U.S. Department
of Transportation

**Federal Aviation
Administration**

Office of Airport Safety and Standards
Airport Engineering Division

800 Independence Ave., SW
Washington, DC 20591

July 13, 2004

Draft Advisory Circular (AC) 150/5320-5C, AIRPORT DRAINAGE which provides guidance for engineers, airport managers, and the public in the design and maintenance of airport surface and subsurface drainage systems is available for review.

The Federal Aviation Administration (FAA) evaluated options for revising the airport drainage manual and decided it would be beneficial to participate in a cooperative effort undertaken by the Department of Defense (DOD) to combine existing surface and subsurface drainage topics covered in different agency manuals into one Unified Facilities Criteria (UFC) document. The resulting manual/advisory circular will serve as the design and analysis standard for surface and subsurface drainage for DOD and the FAA. The current techniques and practices are being reviewed and evaluated in order to take advantage of recent advances in the field of pavement drainage engineering with attention to changes in drainage technology, national regulations, and local requirements.

As a result of a June 2004 review meeting with DOD agencies, a table will be inserted at the beginning of the document to list the policy and procedural differences that exist between the participating agencies. A separate technical expert panel is being assembled and will convene to finalize and incorporate agency comments.

The draft--consisting of 15 files--can be accessed from the following FAA internet website: http://www.faa.gov/arp/publications/acs/draftacs.cfm

Comments received no later than August 27, 2004, will be considered for inclusion in the final advisory circular. CD-ROM copies of this draft AC will be provided upon request (contact Jeff Rapol at 202-267-7474).

Sincerely,

Rick Marinelli
Manager, Airport Engineering Division

Attachment: Table of Contents AC 5320-5C

UFC 3-240-01/ AC 150/5320-5C
12 March 2004

UNIFIED FACILITIES CRITERIA (UFC)

SURFACE AND SUBSURFACE DRAINAGE

U.S. Department of Transportation
Federal Aviation Administration

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

UNIFIED FACILITIES CRITERIA (UFC)

SURFACE AND SUBSURFACE DRAINAGE[1]

Any copyrighted material included in this UFC is identified at its point of use.
Use of the copyrighted material apart from this UFC must have the permission of the copyright holder.

U.S. ARMY CORPS OF ENGINEERS (Preparing Activity)

NAVAL FACILITIES ENGINEERING COMMAND

AIR FORCE CIVIL ENGINEER SUPPORT AGENCY

Record of Changes (changes are indicated by **1**\ ... /**1**/)

Change No.	Date	Location

[1]This UFC supersedes TM 5-820-1/AFM 88-5, Chap 1, dated August 1987; TM 5-820-2/AFM 88-5, Chap 2, dated March 1979; TM 5-820-3/AFM 88-5, Chap 3, dated June 1991; TM 5-820-4/AFM 88-5, Chap 4, dated October 1983; TM 5-852-7/AFM 88-19, Chap 7, dated April 1981; NAVFAC DM 21.06, dated April 1986; EI 02C202, dated October 1995.

FOREWORD

The Unified Facilities Criteria (UFC) system as prescribed by MIL-STD 3007, provides planning, design, construction, operations, and maintenance criteria, and applies to all service commands having military construction responsibilities. UFC will be used for all service projects and work for other customers where appropriate.

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Command (NAVFAC), and Air Force Civil Engineer Support Agency (AFCESA) are responsible for administration of the UFC system. Technical content of UFC is the responsibility of the cognizant DoD working group. Recommended changes with supporting rationale should be sent to the respective service proponent office, as noted below. Defense agencies should contact the preparing service for document interpretation and improvements.

- HQUSACE, ATTN: CECW-E, 441 G Street, NW, Washington, DC 20314-1000, by electronic Criteria Change Request (CCR) form on the TECHINFO site listed below.
- Commander, Atlantic Division, Naval Facilities Engineering Command, 1510 Gilbert Street (ATTN: NAVFAC Engineering Innovation and Criteria Office), Norfolk, Virginia 23511-2699, or ufc@efdlant.navfac.navy.mil, by commercial telephone (757) 322-4200 or DSN 262-4200, or by facsimile machine to (757) 322-4416
- Air Force Civil Engineer Support Agency, 139 Barnes Drive, Tyndall Air Force Base, Florida 32403-5319, or larry.spangler@Tyndall.af.mil.

UFC are effective upon issuance. UFC are distributed only in electronic media from the following sources:

- USACE TECHINFO Internet site http://www.hnd.usace.army.mil/techinfo/index.htm.
- NAVFAC Engineering Innovation and Criteria Office Internet site http://criteria.navfac.navy.mil.
- Construction Criteria Base (CCB) system maintained by the National Institute of Building Sciences at Internet site http://www.nibs.org/ccb.

Hard copies of UFC printed from electronic media should be checked against the current electronic version prior to use to ensure that they are current.

