Manual

Road Drainage

July 2015

Queensland Government

Feedback: Please send your feedback regarding this document to: tmr.techdocs@tmr.qld.gov.au

Contents

1 Framework 1

1.1 Introduction 1

1.1.1 Overview of 2nd Edition of the Road Drainage Manual 1
1.1.2 Applicability of this manual 1
1.1.3 Importance of road drainage 2
1.1.4 Reference documents and manuals (including relationship to Austroads' Guide to Road Design) 2
1.1.5 Structure of this manual 3

1.2 Limits of manual 4

1.2.1 General 4
1.2.2 Hydrology/hydraulics 5
1.2.3 Environmental design 7
1.2.4 Catchment hydrology 7

1.3 Road infrastructure delivery 8

1.3.1 Introduction 8

1.4 Legislation and policy 8

1.4.1 Introduction 8
1.4.2 Relevant legislation and other authorities 8
1.4.3 Key aspects of road drainage policy 9
1.4.4 Community engagement 9
1.4.5 Effects on landowners 10

1.5 Guiding principles 11

1.5.1 Drainage infrastructure and land use 11
1.5.2 Assessment of future development 12
1.5.3 General hydraulic and environmental consideration 12
1.5.4 Economic considerations 13
1.5.5 Maintenance 13

1.6 Drainage issues 13

1.6.1 Planning the drainage system 13
1.6.2 Urban drainage 14
1.6.3 Rural drainage systems 14

1.7 Climate change 15

1.7.1 Rainfall and floods 15
1.7.2 Sea level 16
1.7.3 Conclusion and recommendations 17

2 General design requirements 18

2.1 Introduction 18

2.1.1 Definitions 18
2.1.2 Determining and understanding requirements 18
2.1.3 Immunity criteria 19
2.1.4 Design life/service life 19
2.1.5 Reducing the cost of drainage infrastructure 20

2.2 Road locality 20

2.2.1 Road environment 20
2.2.2 External environment 20

2.3 Design considerations 21

2.3.1 Identifying design considerations 21
2.3.2 Geometric considerations 21
2.3.3 Geographic considerations 21
2.3.4 Environmental considerations 22
2.3.5 Selection of drainage infrastructure 22

2.3.6 Maintenance considerations ... 25
2.3.7 Safety considerations ... 26
2.3.8 General construction considerations ... 26
2.3.9 Staged construction of roads ... 27

2.4 Design controls ... 29

2.5 Design criteria ... 29
2.5.1 Terminology ... 29
2.5.2 General hydraulic criteria ... 31
2.5.3 Cross-drainage criteria ... 38
2.5.4 Longitudinal drainage criteria ... 39
2.5.5 Road surface drainage criteria ... 41
2.5.6 Immunity criteria for the National Land Transport Network ... 41
2.5.7 Immunity criteria for state-controlled roads – rural catchments ... 41
2.5.8 Immunity criteria for state-controlled roads – urban catchments ... 42
2.5.9 Environmental criteria ... 43

2.6 Water sensitive urban design ... 43

2.7 Extreme rainfall events and providing resilient infrastructure ... 44
2.7.1 Erodible soil environments ... 45
2.7.2 Excessive flooding ... 45

2.8 'Self cleaning' sections ... 45

3 Strategic planning and development control ... 46

3.1 Introduction ... 46

3.2 Strategic planning ... 46
3.2.1 Introduction ... 46
3.2.2 Flood immunity ... 46
3.2.3 Community impacts ... 48
3.2.4 Acceptance of a lower standard ... 50

3.3 Development control ... 50
3.3.1 Introduction ... 50
3.3.2 Departmental impacts ... 51
3.3.3 Development impacts ... 52
3.3.4 System augmentation ... 54

4 Data collection ... 56

4.1 Introduction ... 56

4.2 Types of data ... 56
4.2.1 Strategic data ... 57
4.2.2 Project data ... 59
4.2.3 Sources of data ... 60

4.3 Environmental assessment ... 61
4.3.1 Vegetation ... 61
4.3.2 Fauna ... 62

4.4 Forms and checklists ... 63

4.5 Field inspections ... 63

4.6 Rainfall ... 64

4.7 Flood data ... 64

4.8 Drainage and flow patterns ... 66

4.9 Waterway characteristics ... 66

4.10 Water quality data ... 67

4.11 Topography ... 68

4.12 Soils 68
4.12.1 Natural soils 68
4.12.2 Acid sulphate soil information 69
4.13 Existing infrastructure 69
4.14 Survey 70
4.14.1 Aerial imagery 70
4A Appendix: Data collection checklist 71
5 Hydrology 75
5.1 Introduction 75
5.2 Rainfall 75
5.3 Rainfall – runoff relationship 75
5.4 Methods available for runoff calculation 75
5.5 Rational method 75
5.6 Catchment area 75
5.7 Time of concentration 75
5.7.1 General 75
5.7.2 Rural catchments 75
5.7.3 Urban catchments 76
5.8 Rainfall intensity – frequency – duration 76
5.9 Runoff coefficient 76
5.9.1 Rural catchments 76
5.9.2 Urban catchments 76
5.9.3 Adjustment factors 76
5.10 Partial area effects 77
5.10.1 Rural catchments 77
5.10.2 Urban catchments 77
5.11 Progressive catchments 77
5.12 Worked example (rural): rural runoff 77
5.13 Worked example (urban): urban runoff 77
6 Approach to drainage design 78
6.1 Overview 78
6.2 Geometric design of drainage 79
6.3 Computer modelling of drainage solutions 80
6.4 Preliminary selection decisions 80
6.5 Bridges 82
6.5.1 Overview 82
6.5.2 Riparian and wildlife corridors 82
6.5.3 Bridge location and waterway alignment 82
6.5.4 Bridge geometry 82
6.5.5 Road grade and hydraulic clearance 83
6.5.6 Span lengths and pier location 83
6.5.7 Scour protection 83
6.5.8 Overtopping 83
6.5.9 Maintenance 83
6.6 Culvert size and type 83
6.7 Open channels 83

6.8 Bank protection and linings ... 84

6.9 Longitudinal drainage ... 84

6.10 Location ... 85

6.10.1 Location example ... 86
6.10.2 Culvert locations ... 86

6.11 Water quality ... 86

7 Environmental consideration and design ... 88

7.1 Introduction ... 88

7.2 Legislative requirements and general environmental duty ... 88

7.3 Environmental values and water quality objectives ... 88

7.4 Pollution control: water quality ... 88

7.4.1 Establishing pollution control requirements ... 89

7.5 Water quality treatment devices and design guidelines ... 98

7.5.1 Filter strips ... 98
7.5.2 Grassed swales ... 100
7.5.3 Trash racks ... 102
7.5.4 Proprietary devices ... 104
7.5.5 Constructed wetlands ... 105
7.5.6 Buffer zones ... 108
7.5.7 Water quality ponds ... 109

7.6 Fauna passage ... 110

7.6.1 Identifying fauna passage criteria ... 110
7.6.2 Identify terrestrial and aquatic fauna pathways ... 111
7.6.3 Identify the species group ... 111
7.6.4 Consult with the relevant authority ... 111
7.6.5 Identify criteria affecting drainage design ... 112

8 Open channel design ... 113

8.1 Introduction ... 113

8.1.1 Open channels ... 113

8.2 General considerations ... 113

8.3 Local authority requirements ... 113

8.4 Fundamentals of open channel flow ... 114

8.4.1 Stream dynamics ... 114
8.4.2 Assumptions for analysis ... 114
8.4.3 Fundamental equations ... 114
8.4.4 Application of fundamental equations ... 116
8.4.5 Energy principles ... 116
8.4.6 Hydraulic jump ... 116
8.4.7 Hydraulic drop ... 116

8.5 Erosive velocities in natural streams ... 116

8.6 Backwater ... 116

8.6.1 Tidal waters ... 116
8.6.2 Downstream tributary ... 116

8.7 Tailwater levels ... 117

8.7.1 Tailwater effects ... 117
8.7.2 Design tailwater levels ... 117

8.8 Open channel design ... 117

8.8.1 Design methodology ... 117
8.8.2 Channel transitions ... 117

8.8.3 Energy losses in channel bends ... 117
8.8.4 Superelevation in channel bends ... 117
8.9 Grassed channels ... 117
8.9.1 Normal grassed channels ... 117
8.9.2 Reinforced grassed channels ... 117
8.10 Channels lined with hard facings ... 118
8.10.1 General ... 118
8.10.2 Riprap and rock filled wire mattresses/gabions ... 118
8.10.3 Concrete lined channels ... 118
8.11 Channel drops ... 118
8.12 Baffle chutes ... 118
8.13 Worked examples ... 118
9 Culvert design ... 119
9.1 Introduction ... 119
9.1.1 Overview ... 119
9.1.2 Constructability ... 119
9.1.3 Computer programs ... 120
9.2 General requirements ... 120
9.2.1 Pipe joint types ... 120
9.2.2 Geometric tolerances and cover requirements ... 121
9.2.3 Skew angle/skew number ... 121
9.2.4 Minimum culvert size ... 121
9.2.5 Outlet flow velocity ... 121
9.2.6 Structural and configuration requirements of culverts ... 122
9.2.7 Culverts in expansive soil areas ... 128
9.2.8 Flap gates (tides and floods) ... 134
9.2.9 Multiple barrels ... 135
9.2.10 Reduction in culvert size ... 135
9.2.11 Splay pipes ... 135
9.3 General process for culvert design ... 136
9.4 Location of culverts ... 138
9.5 Allowable headwater ... 139
9.6 Preliminary selection of culvert size ... 140
9.7 Requirements for fauna passage ... 140
9.7.1 Considerations for fish passage ... 140
9.7.2 Culvert specifications for fish passage ... 140
9.7.3 Considerations for terrestrial passage ... 140
9.7.4 Culvert features for fauna passage ... 140
9.7.5 Stock underpass ... 142
9.8 Selection of culvert type ... 142
9.9 Typical culvert operating conditions ... 143
9.9.1 Inlet control conditions ... 143
9.9.2 Outlet control conditions ... 143
9.10 Hydraulic calculations ... 143
9.10.1 Control at inlet ... 143
9.10.2 Control at outlet ... 143
9.10.3 Determination of tailwater ... 143
9.11 Design procedure ... 143
9.11.1 Hydraulic design ... 144
9.11.2 Practical design ... 144

9.12 Minimum energy loss culverts 144
9.13 Blockage of culverts 145
9.14 Consideration of large or extreme events 145
9.15 Culvert outlet protection 145
9.16 Special energy dissipation structures at culvert outlets 146
9.17 'Self cleaning' culverts 146
9.18 Inlet structures 146
9.19 Managing sediment 147
9.20 Safety 147
9.20.1 Culverts used as walkways and bikeways 147
9.20.2 Barriers to flow 147
9.20.3 Additional safety considerations 148
9.21 Designing for resilience 148
9.21.1 Specific design criteria for downstream protection of road embankments at culverts 148
9.22 Worked examples 149
9A Appendix: Design form 150
9B Appendix: Structural assessment/decision process 151
9C Appendix: Structural failure risk assessment 152
9D Appendix: Culvert wingwall length calculations 154
10 Floodway design 156
10.1 Introduction 156
10.2 Additional considerations 156
10.3 Geometric and safety issues 157
10.4 Environmental factors 157
10.5 Hydraulic design 157
10.5.1 Floodway terminology 157
10.5.2 Flow over the road 157
10.5.3 Full floodway design calculations 157
10.6 Time of submergence/closure 157
10.6.1 Time of submergence 157
10.6.2 Time of closure 157
10.6.3 Issues related to times 158
10.6.4 Calculation of time of submergence or closure 158
10.6.5 Procedure for estimating AATOC/AATOS 158
10.7 Floodway protection 158
10.7.1 Types of protection 158
10.7.2 Floodways with grassed batters 158
10.7.3 Floodways with other than grassed batters 158
10.8 Worked examples 159
10A Appendix: Worked examples 160
11 Road surface and subsurface drainage design 162
11.1 Introduction 162
11.1.1 Road surface flows 162
11.1.2 Subsurface flows 163

11.2 Road surface drainage 163

11.2.1 Pavement runoff 163
11.2.2 Roadway flow width criteria. 163
11.2.3 Kerb and channel flow 167
11.2.4 Edge and median drainage 168
11.2.5 Table drains and table drain blocks 169
11.2.6 Diversion drains and diversion blocks 169
11.2.7 Batter drains 170
11.2.8 Catch drains and catch banks 170
11.2.9 Road batter stabilisation 170
11.2.10 Drainage pits 171
11.2.11 Access chambers 179
11.2.12 Access chamber tops 179
11.2.13 Reduction in pipe size 179
11.2.14 Surcharge chambers 179
11.2.15 Pipeline requirements 179
11.2.16 Splay pipes 180
11.2.17 Structural requirements of pipelines 180
11.2.18 Flow velocity limits 180
11.2.19 Pipe grade limits 180
11.2.20 Discharge calculations 180
11.2.21 General design procedure 181
11.2.22 Hydraulic calculations 181

11.3 Aquaplaning 181

11.3.1 What is aquaplaning? 181
11.3.2 Causal factors 182
11.3.3 Road surfacing 182
11.3.4 Tyres 182
11.3.5 The road-tyre interface 182
11.3.6 Skid resistance 182
11.3.7 Assessment – water film depth 182
11.3.8 Assessment – aquaplaning potential 183
11.3.9 Quick assessment 183
11.3.10 Puddles/wheel ruts 183
11.3.11 Guidance to reduce aquaplaning potential 183
11.3.12 Worked example 183

11.4 Subsurface drainage 183

11.4.1 Moisture in roads 184
11.4.2 Control of road moisture 185
11.4.3 Types of subsurface drainage 186
11.4.4 Requirements of filter materials 190
11.4.5 Design procedure 191
11.4.6 Location of subsoil drains 191
11.4.7 Transverse subsurface drains 194
11.4.8 Cut-off drains 194
11.4.9 Design of cut-off drains 194
11.4.10 Size of drain 194
11.4.11 Materials 194
11.4.12 Access to subsurface drains 194
11.4.13 Lowering of ground water table 195
11.4.14 Schilfgaarde's Method 195
11.4.15 Draining an inclined aquifer 195
11.4.16 Design of a filter blanket to lower a water table 195
11.4.17 Capillary rise in soils 195

12 Basins 196

12.1 Overview 196

12.2 Detention basins 196

12.2.1 Introduction ... 196
12.2.2 Advantages and disadvantages of detention basins ... 196
12.2.3 Initial design and feasibility ... 196
12.2.4 Simple hydrologic method of routing ... 196
12.2.5 Other design considerations ... 196

12.3 Extended detention basin ... 196

12.3.1 Description ... 196
12.3.2 Design guidelines ... 197

12.4 Sediment basins ... 197

12.4.1 Description ... 197
12.4.2 Design procedure – Sediment basin for temporary erosion and sediment control ... 197
12.4.3 Design procedure – Sediment basin for permanent stormwater treatment ... 197

13 Erosion and sediment control ... 198

13.1 Introduction ... 198

14 Operation, maintenance and remediation ... 200

14.1 Introduction ... 200

14.2 Legal aspects ... 200

14.3 Operation ... 200

14.3.1 Period of inspection ... 200
14.3.2 Performance ... 200
14.3.3 Reporting of deficiencies ... 200

14.4 Maintenance ... 201

14.4.1 The maintenance process ... 201
14.4.2 Types of maintenance ... 201
14.4.3 Metal culverts ... 201

14.5 Drainage failures ... 201

14.5.1 Introduction ... 201
14.5.2 Causes of failure ... 201
14.5.3 Types of failure ... 201
14.5.4 Environmental impacts of failures ... 201
14.5.5 Identifying failures ... 201
14.5.6 Reporting of failures ... 201

14.6 Remediation ... 201

14.6.1 Introduction ... 201
14.6.2 Remediation options ... 202
14.6.3 Evaluation ... 202
14.6.4 Metal culverts ... 202

Glossary ... 203

References ... 216

Tables

Table 1.1.5 – Structure of this Road Drainage Manual ... 4

Table 2.5.1 – EY, AEP, ARI preferred usage (shading indicates term to use used) (adapted from BoM 2013) ... 31

Table 2.5.7 – Design immunity criteria for state-controlled rural roads ... 42

Table 2.5.8 – Design immunity criteria for state-controlled urban roads ... 43

Table 4.3.1 – Data sources 62
Table 4A.1 – Environmental assessment 71
Table 4A.2 – Vegetation coverage 71
Table 4A.3 – Other forms and checklists 71
Table 4A.4 – Field inspections 72
Table 4A.5 – Rainfall 72
Table 4A.6 – Flood data 72
Table 4A.7 – Drainage and flow patterns 73
Table 4A.8 – Waterway characteristics 73
Table 4A.9 – Water quality data 74
Table 4A.10 – Topography 74
Table 4A.11 – Soils 74
Table 4A.12 – Existing infrastructure 74
Table 6.4 – Preliminary selection of drainage infrastructure 81
Table 7.4.1.2– Design objectives for management of stormwater quality 91
Table 7.4.1.6 – Design elements associated with treatment devices 95
Table 7.4.1.7 – Pollutant removal performance of various treatment devices 97
Table 7.6.4 – Commonly triggered legislation for the protection of fauna 111
Table 9.2.7.5 – Required tests 132
Table 9.8 – Culvert types for different conditions 143
Table 9C.1 – Risk rating – major 152
Table 9C.2 – Risk rating – W = 375 to 600 mm 152
Table 9C.3 – Risk rating – W = 675 to 1200 mm 153
Table 9C.4 – Risk rating – W = 1350 to 1800 mm* 153
Table 9D.1 – Culvert description and symbols 154
Table 10A.1 – Times of submergence 160
Table 10A.2 – Average annual times of submergence 161
Table 11.2.2.2 – Roadway flow limitations – major storm 167

Figures

Figure 2.3.5.1 – Primary drainage infrastructure types 23
Figure 3.2.2 – Murray River Crossing of Bruce Highway 47
Figure 3.2.3.3 – Flooding in Mackay 50

Figure 3.3.3 – Detention basin in a residential subdivision 52

Figure 4.7 – Annual median rainfall for Queensland 65

Figure 7.5.1.1 – Grass filter strip 98

Figure 7.5.3.1(a) – Trash rack 102

Figure 7.5.3.1(b) – Trash rack and pollutants 103

Figure 8.4.3 – Natural streams in Queensland 114

Figure 9.2.3 – Skew angle/skew number 121

Figure 9.2.6.6 – Slab link box culvert under construction 126

Figure 9.2.6.8(a) – Corrugated steel pipes 127

Figure 9.2.6.8(b) – Culvert lining detail 128

Figure 9.2.7(a) – Longitudinal cracking of apron failure 129

Figure 9.2.7(b) – Vertical displacement of apron failure 129

Figure 9.2.7.3 – Failure mechanism of base slabs in expansive soils 131

Figure 9.5 – Box culverts with riprap 139

Figure 9.7.4 – Koala fencing 141

Figure 9.12 – Minimum energy loss culvert on Gateway Motorway 144

Figure 9C(a) – Structural risk assessment – minor culverts 153

Figure 9D – Culvert wingwall length calculations 155

Figure 10.1 – Little Annan River floodway 156

Figure 10.6.3 – Typical deck level/time of submergence relationship 158

Figure 10A(a) – Plotted design floods 160

Figure 11.2.2.1(a) – Allowable flow widths on roadways –10% AEP (≈ ARI 10-year) flood (cross-section views) 164

Figure 11.2.2.1(b) – Allowable flow widths on roadways – 10% AEP (≈ ARI 10-year) flood (plan views) 165

Figure 11.2.3.1(a) – General kerb profiles or shapes 168

Figure 11.2.3.1(b) – Edge treatment at erodible slopes 168

Figure 11.2.10.2 – Procedure to determine kerb inlet positions on grade 174

Figure 11.2.10.7(a) – Field inlet under weir flow 176

Figure 11.2.10.7 (b) – Under orifice flow conditions 176

Figure 11.2.10.7(c) – Minimum lip width required for scour protection 178

Figure 11.4.1 – Sources of moisture (Adapted from ARRB (1987)) 185

Figure 11.4.3(a) – Drainage for surface infiltration with subsoil drains 186

Figure 11.4.3(b) – Drainage for surface infiltration with free draining layer 187

Figure 11.4.3(c) – Drainage trenches to lower water table 187

Figure 11.4.3(d) – Horizontal filter blanket to lower water table.. 187

Figure 11.4.3(e) – Trenches to intercept flow through an inclined permeable layer........................... 188

Figure 11.4.3(f) – Permeable filter to lower the effect of head from a permeable aquifer 188

Figure 11.4.3(g) – Standard subsoil drains 189

Figure 11.4.3(h) – Subsoil drain outlets and cleanouts.. 190

Figure 11.4.6(a) – Location of subsoil drains (divided road)... 192

Figure 11.4.6(b) – Subsoil drains – Low embankment or transition from embankment to cut............ 192

Figure 11.4.6(c) – Subsoil drains in cuttings 193

Figure 11.4.6(d) – Transverse, strip filter subsurface drain 194

1 Framework

1.1 Introduction

1.1.1 Overview of 2nd Edition of the *Road Drainage Manual*

The *Road Drainage Manual*, 2nd Edition, sets out a multi-disciplinary approach to the provision of drainage infrastructure. It is a guide to those involved in the planning, design, operation and maintenance of road drainage infrastructure for small, simple rural and urban catchments. It does not include the hydrology/hydraulics for major waterways and/or floodplains, complex catchments or significant drainage structures such as bridges. The sizing and location of drainage structures are addressed by taking into account relevant hydraulic, environmental, safety and maintenance requirements.

In 2014, the 2nd Edition of the *Road Drainage Manual* was edited to incorporate and cross-reference formally to the Austroads *Guide to Road Design – Drainage Set* (Parts 5, 5A and 5B). Further details of this update and its effects on how the manual is to be read are presented in Section 1.1.4. In addition, the department has adopted the Australian Rainfall and Runoff (ARR) approach on describing the occurrence of flood events. These changes are detailed in Section 2.5.1.

Previous guidance on the effects of climate change and the allowances to be made for departmental drainage designs has been reviewed and updated. A discussion of this review and the resulting recommendations are presented in Section 1.7. Ongoing review of this issue is required and will continue.

1.1.2 Applicability of this manual

This manual represents the policy of the Department of Transport and Main Roads with respect to the planning, design, operation and maintenance of road drainage infrastructure and must be applied on all road infrastructure projects for which the department is responsible. As such, the manual applies equally to all personnel, departmental or not, that are involved in the drainage aspects of departmental projects, including:

- departmental management
- departmental and/or consulting project (preconstruction/design/construction/maintenance) managers
- planners (strategic/project/town)
- development control officers
- civil designers (engineers/technologists/designers)
- surveyors
- environmental scientists/engineers
- geologists/geotechnical engineers
- construction/maintenance personnel.

This manual facilitates the development and implementation of drainage solutions for state-controlled roads and roads within Queensland that are part of the National Land Transport Network (Auslink). It operates from Phase 3 *Corridor planning and stewardship* to Phase 6 *Program finalisation* of the department's Road System Manager Framework and, therefore, provides guidance in relation to the sustainable planning, design, construction, operation and maintenance of most road drainage infrastructure in both urban and rural environments throughout Queensland. Limitations to the application and use of this manual are outlined in Section 1.2.

The manual is to be used by appropriately qualified and experienced personnel or others who have received appropriate training and are supervised by qualified and experienced personnel.

The manual also integrates best practice and environmental management techniques into the provision of road drainage. It includes technical governance requirements for the selection, design and construction of appropriate drainage structures that satisfy hydraulic requirements while minimising the potential for environmental and asset harm.

1.1.3 Importance of road drainage

It is recognised that a road requires a drainage system to deal with stormwater runoff; therefore, the drainage system becomes an important and integral consideration in the planning and design of road infrastructure.

To provide an appropriate and economic drainage system, all road projects (irrespective of location, size, cost or complexity) must consider and address:

- provision of an acceptable level of flood immunity and accessibility
- effects of flooding of public and private property
- conveyance of stormwater through the road reserve at a developmental and environmental cost that is acceptable to the community as a whole
- protection of the roadway asset
- safety of all road users
- pollutant discharge from the road reserve to receiving waters
- land degradation caused by erosion and sedimentation during road construction, operation and maintenance
- any effect on habitats for terrestrial and aquatic flora and fauna
- any effect on the movement of terrestrial and aquatic fauna.

This requirement particularly applies to projects where it is proposed to keep the existing drainage infrastructure. The original design intent must be reviewed and understood, and the existing system needs to be assessed against the aspects listed previously for performance, adequacy and continued durability. Design must ensure that the original intent is restored, deficiencies corrected and modifications/changes appropriately considered and detailed.

1.1.4 Reference documents and manuals (including relationship to Austroads' *Guide to Road Design*)

This manual is underpinned by an integrated, multi-disciplinary approach: that is, the user of this manual must focus at all times on the consideration of hydrologic, hydraulic, environmental, surrounding land use, maintenance and safety factors and whole-of-life costs. Typically, these factors should be considered concurrently.

In using this manual, reference will need to be made to other departmental documents developed to assist in the planning, design, construction and maintenance of drainage infrastructure on state-controlled roads in Queensland.

These reference documents include:

- *Road Planning and Design Manual* (2nd edition) (RPDM)
- *Guidelines for Strategic Road Network Planning*
- *Road Project Environmental Processes Manual*
- *Environmental Legislation Register*
- *Road Landscape Manual*
- *Roads in the Wet Tropics Manual*
- *Soil Management Manual.*

Drainage is an integral component of road infrastructure. Drainage design cannot be separated from the overall road planning and design process. Drainage must always be considered in conjunction with the geometric design of a road. It is important to note that the department's RPDM is its primary road design reference. Although this *Road Drainage Manual* has been published as a separate document, it has a complementary relationship with the RPDM and, therefore, planners and designers, in particular, must use these two manuals in conjunction with each other.

In the interest of national uniformity and eliminating duplication of material, the RPDM has been restructured to refer users primarily to the Austroads *Guide to Road Design* series for its technical requirements. In recognition of the merit in this, this *Road Drainage Manual*, while retaining its previous structure, has also been updated to refer users, wherever practical, directly to the content in the Austroads *Guide to Road Design* – Drainage Set, comprising:

- Part 5: *Drainage – General and Hydrology Considerations*
- Part 5A: *Drainage – Road Surface, Networks, Basins and Subsurface*
- Part 5B: *Drainage – Open Channels, Culverts and Floodways*.

Where such references are made, the relevant section in Austroads *Guide to Road Design* – Parts 5, 5A or 5B will be quoted as being accepted or accepted with amendments and the corresponding content will have been removed from this *Road Drainage Manual*. Where a section of the Austroads *Guide to Road Design* is accepted with amendments, the amendments can take one of two forms:

1. **Addition(s)**: where the *Road Drainage Manual* provides additional guidance specific to departmental policies and practices.
2. **Difference(s)**: where the *Road Drainage Manual* provides guidance specific to departmental policies and practices, to be used instead of that contained within the quoted sections of Austroads *Guide to Road Design*.

1.1.5 Structure of this manual

This manual has been designed so that, at any stage of drainage infrastructure delivery, users can refer to the chapter or section that is applicable to their needs; however, reference to other chapters and manuals will be required. To facilitate this, references have been made to other, relevant sections of this manual, other manuals, guidelines and policies where possible. In particular, as described in

Section 1.1.4, the user will now be referred, wherever practical, directly to the content in Austroads *Guide to Road Design* — Parts 5, 5A and 5B. Additionally, checklists and flow charts are provided throughout this manual to assist the user to proceed from section to section of this manual.

Table 1.1.5 outlines the structure of this manual. It should be noted that, apart from Chapter 13, all chapters contain direct cross-references to Austroads *Guide to Road Design* — Parts 5, 5A and 5B.

Table 1.1.5 – Structure of this Road Drainage Manual

Chapter	Title of chapter	Purpose of chapter(s)
1	Framework	Sets the context and limitations of this manual
2	General Design Requirements	Defines the general design requirements (including considerations, controls, criteria and standards) for planning and design
3	Strategic Planning and Development Control	Defines the base drainage requirements for strategic planning (Road Route Strategies and Road Link Plans) and development applications
4	Data Collection	Defines strategic and project data Establishes importance of data collection and retrieval\ Describes the data collection process and identifies sources of data
5	Hydrology	Describes the processes for determining and analysing hydrologic data to quantify specific design criteria
6	Approach to Drainage Design	Describes the design methodology and process to be followed for drainage components
7	Environmental Consideration and Design	Provides guidance for understanding environmental assessments and the consideration of requirements in design
8	Open Channel Design	
9	Culvert Design	
10	Floodway Design	
11	Road Surface and Subsurface Drainage Design	
12	Basins	Provides hydraulic design methods for design of various basins
13	Erosion and Sediment Control	Provides the requirements for drainage in construction
14	Operation, Maintenance and Remediation	Emphasises the importance of performance monitoring and maintenance of drainage infrastructure
	Glossary	
	References	

1.2 Limits of manual

1.2.1 General

The following sections outline the limitations placed on civil designers in road drainage design and the use of this manual; furthermore, it should be noted that this manual is not a complete drainage guide covering all aspects of road drainage. It is a guide for small, simple rural and urban catchments only and does not include, in detail, the hydrology/hydraulics for major waterways and/or floodplains, complex catchments or significant drainage structures (such as bridges).

1.2.2 Hydrology/hydraulics

This section details the requirements placed on internal and consulting engineering services regarding hydrologic assessment and hydraulic design.

1.2.2.1 Departmental civil designers

Departmental civil designers engaging in drainage design must be suitably qualified; that is, have demonstrated capability in drainage design.

1.2.2.2 Approved software for use by departmental civil designers

Software packages deemed approved for use on projects by departmental civil designers are:

- Hydrology:
  - RAIN (departmental software)
  - Bureau of Meteorology (BoM) website
- Hydraulic design:
  - Drainage, Drainage analysis and Drainage dynamic modules within 12d Model™
  - PC DRAIN™
  - DRAINS™
  - CulvertMaster and FlowMaster®
- 3D modelling and quantity calculation
  - CULVERT (departmental software) (refer Section 1.2.2.5).

Use of any other software package must be approved in writing by Director (Road Design), Road Design section, Engineering & Technology Branch; refer also to Sections 1.2.2.5, 1.2.2.6 and 1.2.2.7.

1.2.2.3 Prequalification of consultant engineers and designers

Engineering consultants must be prequalified with the department in the prequalification category of hydraulic design before providing any drainage advice or undertaking any drainage design or review on behalf of the department.

1.2.2.4 Approved software for use by prequalified consultants

Software packages approved for use on departmental projects by prequalified consultants are:

- Hydrology:
  - RAIN (departmental software)
  - RORB
  - RAFTS™
  - URBS™
  - WBNM
  - Bureau of Meteorology (BoM) website

- Hydraulic design:
  - Drainage, Drainage analysis and Drainage dynamic modules within 12d Model™
  - HEC-RAS
  - MIKE 11™
  - PC DRAIN™
  - DRAINS™
  - SWMM™, XPSTORM™
  - CulvertMaster and FlowMaster®
- 3D modelling and quantity calculation
  - CULVERT (departmental software) (refer Section 1.2.2.5)
- Hydraulic design – 2D Modelling:
  - SOBEK™, DELFT-FLS™
  - MIKE FLOOD™, MIKE 21™
  - TUFLOW™
  - SMS™
- Water quality:
  - MUSIC™
  - AQUALM™.

The department may allow prequalified consultants to use other software packages, but use of any other software package must be approved in writing by Director (Hydraulics and Flooding), Hydraulics and Flooding Section, Engineering and Technology Branch.

Refer also to Sections 1.2.2.5, 1.2.2.6 and 1.2.2.7.

1.2.2.5 Mandated software for use by all civil designers

The department may require the use of specific software on projects. This requirement will be specified either within this manual and/or the relevant project documentation.

All departmental designers and prequalified consultants are required to undertake 3D modelling and quantity calculation of cross-drainage (culvert) infrastructure using the department's CULVERT software. Using this program ensures departmental processes and practices are followed for:

- drawing drainage cross-sections (such as location, skew, invert heights, culvert component details, bedding and backfill material quantities, and so on) when used within 12d Model™, and
- producing a culvert electronic model that allows splicing into and storage with the project electronic model when used within 12d Model™.

1.2.2.6 Other computer-based tools

Further to Sections 1.2.2.2 and 1.2.2.4, any spreadsheet or computer-based tool developed and then used to assist with drainage design must be checked and tested for applicability, accuracy of results and compliance to current standards and methodologies as prescribed in this manual/departmental Standard Specifications and Standard Drawings. Certification of design is deemed to cover use of these spreadsheets/tools.

1.2.2.7 Currency of software

While it is desirable that all software packages used, as listed in Sections 1.2.2.2 and 1.2.2.4, be the latest version, it is not a requirement; however, it is a requirement that project workings must clearly state the software package and version being used.

It is also a requirement that users check/test software to be used for compliance with current standards and methodologies as prescribed in this manual/departmental Standard Specifications and Standard Drawings. There is often a time lag between the release of updated manuals/standards/specifications and updates to software packages. Where software is not compliant and difference is minor (major differences would prohibit use), any output must be adjusted accordingly and adjustments recorded and checked.

Again, certification of design is deemed to cover this requirement.

1.2.2.8 Structural design of drainage elements

This manual does not cover the structural design of drainage elements and structures. While there are standard designs for many drainage elements, non-standard drainage elements and structures must be referred to the department's Bridge and Marine Engineering section located within the Engineering and Technology Branch or suitably prequalified consultants. Where design is conducted by a suitably prequalified consultant, design must be approved by the department's Bridge and Marine Engineering section.

Examples of these non-standard structural drainage elements include:

- all bridges
- any proposal to replace an existing bridge with a culvert
- any culvert installation using non-standard components.

1.2.3 Environmental design

While this manual promotes environmentally sustainable drainage, it does not give guidance on all relevant environmental design considerations and criteria. Project-specific requirements as defined in environmental approvals, licences and permits will need to be incorporated. Further information on environmental design is included in Chapter 7.

1.2.4 Catchment hydrology

Sections 6.4.1 and 6.4.2 of the Austroads Guide to Road Design – Part 5 are accepted for this section, subject to:

Addition(s)

1. Designs and/or reviews of designs involving complex catchment characteristics are beyond the capability of rational method and more detailed computer modelling is generally required. In these cases, a project should be referred to the department's Hydraulics and Flooding Section or suitably prequalified consultants.

Complex urban catchments include:

- retention/detention basins or other flood storage areas
- complex flow path(s) and/or channel system.

1.3 Road infrastructure delivery

1.3.1 Introduction

The department's delivery process for road infrastructure is described in the RPDM, Volume 3, Part 8.

Drainage requirements are normally established during the identification of the project solution options and selection process.

Actual information and data inputs for drainage projects are usually enhanced as investigations are progressively completed and the solutions developed through an iterative process. This can occur over several years and may involve various studies that are commissioned during the project solution identification process. The outputs from these studies usually identify a range of issues to be addressed by the designer. The issues are included in a design report with the designer, including statements on how these issues were considered and incorporated into the design.

All drainage risks are to be recorded in a register with all risks being mitigated or removed as the design evolves. Remaining risks at the end of the design development process are to be costed and the total cost included in the project estimate contingency amount.

1.4 Legislation and policy

1.4.1 Introduction

The department has obligations under state and federal legislation, as well as state government policies.

The department also provides direction through a number of key corporate documents, including the department's strategic plan, road network strategy, roads implementation program and sustainability framework and statement.

1.4.2 Relevant legislation and other authorities

The following Queensland legislative acts are most pertinent to road drainage:

- *Aboriginal Cultural Heritage Act 2003*
- *Torres Strait Islander Cultural Heritage Act 2003*
- *Nature Conservation Act 1992*
- *Land Act 1994*
- *Coastal Protection and Management Act 1995*
- *Environmental Protection Act 1994*
- *Fisheries Act 1994*
- *Professional Engineers Act 2002*
- *Sustainable Planning Act 2009*
- *Soil Conservation Act 1986*

- *State Development and Public Works Organisation Act 1971*
- *Transport Infrastructure Act 1994*
- *Water Act 2000*
- *Workplace Health and Safety Act 2011.*

The following Commonwealth legislative act may also apply to road drainage on Queensland roads:

- *Environment Protection and Biodiversity Conservation Act 1999* (Cth).

The Queensland Government has also constituted numerous statutory authorities across the state to perform specific functions with relation to water resources in local geographic areas, such as water authorities, river improvement trusts, basin commissions and water supply authorities.

The *Workplace Health and Safety Act 2011*, the Workplace Health and Safety Act Regulation 2011 and the Work Health and Safety and Another Regulation Amendment Regulation (No. 1) 2013 set out the requirements for safety requirements in workplaces.

Designers of drainage infrastructure need to consider each installation as a workplace during maintenance operations and incorporate provisions that permit maintenance work to be completed in an appropriate way that manages exposure to risk in accordance with amendments to the *Workplace Health and Safety Act* issued in June 2007 (which addresses safety in design and obligations of designers).

It is recommended that project teams include, or have access to, personnel who are current in their knowledge, understanding and application of the relevant legislation, the functions and responsibilities of local authorities and so on.

1.4.3 Key aspects of road drainage policy

Areas of hydraulic design that may require considerations include:

- changes to afflux from drainage works that cause adverse effects on neighbouring property
- diversion of runoff to a different point of discharge than that occurring naturally
- concentration of runoff into a culvert or open channel which is not a watercourse and where the concentration is not dissipated by the time the downstream flow reaches a property or development boundary
- changes to stream morphology
- outlet works on drainage structures which do not sufficiently dissipate energy, prevent scour or limit siltation.

All of these situations should be avoided. If avoidance is not possible, the relevant stakeholders must be consulted. For a discussion of the wider legal issues relevant to the design of stormwater and drainage, refer to the 2008 edition of the *Queensland Urban Drainage Manual* (QUDM), as published by the Department of Natural Resources and Water (currently the Department of Environment and Heritage Protection).

1.4.4 Community engagement

The department has a strong commitment to engaging all stakeholders, including other levels of government, industry and the public. This is outlined in the department‘s community engagement policy, standards, principles and guidelines.

Community engagement can assist in integrating economic, social, environmental and engineering objectives of road infrastructure delivery. With respect to road drainage, community engagement is both:

- a process to improve departmental understanding of stakeholder expectations
- an avenue for stakeholders to be advised of constraints, technical issues and possible options.

Public requests to reduce standards can be considered, but not adopted at the expense of policy, safety and sustainable engineering.

The degree and timing of community engagement regarding drainage will vary between projects; however, the department emphasises the need to commence community engagement as early as possible before decisions are made.

Flooding and drainage issues are important to the community and effort is required to gather and understand these concerns. Members of the public may also provide local data/knowledge for use in the environmental assessment or design of a project.

Flooding and drainage are relevant in several parts of community engagement programs, with the main aspects being:

- Data collection: Information gathered from the community and other stakeholders, particularly those who have long-term firsthand knowledge of the area, is often very valuable and helps to establish parameters for hydraulic analysis. In the early phases of a project, the consultation program should gather as much relevant data on flooding as possible. This information can include detailed data such as historical flood levels or more general descriptions of flow patterns or how often a road is closed.
- Assessment of flood criteria: The community and stakeholders may have opinions on the level of service that would be acceptable. While this is only one input to this question, it is valuable and can assist in determining the most appropriate level to be adopted.
- Assessment of effects: The community who may be affected by a road project (such as areas where afflux occurs) can be consulted to discuss the individual levels of effects.

1.4.5 Effects on landowners

Road drainage may affect neighbouring landowners and these landowners may be concerned if there are adverse effects. There is even the potential for legal action in some situations, so these effects must be carefully analysed. In some cases, adverse effects are unavoidable and appropriate mitigation or compensation may be required.

Adverse effects on landowners include:

a) afflux or changes in flood levels on the property: in particular, roads may increase upstream flood levels

b) changes in distribution of flood flows: for example, the road drainage may divert flow and this could be a problem, if additional flow is diverted on to a property or if water is diverted away from a farm dam

c) changes in flow velocity: flow velocity is increased through bridges and culverts and this could cause scour damage

d) concentration of flow: culverts may concentrate flow that was previously widespread sheet flow and this could cause scour or other problems

e) scour: concentrated and high velocity flows near culverts/bridges may cause damage to neighbouring properties

f) water quality: runoff from the road surface and high velocity flows could cause downstream water quality effects

g) duration of inundation: this can be an issue with agricultural land and some urban areas, if the road increases the time of inundation.

1.5 Guiding principles

This section introduces guiding principles that should be part of the various consideration processes involved in the planning, designing, constructing and maintaining road drainage infrastructure.

1.5.1 Drainage infrastructure and land use

Changes in land use may create changes to existing drainage patterns with associated environmental, commercial or social consequences. The management of drainage resulting from different land uses or changes to land uses is usually undertaken by a primary authority with responsibility for the catchment, which is usually a local authority. Reference to relevant government departments and statutory authorities should be undertaken as applicable.

Roads are a major land use and do influence natural, built, commercial and social environments. These influences result from the design and selection of drainage infrastructure and associated works and designers, constructors and maintenance personnel need to be cognisant of the influence of their designs, construction practices and procedures.

Inappropriate road drainage infrastructure, for example, can change the characteristics of a waterway by altering:

- flooding patterns, including flow distribution
- flood heights
- peak water levels
- water velocities, especially through bridges and culverts
- duration of inundation
- erosion and sedimentation patterns
- fauna transfer
- terrestrial and aquatic fauna habitats.

These changes may affect service and cause issues that require additional unplanned investment to address:

- flood mitigation works
- erosion and sedimentation problems
- reductions in adjoining land valuations
- salinity issues
- increases in pollutant levels.

1.5.2 Assessment of future development

The department needs to plan and design drainage works based on assumptions of future catchment and floodplain conditions. This can be difficult but, nonetheless, important. Changes in conditions can occur during the life of drainage infrastructure. These changes can affect the runoff to the road or changed floodplain/channel conditions may affect flood levels adjacent to the road.

The department has a responsibility to provide advice on any development applications that affect the department's infrastructure, and can ensure that suitable mitigation measures are applied before approval can be provided. Mitigation measures include detention storages, channel works or other similar measures. As well as being effective initially, some mitigation measures may not be effective in the long term and comments need to be made on these; for example, localised dredging may be filled by later sediment movement or cleared channel vegetation may regrow. As well, cumulative effects may need to be considered, where individual developments may have minor effects that are acceptable, but the effects of a number of similar developments may be unacceptable when all have occurred.

It is important that the department maintain close review of any potential effects on drainage and ensure that these are managed appropriately.

1.5.3 General hydraulic and environmental consideration

This section provides an overview of general hydraulic and environmental considerations relating to drainage infrastructure.

A road embankment may form an obstruction to a natural waterway, bushland corridor or floodplain if there are insufficient or unsuitable bridge and/or culvert openings in the road. Considerations may therefore be required of:

- an unacceptably high increase in upstream flood level (afflux) may have adverse effects on property, infrastructure or the environment
- an increase in stream velocities through the structures may initiate or cause continuing erosion downstream of the road
- movement of fish may be affected by higher velocities or changes in the channel invert level and/or extended culvert lengths
- restricted flow may cause increased time of inundation of the land upstream of the road and, in some cases, the road may be designed as part of a large retention basin so peak discharges in floods are reduced

- roads may restrict the movement of fauna from one side of the road to the other. This will be identified in environmental studies and drainage structures may then be designed to allow for this movement (such as one culvert cell with a higher invert level).

1.5.4 Economic considerations

The provision of road drainage infrastructure is typically a consideration of the desired level(s) of flood immunity. Solutions to deliver the preferred levels of immunity may be delivered at initial construction, staged construction may be used to achieve higher levels over time or the lower levels may be acceptable if alternative routes are available.

Where budgets restrict construction of infrastructure that delivers the desired level of flood immunity, a risk analysis that details the costs of providing infrastructure versus those of not providing drainage infrastructure to the nominated standard is necessary.

While budget may affect some aspects of road design, other factors such as safety cannot be compromised.

1.5.5 Maintenance

The provision of any type of road drainage infrastructure should not be undertaken without due consideration of maintenance practices. Key issues include:

- the need to provide adequate access for maintenance purposes: a lack of access will lead to a corresponding lack of maintenance and possible failure of drainage infrastructure with respect to performance
- consideration of the cost and frequency of maintenance activities
- an understanding of what equipment will be needed to undertake the maintenance work
- assessment of maintenance equipment use and that it could lead to failures
- assessment of the maintenance activity and possible special safety considerations.

Specific guidelines relating to the consideration of maintenance issues are provided at several locations within this manual – in particular, Chapter 14.

