Contents

Chapter 1 Design Policy 1-1
1-1 General 1-1
1-2 Responsibility 1-2
1-3 Hydraulic Reports 1-3
1-4 Storm Frequency Policy and Recommended Software/Design Tools 1-8
1-5 Hydraulic Report Review Schedule 1-11
Appendix 1-1 Conversion Table 1-14
Appendix 1-2 Environmental Documentation 1-15
Appendix 1-3 Hydraulic Report Outline 1-16
Appendix 1-4 Hydraulic Report Checklist 1-17

Chapter 2 Hydrology 2-1
2-1 General Hydrology 2-1
2-2 Selecting a Method 2-2
2-3 Drainage Basin 2-5
2-4 Cold Climate Considerations 2-5
2-4.1 Calculating Snowmelt 2-5
2-4.2 Additional Considerations 2-6
2-5 The Rational Method 2-7
2-5.1 General 2-7
2-5.2 Runoff Coefficients 2-8
2-5.3 Time of Concentration 2-10
2-5.4 Rainfall Intensity 2-13
2-5.5 Rational Formula Example 2-16
2-6 Single-Event Hydrograph Method: Santa Barbara Urban Hydrograph 2-16
2-6.1 Design Storm Hyetograph 2-17
2-6.2 Runoff Parameters 2-18
2-6.3 Hydrograph Synthesis 2-22
2-6.4 Level Pool Routing 2-23
2-6.5 Hydrograph Summation 2-24
2-7 Continuous Simulation Method (Western Washington Only for Stormwater) 2-24
2-7.1 Modeling Requirements 2-25
2-8 Published Flow Records 2-28
2-9 USGS Regression Equations 2-29
2-10 Flood Reports 2-31
2-11 Mean Annual Runoff 2-32
Appendix 2-1 USGS Streamflow Gage Peak Flow Records 2-33
Appendix 2-2 USGS Regression Equations 2-93
Appendix 2-3 Isopluvial and MAP Web Links and Mean Annual Runoff Data 2-103

Chapter 3 Culvert Design 3-1
3-1 Overview 3-1
3-1.1 Metric Units and English Units. 3-1
3-2 Culvert Design Documentation 3-2
3-2.1 Common Culvert Shapes and Terminology 3-2
3-2.2 Hydraulic Reports 3-3
3-2.3 Required Field Data 3-3
3-2.4 Engineering Analysis 3-5
3-3 Hydraulic Design of Culverts 3-7
3-3.1 Culvert Design Flows 3-8
3-3.1.1 Precast Reinforced Concrete Three Sided Structure 3-9
3-3.1.2 Additional Requirement for Culverts Over 20′ 3-10
3-3.1.3 Alignment and Grade. 3-10
3-3.1.4 Allowable Grade 3-10
3-3.1.5 Minimum Spacing 3-11
3-3.1.6 Culvert Extension. 3-11
3-3.1.1 Temporary Culverts 3-12
3-3.2 Allowable Headwater 3-12
3-3.2.1 General. 3-12
3-3.2.2 Allowable Headwater for Circular and Box Culverts and Pipe Arches 3-13
3-3.2.3 Allowable Headwater for Bottomless Culverts 3-15
3-3.3 Tailwater Conditions. 3-15
3.3.4 Flow Control 3-16
3-3.4.1 Culverts Flowing With Inlet Control 3-16
3-3.4.2 Calculating Headwater for Inlet Control 3-17
3-3.4.4 Calculating Headwater for Outlet Control. 3-26
3-3.4.5 Outlet Control Nomographs. 3-28
3-3.5 Velocities in Culverts — General 3-42
3-3.5.1 Calculating Outlet Velocities for Culverts in Inlet Control 3-43
3-3.5.2 Calculating Outlet Velocities for Culverts in Outlet Control 3-44
3-3.6 Culvert Hydraulic Calculations Form. 3-50
3-3.7 Computer Programs 3-55
3-3.8 Example 3-56
3-4 Culvert End Treatments 3-61
3-4.1 Projecting Ends 3-61
3-4.2 Beveled End Sections 3-62
3-4.3 Flared End Sections 3-63
3-4.4 Headwalls and Slope Collars 3-64
3-4.5 Wingwalls and Aprons 3-65
3-4.6 Improved Inlets 3-66
3-4.7 Energy Dissipators 3-67
3-4.8 Culvert Debris. 3-68
3-5 Miscellaneous Culvert Design Considerations 3-72
3-5.1 Multiple Culvert Openings 3-72
3-5.2 Camber 3-73
3-5.5 Angle Points 3-73
3-5.6 Upstream Ponding. 3-74
3-5.7 Misc Design Considerations – Siphons 3-75