AUTHORIZED BY:

Dwight A. Beranek, P.E. Chief, Engineering and Construction Division U.S. Army Corps of Engineers	Dr. James W Wright, P.E. Chief Engineer Naval Facilities Engineering Command
Michael Aimone, P.E. Deputy Civil Engineer Deputy Chief of Staff, Installations & Logistics Department of the Air Force	Frank Lane Director of Analysis & Investment Deputy Under Secretary of Defense for Installations Department of Defense

CONTENTS

Page

CHAPTER 1 INTRODUCTION

Paragraph 1-1 PURPOSE 1-1
1-2 SCOPE 1-1
1-3 REFERENCES 1-1
1-4 UNITS OF MEASUREMNET 1-1
1-5 APPLICABILITY 1-1
1-6 GENERAL INVESTIGATIONS 1-1
1-7 ENVIRONMENTAL CONSIDERATIONS 1-2
1-7.1 National Environmental Policy 1-2
1-7.2 Executive Orders 1-2
1-7.3 Environmental Considerations in DOD Actions 1-2
1-7.4 U.S. Army Environmental Quality Program 1-3
1-7.5 U.S. Air Force Environmental Quality Program 1-3
1-7.6 U.S. Navy Environmental Quality Program 1-4
1-7.7 FAA Environmental Quality Program 1-4
1-7.8 Environmental Impact Analysis 1-4
1-7.9 Environmental Effects of Surface Drainage Systems 1-5
1-7.10 Discharge Permits 1-5
1-7.11 Effects of Drainage Facilities on Fish 1-5
1-8 DESIGN COMPUTER PROGRAMS 1-6
1-8.1 Hydraulic Design Programs 1-6
1-8.2 Storm Water Management Programs 1-7
1-8.3 DRIP (Drainage Requirement in Pavements) 1-7
1-8.4 CANDE-89 (Culvert Analysis and Design) 1-7
1-8.5 MODBERG 1-8
1-8.6 DDSOFT (Drainage Design Software) 1-8
1-8.7 NDSOFT (Normal Depth Software) 1-8
1-8.8 PIPECAR 1-8
1-8.9 Visual Urban (HY-22) Urban Design Drainage Design Problems 1-8

CHAPTER 2 SURFACE HYDROLOGY

Paragraph 2-1 PURPOSE AND SCOPE 2-1
2-2 HYDROLOGIC CRITERIA 2-3
2-2.1 Definitions 2-3
2-2.2 Design Objectives 2-4
2-2.3 Degree of Drainage Required 2-4
2-3 RAINFALL 2-5
2-3.1 Design Storm Frequency 2-6
2-3.2 Storms of Greater Severity Than Design Storm 2-6

2-3.3 Design Storm Index 2-6
2-4 INFILTRATION 2-8
2-4.1 Definition 2-8
2-4.2 Variability 2-8
2-4.3 Rate 2-8
2-5 SNOWMELT 2-8
2-6 SUPPLY 2-9
2-6.1 Average Rates of Supply 2-9
2-6.2 Weighted Standard Supply Curves 2-9
2-7 RUNOFF 2-9
2-7.1 Notation 2-10
2-7.2 Overland Flow Equation 2-10
2-7.3 Effective Length 2-10
2-7.4 Ponding 2-10
2-7.5 Effect of Paved Area on Determination of Effective Length 2-11
2-7.6 Relation of Overland Flow is Standard Supply Curves 2-12
2-8 ICING 2-19
2-8.1 Description 2-19
2-8.2 Types 2-20
2-8.3 Natural Factors Conducive to Icing Formation 2-21
2-8.4 Effects of Man's Activities on Icing 2-21
2-8.5 Methods of Counteracting Icing 2-22
2-9 AREAS OTHER THAN AIRFIELDS 2-29
2-9.1 Design Storm 2-29
2-9.2 Infiltration and Other Losses 2-30
2-9.3 Runoff Computations 2-31

CHAPTER 3 SURFACE DRAINAGE FACILITIES FOR AIRFIELDS AND HELIPORTS

Paragraph 3-1 PURPOSE AND SCOPE 3-1
3-2 DESIGN OBJECTIVES FOR AIRFIELD AND HELIPORT SURFACE DRAINAGE 3-1
3-2.1 Surface Runoff From the Design Storm 3-1
3-2.2 Surface Runoff From Storms Exceeding the Design Storm 3-1
3-2.3 Reliability of Operation 3-1
3-2.4 Maintenance 3-1
3-2.5 Coordination 3-1
3-2.6 Safety Requirement 3-1
3-2.7 Future Expansion 3-1
3-2.8 Environmental Impact 3-1
3-3 DRAINAGE PROTECTION REQUIRED 3-2
3-3.1 Degree of Drainage Protection 3-2
3-3.2 Frequency of the Design Storm 3-2
3-4 HYDROLOGIC CONSIDERATIONS 3-2
3-4.1 Definitions 3-2

