydraulic analysis of complex geometry tidal water bodies
- Hindcasting of historical hurricane events
- Determination of design wave parameters
- Analysis of inlet or channel instability, either vertically or horizontally
- Prediction of potential wave scour at bridges and seawalls
- Design of countermeasures for wave induced erosion/scour at bridge abutments and approaches
- Prediction of barrier island overtopping and channel cutting
- Design of countermeasures for inlet instability, wave attack, or channel cutting
- Prediction of global coastal sediment transport or design of countermeasures to control global sediment transport
- Determination of design hurricane parameters
- Assessment of wave loading on bridges and other structures (FDOT 2021)

16.2.2. Coastal Engineer Qualifications

A Coastal Engineer should hold an M.S. or Ph.D. in Coastal Engineering or a related engineering field. The Coastal Engineer should have extensive experience in coastal hydrodynamics, wave mechanics, and sediment transport processes, as demonstrated by publication in technical journals with peer review or project involvement. The Coastal Engineer should also have demonstrated expertise and experience in computer modeling of storm surge, waves, etc. if the project requires it. Without the commensurate education or expertise within the discipline, demonstrated experience in computer modeling will not provide sufficient qualification as a Coastal Engineer (AASHTO 2014). In addition, the Coastal Engineer shall be a Professional Engineer licensed to practice in the State of North Carolina, and the Coastal Engineer must sign and seal all reports and plans.

16.3. Level of Analysis

The appropriate level of analysis is dependent on several factors. It involves a risk analysis of the criticality of the facility (such as cost or emergency response) and tolerance for closure due to overtopping or damage. The figure below provides a qualitative means for depicting the relative level of analysis that may be required, as a function of criticality of the infrastructure and distance from the coast.

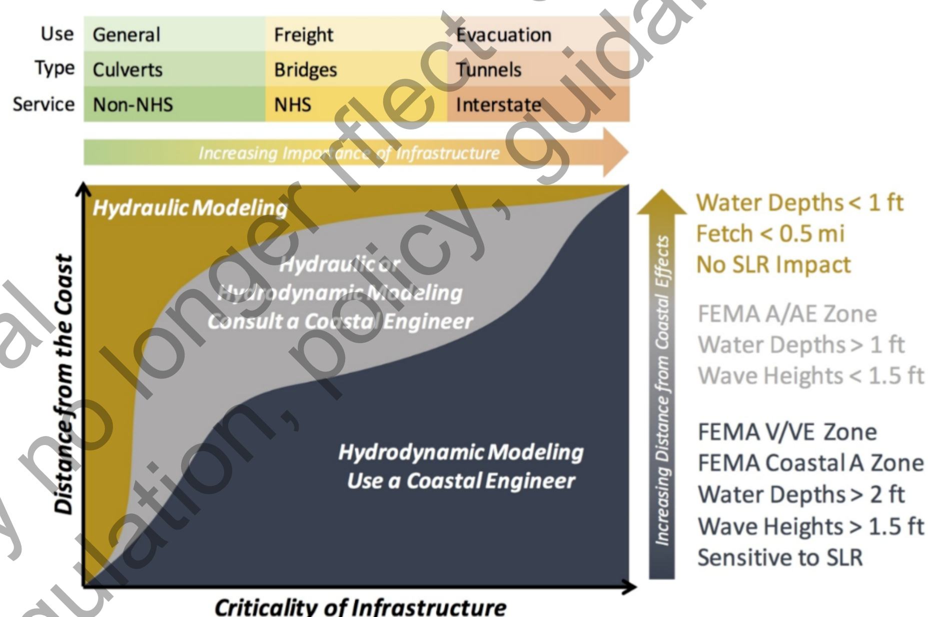

Figure 1. When and Where to Apply Hydraulic and Hydrodynamic Models as a Function of Distance from the Coast and Importance of Infrastructure (FHWA. B. Webb (Author) 2017)

A more quantitative description of level of analysis in common use identifies three levels, with increasing complexity of analysis to correspond with increasing cost and criticality of the infrastructure.

- Level I generally utilizes readily available data and empirical equations. It requires the least effort but is also the least accurate. It may also be over-conservative, particularly for most bridge locations. Use Level I for small scale, low-risk infrastructure where a more in-depth analysis is not feasible and there is a low cost for potential over-conservatism in design. Its use may also be applicable in the preliminary planning stage for larger-scale infrastructure.

- Level II is a mid-level approach that uses numerical models and improved data, which may include bathymetry, for more accurate results than a Level I analysis. A Level II analysis may be performed either initially or following a Level I analysis.

