Chapter 1

GENERAL

SOUTH DAKOTA DRAINAGE MANUAL

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Chapter 1
GENERAL

1.1 INTRODUCTION

For highway applications, hydraulics is the science of collecting, transporting and disposing of surface water originating on or near the highway right-of-way or flowing in the streams crossing or bordering that right-of-way. Proper drainage control is one of the essential elements of highway construction, and the cost for the adequate removal of surface water justifies a careful and scientific approach to the design of drainage facilities. A large portion of highway construction costs is devoted to culverts, bridges and other drainage structures.

In hydraulic design, the basic objective is to protect the highway from damage due to storm and subsurface waters and considering the effects of the proposed improvement on traffic and property. Preventing the accumulation and retention of water on and adjacent to the roadway is addressed by the following general objectives:

- anticipating the amount and frequency of storm runoff;
- determining natural points of concentration and discharge and other hydraulic controls;
- providing the most efficient disposal facilities consistent with cost, the importance of the road, maintenance and legal obligations; and
- removing detrimental amounts of subsurface water.

The *South Dakota Drainage Manual* presents the South Dakota Department of Transportation's hydraulic guidelines, procedures and practices to meet these objectives. Specifically, Chapter 1 addresses in-house operational procedures related to drainage, and the Chapter discusses the hydraulic design literature.

1.2 BASIC APPROACH

The following describes the basic approach for the *South Dakota Drainage Manual*:

1. Audience. The following users are the intended audience for the *Manual*:

   - the Bridge Hydraulics Section,
   - hydraulic designers,
   - road designers,
   - bridge designers,
   - county and city personnel, and
   - consultant engineers.

2. Application. The *Manual* is an application-oriented document that provides design criteria, practices and procedures for roadway drainage and bridge waterway openings tailored to the prevailing conditions in South Dakota. It is not intended to be a hydraulics textbook or a step-by-step training manual, but should be viewed as a valuable reference or guide to the user.

3. Coordination with AASHTO *Model Drainage Manual*. The AASHTO Technical Committee on Hydrology and Hydraulics produced the 2005 *Model Drainage Manual* (*MDM*) for use by State Departments of Transportation nationwide. The *MDM* presents design theories, concepts, guidelines, criteria and procedures for use by the hydraulic designer and hydraulic engineer. The *South Dakota Drainage Manual* has been prepared using the *MDM* as a basis with State-specific modifications.

4. Coordination with Hydraulic Literature. The Federal Highway Administration has published many hydraulic design documents in two general formats — the Hydraulic Design Series (HDS), which are the more established and accepted resources, and the Hydraulic Engineering Circulars (HEC), which are more subject to revision and constantly evolving. These documents are essential resources in hydraulic design for highway structures throughout the nation. Section 1.5 briefly describes many of the FHWA hydraulic design publications and notes their usage in South Dakota.

5. Example Problems. The *Manual* provides selected example problems on hydraulic design that are intended to illustrate the specific hydraulic design criteria, practices and guidelines used by SDDOT for the selected applications.

1.3 FUNCTIONAL RESPONSIBILITIES

This Section briefly discusses the drainage design responsibilities for selected units within the South Dakota Department of Transportation.

1.3.1 Office of Road Design

The responsibilities of the road designer with respect to roadway drainage design include the following:

- pipe culverts, riprap and gabions, where the drainage area is less than 1000 acres;
- where applicable, the design for fish passage through pipe culverts;
- roadway surface drainage and storm drainage systems;
- roadside channels including ditch linings;
- storage facilities; and
- temporary and permanent erosion and sediment control.

The Office of Road Design is also responsible for developing the SDDOT drainage practices, procedures and criteria for the design of roadway drainage appurtenances. In general, within this *Manual*, the term "hydraulic designer" is used when noting a hydraulic activity that is performed by road design personnel.