3-4.2 Design Methods 3-2
3-5 RAINFALL 3-3
3-5.1 Intensity-Frequency Data 3-3
3-5.2 Standard Rainfall Intensity-Duration Curves 3-3
3-5.3 Incomplete Data 3-3
3-5.4 Design Frequency 3-3
3-5.5 Storms of Greater Severity than the Design Storm 3-4
3-6 INFILTRATION 3-4
3-7 RATE OF SUPPLY 3-5
3-7.1 Average Rate of Supply 3-5
3-7.2 Weighted Standard Rate of Supply Curves 3-5
3-8 RUNOFF 3-5
3-8.1 Overland Flow 3-5
3-8.2 Effective Length 3-5
3-8.3 Maximum Rate of Runoff 3-6
3-9 STORAGE 3-6
3-10 DESIGN PROCEDURES FOR THE DRAINAGE SYSTEM 3-15
3-10.1 Information Required 3-15
3-10.2 Grading 3-15
3-10.3 Classification of Storm Drains 3-16
3-10.4 Storm-Drain Layout 3-17
3-10.5 Typical Design Procedures 3-19
3-11 DESIGN PROCEDURE 3-19
3-11.1 Rainfall 3-19
3-11.2 Effective Length 3-24
3-11.3 Runoff 3-25
3-11.4 Storage 3-27
3-11.5 Drain-Inlet and Drain Capacities 3-35

CHAPTER 4 HYDRAULICS AND DRAINAGE STRUCTURES

Paragraph 4-1 HYDRAULICS 4-1
4-1.1 Purpose 4-1
4-1.2 Scope 4-1
4-1.3 Problem Areas 4-1
4-1.4 Design 4-1
4-1.5 Outfall Considerations 4-2
4-1.6 Drainage Law 4-2
4-2 AIRFIELDS 4-3
4-2.1 Drainage Pipe 4-3
4-2.2 Inlets and Box Drains 4-12
4-2.3 Gutters 4-20
4-2.4 Storm Drains and Culverts 4-21
4-2.5 Open Channels 4-44
4-2.6 Chutes 4-51
4-2.7 Construction Drainage 4-56

4-2.8 Notation 4-57
4-3 FUEL/WATER SEPARATORS 4-59
4-4 AREAS OTHER THAN AIRFIELDS 4-59
4-4.1 General 4-59
4-4.2 Channels 4-59
4-4.3 Bridges 4-63
4-4.4 Curb-and-Gutter Sections 4-65
4-4.5 Culverts 4-67
4-4.6 Underground Hydraulic Design 4-102
4-4.7 Inlets 4-121
4-4.8 Vehicular Safety and Hydraulically Efficient Drainage Practice 4-127
4-4.9 Pipe Strength, Cover, and Bedding 4-129
4-4.10 Manholes and Junction Boxes 4-144
4-4.11 Detention Pond Storage 4-144
4-4.12 Outlet Energy Dissipators 4-144
4-4.13 Drop Structures and Check Dams 4-148
4-4.14 Miscellaneous Structures 4-148
4-4.15 Notation 4-150

CHAPTER 5 EROSION CONTROL AND RIPRAP PROTECTION

Paragraph 5-1 PLANNING AND DESIGN CONSIDERATIONS 5-1
5-2 RIPRAP PROTECTION 5-2
5-3 SELECTION OF STONE SIZE 5-2
5-4 RIPRAP GRADATION 5-2
5-5 RIPRAP DESIGN 5-3

CHAPTER 6 DESIGN OF SUBSURFACE DRAINAGE SYSTEMS

Paragraph 6-1 INTRODUCTION 6-1
6-1.1 Purpose 6-1
6-1.2 Scope 6-1
6-1.3 Definitions 6-1
6-1.4 Bibliography 6-3
6-1.5 Effects of Subsurface Water 6-3
6-1.6 Sources of Water 6-3
6-1.7 Subsurface Drainage Requirements 6-5
6-1.8 Laboratory Tests 6-5
6-1.9 Drainage of Water from Soil 6-5
6-2 PRINCIPLES OF PAVEMENT DRAINAGE 6-6
6-2.1 Flow of Water Through Soils 6-6
6-2.2 Factors Affecting Permeability 6-6
6-2.3 Quantity and Rate of Subsurface Flow 6-9
6-2.4 Use of Drainage Layers 6-13
6-2.5 Use of Filters 6-13