- Level III is the most costly and time-consuming but produces the most accurate results. It will likely require the measurement of bathymetry and model calibration parameters such as water elevations and waves. A qualified Coastal Engineer should perform the analysis due to the required extensive computer modeling required, as defined in Section 16.2. A Level III analysis is appropriate for high cost (including due to repair or replacement), and/or critical infrastructure for which the cost of failure is high (AASHTO 2008).

In 2013, NCDOT commissioned a report entitled *NCDOT Bridge Superstructure Level III Wave Vulnerability Study* (NCDOT. D.M. Sheppard, Ph.D, P.E. Dompe, P.E. (Authors) 2013), which covered the North Carolina coastline using historical and simulated data. The study included hindcasting of 62 of the most severe storms in the state over the last 160 years, and developed extreme value analyses on water elevations, wave heights, and depth averaged current velocities in the state's coastal areas. While the report focused on obtaining storm surge and wave data at key sites to assess existing bridge vulnerability, data can be readily extracted from the study's GIS database for any coastal location in North Carolina to improve upon a Level I or II analysis. A complete list of these design parameters is available on the Hydraulics Unit website. The 2013 report was prepared for the 100-year return period only, and the GIS database was updated in 2015 to include the 5-, 10-, 25-, and 50-year return periods. It should be noted that this study was completed neglecting the effects of Sea Level Rise, so evaluate the applicability of data obtained from the study accordingly. While this data is acceptable for planning-level design, consider developing a more detailed and up-to-date hydrodynamic model for final design when the infrastructure type or risk assessment requires a Level III analysis.

16.4. Sea Level Rise (SLR)

In order to protect a facility from a premature obsolescence (and the increasing maintenance that this may require), or even loss of service, whether temporary or permanent, the potential effects of Sea Level Rise (SLR) anticipated to occur over its design life should be considered when establishing parameters for siting and designing the facility.

Future projections of global average sea level are based on the response of climate models to various atmospheric scenarios, which are called Representative Concentration Pathways, or RCPs. Among the most commonly-referenced are RCP 4.5, an intermediate/moderate greenhouse gas emissions scenario, and RCP 8.5, a high greenhouse gas emissions scenario. RCP 2.6, a low greenhouse gas emissions scenario, is no longer considered likely (NCICS. K.E. Kunkel, D.R. Easterling, et al. (Authors) 2020). It should be noted that to date, 21st century greenhouse gas emissions are closely tracking with the median RCP 8.5 scenario (PNAS. C.R. Schwalm, S. Glendon, P.B. Duffy (Authors) 2020), and it is recommended that for near-term (mid-century or shorter) projections, the median RCP 8.5 be used as minimum design values. For longer-range planning, it is best to examine the probability of exceedance for different RCP scenarios and determine the level of risk that is acceptable.

Determination of an appropriate design value of SLR for the facility in question is a complex process that may include an assessment by a coastal engineer of the probability of exceedance at the end of the facility's service life, as well as the cumulative probability of exceedance over the life of the facility, for a range of heights and appropriate RCP scenarios. Higher values of SLR should be used for critical infrastructure or when the risk tolerance is low, such as infrastructure that is highly sensitive to increases in sea level, or for which redundancy is minimal or non-existent (NCHRP. R. Kilgore, W.O. Thomas, Jr., et al. (Authors) 2019).

A determination of an acceptable level of risk will be influenced by whether the design goal is for low risk of failure (inundation) during the entirety of the facility's service life, or for acceptance of a greater risk of inundation in the latter years of its life, possibly combined with adoption of a design that would allow for possible future rehabilitation by raising of the facility. Additionally, the question of retreat or abandonment may need to be addressed in those areas where predicted SLR levels would indicate that areas served by the facility would be permanently inundated, thus negating the function of the transportation facility. In such cases, it may be appropriate to limit the value of design SLR to what is practical for survivability of the areas being served.

Research into and projections of Sea Level Rise are an ongoing effort that continues to evolve. The State Hydraulics Engineer should be consulted for current policy and guidance for assignment of an appropriate SLR design value.

When defining the appropriate amount of SLR to accommodate in the siting and design of a facility, it is important to distinguish between Global Mean Sea Level (GMSL) and Local (or Relative) Mean Sea Level (LMSL). GMSL is the global average of all the world's oceans. LMSL accounts for local land subsidence or uplift, in addition to local hydrodynamic and oceanographic factors, to report the localized Mean Sea Level (MSL) relative to the land. Thus, a rate of increase determined for one locality will not necessarily be applicable to another. For example, NOAA gauge data through 2019 shows relative sea level trends for Wilmington, Oregon Inlet, and Duck of 2.47 mm/yr., 5.08 mm/yr., and 4.77 mm/yr. respectively (NOAA n.d.). It is important to note that these are averages over the life of the gauge, and may not accurately represent any current acceleration in rate of increase.