1.3.2 Office of Bridge Design

1.3.2.1 General

The Office of Bridge Design provides a variety of engineering services for the design of drainage and structures on the State highway system. The Office includes the following Sections:

- Bridge Design Section,
- Bridge Hydraulics Section,
- Bridge Maintenance Section, and
- Bridge Construction Section.

Specifically for preconstruction, the Office of Bridge Design is responsible for the hydraulic and structural design of all new bridges and box culverts required on the State highway system. The Office is also responsible for the design of all projects to rehabilitate or reconstruct existing bridges and box culverts on the State highway system.

1.3.2.2 Bridge Designer

The bridge designer is responsible for the following design decisions related to the waterway opening:

- number of spans over a waterway,
- location of piers in a waterway, and
- bridge length over a waterway.

1.3.2.3 Bridge Hydraulic Engineer

The SDDOT Bridge Hydraulic Engineer is responsible for establishing SDDOT hydraulic guidelines, practices and criteria for those hydraulic activities that are the responsibility of the hydraulic engineer and the hydraulic designer. The SDDOT Bridge Hydraulic Engineer also serves as a technical resource to in-house hydraulic designers, engineers, consultants and local agency staff and will review their work, where applicable.

1.3.2.4 Hydraulic Engineer

The hydraulic engineer reports to the SDDOT Bridge Hydraulic Engineer and is responsible for:

- all drainage area calculations except those for urban roadway storm drainage design;

- where the drainage area is greater than or equal to 1000 acres, the hydraulic design of:

    + culverts,
    + open channels,
    + riprap, and
    + gabions;

- the hydraulic design (i.e., type, size and location) of all box culverts regardless of drainage area size;

- design of fish passage through box culverts;

- the hydraulic design of energy dissipators;

- the hydraulic design of bridge waterway openings;
- bridge deck drainage design;
- hydraulic scour and erosion protection for major structures;
- FEMA/NFIP compliance;
- water-related permits (e.g., Section 404); and
- USCG Section 9/Section 10 Navigational Permits.

1.3.3 Materials and Surfacing Office

The drainage design responsibilities of the Materials and Surfacing Office include:

1. Subsurface Drainage. For pavement structures, the Office will determine those treatments necessary to ensure the structural integrity of the pavement (e.g., subgrade undercuts, geotextiles, subsurface drainage system).
2. Scour. The Geotechnical Section within the Office will work with the hydraulic engineer to evaluate the native soils that surround bridge foundations to identify soil properties such as erodibility.
3. Materials. The Office is responsible for the evaluation and selection, where necessary, for materials used in drainage appurtenances.

1.3.4 Environmental Office

The drainage design responsibilities of the Environmental Office include:

1. Environmental Documents. The Environmental Office prepares environmental documents for SDDOT projects (e.g., Environmental Impact Statements, Environmental Assessments, Categorical Exclusions, 4(f) Assessments, wetland findings, storm water permits). These documents assess the drainage impacts of SDDOT projects on adjacent properties (e.g., water, wildlife and fisheries).
2. External Agency Coordination. The Environmental Office facilitates the timely letting of construction projects by obtaining a consensus among SDDOT and other State and Federal resource agencies concerning the development of highway construction projects with respect to environmental impacts. The resource agencies include, but are not limited to:
    - South Dakota Department of Game, Fish and Parks;
    - South Dakota Department of Environment and Natural Resources;

- South Dakota Historic Preservation Office;
- Federal Highway Administration;
- US Fish and Wildlife Service;
- US Forest Service;
- National Park Service; and
- US Army Corps of Engineers.

Some of the environmental issues for which the hydraulic engineer and/or the hydraulic designer may need to coordinate with the Environmental Office are:

- wetlands;
- the design for fish passage (e.g., coordinating with US Fish and Wildlife and South Dakota Department of Game, Fish and Parks);
- defining the habitats of endangered species (e.g., Topeka Shiner streams);
- encroachments (e.g., floodplains);
- water quality (e.g., wetlands, ground water, erosion control); and
- Section 404 permits.