6-2.6 Use of Separation Layers 6-14
6-2.7 Use of Geotextiles 6-15
6-3 DESIGN OF THE PAVEMENT SUBSURFACE DRAINAGE SYSTEM 6-15
6-3.1 General 6-15
6-3.2 Methods 6-15
6-3.3 Design Prerequisites 6-16
6-3.4 Criteria for Subsurface Drain Systems 6-18
6-3.5 Placement of Subsurface Drainage System 6-20
6-3.6 Material Properties 6-22
6-4 STABILIZATION OF DRAINAGE LAYER 6-24
6-4.1 General 6-24
6-4.2 Choke Stone Stabilization 6-24
6-4.3 Asphalt Stabilization 6-24
6-4.4 Cement Stabilization 6-24
6-5 CONSTRUCTION OF THE DRAINAGE LAYER 6-25
6-5.1 Experience 6-25
6-5.2 Placement of Drainage Layer 6-25
6-5.3 Compaction 6-25
6-5.4 Protection After Compaction 6-25
6-5.5 Proof Rolling 6-26
6-6 COLLECTOR DRAINS 6-26
6-6.1 Design Flow 6-26
6-6.2 Design of Collector Drains 6-27
6-6.3 Trench Construction 6-30
6-6.4 Lateral Outlet Pipe 6-32
6-6.5 Cross Drains 6-34
6-6.6 Manholes and Observation 6-35
6-7 MAINTENANCE OF SUBSURFACE DRAINAGE SYSTEMS 6-35
6-7.1 Monitoring Program 6-35
6-7.2 Maintenance Guidelines 6-36

CHAPTER 7 FROST PROTECTION DESIGN FOR AIRFIELD PAVEMENTS

Paragraph 7-1 SCOPE 7-1
7-2 RELATED CRITERIA 7-1
7-3 DEFINITIONS 7-1
7-3.1 Average Daily Temperature 7-1
7-3.2 Degree Days 7-1
7-3.3 Design Freezing Index 7-1
7-3.4 Freezing Index 7-1
7-3.5 Frost 7-2
7-3.6 Mean Daily Temperature 7-2
7-3.7 Mean Freezing Index 7-2
7-4 EFFECTS OF FROST ACTION 7-3
7-4.1 Frost Heaving 7-3

7-4.2 Formation of Ice Lenses 7-3
7-4.3 Thawing and Reduction in Bearing Capacity 7-3
7-5 GENERAL PRELIMINARY DESIGN DATA 7-3
7-6 INVESTIGATION FOR FROST DESIGN 7-4
7-6.1 Subsoil Investigations 7-4
7-6.2 Classification of Soils for Frost Susceptibility 7-5
7-6.3 Temperature Design Values 7-5
7-6.4 Local Frost Data 7-6
7-6.5 Water Source for Ice Formation 7-6
7-7 FROST PROTECTION DESIGN 7-7
7-7.1 Need for Frost Protection 7-7
7-7.2 Design Approach 7-7
7-7.3 Design to Prevent Subgrade Freezing 7-7
7-7.4 Design to Limit Frost Penetration in Subgrade 7-8

CHAPTER 8 GUIDELINES FOR DESIGN OF STORM DRAINS IN THE ARCTIC AND SUBARCTIC

Paragraph 8-1 GENERAL 8-1
8-2 GRADING 8-2
8-3 TEMPORARY STORAGE 8-2
8-4 COMPUTATION OF STORM DRAIN CAPACITIES 8-3
8-5 MATERIALS 8-3
8-6 STRUCTURAL DESIGN 8-3
8-7 SERVICE LIFE AND DURABILITY 8-3
8-7.1 Corrosion 8-4
8-7.2 Abrasion 8-4
8-8 SHAPE OF DRAINAGE STRUCTURES 8-4
8-9 MAINTENANCE 8-4
8-10 JOINTING 8-4
8-11 END PROTECTION 8-4
8-12 ANCHORAGE AND BUOYANCY 8-5
8-13 PIPING 8-5
8-14 DEBRIS AND ICING CONTROL 8-5
8-15 TIDAL AND FLOOD EFFECTS 8-6
8-16 FISH PASSAGE 8-6
8-17 EROSION CONTROL 8-6
8-18 INSTALLATION 8-6
8-19 SAFETY REQUIREMENTS 8-6