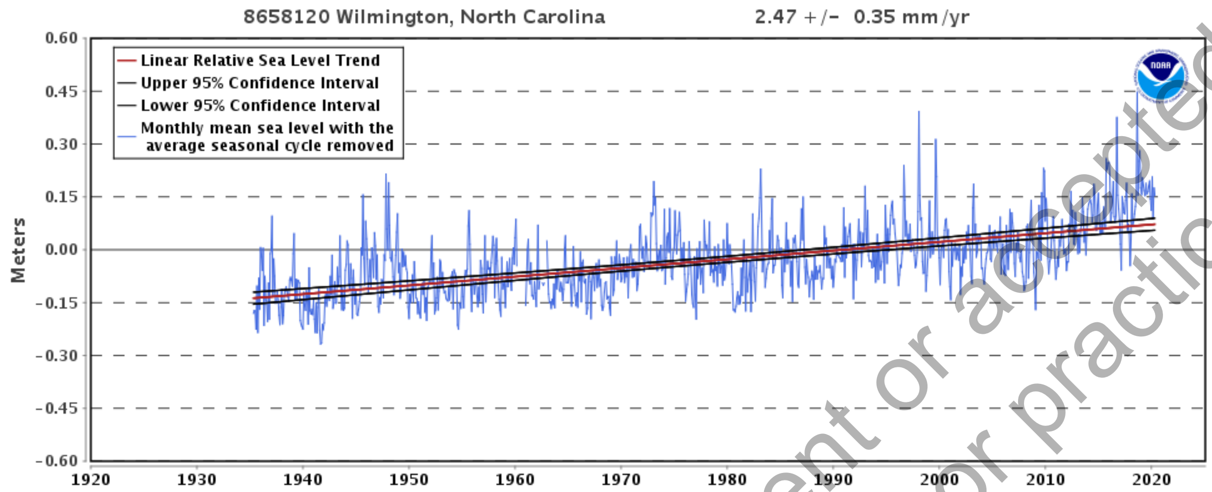

Figure 2. NOAA Gauge Plot of Monthly MSL Data for Wilmington, NC from 1935 to 2019 Showing Relative Sea Level Trend of 2.47 mm/yr. (NOAA n.d.)

16.5. Still Water Level (SWL)

Still Water Level (SWL) is the average water surface elevation at which the water level would be without wind-generated wave action and includes the effects of astronomical tides, as well as storm surge and Sea Level Rise (SLR), as applicable. Evaluate the applicability of these three components when selecting a design SWL. Mapping and navigational charts are typically referenced to a defined SWL.

16.5.1. Tides

Water levels in the coastal environment are constantly fluctuating due to astronomical tides, among other factors. While tides present a level of complexity that is not present further inland, they are predictable with historical data. The design engineer should understand common terminology and use of historical tidal data as recorded by tidal gages.

16.5.1.1. Tidal Datums

A tidal datum is a standard elevation defined by a certain phase of the tide. Tidal datums are used as references to measure local water levels and should not be extended into areas having differing oceanographic characteristics without substantiating measurements. Datums are referenced to fixed points known as benchmarks so they may be recovered when needed (NOAA n.d.).

The following table defines some of the more commonly referenced tidal datums. Refer to the National Oceanic and Atmospheric Administration's (NOAA's) website at https://tidesandcurrents.noaa.gov/datum_options.html for a complete list.

Table 1. Common Tidal Datums

MHHW	Mean Higher High Water	The average of the higher high water height (the higher of the two high tides) of each tidal day observed over the National Tidal Datum Epoch. For stations with shorter series, comparison of simultaneous observations with a control tide station is made in order to derive the equivalent datum of the National Tidal Datum Epoch.
MHW	Mean High Water	The average of all the high water heights observed over the National Tidal Datum Epoch. For stations with shorter series, comparison of simultaneous observations with a control tide station is made in order to derive the equivalent datum of the National Tidal Datum Epoch.
MTL	Mean Tide Level	The arithmetic mean of mean high water (MHW) and mean low water (MLW).
MSL	Mean Sea Level	The arithmetic mean of hourly heights observed over the National Tidal Datum Epoch. Shorter series are specified in the name; e.g. monthly mean sea level and yearly mean sea level.
MLW	Mean Low Water	The average of all the low water heights observed over the National Tidal Datum Epoch. For stations with shorter series, comparison of simultaneous observations with a control tide station is made in order to derive the equivalent datum of the National Tidal Datum Epoch.
MLLW	Mean Lower Low Water	The average of the lower low water height (the lower of the two low tides) of each tidal day observed over the National Tidal Datum Epoch. For stations with shorter series, comparison of simultaneous observations with a control tide station is made in order to derive the equivalent datum of the National Tidal Datum Epoch. Navigational charts typically reference MLLW.