1.6 Drainage issues

This section outlines key drainage issues of which planners and designers need to be aware and to incorporate into their thinking during the planning, designing, constructing and maintaining road drainage infrastructure.

1.6.1 Planning the drainage system

Planning of the drainage system will likely involve input from professionals in many fields, and requires detailed consideration of environmental, recreational, transportation, traffic, social, economic and infrastructure needs. Because of the high costs associated with drainage works, the drainage aspects of a project should be placed high in the hierarchy of the planning process.

Drainage is a grade-related service (that is, it relies on gravity) and, therefore, can often impose a significant constraint within the planning process.

1.6.2 Urban drainage

Extracts from QUDM (Department of Energy and Water Supply (DEWS), 2013) are included in this section to enhance understanding of urban drainage systems, although this is beyond the scope of this manual.

QUDM is not a standalone planning and design guideline for stormwater management. It must be used in coordination with other recognised manuals dealing with specialised stormwater topics.

The list of broad stormwater objectives of QUDM (DEWS, 20013) (as listed in Section 1.03 of that manual) are to:

a) protect and/or enhance downstream environments, including recognised social, environmental and economic values, by appropriately managing the quality and quantity of stormwater runoff

b) limit flooding of public and private property to acceptable or designated levels

c) ensure stormwater and its associated drainage systems are planned, designed and managed with appropriate consideration and protection of community health and safety standards, including potential effects on pedestrian and vehicular traffic

d) adopt and promote 'water sensitive' design principles, including appropriately managing stormwater as an integral part of the total water cycle, protecting natural features and ecological processes within urban waterways, and optimising opportunities to use rainwater/stormwater as a resource

e) integrate stormwater systems appropriately into the natural and built environments while optimising the potential uses of drainage corridors

f) ensure stormwater is managed at a social, environmental and economic cost that is acceptable to the community as a whole and that the levels of service and the contributions to costs are equitable

g) enhance community awareness of, and participation in, the appropriate management of stormwater.

All of these objectives may not be relevant in all circumstances and individual objectives may be expanded to highlight site-specific issues.

1.6.3 Rural drainage systems

Many departmental drainage structures in rural areas are located on channels (both natural and artificial) and include farm drains, natural gullies, creeks and rivers.

Most of the guidance in this manual, and many other manuals, is concerned with these watercourses, and appropriate hydraulic design is needed for each. These design considerations include selection of appropriate structures, sizes and locations, as well as assessment of afflux, flood immunity and scour. In some cases, future catchment development may need to be considered. This is especially important if urbanisation is possible in the future; however, in purely rural catchments, specific consideration may need to be provided for special circumstances, such as soil conservation works, farm dams or laser levelling of farmland.

There are particular drainage problems with extensive flat floodplains where shallow overland flow occurs. There is a risk that this overland flow will be concentrated by drainage structures and sufficient structures must be placed in suitable locations to limit this concentration and to spread the flow. In these sheet flow situations, even small structures, such as levees, can affect flow patterns significantly and these changes in flow patterns must be considered so structures are located correctly.

In some agricultural areas, the duration of flood inundation is important; therefore the design of roads and road drainage must consider this aspect.

1.7 Climate change

The department needs to consider the possible effects of climate change on a number of aspects in the design, planning and operation process and part of this consideration is for road drainage.

Allowance for climate change is important since transport infrastructure has a long design life and the infrastructure is critical and needs to operate to design standards for this design life. There may be changes in design parameters for flood estimates during the design life and these should be incorporated into the planning and design process.

Australian Rainfall and Runoff is the standard guideline for flood estimation in Australia, and the department takes guidance from this publication. The guidance in this *Road Drainage Manual* therefore incorporates the best currently available information, but must also allow for future changes to guidance in publications published in the future.

There are two aspects for drainage design that need to consider climate change. These are changes in rainfall intensity (including the catchment conditions that are relevant to convert this rainfall into floods) and possible sea level changes, including average sea levels as well as tidal ranges and storm tides.

A discussion paper has been prepared by Westra (2011) which includes information related to the effects of climate change on flood estimation, covering the components of flood estimation and the likely changes. The paper was prepared as part of the update of *Australian Rainfall and Runoff*, the key document for flood estimation in Australia, and it has formed the basis for this document.

1.7.1 Rainfall and floods

There are guidelines available concerning changes to rainfall intensity, which frequently recommend an increase in rainfall. Part of the basis for this conclusion is that many global climate models apply the Clausius-Clapeyron relationship, which indicates an increase of 7%/°C in water vapour content and rainfall. While this may be suitable in theory, there is uncertainty in whether there is an actual change in rainfall of the same percentage.

When analysing the effects on rainfall from climate change, there are two components – namely total or average rainfall, and high intensity rainfall events. The possible effects on the two types of rainfall may be quite different, but for flood estimation, only the high intensity, flood producing, rainfall is of interest.

The Bureau of Meteorology has analysed historical rainfall data and has not found any clear observational evidence for any trends in rainfall data over long periods of record — either long-term means or short duration high intensity rainfall — though some analysis of rainfall has shown a small increase in intensity of daily rainfall data. Some analysis of data has also shown an increase in short duration (sub-daily) rainfalls.

Modelling, with both global models and local downscaling approaches, indicates that, theoretically, there could be an increase in rainfall intensity, particularly for short duration rainfall, though this increase is highly uncertain.

A possible reason for a change in rainfall totals and intensity could be a change in the precipitation type; for example, changes in locations for tropical cyclones or types and locations of thunderstorms could change the rainfall probabilities and the production of floods. These factors, however, are also quite uncertain.

The conclusion of the report by Westra (2011), concerning rainfall, was that there was some evidence of an increase in short duration rainfall depths, but this was uncertain and there was limited indication in historical rainfall data of any trends.

In addition to the rainfall data, flood discharges also depend on antecedent catchment conditions, which may vary with changes in climate conditions. These catchment conditions affect soil moisture for the catchment at the beginning of flood producing rainfall events and catchment vegetation coverage. These include factors such as mean annual rainfall, precipitation intermittency, relative humidity, evapotranspiration and pre-flood baseflow. These factors may have a significant effect on floods and may change with changing climate, but possible effects on flooding are highly uncertain.

To combine the influence of rainfall and catchment conditions, trends were analysed in annual maximum series of flood peak discharges for 491 stream gauging stations throughout Australia with between 30 and 97 years of record by Ishak et al (2013). This paper found that there was a statistically significant trend in flood peak discharges for many stations. This trend, however, was downward rather than an increase in most of the stations showing a trend, with a small number of stations showing an increase in the north-west of Western Australia (not statistically significant) and a decreasing trend especially in southern regions. The conclusion of the paper said that the apparent trend could not be conclusively said to be either natural or anthropogenic and did not make any conclusion related to climate change.

The analysis of flood peak discharges should account for both the effects of rainfall and catchment antecedent conditions so, while there may be some evidence of an increase in rainfall intensity, especially for short duration rainfall events, this is uncertain and may be negated by catchment changes.

ARR is currently carrying out research projects on the future trends of rainfall intensity and the influence of this on flood peak discharges, but this research is still underway.

For the interim, the department is therefore recommending that design rainfall intensity should not be changed to account for climate change; however, there is continuing research so any future research may change this conclusion and this approach may need to be changed.

It is noted that Intensity-Frequency-Duration (IFD) data have been released by the Bureau of Meteorology for ARR in 2013. These data update the previously applied IFD data from 1987 and are based on an assumption of current climate conditions without trends. The Bureau of Meteorology, which carried out this work, did not identify sufficient trends to negate the use of the whole data record in the calculation of IFD data.

1.7.2 Sea level

The 2010 edition of the *Road Drainage Manual* recommended an allowance of 0.3 m for sea level rise, with no comment on various tidal levels or storm tides. It was assumed that all parameters increased by the same 0.3 m. There are a number of different recommended changes in sea level provided in guidelines elsewhere in Queensland as well as throughout Australia.

The basic data for defining an appropriate level for sea level rise are included in the Intergovernmental Panel on Climate Change (IPCC) reports. The Fourth Assessment Report was released in 2007 and the Fifth Assessment Report was released in 2013 (IPCC, 2007 and 2013).

Because of the extended design life of transport structures, the sea level projection to 2100 is recommended.

IPCC (2007) projected an increase in sea level of 0.28–0.43 m, with a possible additional 0.1–0.2 m to allow for ice sheet contributions by 2100, while IPCC (2013) projected an increase of 0.43–0.73 m by 2100. The range covers different emission scenarios.

The *Queensland Coastal Plan* (DEHP, 2012) adopted an increase in mean sea level of 0.8 m to be used in assessment of coastal hazards in coastal regions of Queensland.

CSIRO (2013) has provided a summary of sea level projections, based on the IPCC Fourth Assessment Report and has shown a possible range of sea level increase projections from 0.34–0.54 m by 2100.

While there are uncertainties in the projection of mean sea level rise, there are even more uncertainties in how the different tidal levels and storm tide levels are affected by climate change.

It is therefore recommended that the allowance for sea level rise in coastal areas of Queensland should be based on the higher end of the IPCC Fifth Assessment Report at 0.6 m by 2100.

Because of uncertainty, it is suggested that all tidal levels and storm tides be adjusted by the same projection of 0.6 m.

1.7.3 Conclusion and recommendations

The allowance for climate change for departmental drainage designs should be:

- no change in rainfall IFD data for the interim until a recommendation is made for ARR
- an adjustment for sea level rise of 0.6 m should be made for mean sea level, as well as for all tidal levels, to allow for the projection of sea level increase to 2100.

2 General design requirements

2.1 Introduction

The purpose of this chapter is to introduce and discuss a number of general design requirements for road drainage infrastructure. The requirements presented cover a range of topics. More specific design requirements are contained in relevant chapters.

The intention is that this chapter should be referenced first to establish general and some specific drainage requirements for a project. Topic-specific chapters, such as chapters 7, 8, and 9, should be then referenced as applicable/required.

2.1.1 Definitions

The term 'design requirements' encompasses all design:

- considerations
- controls
- criteria
- standards that must be included in or be part of the design process.

Design considerations encompass all aspects, issues, functionality, expectations, demands, constraints, risk and cost that need to be appropriately addressed, or to be taken into account, in order to satisfy design criteria and determine trade-offs. Refer to Section 2.3 for further discussion regarding design considerations.

Design controls are aspects of the road environment or project that cannot be changed, or are extremely difficult to change and, therefore, place some restriction or control on the design. Refer Section 2.4 for further discussion regarding design considerations.

Design criteria set the expected level of achievement or conformance for relevant design parameters or design inputs. The design criteria ensure that the end result can be judged and defended. An example of a design criterion with respect to road drainage would be the Annual Exceedance Probability (AEP) for the design of a particular project or structure. Section 2.5 presents a number of fundamental design criteria while more specific criteria will be found in relevant, topic-specific chapters.

Design standards, however, set approved or prescribed values or limits for specific elements of design or set procedures and/or guides that must be followed. A design standard with respect to road drainage would be the use of the Rational Method to determine the runoff from a small rural catchment. Design standards are presented throughout this manual.

Both design criteria and design standards set the mandatory limits designers must work within and/or achieve.

2.1.2 Determining and understanding requirements

To assist in determining and understanding the design requirements for a road project, the *Road Planning and Design Manual* (RPDM) describes a 'Hierarchy of Roads' and this provides an overview of the road network and defines the roads that the Department of Transport and Main Roads has stewardship for in Queensland. It develops the philosophy that the road hierarchy provides 'a useful planning tool' for many decision-making activities concerning the road network. This hierarchy permits the department to set the design requirements for projects on roads, according to their function within the network.

The department also sets the ‘design criteria’ and ‘design standards’ for road links that will deliver a planned level of service. Therefore, the overall standard of drainage infrastructure for a specific road project needs to reflect and be consistent with the function of that road within the road hierarchy.

In order to satisfy the relevant design criteria for a project, and to determine appropriate trade-offs, a number of aspects, issues, functional requirements, expectations, demands, constraints, risk elements and costings need to be appropriately addressed or taken into account. These ‘design considerations’, with respect to drainage infrastructure, are progressively identified and developed to address geographic, hydraulic, environmental, cultural, native title and land use issues.

During pre-project planning, target drainage criteria for the road are established and documented in relevant Road Route Strategies and Road Link Plans. The respective design criteria are then progressively addressed during the design development phase. Excessive cost to provide drainage to the specified design criteria may result in a review of the criteria in order to achieve a ‘fit for purpose’ outcome or may result in the project being delivered in stages over multiple years to achieve the desired outcome.

2.1.3 Immunity criteria

All elements within a drainage system must be designed to provide immunity against some level of exceedance which is usually expressed as being able to cope with a storm of a given AEP. The standards applicable to each element will depend upon the specific circumstances and the requirements of the authority that controls stormwater management at the site. The immunity criteria discussed within this manual, and set in the design brief/contract documentation, relate to individual drainage components (such as cross- or longitudinal drainage) and not the road project, section or link. Furthermore, by setting the immunity criteria for various drainage components on a project does not imply that the road inherits the same immunity level(s). It is extremely difficult to assess immunity and set criteria for a road, though methods for assessing entire links are under development.

Refer Chapter 3 (particularly Section 3.2.3.2) for a more detailed discussion regarding this issue.

2.1.4 Design life/service life

It is important to define, in general terms, the difference between design life and service life.

The design life of a component or system of components is the period of time during which the item is expected, by its designers or as required by specification, to work or perform its intended function within specified design parameters/operating conditions. In other words, the design life is the life expectancy of the item under normal/specified operating conditions.

With respect to road drainage, operating conditions can include:

- environmental/atmospheric/geographic conditions
- foundation, bedding and support/cover conditions
- traffic and loading.

For example, the department may specify the design life for a new structural component (such as a culvert) as 100 years. Therefore, it is expected that the culvert will last 100 years before replacement or major repair is expected.

The service life of a component or system of components is the period of time over which the item actually provides adequate or satisfactory performance before repair or replacement is required.

If the operating conditions over the life of the component or system remain within the original design parameters, theoretically, the design life will equal service life. However, if the operating conditions are or move outside of the original design parameters, service life will be less than design life. In some situations, this reduction in time can be considerable, leading to premature failure.

In relation to drainage infrastructure, designers should be mindful of these two terms and ensure, where possible, that the designed drainage components or system are appropriately selected for the anticipated operating conditions. For example, concrete culvert components will have a reduced service life if standard culvert components are used in:

- streams carrying abrasive material (such course gravel or small stones)
- aggressive environments, such as sea water
- situations where they are subject to excessive peak loads (generally from overloaded vehicular traffic).

2.1.5 Reducing the cost of drainage infrastructure

Reducing the cost of infrastructure is an important factor in the determination of design solutions. Costs should be whole-of-life costs, not just initial capital costs and consideration of resilience to extreme weather events should be included. Unfortunately, this is difficult to quantify at this stage and further research and development work is required in order to provide more constructive and beneficial guidance.

Caution should be exercised in adopting new methods, materials or products that have not been referred to the department’s Engineering and Technology Branch for review and acceptance. It is critical to ensure that the overall outcome and/or performance of the method, material or product is satisfactory over the life of the infrastructure as sometimes cheaper options at the time of construction may not meet required long-term performance expectations and end up costing the department much more to repair, modify or replace.

2.2 Road locality

There are two major environments or zones potentially affected by drainage and are defined as ‘the road environment’ and ‘the external environment’.

2.2.1 Road environment

The road environment is the zone which the Department of Transport and Main Roads has responsibility for and, therefore, is under its control. It is defined as the road corridor as defined by property boundaries (also known as ‘road reserve’). It is important to note that not all boundaries are clearly defined, particularly within large western properties and reserves. In these situations, the road reserve is usually based about the existing road centreline and planners and designers need to further investigate to establish applicable boundaries.

2.2.2 External environment

The external environment is the zone outside of the road corridor, which may include sensitive areas, such as wetlands rainforest, sand dunes, waterways or private properties or other infrastructure (such as railways). The external environment may extend for some distance from the road environment and is not the responsibility of the department. However, the department needs to liaise or work with relevant stakeholders and authorities with respect to any proposed project as drainage work within the road environment may affect the external environment both upstream and downstream from the project.

2.3 Design considerations

2.3.1 Identifying design considerations

Section 4.3.1 of the Austroads *Guide to Road Design* — Part 5 is accepted for this section.

2.3.2 Geometric considerations

Section 4.3.1 of the Austroads *Guide to Road Design* — Part 5 is accepted for this section.

2.3.2.1 Stream geometrics

Section 4.3.1 of the Austroads *Guide to Road Design* — Part 5 is accepted for this section subject to the following amendment:

Addition(s)

1. It is important to note that licences are required from the Department of Environment and Heritage Protection to change the alignment of any defined watercourse. Experience has shown that the process of obtaining relevant licences may be difficult.

2. Designers must include an understanding of stream morphology when considering stream geometrics. Streams are dynamic and can change over time. This aspect is important.

2.3.2.2 Road geometrics

Section 4.3.1 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section.

2.3.3 Geographic considerations

Section 4.3.1 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section subject to:

Addition(s)

1. Geographic conditions play a significant role in the determination of what type of drainage structure and/or controls may be adopted at a given location. Structures and controls that are appropriate in one part of the state may not be suitable in other areas. This is also true for the prevention of erosion.

   This section discusses some key issues for different situations and regions across the state.

   Most of the department’s roads are located in rural regions, so standard practices for the planning and design of road drainage should address most of the issues that will arise in these areas. However, it is important to note that these issues can also apply in urban regions. The design of drainage systems in all regions should ensure that the road level and associated drainage infrastructure is adequate to provide the specified level of flood immunity.

2. Locations subject to inundation by water, such as floodplains or coastal areas, either by tidal flow or backwater, require careful consideration of how drainage infrastructure will operate under a range of water levels. The presence of high and low water levels requires significantly different approaches:

- when downstream water levels are high, the hydraulic capacity of a structure may be limited
- when downstream water levels are low, high velocities can result, thereby maximising the potential for erosion to occur.

It is therefore very important that both cases are considered during the design of drainage infrastructure.

Regular inundation (i.e. changing water levels) can also accelerate the erosion process through the saturation of banks which may then fail as water levels reduce.

In coastal regions, the effects of tidal influence and climate change allowance (refer Chapter 1) on areas of inundation will need to be assessed.

2.3.4 Environmental considerations

Section 4.3.1 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section subject to the following amendment:

Addition(s)

1. There are two important documents that should also be referenced when considering water quality issues. The first is *Australian Runoff Quality – A guide to Water Sensitive Urban Design* (2006), published by Engineers Australia and the second is *Water Sensitive Urban Design – Technical Design Guidelines for South East Queensland* (2006), published by Moreton Bay Waterways and Catchments Partnership.
2. Transport and Main Roads' *Fauna Sensitive Road Design Manual* should also be referred to with regard to fauna movement considerations.

2.3.5 Selection of drainage infrastructure

Determining the type of structure for any crossing is an important consideration and there are a number of factors that need to be addressed in this process. It may be necessary to assess several options of different crossing types and sizes in order to appropriately meet the design requirements and objectives. There are three main types of cross-drainage structures used on roads and each has particular advantages and disadvantages. The three types are bridges, culverts and floodways as shown in Figure 2.3.5.1.

2.3.5.1 Relevant factors

The relevant factors that need to be considered in selecting infrastructure are grouped into 'hydraulic' and 'other' factors.

The hydraulic factors include:

- Flood discharge: Defined waterways with a large discharge are more suited to a bridge because of the larger waterway area. The large discharge will also generally occur in rivers or large creeks, where a bridge is more appropriate and cost effective. Depending on location and importance of road, in flat terrain where the waterways are less defined and road embankment is typically low, a floodway may be the better option.

- Stream channel conditions and topography: Similarly, with the consideration of discharge, the shape and size of the channel and the catchment will also indicate a bridge, culvert or floodway. Large and well-defined channels will be better suited to a bridge, while less well-defined, smaller channels will be more suited to a culvert, especially where multiple openings are required (such as on floodplains). Floodways again could be considered, particularly in flat terrain/low embankment situations.
- Afflux constraints: The most suitable structure may be indicated by the amount of flow that can pass through/over the structure with acceptable afflux. The location and extent of afflux needs to be considered in detail and the alternatives assessed to minimise afflux.
- Debris properties: Culverts will normally have a smaller waterway area and present a greater obstruction to the flow. They are more prone to collection of debris. If there is a large amount of debris conveyed by a stream, a bridge or larger culvert may be more suitable.
- Scour risk: Scour can be affected by the size and type of waterway structure. If a structure concentrates flow significantly, risk of scour may be increased, so structures that spread the flow may be favoured in these locations. This is especially important for drainage in floodplains where the flow paths may not be well defined.

Figure 2.3.5.1 – Primary drainage infrastructure types

Other relevant factors that need to be considered include:

- Road alignment: Sometimes the alignment of the road is well-defined and this may not be the best arrangement for drainage. This may sometimes occur where land tenure needs to be considered and the alignment follows streams rather than crossing at a zero skew. In these cases, the sizing and locating of drainage structures must be carefully considered.
- Level of serviceability: This includes the required flood immunity or 'trafficability', and the type of structure that will be best for meeting this requirement.
- Navigation: Structures crossing rivers where boat traffic needs to be considered must allow for specified clearances for this traffic.
- Soil conditions: Particular soil conditions, such as marine mud or acid sulphate soils, for example, may be a problem and this can affect the selection of drainage structures.
- Fauna and fish movement: This is an important consideration in many locations.

2.3.5.2 Bridge, culvert or floodway

There are a number of factors and issues that need to be considered in the selection of the most suitable/appropriate structure for a particular crossing. These are listed in Table 4.4 of the Austroads *Guide to Road Design* – Part 5.

2.3.5.3 Culvert types

Selection of the culvert type is important in some applications. The choice is between the predominate types:

- pipes (any material type)
- box culverts including slab link culverts
- slab deck culverts (cast in situ)
- multi-plate arches.

Arches and 'cast in situ' culverts are not common and, if being considered, specialist advice must be obtained, including from the department's Bridge and Marine Engineering section, located within the Engineering and Technology Branch.

There are two issues of particular concern for selecting the type of culvert. The first is related to the waterway area at low flow depths and, secondly, the extent to which the culvert spreads the flow.

Box culverts and slab deck culverts provide for a greater waterway area at shallow depths, while pipes need to flow at a greater depth before the maximum flow capacity is reached. The use of pipes, however, does tend to spread the flow to a greater extent, which is often desirable for consideration of concentration of flow and risk of scour.

A further consideration for pipe culverts is material type. There are several different material types available:

- reinforced concrete
- corrugated steel (plate or rolled)
- polyethylene and polypropylene
- fibre reinforced.

Reinforced concrete pipes (RCPs) are the most common type used by the department. This is primarily due to the product's availability, strength, serviceability, durability, overall cost (design, construction and operation) and confidence in the product meeting design/service life requirements.

The selection of steel rather than concrete for the culvert material can be suitable as these culverts are generally quicker and easier to construct, as well as easy (and potentially cheaper) to handle and transport. Designers should note that traditional steel culverts are no longer used by the department as they do not meet the required 100 years' design life. To achieve this requirement, steel culvert must have added protective coatings (refer to Section 9.2.6.8). Steel culverts with protective coatings need to be product approved by the department's Bridge and Marine Engineering section.

Polyethylene and polypropylene pipes are available, but are not currently approved for use as culverts under a state-controlled road. They can be considered for applications which are not subjected to traffic loading. In these instances, confirmation of acceptance for the proposed use of these culvert types should be sought from the department.

Fibre-reinforced pipes are also limited to smaller diameter sizes. These pipes have some flexibility within the walls of the culvert and tolerate construction loads and low cover installations better than reinforced concrete pipes. Fibre-reinforced pipes must meet the requirements within MRTS26 *Manufacture of Fibre Reinforced Concrete Drainage Pipes* September 2014 (TMR 2014a) and be product approved by the department's Bridge and Marine Engineering section.

Considerations in selecting culvert type and material type are product and installation costs, availability (including transport of product to site), constructability, site conditions, environmental requirements, product longevity and serviceability and will also influence the decision as to which structure type and material type is most appropriate for a given site.

Many of these aspects and issues will be discussed and/or addressed throughout the remaining chapters of this manual.

2.3.6 Maintenance considerations

The provision for maintenance is an integral component of the planning and design phases of road drainage. Adequate maintenance is necessary for the proper operation of the drainage system. The lack of maintenance is one of the most common causes of failure of drainage systems (and erosion and sediment controls). This may be attributed to reasons such as a significant reduction in hydraulic or storage capacity (such as blockage by debris or sediment). Inspection, mowing, channel clearing and repair, cleaning out culverts and repairs to protective treatments are just some of the maintenance operations that need to be easily and safely undertaken over the life of the structure.

Specific details on maintenance procedures and requirements for road drainage systems are provided in Chapter 14.

To enable maintenance to be properly and safely undertaken during road construction and operation, consideration must be given at the design stage to the requirement of the *Workplace Health and Safety Act 1995* to make a safe maintenance workplace.

2.3.7 Safety considerations

Section 2 of the Austroads *Guide to Road Design* – Part 5 (in its entirety) is accepted for this section subject to the following amendments.

Addition(s)

1. Reference should also be made to Chapter 12 of *Queensland Urban Drainage Manual* (QUDM) (DEWS 2013).
2. Maintenance access – safe access needs to be provided to all drainage structures that require either ongoing (that is, mowing of drains) or occasional (being removal of debris) maintenance. This access is required for vehicles and maintenance crews, depending on the type of maintenance that will be undertaken. Safe access to erosion and sediment control devices during the construction phase should also be allowed.
3. Traffic safety – projecting culvert ends have the potential to act as obstructions to 'out of control' vehicles. Where there are no safety barriers, culvert ends should be designed to not present an obstruction. If obstructions from projecting culverts or head walls are unavoidable then safety barriers should be considered.
4. Energy dissipators – reference should also be made to Chapter 12 of QUDM (NR&W 2008).

Energy dissipators are very costly to build and maintain, and changes to the design, such as flattening of channel gradient to reduce high velocities, is preferred.

2.3.8 General construction considerations

Designers need to consider how drainage infrastructure is to be built. Non-standard structures — that is, structures that don't comply with departmental Standard Drawings and Specifications — will be more difficult, take more time and, therefore, be more costly to build. Specialist advice should be sought to ensure that proposed non-standard structures are not only 'buildable', but also meet acceptable hydraulic and durability performance criteria over the life of the structure.

Generally, road construction projects should be undertaken during the dryer months of the year, particularly projects that include major drainage structures. This can be challenging in areas with high rainfall wet seasons (for example, monsoonal influence) and where the wet season also affects access to the construction site.

While designers must develop drainage solutions that are efficient in terms of purpose (hydraulic performance, immunity and so on) and whole-of-life costs (construction and maintenance), where expected project construction is likely to be affected by the wet season, speed of construction can become a consideration in the development of drainage options. With respect to culverts, caution should be exercised and specialist advice sought as while RCP culverts are quicker to construct than reinforced concrete box culverts (RCBC) structures, RCBC structures with single pour base slabs, when under construction, are considered less prone to 'damage' due to heavy rainfall or minor channel flows.

2.3.9 Staged construction of roads

Table 4.1 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section subject to the following amendments.

Addition(s)

1. Whole-of-life considerations dictate that the design of a road takes proper account of both expected and potential changes that will or may occur as traffic grows and the surrounding land use develops or changes.

   If designs ignore the requirements for future upgrading, future projects will be more difficult and much more expensive to implement than they would have been if appropriate provisions were included in the original design.

   The fundamental elements to be addressed in designs to allow for future upgrades include:

   - carriageway or formation widening (such as for an additional through, auxiliary and/or overtaking lane, for a noise barrier, for a safety barrier)
   - duplication of carriageways
   - intersection and interchange changes or upgrades.

Providing for the future cross-section and ultimate road configuration when designing drainage systems requires careful consideration of the various components of the drainage system.

2.3.9.1 Cross-drainage

Aspects of cross-drainage that require special consideration for staged construction include:

- hydraulic efficiency and capacity of the culvert in its initial (short) and ultimate (long/extended) forms
- possible change in culvert operation (inlet control/outlet control) and subsequent outlet velocity changes
- potential variation in afflux and/or allowable headwater changes
- positioning of culvert inlets and outlets (within the stream)
- changes to the inlet/outlet of adjacent culverts (in the same stream) where these are located within the median of a dual carriageway and where future widening will be within the median (for example, culverts may become connected)
- environmental considerations (such as scour prevention measures, fish or animal passage)
- resumptions (such as land required to accommodate future culvert inlets and outlets, allowance for maintenance access)
- cover over future culvert extensions due to carriageway widening (on the outside of the formation and/or in the median).

2.3.9.2 Longitudinal drainage

Aspects of longitudinal drainage that require special consideration for staged construction include:

- drainage of the ultimate median which must be provided for with:
  - height of pipes and inlets designed to fit the initial and ultimate shapes of the median and carriageway
  - designed capacity and hydraulic operation suitable for the initial and ultimate configurations
  - conversion of an open channel within the median to an underground piped system and the requirements for outlets
  - road safety impacts with drainage inlets structures within the median.
- drainage connections to bridges (including any pollutant control devices) may need to be designed for the ultimate configuration (for example, need to cope with additional surface runoff from a widened structure)
- resumptions (such as land required to accommodate catch drains, diversion drains or channels, maintenance access, sedimentation basins)
- environmental considerations (such as size and location of sedimentation basins).

2.3.9.3 Surface drainage

Aspects of surface drainage that require special consideration for staged construction include:

- aquaplaning (for example, pavement widening may create a problem where before there was none, the application of superelevation in the initial stage may need to suit the ultimate stage)
- use of crowned multi-lane one-way carriageways to reduce aquaplaning will impact on drainage design (for example, a third lane added to the median inside of a two-lane carriageway may be crowned and so drain towards the median)
- addition of kerbing/kerb and channelling in the future (such as channelisation of an unchannelised intersection when widening a two-lane carriageway to three lanes).

2.3.9.4 Subsurface drainage

Aspects of subsurface drainage that require special consideration for staged construction include:

- location and capacity of sub-soil drains
- location of outlets and cleanout points to allow for ultimate shape
- changes to the water table and groundwater flows.

2.3.9.5 Medians and obstructions

In divided roads where the ultimate median has a concrete safety barrier and the median width is at or near the absolute minimum, the ultimate median drainage system will require the use of drop inlets to an underground drainage which can be located beneath the barrier itself.

The location of obstructions or immovable features, such as bridge piers and abutments, must be carefully considered to enable the future stage development of the cross-section of the road to be implemented without major change to these features.

Preserving the required aboveground horizontal and vertical clearances to these features is essential in this process, as well as providing underground clearances from footings or abutments to the underground stormwater drainage system.

2.4 Design controls

Design controls are aspects of the road environment or elements of the project that cannot be changed or are extremely difficult or costly to change. These aspects and elements, therefore, place restrictions and controls on the design. Design controls can either place a direct restriction on a project or at least influence the development of design options becoming design considerations.

One example of a design control with respect to drainage may be the width of the road reserve. Where resumptions are undesirable, the existing right-of-way could limit the available space for drainage infrastructure and therefore control what can be done.

Another example may be the location of the horizontal alignment/centreline. While the design of the horizontal alignment should consider drainage elements, there are many reasons why the location of the horizontal alignment may be fixed. This could then directly restrict or influence the drainage design. While it is possible, vertical alignment should rarely be a design control over drainage design as both elements need to be developed holistically in order to achieve an appropriate design solution.

2.5 Design criteria

2.5.1 Terminology

Drainage infrastructure for a road project is planned and designed to provide a standard or level of flood immunity that conforms to good engineering practice and that also meets government and community expectations. Flood immunity is specified in terms of the probability that a specified event (that is, rainfall or discharge) will be exceeded. Conventionally, and in prior versions of this manual, flood immunity had been based on an Average Recurrence Interval (ARI), defined as the average interval in years between exceedances of the specified event. Now, however, the department has adopted a different probability terminology in line with the latest edition of *Australian Rainfall and Runoff*.

The new terminology is to specify flood immunity in terms of either an AEP or a number of Exceedances per Year (EY). The AEP, expressed as a percentage, is defined as ‘the probability that a given condition, such as rainfall total accumulated over a given duration or flow rate, will be exceeded in any one year’. The reasoning for adopting this changed terminology is that it better meets requirements in terms of providing:

- clarity of meaning
- technical correctness
- practicality and acceptability (BoM 2013).

The preferred use of the adopted terminology is presented in Table 2 5.1. It can be summarised as (BoM 2013):

- AEP will be used for design events (rainfalls and floods), including and rarer (less frequent) than those with a 10% AEP.
- AEPs are to be expressed as an exceedance probability using percentage probability – for example, a design rainfall will be described as having a 1% AEP.

- Events that are more frequent than those with a 50% AEP will be expressed as XEY; for example, a design event (rainfall or flood) with a six-month recurrence interval will be expressed as having two 2EY.
- The use of Average Recurrence Interval (ARI) is discouraged as it is problematic for frequent events in seasonal climates and leads to confusion with the public for rare events.

It is recognised that the Austroads *Guide to Road Design* — parts 5, 5A and 5B use the ARI terminology and therefore practitioners will still need to be familiar with this. Table 2.5.1 can be used to translate between ARI terminology and AEP or EY terminology. Alternatively, with ARI expressed in years, the relationship to AEP is:

$$AEP\ (\%) = \left(1 - \exp\left(\frac{-1}{ARI}\right)\right) \times 100(\%)$$

Some hydraulic calculations (for example, the hydrograph method of determining Average Annual Time of Submergence/Average Annual Time of Closure) currently contain ARI terms in their equations. In these instances the probability term needs to be expressed as an ARI.

It should be noted that the equivalence between EY, AEP and ARI for events more frequent than an AEP of 1 in 10 reflects the differences that arise when using an annual rather than a partial series to calculate exceedances. This 'bias correction' was allowed for in the Australian Rainfall and Runoff 87 (ARR87) design information, but not in the Intensity-Frequency-Duration (IFD) 2013 rainfalls provided by the Bureau of Meteorology. Accordingly, the IFD 2013 rainfalls for an AEP of 1 in 2 are equivalent to rainfalls with an ARI of 1.44 estimated using ARR87 information. Similarly, the IFD 2013 rainfalls for an AEP of 1 in 5 are equivalent to rainfalls with an ARI of 4.48 estimated using ARR87 information. Thus, if the design rainfalls between ARR87 and IFD 2013 are to be compared for AEPs more frequent than 1 in 10, then the appropriate adjustments must be made.

Table 2.5.1 – EY, AEP, ARI preferred usage (shading indicates term to use used) (adapted from BoM 2013)

EY	AEP (%)	AEP (1 in x)	ARI	Typical uses in engineering design
6	99.75	1.002	0.17	Water sensitive urban design
4	98.17	1.02	0.25	
3	95.02	1.05	0.33	
2	86.47	1.16	0.50	
1	63.21	1.58	1.00	
0.69	50.00[1]	2	1.44	Stormwater/pit and pipe design
0.5	39.35	2.54	2.00	
0.22	20.00[1]	5	4.48	
0.2	18.13	5.52	5.00	
0.105	10.00	10	9.49	
0.1	9.51	9.51	10	
0.051	5.00	20	19.5	
0.05	4.87	20.53	20	
0.02	1.98	50.51	50	
0.01	1.00	100	100	
0.005	0.50	200	200	
0.002	0.20	500	500	
0.001	0.10	1000	1000	
0.0005	0.05	2000	2000	Floodplain management and waterway design
0.0002	0.02	5000	5000	Design of critical infrastructure (for example, dams)

Note:

[1] It should be noted that for the 20% and 50% AEP the usual conversion to EY or ARI as simply the inverse of AEP does not apply – the corresponding correct EY and ARI values are shown in the table.

Within a project, the design criteria will vary in accordance with road type and whether the design relates to cross-drainage, surface drainage, urban drainage, or construction phase drainage, including erosion and sediment control. Guidance as to suitable AEPs/EYs for each of these situations is provided in the following sections.

2.5.2 General hydraulic criteria

Hydraulic criteria include:

a) design discharge

b) flow velocities

c) permissible velocities

d) flood and stream gradient

e) fauna passage requirements

f) fish passage requirements

g) erosion and sediment control

h) permissible afflux

i) tailwater levels and backwater potential

j) pollution control (water quality criteria)

k) road closure periods/AATOS/AATOC

l) inundation of adjacent land

m) maintenance of flow patterns.

Establishing the hydraulic criteria requires an understanding of the hydrologic and hydraulic conditions of the site or project.

2.5.2.1 Design discharge

The design discharge is the flow rate of the defined probability (or Average Recurrence Interval) for the required drainage works. Usually, the design discharge is used to provide the size of the drainage structure and the level of the road. The design discharge is expressed as a flow rate, usually as cubic metres per second (m^3/s).

Usually, the discharge is calculated directly by a hydrology procedure, such as the Rational Method for the drainage structure and this discharge is used directly.

In more complex situations, the design discharge is calculated while accounting for attenuation or diversions.

2.5.2.2 Flow velocities

The flow velocity is a critical parameter used in design of drainage structures. It is the velocity of the flow of the water in the flow path. The flow velocity can be calculated for a particular location in a stream cross-section or it can be an average over a portion or the whole of the cross-section.

Flow velocity can be calculated using Manning’s Equation by a hydraulic model or it can be measured during an actual flood event.

Flow velocities are usually calculated initially for the natural channel, without any drainage works. This velocity indicates the natural conditions which can be used as a basis for the consideration of the drainage works. Flow velocities can then be calculated for the conditions with the addition of the proposed infrastructure.

Flow velocity in a flow path depends on the slope and geometry of the flow path, as well as the channel roughness and the amount of flow. It is often very variable across a cross-section and along a reach of a stream.

2.5.2.3 Permissible velocities

When designing a drainage structure or channel, the flow velocity is an important input to the design process. This is because excessive flow velocities will cause scour.

The risk of scour depends on the gradient (slope) and geometry of the channel, the soil conditions and the vegetation cover. When the velocity of the flow increases beyond a limit, the risk of scour will increase. In the design, the permissible flow velocities need to be defined to help in the design process.

The process used is as follows:

- The drainage structure (culvert, bridge, floodway or channel) is designed based on the best available information.
- The design flow velocity for the preliminary design is calculated.
- The maximum permissible flow velocity is compared to the calculated design velocity.
- The design may be modified to meet this limit by increasing the waterway area or reducing the slope.
- If this is impossible because of constraints, appropriate mitigation measures will be needed.

The permissible velocities depend on the material of the channel bed, the type of soil, channel gradient and shape as well as vegetation cover. Permissible flow velocities are listed in tables that can be found in Chapter 8.

While the permissible flow velocities are set mainly to counter the risk of scour, the permissible flow velocity may also depend on other environmental factors, such as the allowance for fish passage.

2.5.2.4 Flood and stream gradient

Flood and stream gradients are considerations in drainage designs, since these affect stream discharges (hydrology) and flow velocities and flood levels (hydraulics).

As discussed in Chapter 8, there are three different gradients or slopes that are relevant in road drainage design:

- Energy gradient – the profile of the energy line in a flood. While this slope is not easily measured, it is the gradient used in the hydraulic calculations. It is usually estimated for use in calculations.
- Water surface slope – the profile of the surface of the water. This is the slope measured by observing a series of flood levels along the waterway. In open channels, the water surface slope is also the Hydraulic Grade Line (HGL).
- Bed slope – the profile or slope of the bed of the channel. This slope can be measured from survey data or topographic maps. While not directly used in the hydraulic analysis, for reasonably uniform channels, the bed slope can be used to approximate the water surface slope/energy gradient.

Another term used is ‘ground’ or ‘catchment slope’ and the value is used in some hydrology procedures. The value is a representative slope for the whole catchment.

Higher gradients lead to greater flow velocities, which result in lower flood levels, but increased risk of scour.

2.5.2.5 Fauna passage requirements

When a road is built, it tends to fragment habitat and lead to greater risk to fauna that cross the road. Since the drainage structures cross under the road, these can potentially be used to provide a safe means for fauna to cross between habitats. To provide this, the drainage structures may need to be modified to make this passage easier. Both terrestrial and aquatic fauna (especially fish) need to be considered. Fish passage is an especially important case and this is described in Section 2.5.2.6.

When considering the requirements for fauna transfer, several issues must be considered as follows:

- consult with environmental experts to confirm that the best information possible is being incorporated
- identify the relevant environmental issues
- identify fauna types that may use the transfer
- determine the appropriate requirements.

Usually the culvert can operate effectively as a drainage structure while also providing a means for fauna to cross the road.

Particular considerations for the fauna transfer are as follows:

- normally it is important to supply a dry passageway so that the fauna can move through the culvert without getting wet
- this can be provided by dividing the culvert into wet and dry cells, with the inverts of some cells kept higher than others. When larger floods occur, the whole culvert set will operate
- a low flow channel can provide the same benefit
- fencing may be needed to direct the fauna towards the culvert, but hydraulic issues should be considered
- the culvert should not provide habitat for the fauna, since this habitat will be removed when a flood occurs
- lighting may be needed in long culverts so that fauna can enter the culvert is not discouraged by the dark
- vegetation is required at the entrance and exit of the culvert to provide cover in otherwise exposed areas.

2.5.2.6 Fish passage requirements

A waterway barrier is any structure that limits fish movement along the waterway. Examples of waterway barriers include:

- dams
- weirs
- bridges
- culverts
- tidal barriers
- fords
- causeways/floodways
- silt curtains
- any other barriers that restrict fish movement.

Changing the flow velocities of a creek can also be a barrier to small juvenile fish moving upstream and completing their life cycle.

For further information on fish passage, refer to Chapter 7 or contact a departmental Environmental Officer.

2.5.2.7 Erosion and sediment control

One of the most important environmental concerns for road drainage is erosion and sediment control. This should be considered in all situations and appropriate assessment and mitigation measures must be supplied. Scour at drainage structures can be a serious environmental problem, as well as providing a risk of structure failure and possible road embankment failure.

Control of scour at culverts and channels needs to consider the permissible flow velocities noted in Section 2.5.2.3 and Chapter 8, which indicates the velocity limits where scour begins to become a problem. While these are good guidelines, each individual situation needs to be considered on its own merits, since there may be a large variation for different situations.

Where necessary, erosion control measures will be needed and these are described in later sections of this manual. Water quality design criteria is discussed in Section 2.5.2.10.

Temporary erosion and sediment control during construction of drainage is the responsibility of the Contractor. Information on the department's temporary erosion and sediment control requirements can be found within MRTS52 *Erosion and Sediment Control*.

2.5.2.8 Permissible afflux

Afflux is the increase in peak water levels produced by the introduction of a culvert or bridge and is the comparison between the water levels for the existing conditions and the proposed conditions once the road has been built. Afflux is defined for a particular location and will vary across the floodplain or along the length of a channel.

The allowable afflux is often a controlling factor in design of drainage structures and can be a serious community concern. While the department must assess the afflux expected during the planning and design process, local authorities will often specify the requirements that they expect in a region.

Afflux is usually caused by a constriction in a flow path, from the construction of a culvert, bridge or floodway. However, in some cases, especially in flat terrain and where flow may be diverted from one catchment to another, it could be caused by a redistribution of flow. Afflux can also be negative – that is, a reduction in flood level, downstream of a constriction or where flow is diverted away from a stream or creek.

The point of maximum afflux occurs immediately upstream of the road and then dissipates while moving further upstream. There is a point where the afflux drops to zero and the influence of the bridge on flood levels disappears. In flat terrain, this point may be a considerable distance upstream, but in steep country with high flow velocities, the afflux may extend only a very short distance.

The afflux also reaches a maximum at the point of overtopping of the road. Smaller floods will be conveyed easily through the structure, while larger floods may eventually drown out the structure. For very large floods, there may be no impact on flood levels, where the structure is submerged to a significant depth.

Afflux needs to be considered in all drainage designs. During the planning phase, any properties, infrastructure or other features upstream of the crossing must be reviewed. These structures then need to be considered in the design and the impact on flood levels at each of these must be included in the design process. If there is nothing that could be adversely impacted by an increase in flood levels, afflux does not necessarily form a part of the design. In this case, the maximum permissible flow velocity through the structure is the critical factor.

The allowable afflux will vary for individual locations. In some particularly sensitive areas, no afflux may be the appropriate limit. This would be in areas where there are already flood-prone properties and even a small increase in level could cause a significant increase in damage. In some locations, a small amount of afflux may be acceptable. In regions where upstream development does not provide a control, the flow velocity and/or allowable headwater requirement generally set the limit. In this instance, the afflux is often of the order of 250 mm, though higher afflux may be possible in some situations.

Afflux is reduced usually by increasing the waterway area of the drainage structure, but it can also be reduced by channel works or other mitigation measures.