APPENDIX A REFERENCES A-1

APPENDIX B BIBILIOGRAPHY B-1

APPENDIX C DESIGN EXAMPLES C-1

APPENDIX D COVER TABLES D-1

FIGURES

Figure	Title	
2-1	Design Storm Index for Alaska and Canada	2-1
2-2	Design Storm Index, 1-hour Rainfall Intensity-Frequency Data for Continental United States Excluding Alaska	2-5
2-3	Supply Curves for Arctic and Subarctic Regions	2-6
2-4	Rates of Runoff and Rates of Supply Corresponding to Standard Supply Curves No. 2.0 and 2.2; n = 0.40 and S = 1 percent	2-7
2-5	Airfield Drainage-Overland Flow Relations. Modification in L required to compensate for differences in n and S	2-11
2-6	Retardance Coefficients for Flow in Turfed Channels	2-12
2-7	Supply Curve No. 0.2	2-13
2-8	Supply Curve No. 0.4	2-14
2-9	Supply Curve No. 0.6	2-15
2-10	Supply Curve No. 0.8	2-16
2-11	Supply Curve No. 1.0	2-17
2-12	Supply Curve No. 1.2	2-18
2-13	Typical Cross Section of a Frost Belt Installation	2-27
2-14	Earth Embankments with Impervious Barriers	2-28
3-1	Standard Rainfall Intensity-Duration Curves or Standard Supply Curves	3-4
3-2	Rates of Runoff Corresponding to Supply Curves No. 0.4 and 0.6; n = 0.40 and S = 1 percent	3-7
3-3	Rates of Runoff Corresponding to Supply Curves No. 0.6 and 1.0; n = 0.40 and S = 1 percent	3-8
3-4	Rates of Runoff Corresponding to Supply Curves No. 1.2 and 1.4; n = 0.40 and S = 1 percent	3-9
3-5	Rates of Runoff Corresponding to Supply Curves No. 1.6 and 1.8; n = 0.40 and S = 1 percent	3-10
3-6	Rates of Runoff Corresponding to Supply Curves No. 2.0 and 2.2; n = 0.40 and S = 1 percent	3-11
3-7	Rates of Runoff Corresponding to Supply Curves No. 2.4 and 2.6; n = 0.40 and S = 1 percent	3-12
3-8	Rates of Runoff Corresponding to Supply Curves No. 2.8 and 3.0; n = 0.40 and S = 1 percent	3-13
3-9	Rates of Runoff Corresponding to Supply Curves No. 3.2 and 3.4; n = 0.40 and S = 1 percent	3-14
3-10	Diagram for Estimating 2-yr 2-hr Rainfall	3-19
3-11	Rates of Runoff Versus Duration of Supply for Turfed Areas; L = 20, 40, 60, 80, 100, and 125 ft	3-22
3-12	Rates of Runoff Versus Duration of Supply for Turfed Areas; L = 150, 200, 250, 300, 400, 500, and 600 ft	3-22
3-13	Rates of Runoff Versus Duration of Supply for Turfed Areas, L = 800, 1,000, and 1,200 ft	3-23

3-14 Computation of Hydrograph to Represent Runoff from a Supply of Specified Duration 3-23
3-15 Consolidated Design Curve Composite of Peak Runoff Rates and Critical Durations of Supply Shown in Figures 3-7 through 3-14 3-27
3-16 Sample Computations of Storage Required with Selected Drain-Inlet Capacity to Provide for Runoff from an Acre of Turf Under Assumptions Designated 3-29
3-17 Drain-Inlet Capacity Versus Maximum Surface Storage; L = 0 and 40 ft 3-30
3-18 Drain-Inlet Capacity Versus Maximum Surface Storage; L = 100 and 200 ft 3-31
3-19 Drain-Inlet Capacity Versus Maximum Surface Storage; L = 300 and 400 ft 3-32
3-20 Drain-Inlet Capacity Versus Maximum Surface Storage; L = 600 and 800 ft 3-33
3-21 Drain-Inlet Capacity Versus Maximum Surface Storage; L – 1,000 and 1,200 ft 3-34
3-22 Nomograph for Computing Required Size of Circular Drain Smooth Interior, Flowing Full; n = 0.012 3-37
3-23 Nomograph for Computing Required Size of Circular Standard Corrugated Metal Pipe, 25 percent Paved Invert, Flowing Full; n = 0.021 3-38
3-24 Nomograph for Computing Required Size of Circular Standard Corrugated Metal Pipe, Unpaved, Flowing Full; n = 0.021 3-39
3-25 Nomograph for Computing Required Size of Circular Structural Plate Pipe, Unpaved, Flowing Full; n= 0.033 3-40
4-1 Three Main Classes of Conduits 4-6
4-2 Free-Body Conduit Diagrams 4-7
4-3 Trench Beddings for Circular Pipe 4-8
4-4 Beddings for Positive Projecting Conduits 4-9
4-5 Installation Conditions Which Influence Loads on Underground Conduits 4-9
4-6 Determination of Typical Inlet Grating Discharge Curve 4-14
4-7 Examples of Typical Inlet Grates 4-16
4-8 Examples of Inlet Design 4-17
4-9 Typical Inlet and Box Drain Designs for Airfield and Heliport Storm Drainage Systems 4-18
4-10 Repair Box Drains 4-19
4-11 Drainage Gutters for Runways and Aprons 4-21
4-12 Culvert Headwalls and Wingwalls 4-23
4-13 Types of Scour at Storm-Drain and Culvert Outlets 4-24
4-14 Square Culvert-Froude Number 4-26
4-15 Predicted Scour Depth Versus Observed Scour Depth 4-27
4-16 Predicted Scour Width Versus Observed Scour Width 4-28
4-17 Predicted Scour Length Versus Observed Scour Length 4-29
4-18 Predicted Scour Volume Versus Observed Scour Volume 4-30