Specifically for fish passage through culverts, the Environmental Office identifies the need to accommodate fish passage; the hydraulic engineer or hydraulic designer determines how to provide the accommodation.

1.3.5 Consultant-Designed Projects

For those projects designed by Consultants, the following summarizes the division of responsibilities for drainage design:

1. Consultant. In general, the Consultant is responsible for all hydrologic and hydraulic computations on SDDOT-assigned projects. Consultants are responsible for performing their analyses consistent with the drainage guidelines and criteria adopted by SDDOT.
2. SDDOT. SDDOT will review the Consultant’s proposed drainage design.

1.4 LOCAL AGENCY HIGHWAY PROJECTS

1.4.1 General SDDOT Administration

1.4.1.1 Office of Local Transportation Programs

The SDDOT Office of Local Transportation Programs (LTP) provides financial and technical assistance to county and city governments for the construction and reconstruction of roads, streets and bridges. The Office is responsible for:

- administering State and Federal contracts,
- conducting TS&L inspections on local projects, and
- facilitating plan review.

The design for local agency highway projects is typically accomplished through contracts with consulting engineering firms (e.g., survey, roadway, hydraulics, structural design). LTP administers these projects in coordination with the local government.

1.4.1.2 Secondary Road Plan

The Secondary Road Plan is an agreement between SDDOT, through the Office of Local Transportation Programs, and the counties and cities of South Dakota. The Secondary Road Plan is a guideline for use in planning, designing and constructing roads and bridges on local government highway systems.

1.4.2 Office of Bridge Design

1.4.2.1 General Oversight

The Office of Bridge Design provides hydraulic and structural design guidance for projects that are on the local municipal/county systems in South Dakota (i.e., those that are not on the State highway system). Specific responsibilities of the SDDOT Bridge Hydraulic Engineer for local agency highway projects are to:

- review hydrologic and hydraulic data,
- review the local project’s preliminary layout, and
- review final bridge and roadway drainage plans.

SDDOT local agency projects are coordinated and reviewed by the Office of Local Transportation Programs prior to letting.

1.4.2.2 Local Transportation Programs Hydraulic Design

As a general statement, the hydraulic design for local agency highway projects is governed by the same laws, regulations, guidelines and criteria as those that apply to State highway system projects. However, there are some distinctions. The Secondary Road Plan documents the unique hydraulic design procedures and criteria that apply to local agency projects. In addition, where applicable, the *South Dakota Drainage Manual* documents hydraulic design criteria that specifically applies to local projects (e.g., design flood frequencies, roadway overtopping).

1.5 HYDRAULIC LITERATURE

The following publications are the primary references used in the production of the *South Dakota Drainage Manual*. The 2005 edition of the AASHTO *MDM* (Section 1.5.1) is the primary source of guidelines, design procedures and example problems. The Bridge Hydraulic Engineer has a reference copy of the *MDM* and an electronic version that is available for copying. The FHWA hydraulic publications (Sections 1.5.2 through 1.5.17) are the primary references for current procedures and for more detailed information. All of the FHWA publications are available from its website. Hydraulic software references are provided in Chapter 18.

1.5.1 2005 AASHTO *Model Drainage Manual*

The *South Dakota Drainage Manual* has been prepared based on the 2005 edition of the AASHTO *MDM*. Where practical, the text and graphics in the *MDM* have been incorporated into the *Manual* with modifications to reflect SDDOT practices.

1.5.2 Hydraulic Design Series 1 "Hydraulics of Bridge Waterways"

1.5.2.1 Description

HDS 1 is intended to provide a means of determining the effect of a given bridge on the flow in the stream using a single cross section. This method was the standard method of determining bridge backwater before microcomputers became available in the 1980s. It does not prescribe criteria on the allowable amount of backwater or frequency of the design flood; these are issues that must consider the class of highway, density of traffic, seriousness of flood damage, foundation conditions and other factors. HDS 1 presents discussions on the following topics:

- computation of backwater,
- water levels across approach embankments,
- maximum backwater,
- stage-discharge condition,
- scour,
- flow types, and
- field and design procedures.