Reducing the afflux may lead to higher costs for drainage infrastructure and it may be impossible to reduce the afflux at some sensitive locations, even with extensive mitigation measures. In these cases, careful assessment of the hydraulics and potential damage is needed and this should be followed by consultation with affected property owners to develop an acceptable result.

2.5.2.9 Tailwater levels and backwater potential

Tailwater is important for drainage design as it sets the water level at the outlet of a drainage structure. It, therefore, can control the hydraulic performance of the structure.

Tailwater levels must be calculated as part of the hydraulic design for all drainage structures. There are a number of situations required for the calculation of tailwater, as follows:

- Normal stream depth – in this case, the tailwater level is defined by the normal water level in the downstream channel and this depends on the conditions of the stream or creek. These conditions are the slope, channel geometry and stream roughness. The tailwater level is calculated using Manning's Equation, backwater analysis or a stream rating curve.
- If there is a downstream confluence (junction) with another stream, the tailwater level may be held at a higher level than would naturally be the case. In this case, the flow is at a lower velocity and the water levels are higher, which means that the culvert will not operate as efficiently as it would if the downstream water level was lower. This is especially the situation if the road crosses a tributary just before this tributary joins a major stream. Two cases need to be analysed. First, assuming a major flood in the downstream catchment of the major stream. This may result in a higher flood level in the tributary, which may be critical for the design. Second, assuming normal to low flows in major stream, a local catchment flood in tributary may result in lower flood levels but make a critical case for the consideration of velocities through the structure.
- Similar to the tributary situation, a downstream lake or dam can affect the tailwater level. In this case, the stream flows into a lake, natural or artificial, and this body of water holds up the flood levels and thereby increases the tailwater level. This increase can occur over time, giving a dynamic tailwater.
- Another infrastructure crossing or artificial constriction downstream of proposed crossing can affect tailwater levels.

- If the road crossing is close to the ocean or an estuary, the tailwater level may be controlled by the level of the ocean. In this case, the water level will depend on tidal levels, as well as possible effects from storm tides or waves. The assessment of an appropriate tidal tailwater level for design of drainage structures is a difficult problem. A major issue is the risk of occurrence of a particular tide at the same time as a major flood. Analysis of a range of tidal levels may be of value as for the consideration of a downstream tributary. If a high tide is analysed, this may give the critical event for flood levels on the road, but the flow velocities will be low. On the other hand, analysis of a lower tide will give lower flood levels, but the flow velocities may be critical for the design.

2.5.2.10 Pollution control – Water quality design criteria

Section 3.4.1 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section, with the following additions / amendments.

Addition(s)

1. Performance criteria: Departmental projects shall endeavour to meet the intent of Queensland's *State Planning Policy*. These objectives (February 2015) are:
   - 75 – 85% minimum reduction in total suspended solids from unmitigated development
   - ~60% reduction in total phosphorus
   - 40 – 45% reduction in total nitrogen
   - 90% reduction in gross pollutants (> 5mm).
2. For further advice on the water quality design criteria for a specific project, refer to the environmental assessment for that project.
3. Guidelines for the selection of specific pollution control options for a project are set out in Chapter 7.
4. In urban catchments, reference should also be made to *Australian Runoff Quality – A Guide to Water Sensitive Urban Design* (EA 2006) and to QUDM (DEWS, 2013).

2.5.2.11 Road closure periods/average annual times of submergence or closure

Consideration of times of closure is important in some situations to supplement the flood immunity assessments. The TOC is a measure of the disruption to traffic and in some ways is a better measure of the performance of the road. This measure can be expressed as either the AATOS or AATOC (the average time each year when the road is affected) or as the duration of submergence or closure.

More details on this topic are provided in Section 2.2.5.3 and Chapter 10, which includes the methods of calculation.

2.5.2.12 Inundation of adjacent land

Roads can provide a restriction to flow across a flow path or floodplain and can cause ponding upstream. This inundation must be considered carefully (extent and duration of) in the planning and design of the road and any adverse impacts identified and mitigated. These impacts are important in urban areas where there may be development or infrastructure that may be affected. However, there may also be concerns in rural areas, where there may be impacts on agricultural land.

Generally, the drainage systems for roads are sufficiently large enough that the duration of ponding is not increased greatly, but this may be possible in some situations. These cases need particular attention.

2.5.2.13 Maintenance of flow patterns

The road is a linear structure across the floodplain and, therefore, may divert flow across the floodplain, especially in flat areas. This diversion may have impacts on both economic and environmental factors. Any diversions should be identified and, generally, there should be minimised to maintain the existing flow patterns as well as possible.

In some situations, diversions may be worth considering, especially where there are benefits to the cost and complexity of the drainage system, but the potential impacts must be carefully assessed to determine if they are acceptable.

2.5.3 Cross-drainage criteria

The design criteria for cross-drainage for a particular project may be set either by the client or by departmental strategies and may be based on any of the following conditions:

- Flood immunity — This is defined as the AEP of a flood that just reaches the height of the upstream shoulder of the road. In other words, the road surface remains above / is immune to the flood of set AEP. Furthermore, freeboard may be required to ‘lower’ the water level further to keep the pavement dry and/or provide a buffer in case of error in calculation.

  Another definition that has been used is the AEP of a flood that just reaches the point of overtopping the highest point of the road. This definition is used to calculate the flood immunities in the bridge information system.

- Trafficability — In some instances, it is desirable to allow traffic to continue to use the road while floodwater crosses the road surface. The design criteria, therefore, may be specified in terms of the ARI of the flood at the limit of trafficability. This limit is based on a combination of depth and velocity of flow over the road or floodway and is defined as occurring when the total head (static plus velocity) at any point across the carriageway is equal to 300 mm. The road is defined as closed if the flow is greater than this limit. This standard is in line with recommendations made by Austroads.

- Time of Submergence (TOS) — This is a measure of the expected time that the road is submerged in any flood but especially in a major flood such as the 2% AEP (≈ ARI 50 years) event. Submergence is defined as the point where the road is just overtopped, even by very shallow water.

- Average Annual Time of Submergence (AATOS) — This is a measure of the expected average time per year of submergence of the road caused by flooding. It is expressed as time per year.

- Time Of Closure (TOC) — This is a measure of the expected time of closure of a road (road not trafficable) in any flood but especially a major flood such as a 2% AEP (≈ ARI 50 years) event.

- Average Annual Time of Closure (AATOC) — This is a measure of the expected time of closure of the road due to flooding, expressed as time per year.

The times of submergence and closure provide useful data to supplement the flood immunity results. They give an indication of the extent of disruption to transport that may result from flooding on the road. In some cases, low flood immunity may be acceptable if the times of closure are low and the expected disruption is relatively minor.

The average annual times of submergence and closure depend on the frequency of submergence / closure as well as the duration of each occurrence. For example, two streams may have a similar AATOS, but a quite different flood immunity, if one is closed frequently for short durations, while the other is closed more rarely for longer times. The impacts of these different patterns can be analysed to determine the most appropriate design for each particular crossing.

The time of submergence / closure is related to catchment area and response times as well as the flood immunity. These times are calculated either from design flood events or from stream flow data, as described later in this manual.

A TOC assessment can be undertaken at an individual crossing level, but the method can also be extended to consider an entire road link. The method should normally be linked to an economic assessment, so that the right level of immunity can be selected, with cost of the crossing balanced against the cost of delay (as represented by the AATOC).

A TOC assessment of an entire road link is a powerful method enabling the best value upgrades along the link to be identified and prioritised. This type of assessment requires consideration of a number of factors including:

- the criticality of the road link, including to the economics of the region
- traffic volumes and vehicle classes per sub-link
- flood immunity of the entire road link (not just an individual crossing), analysed using sophisticated hydrologic and hydraulic techniques.

Integration of these factors allows an economic analysis of delay due to flooding to be quantified (in dollars per annum) per sub-link. This can then be compared with the capital cost of varying levels and locations of upgrade, thus allowing benefit/cost and other forms of analysis, and prioritisation in a transparent and defendable way. Such an analysis allows the priority areas of an entire road link to be identified for upgrade and provides the economic justification that feeds into the business case.

Refer Sections 2.2.5.6, 2.2.5.7 and 2.2.5.8 for specific detail regarding flood immunity criteria for cross-drainage for various road types.

2.5.4 Longitudinal drainage criteria

The requirements for longitudinal drainage will vary from project to project. The design considerations for the site will dictate the choice between alternative longitudinal drainage options, such as kerb and channel, grassed swales, and lined or unlined table drains. It is also important that the longitudinal drainage (drain type and capacity) of the adjoining projects be considered, when determining the criteria for the site being planned or designed, to ensure consistency of drainage capability and to mitigate potential system failure.

In urban environments, kerb and channel has historically been favoured for most roads, though grassed channels and swales are also common on divided roads.

Reference should be made to the RPDM to determine the cross-sectional components of table drains and other drains associated with the formation/carriageway.

The following criteria are to be considered in determining the standard for longitudinal drainage. It is important to note that the standard for longitudinal drainage should be compatible with the standard adopted for cross-drainage as these two components of the drainage system typically work in combination.

Refer to Sections 2.5.2.5.7 and 2.5.2.5.8 for specific detail regarding flood immunity criteria for longitudinal drainage for various road types.

2.5.4.1 Shape of table drains

Section 2.13.1 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section subject to the following amendment.

Addition(s)

1. Parabolic drains can also be used, although these are difficult to construct/maintain.

2.5.4.2 Minimum grades

The minimum grade for unlined drains, including table drains, is 0.5% and 0.2% for lined drains; however, 0.3% may be regarded as the minimum practical slope for construction (allowing for construction tolerances). This is to ensure that the drain will flow and, if applicable, minimise ponding against formations and pavements. This criterion also applies to both crest and sag vertical curves where grades fall below 0.5%. Generally, to achieve the required minimum grades, widening of the table drains is needed over the critical length (length where grade is less than that required). Widening of the table drain means that, when travelling away from the vertical curve apex, the table drain invert is gradually shifted away from and then back closer to the shoulder edge, in order to deepen the drain and effect sufficient grade. However, this solution may not always work, therefore modification/adjustment of the road geometry may need to be made.

2.5.4.3 Flow velocities

Flow velocities in longitudinal drainage should be limited to prevent erosion. Limiting flow velocities is preferred over maintaining high flow velocities and providing armouring. Acceptable velocities should be based on the soil conditions and characteristics of the site.

2.5.4.4 Flow depths

Flow depths should be limited to prevent erosion and inundation of the pavement. An increase in the number of outflow points (such as turnouts or level spreaders) from the longitudinal drainage should be considered to assist in managing depth of flow.

2.5.4.5 Median drainage

Section 2.12.1 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section subject to the following amendment.

Addition(s)

1. Median longitudinal drainage will usually have a concrete lined invert to assist maintenance and reduce the risk of errant vehicles rolling after hitting ruts caused by tractor mowing.

2.5.4.6 Bridge runoff

Road runoff from bridge scuppers should be discharged into a sediment basin, gross pollutant trap or other relevant first flush containment removal device. This is particularly important where the scupper would direct bridge runoff into a base flow channel or upstream of a sensitive environment (such as wetland, fish habitat reserve).

Reference should also be made to Standard Drawing No. 1178 (DMR 2009).

2.5.5 Road surface drainage criteria

The requirements for surface drainage primarily relate to safety (such as aquaplaning and ponding) and are dealt with in Chapter 11.

For surface drainage, the main criterion is the allowable flow width on the road. However, flow velocity also needs to be addressed, particularly when pedestrian movement is adjacent to or crosses the flow.

Refer to Sections 2.2.5.7 and 2.2.5.8 for specific detail regarding flood immunity criteria for road surface drainage for various road types.

2.5.6 Immunity criteria for the National Land Transport Network

Generally, the adopted flood immunity criteria for cross-drainage on the National Land Transport Network (Auslink) is 1% AEP (ARI 100 years) and for other drainage components, refer tables 2.5.7 and 2.5.8 as applicable.

For major projects on the Auslink network, the Australian Government's Department of Infrastructure and Regional Development will set project-specific drainage design criteria, which may differ from the AEP (ARI) values specified in this manual and may also include TOC requirements. The criteria will be agreed and set in relevant project documentation and approvals.

2.5.7 Immunity criteria for state-controlled roads – rural catchments

For rural catchments, the generally accepted design criteria for various drainage components are specified in Table 2.5.7.

In some situations, it might not be possible to design for this level of flood immunity without causing intolerable impacts on existing development or because of extensive flooding that could not be managed without unacceptable cost. In such situations, the design AEP may be adjusted to allow a lower level of immunity (equivalent ARI relaxed to a lower recurrence interval). In this instance, assessment and use of TOC/TOS for design criteria may be more appropriate. Refer discussion in Chapter 1 regarding road infrastructure delivery.

This criterion also applies to rehabilitation and reconstruction projects where existing structures are assessed as hydraulically or structurally deficient and need to be completely replaced.

Designers should check departmental strategies for flood immunity or trafficability requirements for specific routes and individual projects (refer Chapter 3).

Table 2.5.7 – Design immunity criteria for state-controlled rural roads

Location	AEP/EY* (ARI)
Cross drainage – excl. floodways	2% AEP (≈ ARI 50 years)
Diversion channels	2% AEP (≈ ARI 50 years)
Road surface drainage[A]	10% AEP (≈ ARI 10 years)
Bridge deck drainage	10% AEP (≈ ARI 10 years)
Road surface drainage of pavements	1 EY (ARI 1 year)
Water quality treatment devices	1 EY (ARI 1 year)

Notes:

[A] Road surface drainage includes kerb and channel, table drains, diversion drains, batter drains and catch drains.

* Refer to Section 2.2.1.3 for a discussion on the terminology of event probability.

2.5.8 Immunity criteria for state-controlled roads – urban catchments

The design AEP (ARI) for a project in urban areas will often be influenced by the capacity or capability of the existing drainage system or network that the new work needs to connect into.

For urban catchments, the generally accepted design criteria for various drainage components are specified in Table 2.5.8. The department has also adopted the AEP criteria as described in Table 7.02.1 of QUDM (DEWS 2013). Key values are included in Table 2.5.8. Designers should confirm the requirements of any existing/connecting systems with the relevant authority.

Urban drainage systems are generally based on the major/minor drainage system or dual-drainage system. This type of system or drainage concept has two distinct components:

- The minor drainage system is designed to contain and convey fully a design minor stormwater flow of specified AEP with road flow limited in accordance with the requirements set out in Chapter 11. Refer to the Glossary for full definition.
- The major drainage system conveys the floodwater beyond the capacity of the minor drainage system and up to a specified AEP. Refer to the Glossary for full definition.

The minor and major design storms correspond to the rainfall events for the AEP chosen for the design of the minor and major systems respectively.

Designers should note that the design discharge for the major system AEP may require that the capacity of the gully inlets and underground pipes is increased beyond that required by the design discharge for the minor system AEP, in order to meet the major system design criteria.

Another important design consideration is that, with any proposed drainage system adjacent to sensitive areas where flood inundation will not be tolerated, the design of the major drainage system should also consider the flow conveyed in the underground minor drainage system, should this system fail due to malfunction or blockage.

Table 2.5.8 – Design immunity criteria for state-controlled urban roads

Location	AEP/EY (ARI)
Major system – includes all above and below ground components	2% AEP or 1% AEP (≈ ARI 50 years or 100 years)[A]
Minor system components	
Cross drainage – excl. floodways	2% AEP (≈ ARI 50 years)
Diversion channels	2% AEP (≈ ARI 50 years)
Road surface drainage including intersections[B]	10% AEP (≈ ARI 10 years)
Bridge deck drainage	10% AEP (≈ ARI 10 years)
Sediment basins	0.5 EY (ARI 2 year)
Road surface drainage of pavements	1 EY (ARI 1 year)
Water quality treatment devices	1 EY (ARI 1 year)

Notes:

[A] Refer to relevant local authority for confirmation of required Design Storm AEP, particularly where connecting/discharging to an existing system under their control.

[B] Road surface drainage includes kerb and channel, underground pits and pipe networks, table drains, diversion drains, batter drains and catch drains.

AEP/ARI for the design of retention and detention basins is project-specific and must be specified in the design brief.

* refer to Section 2.2.5.1 for a discussion on the terminology of event probability

2.5.9 Environmental criteria

The environmental considerations and strategies for managing aspects of a project (refer to Section 2.2.3.4) that are predicted to cause environmental harm will most likely become environmental criteria for the project.

Chapter 7 deals further with the development of environmental criteria.

2.6 Water sensitive urban design

Section 3.5 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section subject to the following amendments.

Addition(s)

1. Conventional water management has been compartmentalised with water supply, wastewater and stormwater traditionally treated as separate entities. However, integrated water management needs to consider the total water cycle and this concept is increasingly being accepted and/or adopted.

   While the principal concern for the department is related to stormwater drainage, the department also has an interest in a range of other issues, such as the use of water for construction and water quality controls.

   Roads may represent a relatively small proportion of the total catchment, but they sometimes contribute significantly to water quality concerns. This is especially the case on roads with high traffic volumes where a number of different contaminants may be produced. Between rainfall events, contaminates can build up and then runoff at a greater rate than normal into receiving waters.

The principles that the department need to consider include:

a) consider all parts of the water cycle, natural and constructed, surface and subsurface, recognising them as an integrated system
b) consider all requirements for water, both anthropogenic (human activity) and ecological
c) consider the local context, accounting for environmental, social, cultural and economic perspectives
d) include all stakeholders in the process
e) strive for sustainability, balancing environmental, social and economic needs in the short, medium and long term.

The department also needs to be aware of all water-related issues, not only in the road reserve, but also both upstream and downstream.

2.7 Extreme rainfall events and providing resilient infrastructure

Section 4.9 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section subject to the following amendment.

Addition(s)

1. Road infrastructure is not designed to be immune from all rainfall and flooding events. Bridges and roads are frequently and purposely designed to be overtopped and inundated for short periods of time. Design elements are to be chosen that enhance the infrastructure performance in these conditions, such as bound pavements, asphalt surfacing, subsoil and pavement drainage to cope with near surface water flows and high water tables, batter and scour protection, debris loading, and so on.

   Resilience to large and extreme rainfall and runoff events can be improved by:

   - improving the road network's ability to survive future flooding events by reducing the extent of damage sustained in a large and extreme event
   - reducing the work and/or time required for the network to be reinstated to unrestricted use following a future event without changing the design flood specification.

   It is important to note that any outcomes (adverse or otherwise) resulting from an extreme rainfall event could occur within both the road and external environments (refer Section 2.2), therefore identification of possible outcomes should not be limited to the road reserve and/or chainage limits of the project.

   The following sections outline some situations where the design of a project should be assessed for adverse outcomes and risks that may occur during an extreme rainfall event. However, other situations may also exist where assessment should be undertaken, therefore careful engineering consideration and judgement should be exercised. Assistance in identifying or confirming situations requiring assessment and at what level (AEP) assessment should be undertaken at can be provided by Director (Hydraulics and Flooding), Hydraulics and Flooding Section, Engineering and Technology Branch.

2.7.1 Erodible soil environments

Section 4.9.3 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section subject to the following amendment.

Addition(s)

1. Part of the road drainage design process is the determination of acceptable or maximum allowable velocities for stormwater flows. It should be noted that these velocities are largely based on research that identified the velocity when erosion/scour started to occur in different soil/stream types. The maximum allowable velocities for a project are then used in the design of various drainage structures/devices (for example, culverts and channels) to ensure design discharge through those devices is below the set maximum allowable velocity for that location. Some design solutions that may be adopted, equal or are just below the set maximum allowable velocity.

2.7.2 Excessive flooding

Section 4.9.4 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section subject to the following amendment.

Addition(s)

1. Higher peak water levels upstream of a drainage structure in extreme rainfall events may produce larger flow velocities through the structure than for the nominated design AEP event. The higher velocity may cause scour problems or could cause the catastrophic failure of the structure itself.
2. Where flood impacts would be significant/very severe, it is necessary (and can be specified in design/contract documentation) to consider floods up to the Probable Maximum Flood (PMF). The PMF is defined as the largest flood event that can reasonably be expected. In some situations, extreme events, though smaller than the PMF, may be more appropriate.
3. If the situation of excessive flooding is considered applicable on a project, specialist advice needs to be sought from the department's Hydraulics and Flooding Section or a suitably prequalified consultant.

2.8 'Self cleaning' sections

Section 4.8.5 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section subject to the following amendments.

Addition(s)

The requirement for 'self cleaning' sections and the selected design AEP must be specified in the design brief/contract documents.

3 Strategic planning and development control

3.1 Introduction

This chapter addresses two departmental functions that are important in the pre-planning of a road corridor or link and the ongoing stewardship of a road with respect to drainage.

The first is concerned with strategic planning and the major drainage considerations required when developing strategies and plans for state-controlled roads and roads within the National Land Transport Network (Auslink). The second is concerned with the possible effects on road drainage systems, due to the development of the road and external environments (refer to Section 3.2.2).

3.2 Strategic planning

3.2.1 Introduction

Chapter 2 has described various design considerations, controls, criteria and standards that apply when planning a drainage system. This section expands on these aspects, with a focus on strategic, pre-project planning.

The design considerations for the strategic planning of drainage include:

- flood immunity
- community impacts
- safety
- environmental impacts.

This section will discuss key aspects affecting flood immunity and community impacts. These aspects need to be carefully considered and initially addressed when allowing for road drainage at the strategic level of planning. Safety and environmental considerations will not be discussed; however, it is essential that any planned or proposed changes to the road environment through the development of the road should not have an adverse effect on safety and the environment.

3.2.2 Flood immunity

In the planning of a road corridor, link or project, the flood immunity expected/required is an important consideration. However, as stated in Section 2.1.3 and detailed in this chapter, the assessment/determination of flood immunity for a road is extremely difficult.

The accepted practice is to assess/prescribe the flood immunity for individual types of drainage infrastructure, such as cross-drainage and surface drainage infrastructure, along the road. The department's general design criterion for flood immunity for cross-drainage on state-controlled roads is to achieve a design that provides for an Annual Exceedance Probability (AEP) of 2% (≈ Average Recurrence Interval (ARI) 50 year). Projects on roads within Auslink usually require immunity for an AEP of 1% (ARI 100 year). Designers should refer to Section 2.5 for specific requirements.

While all road planning and design projects should aim for these objectives, there are a number of considerations that affect this objective in particular circumstances. This section discusses some of these circumstances and outlines how these additional issues can be incorporated into the process.

For the project concerned, additional considerations are needed in the assessment of flood immunity required. These include:

- Project economics – in some circumstances, provision of a required level of flood immunity may come at a very high cost, which may be difficult to justify because of the function of the road. This situation often occurs in large flat floodplains, where there is an extensive length of road across the floodplain.
- Road alignment and corridor – in some situations, the road alignment and corridor width may make a high level of flood immunity difficult to achieve and a lower level may need to be adopted. This situation usually occurs in areas with significant controls or constraints where there are environmental issues or in urban areas.
- Community impacts – these impacts may affect the flood immunity standard to be adopted, especially in flat areas. Often in these situations, there will be a significant width of flow in the natural or existing environment. If the road is to be upgraded to a higher level of flood immunity, a significant flow must be directed under the road, which will tend to concentrate the flow. In this case, afflux is difficult to manage without a significant amount of cross-drainage. A lower level of flood immunity will allow extra flow across the road and, thereby, result in a better outcome related to afflux. This benefit may be greater than the concern with the reduced flood immunity.
- Flood immunity along a road link – in this case, the flood immunity along a whole road link needs to be considered. If there is a drainage crossing on the road link where it is clear that it cannot be upgraded to a 2% AEP (≈ ARI 50 year) flood immunity, the upgrade of other crossings on the link may not be justified, because the whole link may be closed anyway whether or not the particular crossing is upgraded. This issue can be influenced by the availability of an acceptable alternate route.

In all of these cases, the required level of flood immunity would usually be technically achievable, though at a cost that cannot be justified for the benefit gained. For example, the Murray River Crossing in north Queensland, as shown in Figure 3.2.2, has been designed based on a Time of Closure (TOC) criteria, as the cost to construct the highway to normal levels of immunity was prohibitive.

The consequences of adopting a lower level of flood immunity can be analysed by consideration of the extent of traffic disruption and the economic impacts of this disruption. This can be considered in conjunction with the assessment of TOC discussed here.

While it may be acceptable to adopt a flood immunity standard for a project that does not meet the general criterion, in all cases it is essential that the justification for the decision should be clearly detailed.

Figure 3.2.2 – Murray River Crossing of Bruce Highway

3.2.3 Community impacts

3.2.3.1 Time of Closure

Sections 4.5.2 and 4.5.3 of the Austroads *Guide to Road Design* – Part 5 and 4.4.3 of the Austroads *Guide to Road Design* – Part 5B are accepted for this section subject to the following amendments.

Addition(s)

1. It may be the case that a road with a low level of flood immunity is closed for short periods of time (though frequently), in which case there may be limited disruption to transport and the low flood immunity may not be a serious concern.

TOC depends on the catchment response time. Small and steep catchments flow faster and the TOCs will be relatively short, while large and flat catchments will have a longer TOC. Therefore, a small steep catchment where the flood immunity of the road is low may suffer a similar amount of traffic disruption, over a long period of time, as a large flat catchment with a higher flood immunity standard. This means that additional data for selection of an appropriate flood immunity standard can be gained from consideration of TOC.

Because of this factor, TOC can be considered in conjunction with the flood immunity, possibly to adjust the design criteria for a particular crossing.

Through the analysis of TOC, the costs of traffic disruption can be analysed and decisions made on the level of flood immunity that can be justified for the investment.

This analysis is an important consideration in the road planning process but, as with the possible adoption of a lower level of flood immunity, careful justification of the TOC is needed in the analysis.

3.2.3.2 Risk of link closure

When planning the desired immunity level of a road link, an important concept that is often not understood or implemented well, is the assessment of the risk of closure. This concept or issue is particularly important where there is no realistic alternative route available.

The key part of the risk assessment that is poorly understood is the link between the design AEP for cross-drainage structures and the probability of closure of the road link. The probability of closure for an existing road link is not simply based on the minimum AEP standard of all cross-drainage structures along the road link. Equally, it is incorrect to set the acceptable level of risk of closure for the road link and then adopt this level (in the form of an AEP) for the design of each drainage crossing. This will not necessarily achieve the desired level of immunity or risk of closure.

The department usually designs individual cross-drainage structures to a standard of 2% AEP (≈ ARI 50 year). Statistically this means the probability of the road being closed at one of these crossings is 2% annually. However, due to the independence of rainfall events over time and potentially between catchments, any drainage crossing along the link could close, due to a greater than 2% AEP (≈ ARI 50 year) event, independent of all other crossings. This situation, when considered across the whole road link, could greatly increase the risk (probability) of closure of the road link.

The assessment of probability of closure for a road link requires the determination of dependency between the crossings: that is, are the crossings along a road link independent of each other or not? The level of dependency influences the level of probability and therefore risk of closure.

This can be explained by use of an example. Assume a road link with five drainage crossings, each designed with a flood immunity of 2% AEP (≈ ARI 50 year). If all of the crossings on the road link are totally dependent, then a single rainfall event greater than 2% AEP (≈ ARI 50 year) will close all of the crossings at the same time. This gives the road link a probability of closure of 2% (1 in 50). However, if the crossings are fully independent, each crossing can be subjected to its own greater than 2% AEP (≈ ARI 50 year) rainfall event at different times to the other crossings. Therefore, the risk of closure of each crossing is independent of what occurs at the other crossings. This situation can give the road link a probability of closure of about 10% (1 in 10).

Normally, the crossings are dependent to a certain extent and the risk will be between the two cases described. In this case, a single event may affect more than one crossing at a time on some occasions, but they will be affected independently at other times.

Crossings will be fully dependent if the length of the road link is small and a single rainfall event will always affect all crossings together. The dependence decreases as the length of the road link increases and the probability of a single rainfall event affecting all catchments reduces. The dependence is low when there are many small catchments. In this case, each small catchment may be affected by a localised short duration storm event, which will only extend over a limited geographical area, and these events may occur anywhere along the road.

For example, if there is a long length of road with 50 small catchment areas, each with its own crossing designed for a 2% AEP (≈ ARI 50 year) flood event, the risk of closure of the road link is quite high in every year.

The analysis of this risk is complex and depends on an assessment of the catchment types, the expected rainfall mechanism and the distance between crossings.

Calculation of the risk of closure of the whole link needs to consider the flood immunity of each individual crossing as well as the degree of independence of the crossings.

The analysis of this combined risk is a complex statistical analysis. However, it should be considered in many projects, to ensure that there is a good understanding of the total risk of closure. For further discussion and/or advice regarding this type of analysis, contact the Director (Hydraulics and Flooding), Hydraulics and Flooding Section, Engineering and Technology Branch.

3.2.3.3 Flood impacts

While the risk of traffic disruption, as shown in Figure 3.2.3.3, is the main criterion for selection of suitable flood immunity, the impacts on the local environment and community also contribute to the selection of flood immunity.

The impacts on the community result especially from directing flow from a wide flow path over the road through a relatively narrow set of drainage structures.

Figure 3.2.3.3 – Flooding in Mackay

In order to meet the initial required immunity level, the provision of sufficient drainage structures may not be justified by cost and therefore a lower flood immunity may seem to be an appropriate option. In this case, the additional cost of providing the extra drainage to meet the initial required immunity must be balanced against the extra inconvenience (time and cost) of more extensive road closures that would result from selecting a lower level of flood immunity.

However, this situation may be justified, especially in flat floodplains where there are extremely wide flow paths. The justification also depends on the traffic volume and the nature of the traffic using the roadway.

3.2.4 Acceptance of a lower standard

While the drainage design for state-controlled roads and roads within Auslink should provide for the general required level of flood immunity, there are situations where this standard is impossible to meet. In this case, and after careful consideration of the issues presented here, a lower standard of flood immunity may be adopted.

However, if this is the case, the justification of this decision must be documented.

3.3 Development control

3.3.1 Introduction

There are two aspects of development control related to drainage that the department must consider.

First, the department could be regarded as a developer because it controls and directs the construction of road infrastructure and this development may have an impact on the surrounding environment, both natural and built. Road planning, therefore, must determine, assess and mitigate any impacts to an acceptable level.

Second, the department needs to be aware of development near roads and/or in a catchment that may impact on existing departmental drainage infrastructure. This impact could be a change in flood levels or flows or a diversion of runoff. The department is consulted on development approvals when the proposed development is within 100 m of an existing or future planned state-controlled road. This criterion provides for a number of developments, but there are occasions where the proposed development is in the catchment draining to the road crossing, but further away. Development anywhere in the catchment may have an adverse impact on the road drainage, even if it is remote from the road. In this case, the department must maintain surveillance of development and make appropriate allowances or provide advice to developers or a council. Consultation with local authorities assists in this provision.

Both of these aspects must be analysed to ensure that the department's road infrastructure is and/or remains acceptable from the point of view of drainage considerations. To enable analysis of these aspects, the department must firstly determine or establish the hydrologic/hydraulic conditions of the site including the capacities (and immunity level) of any existing drainage infrastructure.

This is a complex area and it is difficult to provide any clear-cut criteria, but there are some general principles that should be considered in assessment of development and this section has some comments on relevant issues.

3.3.2 Departmental impacts

When the department builds a new road or rebuilds/upgrades an existing road, the drainage impacts of this road must be considered. There are three main aspects, namely afflux, the concentration of flow and flow diversions.

Permissible levels of afflux are discussed in Chapter 2 and should be referenced in all cases. Afflux is a critical consideration/criterion as it is often the controlling factor in drainage designs. New road embankments and changes to existing embankments (even by small amounts) will create or change water levels both upstream and downstream of the crossing. These impacts need to be determined and mitigated.

Generally, floodplain flow will tend to be concentrated when directed through culverts under the road. This concentration of flow provides a higher risk of scour at the culvert outlet. The design, therefore, must consider this risk and make appropriate allowances.

Roads may actually change the direction of flow in some circumstances, and this diversion could have serious adverse impacts on the environment and neighbouring property owners. The design must carefully review the possible flow redirection and generally minimise any diversions.

The impact of road drainage on flooding is usually analysed for the range of floods down to an AEP of 1% (up to ARI 100 year), the most commonly used flood criterion for floodplain management in local authorities.

However, in some circumstances, it may be appropriate to consider larger floods, even extreme events. This situation usually arises in urban areas, or where there are particularly sensitive locations. It is also only relevant where the road construction may cause obstruction to flow for larger floods, while allowing the smaller floods up to 1% AEP (ARI 100 year) to pass through the drainage structures. Occasions where this may be important is where there is a high embankment, where there may be safety or noise barriers on the road or where overpasses cause obstructions.

The road design should be reviewed in all cases, and specific analysis should be conducted in cases where this is considered necessary. A risk assessment should be carried out in each case and if necessary, modifications should be made to the design.

3.3.3 Development impacts

The most important development issue of concern for the department is urbanisation (including residential and commercial development). Urbanisation increases stormwater runoff from a catchment. However, while urbanisation may be the most significant development that may affect road drainage, there are other forms of development that may also have an impact. These include:

- levees and other farm works – these may divert flows across the floodplain and may, therefore, change the point where flow must cross the road
- dams, detention basins and other water storages may affect flood levels and discharges. Refer to Figure 3.3.3.

Figure 3.3.3 – Detention basin in a residential subdivision

Urbanisation increases stormwater discharge by increasing the impervious area in a catchment and by improving the channel conditions. The combination of these two factors increases the volume of runoff and the peak discharge, and changes the time the peak discharge occurs, both of which may affect the existing road drainage. Furthermore, urbanisation generally provides artificial flow paths and can reduce the floodplain storage by the filling of depressions and so on. These aspects also increase the flood discharge. Any increase in discharge will most likely affect the flood immunity of the road as it would have been designed for less runoff. The impacts to departmental drainage structures (located downstream of development) can be the increased chance of overtopping the road and/or increased outlet velocities. These factors, in turn, increase the risk of scour, water quality problems and safety concerns. Also, the increased discharge will most likely increase the peak water levels at that location, increasing the level of flooding.

Urbanisation or development downstream of departmental drainage structures may change the condition of the outlet channel (in the external environment). Change or improvement in the channel will most likely change the tailwater level at the structure. If the channel can drain the stormwater away more quickly than before the changes were made, the tailwater at the structure will drop. This can change the operation of the culvert and, in turn, could mean increased outlet velocities. If the channel capacity is reduced or restricted, the tailwater at the structure will increase which will reduce the capability of the culvert which will typically increase flooding on the upstream side of the structure.

Where development is planned that may affect the department's drainage systems, the development should be reviewed to ensure that the existing operation and conditions of departmental owned/controlled drainage structures is not adversely affected.

These reviews should not be limited to cross-drainage infrastructure and must include the following departmental drainage infrastructure:

- longitudinal drainage (table drains, kerb and channel and so on)
- diversion channels
- energy dissipation measures
- retention/detention basins
- levees
- catch banks/drains
- underground systems (pits and pipes) and subsoil drains
- water treatment/quality devices (including sediment basins)
- any other environmental protection device/measure related to drainage.

The department should check for:

- worsening of flood levels (afflux) upstream and downstream of the road
- any increase in the risk of water occurring on/overtopping the road
- any change in the risk of scour because of larger flows/higher velocities
- any increased risk of environmental harm or change in water quality.

As well as individual impacts, cumulative impacts should also be considered. These impacts are where the development currently being proposed is one of several (or many) that may occur. One individual development may not have an adverse impact, but further similar developments may be unacceptable when they are all combined.

Stormwater management reports should be received from developers, or consultants for developers, for all proposed developments where the runoff or flooding may affect a state-controlled road. These reports should be reviewed to assess the potential impacts and, if there are impacts, acceptable mitigation measures should be proposed.

Key requirements of these reports are:

- The flood report should be prepared by a suitably qualified and experienced consultant.
- The hydrologic and hydraulic modelling should be appropriate for the required assessment and should be described fully in the report.
- The analysis should calculate the flood discharges and flood levels for a range of AEPs (ARIs).
- The base case should calculate the flood discharges and levels for the existing conditions, and clearly show the results where the flow crosses the state-controlled road. It is possible that the base case shows that the road has a flood immunity that does not meet the departmental criterion, but the objective of this analysis is to show no worsening of drainage performance when compared to the base case.
- The developed case should include the proposed development and should calculate the flood discharges and levels at the state-controlled road.

- If there is an adverse impact, mitigation measures must be provided. Adverse impacts include an increase in flood discharge or flood level at the road. If there is an increase in flood level or discharge, but the road still maintains the required flood immunity, this may still be regarded as adverse, since other similar developments could make conditions worse. The flood discharges and levels for the mitigated case should be shown at the state-controlled road crossing and these must be no worse than for the base case.
- Mitigation measures may include detention basins, channel works, diversions or other works that ensure that the flood conditions are not worsened. It is important that mitigation measures at one crossing should not worsen conditions at other locations.
- The study should be supported by a comprehensive report that describes the analysis undertaken and presents assumptions with the results.

3.3.4 System augmentation

As stated in Section 3.1, the department must first determine or establish the hydrologic/hydraulic conditions at the site including the capacities (and immunity level) of any existing drainage infrastructure. When these existing conditions are compared to the drainage outcomes of any proposed development, the differences and potential impacts can be determined and understood.

In the event that the department believes that a proposed development will have adverse effects on its existing drainage infrastructure, a financial contribution from developers can be requested to allow the department to undertake appropriate work to augment or upgrade the existing drainage infrastructure in order to handle the changed conditions (hydrologic and/or hydraulic) caused by the development.

To allow discussion and negotiation in regard to any financial contribution from a developer, a reasonable basis for negotiation needs to be established. The following cases outline different situations that can, in turn, form the basis of discussion/negotiation with developers.

3.3.4.1 Case 1

If it is determined that the existing departmental drainage infrastructure meets current and planned (immunity and environmental) requirements and currently performs/operates satisfactorily, then any change required to the existing drainage infrastructure to enable it to adequately handle the changed hydrologic, hydraulic and/or environmental conditions caused by the development should be met by the developer.

3.3.4.2 Case 2

If it is determined that the existing departmental drainage infrastructure meets current and planned (immunity and environmental) requirements, but does not currently perform or operate satisfactorily, then the department would be responsible to undertake remedial work to enable the infrastructure to adequately perform/operate while any change required to the existing drainage infrastructure to enable it to adequately handle the changed hydrologic, hydraulic and/or environmental conditions caused by the development should be met by the developer.

3.3.4.3 Case 3

If it is determined that the existing departmental drainage infrastructure does not meet current or planned (immunity and environmental) requirements, then the changes required to the existing drainage infrastructure to meet current or planned (immunity and environmental) requirements is the responsibility of the department while any additional augmentation to the infrastructure required to adequately handle any additional hydrologic, hydraulic and/or environmental conditions caused by the development should be met by the developer.

4 Data collection

4.1 Introduction

In this chapter, general guidance is provided on how to source and collect data and how to conduct site surveys/assessments to assist in the planning and design of road drainage infrastructure. This data is required to quantify the design requirements as described in Chapter 2.

The various forms of data used in the planning and design of drainage infrastructure are broadly categorised as either ‘strategic data’ or ‘project data’.

Designers should ensure that collected data is appropriately stored for easy retrieval, not only during the preconstruction activities of the project, but also in the future.

This chapter discusses:

a) types of data

b) the importance and sources of strategic data

c) types of project data, sources and application

d) the importance of site surveys and assessments to an overall project

e) methods for collecting and recording data.

4.2 Types of data

Data is progressively collected, analysed and used throughout all preconstruction activities at a level of detail that is appropriate for the purpose being considered. Data that is collected and used for network planning and the development of Road Route Strategies (DMR 2008a) is strategic and regional in nature. The data may become more focused and geographically-specific as the strategies are used to prepare Road Link Plans (DMR 2008a). Data collected for these purposes is defined as ‘strategic data’.

In the development of specific project proposals, the strategic data needs to be reviewed and expanded with the introduction of more detailed, project-specific data. As a project proposal progresses through various preconstruction activities, refinement of data occurs through various investigations and studies and as new design specific data is obtained.

During the construction activities, more data is collected, usually as as-constructed detail. Once a project is completed and becomes operational, further data regarding the operations and maintenance of the road should be recorded as part of the asset management process.

Data collected during preconstruction, construction and operational/maintenance activities is defined as ‘project data’.

Both strategic and project data, with respect to drainage, is useful not only to the department, but also to others who are interested in information such as flood levels and so on. Local authorities, developers and consultants may refer to the department for assistance in providing observed flood levels and so on in areas of interest and this assistance should be given where relevant/appropriate.

Data that has been obtained from various sources for use in planning and design work should be retained as part of the documentation for the project.

4.2.1 Strategic data

Strategic data is usually regional in nature and is required for network planning and the preparation of Road Route Strategies/Road Link Plans (DMR 2008). It may also be required for the planning and design of drainage infrastructure. It can be considered in four types of information:

Type 1 – planning instruments such as:

- regional strategic land-use plans
- statutory and advisory land-use management plans
- land-based and marine national parks
- land-based and marine estuarine environmental protection and management plans
- other land and water-based management plans
- Australian Government planning instruments
- local authority town planning schemes
- urban and rural drainage management plans, initiated under Queensland Government legislation.

Type 2 – naturally occurring events such as:

- storm event data
- flooding event data
- abnormal highest astronomical tide event data
- storm surge event data.

Type 3 – drainage and water management infrastructure such as:

- specific drainage infrastructure
- water catchment storages (such as aquaculture, fish)
- irrigation schemes.

Type 4 – Private or Public Utility Plant (PUP) such as:

- communications systems
- municipal services
- trunk distribution systems for oil, gas, water and effluent
- electricity transmission lines
- state and interstate railways and industry narrow gauge rail systems.

4.2.1.1 Planning instruments

The department may be a participant in the planning processes that create some of these instruments to ensure appropriate road service delivery is provided through Queensland. However, planners and designers need to work within the overall statutory and advisory planning framework when developing various strategic network plans and when planning and designing specific projects.

As these instruments may change over time, it is not advisable to attempt to store this type of data, but rather obtain current information at the start of each new project and review the currency of this information as the phases of a project progress.

Land-use planning is one form of data that can change within the department's planning and design time frame. In rapidly developing urban areas, upstream and downstream land-uses could change through:

- issue or the review of a regional land-use plan
- amendments to the planning scheme, or
- the completion of a new planning scheme.

All relevant Department of Transport and Main Roads regional and district offices need to be part of the regional planning and local authority planning processes to ensure that drainage infrastructure is consistent with land-use planning.

4.2.1.2 Naturally occurring events

Section 4.9.1 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section.

4.2.1.3 Drainage and water management infrastructure

Local authorities and various statutory authorities manage urban and rural drainage systems that are designed for:

- existing and future land-uses in the catchment
- specific hydrological and environmental parameters
- local drainage parameters.

Planners and designers need to obtain data relating to the design of these facilities so that the department's drainage infrastructure is compatible with local authority planning and design.

Drainage infrastructure located in the catchments of existing or planned municipal water storages may need to conform to requirements of the relevant catchment authority, particularly in matters of water quality and erosion and sediment control. Planners and designers should consult with the catchment management authority to ascertain requirements for drainage in the catchment under review.

Authorities managing irrigation schemes may have similar requirements for drainage infrastructure to municipal catchment management authorities and these requirements should be obtained. Details of existing irrigation infrastructure should be confirmed by survey and any expansion plans obtained from the authority.

4.2.1.4 Private/Public Utility Plant

As the department generally approves the location of service infrastructure within the road corridor, documentation associated with these approvals provides an initial source of data for new drainage projects. This data needs to be verified with the agency involved and any information supplied should be confirmed with site measurements and ground survey.

Existing services in the vicinity of drainage infrastructure needs to be located by survey to ensure:

- that the service installation does not impair drainage performance
- maintenance of drainage infrastructure can be completed without damage to the service or the drainage
- the extent of any PUP relocation requirements to enable drainage to be correctly installed can be determined.

4.2.2 Project data

Project data is more relevant to the planning and design of specific projects and largely relates to the physical characteristics of a site and the surrounding catchment. It may be collected or measured at varying times in the different phases of the planning process and at different levels of detail.

Project data includes:

- land-use
- topographic information
- catchment information
- rainfall data
- stream flow and flooding information
- stream flow patterns
- tidal information
- waterway characteristics and stability
- water quality
- sedimentation issues
- soils data
- erosion history
- vegetation constraints
- acceptable time of inundation
- fauna habitats
- downstream conditions
- service installations
- obstructions.

Specific project and routine maintenance inspections provide opportunities to obtain data and to review the in-service performance of the infrastructure. Inspections should have similar objectives to those outlined in Section 4.9.1 of the Austroads *Guide to Road Design* – Part 5 for inspections following extreme events, and the findings recorded in the district database.

The quality of data collected has a direct bearing on the successful design and implementation of drainage infrastructure and is strongly linked to an effective site assessment and planning process. It is important that adequate data is collected in the early stages of a project and that it is stored in a readily available format for use in all subsequent phases.