4-19 Dimensionless Scour Hole Geometry for Minimum Tailwater 4-31
4-20 Dimensionless Scour Hole Geometry for Maximum Tailwater 4-31
4-21 Recommended Size of Protective Stone 4-33
4-22 Length of Stone Protection, Horizontal Blanket 4-33
4-23 Recommended Configuration of Riprap Blanket Subject to Minimum and Maximum Tailwaters..... 4-34
4-24 Preformed Scour Hole 4-34
4-25 Culvert Outlet Erosion Protection, Lined Channel Expansion 4-35
4-26 Maximum Permissible Discharge for Lined Channel Expansions 4-35
4-27 Flared Outlet Transition 4-36
4-28 Stilling Well 4-37
4-29 U.S. Bureau of Reclamation Impact Basin..... 4-38
4-30 Saint Anthony Falls Stilling Basin..... 4-39
4-31 Design Chart for SAF Stilling Basin 4-41
4-32 Recommended Riprap Sizes 4-43
4-33 Scour Hole Riprap Sizes..... 4-44
4-34 Retardance Coefficients for Flow in Turfed Channels..... 4-46
4-35 Details and Design Chart for Typical Drop Structure 4-49
4-36 Details and Typical Drainage Chute..... 4-51
4-37 Details of Typical Drop Intake 4-53
4-38 Drop Structure Calibration Curve..... 4-54
4-39 Air Entrainment in Chute Flow 4-55
4-40 Superelevation Formulas 4-62
4-41 Nomograph for Flow in Triangular Channels 4-66
4-42 Inlet Control 4-71
4-43 Headwater Depth for Concrete Pipe Culverts with Inlet Control 4-72
4-44 Headwater Depth for Oval Concrete Pipe Culverts Long Axis Vertical with Inlet Control 4-73
4-45 Headwater Depth for Oval Concrete Pipe Culverts Long Axis Horizontal with Inlet Control 4-74
4-46 Headwater Depth for Corrugated Metal Pipe Culverts with Inlet Control 4-75
4-47 Headwater Depth for Structural Plate and Standard Corrugated Metal Pipe-Arch Culverts with Inlet Control..... 4-76
4-48 Headwater Depth for Box Culverts with Inlet Control 4-77
4-49 Headwater Depth for Corrugated Metal Pipe Culverts with Tapered Inlet-Inlet Controls..... 4-78
4-50 Headwater Depth for Circular Pipe Culverts with Beveled Ring Inlet Control 4-79
4-51 Outlet Control..... 4-80
4-52 Head for Circular Pipe Culverts Flowing Full, n = 0.012 4-83
4-53 Head for Oval Circular Pipe Culverts Long Axis Horizontal or Vertical Flowing Full, n = 0.012..... 4-84
4-54 Head for Circular Pipe Culverts Flowing Full, n = 0.024 4-85
4-55 Head for Circular Pipe Culverts Flowing Full, n = 0.0328 to 0.0302..... 4-86

4-56 Head for Standard Corrugated Metal Pipe-Arch Culverts Flowing Full, n = 0.024 4-87
4-57 Head for Field-Bolted Structural Plate Pipe-Arch Culverts 18 in. Corner Radius Flowing Full, n = 0.0327 to 0.0306 4-88
4-58 Head for Concrete Box Culverts Flowing Full, n = 0.012 4-89
4-59 Tailwater Elevation at or Above Top of Culvert 4-90
4-60 Tailwater Below the Top of the Culvert 4-91
4-61 Circular Pipe—Critical Depth 4-92
4-62 Oval Concrete Pipe Long Axis Horizontal Critical Depth 4-93
4-63 Oval Concrete Pipe Long Axis Vertical Critical Depth 4-94
4-64 Standard Corrugated Metal Pipe-Arch Critical Depth 4-95
4-65 Structural Plate Pipe-Arch Critical Depth 4-98
4-66 Critical Depth Rectangular Section 4-99
4-67 Culvert Capacity Circular Concrete Pipe Groove-Edged Entrance 18 in. to 66 in. 4-103
4-68 Culvert Capacity Circular Concrete Pipe Groove-Edged Entrance 60 in. to 180 in. 4-104
4-69 Culvert Capacity Standard Circular Corrugations Metal Pipe Projecting Entrance 18 in. to 36 in. 4-105
4-70 Culvert Capacity Standard Circular Corrugations Metal Projecting Entrance 36 in. to 66 in. 4-106
4-71 Culvert Capacity Standard Circular Corrugations Metal Headwall Entrance 18 in. to 36 in. 4-107
4-72 Culvert Capacity Standard Circular Corrugations Metal Headwall Entrance 36 in. to 66 in. 4-108
4-73 Culvert Capacity Standard Corrugations Metal Pipe-Arch Projecting Entrance 25 in. by 16 in. to 43 in. by 27 in. 4-109
4-74 Culvert Capacity Standard Corrugations Metal Pipe Arch Projecting Entrance 50 in. by 31 in. to 72 in. by 44 in. 4-110
4-75 Culvert Capacity Standard Corrugations Metal Pipe-Arch Headwall Entrance 25 in. by 16 in. to 43 in. by 27 in. 4-111
4-76 Culvert Capacity Standard Corrugations Metal Pipe-Arch Headwall Entrance 50 in. by 31 in. to 72 in. by 44 in. 4-112
4-77 Culvert Capacity Square Concrete Box 90 Degree and 15 Degree Wingwall Flare 1.5 ft by 1.5 ft to 7 ft by 7 ft 4-113
4-78 Culvert Capacity Square Concrete Box 30 Degree and 75 Degree Wingwall Flare 1.5 ft by 1.5 ft to 7 ft by 7 ft 4-114
4-79 Culvert Capacity Rectangular Concrete Box 90 Degree and 15 Degree Wingwall Flare 1.5 ft, 2.0 ft, and 2.5 ft Heights 4-115
4-80 Culvert Capacity Rectangular Concrete Box 90 Degree and 15 Degree Wingwall Flare 3 ft and 4 ft Heights 4-116
4-81 Culvert Capacity Rectangular Concrete Box 90 Degree and 15 Degree Wingwall Flare 5 ft and 6 ft Heights 4-117
4-82 Culvert Capacity Rectangular Concrete Box 30 Degree and 75 Degree Wingwall Flare 1.5 ft, 2.0 ft, and 2.5 ft Heights 4-118