Chapter 4 Open Channel Flow 4-1
4-1 General 4-1
4-2 Determining Channel Velocities 4-2
4-2.1 Field Measurement 4-3
4-2.2 Manning's Equation 4-4
4-2.2.1 Hand Calculations 4-5
4-2.2.2 Field Slope Measurements 4-8
4-2.2.3 Manning's Equation in Sections 4-9
4-3 Roadside Ditch Design Criteria 4-11
4-4 Critical Depth 4-11
4-4.1 Example Critical Depth in a Rectangular Channel 4-13
4-4.2 Example Critical Depth in a Triangular Channel 4-13
4-4.3 Example Critical Depth in a Trapezoidal Channel 4-14
4-4.3 Example Critical Depth in a Circular Shaped Channel 4-14
4-5 River Backwater Analysis 4-14
4-6 River Stabilization 4-16
4-6.1 Bank Barbs 4-17
4-6.1.1 Riprap Sizing for Bank Barbs 4-20
4-6.1.2 Riprap Placement for Bank Barbs 4-22
4-6.1.3 Vegetation 4-22
4-6.2 Drop Structures 4-23
4-6.3 Riprap Bank Protection 4-25
4-6.3.1 Riprap Sizing for Bank Protection 4-26
4-6.3.2 Placement of Riprap Bank Protection 4-29
4-6.3.3 Scour Analysis for Bridges and Three Sided Culverts 4-30
4-6.4 Engineered Log Jams and Large Woody Debris 4-31
4-7 Downstream Analysis 4-32
4-7.1 Downstream Analysis Reports 4-33
4-7.2 Review of Resources 4-33
4-7.3 Inspection of Drainage Conveyance System 4-34
4-7.4 Analysis of Off Site Affects 4-34
4-8 Weirs 4-35
4-8.1 Rectangular Weirs 4-36
4-8.2 V-Notch Weirs 4-37
4-8.3 Trapezoidal or Cipoletti Weirs 4-37
Appendix 4-1 Manning's Roughness Coefficients (n) 4-1

Chapter 5 Drainage of Highway Pavements 5-1
5-1 Roadway and Structure Geometrics and Drainage 5-1
5-2 Hydrology 5-2
5-3 Rural Highway Drainage 5-2
5-3.1 Downstream End of Bridge Drainage 5-3
5-3.2 Slotted Drains and Trench Systems 5-3
5-3.3 Drop Inlets 5-4
5-4 Gutter Flow 5-4
5-5 Grate Inlets and Catch Basins 5-6
5-5.1 Inlet Types 5-7
5-5.2 Capacity of Inlets on a Continuous Grade 5-12
5-5.3 Side Flow Interception 5-14
5-5.4 Capacity of Inlets in Sag Locations 5-20
5-6 Hydroplaning and Hydrodynamic Drag 5-26

Chapter 6 Storm Drains 6-1
6-1 Introduction 6-1
6-2 Design Criteria 6-2
6-3 Data for Hydraulics Report 6-5
6-4 Storm Drain Design – Handheld Calculator Method 6-6
6-4.1 General 6-6
6-4.2 Location 6-6
6-4.3 Discharge 6-6
6-4.4 Drain Design Section 6-9
6-4.5 Drain Profile 6-11
6-4.6 Remarks 6-11
6-5 Storm Drain Design – Computer Analysis 6-11
6-6 Hydraulic Grade Line 6-12
6-6.1 Friction Losses in Pipes 6-14
6-6.2 Junction Entrance and Exit Losses 6-14
6-6.3 Losses From Changes in Direction of Flow 6-15
6-6.4 Losses From Multiple Entering Flows 6-16
6-7 Drywells 6-17
6-8 Pipe Materials for Storm Drains 6-17
6-9 Subsurface Drainage 6-18

Chapter 7 Fish Passage 7-1
7-1 Introduction 7-1
7-2 Designing for Fish Passage 7-1
7-2.1 General 7-1
7-2.2 Types of Structures 7-2
7-2.3 Culvert Design Approach 7-2
7-2. River Training Devices 7-3

Chapter 8 Pipe Classifications and Materials 8-3
8-1 Classifications of Pipe 8-3
8-1.1 Drain Pipe 8-4
8-1.2 Underdrain Pipe 8-4
8-1.3 Culvert Pipe 8-5
8-1.4 Storm Sewer Pipe 8-9
8-1.5 Sanitary Sewer Pipe 8-10
8-2 Pipe Materials 8-11
8-2.1 Concrete Pipe 8-11
8-2.2 Metal Pipe – General 8-13
8-2.3 Thermoplastic Pipe – General. 8-16
8-2.4 Ductile Iron Pipe. 8-20
8-2.5 Solid Wall HDPE 8-20
8-3 Vacant. 8-20
8-4 Pipe Corrosion Zones and Pipe Alternate Selection 8-20
8-4.1 Corrosion Zone I. 8-21
8-4.2 Corrosion Zone II 8-22
8-4.3 Corrosion Zone III 8-23
8-5 Corrosion 8-29
8-5.1 pH 8-29
8-5.2 Resistivity 8-30
8-5.3 Methods for Controlling Corrosion 8-30
8-6 Abrasion. 8-32
8-7 Pipe Joints 8-34
8-8 Pipe Anchors 8-35
8-8.1 Thrust Blocks 8-35
8-9 Pipe Rehabilitation and Abandonment. 8-35
8-9.1 Pipe Replacement 8-35
8-9.2 Trenchless Techniques for Pipe Replacement. 8-36
8-10 Pipe Design 8-37
8-10.1 Categories of Structural Materials 8-37
8-10.2 Structural Behavior of Flexible Pipes. 8-37
8-10.3 Structural Behavior of Rigid Pipes 8-38
8-10.4 Foundations, Bedding, and Backfill 8-39
8-11 Structural Analysis and Fill Height Tables 8-40
8-11.1 Pipe Cover. 8-40
8-11.2 Shallow Cover Installation 8-40
8-11.3 Fill Height Tables 8-42