For example, the collection of soils data at the planning or design phase of a project will facilitate the selection of appropriate erosion and drainage controls and the preparation of an appropriate Erosion & Sediment Control Plan (ESCP) for the construction phase.

Site assessment is also strongly linked to risk assessment. A thorough site assessment, where data is added at each stage of the project, will lead to a reduced risk of adverse impacts to the surrounding environment or to the road itself. This, in turn, will lead to reduced costs in the long term.

The identification of special environmental characteristics of a project site is a key requirement while undertaking a site assessment, though it is expected that most such characteristics will be identified as part of the environmental assessment process. Knowledge of special conditions and factors which influence sensitive environments facilitates environmentally responsible drainage design as defined in subsequent sections of this manual.

4.2.3 Sources of data

Different phases and steps during the preconstruction process may use the same data. This data may be obtained from field investigations, studies and recorded information in various forms such as:

- existing field inspection records
- topographic maps
- documentation obtained during the environmental assessment process
- existing design drawings
- geotechnical investigations
- survey records
- land resource manuals
- aerial photographs
- published references (such as *Australian Rainfall and Runoff* (ARR))
- previously published reports and investigations (being feasibility studies)
- concept and link studies
- acid sulphate soils (ASS) maps
- vegetation maps
- flood maps
- various electronic data sources (such as geospatial data, mapinfo, Queensland Globe). The department’s Geospatial Technologies Unit can assist with this.

Data is available from various departmental sources, from land owners and organisations, such as:

- Bureau of Meteorology (federal)
- Department of Environment and Heritage Protection (state)
- Department of State Development, Infrastructure and Planning (state)

- Department of Natural Resources and Mines
- Queensland Rail
- historical societies
- local authorities
- port authorities
- industry organisations
- environmental groups, including catchment management groups and river trusts.

Table 4.3.1 has been prepared to indicate the type of data available from each of these external organisations.

4.3 Environmental assessment

For every infrastructure project, the department has a responsibility to consider the project's potential environmental effects and/or impacts and to then develop appropriate mitigating measures as necessary. Therefore, an environmental assessment for the project is required and this assessment should be undertaken as early as possible in a project's development.

4.3.1 Vegetation

The vegetation surrounding a project site reduces raindrop impact on the soil, as well as stabilising the soil. These factors are important in erosion control. The vegetation also filters runoff containing sediment. Knowledge of the vegetation characteristics of the project site:

- assists in the determination of the existing degree of disturbance (if any) of the site and its potential for erosion
- enables the protection of species with conservation significance
- guides the selection of species for revegetation
- assists in determining roughness (Manning's Equation's 'n')
- contributes to the determination of the coefficient of runoff
- assists in the identification of constraints to drainage design.

The collection of vegetation data, both terrestrial and aquatic, is an important process. This data is then used in other assessment and design processes referred to in this manual.

The environmental assessment for a project should gather the following data (with mapping) where possible:

- extent and location of all vegetation types (terrestrial, littoral, intertidal, aquatic, trees, shrubs, vines and grasses) in and around the road environment
- description and location of any vegetation corridors that traverse the road environment
- description of the conservation significance of vegetation communities within the study area
- description of any rare or endangered species
- extent and location of any cleared vegetation and incidence of exotic species and weeds
- description and location of flora used traditionally for food, spiritual and/or cultural purposes.

Table 4.3.1 – Data sources

Data type	External organisation
Rainfall data (historic)	1, 2, 6, 9
Flood levels (historic)	1, 2, 4, 5, 6, 9
Tidal data	1, 7, 9, 13
Cross-sections	2, 4, 6, 7
Topography	2, 6, 12
Soil information	2, 3, 12
Flora and fauna	2, 3, 6, 8, 12
Survey data	2, 4, 6, 7,
Water quality	2, 3, 6, 8
Existing infrastructure	2, 4, 6, 7, 9, 10
Aerial photography	2, 3, 6, 11

Notes:

1 Bureau of Meteorology
2 Department of Natural Resources and Mines
3 Department of State Development, Infrastructure and Planning
4 Queensland Rail
5 Historical societies
6 Local authorities
7 Port authorities
8 Environment groups
9 Local residents
10 Service providers
11 Web-based data sites
12 Department of Transport and Main Roads geographic information systems
13 Department of Transport and Main Roads (Maritime Safety Queensland)

4.3.2 Fauna

Recognition of the impacts of road corridor development on fauna populations has led to modifications in the way that roads are now designed. Fauna can influence drainage design significantly.

Research has been undertaken on developing practices that help facilitate fauna movement through passages in the road corridor via drainage structures in a way that minimises fauna mortalities on the road. The provision of fauna passage is important and may influence the physical dimensions of a drainage structure.

The location of drainage structures and discharge points may also affect fish or bank-dwelling species such as platypus.

Again, the environmental assessment for a project should gather the following data (with mapping) where possible:

- species diversity and abundance for terrestrial, littoral, intertidal and aquatic and avifauna
- description and location of any rare or endangered species
- fish habitat/passage requirements
- occurrence, distribution and requirements for migratory species
- species important for traditional, recreational and/or commercial fisheries

- any local terrestrial, aquatic or avifauna used traditionally for food, spiritual and/or cultural purposes.

Appendix 4A provides further information on data collection and site assessment for fauna passage through drainage infrastructure.

4.4 Forms and checklists

To assist in the collection and retention of data, the department has prepared a number of pro formas for use in data collection. These forms should be used as they provide:

- a checklist to ensure all relevant data has been obtained
- media to record data while on site.

Forms currently in use by the department include:

- Bridge Hydraulics Design Summary (Form HYD5).

An overall checklist for the collection of data is provided as Appendix 4A.

4.5 Field inspections

Field inspections of catchments, existing drainage and possible sites within a proposed project area are essential for the planning of major drainage works and for the design of all drainage systems.

Field inspections provide opportunities to understand the site and to assist in formulating the risk profile for the project. Where possible, field inspections by the designer should be organised to be completed in conjunction with field survey, soil and environmental investigations to provide a more integrated data collection process.

More specifically, site inspections allow the designer to:

- obtain an appreciation of the site and its constraints
- validate the reliability and currency of existing records and information (including anecdotal information)
- verify characteristics and parameters that are to be used in the drainage planning and design process
- speak to landowners regarding site issues, drainage and flooding history
- identify and photograph site features that may impact on the selection of future drainage infrastructure.

In particular, field inspections should focus on obtaining an understanding of:

- drainage patterns
- waterway characteristics
- evidence of flooding through existence of debris levels
- evidence of erosion or deposition
- soil types
- extent and type of vegetation including vegetative communities
- potential sources of debris

- existing infrastructure
- location and level of adjacent buildings
- locations for future controls (such as retardation or sediment basins).

The department's Surveying Standards Part 2 Chapter 2 – Bridge Surveys – provides a thorough guide to the collection of data.

Data contained in each of these forms has been combined and included in the checklist in Appendix 4A.

4.6 Rainfall

The duration and intensity of rainfall are major components with respect to the determination of runoff and of erosivity potential. Both vary with geographic position and with the time of year. Thus, rainfall distribution, seasonality and intensity must be considered in order to determine flow rates and the potential for erosion. For more detailed explanations, reference may be made to the latest release of *Australian Rainfall and Runoff, A Guide to Flood Estimation.*

a) Rainfall distribution

   The distribution of median annual rainfall across Queensland is shown in Figure 4.7. The rainfall isohyets shown in Figure 4.7 are generally parallel to the coast, except where topographic features modify the pattern. In particular, significantly higher rainfall occurs between Ingham and Cooktown, Proserpine and Sarina, and north and south of Brisbane where there are high ranges aligned perpendicular to the main onshore winds.

b) Rainfall seasonality

   Rainfall is summer dominant throughout the state, but the volume of rain that falls during the other months varies considerably between regions. South of the Tropic of Capricorn and east of a line between Emerald and Mitchell, there is a significant winter peak in many years.

c) Rainfall intensity

   Rainfall intensity varies with the type of rainfall event (such as advective, cyclonic or frontal), but is generally higher during the summer months than the winter months.

4.7 Flood data

While the majority of structures are sized using statistically derived flows, the collection of historic flood data can also provide valuable information. Flood data can consist of:

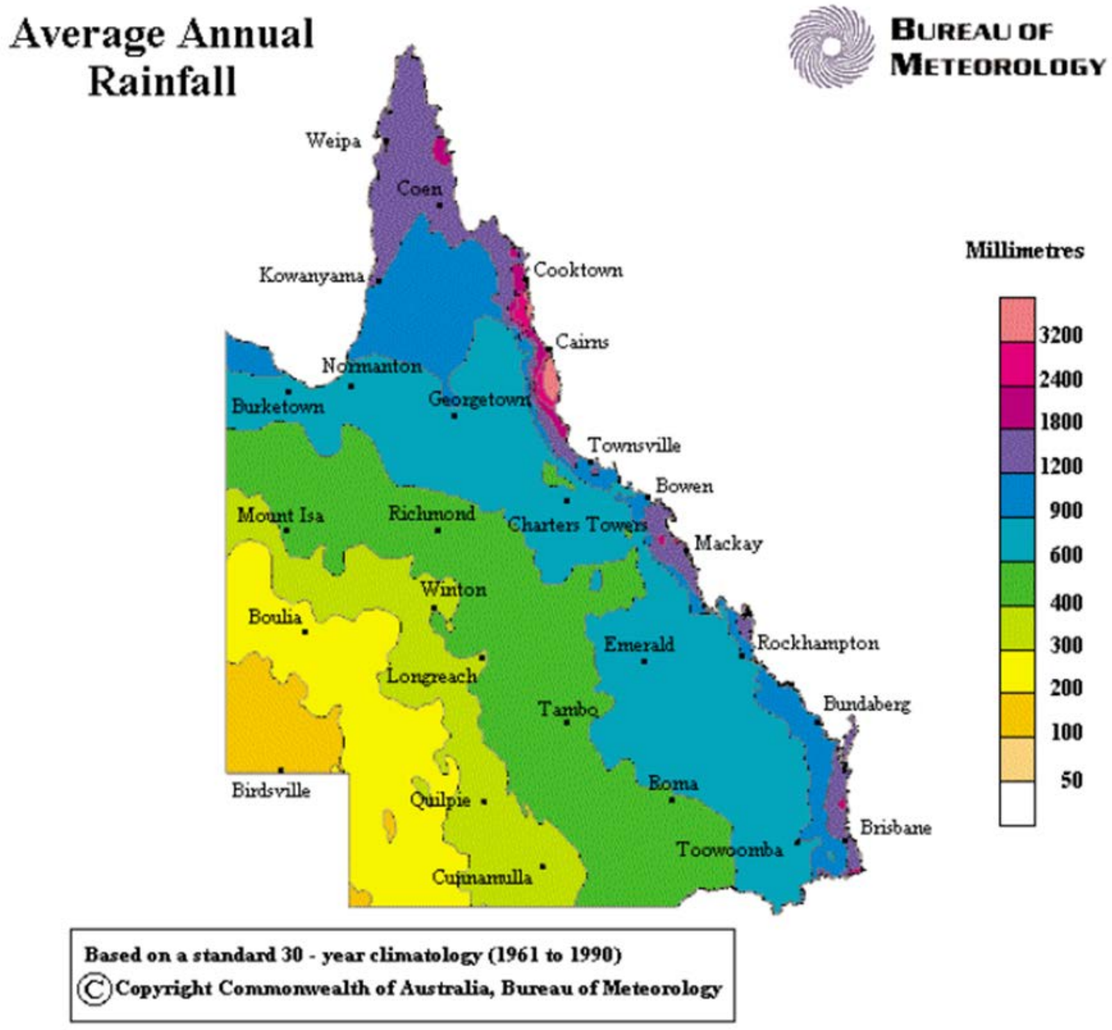
- gauging station records
- recorded peak levels
- mapping of flow patterns
- debris marks
- water stains
- photographs or videos
- anecdotal evidence.

Sources of historic flood data can include landowners, local authorities, Queensland Rail (for example, design drawings often highlight peak flood levels), Department of Natural Resources and Mines and the Bureau of Meteorology.

All data obtained must be evaluated for accuracy and correlated across different sources where possible. This is particularly true with respect to anecdotal evidence of flood heights provided by individuals as:

- the observations did not coincide with flood peak
- there was a lack of visibility (night time flood)
- a significant time (years) has elapsed since the observation
- personal observations can change as time passes.

Figure 4.7 – Annual median rainfall for Queensland



To be useful, it is essential that all flood height information be related to a recognised level datum.

For large scale and some urban projects, historic flood data may be used for the calibration of mathematical models. Information should also be sought in relation to flood gradients, rates of rise or fall, velocities and flow patterns (directions of flow).

For smaller projects, flood data is often scarce and, hence, may only provide an indication of historic peaks, with no means available to estimate the average exceedance probability (AEP) of the flood event.

4.8 Drainage and flow patterns

An understanding of drainage and flow patterns is required to help ensure that adequate provisions are made for upgraded or future drainage infrastructure. This is particularly important at sites where there is no existing drainage infrastructure.

While flow patterns may be simple to ascertain in waterways, careful consideration is required in relation to overland or floodplain flow.

Drainage and flow patterns may be determined through the review of available topographic maps and aerial photography, and through field inspection. For many sites, all three techniques should be used.

Elements that need to be considered include:

- direction of flow particularly in flat areas
- width of flow
- possible backwater from downstream impacts, such as rivers or weirs
- potential for spill into or from adjacent flow paths
- obstacles to flow.

4.9 Waterway characteristics

The characteristics of a waterway may be considered in terms of geometry, hydraulics and the environment.

Geometric characteristics are based on the physical dimensions of the waterway and include:

- channel width and depth
- cross-section
- bed slope
- channel form.

Channel form relates to the geomorphic characteristics of the channel and notes should be made of the following issues:

- Is the waterway straight or meandering?
- Is the channel clear or obstructed by banks or islands?
- Are there sequences of pools and riffles?
- Is there a clear distinction between channel and floodplain?
- Is the stream in a pristine state or has it been degraded?
- Are the banks steep?
- Are the banks stable?
- Is there any evidence of current or past bank slumping?

- Are there any other signs of erosion or deposition of material? If so, what type of material is evident?
- Does the waterway appear to be stable in location?
- Is the low flow channel likely to alter in location?
- Is the waterway consistent in appearance, or are there pool and riffle sequences?

Hydraulic characteristics relate to the actual flow within the waterway. It is important to note that most field inspections occur during times of little or no flow and, hence, the data collected is unlikely to provide a good indication of flood characteristics. Hydraulic characteristics include:

- flow depth
- velocity (note locations where velocities show variation)
- backwater effects (that is, inundation by downstream water levels, which may drown out or control upstream water levels)
- nature and state of vegetation within channel/floodplain.

The environmental characteristics of a waterway may also be characterised by its water quality, soils and vegetation. These are discussed in subsequent sections.

4.10 Water quality data

Water quality data may be required in those instances where:

- proposed works will be discharging runoff into a waterway defined as sensitive
- major works are constructed across a waterway
- there is a need to design pollution control measures.

Therefore, while the collection of water quality data will not be required for all projects, water quality should always be a consideration. The extent of this consideration should be dependent both on the sensitivity of the waterway and on the scale of the project.

In some cases, reports on water quality investigations will be provided through the mechanisms of the environmental assessment process.

Existing water quality data within the study area provides an indication of the health of the aquatic ecosystem. This data is useful for identifying potential changes which may be brought about by the proposed project, and in particular, how runoff and drainage may cause adverse impacts on the existing characteristics.

On the lowest level, the assessment of water quality may be as simple as noting the condition of the water at the time of the inspection (such as stagnant, brackish, colour, turbidity, odour, and so on).

For many waterways, water quality monitoring may be in place. For major projects, specific water quality monitoring may be required. Typically, monitoring should occur both upstream and downstream of the site, so that background levels of pollution can be recorded, and impacts of drainage works monitored.

Australian Runoff Quality – A guide to Water Sensitive Urban Design (EA 2006) is a design guideline that provides an overview of current best practice in the management of urban stormwater in Australia.

4.11 Topography

The collection of topographic data is relevant to the assessment of both flow and the potential for erosion. Topographic mapping is required to allow catchment definition and, in the absence of survey, an assessment of the longitudinal gradient of waterways.

Topographic data is normally obtained from published topographic maps (Sunmap/Department of Natural Resources and Mines) or orthophotos (Department of Natural Resources and Mines) or local authorities. In addition, the use of digital terrain models is becoming far more common with time. These are based on aerial laser survey and photography and are often held by local authorities or created for specific projects.

Typically, the scale of available mapping varies significantly in accordance with proximity to population centres. Mapping with a scale of 1:100,000 is available for most areas, though this is sometimes insufficient to provide an accurate assessment of catchment boundaries or waterway slope. In these cases, reference to aerial photographs or field inspection notes can be of assistance.

4.12 Soils

Section 3.6.1 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section.

4.12.1 Natural soils

Information on the distribution and description of soils within Queensland is available from the Department of Transport and Main Roads, the Department of Environment and Heritage Protection and CSIRO.

Soil information may be available, from these organisations, in the following formats:

- printed hardcopy maps produced following soil surveys of specific study areas
- published soil survey reports that accompany the maps and describe the soil mapping units in more detail – some of these reports also contain chemical and physical analytical data for samples taken from soil profiles representing the major soils present within the study area
- digital GIS soil maps of specific study areas, most commonly provided as either ArcInfo Export, ArcView/ArcMap Shape or MapInfo TAB files
- digital GIS databases associated with the maps and often providing additional information such as landform, geology, dominant soils within each mapping unit, associated soils and the proportion of the mapping unit that each covers
- digital ACCESS databases that contain additional information for the mapping units
- digital ACCESS databases that provide soil profile information for all sites recorded as part of the soil survey.

Specific soil maps and associated reports have also been produced for selected transport corridors.

Care should be taken when using published soils information as the quality of the data may vary due to:

- original purpose of the survey
- mapping scale (or level of intensity) of the survey information
- methodology used in the survey.

Any associated chemical laboratory methods may vary over time and should be checked before proceeding with data interpretation.

4.12.2 Acid sulphate soil information

The Department of Environment and Heritage Protection is the lead agency for information and advice on acid sulphate soil (ASS), and is continually developing ASS risk maps that show areas dominated by actual (AASS) and potential (PASS) ASS. These maps present information on presence or 'depth to' AASS horizons and presence or 'depth to' PASS horizons. They are available in hard copy and electronic forms at a range of scales.

For more information and mapping:

- access the Department of Transport and Main Roads geographic information systems (GIS) (mapinfo)
- access the Department of Natural Resources and Mines' fact sheets, such as *Acid sulfate soils in Queensland* on its website
- contact the Queensland Acid Sulphate Soils Investigation Team (QASSIT), Department of Natural Resources and Mines
- access CSIRO and the National Committee for Acid Sulphate Soils (NatCASS) soil databases.

4.13 Existing infrastructure

At all locations, it is important to identify existing infrastructure and PUP, which may act as constraints to the design and location of future drainage measures. At all sites, it is important to note the location and existence of:

- adjacent dwellings or other buildings with floor levels
- existing culverts and bridges
- infrastructure associated with the supply of services such as communications, gas, water supply, sewerage
- industrial pipelines
- irrigation infrastructure.

The existence of infrastructure may exert a strong influence on the design of hydraulic structures. Constraints can include:

- maximum allowable upstream water levels (for example, based on potential for flooding of existing buildings and infrastructure)
- obstructions to flow
- diversion of flow
- need to maintain pedestrian safety.

For larger projects, it may also be necessary to obtain details of major infrastructure, such as dams or weirs.

4.14 Survey

In obtaining survey for a project, reference should be made to the current departmental surveying standards. In particular, reference should be made to the relevant geomatic survey section, as well as the general information section. These standards are available on the department's intranet and internet sites. The geomatic type 'Bridge Surveys' provides comprehensive details as to the requirements for bed levels, bed gradient and channel cross-sections. Reference is also made to the need to identify additional information as described in other sections of this chapter.

When specifying requirements for survey, it is important to ensure that cross-sections are surveyed perpendicular to the direction of flow, both within the channel and on the floodplain.

The most appropriate and cost effective method of data capture should be assessed for each project. Options include traditional ground survey, photogrammetry and Airborne Laser Scanning /Light Detection and Ranging. Also, any existing geographical data (within GIS) should be reviewed.

For advice and/or additional information, refer to the regional or district survey manager and/or Geospatial Technologies Unit within the Engineering and Technology Branch.

4.14.1 Aerial imagery

Aerial imagery is a valuable source of information for the design and assessment of drainage infrastructure, though it is important to be aware of the dates and times at which the image was captured. Aerial imagery may be used to determine, at the time of capture:

- extent, density and patterns of vegetation
- delineation of overland flow paths
- locations of active erosion (such as meanders)
- waterway dimensions where access is poor
- land use.

Historical photographs and imagery can also be a valuable source of information in relation to assessing historic flood heights, flow patterns, and waterway characteristics.

Care must be taken in the assessment, where the date and time of the capture is not known. Field inspections should be used to confirm the currency of existing information.

4A Appendix: Data collection checklist

Data collection checklist

Region/district:	
Project name:	
Contract/project number:	

Each section must be considered for applicability to project. Sub-components should be checked when data is collected or noted as not applicable to the project.

Table 4A.1 – Environmental assessment

Item	Check
Has vegetation and fauna data been obtained from an environmental assessment?	❑

Table 4A.2 – Vegetation coverage

Item	Check
Have aerial photographs been sought?	❑
Has a field assessment of vegetation coverage been undertaken?	❑

Table 4A.3 – Other forms and checklists

Item	Check
Bridge Hydraulics Design Summary (Form HYD5)	❑
Local forms/checklists	❑

Table 4A.4 – Field inspections

Item	Check
Existing land use	❑
Evidence of flooding – indications of flood heights (debris, etc.)	❑
Evidence of erosion or deposition	❑
Potential sources of debris	❑
Potential sites for future control measures	❑
Extent and nature of vegetation (refer also Table 4A.2 in this Appendix)	❑
Drainage and flow patterns (refer also Table 4A.7 in this Appendix)	❑
Waterway characteristics (refer also Table 4A.8 in this Appendix)	❑
Water quality (refer also Table 4A.9 in this Appendix)	❑
Soil characteristics (refer also Table 4A.11 in this Appendix)	❑
Building infrastructure (refer also Table 4A.12 in this Appendix)	❑
Drainage and other infrastructure (refer also Table 4A.12 in this Appendix)	❑

Table 4A.5 – Rainfall

Item	Check
Has the following rainfall data been obtained?	
Statistical data	❑
Historical records	❑

Table 4A.6 – Flood data

Item	Check
Have gauging station records been obtained?	❑
Have recorded peak water levels been obtained?	❑
Have debris marks, water stains, etc., been identified?	❑
Has anecdotal evidence been obtained?	❑
For large-scale projects, has historical flood data been sought?	❑
Has flood data been assessed for accuracy? (surveyed or anecdotal)	❑

Table 4A.7 – Drainage and flow patterns

Item	Check
Verify direction of flow (particularly important in flat terrain)	❑
Width of flow (including low and high banks)	❑
Potential for overflow into or from adjacent flow paths	❑
Identify obstacles to flow	❑
Existing and potential drainage patterns	❑

Table 4A.8 – Waterway characteristics

Item	Check
Have the following geometric characteristics been obtained?	
Channel width and depth	❑
Cross-section	❑
Bed slope	❑
Channel form	❑
Have the following geomorphic characteristics been considered?	
Is the waterway straight or meandering?	❑
Is the channel clear, or obstructed by banks or islands?	❑
Is there a clear distinction between channel and floodplain?	❑
Are the banks steep?	❑
Are the banks stable?	❑
Is there any evidence of current or past bank slumping?	❑
Are there any other signs of erosion or deposition of material? If so, what type of material is evident?	❑
Does the waterway appear to be stable in location?	❑
Is the low flow channel likely to alter in location?	❑
Is the waterway consistent in appearance, or are there pool and riffle sequences?	❑
Have the following hydraulic characteristics been obtained?	
Flow depth	❑
Velocity (note locations where velocities show variation)	❑
Backwater effects (that is, inundation by downstream water levels, which may drown out or control upstream water levels)	❑

Table 4A.9 – Water quality data

Item	Check
Has relevant data been sought from the following sources?	
• Department of Environment and Heritage Protection	❑
• Department of Energy and Water Supply	❑
• MRTS 16 – Landscape and Revegetation Works	❑
• Local authorities	❑
Will onsite water quality monitoring be required?	❑
Has the presence of acid sulphate soils been checked?	❑

Table 4A.10 – Topography

Item	Check
Has relevant data been sought from the following sources?	
• Department of Natural Resources and Mines	❑
• Local authorities	❑
Have aerial photographs, topographic maps, orthophotos and survey/digital terrain models been sought?	❑

Table 4A.11 – Soils

Item	Check
Has data been sought from the following sources?	
• Published soil maps and reports including TMR Soil Group	❑
• Department of Natural Resources and Mines or CSIRO soil database	❑
• MRTS16 – Landscape and Revegetation Works	❑
• Field investigations at each site	❑

Table 4A.12 – Existing infrastructure

Item	Check
Has the existence and location of the following been identified?	
• Adjacent dwellings/buildings – where flooding could be a sensitive issue, include floor levels or other control points etc.	❑
• Existing drainage infrastructure (e.g. bridges, culverts, subsoil drains, pipelines, environmental/water quality devices)	❑
• Private/Public Utility Services (e.g. communications, gas, power, water, sewerage etc.)	❑
• Industrial pipelines	❑
• Irrigation infrastructure	❑

5 Hydrology

5.1 Introduction

Section 6.1 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section.

5.2 Rainfall

Section 6.3 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section. Sections 6.3.1 and 6.3.2 in the Austroads *Guide to Road Design* – Part 5 of *Rainfall Intensity*, *Frequency* and *Duration* and the corresponding tables are addressed in Section 5.8 of this manual.

5.3 Rainfall – runoff relationship

Section 6.2 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section.

5.4 Methods available for runoff calculation

There are several techniques available for flood estimation in various-sized catchments and these procedures are described, in detail, in the latest release of *Australian Rainfall and Runoff, A Guide to Flood Estimation,* Vol. 1.

Methods and techniques for determining flood discharges or runoff estimation in larger catchments, usually associated with major structures, such as bridges and floodways, are not described in this manual.

While there are many methods for flood estimation, the standard method of routine runoff calculation used by the department for small rural and urban catchments is the Rational Method.

The Rational Method is a simple, statistical method used to calculate peak discharge from a catchment for a given Annual Exceedance Probability (AEP).

5.5 Rational method

Sections 6.6.1 (for rural catchments) and 6.7.1 (for urban catchments) of the Austroads *Guide to Road Design* – Part 5 are accepted for this section. The method should be applied with consideration to the background and applicability statements contained within sections 6.4.1 and 6.4.2 of the Austroads *Guide to Road Design* – Part 5.

5.6 Catchment area

Sections 6.4.2 and 6.5.1 of the Austroads *Guide to Road Design* – Part 5 are accepted for this section.

5.7 Time of concentration

5.7.1 General

Sections 6.6.2 (for rural catchments) and 6.7.2 (for urban catchments) of the Austroads *Guide to Road Design* – Part 5 are accepted for this section.

5.7.2 Rural catchments

Section 6.6.2 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section.

5.7.3 Urban catchments

Section 6.7.2 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section subject to the following amendments.

Addition(s)

1. Channel flow

   Note: The slope of the energy line is often difficult to determine, therefore use a representative slope of the channel (So) in the vicinity of the site to estimate the slope of the energy line – that is, So ≈ S.

5.8 Rainfall intensity – frequency – duration

Sections 6.3.1 and 6.3.2 of the Austroads *Guide to Road Design* – Part 5 are accepted for this section, subject to the following amendments.

Addition(s)

1. In 2013, the Bureau of Meteorology released the new Intensity – Frequency – Duration (IFD) design rainfalls as part of the revision of Engineers Australia's design handbook, *Australian Rainfall and Runoff: A Guide to Flood Estimation*.

Design rainfall IFD should be derived using the online tool on the Bureau of Meteorology website. At mid-2014, this tool enabled the derivation of IFD information based on both the Australian Rainfall and Runoff 1987 (ARR87) methods and the updated 2013 approach.

The Bureau of Meteorology and Engineers Australia have provided guidance on their websites as to when each of the two rainfall estimates should be used. **The methods for the determination of design flows outlined in this manual should continue to use the ARR87 rainfall estimates.**

5.9 Runoff coefficient

The runoff coefficient, 'C', is a statistical composite of several aspects, including the effects of rainfall intensity, catchment characteristics, infiltration (and other losses) and channel storage. It should not be confused with the volumetric runoff coefficient which is the ratio of total runoff to total rainfall.

5.9.1 Rural catchments

Section E1 of the Austroads *Guide to Road Design* – Part 5 Appendix E is accepted for this section.

5.9.2 Urban catchments

Sections E2, E3, E4 and Table 6.8 of the Austroads *Guide to Road Design* – Part 5 Appendix E are accepted for this section subject to the following amendments.

Addition(s)

1. The runoff coefficient must account for the future development of the catchment as depicted in the planning scheme or zoning maps for the relevant local government, but should not be less than the value determined for the catchment under existing conditions.

5.9.3 Adjustment factors

Section 6.7.3 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section.

5.10 Partial area effects

Section 6.6.4 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section, subject to the following amendments.

Addition(s)

1. Two generally accepted procedures for use with the Rational Method for the calculation of peak flow rates from partial areas are presented in the following sections. One method is for rural catchments and the other for urban catchments. It is recommended that the hydrologic assessment of catchments with unusual or widely varying surface features should be undertaken by the Hydraulics and Flooding Section, Engineering and Technology Branch or a suitably prequalified consultant using an appropriate numerical runoff-routing model.

5.10.1 Rural catchments

Section 6.6.4 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section.

5.10.2 Urban catchments

Section 6.7.4 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section.

5.11 Progressive catchments

Section 6.6.5 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section subject to the following amendments.

Addition(s)

1. Should the situation occur in an urban environment where one stream crosses a road several times, then specialist assistance is required from either the Hydraulics and Flooding Section, Engineering and Technology Branch or a suitably prequalified consultant.

5.12 Worked example (rural): rural runoff

Section 6.8 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section.

5.13 Worked example (urban): urban runoff

Section 6.9 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section.

6 Approach to drainage design

6.1 Overview

This chapter outlines an approach to the selection and design of various road drainage infrastructure in order to provide for a specified hydraulic capacity and other related design requirements.

Although the emphasis in this and subsequent design chapters is on the 'design of drainage infrastructure', this approach can also be used to complete planning or preliminary drainage design during the pre-project and concept phases within the Road System Manager Framework. In these instances, it is the responsibility of the civil designer to ascertain the extent of design work required.

For a road project, drainage design is completed for a specific horizontal and vertical alignment and cross-sectional detail during detailed design. However, during the concept and development phases, drainage design may be used to assist in the fixing of the road geometry and to facilitate a more economical design for the overall road project.

Road alignments and cross-sectional details, therefore, may change during these phases and, in turn, drainage design needs to be reviewed each time the road geometry changes.

Drainage design starts with the preliminary selection of infrastructure that might be suitable for a particular location in a road project using the results of the analyses described in Chapter 5.

This initial selection and sizing is made by:

a) establishing the cross-sectional geometry at the drainage site (for both the road and channel) to determine maximum width/height of structure (such as allowing for appropriate cover requirements)

b) sizing for hydraulic requirements based on the determined/estimated design discharge

c) sizing for fauna passage (if required).

With this initial selection and sizing made, the designer then:

d) identifies ancillary drainage works (headwalls, wing walls, aprons and erosion protection works) required in the vicinity of the selected cross-drainage structure

e) reviews the geometry of the cross-drainage with the ancillary works in place

f) reviews the results in terms of the design criteria including cost and constructability

g) repeats the process until an acceptable design is completed.

Computer modelling facilities can streamline the iterative process (refer Section 6.3).

During this iterative process, the designer may need to revisit the analyses completed in Chapter 5 to address topics that may not have been considered in the completed analyses or that may require review.

With the selection of the components of the drainage structure or system completed, the design of the system components can be completed by reference to the appropriate design chapters 7, 8, 9, 10, 11 and 12.

Each of these chapters incorporates sections that address the application of local environmental design criteria that are necessary to:

- select and design the most appropriate type of infrastructure
- design-related environmental treatments that address identified impacts of the infrastructure.

This manual does not include the design of bridges but guidelines on the location and layout of a bridge are provided in Section 6.5.

6.2 Geometric design of drainage

Establishing the geometry of a drainage site is an initial part of the design process. Early sizing of drainage in the planning phase requires some assumption of the road alignments and cross-sections to provide dimensional inputs (height and width) to calculations of possible drainage solutions.

Site-specific geometry is also necessary for the calculation of quantities for use in estimates of cost for:

- comparison of drainage alternatives
- preparation of estimates of cost as required in the stages of the planning and design process.

As the planning and design process progresses with the selected infrastructure, geometric design of the proposal is developed by:

- locating and aligning the structure with the watercourse or drainage path and any identified fauna passage requirements
- determining the length of the structure and setting invert levels using hydraulic slope requirements
- checking maximum allowable afflux related to neighbouring properties and design culvert appropriately
- determining and designing any mitigation works required to address unacceptable afflux levels
- checking appropriate distribution of culverts to maintain existing flow patterns
- checking maximum allowable outlet flow velocity and sizing culvert appropriately or designing suitable outlet scour protection measures
- checking both culvert inlet and outlet control conditions with proposed design levels – maximum outlet velocities can be determined and compared against maximum allowable outlet flow velocities
- determining tailwater level based on hydraulic gradient of existing channel flow for a design event, including a check for backwater effect
- reviewing surface water flow paths to ensure water is quickly shed from the road surface (within allowable depths of flow) to reduce potential for aquaplaning
- ensuring table drains slopes are equal to or greater than the minimum allowable
- ensuring diversion drains (outlets to table drains) are available, preferably within the existing road reserve, or beyond, by agreement with the affected property owner
- checking cover, backfilling and structural requirements for culverts, including laying method and class of culvert (where applicable)

- checking consistency of longitudinal and cross-drainage
- checking for any bypass flows to adjoining culverts/catchments and mitigate as necessary
- checking for the risk of blockage of culverts and designing the works suitably
- locating and sizing necessary environmental drainage works
- selecting headwalls, wingwalls, aprons, cut-off walls and erosion protection works as applicable.

6.3 Computer modelling of drainage solutions

Computer modelling can assist the planning and design process with the detailed hydrologic and hydraulic calculations and with the presentation and storage of data.

The department has standardised on 12d Model™ as the modelling system for the road delivery system as a project passes from survey to planning to design to construction and operation. This package has some drainage design functionality, but does not cover all aspects of road drainage.

Various software packages are available and those approved for use in the planning and design of road drainage infrastructure are detailed in Chapter 1.

6.4 Preliminary selection decisions

Knowing where to start is often a time consuming process and Table 6.4 has been prepared to assist designers with preliminary selections of drainage structures. This selection process of drainage infrastructure is further developed throughout this chapter.

In urban drainage, many of the design requirements for drainage may have been established and the selection process is initiated by reference to the appropriate local authority drainage planning scheme and the *Queensland Urban Drainage Manual* (QUDM), published in 2013 by the Department of Energy and Water Supply.

For the majority of designs, it will be obvious as to whether a bridge, culvert or possibly a floodway is required at a given location. This decision will be made on the basis of matter, such as:

- catchment area and hydrology
- road alignment
- serviceability
- existing waterway bank height
- potential for debris (including accumulation of)
- environmental constraints
- geotechnical considerations
- need to allow for the passage of large fauna
- stream flow activity.

In the case of an active or permanent stream, building a bridge will be easier and will have less impact on the environment.

For multiple reinforced concrete box culverts, slab link box culverts and multiple reinforced concrete culverts with a total length greater than 10 m along the road centreline in expansive soil conditions, refer to Section 9.2.7 in Chapter 9.

A floodway is a low level section of road designed to allow flood waters to cross the road without damaging the road. They are only provided where traffic volumes are low and where the time of submergence/closure is considered acceptable.

A floodway may incorporate a culvert designed to pass low flows under the road or to reduce ponding and may also be incorporated into a bridge or culvert solution where the bridge or culvert is designed to pass a lower level flood than the design flood.

Table 6.4 – Preliminary selection of drainage infrastructure

Selection issue	Factors	Decision
Bridge	Significant catchment	Consider bridge if floodway is unacceptable
Floodway	Wide shallow flow Low traffic volume	Consider floodway if time of submergence is acceptable; however, check immunity option as it may be more economical due to possible high cost of floodway protection
Culvert type	Waterway geometry Flat topography Fauna passage	Pipe culverts are default type selected; however, box culverts are more suitable for situations where there is: • minimal available waterway area • insufficient cover to allow pipes • fauna passage or the passage of people/vehicles or large animals is required • supplier location • fish passage
Culvert location	Stream alignment Road alignment Geomorphology	Desirable skew is 0° (i.e. no skew) Skew intervals of 5° are preferable Skew of culvert should not be more than 45° Do not locate culverts on the bends of actively moving watercourses In urban drainage systems, preferable to use bearings for precise culvert alignment
Environmental sensitivity	Sensitive flora or fauna Fish passage Permanent stream	Consider a bridge rather than culverts Control pollutant runoff Maintain a natural stream bed Minimise disturbance of bed and banks
Need for channel lining	Soil type Limited available width Steep gradient Velocity Channel shape	Where dispersive soils are present, a barrier must be placed between flowing water and the soil Velocity reductions by flattening grade or widening the channel will often allow a less expensive or more natural lining to be used (such as vegetation, crushed rock, etc.) Consider the incorporation of check dams, drop structures or a change in alignment

Selection issue	Factors	Decision
Type of bank protection (where velocities are considered excessive)	Soil types Flow velocity	Revegetation – planting of riparian vegetation is favoured Erosion mats – long-term stability will need to be addressed Rock riprap – must be properly designed Gabions – can be used on steep banks Grout mats – flexible, but will not provide good habitat Concrete – usually a last resort
Use of swales (versus lined table drains or kerb and channel)	Available space Rainfall Water quality Low erodible soils	Swales may be used where: • there is sufficient space • where grade is sufficient to prevent permanent ponding of water regular rainfall or watering will occur • water quality benefits are desired
Need for outlet protection	Outlet velocities Soil type Erosion risk rating	Outlet protection may be required where outlet velocities are sufficient to cause erosion Management options include: • change culvert design by reducing slope • replace or cover dispersive soils • reduce velocities through dissipation (subject to safety considerations) • provide protection

6.5 Bridges

6.5.1 Overview

Section 4.10.2 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section subject to the following amendments.

Addition(s)

1. Additional information on the design of bridges can be found in:

- *Waterway Design* (Austroads 1994)
- *Bridges and Retaining Walls*, RPDM (DMR 2006).

6.5.2 Riparian and wildlife corridors

Section 3.3.9 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section.

6.5.3 Bridge location and waterway alignment

Section 4.10.4 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section.

6.5.4 Bridge geometry

Section 4.10.5 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section.

6.5.5 Road grade and hydraulic clearance

Section 4.10.5 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section subject to the following amendments.

Addition(s)

1. Reference should also be made to the *Road Planning and Design Manual* (RPDM) for details on road geometry in relation to bridges.
2. It is important to note that it may be a legal requirement for other departments/authorities to approve bridge spans and vertical clearance. Further advice in relation to this should be sought from the department.

6.5.6 Span lengths and pier location

Section 4.10.5 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section.

6.5.7 Scour protection

Section 4.10.5 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section.

6.5.8 Overtopping

Section 4.10.5 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section.

6.5.9 Maintenance

Section 4.10.5 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section.

6.6 Culvert size and type

The choice of culvert size is heavily influenced by the permissible afflux or headwater level, the likely depth of flow, watercourse shape (that is, channel or floodplain) and, in some cases, the need to cater for fauna passage, pedestrian, vehicle or bikeway access, or stock movement.

The selection of culvert type is closely linked to the determination of size and, hence, both must be considered jointly. In many cases, a number of iterations will be required before culvert dimensions can be finalised.

For the preliminary sizing in the proposal development and options analysis, initial size estimates can be determined on the basis of permissible velocity and afflux/headwater level.

In addition, ambient conditions can dictate the suitability of certain culvert types. For example, in corrosive environments (such as coastal regions), some types of culverts may not be appropriate.

For preliminary design, more rigorous design work is required and the complete design process needs to be completed for the detailed design.

6.7 Open channels

Open channels may form part of a specific drainage infrastructure solution where space permits in the road area or where it is part of a drainage planning process by a local authority or a drainage initiative of another government department.

As part of a specific drainage infrastructure solution, they can be used for:

- inlet or outlet channels
- longitudinal diversion drains

- stream diversions
- overflow channels
- connections to other drains.

Appropriate soil and environmental analyses will need to be used to design the channel to deliver the required hydraulic capacity with appropriate environmental safeguards.

Local authorities or government departments may provide the designer with specific drainage requirements through programs such as:

a) soil conservation plans

b) master drainage plans

c) various environmental waterway plans.

Velocity control and protection of channel bed and banks are key elements in open channel design (refer Chapters 8 and 9).

Open channels should be designed with consideration of water quality issues. High flow velocities, often found in lined and artificial channels, cause high velocities that increase the risk of scour and transport of pollutants. Open channels can be designed as swales to allow the collection of pollutants before they can enter receiving waters.

Where open channels are part of a drainage design, the design needs to be completed early in the design process to assist in determining headwater and tailwater levels used for cross-drainage design.

6.8 Bank protection and linings

The choice of bank protection or channel lining (whether natural or artificial) is relevant to the design of open channels, chutes, floodways and swales. The decision as to which type of lining is the most appropriate for the site is dependent on factors such as soil type, potential for vegetation growth, available space and flow velocity. Bank protection and lining can also influence water quality and the conveyance of pollutants.

6.9 Longitudinal drainage

Site constraints and design standards dictate that it is not always possible to choose between longitudinal drainage options, such as kerb and channel, grassed swales and lined or unlined table drains.

In urban environments, kerb and channel has historically been favoured for most roads, though grassed channels are also common on divided roads.

In rural areas, earth drains are more common.

However, in some cases it will be possible to choose between these alternatives. When a choice is available, the designer will need to consider the following:

- Gradient of the channel – steep gradients will allow narrower drainage channels to be used, but can lead to high velocities which, in turn, may require linings with higher resistance to erosion.
- Available flow width – the flow width for any option must be compared to the available width for longitudinal drainage. Flow width is dictated by gradient, shape of the drainage path, and roughness of the flow path.

- Need to improve water quality – where water quality improvement is required, use could be made of grass swales rather than an impervious lining. Channels with high flow velocities are more prone to poor water quality. For grass swales to be a viable option, there must be sufficient room to cater for shallow flow and the designer must consider issues relating to the survival and maintenance of the proposed vegetation.
- Survival of vegetation in the area – in arid areas, it is often not practical to design a flow path that is reliant on the existence of vegetation to provide protection to soils. Only vegetation suited to the climate of the region should be considered.
- Maintenance requirements of longitudinal drainage – as with all types of drainage and pollution controls, a lack of maintenance will lead to failure of the design. In those locations where maintenance may not be readily available, it may be necessary to propose a low maintenance solution.
- Water sensitive design – throughout urban areas, there is an increasing trend to adopt a 'water sensitive' approach to drainage design.
- Riparian corridors – the design of the channel should consider maintaining or enhancing the riparian corridors to prevent adverse impacts on water quality and to maintain environmental values, including fauna movements.

6.10 Location

For major drainage infrastructure, such as culverts or bridges, the location of a structure can have a significant bearing on both environmental impacts and waterway stability. This is also true of several other types of drainage infrastructure, including open channels and drop structures.

Geometric design is an integral part of the location process as outlined in Section 6.2 and is an essential in determining location in those areas where:

- the watercourse is not stable
- bed or bank erosion may result from the presence of new infrastructure
- soils are highly erodible
- the area has high environmental sensitivity
- bed slopes are steep
- the face of a structure is not perpendicular to the watercourse.

Where potential problems have been identified, it is important that:

a) an alternative location or alignment is identified, or

b) appropriate protective measures are put in place to prevent or mitigate the potential impacts.

Alternative 'a)' should be the first preference, but will not always be possible in areas where the alignment is fixed.

In those instances where a river or creek is obviously active (eroding or accreting), a geomorphic analysis may be required.

6.10.1 Location example

A proposed new road will cross Sandy Creek at a point where the creek has active bank erosion owing to the existence of a meander. A series of box culverts is proposed at this location. The following courses of action could be considered:

- Option 1: Propose a local realignment of the road such that the crossing of Sandy Creek will occur at a stable location
- Option 2: Stabilise the meander if constrained for space
- Option 3: Consider realignment of the creek away from the proposed crossing.