4-83 Culvert Capacity Rectangular Concrete Box 30 Degree and 75 Degree Wingwall Flare 3 ft and 4 ft Heights 4-119
4-84 Culvert Capacity Rectangular Concrete Box 30 Degree and 75 Degree Wingwall Flare 5 ft and 6 ft Heights 4-120
4-85 Capacity of Grate Inlet in Sump Water Pond on Gate 4-124
4-86 Capacity of Curb Opening Inlet at Low Point in Grade 4-125
4-87 Standard Type “A” and Type “B” Inlets 4-128
4-88 Type “C” Inlet—Square Grating 4-129
4-89 Standard Type “D” Inlet 4-130
4-90 Standard Storm Drain Manhole 4-146
4-91 Standard Precast Manholes 4-147
4-92 Junction Details for Large Pipes 4-147
4-93 Outlet Security Barrier 4-149
6-1 Collector Drain Used to Remove Infiltration Water 6-4
6-2 Collector Drain to Intercept Seepage and Lower the Ground-Water Table 6-4
6-3 Permeability Test Data (from Lambe and Whitman, with permission) 6-8
6-4 Pavement Geometry for Computation of Time for Drainage 6-12
6-5 Design Storm Index, 1-hr Rainfall Intensity-Frequency Data for Continental United States Excluding Alaska 6-16
6-6 Drainage Layer Placed Beneath Base Course 6-21
6-7 Drainage Layer Placed Directly Below Surface Layer 6-21
6-8 Plan View of Subsurface Drainage System 6-27
6-9 Typical Concrete Pavement Interior Subdrain Detail 6-28
6-10 Typical Edge Subdrain Detail for Flexible Pavements 6-28
6-11 Typical Flexible Pavement Interior Subdrain Detail 6-29
6-12 Typical Edge Subdrain Detail for Flexible Pavements 6-29
6-13 Schematic of Dual Outlet System Layout (Baumgardner 1998) 6-33
6-14 Illustration of Large-Radius Bends Recommended for Drainage Outlet 6-33
6-15 Recommended Outlet Design Detail 6-33
6-16 Example Design for a Headwall 6-34
7-1 Example Determination of Freezing Index 7-2
7-2 Upward Movement of Moisture into Base Course During Thaw Period 7-4
7-3 Distribution of Design Freezing Index Values in the Continental United States 7-6
7-4 Empirical Relationship Between Freezing Index and Frost 7-8
C-1 Drainage Problem: Airfield in Subarctic Region – Hangar, Taxiway and Apron C-1
C-2 Modular Framework of the DRIP Program C-7
C-3 The Opening Screen of DRIP C-8
C-4 The Design and Analysis Window C-8
C-5 Roadway Geometry Design Window C-11
C-6 Sieve Analysis Window for Permeable Bases C-13

C-7 Time to Drain Design Window C-15
C-8 DRIP Window for Aggregate Separator Layer Design C-17
C-9 Pipe Edgedrain Design Window..... C-19
C-10 Sample Computations of Layout of Primary Storm Drainage System..... C-20
C-11 Froude Number and Depth of Flow Required for Incipient Tranport of Cohesionless Material..... C-44
C-12 Depth of Flow and Unit Discharge for Incipient Transport of Cohesionless Material..... C-45
C-13 Flow Characteristics of Trapezoidal Channels with 1V-on-3H Side Slopes..... C-47
C-14 Froude Number and Depth of Flow for Incipient Failure of Riprap-Lines Channel..... C-48
C-15 Depth of Flow and Unit Discharge of Incipient Failure of Riprap-Lined Channel..... C-49
C-16 Flow Characteristics of Rectangular Channels C-51
C-17 Discharge Characteristics of Various Channels..... C-52
C-18 Design Example – Solution One C-55
C-19 Design Example – Solution Two C-56