1.5.2.2 Department Application

HDS 1 has been used as a resource in the development of Chapter 14 "Bridge Hydraulics" in the *South Dakota Drainage Manual*.

1.5.3 Hydraulic Design Series 2 "Highway Hydrology"

1.5.3.1 Description

HDS 2 discusses the physical processes of the hydrologic cycle that are important to highway engineers. These processes include the approaches, methods and assumptions applied in design and analysis of highway drainage structures.

Hydrologic methods of primary interest are frequency analysis for analyzing rainfall and ungaged data; empirical methods for peak discharge estimation and hydrograph analysis and synthesis. The document describes the concept and several approaches for determining time of concentration. The peak discharge methods discussed include log Pearson Type III, regression equations, the SCS (now NRCS) graphical method (curve number method) and Rational Method. The technical discussion of each peak flow approach also includes urban development applications. HDS 2 presents common storage and channel routing techniques related to highway drainage hydrologic analyses. The document describes methods used in the planning and design of stormwater management facilities. Special topics in hydrology include discussions of arid lands hydrology, wetlands hydrology, snowmelt hydrology and hydrology modeling, including geographic information system approaches and applications.

1.5.3.2 Department Application

HDS 2 should be used, where applicable, at the discretion of the designer. HDS 2 has been used as a resource for Chapter 7 "Hydrology" of the *South Dakota Drainage Manual*.

1.5.4 Hydraulic Design Series 3 "Design Charts for Open-Channel Flow"

1.5.4.1 Description

HDS 3 contains charts that provide a direct solution of the Manning equation for:

- uniform flow in open prismatic channels of various cross sections,
- instructions for using the charts,
- a table of recommended values of n in the Manning equation,
- tables of permissible velocities in earth and vegetated channels,
- instructions for constructing charts similar to those presented, and
- a nomograph for use in the solution of the Manning equation.

The designer is cautioned not to use the open-channel flowcharts presented in this publication as a means of estimating the size of the culvert required for a given discharge because the hydraulics of culverts is not uniform flow at normal depth. The head required to force flow into a culvert may be several times the head required to maintain uniform flow.

1.5.4.2 Department Application

HDS 3 may be used, where applicable, at the discretion of the designer.

1.5.5 Hydraulic Design Series 4 "Introduction to Highway Hydraulics"

1.5.5.1 Description

HDS 4 provides an introduction to highway hydraulics. Hydrologic techniques presented concentrate on methods suitable to small areas, because many components of highway drainage (e.g., culverts, storm drains, ditches) service primarily small areas. A brief review of fundamental hydraulic concepts is provided, including continuity, energy, momentum, hydrostatics, weir flow and orifice flow. HDS 4 then presents open channel flow principles and design applications, followed by a parallel discussion of closed conduit principles and design applications. Open channel applications include discussions on stable channel design and pavement drainage. Closed conduit applications include culvert and storm drain design. Examples are provided to help illustrate important concepts. An overview of energy dissipators is provided and the document concludes with a brief discussion on construction, maintenance and economic issues.

1.5.5.2 Department Application

HDS 4 should be used, where applicable, at the discretion of the designer.

1.5.6 Hydraulic Design Series 5 "Hydraulic Design of Highway Culverts"

1.5.6.1 Description

HDS 5 combines culvert design information previously contained in Hydraulic Engineering Circulars (HEC) No. 5, No. 10 and No. 13 with hydrologic, storage routing and special culvert design information. The result is a comprehensive culvert design publication. Hydrologic analysis methods are described and references cited. Culvert design methods are presented for both conventional culverts and culverts with inlet improvements. HDS 5 includes storage routing techniques that permit the designer to account for ponding effects upstream of the culvert. Unique culvert applications, erosion and sediment control, debris control, structural aspects and long-span culverts are discussed and references cited. Inlet control, outlet control and critical depth design charts are included for a variety of culvert sizes, shapes and materials. New dimensionless culvert design charts are provided for the design of culverts lacking conventional design nomographs and charts. The appendices of the publication contain the equations and methodology used to construct the design charts, information on the hydraulic resistance of culverts and methods of optimizing culvert design using performance curves and inlet depression.