Option 1 would be favoured wherever possible, with Option 2 the next favoured alternative. The use of 'hard' solutions (such as riprap lining) or creek realignment (Option 3) is not favoured as changes to the creek at one location will often transfer problems to other nearby locations.

6.10.2 Culvert locations

To minimise environmental impacts, culverts should be located:

- where satisfactory ground conditions and soil conditions exist
- away from reaches of highly unstable channel
- away from bends in the watercourse
- where possible adverse effects on other existing bridges and hydraulic structures can be avoided
- where ecological impact is acceptable
- where aesthetic considerations are favourable.

6.11 Water quality

When water quality (pollution) control devices are required as part of the road drainage system, additional considerations must be taken into account.

For example, the hydraulics of the drainage system may not be conducive to efficient pollutant removal or, conversely, the proposed pollution control device may compromise the hydraulic efficiency of the system.

Questions that must therefore be addressed when incorporating water quality controls into a drainage system include:

a) 'Does the device require a large hydraulic head loss to operate?'

b) 'Will the device lead to upstream flooding in flat areas?'

c) 'Is the gradient of the system too steep (resulting in high velocities) to allow effective pollutant removal?'

d) 'Can the device be accessed for maintenance purposes?'

Examples of design implications are:

- Wetlands or sediment basins may not operate effectively if subject to high velocities during flood events. A high flow bypass is often required

- When trash racks are installed, provision must be made for high head losses associated with blockage of the racks. In this case, consideration of the potential for flooding of upstream property must also be assessed.
- Pollution control devices placed in areas with high tailwater levels may not operate, particularly where there is reliance on a floating boom to trap litter.

Chapter 7 provides design procedures for pollution control.

7 Environmental consideration and design

7.1 Introduction

Road infrastructure environmental issues should be identified and assessed throughout the road planning and design process. Project-specific environmental assessment provides information about the condition of the existing environment, the proposed project area, associated environmental impacts of the proposal and the identification of any opportunities for environmental management.

In this chapter, an approach to acknowledging and addressing the relationship between site drainage and requirements for water pollution control, design of water pollution control measures and fauna passages are examined. Basic principles and design criteria for the mitigation of these environmental issues will also be discussed.

This chapter relates to the ongoing potential impacts from the operation of roads that can be mitigated through good drainage design. Construction impacts are not discussed in this chapter but managed through environmental management plans and erosion and sediment control. Design aspects of erosion and sediment control issues during construction are discussed in Chapter 13.

This chapter links in with Chapter 12 on basins. Understanding pollution sources, transport mechanisms and removal techniques in this chapter will assist in applying the design principles and practices of this chapter and that of Chapter 12.

7.2 Legislative requirements and general environmental duty

The *Environmental Protection Act 1994* places an obligation upon all persons in Queensland who are carrying out activities which may cause environmental harm. Under this Act, the department and all persons working for the department must adopt all reasonable and practical measures to prevent or minimise environmental harm. This is called the general environmental duty.

Other general requirements on permanent water quality are discussed further in Section 7.3. General requirements regarding fauna are detailed in Section 7.6.

Depending on the location and scope of work, there may also be project-specific legislative requirements. Project-specific legislative requirements with regard to design requirements will be outlined in the project environmental assessment.

For up-to-date information on general legislative requirements, contact your local departmental environmental officer and/or refer to the department's Environmental Legislation Register.

7.3 Environmental values and water quality objectives

The Queensland Government, through the Environmental Protection (Water) Policy 2009, details environmental values that it is seeking to protect and enhance for the majority of waterbodies within Queensland. Specific water quality objectives are then set for these values.

The environmental values and the water quality objectives for waterbodies that the road is draining into can therefore provide an indication of the level of treatment that should be incorporated into road drainage design.

7.4 Pollution control: water quality

A key environmental consideration related to drainage (via stormwater, site water runoff, rainfall, litter and spills) is pollutant export and its resulting impact on water quality. Pollutants contained in runoff and drainage from road corridors have the potential to adversely affect the water quality and aquatic biota of receiving waters with short- or long-term impacts.

For any given project, the significance and impact of pollutant export will depend upon:

- the relative sensitivity of the receiving environment
- traffic type and volume
- road project infrastructure type and form (such as off-ramp, traffic lights, bend in road, steep hill, and so on)
- climatic factors experienced in the locality.

Therefore, pollution control techniques must be established and implemented according to many factors, including the type, source, concentration of pollutant export and the risk of harm the pollutant may have on the receiving environment.

7.4.1 Establishing pollution control requirements

When identifying the need for pollution control, the following steps should be completed:

a) Determine management objective (Section 7.4.1.1)

b) Determine water quality design criteria (Section 7.4.1.2)

c) Identify pollutant sources and estimation of pollutant loads (Section 7.4.1.3)

d) Identify pollutant transport processes (Section 7.4.1.4)

e) Identify pollutant removal processes (Section 7.4.1.5)

f) Assess potential pollutant control devices (Section 7.4.1.6)

g) Calculate potential pollutant removal (Section 7.4.1.7)

h) Implement treatments (Section 7.4.1.8)

i) Evaluate the working efficacy of pollutant removal processes and review if necessary (Section 7.4.1.9).

7.4.1.1 Determine management objective

The project's management objective in relation to water quality should be determined based on a number of elements:

- Scale and scope of project
  - Low: minimal drainage works involved in scope of works, gravel roads
  - Medium: projects involve some drainage design, drainage already existing, some ability to make minor amendments to existing drainage and/or retrofit water quality measures
  - High: greenfield projects, major opportunities to optimise drainage design and achieve water quality objectives
- Quality of receiving environment.

7.4.1.2 Determine water quality design criteria

Design criteria for water quality may be set as:

1. reduction in mean annual load compared to unmitigated development (%)
2. concentration of various pollutants in runoff.

Reduction in mean annual load

Stormwater policies and guidelines for water sensitive urban design are increasingly using reduction in annual pollutant load as the design criteria.

In Queensland, the design objectives in Table 7.4.1.2 have been set for all low erosion risk Environmentally Relevant Activities (through *Stormwater Guideline – Environmentally Relevant Activities*, Department of Environment and Heritage Protection, 2014) and for development in urban areas subject to local planning schemes (through the *State Planning Policy*).

This approach is recommended to be adopted for road design.

Table 7.4.1.2– Design objectives for management of stormwater quality

Region	Minimum reductions in mean annual loads from unmitigated development (%)				Notes
	Total suspended solids (TSS)	Total phosphorus (TP)	Total nitrogen (TN)	Gross pollutants	
Cape York / Far North Queensland	80	60	45	90	TSS – DEHP has 75% for Eastern and Northern Cape York TP – DEHP has 65% for SW and Central South Cape York TN – DEHP has 35% reduction for (Eastern Cape York) and 40 elsewhere
Wet Tropics	80	60 (DSDIP) 65 (DEHP)	40	90	
Dry Tropics	80	60 (DSDIP) 65 (DEHP)	40	90	Townsville City Council has adopted 65% for TP
Central Queensland (north)	75	60	35* (DEHP) 40 (DSDIP)	90	
Central Queensland (south)	85	60 (DSDIP) 70 (DEHP)	45	90	
South East Queensland	80	60	45	90	
Western Queensland	85	60 (DSDIP) 70 (DEHP)	45	90	

From:

- *Stormwater Guideline – Environmentally Relevant Activities* (Department of Environment and Heritage Protection, 2014)
- *State Planning Policy* (Department of State Development, Infrastructure and Planning, 2014)

Note: Within the *State Planning Policy,* these stormwater management design objectives relate only to urban centres.

Runoff pollutant concentration

Chapter 7 of Engineers Australia's *Australian Runoff Quality* outlines a methodology for estimating permissible concentrations of runoff to meet receiving water quality guideline levels such as those within the Environmental Protection (Water) Policy 2009. This methodology involves the development of models that include equations for water body hydrodynamics and associated physico-chemical and biological processes.

7.4.1.3 Identify pollutant sources and estimation of pollutant loads

Section 3.4.2 of Austroads' *Guide to Road Design* – Part 5 provides an overview of potential pollutants within road runoff. Increased alkalinity of stormwater from concrete systems is a relatively new issue with potential impact on biodiversity being investigated (Wright et al, 2010).

The pollutant loads associated with corridor drainage will be a sum of the direct pollutant concentrates from the road (such as heavy metals from brakes, oils from vehicles) and indirect impacts from catchment areas draining to corridor (such as nutrient runoff from agriculture or litter from urban areas).

Road runoff pollutant loads can be estimated by:

- analysis of data from a representative storm-event monitoring program combined with simple computations
- an appropriate water quality model.

The method selected will depend on the management objective, water quality criteria chosen and data availability. Average long-term pollutant loads can be estimated from historic rainfall data, baseline monitoring and from simple information about the catchment and road corridor, or qualitative understandings of catchment and management techniques.

Event Mean Concentrations

Event Mean Concentration (EMC) can be estimated by monitoring mean pollutant concentration and discharge over a storm event. EMC within one catchment can, however, differ significantly from storm to storm. The EMC depends on many catchment and climate characteristics and can vary in magnitude between catchments.

Therefore, a good event monitoring program is essential where accurate estimates of pollutant loads are required. Significant errors in estimating long-term pollutant loads can result without monitoring programs. Typical errors in estimating long term pollutant loads are as follows:

- no monitoring – 100 to more than 1000 per cent
- some periodic monitoring – 50 to more than 500 per cent
- detailed event monitoring – 20 to 100 per cent.

Pollutant loads

Simple computations can be used as a guide to calculate approximate estimates of pollutant loads. This can be useful when assessing potential pollutant loads in rainfall volumes.

The average long-term pollutant load of an area can be estimated using the following formula:

Pollutant load = runoff x EMC where EMC = Event Mean Concentration

Water quality modelling

Computer models may be used to estimate runoff quantity and quality from a road corridor to provide estimates for:

- characterising peak, mean and average annual pollutant loads
- determining seasonal and spatial characteristics.

A number of water quality and stormwater system models exist, which are designed for use by engineers, managers, planners and other staff from private to public organisations.

A commonly used catchment model used to assist water quality management is the Model for Urban Stormwater Improvement Conceptualisation or 'MUSIC' (Wong et al 2002). MUSIC modelling is a decision support tool that can assist in the planning of stormwater quality management strategies.

MUSIC allows the user to determine the likely stormwater quality resulting from specific catchments, predict specific stormwater treatment device performance and create subsequent management plans and evaluate their success.

MUSIC can operate over a range of spatial and temporal scales. It can be used with several other models, such as models used for soils, hydrology, rainfall, operation of culverts, and so on (Wong et al 2002 and eWater 2008).

7.4.1.4 Identify pollutant transport processes

The determination of additional design criteria to enhance or maintain the downstream water quality will require the knowledge of relevant pollutant transport mechanisms.

Pollutant runoff from a roadway will be generally transported by the roadway drainage infrastructure and will concentrate in gutters, pipes and channels. The pollutants associated with the stormwater runoff will be transported as coarse or bottom sediments, suspended (fine) particles or in solution. The rate of pollutant transport is dependent on pollutant size, water velocity, depth and the degree of turbulence.

Fine particulates and dissolved pollutants (such as heavy metals) can become attached to sediments or flocculate to form larger particles. Most of the pollutants in sediments are found attached to smaller particles owing to their greater surface area relative to larger particles. Pollutants attached to fine particles are easily transported because small flows (and hence low velocities) are sufficient to mobilise and keep them in suspension.

Heavy metals from motor vehicles and atmospheric fallout may deposit directly onto road surfaces or become entrained in air flows and deposited some distance away depending on their particle size. Particulate material on the road surface, such as sediment, bituminous products, rubber from tyre wear and particles coated with oils, actively adsorb heavy metals. The particulates and associated heavy metals temporarily bind themselves to the road surface and particulate material until they are dislodged and transported by rainfall events.

Heavy metals contained in road runoff will be distributed in either bound or soluble forms. Chromium, iron, nickel, lead and hydrocarbons are predominantly adsorbed to sediments and particulate matter. This provides an opportunity for heavy metal removal by targeting the removal of sediments from runoff.

Cadmium, copper and zinc appear at higher percentages in the soluble phase and, thus, are required to be removed by storage and/or uptake by aquatic biota (such as insects, aquatic plants, and so on) (Peterson and Batley 1992).

7.4.1.5 Identify pollutant removal processes

Stormwater quality improvement measures rely on a variety of mechanisms for reducing pollutant levels within stormwater. The mechanisms employed may be either or a combination of physical (such as stormwater grate, continuous deflection systems), or biological (such as macrophytes) processes and their effectiveness may be dependent on the site conditions and stormwater characteristics. Stormwater pollution removal devices can be grouped into three categories based on their dominant treatment processes:

- primary treatment – physical screening or rapid sedimentation techniques (for example, typically retained contaminants include gross pollutants and course sediments)
- secondary treatment – sedimentation of finer particles and filtration/chemical techniques (for example, typically retained contaminants consist of fine particles and attached pollutants)
- tertiary treatment – enhanced sedimentation and filtration, biological uptake, adsorption onto sediments (for example, typically retained contaminants are nutrients and heavy metals).

There is general industry recognition to, where possible, incorporate a combination of treatment mechanisms in one location, to optimise the amount and range of pollutants removed from stormwater runoff. In other circumstances where space limitations and certain practicalities impose, single treatment measures are used to achieve prescribed regional Water Quality Objectives (WQOs).

Depending on size and condition of a site, relative need and practicality, timeframes, materials and cost, stormwater pollution treatment measures may be applied using either an ‘outlet’ or ‘treatment train’ approach.

The outlet approach involves a single treatment measure at the road corridor catchment outlet that discharges directly into the downstream environment.

The treatment train approach requires a number or sequence of different treatments throughout the road corridor catchment before discharge to the receiving environment. The sequence of treatment measures are designed to remove different types and sizes of pollutants, thus optimising the amount and range of pollutants removed from discharge waters

The selection of the treatment controls for a road corridor catchment under consideration will depend on a wide range of key selection criteria to enable achievement of water quality design objectives.

The selection of the most appropriate stormwater treatment methods should be influenced by a number of environmental and design elements such as:

a) Slope – treatment devices that do not store flow may require small velocities and hence gentle slopes

b) Hydraulic head – head losses in treatment devices can exert a minor to large impact upon the hydraulic grade line. As a result, head losses from a treatment device may adversely impact upon upstream flood levels, particularly when retrofitting a device into an area

c) Soil type – differing treatment devices may be reliant upon either infiltration or storage of stormwater runoff. For example, stormwater infiltration will yield better results on highly permeable soils, while the storage of stormwater will require soils with very low permeability.

d) Land availability and catchment area – the availability of sufficient appropriate land within a sub-catchment that can be used for a treatment device may be restricted, thereby reducing the size, effectiveness or even the option of using the device.

e) Habitat enhancement – treatment devices that are able to offer either a wildlife and/or aquatic habitat enhancement may improve aesthetics.

f) Water table – a high water table depth may reduce the effectiveness for a treatment device relying on infiltration.

g) Safety hazard – treatment devices may introduce new safety hazards that may have not been present before installation (such as waterborne pathogens, drowning risk, and so on.)

h) Water supply – treatment devices, such as wetlands or ponds, may require a permanent water supply to ensure the long-term effectiveness of the device.

i) Pests – treatment devices, such as wetlands or ponds may increase the potential for nuisance from pests such as mosquitoes and weeds.

j) Maintenance – treatment devices will vary significantly with regard to their maintenance cost, accessibility, equipment and scheduling to ensure the desired effectiveness is consistently maintained.

7.4.1.6 Assess potential pollutant control devices

Each potential pollutant control device needs to be assessed to determine if it is suitable for the site conditions. Each pollutant control device can be accepted or rejected on the basis of screening criteria to provide a shortlist. Table 7.4.1.6 provides a means of assessing common design elements in order to determine if a particular control device is suitable for a specific site condition.

Table 7.4.1.6 – Design elements associated with treatment devices

Pollutant control device	Area served (ha)	Slope	Head requirement	Soil type	Capital cost	Maintenance cost	General configuration
Oil grit separators	<1	Note 1	Low	NA	Moderate	Moderate	
Open gross pollutant trap	>2 >40	Note 1	High	NA	High	Moderate High	
Closed gross pollutant traps	<15		Low	NA	High	Moderate	
Trash rack	<20 40	Note 1	Low Moderate	NA	Moderate	Low Moderate	
Downward inclined screen		Note 1	High	NA	Moderate High	Low Moderate	

Pollutant control device	Area served (ha)	Slope	Head requirement	Soil type	Capital cost	Maintenance cost	General configuration
Extended detention basin (see Chapter 12 for design)	>5	Note 1	Low	All	High	Moderate High	Outlet structures include weirs or outlet pipes Energy dissipater at both basin inlet and outlet to control velocities
Sand filter (depth of)	<2 can be designed larger	Note 1	High	Generally housed in concrete	High	Moderate High	Min filtration depth of 400 mm on recommended filtration time Energy dissipater at inlet
Filter strips	<2	Note 1	Low	All	Moderate	Low	Requires considerable land Length of strip generally >6 m
Buffer zones		Note 1	Low	All	Moderate	Low	
Grassed swales	<2	<5%	Low	Sand to sandy loam	Moderate	Low	Recommended min length of 30 m Bottom width between 0.6 m to 2.5 m recommended
Constructed wetlands		Note 1	Low Moderate	Loam to clay feasible in sand to sandy loam	High	Moderate	
Water quality ponds	>5	Note 1	Low Moderate		High	Moderate	

Source: Derived from NSW EPA (1997) and Mudgway et al (1997)

Note:

1. From 0–5% slope preferred, but the range can be extended beyond 5%. Buffer zones should only be extended beyond 5% with careful design.

7.4.1.7 Calculate potential pollutant removal

The final selection of potential pollutant control devices should be made by comparing all potential treatments as follows with the required water quality design criteria.

a) Determine the pollutant removal of each shortlisted control device based on relevant performance data or Table 7.4.1.7.

b) Determine the area of the catchment for which the device(s) can treat runoff.

c) Factor the mean removal rate of each pollutant parameter by the ratio of area treatable by the device to total catchment area. For example, if a pollution control device has a 60% removal efficiency and will treat 50% of the catchment area, then the overall pollutant removal efficiency will be 30%.

Table 7.4.1.7 – Pollutant removal performance of various treatment devices

Treatment control	Pollutant removal efficiency (%)						
	Suspended solids (TSS)		Total phosphorous TP	Total nitrogen TN	Oil and grease	Litter	Notes
	Coarse sediment	Fine sediment					
Primary treatment devices							
Oil grit separators	50–75	10–50	0–10	0–10	50–75	10–50	0–10% reduction in bacteria
Gross pollutant trap	60–100	20–30	20	20	10–20	50–75	0–10% reduction in bacteria
Trash rack	10–50	0–10	0–10	0–10	0–10	10–50	0–10% reduction in bacteria
Secondary treatment devices							
Extended detention	50–75		10–66	10–35			Significant reduction in lead, zinc and bacteria
Sand filter	60–90		35–80	40–70			Significant reduction in iron and lead, Some reduction in zinc, copper
Filter strips	5–95 Generally ~ 74%		50–79	50–73			
Grassed swales	80		4–25	-4–11			Significant reduction in lead and zinc
Tertiary treatment devices							
Constructed wetlands	40–98		-33–97	-9–43			Reduction in metals
Water quality ponds	30–98		0–80	30–85			Reduction in metals

Derived from NSW EPA (1997) and Mudgway et al (1997).

Note: These percentages are indicative only and appropriate design procedures should be followed.

7.4.1.8 Implement treatments

Design guidelines for the installation of selected control devices can be found in Section 7.5. The document *Water Sensitive Urban Design: Technical Design Guidelines for South East Queensland* (Healthy Waterways) is also accepted for south-east Queensland.

Ensure requirements for maintenance are incorporated into the Road Asset Maintenance Contract (RAMC) or Road Maintenance Performance Contract (RMPC) and suitable budget allowed for to ensure ongoing performance of measures.

7.4.1.9 Evaluate the working efficacy of pollutant removal processes and review if necessary

If stormwater runoff or drainage from a site contains levels of pollutants that do not comply with the requirements, then a review of the working efficacy of the pollutant removal processes is required.

Visual inspections of catchment waters should be undertaken to determine the presence of litter build-up, sediment or chemical plumes or other contamination.

An onsite assessment of the physical state (integrity) of the pollutant removal devices should be carried out regularly and any maintenance should be undertaken to restore devices to the desired working condition and standard.

7.5 Water quality treatment devices and design guidelines

The following section will guide the user through descriptions of pollution removal devices for runoff, advantages and limitations, and design guidelines.

7.5.1 Filter strips

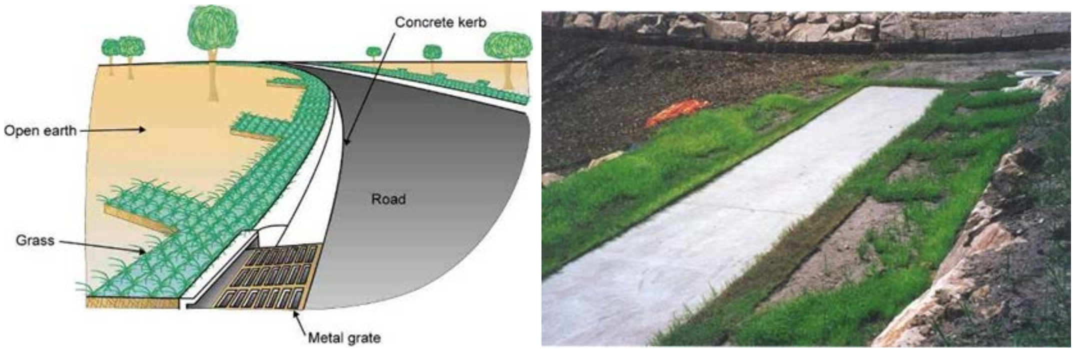
7.5.1.1 Description

Filter strips are grassed or vegetated areas used to control polluted runoff from the pavement surface or other disturbed areas within the road corridor as shown in Figure 7.5.1.1. Flow over filter strips is usually shallow sheet flow. They are generally located adjacent to regions where there is a sensitive receiving environment (such as water course or wetland). They can treat runoff containing sediments, heavy metals and other pollutants.

Advantages of filter strips include:

- increase rate of infiltration, which can reduce and delay storm runoff
- high removal rates of pollutants
- retention of pollutants close to source
- improved aesthetic appeal of an area
- relatively inexpensive construction.

Figure 7.5.1.1 – Grass filter strip



Source: Environmental Best Management Practices (BCC 1996)

Disadvantages of filter strips include:

- limited removal of fine sediment and dissolved pollutants
- sizeable land areas required with limited public access
- a sunny aspect for plant growth
- reduced effectiveness for concentrated flows and high flow depths
- strips are only suitable for gentle slopes (< 5%)
- regular inspections are required to assess the condition of the strips.

7.5.1.2 Design guidelines

The primary purpose of the filter strip is removal of sediment, with some removal of soluble pollutants by biological uptake and by infiltration into the subsoil. The objective of a filter strip is to generate a dense and diverse vegetation cover to maximise infiltration, provide adequate contact time between runoff and vegetation and to minimise erosion.

Horner et al. (1994) cited a technique for sizing filter strips and grass swales. It was developed in Seattle, USA, and the results indicate that optimum pollutant retention occurs when the hydraulic residence time is nine minutes. The performance of pollutant retention deteriorates when the residence time falls below five minutes.

This design technique is summarised in the following 10-point process:

1. Calculate the design discharge for the nominated exceedance years (EY). Pollutant control devices are usually sized for storm events between 4 EY and 1 EY.
2. Determine the bed slope So (m/m) of the filter strip. Filter strip performance has been found to reduce if located on grades exceeding 5% and particularly if the slope exceeds 15% (Schueler et al., 1992).
3. Set the design flow depth. A maximum depth of flow over the filter strip of 12 mm is recommended.
4. Solve for flow width using suitable methods of hydraulic analysis, such as Manning's Equation:

$$Q = \frac{AR^{2/3}S_o^{\ 1/2}}{n} = VA$$

where	*Q*	=	*design runoff rate (m³/s)*
	R	=	*hydraulic radius = A/P*
	A	=	*cross-sectional area (m²)*
	P	=	*wetted perimeter (m)*
	S_o	=	*longitudinal bed slope (m/m)*
	n	=	*Manning's roughness coefficient*
	V	=	*average velocity (m/s)*

Suggested Manning's Equation's 'n' values are 0.20 for regularly mown areas and 0.25 for natural grasses or infrequently mown areas. A minimum width of 15 m is recommended for water quality enhancement.

5. Determine the flow area based on the calculated flow width and established flow depth.
6. Calculate the resulting velocity. Reduce the flow, increase the flow width or reduce the depth of flow if the velocity exceeds 0.3 m/s, which is the velocity at which most grasses are knocked over.
7. Using the resulting velocity, calculate the flow length to achieve a residence time in the filter strip of nine minutes. An absolute minimum residence time should be five minutes. To maintain sheet flow, the minimum length of a filter strip will generally be 6 m.
8. To avoid erosion of the filter strip, major storm events should preferably bypass the filter strip. Typically, the major storm would be defined as the Annual Exceedance Probability (AEP) 2% or AEP 1% Average Recurrence Interval (ARI) 50-year or ARI 100-year event.
9. Where flow bypass is not incorporated, peak velocities resulting from major storm events should be determined from hydraulic analysis.
10. If the estimated peak velocity is greater than the determined erosive velocity of the filter strip (refer to Chapter 8), then the strip must be enlarged to accommodate the flow. Once the flow depth is established, the final dimensions (including depth) of the filter strip can be specified.

More specific design considerations include:

- The slope of the filter strip should be uniform and the cross-section should be a level plane to maintain sheet flow.
- If grass filter strips are located on slopes lower than 2%, consideration should be given to installing a subsoil drainage system.
- Flow entering the filter strip should be evenly distributed as sheet flow across the upstream end. Level spreaders should be provided to ensure the filter strips does not receive direct discharges.
- Need to establish grasses – watering, weed management.

Additional design information may be obtained from the following design references:

- *Water Sensitive Urban Design: Technical Design Guidelines for South East Queensland (Healthy Waterways)* (2006)
- Camp Dresser and McKee (1993)
- Horner et al (1994)
- Schueler et al (1992), and
- Standing Committee on Rivers and Catchments (1991).

7.5.2 Grassed swales

7.5.2.1 Description

Grassed swales are grass-lined flow paths, often running adjacent to a road pavement, which provide an alternative to concrete kerbing and guttering. They can also be used in road medians and verges. If properly maintained, grassed swales can reduce runoff volumes, attenuate storm flows, enhance infiltration and improve water quality.

Water quality enhancement occurs mainly through the removal of coarse sediments and attached particulates. The improvement in water quality is achieved by increased settling, filtration by swale vegetation and some removal of soluble pollutants through infiltration into the subsoil. Pollutants, such as hydrocarbons, may be digested and processed by soil microorganisms within the swale.

Advantages of grassed swales include that they:

- increase infiltration, thereby reducing and delaying storm runoff
- retain particulate pollutants close to the source
- enhance aesthetic appeal
- reduce construction costs as grassed swales are relatively inexpensive to construct.

Disadvantages of grassed swales include that they:

- have limited removal of fine sediment and dissolved pollutants
- require considerable land areas compared with kerb and channel
- may interfere with driveways in higher density development
- are less effective for concentrated flows and high flow depths
- are only suitable for gentle slopes (less than 5%)
- require adequate maintenance to avoid weed infestation, boggy base, mosquitoes and soil erosion
- are, in general, most suitable for areas with relatively highly permeable soils

7.5.2.2 Design guidelines

Design guidelines for grass swales follow the same guidelines as those provided for filter strips (Section 7.5.1) but with the following amendments.

1. Grass swales should be located on grades of 4% or less. However, slopes of up to 6% can be adopted if small check dams (or mounds) are located in the swale every 15 m to 30 m to reduce flow velocities. For slopes of 2% or less, consideration should be given to installing a subsoil drainage system to ensure effective drainage and infiltration.
2. Recommended depth of flow is one-third of the grass height in infrequently mowed swales; half the grass height, to a maximum of 75 mm, in regularly mowed swales.
3. Swales should be trapezoidal, with a recommended bottom width between 0.6 and 2.5 m (Horner et al. 1994). If a wider base is required, the flow could be diverted into more than one swale. The side slopes should not be steeper than 1 on 3. If steeper slopes are used, up to 1 on 2, permanent stabilisation may be required. Triangular cross-sections are not recommended, as the flow can become channelised in the bottom of the swale.
4. To maintain sheet flow, the minimum length of a swale is generally 30 m.

More specific design considerations include:

- The base of the swale should be level, with the longitudinal grade of the swale either uniform or with gradual changes only. Particular attention should be paid to these requirements during construction.
- The integrity of a swale may be impaired if flows greater than the design event enter the swale. Velocities exceeding the design velocity can be expected to result in reduced swale pollutant removal efficiency until the grass has recovered. Such flows may also result in scouring of the swale. A bypass for high flows could be installed to prevent large concentrated flows eroding the swales.
- The depth to groundwater should be considered when designing a swale. If the water table is shallow, the grass species will need to tolerate this situation. Further, a shallow soil depth for pollutant retention presents a possible risk of pollution entering the groundwater.
- Need to establish grasses – watering, weed management.

Additional design information may be obtained from the following design references:

- Healthy Waterways WSUD Technical Design Guidelines (2006)
- NSW Department of Housing (1998)
- Camp, Dresser and McKee (1993)
- Horner et al (1994)
- Schueler et al (1992)
- Standing Committee on Rivers and Catchments (1991).

7.5.3 Trash racks

7.5.3.1 Description

Trash racks can be installed in drainage channels or outlets to trap litter and other gross pollutants. They generally comprise a series of vertical or horizontal steel bars, which form a physical barrier to objects larger than the bar spacings. An example of a trash rack is shown in Figure 7.5.3.1(a).

Trash racks can be designed to be perpendicular, angled or staggered to the direction of flow. They can be located either ‘online’ or ‘offline’. With an online arrangement, trash racks are placed within an existing channel or drainage system. With an offline arrangement, a flow diversion mechanism is installed, which directs low and medium flows into the trash rack while high flows bypass the trash rack.

Figure 7.5.3.1(a) – Trash rack

Source: Brisbane City Council

Advantages of trash racks include that they:

- are simple to construct
- trap all pollutants larger than the bar spacing and also retains smaller pollutants when the rack becomes partially blocked
- can be retrofitted into existing drainage systems
- collect litter at a single point.

Disadvantages of trash racks include that:

- they have potential to cause upstream flooding when material accumulates behind the trash rack (refer Figure 7.5.3.1(b))
- scouring at the base or sides of the rack if adequate protection is not implemented
- maintenance intensive, requiring manual cleaning either on an ‘as needs’ basis or as part of the programmed works for maintenance
- trapped material may be resuspended during large storm events.

Figure 7.5.3.1(b) – Trash rack and pollutants

7.5.3.2 Design guidelines

The most commonly used technique for sizing trash racks is an approach described in Department of Urban Services ACT Government (1994).

1. The length of the trash rack should be determined in conjunction with the trash rack height and the available space.
2. The height of the designed rack should be such that the rack is not overtopped by the design flood flow when 50% blocked.

3. Under submerged conditions, the required height of the trash rack is twice the depth at critical flow through the unblocked trash rack. For a trash rack consisting of vertical 10 mm bars at 40 mm spacing, this leads to:

$$H = 1.26\left(\frac{Q}{L_r}\right)^{2/3}$$

where	H	=	*rack height (m)*
	Q	=	*design flow (m³/s)*
	L_r	=	*length of rack (m)*

4. The presence of downstream hydraulic controls can lead to submergence of the trash rack. Under these conditions (Beecham and Sablatnig 1994):

$$h = k\left(\frac{v^2}{2g}\right)$$

and

$$k = 1.45 - 0.45\left(\frac{A_n}{A_g}\right) - \left(\frac{A_n^2}{A_g^2}\right)$$

where	h	=	*head loss through the trash rack (m)*
	k	=	*rack coefficient*
	v	=	*average velocity through rack (m/s) = Q/An*
	g	=	*gravitational acceleration (9.81 m/s²)*
	A_n	=	*net area through bars (m²)*
	A_g	=	*gross area of racks and supports (m²).*

5. Trash racks have the potential to exacerbate upstream flooding if blocked. Hydraulic analysis should be carried out to investigate impacts arising from the rack being 50% and 100% blocked. The trash rack should be assessed for the EY 0.5, EY 0.2, AEP 2% and AEP 1% (ARI 2-year, 5-year, 50-year and 100-year) flood events.

Additional design information may be obtained from Department of Urban Services (1994), and Willing and Partners (1992).

7.5.4 Proprietary devices

7.5.4.1 Description

There are a number of manufactured devices, which are designed to remove specific pollutants such as coarse sediment, oil, grit and hydrocarbons from runoff. Each proprietary device is specifically designed to treat one or more pollutants associated with stormwater. The majority of these devices are designed to be located underground, as part of the stormwater network.

7.5.4.2 Design guidelines

The design considerations outlined in this section are for general guidance purposes only. Propriety pollutant control devices should be designed in accordance with the manufacturers' recommendations in order to achieve the required pollutant control objectives.

Before devices can be considered and their suitability assessed, the pollutants to be removed from a flow need to be determined and the treated water quality objectives set. This involves establishing appropriate design criteria, such as:

- surface and underground drainage gradients
- catchment area
- pollutant characteristics (such as sediment diameter)
- location of installation
- requirements for maintenance access.

The assessment and selection of appropriate proprietary devices should include consideration of:

- ability to meet required water quality objectives
- proven ability to achieve the desired pollutant removal rate
- capital costs
- construction materials
- installation procedures
- drainage design criteria
  - head loss
  - crossfall
  - hydraulic capacity
- maintenance procedures, such as:
  - access
  - frequency and cost
  - spills
  - disposal of pollutants
  - inspection of control device.

7.5.5 Constructed wetlands

7.5.5.1 Description

Constructed wetlands are structures built with predominantly natural materials to reproduce the physical, chemical and biological processes of natural wetlands. They are used to remove a range of pollutants, including suspended solids, nutrients, heavy metals and other toxic or hazardous compounds. Their pollutant trapping efficiency varies with the type of pollutant, being moderate for oil and grease, moderate to high for sediments and nutrients.

Wetlands typically comprise an upstream inlet zone, a shallow macrophyte zone and a high flow bypass channel. The upstream inlet zone consists of a relatively deep, open water body or sediment basin with some fringing aquatic vegetation. The downstream macrophyte zone is a more permanent shallow water body with extensive vegetation. The bypass channel is used to protect the macrophyte zone from scour and vegetation damage (*Water Sensitive Urban Design: Technical Design Guidelines for South East Queensland* (*Healthy Waterways),* 2006).

Advantages of wetlands include that they:

- potentially achieve high sediment and nutrient retention efficiencies
- can be incorporated into the road corridor, thereby providing improved habitat and visual amenity in disturbed areas
- potentially can be retrofitted into existing sediment ponds/or detention basins.

Disadvantages of wetlands include that they have:

- either pre-treatment or removal mechanisms at the inlet to remove coarse sediment and litter
- large areas for construction
- a reliable inflow to ensure they remain 'wet', unless the wetland is designed to be ephemeral.

In addition, wetlands may:

- have a treatment performance which is highly sensitive to hydrologic and hydraulic design
- take up to three years to achieve optimal performance
- have a potential impact on public health and safety
- have adverse interactions (pollutant exchange) with groundwater in some situations.

Constructed wetlands generally require large areas of land, resulting in high construction costs. Maintenance cost of wetlands can be kept relatively low if the design provides for mechanised sediment removal facilities, as well as the inclusion of upstream pre-treatment devices for the trapping of coarse sediment and litter.

7.5.5.2 Design guidelines

Urban Stormwater Best Practice Environmental Management Guidelines (CSIRO 2006) outlines a number of design principles to consider before construction. These include:

- Establish a uniform flow distribution throughout the wetland. Avoid creating stagnant areas
- To enhance sedimentation, maximise the amount of time macrophytes are in contact with flow. This can be done by providing low flow velocities with healthy vegetation.
- Provide adequate wetland pre-treatment.
- Minimise organic matter loading.
- Maintenance requirements must be met in order to manage sediment build up and weed occurrence.

The design procedure outlines five general steps in the design of constructed wetlands and the reference, *The Constructed Wetlands Manual* – Department of Land and Water Conservation (NSW) 1998, is relevant to these five design steps.

1. Wetland location

Constructed wetlands can be located on a watercourse or adjacent to a watercourse. For road corridors, the preferred location is adjacent to a watercourse. In this case, the drainage system of the road can be designed to direct runoff from the local catchment and pavement surface into the wetland rather than directly into the watercourse. A high flow bypass channel around the wetland system can be designed such that sediments and vegetation within the wetland are not damaged during flood events.

The location of a wetland will depend on a number of factors, including:

- aquatic habitat and riparian vegetation of the receiving environment
- wetland size and available space in the road reserve
- topography
- reliability of low flows to maintain a permanent wetland
- groundwater conditions
- maintenance requirements.

2. Wetland size

The components of the wetland that need to be sized are the temporary and permanent storage volumes. The permanent storage zone encourages biofilm growth on the macrophytes (plants such as reeds, rushes and sedges) and maintains sedimentation. The temporary storage zone can be used to attenuate peak flows and to increase hydraulic residence time, thereby maximising the rate of pollutant removal.

As a rule of thumb, wetland areas in south-east Queensland should cover 2% – 4% of the contributing catchment area.

3. Pre-treatment measures

The removal of coarse sediment upstream of the wetland will minimise changes to depth profile and damage to macrophytes. The installation of a sediment trap and trash rack upstream of the wetland are recommended and will assist greatly in reducing the frequency and cost of maintenance.

4. Macrophyte planting requirements

A wetland should be divided into a number of zones to encourage macrophyte diversity. An open water zone will encourage UV disinfection and oxygenation. Shallow marsh, marsh and deep marsh zones encourage macrophyte diversity and uniform flow across the wetland.

5. Outlet structure

Outlet structures are important as they control the water level within the wetland. An appropriate water level optimises water quality improvement, achieves macrophyte diversity and provides for weed and mosquito control.

Four outlet varieties discussed in Victorian Stormwater Committee (1999) are risers, weirs, culverts and siphon outlets. These outlet devices should be assessed to determine the appropriate water level or hydraulic regime each would have on a wetland. The choice of outlet type will also be influenced by the basin morphology and hydrology.

Additional design information may be obtained from:

- *Water Sensitive Urban Design: Technical Design Guidelines for South East Queensland* (Healthy Waterways, 2006)
- *Guidelines for Stabilising Waterways* (SCRS 1991).
- *Bioretention Technical Design Guidelines* (Water by Design, October 2014).

7.5.6 Buffer zones

7.5.6.1 Description

Buffer zones are areas that are left undisturbed to provide some filtering and trapping of sediment (and therefore some heavy metals). Buffer zones are usually established upstream of sensitive receiving environments, such as natural wetlands, streams or bushland. Buffer zones preserve the existing vegetation and landscape, may be used as habitat corridor for wildlife and contribute to preserving biodiversity. They may require fencing to exclude traffic and to prevent damage to the vegetation.

Advantages of a buffer zone include that:

- it is applicable to all development areas
- it is able to reduce runoff volume by 30% to 50% more than grass filter strips
- it has low costs and requires low maintenance.

Disadvantages of a buffer zone include that:

- it has a limited ability to reduce pollutant loads
- it can only trap coarse sediments
- it is suitable for slopes between 1% and 10%.

7.5.6.2 Design guidelines

The design procedure below provides five general steps for the design of buffer zones.

1. Buffer zone dimensions

The performance of a buffer zone generally increases with increasing width and decreasing slope.

As a general guide, the width of a buffer zone (expressed in ‘m’) should be the greater of five times the slope (expressed as percentage (e.g. 50 m buffer width on a 10% slope) or 1.5 times the width of the disturbed area from which the sediments are mobilised. The latter generally applies to grassed buffers adjacent to the road pavement. In some locations these design rules may not need to be applied.

Grassed buffer zones

For maximum efficiency, the depth of sheet flow should not exceed the grass length. Grassed areas should be maintained with a minimum grass length of 50 mm (well-trimmed lawns are less effective although they tend to be more sought after).

2. Performance monitoring requirements

Buffer zones adjacent to high quality watercourses and environmentally sensitive areas should be wide enough to trap all visible sediment within the first quarter of the buffer zone width.

If buffer zones are to be effective, at least 75% of the ground should be covered by vegetation and weed growth should be controlled.

3. Slopes

Buffer zones are recommended for the control of sheet flow on slopes between 1% and 10%.

4. Fencing

Fencing can be used to exclude traffic from buffer zones, thus preventing damage to the vegetation and surface rutting.

5. Planning buffer zones

Buffer zones should be incorporated into the final landscaping plan and should be constructed (or retained) early in the development program.

7.5.7 Water quality ponds

7.5.7.1 Description

A water quality pond is a relatively deep open body of water, possibly with littoral macrophytes (reeds). Wet basins achieve pollutant removal through sedimentation. Their pollutant removal efficiency depends on the stormwater residence time and the amount of runoff detained in the basin. Pollutant removal efficiency increases with longer residence times and greater used storage volumes.

Advantages of water quality ponds include that they:

- can be used to trap coarse sediments and associated pollutants
- have the potential for stormwater re-use
- have a potentially high aesthetic or recreational value
- provide habitat for wildlife
- can generally be constructed at steeper sites than constructed wetlands.

Disadvantages of water quality ponds include that they:

- can be prone to eutrophication and thus have an adverse impact on downstream water quality
- have the potential to breed mosquitoes
- may cause habitat degradation upstream and downstream of the basin
- may require flocculation.

Large pond volumes may be required in regions with high rainfall intensities.

7.5.7.2 Design guidelines

Ideally, a continuous simulation approach should be undertaken due to the highly variable nature of catchment runoff and associated pollutant concentration. From the continuous simulation an appropriate storage volume could be selected on the basis of long-term performance rather than prescribed performance for a single event.

The size and capacity of water quality ponds should be such that stormwater is detained for as long as possible to promote effective treatment of pollutants, but should also guarantee that runoff generated during subsequent storms is captured and treated. The longer the residence time and the more water stored in the pond, the better the pollutant treatment.

Ideally, the pond should be protected from flood flows larger than the design storm flow. Provision of a high flow bypass channel is a means of reducing the risk of pond scouring but it is subjected to the site topographical constraints.

To enhance pollutant removal, the following design features should be considered:

- an effective residence time can be achieved by a pond length to width ratio of between 3:1 and 5:1
- the inlet to the pond should be located as far as possible from the outlet as possible
- to increase the length to width ratio or overcome problems with the inlet being too close to the outlet, berms and baffles may be installed to redirect flows.

The proper design of a pond outlet is critical to its performance. One option is to place a low level culvert at the Mean Operating Level (MOL) of the water quality pond. Between storms, the water level in the pond will drop below the MOL because of evaporation and infiltration losses. During storms, the water level will rise to and beyond the MOL, and water will flow out of the pond through the outlet.

Other outlet options include using orifice outlets, which may enhance flow detention during smaller storms or broad crested weirs. With the latter option, flood attenuation may not be as effective as with culvert or orifice outlets.

An access track should be provided for the maintenance of water quality ponds. Maintenance may include the following:

- mowing of banks and harvesting of macrophytes
- weed removal
- litter removal
- removal of accumulated sediment.

Monitoring of a water quality pond should be undertaken after large storm events at intervals not exceeding six months to assess the performance.

Additional design information may be obtained from Environmental Protection Agency (NSW) (1997), Horner et al (1994), and Schueler et al (1992).

7.6 Fauna passage

Section 3.3.1 of the Austroads *Guide to Road Design* – Part 5, is accepted for this section subject to the following amendments.

Addition(s)

1. Further reading on this topic is available in *Fauna Sensitive Road Design:* Volume 1 (DMR, 2000) and *Fauna Sensitive Road Design:* Volume 2 (DTMR 2010).

7.6.1 Identifying fauna passage criteria

Section 3.3.2 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section.

7.6.2 Identify terrestrial and aquatic fauna pathways

Section 3.3.3 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section subject to the following amendments.

Addition(s)

1. Specifically for fish passage requirements, Queensland Department of Agriculture, Fisheries and Forestry (DAFF) has mapping of fish passage waterways throughout Queensland. The mapping characterises waterways as low (green), moderate (amber), high (red) or tidal (purple) value for fish passage. If the project involves drainage structure works on any DAFF-mapped waterways, consideration of design requirements for fish passage is required.

7.6.3 Identify the species group

Section 3.3.4 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section subject to the following amendments.