TABLES

Table	Title	
2-1	Retardance of Coefficients for Overland Flow	2-11
2-2	Rates of Overland Flow Corresponding to Intensities Shown on Supply Curve 0.2 in Figure 2-2	2-19
2-3	Typical Values of Infiltration Rates	2-31
3-1	Approximate Intensity-Frequency Values	3-20
3-2	Rates of Runoff Corresponding to Intensities and Durations of Supply Represented by Standard Supply Curve No. 2 in Figure 3-5 (n = 0.40, S = 1 percent)	3-26
3-3	Design Example	3-28
4-1	Roughness Coefficients for Various Pipes	4-4
4-2	Maximum Cover Height Reduction Factors for Riveted and Bolted Seams	4-6
4-3	Suggested Coefficients of Roughness and Maximum Permissible Mean Velocities for Open Channels in Military Construction	4-45
4-4	Entrance Loss Coefficients, Outlet Control, Full or Partly Full Entrance Head Loss, $H_e = K_e \frac{V^2}{2g}$	4-82
4-5	Manning's n for Natural Stream Channels (Surface Width at Flood Stage Less Than 100 ft)	4-91
4-6	Suggested Maximum Cover Requirements for Asbestos-Cement Pipe H-20 Highway Loading	4-134
4-7	Suggested Maximum Cover Requirements for Concrete Pipe, Reinforced Concrete, H-20 Highway Loading	4-135
4-8	Suggested Maximum Cover Requirements for Corrugated-Aluminum-Alloy Pipe, Riveted, Helical, or Welded Fabrication 2-2/3-in. Spacing, 1/2-in.-Deep Corrugations, H-20 Highway Loading	4-136
4-9	Suggested Maximum Cover Requirements for Corrugated-Steel-Pipe, 2-2/3-in. Spacing, 1/2-in.-Deep Corrugations	4-137
4-10	Suggested Maximum Cover Requirements for Structural-Plate-Aluminum-Alloy Pipe, 9-in. Spacing, 2-1/2-in Corrugations	4-138
4-11	Suggested Maximum Cover Requirements for Corrugated Steel Pipe, 125-mm Span, 25-mm-Deep Corrugations	4-139
4-12	Suggested Maximum Cover Requirements for Structural Plate Steel Pipe, 6-in. Span, 2-in.-Deep Corrugations	4-140
4-13	Suggested Maximum Cover Requirements for Corrugated Steel Pipe, 3-in. Span, 1-in. Corrugations	4-142
4-14	Suggested Guidelines for Minimum Cover	4-143
4-15	Maximum Permissible Mean Velocities to Prevent Scour	4-145
6-1	Coefficient of Permeability for Sand and Gravel Materials. Coefficient of 55	6-7

6-2 Frost-Susceptible Soils 6-17
6-3 Gradations of Materials for Drainage Layers and Choke Stone 6-22
6-4 Properties of Material for Drainage Layers 6-23
6-5 Criteria for Granular Separation Layer 6-23
6-6 Criteria for Filter Fabric to be Used as a Separation Layer 6-24
6-7 Coefficient of Roughness for Different Types of Pipe 6-30
6-8 Criteria for Fabrics Used in Trench Construction 6-31
6-9 Equipment Description or FHWA Video Inspection Study (Daleiden 1998) 6-36
C-1 Airfield Drainage – Drain Inlet Capacities Required Drainage Section: Taxiway, Hangar and Aprons C-3
C-2 Airfield Drainage – Size and Profile of Underground Storm Drains – Drainage Section: Taxiway, Hangar and Aprons C-4
C-3 Quality of Drainage Rating for Highways and Airfield Pavements C-15
C-4 Airfield Drainage Drain-Inlet Capacities Required to Limit Ponding to Permissible Volumes with Drainage Section on East Side of Airfield and with Supply Curves No. 2.0 for Paved Areas and 1.5 for Turfed Areas C-21
C-5 Airfield Drainage Size and Profile of Underground Storm Drains with Drainage Section on East Side of Airfield and with Supply Curves No. 2.0 for Paved Areas and 1.5 for Turfed Areas C-24
C-6 Hydraulic Design Data on Underground Storm Drains where Ponding is Permissible C-27
C-7 Airfield Drainage Drain-Inlet Capacities Required to Limit Ponding to Permissible Volumes with Drainage Section in which no Ponding of Runoff is Assumed and with Supply Curves No. 2.0 for Paved Areas and 1.5 for Turfed Areas C-30
C-8 Airfield Drainage Size and Profile of Underground Storm Drains with Drainage Section in which no Ponding of Runoff is Assumed and with Supply Curves No. 2.0 for Paved Areas and 1.5 for Turfed Areas C-32
C-9 Hydraulic Design Data on Underground Storm Drains where Ponding is not Acceptable C-33