1.5.6.2 Department Application

SDDOT recommends the use of HDS 5 for the design of all culverts (typically accomplished through software based on HDS 5; see Section 18.2.3). The design method used for Chapter 10 "Culverts" in the *South Dakota Drainage Manual* is based on HDS 5.

1.5.7 Hydraulic Design Series 6 "River Engineering for Highway Encroachments"

1.5.7.1 Description

The Federal Highway Administration document "Highways in the River Environment – Hydraulic and Environmental Design Considerations" was first published in 1975, was revised in 1990, and has now been issued as HDS 6. This document has proven to be a singularly authoritative document for the design of highway-associated hydraulic structures in movable boundary waterways. This revised document incorporates many technical advances that have been made in this discipline since 1990. In addition, Hydraulic Engineering Circulars (HEC) No. 18, No. 20 and No. 23 have been published since 1990. HDS 6 and the HECs provide detailed guidance on stream stability, scour and appropriate countermeasures. In HDS 6, hydraulic problems at stream crossings are described in detail and the hydraulic principles of rigid and movable boundary channels are discussed.

The major topics in HDS 6 are:

- sediment transport,
- natural and human-induced causes of waterway response,
- stream stabilization (bed and banks),
- hydraulic modeling and computer applications, and
- countermeasures.

Case histories of typical human and natural impacts on waterways are also analyzed.

1.5.7.2 Department Application

HDS 6 should be used, where applicable, at the discretion of the designer for assessing and analyzing stream stability problems. HDS 6 has been used as a resource for Chapter 14 "Bridge Hydraulics" of the *South Dakota Drainage Manual*.

1.5.8 Hydraulic Engineering Circular 9 "Debris Control Structures Evaluation and Countermeasures"

1.5.8.1 Description

HEC 9 presents various problems associated with debris accumulation at culvert and bridge structures, provides a procedure for estimating the potential of debris accumulating at a bridge structure and provides general guidelines for analyzing and modeling debris accumulation on a bridge structure to determine the impacts that the debris would have on the water surface profile through the bridge structure and the hydraulic loading on the structure. Various types of debris countermeasures for culvert and bridge structures are discussed within HEC 9. General criteria for selection of these countermeasures and general design guidelines for some of the structural measures are also included. The design guidelines are based on countermeasures that have been implemented by Federal, State and local transportation agencies at culvert and bridge structures.

HEC 9 provides measures for both culvert and bridge structures. Selection of a specific debris countermeasure depends upon the size, quantity and type of debris, the potential hazards to life and property, the costs involved and the maintenance proposed.

1.5.8.2 Department Application

HEC 9 should be used, where applicable, at the discretion of the designer.

1.5.9 Hydraulic Engineering Circular 11 "Design of Riprap Revetment"

1.5.9.1 Description

HEC 11 is a comprehensive design publication that includes discussions on:

- recognizing erosion potential,
- erosion mechanisms and riprap failure modes,
- riprap types including rock riprap,
- rubble riprap,
- gabions,
- preformed blocks,

- grouted rock, and
- paved linings.

Detailed design guidelines are presented for rock riprap, and design procedures are summarized in charts and examples. Design guidance is also presented for wire-enclosed rock (i.e., gabions), precast concrete blocks and concrete paved linings.

1.5.9.2 Department Application

HEC 11 was the procedure used for the design of revetments in natural channels and near structures prior to this *Manual*. Chapter 15 “Bank Protection” of the *South Dakota Drainage Manual* is based on HEC 23.