All tidal datums are referenced to the National Tidal Datum Epoch (NTDE), which is the specific 19-year period adopted by the National Ocean Service as the official time segment over which tide observations are taken and reduced to obtain mean values (e.g., Mean Lower Low Water) for tidal datums. The current epoch is measured from 1983 to 2001 and is actively considered for revision every 20 to 25 years to account for changes in Mean Sea Level over time (NOAA n.d.). The epoch uses 19 years because it is the closest full year to the 18.6-year cycle of the lunar nodes, by which an epoch is defined, and therefore captures the full average of variations in the cycle of lunar nodes, which in turn influences tide levels.

Tidal datums differ from survey datums, and must be converted to the appropriate survey datum from a known elevation (typically found with the recorded data from the tidal gage) prior to use.

16.5.1.2. Tidally-Influenced Geographic Area

Approximate coastal limits of tidal influence can be found in USGS Water Supply Paper 2221 (https://pubs.usgs.gov/wsp/2221/plate-1.pdf) (USGS. G.L. Giese, Hugh B. Wilder, and Garald G. Parker Jr. (authors) 1985).

16.5.1.3. Use of Tide Gages

North Carolina has six active NOAA tide gages from which tidal data may be obtained (from north to south): Duck, Oregon Inlet, Hatteras, Beaufort, Wrightsville Beach, and Wilmington. Historical data also may be obtained from a former gage further south at Southport, NC, Station ID 8659084, which was removed in 2008. Other gages with tidal data can be located further inland.

Obtain current data from these tide gages on the NOAA website at https://tidesandcurrents.noaa.gov. By default, the mapping only shows gages with real-time data, i.e. currently operating gages. Datums from all gages, both current and removed, may be obtained through an *Advanced* search for "Datums" as *Data Type*. Gage datums are typically referenced to MLLW; conversion to the appropriate vertical datum (such as NAVD88) is required, and a conversion tool is available under Datums on the Tides/Water Levels page of the Station Info for each gage.

16.6. 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. Refer to the basic Tidal Prism procedure discussed in HEC-18 (FHWA. L.A. Arneson, L.W. Zevenbergen, P.F. Lagasse, P.E. Clopper (Authors) 2012), as well as more information on this and other more detailed one- and two-dimensional tidal crossing modeling guidance presented in HEC-25 (FHWA. S.L. Douglass, B.M. Webb (Authors) 2020). 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. Refer to the Project ATLAS site (NCDOT n.d.) for approximate coastal limits of tidal influence. Tidal influence should also be confirmed by field evidence and reports from local residents familiar with the project site.

16.6.1. Scour for Coastal/Tidal Bridges

The scour equations developed for inland rivers should be used to estimate and evaluate scour for tidal flows and storm surge (HEC-18, Chapter 9).

Generally, the tidally-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, 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.

If appropriate for the level of analysis required by the infrastructure type or risk assessment, the design engineer may use one of the following two methods for the scour calculation due to storm surge - Simplified Storm Surge Method or Level III Wave Vulnerability Study Method.

16.6.1.1. Simplified Storm Surge Method

1. Compute the volume of storm surge by multiplying the design basin area by the average depth of storage
    - Depth of storage is the difference of the ground and design flood elevations or overtopping elevation, whichever is lower$
2. Determine the flood discharge
    - The volume of storage divided by the duration of surge; available from nearby rain gage sites, or a minimum of six 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. Use 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.

16.6.1.2. Level III Wave Vulnerability Study Method

Develop the following tidal scour design parameters based on data available from the Level III Wave Vulnerability 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.

Contact the Hydraulics Unit to obtain the site-specific GIS data associated with this study, which includes the 5-, 10-, 25-, 50-, and 100-year return intervals. For bridges that overtop below 5-year interval, use 5-year data as the minimum for scour analysis.

Perform the scour computation using the applicable scour equations for contraction, pier, and abutment scour outlined in the previous sections, as applicable. For more information regarding the Level III Wave Vulnerability Study, please see section 16.3.

16.7. References

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16.8. Additional Documentation

Reserved for Future Updates.