Addition(s)

1. It is also important to identify the actual animal species that are using the area. This information will be required for legislative approvals associated with construction of the infrastructure as different species.

   Knowledge of the specific animal will also assist during design of infrastructure. For example, some species of frog prefer trees and leaf litter habitat while others prefer denser understorey of shrubs.

7.6.4 Consult with the relevant authority

It is critical early in the process to identify the legislation that applies to infrastructure being designed including any exemptions or self-assessments available for appropriate design.

This will be available within the environmental assessment for the project. In some cases, additional onsite surveys will be required in order to submit permit application and/or obtain the necessary approvals. The most commonly triggered pieces of legislation are provided in Table 7.6.4.

Table 7.6.4 – Commonly triggered legislation for the protection of fauna

Species	Relevant legislation
Fish and other aquatic fauna	*Fisheries Act 1994* (Qld) Fisheries Regulation 2008 (Qld)
Species and communities of national significance*	*Environmental Protection and Biodiversity Conservation Act 1999* (Cth) Environmental Protection and Biodiversity Conservation Regulations 2000 (Cth)
Other fauna	*Nature Conservation Act 1992* (Qld) Nature Conservation (Wildlife management) Regulation 2006 (Qld) Nature Conservation (Wildlife) Regulation 2006 (Qld) *Queensland Government Environmental Offsets Policy*

For project specific requirements consult the project environmental assessment and project environmental officer.

7.6.5 Identify criteria affecting drainage design

Sections 3.3.6 – 3.3.9 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section subject to the following amendments.

Addition(s)

1. For fish passage requirements (particularly culverts and causeways on waterways classified as moderate to major risk of impact) design criteria is likely to be set by the administering authority through self-assessable codes or through a required development approval. These conditions and requirements take precedence over the Austroads *Guide to Road Design*.

Design of fauna passage is a relatively young field. Design criteria is being improved continuously based on investigations and trials. Consult an environmental officer for the most recent information and design criteria.

8 Open channel design

8.1 Introduction

Section 2.1.1 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section, subject to the following amendments.

Addition(s)

1. Open channels have the advantages of continuous collection of surface runoff, and where the system surcharges, general shallow flow is the most likely outcome rather than more concentrated flooding at upstream inlets of the closed drainage system.

This manual focuses on the analysis and design of channels, smaller streams and creeks. Assessment of larger streams, creeks, rivers and floodplains is complex and should be referred to the Hydraulics and Flooding Section, Engineering and Technology Branch or a suitably prequalified consultant.

8.1.1 Open channels

Sections 2.1.1 and 2.1.3 of the Austroads *Guide to Road Design* – Part 5B are accepted for this section subject to the following amendments.

Addition(s)

1. Open channels may be constructed to specified criteria:

- as part of the road drainage system where space within the road reserve is sufficient to provide for open channels
- as diversion channels, especially where the road is being constructed generally along the line of a watercourse and severs one or more meanders in the stream. Care must be exercised as shortening of the stream will increase the gradient and hence velocity, which may induce scouring and also prevent the upstream passage of fish
- from the outlets of culverts or drainage systems.

8.2 General considerations

Section 2.2 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

8.3 Local authority requirements

The requirements of local government should be sought for any significant open channel design, particularly in developed areas or where the channel forms part of a major drainage system as defined in Chapter 2.

There is a need to check the effects of flows in excess of the design flood and to understand the likely impacts. Where flooding of property is a possibility, the effects of a flood in excess of the design flood should be analysed even if there is no local government requirement.

Other local government requirements may include the provision of access/maintenance berms, barrier fencing and appropriate warning signs to prevent access to the channel and a low flow channel to take a minimum flow.

Water sensitive urban design (WSUD) is an important aspect of pollution control and the design of open channels should consideration these requirements. Chapter 2 outlines the principles of WSUD while Chapter 7 provides more information and detail.

8.4 Fundamentals of open channel flow

8.4.1 Stream dynamics

Section 2.3.1 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

8.4.2 Assumptions for analysis

Section 2.3.2 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

8.4.3 Fundamental equations

Section 2.3.3 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section subject to the following amendments.

Addition(s)

1. For natural channels, a comparison may be made with the photographs in Figure 8.4.3.

Figure 8.4.3 – Natural streams in Queensland

n = 0.03

n = 0.04–0.045

n = 0.05–0.06

n = 0.07

n = 0.08

Notes:

1. Increase in ‘n’ value with an increase in grass, weeds, shrubs and trees.
2. In general, growth of trees in photographs tends to look denser than when seen on a site inspection.
3. Except for n = 0.03, roughness is for bank full flood heights and/or floods in upper branches of the trees.
4. Use photographs with caution. Use in conjunction with Table 2.2 of the Austroads *Guide to Road Design* – Part 5B

8.4.4 Application of fundamental equations

Section 2.3.4 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

8.4.5 Energy principles

Section 2.3.5 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

8.4.6 Hydraulic jump

Section 2.3.6 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

8.4.7 Hydraulic drop

Section 2.3.7 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

8.5 Erosive velocities in natural streams

Section 2.4 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

8.6 Backwater

Section 3.7.1 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section.

8.6.1 Tidal waters

Backwater as a result of tidal flow can affect stream flow and, in turn, drainage infrastructure design. When determining backwater effects on tailwater levels for streams discharging into tidal waters, three factors may influence the final design level:

- tide levels
- storm surges
- climate change.

8.6.1.1 Sea and tide levels

Section 3.7.2 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section.

8.6.1.2 Storm surge

A storm surge is the rise (or fall) of open coast water levels relative to the normal water level and is due to the action of wind stress and atmospheric pressure on the water surface.

Storm surges occur as part of major storms such as cyclones where there are low atmospheric pressures and the wind blows over reaches of the ocean.

The guideline *Storm Tide – Issues for Design of Road Infrastructure in Coastal Areas* (TMR 2014e), is to be referred to for further information and the department's design guidance in relation to this topic.

8.6.2 Downstream tributary

If the crossing is located on a stream which joins another watercourse (larger or smaller) downstream, other issues need to be considered.

As the two open channels have different catchment sizes, they will peak at different times. The combined flow at their junction needs to be assessed.

In this case, two situations need to be considered:

a) major flood on tributary with limited flow in the main stream

b) major flood on the main stream and limited flow in the tributary.

Both cases need to be analysed to provide an understanding of the potential flood conditions at the road. The risk of coincidental flooding in the two streams needs to be considered to determine the combined risk of flooding. Depending on the relative sizes of the two streams, it may not be realistic to expect floods to occur together in the two streams.

8.7 Tailwater levels

Section 2.6 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

8.7.1 Tailwater effects

Section 2.6.1 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

8.7.2 Design tailwater levels

Section 2.6.2 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

8.8 Open channel design

Section 2.7 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

8.8.1 Design methodology

Section 2.7.1 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section subject to the following amendments.

Addition(s)

1. Freeboard is the additional height of channel required above the height of the design flow. This allows for inaccuracies in data used in calculation and possible surcharge due to silt/debris build up and/or grass growth in the channel because of delayed maintenance of the channel.

8.8.2 Channel transitions

Section 2.7.2 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

8.8.3 Energy losses in channel bends

Section 2.7.3 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

8.8.4 Superelevation in channel bends

Section 2.7.4 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

8.9 Grassed channels

Section 2.8 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

8.9.1 Normal grassed channels

Section 2.8.1 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

8.9.2 Reinforced grassed channels

Section 2.8.2 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

8.10 Channels lined with hard facings

8.10.1 General

Section 2.9.1 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

8.10.2 Riprap and rock filled wire mattresses/gabions

Section 2.9.2 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

8.10.3 Concrete lined channels

Section 2.9.3 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

8.11 Channel drops

Section 2.10 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

8.12 Baffle chutes

Section 2.11 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

8.13 Worked examples

Section 2.16 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

9 Culvert design

9.1 Introduction

9.1.1 Overview

Culverts are important hydraulic structures used to convey water across a road corridor or in one of a range of other situations. Culverts must be designed to convey this flow in an acceptable way, considering the hydraulic conditions and the required performance (level of flood immunity) of the road. Environmental and/or other requirements may also need to be considered/incorporated, depending on the specific circumstances.

In particular, the provision of fauna passage, including fish movement, may need to be incorporated into the design. In certain situations (typically where specified by an environmental assessment document), culvert designs will have special requirements to allow the passage of fish or terrestrial fauna.

Other uses for culvert structures may include pedestrian/cyclist movement, vehicular movement (including rail/cane rail), fauna crossing or stock underpass.

While the requirements will differ depending on whether passage is to be catered for, all will require a clear distinction between wet and dry passageways.

The size requirements for passage, as well as hydraulic requirements, need to be considered and the culvert sized appropriately to meet both of these requirements.

If no passage is to be provided, then the culvert is designed solely for hydraulic purposes.

Hydraulic design of culverts is often an iterative process. As such, while the layout of this chapter reflects a typical order of design, this will not always be the case. In many instances, it may be necessary to revisit steps in the design process. Section 9.3 sets out a general process for the design of the culvert, while Sections 9.10 and 9.11 provide more detail. The process adopted is considered as industry practice and while a simplified process, it is appropriate for most culverts designs.

Changes may arise for technical or non-technical reasons and, hence, a clear record of the decision making process should be retained at all times.

Procedures for assessing the erosion potential and control at the inlet and outlets of culverts are included as part of the culvert design process. In some cases, hydraulic structures for permanent erosion control may be required with the design of culvert inlet and outlet structures and energy dissipaters considered.

In some locations, the design will be complex and beyond the methods presented in this chapter. In this instance, computer model development, simulation and testing may assist in design and the designer should contact the Director (Hydraulics and Flooding), Engineering and Technology Branch for further guidance.

9.1.2 Constructability

When designing culverts, construction and future maintenance requirements must be considered with appropriate treatments incorporated into the design. Some guidance with respect to construction requirements and methods can be found within various departmental standard drawings and specifications. However, this must not prevent all hydraulic and environmental requirements from being satisfied.

Relevant standard drawings for culverts are: 1132, 1145, 1248, 1174, 1179, 1284, 1303, 1304, 1305, 1306, 1316, 1317, 1318, 1319, 1320 and 1359 (QDMR 2009b).

The main departmental specifications are MRTS03 *Drainage, Retaining Structures and Protective Treatments* and MRTS04 *General Earthworks*.

For any possible non-standard or complicated culvert configurations, it is highly recommended that designers should involve construction personnel early in the design process to provide site-specific construction/constructability advice.

9.1.3 Computer programs

With reference to Section 1.2.2.5 in Chapter 1 of this manual, the department requires the use of the CULVERT software to model culverts within the 12d Model™ application. The reasoning for this requirement is that the software:

- provides records of the culvert design
- produces the drawing of the designed drainage cross-section to departmental standards; that is, showing chainage, skew number, invert heights, culvert component details (including joint type), quantities of precast components and installation materials, hydraulic design details
- incorporates the culvert model into the project electronic model within the 12d Model™ application.

As with all tools, use of this computer program will require output to be checked and verified.

As a quick check, the head loss through a culvert is typically around 1.4 to 1.7 times the velocity head. Alternatively, review the design charts provided in this chapter (and appendices) or perform a quick manual calculation.

9.2 General requirements

9.2.1 Pipe joint types

There are three types of joints for reinforced pipes:

- flush or butt joint
- rubber ring joint/spigot and socket
- jacking.

Designers should choose the most appropriate joint type for each installation.

Flush or butt joint pipes are best suited where ground movement is not expected. They are an economical option, but installations require a high level of compaction where the resulting soil envelope is extremely stable.

Rubber ring joint/spigot and socket-type pipes allow for ground movement more than flush joint pipes and should generally be used for all sizes of pipe in unstable ground, when pipes are laid in sand, or where pipe movement is possible, such as on the side of fills or at transitions from cut to fill. This type should also be used where the normal groundwater level is above the pipe obvert.

Jacking pipes are used where conventional excavation/laying/backfill methods are not feasible. Designers should refer to manufacturer’s guidelines for selection, use and design detail for jacking pipes.

9.2.2 Geometric tolerances and cover requirements

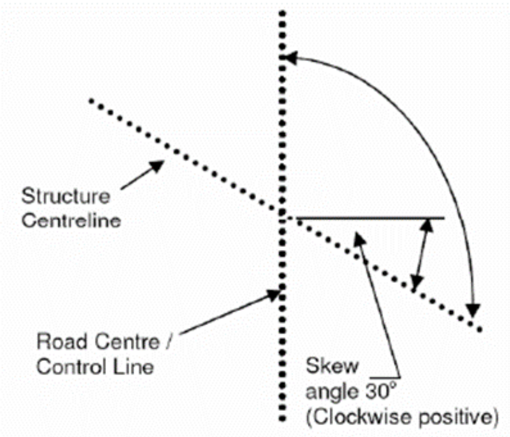
The geometric tolerances for location/position of culverts and minimum cover requirements will be as specified in the drawings or as per the department's specification MRTS03 *Drainage, Retaining Structures and Protective Treatments* April 2015 (TMR 2015b).

9.2.3 Skew angle/skew number

As per MRTS01 *Introduction to Technical Specifications* (TMR 2015c), the determination of the 'skew angle' and/or 'skew number' for a skewed culvert installation is shown in Figure 9.2.3. These terms are used to specify the horizontal orientation of skewed culvert structures relative to the road centreline.

The skew number is the number of degrees measured in a clockwise direction from the road centreline to the structure centreline. Skew number is required for ordering metal structures.

Figure 9.2.3 – Skew angle/skew number



9.2.4 Minimum culvert size

The minimum diameter of any pipe culvert shall be 375 mm.

The minimum waterway dimension (height) of any box section shall be 375 mm; however, in constrained situations and where all reasonable attempts to fit a 375 mm high box section have failed, a minimum 300 mm high box culvert can be used.

9.2.5 Outlet flow velocity

Section 3.7.2 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section subject to amendments.

Addition(s)

1. The calculation of outlet velocity is required for every culvert, and the type and extent of protection should be decided after consideration of the outlet velocity, the natural downstream ground conditions, the natural stream velocities, and the performance of existing culverts in the area.

9.2.6 Structural and configuration requirements of culverts

Loads on buried culverts include:

a) fill over the structure, which is a function of:

- height of fill
- type of fill material
- installation conditions (such as 'trench' or 'embankment')

b) design traffic loads

c) construction traffic loads

d) other or abnormal load conditions.

The load bearing capacity of a culvert is a function of:

- unit strength (for example, pipe class)
- type of bedding and backfill material
- pipe diameter (excluding box culverts).

The following specifies the requirements with respect to the determination of design loadings for buried structures and selection of correct pipe class, based on the department's technical specification MRTS25 *Manufacture of Precast Concrete Pipes* September 2014 (TMR 2014b).

a) Determination of design loads

The methodology to determine the design loads on a culvert is specified in Section 6 of AS 3725. With reference to Section 6.5.3.3 of AS 3725, the calculated distribution of working loads shall comply with the requirements as specified in AS 5100.2. For uniformity, the department has adopted AS 5100.2 to provide the design criteria for loads on all buried structures. The load distribution ratio is to be in accordance with Section 6.12 of AS 5100.2.

It is important to note that (for departmental projects) Table B2 of AS 3725 is not accepted as it is based on a load distribution ratio which is not in accordance with AS 5100.2. At the time of issue, all known pipe load and class determination software available from various companies and associations do not use the department's accepted load distribution ratio. This software must not be used until a proof of change can be verified by the Structures section, Engineering and Technology Branch.

Design loadings need to be determined for SM1600 and HLP400 loads. Table 5.7.2 of MRTS25 *Steel Reinforced Precast Concrete Pipes* shows correct live load pressures (as it is based on AS 5100.2) for W80 wheel load.

b) Determination of pipe class

The design load, as determined above, becomes the proof load for using Table 4.2 of AS 4058 to determine the required pipe class.

It is important to note that civil designers are restricted to specifying culverts up to, and including, Class 10 pipes. Any situation or requirement to use higher class pipes must be reviewed and approved by the Structures section, Engineering and Technology Branch.

c) Support types

The department generally specifies either H2 or HS3 support types – refer AS 3725, Standard Drawing 1359 (QDMR 2009b) and Section 9.2.6 in this chapter. Other support types can be used; however, the use of these types be fully detailed and specified in the project's documents as they are not covered by the department's standard specifications and/or drawings.

9.2.6.1 Structural requirements for new structures

The design life for all culvert types is 100 years. For further details, including design life criteria for ancillary drainage structure components (for example, culvert headwalls), refer to Section 17 of the department's *Design Criteria for Bridges and Other Structures* manual (August 2014).

The following departmental specifications apply to culvert components:

- MRTS03 *Drainage, Retaining Structures and Protective Treatments* – for general drainage structures (TMR 2015b)
- MRTS24 *Manufacture of Precast Concrete Culverts* – for concrete box culvert components (TMR 2015d)
- MRTS25 *Steel Reinforced Precast Concrete Pipes* – for precast concrete pipe components (TMR 2014b)
- MRTS26 *Manufacture of Fibre Reinforced concrete Drainage Pipes* – for fibre-reinforced pipe components (TMR 2014a).

Steel culvert components do not currently have an applicable departmental specification and do not meet the 100-year design life requirement without protective coatings. Refer Section 9.2.6.8 for more details.

9.2.6.2 Structural requirements for existing structures

The road network is increasingly subjected to vehicles carrying heavy loads and, therefore, planners and designers must consider the freight task for the road link. Bridges and culverts designed since 2004 are in accordance with AS 5100, which has SM1600 design loads and HLP 400 vehicles. Bridges and culverts that were designed and constructed prior to 2004 do not have a design loading capability equivalent to current design loads. Of particular concern are pre-2004 culverts that are subject to critical loading, such as structures that have less than two metres of cover (including pavement layers). These structures may influence the freight task capability of the road link in which they are located and should be considered for replacement if they cannot support the anticipated future loads.

Specifically, pre-cast and cast-in-situ culverts purchased or placed in the road network before 1976 were designed for significantly lighter loads and may also be past their design life (which was typically 50 years). This means that pre-1976 culvert structures on the road network with less than two metres of cover are likely to be subjected to repetitive and/or peak loadings that exceed the structural capacity of the aged culvert structure. This reduces their service life and greatly increases the risk of structural failure.

While critical loading is less of an issue for all culverts with two or more metres of cover, dead loads can be. These structures should also be inspected and replaced if found deficient.

The following requirement (policy) is not intended as a network management tool or guide and should only be applied on a project by project basis.

For all planning, design and construction projects (excluding non-drainage related routine maintenance and sprayed reseals), it is strongly recommended that no pre-1976 culvert be retained. Retaining any pre-2004 culverts, including pre-1976 culverts, is an action that will potentially extend the service life of the culvert (or parts of it – such as centre units of culvert extensions) beyond its design life and placing the structure at greater risk of failure. Therefore, each pre-2004 structure to be retained, must undergo the Structural Assessment/Decision Process as shown in Appendix 9B. While this process applies to all culvert structures, major culverts (as defined in the department's *Bridge Inspection Manual* (BIM)) are currently inspected on a regular basis, with records stored in the department's Bridge Information System (BIS). All other culverts are deemed minor culverts and inspections should be carried out based on the philosophy within the BIM. Inspectors should take an inventory of the structure based on BIM Appendix C and assess the 'Condition State' of the structure using BIM Appendix D. This will be based on available information and access to structure. Use of CCTV may be of assistance to inspect small culverts.

The process within Appendix 9B details both the engineering and departmental management components of assessment in order to determine if it is appropriate and/or justified to retain a culvert structure instead of replacing it. Appendix 9C is to be used in conjunction with Appendix 9B and assists the user in determining the risk (probability) of structural failure of a given culvert. Further advice in relation to structural requirements can be obtained from the Director (Bridge and Marine Engineering), Engineering and Technology Branch. Advice in relation to inspections can be obtained from the Director (Bridge Construction Maintenance and Asset Management), Engineering and Technology Branch.

It is highly recommended to replace steel culverts greater than 15 years of age. Departmental experience has shown that these structures do not generally last much longer than 15 to 20 years and structural failure of these types of culverts can occur quickly.

The requirement for inspection may be relaxed if a pre-2004 culvert is assessed as hydraulically deficient when compared to the project's performance and capability requirements. In this instance, the culvert should be replaced to improve hydraulic capability and this would remove the requirement for structural inspection. However, if it is intended to retain the existing structure and simply modify it to meet project performance (hydraulic) requirements, then the 'inspection/decision to retain' process is required.

9.2.6.3 General configuration requirements

Culverts are laid in single or multi-cell installations. Culverts are also laid straight and on a constant slope/grade (also refer Sections 9.2.10 and 9.2.11).

For multi-cell installations, each cell or barrel must be of the same size/dimension.

There are two exceptions to this requirement:

- where a different cell size is required in a multi-cell installation to accommodate passage (human or fauna)
- in a slab link box culvert (SLBC) installation where the spanning slab(s) maybe longer than the width of the box unit (refer manufacturer for additional details).

Where a different cell size is required, the designer should note that design software, standard drawings and specifications do not fully cover these types of installations. Therefore, the designer is required to 'manually' design these installations and include all details and specification in the model/drawings/project documents.

As per the department's specification MRTS03 (TMR 2015b), rubber ring joint/spigot and socket pipes are placed with their spigot end facing the culvert outlet.

9.2.6.4 Reinforced concrete pipes

The strength classes of reinforced concrete pipes (RCPs) generally used are 2, 3 and 4. The minimum strength class for concrete drainage pipes should be Class 2.

Higher strength pipes, expressed as multiples of 2 (6, 8 and 10) are also manufactured to order.

It is important for designers and construction contractors (essential for the latter) to consider construction loads when determining pipe class during design/installation of culverts to avoid overstressing installed pipe units and cause cracks/fractures. While temporary load mitigating measures during construction exist, it may be an economical solution to use a higher class pipe.

With reference to AS 3725 and Standard Drawing 1359 (QDMR 2009b), the support condition normally used is H2 for both embankment and trench installations. The HS3 support condition should be used where the height of the cover is critical and where significant savings can be made by using a lower class pipe.

To illustrate this point, the H2 support condition is typically cheaper to construct than HS3. However, under the same site, load and cover conditions, it may be possible to use a lower strength pipe, together with HS3 support than compared to a higher strength pipe with H2 support. These combinations of pipe strength and support condition should be cost analysed to determine an economical solution.

The load on a pipe installed in a trench depends upon the width of the trench and is particularly sensitive to any changes in this dimension. Therefore, the trench width specified by design is a maximum allowable and not a minimum.

It is important that the maximum allowable trench widths used in the design be strictly adhered to during construction. If any doubt exists as to whether the design trench width can be maintained (for example, wet weather causing erosion and slips of the trench wall), it is recommended that the embankment installation be used to determine allowable heights of embankment.

For heights of cover less than 3 m, the allowable height depends on both live and earth loads. At these lower heights, the live load is a major contributor to the total load on the pipe.

Design engineers can use other support conditions as detailed in AS 3725; however, standard drawings and specifications do not address these.

9.2.6.5 Fibre-reinforced concrete pipes

Table B1 information on fibre-reinforced concrete pipes (FRCPs) of the Austroads *Guide to Road Design* – Part 5 (Appendix B) is accepted for this section with amendments.

Addition(s)

1. They are generally suitable anywhere an RCP could be used (refer Section 2.3.5.3 in Chapter 2 of this manual). The reinforcement is a cellulose (wood fibre) product. Hydraulic design curves for precast RCPs are appropriate, although FRCPs have slightly lower roughness coefficients.

9.2.6.6 Reinforced concrete box culverts

Table B1 of the Austroads *Guide to Road Design* – Part 5 (Appendix B) is accepted for this section subject to amendments.

Addition(s)

1. In accordance with the department's specification MRTS24 (TMR 2015d), standard reinforced concrete box culvert (RCBC) and link slab components have been manufactured to withstand a maximum height of fill (including pavement) of 2.0 m. For higher fills (including pavement), a special design for proposed installation is necessary.

For multi-cell installations, SLBC construction should be considered, as shown in Figure 9.2.6.6. Details are shown on Standard Drawings Nos. 1303, 1316, 1317, 1318, 1319 and 1320 (QDMR 2009b).

RCBCs and SLBC construction can be used with nominal minimal cover above the culverts. Nominal cover has advantages in regions where the height of the overall formation is critical.

In expansive soil areas, RCBCs and SLBC installations require special consideration. Refer Section 9.2.7 for details.

Figure 9.2.6.6 – Slab link box culvert under construction

9.2.6.7 Reinforced concrete slab deck culverts

The standard reinforced concrete slab deck culverts of 2500 mm span allow for a maximum fill of 2500 mm above the slab deck and is a cast-in-situ structure (refer Standard Drawings Nos. 1179 and 1132 (QDMR 2009b)).

9.2.6.8 Corrugated steel pipes

Corrugated steel pipes, as shown in Figure 9.2.6.8(a), offer a lightweight alternative when compared to concrete pipes. The use of such pipes is not generally favoured due to the reduced life spans they have exhibited to date in the field. However, they may be considered if the design life requirement is purposely relaxed to suit the constraints of a particular situation. An example of this is when transport of alternative materials over long distances becomes excessively costly. In making such a choice, the shorter expected life span must be recognised and replacement of the structure appropriately programmed.

Figure 9.2.6.8(a) – Corrugated steel pipes

The following Australian Standards are relevant to corrugated steel pipes:

- AS 2041.1:2011 – Buried corrugated metal structures – Design methods
- AS 2041.2:2011 – Buried corrugated metal structures – Installation
- AS 2041.4:2010 – Buried corrugated metal structures – Helically formed sinusoidal pipes
- AS 2041.6:2010 – Buried corrugated metal structures – Bolted plate structures

The department's specification MRTS03 (TMR 2015b) also contains requirements for supply and construction of metal culverts.

New steel culvert components must have a protective coating applied to both internal and external surfaces in order to meet the required 100-year design life. The protective coatings must conform to:

- galvanising to Z600 in accordance with AS 1397
- a polymer coating to ASTM A742.

Before specifying in design/used in construction, any proposed steel culvert product with this protective coating applied must be approved by the Structures section, Engineering and Technology Branch.

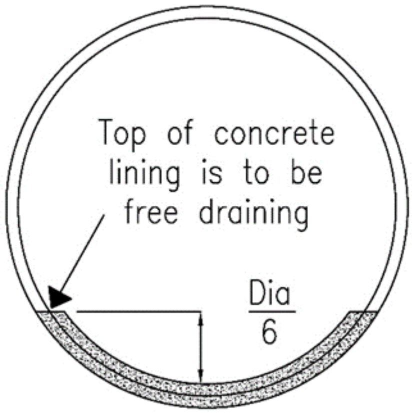
Additional design requirements for helical culverts are:

- the maximum diameter of helical pipe culverts complying with AS 2041 shall be 3600 mm
- the maximum flexibility factor for installation shall not exceed the limits in AS 2041.

Apart from this protective coating requirement, steel culverts must also have invert protection. The invert of all corrugated steel pipe culverts shall be lined with concrete as follows:

- Concrete Class: 32 MPA/9.5
- minimum depth of concrete above corrugations: 50 mm
- minimum height of lining above invert to be D/6 where 'D' denotes diameter as shown in Figure 9.2.6.8(b).

Figure 9.2.6.8(b) – Culvert lining detail



It is important to note that any bolts or lugs that are connected to the culvert to allow anchorage for the concrete invert must also be covered by the protective galvanising/polymer coating.

Further details for concrete lining are contained in the department's specification MRTS03 (TMR 2015b).

The design of corrugated metal helical pipe and arch culverts is not as simple as for concrete culverts and, therefore, should be undertaken by an experienced design engineer. Furthermore, installation of metal culverts is also specialised and, therefore, should be undertaken by qualified/experienced personnel. Assistance and advice with respect to the design and installation of metal culverts can be provided by the Structures section, Engineering and Technology Branch, when required.

9.2.6.9 Plastic flexible pipes

Polyethylene and polypropylene pipes are available, but are not currently approved for use as culverts under a state-controlled road (refer to the department's Technical Note 103 *Vandalism of Plastic Pipe under Roads, Rail and Similar Infrastructure* available on the departmental website). They. They can be considered for applications which are not subjected to traffic loading. In these instances, confirmation of acceptance for the proposed use of these culvert types should be sought from the department.

9.2.6.10 Aluminium culverts

Table B1 of the Austroads *Guide to Road Design* – Part 5 (Appendix B) is accepted for this section.

9.2.6.11 Other structural aspects

All other structural aspects should be referred to the Structures section, Engineering and Technology Branch for advice and/or guidance.

9.2.7 Culverts in expansive soil areas

Expansive soils pose particular problems in civil engineering works due to shrink-swell behaviour. With respect to drainage structures, this movement in the soil places uneven stresses on RCBCs, SLBCs and RCCs and can damage the structure as shown in Figures 9.2.7(a) and (b). In Figure 9.2.7(a), the longitudinal crack stops at the slab which forms the footing of the wingwall. While the apron has risen relative to the wingwall, the outer edge of the apron has dropped and now slopes away from the culvert. Figure 9.2.7(b) shows the vertical displacement across the break in the apron slab. Again, the apron has risen relative to the wingwalls.

Figure 9.2.7(a) – Longitudinal cracking of apron failure

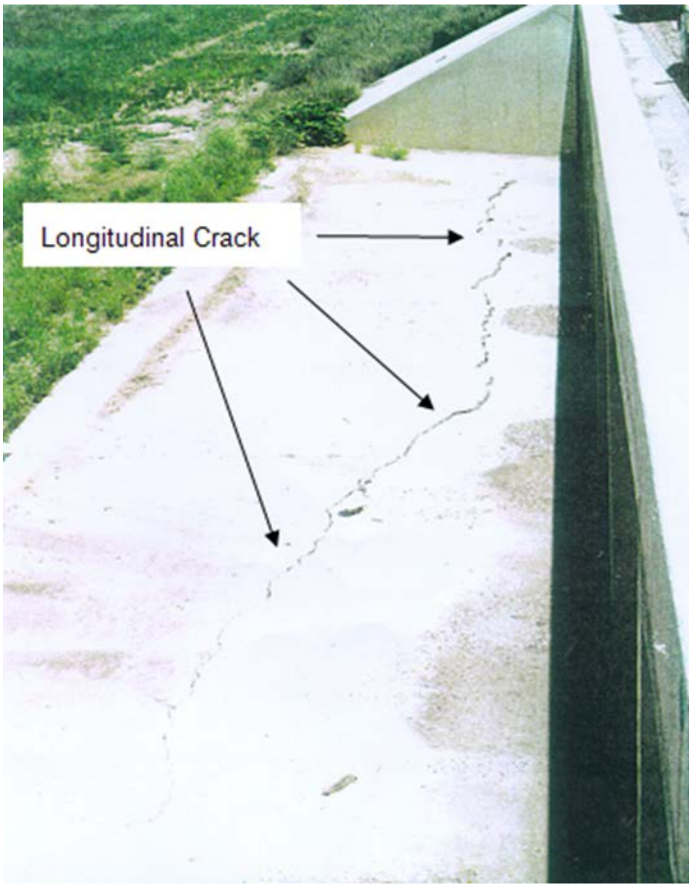


Figure 9.2.7(b) – Vertical displacement of apron failure

Other issues, such as culverts which appear to rise above their original level, approaches to culverts that deform and pavement distress over culverts, are often the result of volume changes in expansive soil foundations and embankments. With differential ground movements taking place at the culvert/approach interfaces, heavy vehicles can inflict high axle impact loads on the structure. The design load of culverts is influenced more by high impact loads of individual axles rather than the behaviour of the entire vehicle. High impacts on structures can dramatically reduce service lives.

This section addresses:

- multiple barrel, RCBCs and SLBCs
- multiple barrel, reinforced concrete culverts (RCCs) with a total length greater than 10 m along the road centreline in expansive soil conditions.

9.2.7.1 Expansive soil potential

The shrink-swell behaviour of expansive soils is caused by moisture movement in the soil brought about by climatic changes producing moisture variations from extreme wet to extreme dry or vice versa. Examples are:

- soils in arid climates, usually in a desiccated state (cracked), which are subjected to occasional unusually high rainfall or prolonged inundation causing the soil to saturate and expand
- soils in semi-arid climates where the moisture conditions of the soil reflect the wet-dry seasonal cycle and may be subjected to occasional climate extremes of drought and flood
- predominantly wet soils which, from time to time, are subjected to a prolonged period of drought and exhibit drying shrinkage.

The shrink-swell behaviour or volume change phenomena is controlled by three major factors:

- intrinsic expansiveness of the soil (generally characterised by shrink-swell index for the soil)
- suction change (site-specific and dependent on the atmospheric conditions)
- applied stress.

Changes in soil moisture produce suction changes which, in turn, produce a loading/unloading effect on the soils and result in volume changes in the soil. The two most important site-specific issues with regard to suction are:

- the postulated suction change at the surface
- the depth over which the suction change manifests, called the active depth (generally between 2–5 m).

While some guidance is available for expansive soil embankments in road construction, the problem with drainage structures in expansive soils is different in that it is a soil/structure interaction condition.

Experience has shown that expansive soil problems generally tend to occur in soils which have a Linear Shrinkage greater than 8% and/or swell strains greater than 5% at OMC (based on a multi-point soaked CBR test).

According to the Unified Soil Classification, these soils range from SC/CL to CH and are not necessarily restricted to high plasticity CH clays.

Therefore, particular design and/or construction considerations need to be adopted to avert damage to culverts where expansive soils are exposed to significant long-term moisture changes.

9.2.7.2 Postulated mechanism of distress

The observed movement in some large culverts is generally a movement of the outer edges of the culvert relative to the central section of the culvert, which is generally immune to the movement. Figure 9.2.7.3 depicts this failure mechanism for two case study sites.

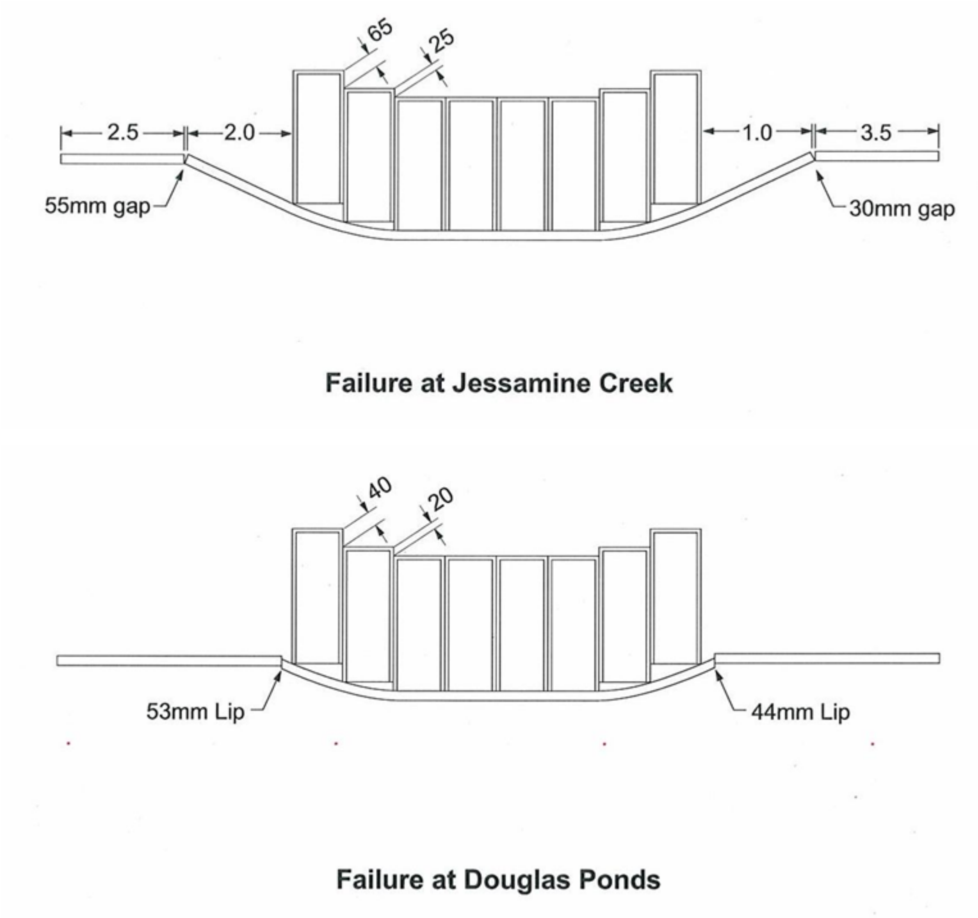
It is considered most likely that the outer edges, being the apron slabs, are subjected to extremes of wetting/drying phenomena, which produce either high swelling pressures or lack of base support.

Most small culverts (< 10 m along the road centreline) generally only suffer small movement, which is satisfactory or exhibit a uniform heave due to their inherent geometric stiffness.

9.2.7.3 Standard drawings

The current standard drawings for culvert bases do not state the design assumptions on which the drawings are based and, most importantly, situations when the drawings are inappropriate for use.

Figure 9.2.7.3 – Failure mechanism of base slabs in expansive soils



The design assumptions on which those drawings are based include:

- the base slabs are designed as a beam on a moisture insensitive, elastic foundation; that is, differential settlement due to moisture changes are not a design consideration in the standard drawing
- the minimum ultimate bearing capacity of the strata under the culvert base is at least 150 kPa, but preferably in excess of 200 kPa.

Sites subject to large settlements or large differential settlements, arising out of moderate or highly expansive soils below the culvert base, are outside the design method of these standard drawings.

9.2.7.4 Amended design procedure

For culverts with a base greater than 10 m along road centreline, specialist geotechnical and structural advice (from the department's Engineering and Technology Branch) should be obtained where highly reactive or expansive clay soils (linear shrinkage > 8% and/or CBR swell > 5%) occur below the culvert bases. This is to determine if non-standard base slabs or other foundation treatments are required.

9.2.7.5 Foundation investigation

An appropriate, special investigation for culvert bases on expansive soils should be undertaken in a similar manner to the proven need for special bridge site investigations. This work should be undertaken under the direction of specialist geotechnical engineers and/or geologists as appropriate. This is required only if preliminary testing indicates the subgrade to be expansive (that is, LS > 8% and/or CBR swell > 5%). This preliminary testing can be undertaken at the regional level.

It is imperative that a vertical profile is established to determine the extent of the actual expansive zone. A field investigation should include:

- trenching or drilling to 2 m depth under or in the vicinity of the proposed culvert location
- in situ moisture content (Q102A) and density testing (Q111A) at every 300 mm in depth or at change of soil horizon, whichever is earlier, to determine the active zone (below the active zone, no significant moisture content changes occur over time). Due to lack of data, AS 2870 – 2011 gives little guidance on active depths for Queensland conditions. For most other states, such as Victoria, where the reactivity of clay profiles has been the subject of extensive research, useful guidance is available
- 50 mm undisturbed tubes taken from each soil horizon, for shrink-swell index testing and filter paper suction measurements
- adequate materials to be sourced from each location for the following laboratory tests.

A laboratory investigation is required for each soil horizon. The required tests are detailed in Table 9.2.7.5.

If instrumented sites are established in different soil/climatic regions, enabling a rational classification of soil/climatic behaviour response patterns, the level of testing can be reduced in the future.

Table 9.2.7.5 – Required tests

Parameter	Test method
Particle size distribution (sieve analysis)	Q103A
Liquid Limit	Q104A
Plastic Limit	Q105
Linear Shrinkage	Q106
Shrink-swell index	AS 2870–2011
Filter paper suction measurement	BRE–IP 4/93

9.2.7.6 Options for the control of distress in culverts

For drainage structures using culvert bases, special measures need to be undertaken to avert distress. Options for control of distress of culvert bases may be categorised into either geotechnical alternatives or structural alternatives. In many cases, geotechnical methods may be used successfully in conjunction with structural methods.

a) Geotechnical methods

There are broadly two geotechnical methods for limiting damage to light structures, such as culverts constructed on expansive soil foundations. These either reduce the expansive potential of the soil or minimise the seasonal fluctuations of the subgrade moisture.

Reducing expansive potential of the foundation – volume stability

Methods for reducing the expansive potential of the foundation may include one of the following:

- excavation of the foundation and replacement with a low permeability granular or non-swelling material
- chemically treating the natural material (for example, lime stabilisation)
- ripping, scarifying and then compacting the soil with moisture and/or density control.

These processes are carried out to a depth beyond the level of seasonal moisture variation within the soil. The areas to be treated would be under the aprons and 1 m beyond the cut-off wall of the apron.

Control of foundation moisture fluctuations – moisture stability

The aim of these methods is to control the moisture fluctuations in the foundation within acceptable limits. Methods of control may include one of the following:

- pre-wetting or ponding a foundation prior to construction
- stabilisation of foundation moisture conditions by a physical limit, such as vertical moisture barriers. This involves the placement of a geomembrane (generally a waterproof fabric) in a trench along the perimeter of the slab to the limit of the estimated active zone depth. These vertical barriers minimise seasonal lateral migration of moisture to and from the foundation soils beneath the foundation slab. Details of backfilling and other technical issues will need to be covered by supplementary specifications
- extending the concrete apron with a flexible apron, such as grout-filled erosion mattress (≈ 3 m wide) underlain by an impermeable membrane (horizontal moisture barrier). This is aimed at shifting the moisture fluctuation zone to be under the extended apron, thus shielding the concrete apron slab from the edge effects.

Prediction of moisture infiltration under sealed areas by numerical methods may be used in estimating the required lateral extent that needs to be provided by the flexible apron.

b) Structural methods

The structural options to control distress of culvert bases are as follows:

Improved layout of culverts

The risk of damage to culvert bases may in some circumstances be reduced by limiting the size of banks of culverts. In wide floodplains, it is considered that a number of banks of culverts distributed across the watercourse will result in a better hydraulic and structural solution.

Other structural solutions

The use of stiffened raft foundations (AS 2870) are technically proven solutions widely used in the building industry. As the culvert distress is commonly observed within the apron area of the slab, any stiffening needs only be confined to the apron slab. Swell pressures can be as much as 200 kPa; that is, much greater than the applied pressure at the base of the slab (typically up to 50 kPa). Each case has to be considered on its own merit.

Other options – bridges

Consideration should be given to using short span bridges founded on freestanding piles extending to the stable material below the active zone. Due to the limited nature of contact between the volumetrically active soil and the foundation elements, being the free standing piles, limited upward thrusts are transmitted to the deck. Therefore, these foundation systems are less influenced by the movement of the ground and allow such designs to be optimised. However, expansive soil issues with bridge abutments and general bridge maintenance requirements would still need to be resolved.

Bridges would not be a practical option for low height structures, but the actual height limit has not currently been determined, and it may vary for different sites.

9.2.7.7 Improved construction practice

Consideration should be given to restricting construction practices which adversely affect the moisture content of the soil. The following practices should be excluded:

- placement of permeable fill behind the culvert (either granular or cement stabilised sand)
- opening a culvert base up for a prolonged period when the moisture content is low
- not allowing adequate time for the culvert base to reduce moisture content after a prolonged wet period.

Supplementary specifications may be required in such situations, and may require specialist input from geotechnical and structural specialists within the department's Engineering and Technology Branch.

9.2.8 Flap gates (tides and floods)

Where the outlet to a culvert may be submerged by tide or a flood from downstream sources, and where it is necessary to prevent the flow of such waters into the culvert, it may be necessary to install flap gates.

However, flap gates will generally cause a higher head loss to occur. Therefore, reference should be made to loss coefficients as provided by the manufacturers.

Where flap gates are required, it will be necessary to ensure that only those culvert types for which gates are available are selected. Obvious impacts on fish passage must also be considered.

Regular maintenance of flap gates is required to ensure their efficient operation. This is especially important for locations where there is significant debris or sediment transport. If regular maintenance is unlikely, then flap gates may not be appropriate.

In addition, if the culvert is expected to pass large quantities of sand, then the outlet should be raised above the downstream invert to avoid sediment blockage of the gate(s).

9.2.9 Multiple barrels

When two or more barrels of pipes are laid parallel, they should be separated by the dimensions as shown on the relevant standard drawing and within MRTS03 (TMR 2015b).

The spacing allows for thorough compaction of the backfill material, which is essential for haunch support and the prevention of settlements.

Multiple pipe culverts should always be treated as an embankment installation when determining the class of pipe required from the allowable height of cover. Even for culverts installed in trench conditions, the height of cover should be calculated for embankment installation.

For multiple cell culverts in a restricted natural waterway, box culverts can make better use of the width available, particularly when SLBCs are used.

For large culverts, it is often possible to use link slabs to reduce costs. In these situations, selection of an odd number of box culvert cells is preferred, though by no means essential. An odd number of cells should only be sought if no other design criteria are compromised.

9.2.10 Reduction in culvert size

New culvert installations must maintain the same size diameter pipe/box dimensions for its whole length.