1.5.10 Hydraulic Engineering Circular 14 “Hydraulic Design of Energy Dissipators for Culverts and Channels”

1.5.10.1 Description

HEC 14 provides design information for analyzing energy dissipation problems at culvert outlets and in open channels. Procedures are provided for designing dissipators that are both internal and external to the culvert and that are located on or below the streambed.

1.5.10.2 Department Application

SDDOT recommends that HEC 14 be used when designing energy dissipators for culverts and channels. HEC 14 procedures are included in HY-8 (see Section 18.2.3). Chapter 11 “Energy Dissipators” of the *South Dakota Drainage Manual* is based on HEC 14.

1.5.11 Hydraulic Engineering Circular 15 “Design of Roadside Channels with Flexible Linings”

1.5.11.1 Description

Flexible linings, as discussed in HEC 15, provide a means of stabilizing roadside channels. Flexible linings can conform to changes in channel shape while maintaining overall lining integrity. Long-term flexible linings such as riprap, gravel or vegetation (either unreinforced or reinforced with synthetic mats) are suitable for a range of hydraulic conditions. Unreinforced vegetation and many transitional and temporary linings are suited to hydraulic conditions with moderate shear stresses.

HEC 15 provides design procedures for the following major categories of flexible lining:

- vegetative linings;
- manufactured linings (RECPs);
- riprap, cobble, gravel linings; and
- gabion mattress linings.

Design procedures for composite linings, bends and steep slopes are also provided. The design procedures are based on the concept of maximum permissible tractive force. Methods for the determination of hydraulic resistance applied shear stress and permissible shear stress for individual linings and lining types are presented.

1.5.11.2 Department Application

SDDOT recommends the use of HEC 15 for the design of linings for constructed roadside channels that have a uniform cross section. HEC 15 design methods for channels are included in the FHWA Hydraulic Toolbox (see Section 18.2.2). Chapter 9 "Roadside Channels" in the *South Dakota Drainage Manual* is based on the 1988 edition of HEC 15. The 2005 edition is referenced and may also be used, as appropriate.

1.5.12 Hydraulic Engineering Circular 17 "Design of Encroachments on Flood Plains using Risk Analysis"

1.5.12.1 Description

The design of all floodplain encroachments should include an evaluation of the inherent flood-related risks to the highway facility and to the surrounding property. When this evaluation indicates that the risk warrants additional study, a detailed analysis of alternative designs is necessary to determine the design with the least total expected cost (LTEC) to the public.

HEC 17 provides guidance in the application of the LTEC decision-making process. The LTEC design process is basically one of optimization, where economic and engineering analyses of alternative designs provide the basis for decision-making.

An essential ingredient in the LTEC design concept is risk analysis. Risk analysis provides the vehicle for analyzing the losses incurred for the various design strategies due to possible states of nature (flood events). All quantifiable losses are included in the risk analysis. These may involve damage to structures, embankments and surrounding property, traffic-related losses and scour due to stream channel damage. The product of the risk analysis is the annual economic risk associated with each design strategy.

Although the emphasis of this document is on bridge crossings, the LTEC decision-making process concept is applicable to other drainage features (e.g., culverts, longitudinal encroachments, countermeasures, foundation elevations).

1.5.12.2 Department Application

HEC 17 should only be used if a risk assessment indicates that a risk analysis is required.

1.5.13 Hydraulic Engineering Circular 18 "Evaluating Scour at Bridges"

1.5.13.1 Description

HEC 18 presents the state of the knowledge and practice for the design, evaluation and inspection of bridges for scour. There are two companion documents — HEC 20 "Stream Stability at Highway Structures" (see Section 1.5.14) and HEC 23 "Bridge Scour and Stream Instability Countermeasures" (see Section 1.5.17). These three documents contain updated material from previous editions and the publication "Interim Procedures for Evaluating Scour at Bridges," issued in September 1988 as part of FHWA Technical Advisory T5140.20 "Scour at Bridges." T5140.20 has since been superseded by T5140.23 "Evaluating Scour at Bridges" dated October 28, 1991.