For culverts being extended:

- a reduction in culvert size is not permitted on the downstream side as the discontinuity between the different pipe sections can ‘catch’ debris causing blockage which, in turn, reduces the capacity of the culvert and/or can cause failure of the culvert
- a reduction in culvert size is permitted on the upstream side provided that the hydraulic capability is not compromised.

This also applies for projects where the inflow to an existing culvert has been reduced and the culvert requires extension.

Where culverts require strengthening by insertion of a sleeve or similar, the internal dimensions/diameter must be maintained for the length of the culvert.

9.2.11 Splay pipes

The use of splay pipe components to construct ‘bends’ in culverts is not permitted.

However, a relaxation of this requirement may be approved for individual cases within a project subject to the following requirements:

- specific locations where it is proposed to use splay pipes to construct bends in culverts are to be reviewed and approved by the department’s design representative
- culverts must conform to relevant departmental specifications
- bends are to be constructed in large culverts only – for pipe diameter of 1200 mm or greater using propriety splay pipe units and for box culverts with widths and heights of 1200 mm or greater using a cast-in-situ chamber without access
- bend angles are restricted to a total or maximum 22.5° culvert deflection in the horizontal plane only (grade of culvert must not change)

- only one bend is allowed in a single culvert installation
- the detailed design of any culvert that includes a bend will require formal approval by the Structures section, Engineering and Technology Branch.

9.3 General process for culvert design

This section describes an approach or general process for the design of culverts. Some of the work described in the following sections may not be required for each design of a culvert.

The design of a culvert commences with assembling the data related to the drainage site, including detailed survey of the site, site inspection data and other site-specific information, including environmental and geotechnical reports.

A generalised approach to the design of the culvert follows:

a) Collate site data

Review survey, topographic information, locality map, photographs, aerial photographs and details from field visit to determine/understand:

- catchment/waterway details, including natural constrictions, bends, low/high flow channel, vegetation, potential overflow to other crossings, and so on
- upstream and downstream conditions and details
- location of any geotechnical issues
- location of environmental constraints or identification of environmental issues
- location of Private/Public Utility Plant (PUP) or other physical constraints
- any stream or channel diversion issues
- any culvert skew requirements
- soils data
- existing and allowable stream flow details (depth, velocity, energy and so on) (refer Chapter 8)
- any possible/identified inlet and outlet erosion issues
- possible sediment/debris issues.

It is also essential to review:

- recorded and observed flood data, and local anecdotal data from residents or local council
- design data for nearby structures
- studies by other authorities near the site, including small dams, canals, weirs, floodplains, storm drains.

From this information, the designer can then commence the design to determine the size and alignment of the culvert.

b) Determine road/channel geometry

Where the road alignment crosses the stream/channel, the designer needs to determine/understand:

- the grade height of the road over the crossing
- location of adjacent low points in the road alignment
- height and width (location) of shoulders (both sides) considering crossfall/superelevation application
- embankment or batter slopes (and possibility of steepening the slopes if height of embankment over culvert is too high)
- pavement thickness
- shape of channel (width of bed and bank slopes) including uniformity of shape over the reach where the culvert will be located
- channel bed slope.

These parameters are required to determine the maximum height, width and minimum length of the culvert. This allows the designer to 'fit' the culvert under road and within the channel. The parameters also allow the determination of the height of headwater that can be developed upstream of the culvert.

c) Determine culvert type and location

Select a suitable culvert type (RCP, RCBC and so on) for site and locate the proposed culvert along the best initial alignment and determine the following:

- an initial trial culvert size and configuration that 'fits' (refer 'b)') and check cover requirements for selected culvert type
- incorporate any environmental requirement such as fauna passage
- set an outlet invert level
- based on the channel bed slope and an initial slope for the culvert, determine the inlet invert level
- check that the inlet invert level is at or just below the natural bed level
- if the inlet level is well below the natural bed level, assess the extent of inlet works needed to avoid/minimise siltation over time
- check/determine available space for possible ancillary erosion or environmental protection devices
- identify and document any possible issues/limitations that may necessitate a review of the culvert design or its location.

d) Determine tailwater level

- Calculate the tailwater level within the existing channel immediately downstream of culvert outlet.

e) Undertake hydraulic design

- determine/set the maximum allowable headwater, including freeboard, for the design
- complete the hydraulic design of proposed culvert to determine headwater, control, outlet velocity Froude number
- undertake several trials based around the initial culvert size/configuration, including cost comparison, to select optimum design.

f) Review hydraulic design output

- check if hydraulic design is reasonable/realistic and if the flood immunity requirements are being achieved
- check generated headwater against maximum allowable headwater
- check outlet velocity against permissible channel velocities
- check extent of any additional inundation due to afflux and review impacts to adjacent property
- assess the likelihood of road overtopping or excessive/erosive outlet velocities in an extreme rainfall event (how close is generated headwater to shoulder point/outlet velocity to maximum permissible).

g) Check connections

- Can surface drains, such as catch drains and diversion drains, be drained to the culvert inlet and/or outlet? (refer Chapter 11)
- Can underground drainage be drained to the culvert inlet and/or outlet? (refer Chapter 11)

h) Assess mitigation treatments

- Determine any inlet or outlet protection devices to address pollution or erosion control concerns.

As the designer works through this step-by-step process, there will be some outcomes that indicate that revisions to the proposed culvert need to be made.

The designer needs make amendments to the proposal and restart the geometric design at an appropriate point and continue the design with the amended culvert proposal.

The culvert design will not be able to be finalised until all related components of the drainage infrastructure are defined by the relevant sections in chapters 8, 9, 10, 11 and 12 are addressed.

9.4 Location of culverts

Sections 3.3, 3.3.1 and 3.3.2 of the Austroads *Guide to Road Design* – Part 5B are accepted for this section.

9.5 Allowable headwater

Section 3.7.5 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section subject to amendments.

Addition(s)

1. Culverts that are designed for hydraulic purposes only are designed to pass the design discharge from one side of the road embankment to the other in a cost effective manner in accordance with individual project requirements.

The velocity of the water through the culvert is usually greater than the approach velocity in the stream because the culvert presents a smaller cross-sectional area of flow than the stream.

As detailed in the previous chapter, the energy in water is measured as head (m). When water flows through a culvert, several losses of energy occur:

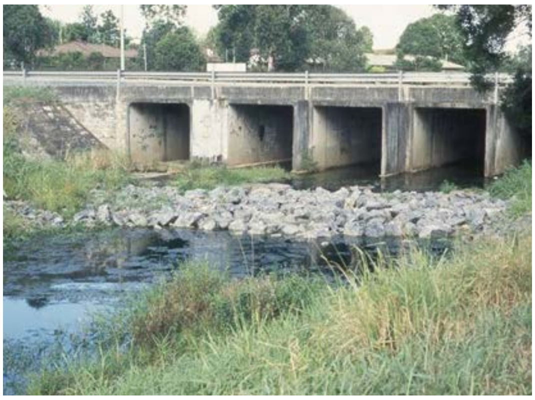
- firstly as the flow accelerates into the culvert (known as entrance loss)
- then there is friction loss along the length of the barrel as water flows against the culvert
- finally as the flow decelerates out of the culvert (known as exit loss).

In order to pass the design discharge through the culvert, extra energy within the flow is required on the upstream side to overcome these losses. This extra energy is generated by 'damming' the flow on the upstream side of culvert/road formation which raises the water level (increases the height of water or head) above that of normal flow levels. This increase in level is known as afflux and it is at its highest just upstream of the culvert entrance.

The overall increase in water depth (afflux) generated by the culvert cannot exceed the allowable headwater for the site.

2. Reduction of the culvert outlet discharge velocity is normally achieved by increasing the waterway area of the culvert; however, this is not always possible and, therefore, outlet protection, as shown in Figure 9.5, may have to be designed.

Figure 9.5 – Box culverts with riprap



9.6 Preliminary selection of culvert size

Section 3.5.2 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section subject to amendments.

Addition(s)

1. For culverts used as walkways and bikeways, the minimum recommended invert level is equal to the level/height of the 39.35% Annual Exceedance Probability (AEP) (2-year Average Recurrence Interval (ARI)) flood event. For the minimum recommended cell height and widths, refer to the department's *Road Planning and Design Manual* (TMR 2013d).

9.7 Requirements for fauna passage

9.7.1 Considerations for fish passage

Culverts are considered as a waterway barrier and can limit fish movement along the waterway. Defined waterways require a culvert design that supports fish passage. Definitions and key requirements are provided in Section 2.5.2.6 in Chapter 2.

Chapter 7 provides an understanding of and reasons for fish movement.

9.7.2 Culvert specifications for fish passage

Section 3.3.7 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section subject to amendments.

Addition(s)

1. Specific requirements for the design of culverts that support fish passage can be found within the self-assessable codes on the Queensland Fisheries' website. The department is working with Queensland Department of Agriculture and Fisheries to review these requirements. For further guidance in relation to this, contact either the Director (Road Design) or the Director (Hydraulics and Flooding), Engineering and Technology Branch.

9.7.3 Considerations for terrestrial passage

Section 3.3.8 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section.

9.7.4 Culvert features for fauna passage

Other features associated with terrestrial passage are discussed below. The value and, hence, need for each of these features must be assessed on a site-by-site basis.

Separate wet and dry cells: Most culvert designs will have requirements for some degree of terrestrial or aquatic movement. Thus, most multi-cell culverts will require both wet and dry cells.

Separate wet and dry cells can be formed by placing individual cells at different invert levels. This may be achieved by having the two outside cells raised at least 100 mm above normal water level or lowering just one central cell below normal water level.

Dry cells can also have a dual use as pedestrian tunnels and bikeways.

Low flow channel: In some cases, in order to satisfy both aquatic and terrestrial passage requirements, it may be desirable to construct a low flow channel into the base slab rather than constructing a raised ledge.

Fencing: Fencing, such as koala-proof fencing, as shown in Figure 9.7.4, or wildlife exclusion fencing, can be used to direct animals to the culvert to avoid animals moving over the road.

For guidelines on the use and design of fauna control fencing, refer to the department's *Fauna Sensitive Road Design* (2000).

Figure 9.7.4 – Koala fencing

Habitat: As a general rule, the cells of a culvert should not be modified to provide or promote habitat of birds and terrestrial animals. The reason for this is that these habitats are not natural and are likely to be destroyed during flood events.

Lizard run: If, for any reason, a dry ledge or dry cell cannot be constructed, then a lizard run may be considered.

Lizard runs are approximately 100 mm wide strips of timber bolted to the waterway embankment side of a culvert cell. They are introduced to a culvert to enable smaller reptiles to move through the culvert at an elevated height.

Lizard runs should be located approximately 300 mm below the obvert of the cell and must extend from ground level at the upstream wingwall, through the culvert to ground level at the downstream wingwall.

Sidewall roughness: As an alternative to constructing a lizard run, the culvert cell wall adjacent to the watercourse bank could be roughened with texture paint, grout or other suitable material to allow for the movement of fauna such as lizards.

Any increase in culvert wall roughness must be taken into account in the hydraulic analysis when designing the culvert. However, it is noted that in a typical road culvert, sidewall friction only represents around 12% of the total head loss.

Street lighting: Many animals move only at night. To assist in the passage of such animals, street lighting adjacent to culverts should be fitted with metal shields to prevent the lighting of the culvert entry and exit.

In some circumstances, it may be desirable to paint the concrete wingwalls and apron in a dark colour (dark green) to minimise the reflection of light.

Lighting: Many terrestrial animals will not enter a dark culvert, so some means of lighting inside the culvert is important. For example, this lighting could be in the form of a break in the median for a major road.

Vegetation: The provision of vegetation at the entrance and exit of a culvert is a key determining factor as to whether native fauna will use the culvert.

Bank vegetation should be extended up to the edge of the culvert. This is especially important if a ‘lizard run’ or ‘fauna path’ has been installed.

In critical flood control regions, this bank vegetation may need to consist entirely of flexible (non-woody) species that provide minimal hydraulic resistance (that is, no shrubs).

9.7.5 Stock underpass

Stock underpasses (also known as ‘cattle creeps’) are primarily designed for the purpose of allowing cattle to be driven under road formations and, therefore, should remain dry most of the time.

If the culvert is to also be used to convey water under the road during storm events, channels leading to and away from the culvert must have sufficiently flattened side slopes to allow easy passage for cattle. The outlet channel must allow the culvert to completely drain after a storm event.

The culvert must be at least 2.4 m in height to allow a person on horseback to be able to ride through the culvert (they can bend low in the saddle).

For cattle to enter a stock underpass, sufficient daylight from the other side needs to be seen by the cattle, otherwise they will baulk and not enter. Suggested number and width of cells is 3 x 2.4 m minimum for culvert up to 15 m in length.

9.8 Selection of culvert type

Further to Section 2.3.5 in Chapter 2 of this manual, the selection of the most appropriate type of culvert is dependent on a range of factors including economics, site conditions and environmental considerations.

Box culverts are generally used where:

- insufficient embankment depth or cover for pipes exists
- channel is narrow and it would be difficult to fit a pipe culvert
- fauna passage is required.

In multi-cell construction, slab linked box culverts (SLBCs) are often an economical choice.

Historically, while the majority of culverts installed consist of concrete pipes or box culverts, the installation of corrugated metal pipes, pipe-arch or arches, may be appropriate and economic in some situations.

Metal culverts have some advantages in lower cost and ease of transport and installation. However, disadvantages, such as corrosion due to construction damage, high compaction standards and higher cover requirements, mean that unless there are large financial savings, or other construction restraints, other more robust and more durable materials should be used.

Table 9.8 provides guidance in the selection of the most appropriate culvert type for different exposure conditions.

Table 9.8 – Culvert types for different conditions

Exposure condition	Concrete box culverts (normal cover)	Concrete box culverts (saltwater cover)	Concrete pipes	Steel corrugated arch[1&2]	Steel helical pipe[1&2]	Aluminium helical pipe[2]
Saltwater	×	✓	✓	×	×	×
Aggressive soil (e.g. low pH, high chloride high sulphate)	×	×	×	×	×	✓
Invert in fresh water for prolonged periods	✓	N/A	✓	×	×	Not economic
Typical condition (i.e. none of above)	✓	N/A	✓	✓	✓	Not economic

Notes:
[1] Refer Appendix C, AS/NZS 2041 1998 Buried Corrugated Steel Pipes
[2] Refer Section 9.2.6.1 for structural requirements

Reference should also be made to Standard Drawing No. 1359 (QDMR 2009b) for installation requirements, cover, spacing and details for H2 and HS3 support conditions (refer Section 9.2.6.4).

9.9 Typical culvert operating conditions

Section 3.8.1 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

9.9.1 Inlet control conditions

Section 3.8.2 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

9.9.2 Outlet control conditions

Section 3.8.3 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

9.10 Hydraulic calculations

Section 3.9 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

9.10.1 Control at inlet

Section 3.8.2 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

9.10.2 Control at outlet

Sections 3.8.3 and 3.9.1 of the Austroads *Guide to Road Design* – Part 5B are accepted for this section.

9.10.3 Determination of tailwater

Section 3.9.2 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

9.11 Design procedure

Section 3.10 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

9.11.1 Hydraulic design

Sections 3.10.1 to 3.10.11 of the Austroads *Guide to Road Design* – Part 5B are accepted for this section subject to amendments.

Addition(s)

1. A copy of the design form referred to in this section (Figure 3.8, Section 3.10.1 the Austroads *Guide to Road Design* – Part 5B) is contained in Appendix 9A for download, print out and use.

9.11.2 Practical design

Section 3.10.12 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

9.12 Minimum energy loss culverts

The early designs based on this principle were known as minimum energy/constant energy and no afflux culverts, although the last title is no longer used. Bridge waterways have also been designed as minimum energy loss structures.

To minimise energy loss through a culvert and the resulting afflux, the design requires carefully shaped inlets and outlets (refer Figure 9.12) and usually a dropped culvert barrel, such that critical flow passes through the system in the design flood. In a minority of these structures, flow is not at critical depth in the barrel in the design flood.

Furthermore, due to the size, material requirements and increased difficultly in construction, minimum energy culverts are generally very expensive options and the benefits of these types of culverts are arguable.

Figure 9.12 – Minimum energy loss culvert on Gateway Motorway

Advantages promoted by others over conventional structures are that:

- by constricting the natural flow to a greater extent, the body or cell has a minimum width, reducing construction costs for this component only
- the flow through the culvert is streamlined and, therefore, has reduced turbulence which, in turn, reduces the erosion potential of the flow and minimises the need for protection
- the minimisation of energy losses results in little or no adverse effect on upstream flood levels.

Problems have been observed in some existing structures and some designers see them as indications for caution in the future design of minimum energy loss structures.

Furthermore:

- each structure is unique and requires considerable, specialist design effort
- the cost of the curved base and extensive shaped wing and apron structures normally surpasses the savings in reduction in number of cells required
- future extensions or changes to these structures significantly change the hydraulic performance and generally require the complete rebuild of affected apron and wing structures
- critical flow is inherently unstable and, therefore, sensitive to small changes in energy and depth of flow. Discharges, both higher and lower than the design discharge, have the potential to give higher affluxes than the design flood. The range of flows for which streamlined flow may occur in any structure is questioned
- an anti-ponding pipe or channel is generally necessary to prevent ponding of water after a flood
- sediment may be deposited after a flood and may not be removed in future flows with the possibility of growth of vegetation requiring removal; that is, provision for maintenance required
- the possibility of debris blocking the culvert barrel is increased because of the smaller cell.

The significance of some of these key points is that too much debris or siltation will change the geometry, such that streamlined flow would not occur.

Minimum energy loss culverts are no longer used or recommended by the department. If an existing minimum energy loss structure requires extension or alteration, then the design must be referred to the Director (Hydraulics and Flooding), Engineering and Technology Branch.

9.13 Blockage of culverts

Section 3.11 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

9.14 Consideration of large or extreme events

Section 3.12 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

9.15 Culvert outlet protection

Sections 3.13 and 3.14 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section subject to amendments.

Addition(s)

1. In all types of culvert outlets, protection of the stream bed would normally be provided by the department’s standard apron treatment as shown on Standard Drawings 1179, 1317 and 1318 (QDMR 2009a). Typically, the distance of protection required, measured from the outlet of the culvert, is 1.5D metres where ‘D’ is the diameter of a pipe or the height of a box culvert.
2. Wingwalls, in conjunction with the apron and cut-off wall, protect the integrity of the embankment from erosion/scour caused by stormwater flows.

   The length of the wingwall (W1 & W2 as per Standard Drawings 1179, 1248, 1303, 1304, 1305 and 1306 (QDMR 2009a)) is calculated based on the slope of the batter – the flatter the batter slope, the longer the wingwall needs to be. The wings should extend to at least the interface between the batter slope and the natural slope. For further detail on calculating wingwall lengths, refer to Appendix 9D.

Should shorter wingwalls be proposed (that is, some of the embankment is exposed to inlet/outlet flow), it is recommended that there be a requirement to mitigate any possible erosion/scour of the exposed embankment via works with a similar durability/design life as normal wingwalls (typically 50 years).

3. Use of pre-cast end/headwalls must comply with the department's Standard Drawing 1243 and Technical Note TN27 – *Guidelines for Design of Precast Culvert and Pipe Headwalls*. NB: For concrete pipe culverts there is to be no step between the culvert invert level and the adjacent apron level. This requires the depth of the recess in the precast end unit to match the thickness of the concrete pipe.

9.16 Special energy dissipation structures at culvert outlets

When rock pad protection is not appropriate due to high velocity and/or high energy flows, non-standard and more specialised energy dissipaters are required. These options can be expensive to design and construct and generally have a potential for high maintenance costs (that is, debris collection). These devices can also be a potential public and wildlife safety hazard.

Use of such energy dissipaters should be considered the exception, not the norm, and should only be used when no other reasonable options are available. The design of these devices/structures should be referred to the Hydraulics and Flooding Section, Engineering and Technology Branch or a suitably prequalified consultant.

9.17 'Self cleaning' culverts

If a 'self cleaning' culvert is required, designers are referred to Section 2.8 in Chapter 2 of this manual for requirements/design parameters.

9.18 Inlet structures

For culvert inlet structures, headwalls and wingwalls of reinforced concrete are usually needed to provide embankment stability and protection against erosion.

Culverts with wingwalls should be designed with an apron extending between the walls. Aprons must be reinforced concrete. The actual configuration of the wingwalls will vary according to the direction of flow and so protection against scour is maximised through inclusion of the apron. Refer to Standard Drawings 1179, 1248, 1179, 1303, 1304, 1305 and 1306 (QDMR 2009b). For more information on wingwall requirements, refer to Section 9.15, Addition 2.

Cut-off walls in the form of a vertical wall constructed below the end, or outside edge, of the apron of a culvert must always be provided at culvert inlets and outlets to prevent undermining and piping failure. For corrugated metal pipe culverts, the cut-off walls also act to counteract uplift at the culvert inlet. If ground conditions upstream of a culvert are non-erosive, consideration may be given to omitting the cut-off wall at the inlet, but this is not recommended.

Use of pre-cast end/headwalls must comply with the department's Standard Drawing 1243 and Technical Note TN27 – *Guidelines for Design of Precast Culvert and Pipe Headwalls*.

An important aspect that designers must check for is the occurrence of a hydraulic jump in the inlet of the culvert. Supercritical flows in the existing channel, at the site of a proposed culvert, will be forced back to subcritical flow by the presence of the culvert. This will force a jump at the culvert entrance which can:

- cause erosion about the inlet if not adequately protected
- affect the hydraulic design of the culvert due to the turbulence.

If this is the case, it is recommended to force the jump to occur some distance upstream of the culvert (by placing a hump across the stream bed), so that the energy and turbulence can dissipate before arriving at the culvert.

9.19 Managing sediment

Sediment deposits within culverts, especially multi-cell culverts, can cause significant operational and maintenance problems.

Occasionally sediment traps (basins) are constructed upstream of culverts. In these cases, an access ramp for maintenance must be provided to allow de-silting of the trap.

In critical areas, or for long culverts where maintenance is extremely difficult, a small sediment trap/weir can be constructed at the inlet to divert low flows to just one or two culvert cells. This will allow the flow to enter the remaining cells only during high flows.

These sediment weirs should be designed to be fully drowned during major flood events, so that no adverse backwater effects occur.

9.20 Safety

9.20.1 Culverts used as walkways and bikeways

Provision for pedestrians and cyclists can be made in sizing a waterway culvert. However, in order to be effective, the approach ramps must allow clear vision through the culvert cell.

It should also be kept in mind that pedestrians will often prefer to cross over a road than under it for reasons of security.

9.20.2 Barriers to flow

9.20.2.1 Trafficability considerations

Consideration needs to be given to the desired trafficability of the road during overtopping flood flows.

Raised median strips can result in traffic movement only on one side of the road during overtopping flows. In critical flood control areas, it may be necessary to use a painted median.

Raised kerbs or pedestrian pathways on the downstream side of a road can cause ponding to occur across the full width of the road, thus reducing trafficability in both directions during flood events.

9.20.2.2 Traffic safety barriers

Median traffic barriers, such as the GM Barrier, can significantly interfere with the passage of overtopping flood flows and the migration of terrestrial wildlife across the road.

If these barriers are likely to interfere with flood waters or terrestrial movement, then the road layout should be designed to avoid the need for such barriers, subject to satisfying safety requirements for road users.

9.20.2.3 Noise fencing

Noise control fencing must allow for the free passage of overtopping flood flows in most cases. Even where culverts have been designed with a large capacity (such as 2% AEP event or ≈ 50-year ARI event), consideration of the impacts of the fence on overtopping flow is also required.

9.20.3 Additional safety considerations

Section 2.2 and 2.7.4 of the Austroads *Guide to Road Design* – Part 5 are accepted for this section. Consideration should also be given to Section 2.7.1 of the Austroads *Guide to Road Design* – Part 5.

9.21 Designing for resilience

Resilience is the ability to survive a disaster event and return to a state of acceptable operating condition quickly after the event. A key objective of the department is to improve the resilience of Queensland's road and transport infrastructure where experience has demonstrated that past flooding events have resulted in significant damage.

9.21.1 Specific design criteria for downstream protection of road embankments at culverts

Downstream scour due to overtopping of road embankments at culvert locations represents a high potential for scour of the road embankment. This can result in removal of the material supporting the culvert.

This advice applies to road embankments with flood immunity less than AEP 2% (50-year ARI).

Whole-of-life cost considerations can be used to determine if these improvements to resilience are justified.

If the height of the embankment is less than 500 mm, downstream slope protection is not needed unless there is a history of scour.

Slope protection for culverts is to be in accordance with the following:

- maximum slope of downstream batter is 1 (vertical) to 3 (horizontal)
- all shoulders shall be sealed
- all headwalls must be permanently physically attached to the culvert even after scour
- the headwall, apron and cut-off wall shall be integral
- minimum depth of cut-off wall of 450 mm
- use of pre-cast end/headwalls must comply with the department's Standard Drawing 1243 and Technical Note TN27 – *Guidelines for Design of Precast Culvert and Pipe Headwalls*. Precast ends to culverts must have cut-off walls
- the downstream embankment face adjacent to a culvert shall be protected with either grouted rock, reinforced concrete or wire mattress (except where protecting sand or non-cohesive material). Note that where wire mattresses are proposed for the protection of non-cohesive embankment materials, proper filter protection, such as geotextile, shall be designed and installed behind the wire mattresses
- all downstream batter protection shall extend to at least the toe of the batter and tie into a cut-off wall of at least 450 mm in depth

- for culverts with a drop less than 2 metres, vegetation may be used if it remains lush and thick for the entire year (typically coastal areas)
- for culverts, batter protection on the downstream side of the road embankment shall extend along the carriageway past the culvert (in both directions) for a distance twice the height of the road embankment or channel width (whichever is the greater).

The Pavement and Structures sections, Engineering and Technology Branch can provide further advice on batter protection.

9.22 Worked examples

Section 3.15 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

9A Appendix: Design form

Figure 9A – Design form

PROJECT:	**Designer:** **Checker / Reviewer:** **Date:**	**Sheet ___ of ___**

HYDROLOGICAL AND DESIGN INFORMATION

Q_1 = ____________ m³/s - ARI ___ yrs TW_1 = ________ m

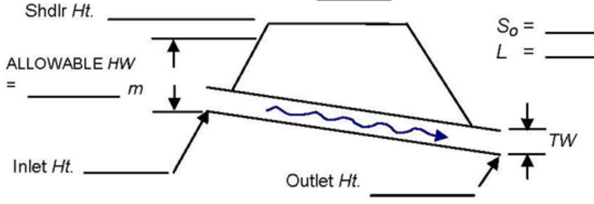
Q_2 = ____________ m³/s - ARI ___ yrs TW_2 = ________ m

Q_3 = ____________ m³/s - ARI ___ yrs

TW_3 = ________ m

Extreme Event Check

SKETCH



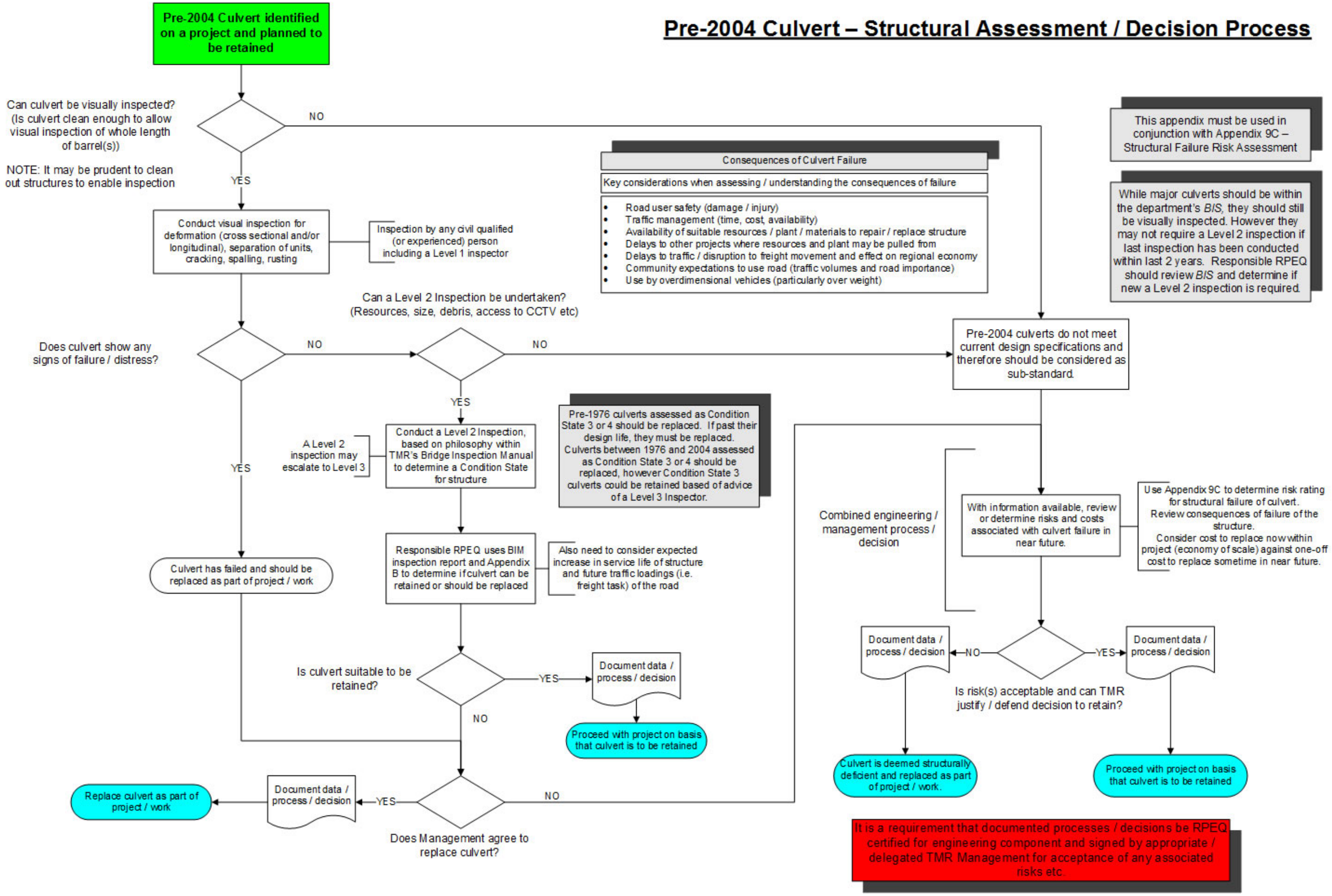
MAXIMUM ALLOWABLE STREAM VELOCITY (V_{max})= ________ m/s

CULVERT DESCRIPTION	Q per Cell ------ Q/B Ratio	Size *D or Ht*	**HEADWATER COMPUTATION** INLET CONT. $\frac{HW}{D}$	HW_i (1)	OUTLET CONTROL k_e	H	d_c	$\frac{d_c + D}{2}$ (2)	TW (3)	h_o	LS_o	HW_o (4)	CONTROLLING HEADWATER	OUTLET VELOCITY (V_o)	Comments (incl. check of Froude No. & *AHW*)
Levee/block: Energy Dissipator:			Figs 9B.1 - 9B.4	HW_i=HW/D x D	Table 9.10.2	Figs 9B.5 - 9B.10	Figs 9B.13 - 9B.15			If $TW > D$, then h_o = TW. Otherwise h_o is greater of (2) & (3)	Length x Slope	HW_o=H + h_o - LS_o	Greater of (1) & (4)	Average outlet velocity: V_o=Q/A. Refer Sect. 9.11.9 When inlet control: Use Figs 9B.11 & 9B.12 to determine part full area for pipes. For boxes, use Manning's to determine normal depth. When outlet control: Depth of flow based on *D*, d_c or *TW* as appropriate.	

Summary and Recommendations:

9B Appendix: Structural assessment/decision process

Figure 9B – Pre-2004 culvert – structural assessment/decision process



9C Appendix: Structural failure risk assessment

General

This appendix assesses the risk (probability) of structural failure in simple terms.

Culverts are categorised as either a 'major culvert' or a 'minor culvert'. Major culverts are defined within the department's *Bridge Inspection Manual* (BIM). These structures are currently inspected on a regular basis with records stored in the department's Bridge Information System (BIS). All other culverts are deemed minor culverts.

Link slab box culverts, cast-in-situ culverts and arch culverts are not covered by this Appendix and assessing risk of structural failure requires specialist advice.

Risk assessment – major culverts

For major culverts, a risk assessment can be undertaken using the 'Whichbridge' component within the BIS.

Table 9C.1 – Risk rating – major

Score	Risk	Recommended action
1500+	High	Replace structure
751 – 1500	Medium	Monitor structure
0 – 750	Low	No action required at this stage

Risk assessment – minor culverts

Risk of structural failure for minor culverts (under critical loading/cover is ≤ 2 m) is a function of:

- W – maximum horizontal dimension of a culvert (such as nominal diameter for circular culverts, nominal span width for box culverts)
- C – depth of cover which is defined as the minimum depth of material (under outer wheel path) from the road surface to top surface of culvert.

Note: When cover exceeds two metres, inspection is still required, but specialist advice is required.

Assessment method is same for both single cell and multi-cell structures.

Table 9C.2 – Risk rating – W = 375 to 600 mm

Assessment criteria	Risk	Recommended action
When C is ≤ 600 mm	High	Replace structure
All other situations	Low	No action required

Table 9C.3 – Risk rating – W = 675 to 1200 mm

Assessment criteria	Risk	Recommended action
When C is ≤ 600 mm	High	Replace structure
When C is between 600 mm and W	Medium	Monitor structure
When C is ≥ W	Low	No action required

*Table 9C.4 – Risk rating – W = 1350 to 1800 mm**

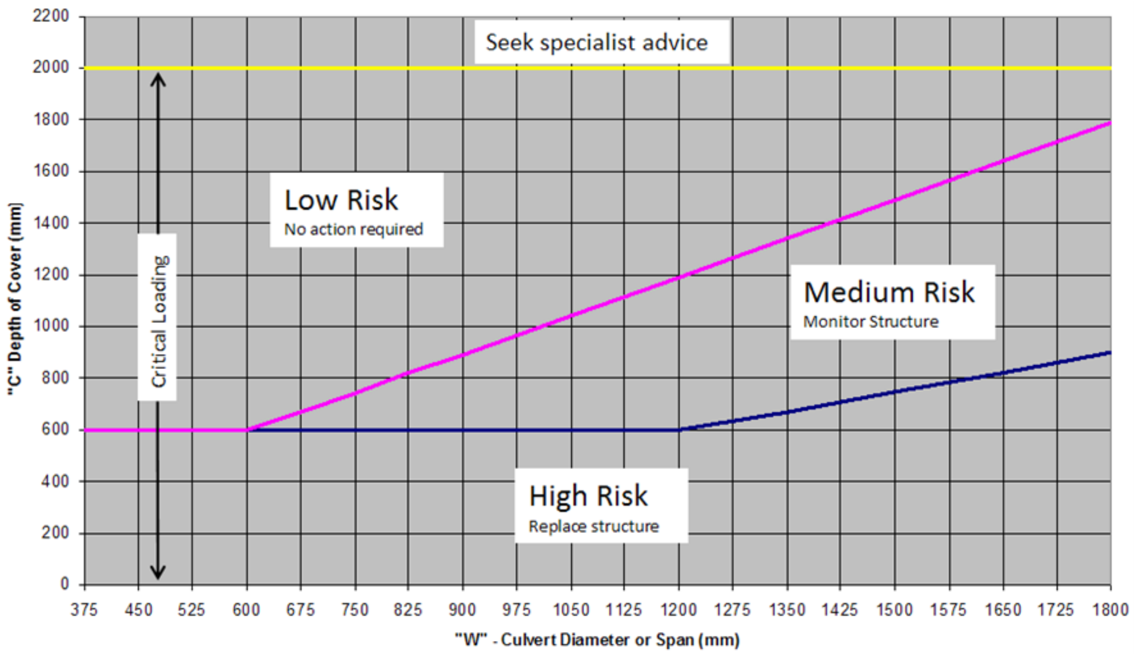
Assessment criteria	Risk	Recommended action
When C is ≤ W/2	High	Replace structure
When C is between W/2 and W	Medium	Monitor structure
When C is ≥ W	Low	No action required

Notes:

*RCBCs greater than 1800 mm (in width) but less than 3.0 m² in waterway area are to be included.

These risk rating tables are combined and shown diagrammatically in Figure 9C(a).

Figure 9C(a) – Structural risk assessment – minor culverts



9D Appendix: Culvert wingwall length calculations

Table 9D.1 – Culvert description and symbols

Description	Symbol
Internal diameter of a pipe culvert or internal height of a box culvert	D
Thickness of pipe or box culvert	T1
External diameter of pipe culvert or external height of box culvert	D2
Skew angle	φ
Wingwall angle 1	α
Wingwall angle 2	β
Batter slope	1 on S
Headwall thickness (typical value is 300mm)	T2

Wingwall angles and lengths are shown in Figure 9D. The following steps are a guide for calculating the lengths of W1 and W2.

1. Calculate the culvert height.

Culvert height = D+T1

2. Find the horizontal distance of W1 perpendicular to the road alignment using the batter slope, refer to Figure 9D *Side Elevation – Wingwall.*

W1 horizontal distance perpendicular to the road = (D+T1)×S - T2

3. Find the horizontal distance of W2 perpendicular to the road alignment using the batter slope, refer to Figure 9D *Side Elevation – Wingwall.*

W2 horizontal distance perpendicular to the road = (D+T1)×S – T2 – (D2 – T1) sin Ø

4. For square culverts adjust W1 and W2 angles using the Figure 9D *Wingwall Angles – Skew Culvert.*

W1 angle = Skew angle + α from the table of angles

W2 angle = skew angle - β from the table of angles

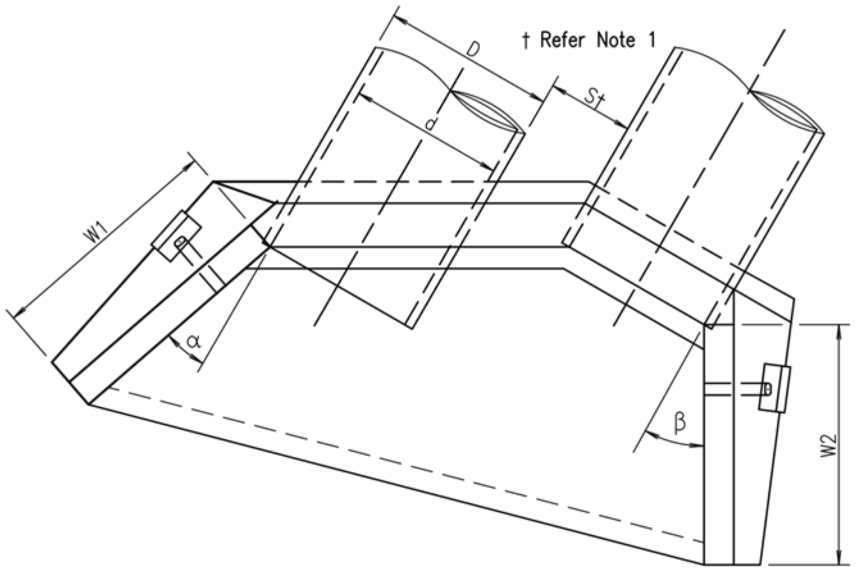
5. Calculate W1.

W1 = [(D+T1)×S-T2]÷Cos (Ø+∝)

6. For skew culverts, adjust the initial perpendicular calculation of W2 for the offset created by the part of the headwall that is square to the culvert cell. Check that is at least 1.5 x the culvert height. If 1.5 x (D+T1) is greater than the above horizontal distance, then choose 1.5 x (D+T1) as the horizontal distance. Calculate W2.

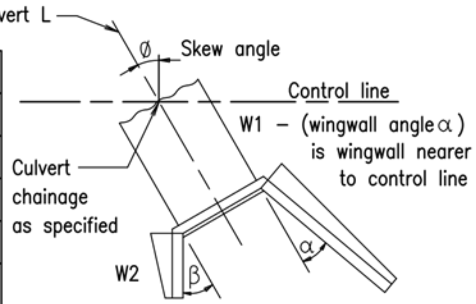
$$W2 = \frac{Horizontal\ distance\ from\ above}{\cos(\emptyset - \beta)}$$

Figure 9D – Culvert wingwall length calculations

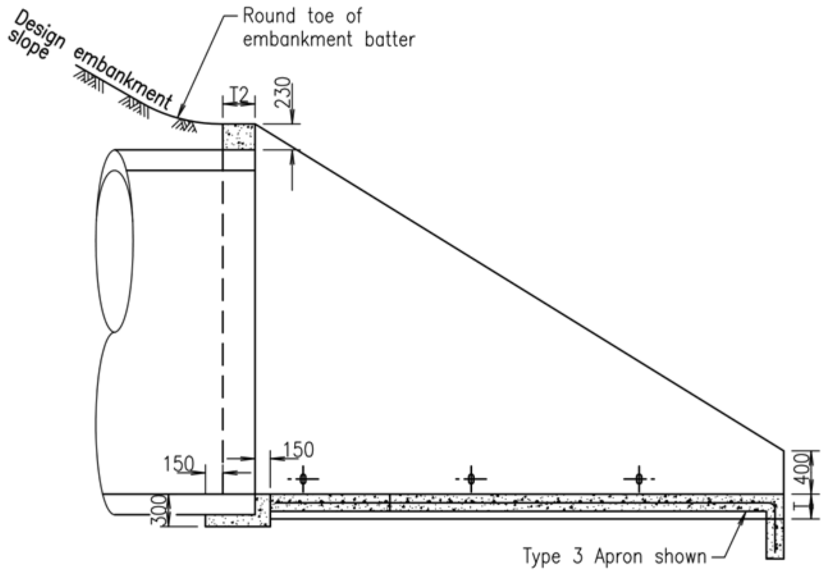


PLAN – MULTIPLE SKEW CULVERT

Skew angle/Ø	Wingwall angle α	Wingwall angle β
0 – 10	30	30
11 – 20	25	30
21 – 30	20	30
31 – 45	15	30



WINGWALL ANGLES – SKEW CULVERT
Not to scale



SIDE ELEVATION – WINGWALL

10 Floodway design

10.1 Introduction

Section 4.1 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section subject to the following amendments.

Addition(s)

1. Floodways are sections of roads which have been designed to be overtopped by floodwater. An example of a flood is shown in Figure 10.1.

Figure 10.1 – Little Annan River floodway

These overtopping floods usually have a 5% Annual Exceedance Probability (AEP) or higher (Average Recurrence Interval (ARI) 20-years or lower), but any crossing can be designed as a floodway. The *Manual of Uniform Traffic Control Devices* (QG 2003) describes floodways as sections of road over which water may flow for short periods in times of flood but the road remains trafficable with care.

Chapter 2 outlines many factors which should be considered before deciding on the design flood immunity for new road works.

10.2 Additional considerations

Section 4.2.1 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section subject to the following amendments.

Addition(s)

1. Floodways may offer environmental advantages over culverts or bridges, since they will tend to spread flows more widely. This means that the risk of scour to waterway and surrounding land is generally reduced because flow is less concentrated.

10.3 Geometric and safety issues

Section 4.2.2 of the Austroads Guide to Road Design – Part 5B is accepted for this section subject to the following amendments.

Addition(s)

1. Exceptions to the level grading in Queensland occur where bridges have been built significantly higher than the flooded approaches on both sides. The bridges have been built on the basis that the approaches will be raised sometime in the future.
2. For further geometric requirements of width, crossfall, vertical and horizontal alignment, refer to the relevant chapters of the department's *Road Planning and Design Manual*. Signage of the floodway is also important and designers are referred to the latest release of the *Manual of Uniform Traffic Control Devices* (QG 2003) for warrants/guidance.

10.4 Environmental factors

Section 4.2.3 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

10.5 Hydraulic design

10.5.1 Floodway terminology

Section 4.2.4 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

10.5.2 Flow over the road

Section 4.3.1 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

10.5.3 Full floodway design calculations

Section 4.3.2 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

10.6 Time of submergence/closure

Section 4.4.1 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

10.6.1 Time of submergence

Section 4.4.2 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

10.6.2 Time of closure

Section 4.4.3 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

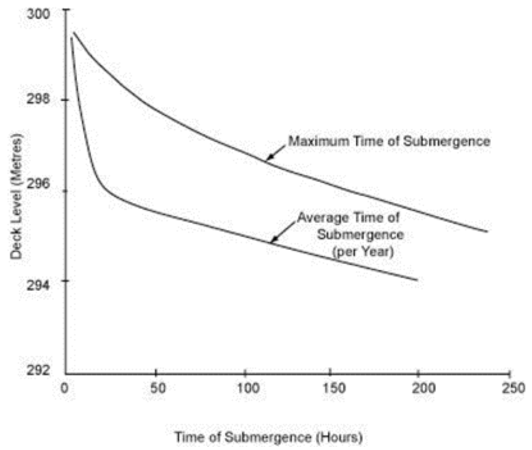
10.6.3 Issues related to times

Section 4.4.4 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section subject to the following amendments.