1.5.13.2 Department Application

HEC 18 will be used for the design, evaluation and inspection of bridges for scour. The scour discussion in Chapter 14 "Bridge Hydraulics" in the *South Dakota Drainage Manual* is based on HEC 18.

1.5.14 Hydraulic Engineering Circular 20 "Stream Stability at Highway Structures"

1.5.14.1 Description

HEC 20 provides guidelines for identifying stream instability problems at highway stream crossings. HEC 20 covers geomorphic and hydraulic factors that affect stream stability and provides a step-by-step analysis procedure for evaluation of stream stability problems. Stream channel classification, stream reconnaissance techniques and rapid assessment methods for channel stability are summarized. Quantitative techniques for channel stability analysis, including degradation analysis, are provided, and channel restoration concepts are introduced.

1.5.14.2 Department Application

SDDOT recommends that HEC 20 be used when assessing stream stability. HEC 20 has been used as a resource in the development of Chapter 14 "Bridge Hydraulics" in the *South Dakota Drainage Manual*.

1.5.15 Hydraulic Engineering Circular 21 "Design of Bridge Deck Drainage"

1.5.15.1 Description

HEC 21 supports sound, economic and low-maintenance designs for bridge deck drainage and bridge end drainage facilities. For the designer of bridge deck drainage systems, water and its removal is a many-faceted problem:

- water may collect in pools or run in sheets,
- water on roadways can slow traffic and cause hydroplaning, and
- snow or ice can make roadways slick and plug drains.

In addition to disrupting the main traffic function of the bridge, uncontrolled water from bridge decks can cause serious erosion of embankment slopes, settlement of pavement slabs, and stains or discoloration on substructure elements.

1.5.15.2 Department Application

SDDOT recommends that HEC 21 be used when designing drainage systems for bridge decks and bridge ends. This discussion in Chapter 14 "Bridge Hydraulics" in the *South Dakota Drainage Manual* is based on HEC 21.

1.5.16 Hydraulic Engineering Circular 22 "Urban Drainage Design Manual"

1.5.16.1 Description

HEC 22 provides a comprehensive and practical guide for the design of storm drainage systems associated with transportation facilities. Design guidance is provided for the design of storm drainage systems which collect, convey and discharge stormwater flowing within and along the highway right-of-way.

Methods and procedures are given for the hydraulic design of storm drainage systems. Design methods are presented for evaluating:

- rainfall and runoff magnitude,
- pavement drainage,
- gutter flow,
- inlet design,

- median and roadside ditch flow,
- structure design, and
- storm drain piping.

HEC 22 also presents procedures for the design of detention facilities and an overview of storm water pumping stations and urban water quality practices.

1.5.16.2 Department Application

SDDOT recommends that HEC 22 be used when designing storm drainage systems. The inlet design procedures are used in the FHWA Hydraulic Toolbox (see Section 18.2.4). Chapter 12 "Storm Drainage Systems" of the *South Dakota Drainage Manual* is based in part on HEC 22.

1.5.17 Hydraulic Engineering Circular 23 "Bridge Scour and Stream Instability Countermeasures"

1.5.17.1 Description

HEC 23 provides design guidelines for bridge scour and stream instability countermeasures that have been implemented by various State Departments of Transportation. Countermeasure experience, selection and design guidance are consolidated from other FHWA publications in this document to support a comprehensive analysis of scour and stream instability problems and provide a range of solutions to those problems. Selected innovative countermeasure concepts and guidance derived from practices outside the United States are also discussed. Management strategies for developing a Plan of Action for scour at critical bridges are outlined and guidance is provided for scour monitoring using portable and fixed instrumentation.

1.5.17.2 Department Application

SDDOT recommends that HEC 23 be used as a guide for designing countermeasures for stream instability and bridge scour. HEC 23 has been used as a resource in the development of Chapter 14 "Bridge Hydraulics" and Chapter 15 "Bank Protection" in the *South Dakota Drainage Manual*.