Addition(s)

1. Average time of submergence or closure may be assessed for a range of selected grade levels and a plot of average time of submergence against level may be produced as in Figure 10.6.3.

Figure 10.6.3 – Typical deck level/time of submergence relationship



In many cases, the plot will reveal a particular grade level above which a relatively large increase in level will result in only a small decrease in time of submergence, and a small reduction in level results in a large increase in average time of submergence. Such a level may be selected as a starting point for economic analysis.

10.6.4 Calculation of time of submergence or closure

Section 4.4.5 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

10.6.5 Procedure for estimating AATOC/AATOS

Section 4.4.6 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section subject to the following amendments.

Addition(s)

1. Refer to Appendix 10A for example AATOC/AATOS calculations.

10.7 Floodway protection

10.7.1 Types of protection

Section 4.5.1 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

10.7.2 Floodways with grassed batters

Section 4.5.2 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

10.7.3 Floodways with other than grassed batters

Section 4.5.3 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

10.8 Worked examples

Section 4.6 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

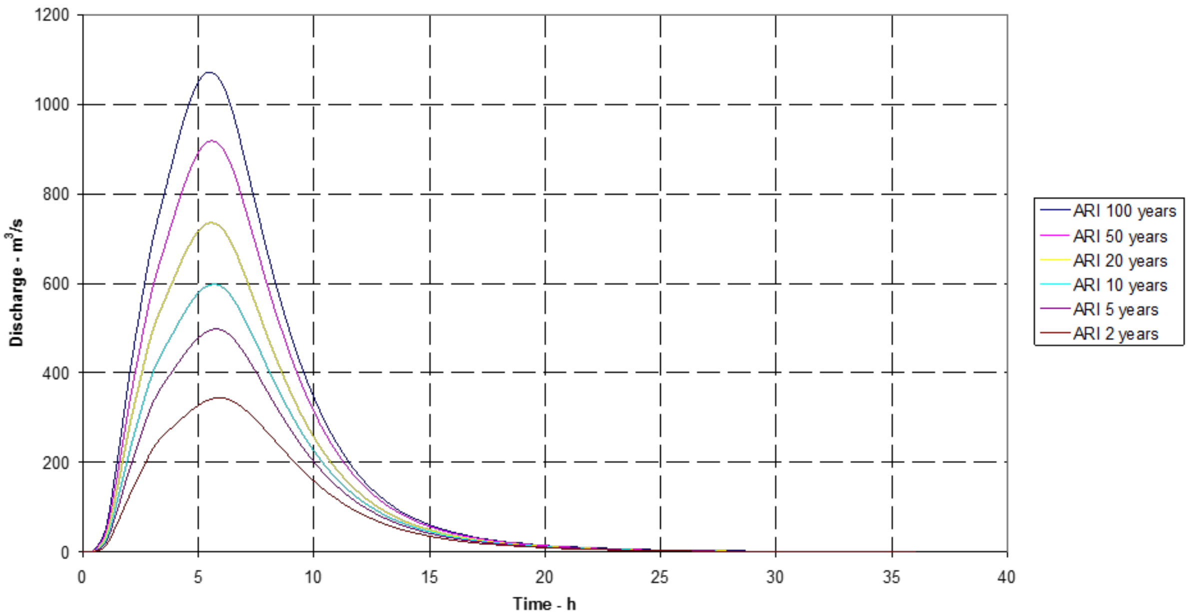
10A Appendix: Worked examples

AATOC examples

The design floods have been calculated for the bridge for a range of probabilities. In this case, the bridge is overtopped for a flood with a discharge of 400 m³/s, so has a flood immunity of approximately Exceedances per Year (EY) 0.33 (ARI 3-years).

The design floods are plotted in Figure 10A(a).

Figure 10A(a) – Plotted design floods



The times of submergence are listed in Table 10A.1

Table 10A.1 – Times of submergence

ARI – years	TOS – hours
2	0.0
5	4.0
10	5.0
20	6.0
50	7.0
100	7.5

The average annual times of submergence (AATOS) are calculated as shown in Table 10A.2, assuming that the time of submergence for the PMF is 12 hours.

Table 10A.2 – Average annual times of submergence

ART (years)	ToS (hours)	FT(t)	fT(T)	Area	Area*ToS
2	0	0.500			
3	0	0.667			
5	4	0.800	0.033	0.133	0.267
10	5	0.900	0.100	0.100	0.450
20	6	0.950	0.050	0.050	0.275
50	7	0.980	0.030	0.030	0.195
100	7.5	0.990	0.020	0.010	0.073
1E+99	12	1.000	0.002	0.010	0.098
				AATOS	1.357

End of example

11 Road surface and subsurface drainage design

11.1 Introduction

Road surface drainage deals with the drainage of stormwater runoff from the road surface and the surfaces adjacent to the road formation. Several elements can be used to intercept or capture this runoff and facilitate its safe discharge to an appropriate receiving location. These elements include:

- kerb and channel
- edge and median drainage
- table drains and blocks
- diversion drains and blocks
- batter drains
- catch drains and banks
- drainage pits
- pipe networks.

Subsurface drainage deals with the interception and disposal of subterranean (groundwater) flows with predominate drainage element being sub-soil drainage.

11.1.1 Road surface flows

After falling onto road surfaces, rainfall runoff drains to the lowest point and in moving across the road surface forms a layer of water of varying thickness. This water can be a hazard to the motorist. Splash and heavy spray are thrown up by moving vehicles, reducing visibility, while the water on the pavement reduces friction between the tyres and road surface.

Excessive water on the pavement, whether ponded or flowing, can represent a real risk of aquaplaning or the build-up of a layer of water between the vehicle tyre and the road surface, which leads to a total loss of grip. While part of road surface drainage, aquaplaning is a critically important aspect of road surface drainage and is discussed within its own section, Section 11.3.

On reaching the lowest point, runoff is channelled along the pavement edge via kerbing/kerb and channelling or discharged over the shoulders to a suitable collection system such as a natural watercourse, table drain or piped drainage system (pipe network).

Some degree of water quality treatment may be needed between the road and the receiving water to remove litter, heavy metals, nutrients and oils. In this regard, there is a growing trend to place some form of grass filter between the road surface and any concrete-lined drain. This form of drainage is known as ‘indirectly connected impervious surface area’ and is a form of water sensitive urban design (see Chapter 7).

In all cases, design of the elements for this runoff must adequately cater for the safety and convenience of road users, including pedestrians, and protect adjacent properties and the road pavement from damage.

Where erosion of the batters is not considered likely, pavement runoff discharged over the shoulders and batters directly to the natural surface may be acceptable in some rural situations such as a level stretch of road in flat country.

Where batter erosion is likely/possible, the use of a concrete or asphalt kerb/dyke should be investigated.

11.1.2 Subsurface flows

Section 8.1 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section subject to the following amendments.

Addition(s)

1. Further consideration should be given to the detailed recommendations in respect of design and installation of subsoil drains contained within Special Report No. 35 *Subsurface Drainage of Road Structures* (ARRB 1987).

11.2 Road surface drainage

11.2.1 Pavement runoff

Pavement runoff is calculated by the Rational Formula:

$Q_y = k.C_y.I_{tc,y}.A$ (refer to Chapter 5)

The contribution to the flow at the kerb or median channel is given by a modification of the Rational Formula and is expressed as:

$$q_y = \frac{C_y.I_{tc,y}.W}{3.6X10^6}$$

where q_v = *contribution per longitudinal metre of pavement (m³/s) for an ARI[1] of y years*

C_v= *runoff coefficient (dimensionless) for an ARI of y years (refer Chapter 5)*

$I_{tc,y}$= *average rainfall intensity (mm/h) for design duration of tc and ARI of y years (refer Chapter 5)*

W = *width of contributing cross-section (m)*

A runoff coefficient C50 of 0.95 (or higher) is typical for most road surfaces.

Where the pavement width varies or the runoff coefficient is different, then total runoffs or lengths for given runoffs have to be calculated algebraically.

11.2.2 Roadway flow width criteria.

For the safety of vehicular traffic other than requirements against aquaplaning, flow width criteria apply. Water depths and velocities are also limited by the width restrictions.

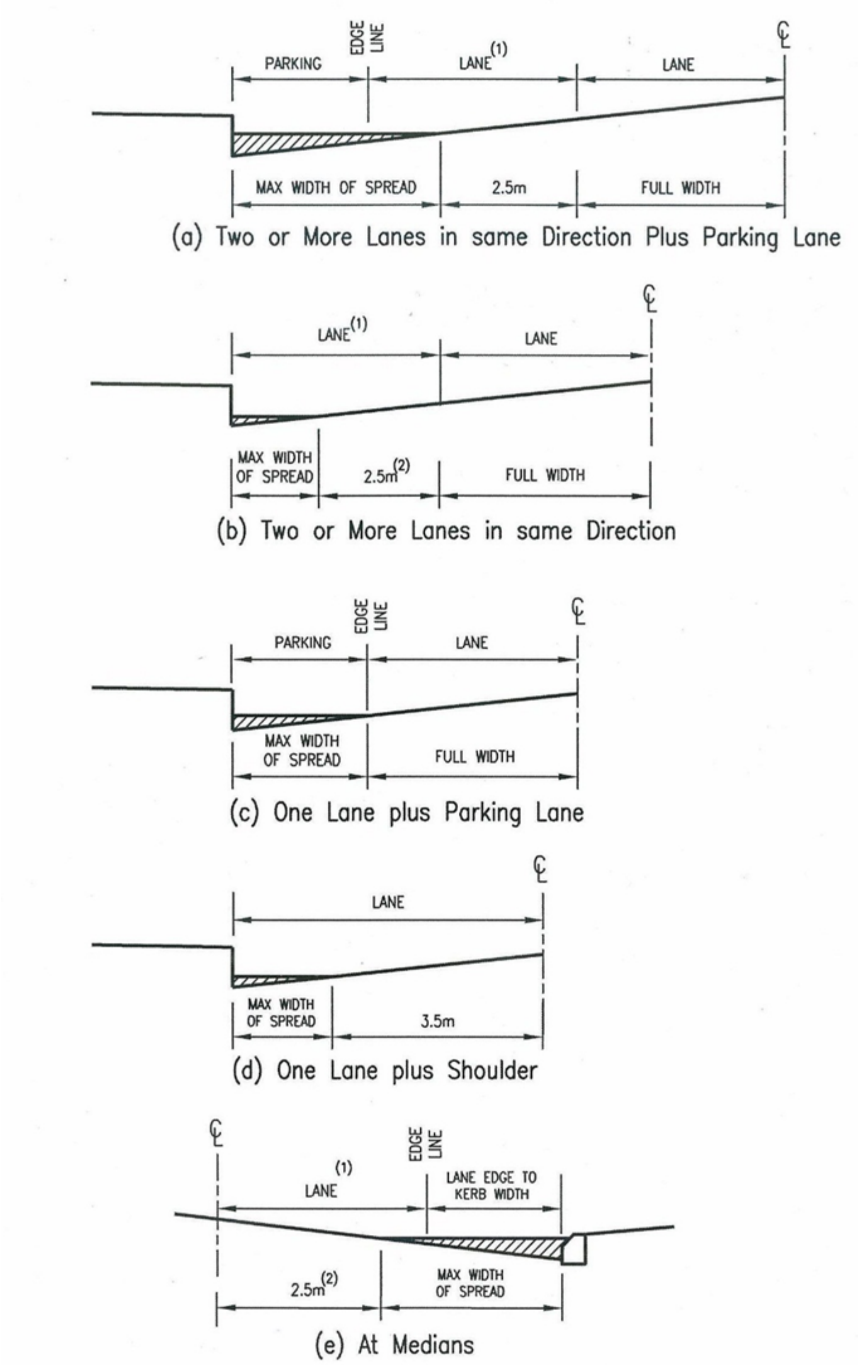
Flow widths in both the minor and major storms need to be considered.

[1] Use of the ARI terminology is retained in this instance as the Rational Method nomenclature was developed using this. The relationship between ARI and the departments preferred AEP terminology is explained in Chapter 2.

11.2.2.1 Minor storm flow limits

Adopting the 10% Annual Exceedance Probability (AEP) (≈ Average Recurrence Interval (ARI) 10-year) flood as that arising from the design minor storm of the same likelihood, flow width criteria are shown on Figures 11.2.2.1(a) and 11.2.2.1(b).

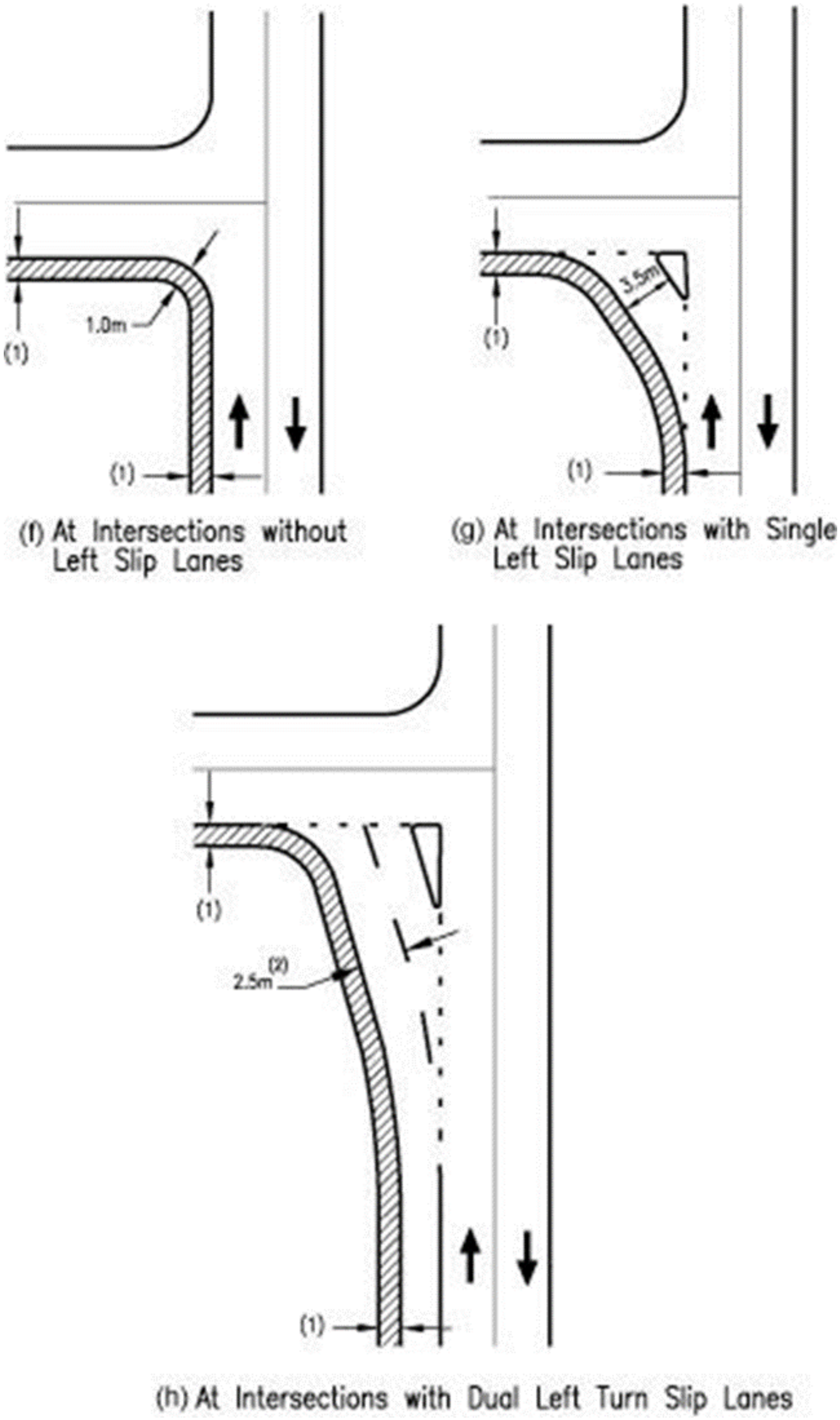
Figure 11.2.2.1(a) – Allowable flow widths on roadways –10% AEP (≈ ARI 10-year) flood (cross-section views)



Notes:

1. Lane includes auxiliary lanes and any parking lane that has the potential in the future to become used as a through lane for full- or part-time.
2. In situations where it is difficult to achieve the required clear width of 2.5 m, the clear width may be reduced to 1.0 m for roads of lesser importance (refer text in Section 11.2.2.1).

Figure 11.2.2.1(b) – Allowable flow widths on roadways – 10% AEP (≈ ARI 10-year) flood (plan views)



Notes:

1. Refer to Figure 11.2.2.1(a).
2. In situations where it is difficult to achieve the required clear width of 2.5 m, the clear width may be reduced to 1.0 m for roads of lesser importance (refer text in Section 11.2.2.1).
3. At pedestrian crossings check both width and velocity (refer text in Section 11.2.2.1).
4. See Section 11.2.2.2 for allowable widths in major storms.

These diagrams represent the following:

a) for two lanes (or more) in the same direction plus parking lane, the maximum allowable width of spread leaves the inside and any lane-locked lanes clear plus 2.5 m clear width in the remaining lane; that is, water is kept out of the wheel paths of lanes. The term ‘lane’ includes auxiliary lanes and any parking lane that has the potential to become used as a full or part-time through lane

b) for two lanes (or more) in the same direction, the maximum allowable width of spread leaves the inside and any lane-locked lanes clear plus 2.5 m clear width in the remaining lane. The term ‘lane’ includes auxiliary lanes

c) for one lane plus parking lane, water is not allowed to spread past the edge of the through lane

d) for one lane, a minimum clear width of 3.5 m is to remain in the lane

e) at medians, the allowable spread of water leaves 2.5 m clear width in the traffic lane next to the median. The term ‘lane’ includes auxiliary lanes

f) at intersections without left slip lanes, the allowable width of spread adjacent to the kerb is 1.0 m

g) at intersections with single left slip lanes, the allowable width of spread leaves 3.5 m clear width in the slip lane

h) at intersections with dual left slip lanes, the allowable width of spread leaves 2.5 m clear in outer turning lane.

In situations where it is difficult to achieve the required clear width of 2.5 m in cases ‘(b)’, ‘(e)’ and ‘(h)’ above, the clear width may be reduced to 1.0 m for roads of lesser importance. This practice is not recommended for reasons of consistency and the use of a reduced clear width must be specified in design brief and/or contract documents or approved by the department.

Where pedestrians will cross the road, allow no more than 0.45 m width of spread in a 1 Exceedances per Year (EY) (ARI 1-year) flood. The 0.45 m requirement is based on the typical overstep/short jump of most people. Checks should also be undertaken on the flow velocity. Where the risk of injury is reasonably foreseeable, velocities should be limited by:

$d_g.V_{avg} \leq 0.4$ m²/s

where d_g = *flow depth in the channel adjacent to the kerb (m)*

V_{avg} = *average velocity of the flow (m/s)*

There is also a water depth-velocity relationship which is applicable for both minor and major floods in the channel next to a kerb. This is for pedestrian safety in longitudinal flows along the kerb and is shown on Table 11.2.2.2.

11.2.2.2 Major storm flow limits

The major storm is usually of a 2% AEP (≈ ARI 50-years) to 1% AEP (ARI 100-years), depending on the local authority. The 1% AEP (ARI 100-years) flood should be used as a check flood at least to allow consideration of any detrimental effects.

Table 11.2.2.2 gives roadway flow limits for a major storm, with particular reference to floor levels of adjacent buildings, pedestrian and vehicle safety.

At sags in state-controlled roads, additional inlets and underground drainage should be provided, if necessary, to limit ponded water in a 2% AEP (≈ ARI 50-years) storm so that there is:

- one lane in each direction of travel, free of water, in a multi-lane road, or
- a width of 3.5 m clear of water down the centre of a two-lane road.

Table 11.2.2.2 – Roadway flow limitations – major storm

Situation	Roadway flow width and depth limitation
Where floor levels of adjacent buildings are above road level	Total flow contained within road reserve Peak water levels at least 300 mm below floor level of adjacent buildings (i.e. freeboard of at least 300 mm)
Where floor levels of adjacent buildings are less than 350 mm above top of kerb • where fall on footpath towards kerb is greater than 100 mm • where fall on footpath towards kerb is less than 100 mm Where no kerb is provided	Water depth to be limited to 50 mm above top of kerb Water depth to be limited to top of kerb in conjunction with a footpath profile that prevents flow from the roadway entering onto the adjacent property. Above depths shall be measured from the theoretical top of kerb
Pedestrian safety[#] a) no obvious danger b) obvious danger	$d_g V_{avg} \leq 0.6$ m²/s $d_g V_{avg} \leq 0.4$ m²/s
Vehicle safety	Maximum energy level of 300 mm above roadway surface for areas subject to transverse flow

Notes:

1. d_g = flow depth in the channel adjacent to the kerb, i.e. at the invert (m)
2. V_{avg} = average velocity of the flow (m/s)
3. [#] Obvious danger is interpreted as areas where pedestrians are directed to or most likely to cross water paths (such as marked crossings and corners of intersections).
4. Table aligns with requirements within *Queensland Urban Drainage Manual* QUDM (2008)

11.2.3 Kerb and channel flow

Section 5.5.1 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section with the following amendments.

Difference(s)

1. The Rational Method in the form of equation 14 as presented in Section 5.5.1 of the Austroads *Guide to Road Design* – Part 5A is not to be used for departmental projects. The pavement runoff is to be determined as per the guidance in Section 11.2.1 of this manual.

11.2.3.1 Kerb types and uses

Approved kerb types with channels are shown in Standard Drawing 1033 (DMR 2009). General kerb profiles or shapes are shown in Figure 11.2.3.1(a).

The use of a concrete or asphaltic concrete kerb at the edge of embankments, as shown in Figure 11.2.3.1(b), is justified if the material forming the embankment will be eroded by flow off the pavement or if, for property protection, it is necessary to restrict runoff to particular locations. Temporary protection must be provided until the slope is completely stabilised by grass.

The criteria for flow in the roadway due to shoulder kerb treatment are as per Section 11.2.2. Flow calculations are by the same method as Section 11.2.3.

The actual dimensions of a shoulder kerb will be job-specific. Installation of a shoulder kerb/dyke could be a danger to vehicles running off the side of the carriageway. If safety is compromised, other forms of erosion protection control will have to be considered.

Figure 11.2.3.1(a) – General kerb profiles or shapes

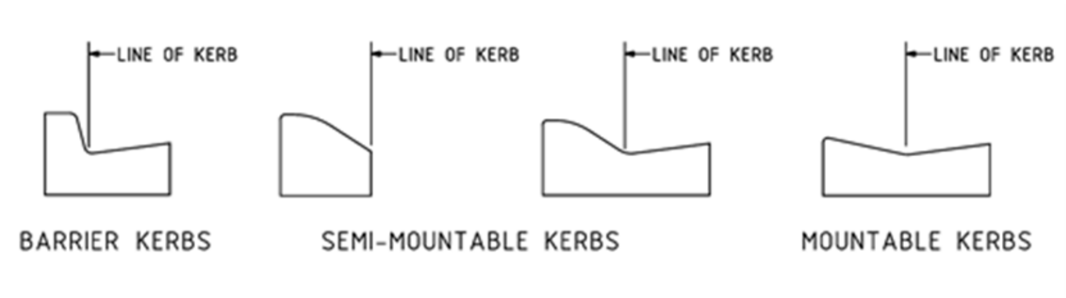
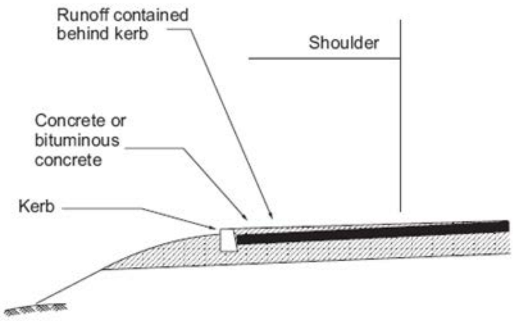


Figure 11.2.3.1(b) – Edge treatment at erodible slopes



11.2.4 Edge and median drainage

In choosing the type of channel to be adopted, consideration should be given to the following factors:

- Capacity: The channel should have adequate capacity for the design flow.
- Erosion: Erosion control is a necessary part of good drainage design. Scour may occur unless the channel is protected where velocities exceed those likely to cause erosion to the material forming the channel. Erosion control involves the selection of a suitable and economical channel lining (including vegetative cover), which will give the desired protection.

For further information on erosion control see Chapters 7, 8 and 13. The type of lining should be consistent with the degree of protection required, overall cost, including maintenance, safety requirements and aesthetic considerations. Erosion control in the form of grass growth may be used in combination with other types of lining. A channel may be grass-lined on the flatter slopes and lined with more resistant material on the steeper slopes.

- Maintenance: Without proper maintenance, a well-designed channel becomes unsightly and will perform unsatisfactorily at the design flow. Maintenance methods should be considered in the design of drainage channels so that the type of channel section adopted will be suitable for the methods and equipment that will be used for maintenance.

For example, in the majority of cases, a concrete invert should be considered for ‘V’-shaped channels because of the difficulty in maintaining the section with the maintenance machinery available. On grades less than 1.5% and for most cross-sections, a concrete invert is essential in assisting the discharge of low flow. Maintenance operations are extremely difficult with saturated conditions in the vicinity of an unlined invert.

11.2.4.1 Design of edge and median drainage

Section 2.12.1 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section subject to the following amendments.

Addition(s)

1. The pavement runoff is calculated using the Rational Method Formula (refer Section 11.2.1), but consideration must be given to the different runoff coefficients for pavement and the median surfaces.

11.2.5 Table drains and table drain blocks

Section 2.13 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

11.2.5.1 Table drains

Section 2.13.1 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section with the following amendments.

Addition(s)

1. Designers must check the hydraulic characteristics of flows in table drains for the design conditions. This is to ensure that sufficient capacity is provided and the table drain is not susceptible to erosion. Determination of depth and velocity of flow within the table drain can be undertaken using Manning’s Equation.

11.2.5.2 Table drain blocks

Section 2.13.2 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section, subject to the following amendments.

Addition(s)

1. A marker post (refer Standard Drawing 1358 (DMR 2009)) should be placed on/adjacent to table drain blocks to alert maintenance personnel of their existence.

11.2.5.3 Adjoining projects

Another important design aspect regarding table drains is where new and previous projects join. The impacts of discharge from one project to the next must be considered/incorporated. The shape and grade of adjoining table drains should also match. Where the shape and grade do not match, a suitable transition or other mitigating treatment must be designed to ensure that scour does not occur and/or that stormwater does not flow out onto the road surface.

11.2.6 Diversion drains and diversion blocks

Section 2.13.3 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

11.2.7 Batter drains

Section 2.14 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

11.2.7.1 Design procedure

Section 2.14.1 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

11.2.7.2 Design notes

Section 2.14.1 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

11.2.8 Catch drains and catch banks

Section 2.15.1 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section subject to the following amendments.

Addition(s)

1. These devices are generally located no closer than 2.0 m from the edge of the cuttings in order to minimise possible undercutting of the top of the batter.

11.2.8.1 Design procedure for catch drains

Section 2.15.3 of the Austroads *Guide to Road Design* – Part 5B is accepted for this section.

11.2.9 Road batter stabilisation

An integral part of surface drainage is the design of erosion control measures to the finished surfaces.

The downstream face of an elevated road embankment across a floodplain will need to be protected from the erosive forces that occur during overtopping. The extent of this protection will depend on the expected tailwater level at the commencement of overtopping (refer Chapter 10).

Some roads are designed to be overtopped and the erosive potential is not as severe as those for floodways. Rather than overtopping, rainfall, wind and runoff from the top of the road formation (unless kerbs are in place) are the key agents for erosion.

Designers need to develop and assess options and determine the most suitable solution for the situation.

The types of protection measures available for consideration are:

- revegetation
- biodegradable blankets in association with permanent revegetation (the relevant specification is MRTS16 *Landscape and Revegetation Works* October 2014 (TMR 2014c))
- chemical surface stabilisers and soil/cement treatment (the relevant specifications are MRTS03 (TMR 2015b) and MRTS16 (TMR 2014c))
- bank protection techniques commonly associated with bridge abutments (relevant standards are MRTS03 (TMR 2015b) and MRTS16 (TMR 2014c) and Standard Drawings 1540, 1541, 1542, 1543, 1544, 1545 and 1548 (DMR 2009), which also shows other types of protection for bridge abutments))
- benching to create permanent drainage lines to reduce surface drainage (relevant specifications are MRTS03 (TMR 2015b), MRTS04 *General Earthworks* October 2014 (TMR 2014d) and MRTS16 (TMR 2014c))

- kerbs at the top edges of the road formations diverting runoff from rainfall on the pavement and shoulders to batter chutes (relevant standards are MRTS03 (TMR 2015b) and Standard Drawing 1033 (DMR 2009))
- catch drains and catch banks used to divert water to batter chutes or completely away from the batter slope (relevant standards are specifications MRTS03 (TMR 2015b) and MRTS16 (TMR 2014c) and Standard Drawing 1178 (DMR 2009))
- proprietary batter chutes.

11.2.10 Drainage pits

Drainage pits are field inlets and gullies collecting surface flows to the underground drainage system and access chambers at pipe junctions and for maintenance.

Inlet locations should be optimised to collect the design surface flows with the minimum number of installations and, of course, to reduce surface water to an acceptable width.

This requires computations for each area contributing flow to the inlets. Areas may comprise both road pavement and adjacent urban, suburban or rural land.

Proprietary pre-cast pit segments and grates or covers are available. The department has standardised some of the more common field inlets, gullies and access chambers as Standard Drawings Nos. 1307, 1308, 1309, 1310, 1311, 1312, 1313, 1321, 1322, 1442, 1443, 1444, 1445 and 1561 (DMR 2009).

Four types of kerb inlets are in common use, they are:

- grate only, such as field inlets and anti-ponding gullies on kerb returns
- side inlet – these inlets rely on the ability of the opening under the backstone or lintel to capture flow. They are usually depressed at the invert of the channel to improve capture capacity
- combination grate and side inlet – these inlets use the backstone arrangement of the side inlet with the added capacity of a grate in the channel
- special site-specific designs for high inflow.

The capacity of the various categories of drainage inlet may be varied by the amount of depression allowed in the gutter adjacent to the kerb opening.

A flush inlet is one in which the normal channel section is continued to and past the inlet without any alteration to its cross-section.

A depressed inlet is one in which the crossfall of the channel is increased, so that the grade of the channel line against the kerb is depressed for the length of the inlet. Depressed inlets provide greater efficiency than flush ones and are shown on the standard drawings with suitable transitions.

All pits should be as shallow as practical. As indicated on standard drawings, pits deeper than 3 metres will require a special design.

This manual does not include inflow capacity charts for drainage pit/kerb inlets. Charts approved for use on departmental projects are:

- Brisbane City Council charts, available from Council's website
- Max Q™ charts for Drainway and Stormway products, available from Max Q™ and as printed in Volume 2 of QUDM (2013).

It is understood that there are pit/kerb inlet configurations currently available that do not exactly match any of the configurations as presented in the approved charts. In these situations, the designer can use engineering judgement and first principles to match, as close as possible, an approved inflow capacity chart to the proposed pit/kerb inlet (citing: opening area, grade, crossfall and approach flow); however, the selected chart must be accepted/approved by the department's design representative before use.

Charts for other configurations/types of pits may become available in the future. Such charts should reflect the theoretical or measured capacity of the inlet. Before use on departmental projects, the supplier of the charts must have them independently tested/verified and then submit them (including verification) for approval to the Director (Road Design), Engineering and Technology Branch.

11.2.10.1 Provision for blockage

Section 5.5.3 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section.

11.2.10.2 Kerb inlets in roads

Section 5.3.4 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section with the following amendments.

Addition(s)

1. Kerb or gully inlets are used where vehicular traffic is expected to reduce the flow width on roadways as well as to drain low lying areas.

   The standard departmental Concrete Gullies shown on Standard Drawings Nos. 1311 and 1312 (DMR 2009) have a combined inlet with a precast side entry (lintel) and grated pit. Precast lintel details are shown on Standard Drawing No. 1313 (DMR 2009).

2. Additional locations where drainage inlets should be provided/considered in kerb and channel.

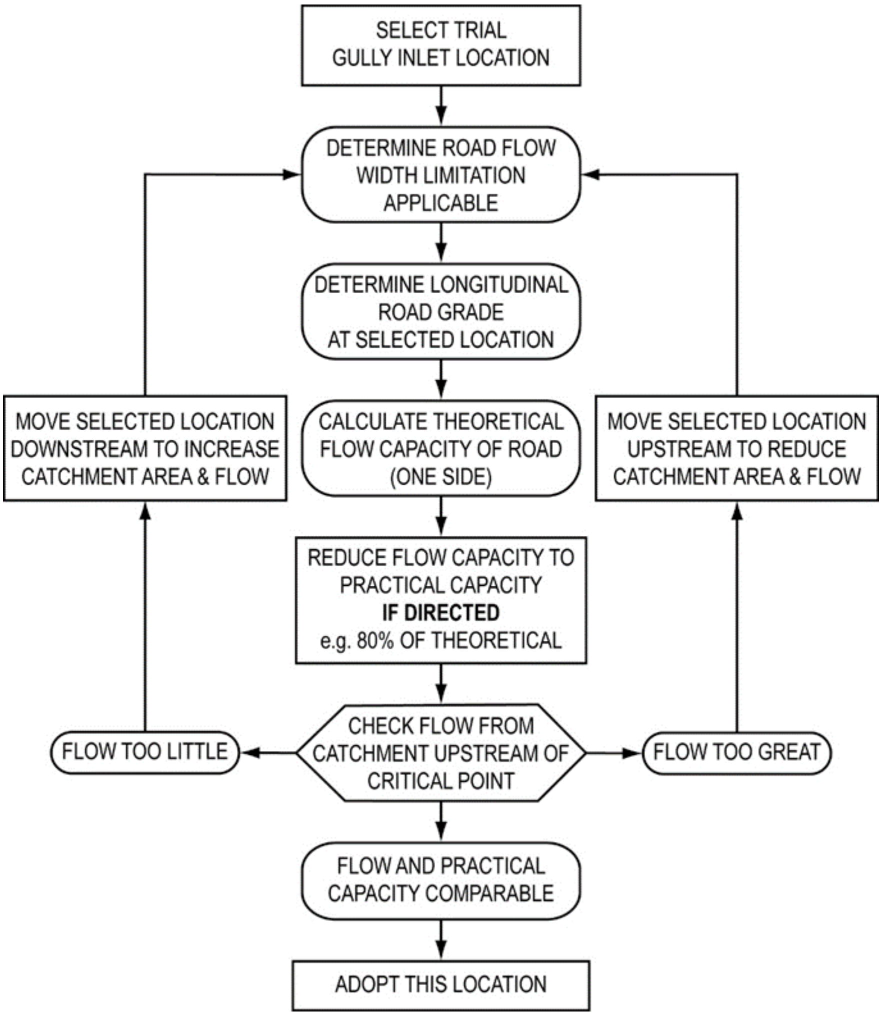
- At the tangent point of kerb returns or small radius convex curves (kerb radius less than 15 m) such that the flow width around the kerb return (that is, beyond the kerb inlet) during the minor design storm does not exceed 1.0 m measured from the invert of kerb and channel. This limitation will also be applicable at important vehicular turnouts or footpath crossovers where high traffic volumes are anticipated, such as at entrances to shopping centres.
- Immediately upstream of a potential pedestrian crossing, set-down point and/or bus stop, such that the flow width does not exceed 450 mm from invert of kerb and channel during the minor design storm.
- Immediately upstream of any reversal of crossfall (for example, application of superelevation) to prevent flow across the road during the minor design storm. The extent to which such flow onto the pavement is permissible depends upon the catchment area involved and the risk of vehicle aquaplaning. The question of aquaplaning is addressed in Section 11.3.

- Where superelevation or reverse crossfall results in flow against traffic islands and medians, kerb inlets shall be provided along the length of the island or median as necessary to meet the flow width limitations as stated in Section 11.2.2 and at the downstream end of the island or median to minimise the flow continuing along the road. Where sufficient width of island or median is available, grated kerb inlets should be recessed so that the grate does not project onto the road pavement. Alternatively side entry inlets with no grate should be installed.
- Where it is anticipated that a parking lane may become an acceleration, deceleration or turn lane in accordance with Section 11.2.2.
- Consideration should be given to the positioning of kerb inlets relative to the side property boundaries. In residential and industrial locations, a kerb inlet located near the side property boundary may cause difficulties with driveway access. In commercial areas, and those where there is likely to be a high volume of pedestrian traffic, kerb inlets should be located to avoid set down points or locations where pedestrian movements are likely to be highest.
- On any higher abutment end of bridge approaches on a grade to minimise flow on to the deck.

3. For kerb inlets on grade.

- Where bypass flow from a kerb inlet is required to follow a kerb return at an intersection, it may be necessary, where the longitudinal grade is steep, to check for the effect of superelevation upon flow spread. A procedure for the calculation of superelevation is given in Chapter 8.
- The procedure detailed in Figure 11.2.10.2 is recommended for determining the location of kerb inlets on grade.

Figure 11.2.10.2 – Procedure to determine kerb inlet positions on grade



Source: QUDM (2013)

Notes:

1. Changes in catchment area may result in changes in time of concentration for a catchment.
2. This procedure is iterative.
3. Selection of the initial trial kerb inlet location may be based on changes in road grade (such as steep to flat), physical restrictions in road (such as median or residential street management devices), or by driveways, entrances or intersections, and so on.

11.2.10.3 Opening size for kerb inlets

Drainage pit inlets can present an important safety issue that designers must consider. Considerable debate exists regarding the recommended maximum clear opening for kerb inlets to provide safety for small children. Even though past history has shown the 'likelihood' to be low, the 'consequences' of a child being swept down a flooded kerb and into a stormwater inlet can be extreme.

After consideration of the various arguments presented to the QUDM Reference Group during the development of the 2008 release of QUDM, the recommendation for 125 mm maximum clear opening was accepted. The Department of Transport and Main Roads also accepts this recommendation. It should be noted the 125 mm opening still presents a risk of a small child partially entering (that is, feet first) the inlet.

A maximum clear opening of 88 mm is required where it is necessary to exclude the entry of the torso of child (based on test procedures in AS 4685.1–2004). Such consideration applies in parks, schools and childcare centres.

11.2.10.4 Design loads

Australian Standard AS 3996–2006 specifies design loads for access covers, road grates and frames. They are to be designed to support, without structural failure, the specified minimum ultimate limit state design loads.

The Class D loading is used where normal vehicular traffic (includes heavy duty commercial vehicles) may be expected. The standard departmental access chamber tops and roadway gullies are designed for this loading.

Class B loading is used for units designed for a footway loading.

Class C loading is used for units in locations where slow moving (light duty commercial) vehicles are expected, such as light maintenance vehicles (light trucks and driven grass cutters/mowers). Departmental field inlets, Types 1 and 2 are in this category.

11.2.10.5 Bicycle safe covers and grates

AS 3996–2006 also specifies two test wheels with pneumatic tyres to ensure the covers and grates are bicycle safe.

At all times where there is a possibility of bicycles, the designer should ensure that bicycle safe covers and grates are specified.

11.2.10.6 High efficiency grates

The term ‘high efficiency hydraulic grates’ refers to non-bicycle safe grates with wider ‘bar’ spacing (the ‘bar’ may be a flat section).

As indicated on the drawings, such grates should only be used in locations where bicycles are prohibited or not likely to have access. The opening between the flat sections should not exceed 52.5 mm.

Of a different design, the high efficiency vaned grate with water deflectors shown on Standard Drawing Nos. 1321 and 1322 (DMR 2009) is bicycle safe.

11.2.10.7 Field inlets

Field inlets are used to drain low lying areas and located in areas where vehicular traffic would not be expected (except for maintenance). Such locations are medians, drainage easements, table drains and catch drains.

Entry of water is from the top only in Field Inlets Type 1 (Standard Drawing No. 1309 (DMR 2009)).

The frame and grate of Field Inlet Type 2 (Standard Drawing No. 1310 (DMR 2009)) is raised to allow side entry of water as well to a depth of 175 mm before water reaches the top of the grate. It is, therefore, more efficient than the Type 1 Inlet and less prone to obstruction. However, it should only be used where the possibility of pedestrians, bicycles and vehicular traffic is remote.

The following discussion has been extracted from QUDM (2013) with some minor modification.

Field inlets (also known as ‘drop inlets’) should be provided in footpaths and medians, and so on as necessary, to drain all low points.

Where there is considerable pedestrian traffic adjacent to a field inlet, for example, in a footpath, a grate with close bar spacing should be used – recommended bar spacing is provided in '(d)' below. Elsewhere, a grate with wide bar spacing is preferable, because of the reduced risk of blockage by debris.

In all situations, an allowance for blockage of 50% of the clear opening area of the grate should be made.

a) Inflow capacity

The inflow capacity of a field inlet depends upon the depth of water over the inlet. For shallow depths, the flow will behave as for a sharp crested weir. For greater depths, the inlet will become submerged and inflow will behave as for an orifice. It is recommended that the capacity of the inlet be checked using both procedures and the lesser inlet capacity adopted.

Under weir flow conditions, (Figure 11.2.10.7(a)) the equation is:

$$Q_g = BF \times 1.66.L.h^{3/2}$$

where	Q_g	=	*flow into field inlet (m³/s)*
	BF	=	*blockage factor = 0.5*
	1.66	=	*weir coefficient*
	L	=	*weir length (m) (see Note)*
	h	=	*depth of water upstream of inlet (relative to weir crest) where flow velocity is low (that is, velocity head is insignificant) otherwise use the height of energy level above the weir crest (m).*

Note: The length referred to in this case is the effective weir length. Thus, for a grated inlet adjacent to a kerb, the side along the kerb should be ignored. For a side inlet, the length referred to is the length of the inlet.

Figure 11.2.10.7(a) – Field inlet under weir flow

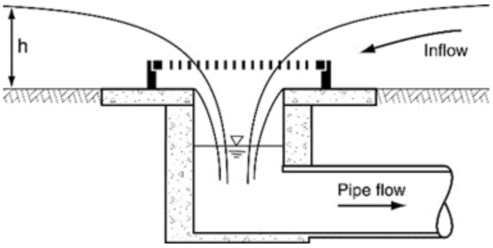
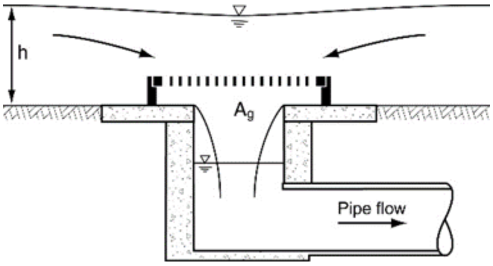


Figure 11.2.10.7 (b) – Under orifice flow conditions



The orifice flow equation depends on the pressure gradient across the orifice. The standard orifice flow equation applies when 'atmospheric' pressure conditions exist downstream of the grate, such as would exist if the design Water Surface Elevation (WSE) is 150 mm below the grate (as per Table 7.16.1 of QUDM (2013) and Figure 11.2.10.7(b) in this chapter).

The following equation is based upon a pressure change coefficient of Kg = 2.75:

$$Q_g = BF \times 0.60.A_g\left(2g.h\right)^{1/2}$$

where	Q_g	=	*flow into field inlet (m³/s)*
	BF	=	*blockage factor = 0.5*
	0.60	=	*is a constant = (1/Kg)1/2 = (1/2.75)1/2*
	A_g	=	*clear opening area of grate (m²)*
	g	=	*acceleration due to gravity (9.81 m/s²)*
	h	=	*depth of approaching water relative to the orifice (m)*
	Kg	=	*pressure change coefficient for the grate*

The pressure change coefficient (Kg) can vary significantly for unusual grate designs. The coefficient used in the equation for orifice flow is based on a typical open mesh grate. It is noted that the pressure change coefficient for the old cast iron 'City Grate' has been adopted as 2.23. Designers of unusual hydraulic structures should seek expert advice or review reference documents on orifice flow.

If the field inlet is fully drowned (that is, no air gap exists below the grate and, thus, the hydraulic pressure below the grate is not atmospheric), then an estimate must be made of the head loss through the structure as per a normal Hydraulic Grade Line (HGL) analysis. Such calculations require considerable experience and hydraulic judgement. Guidance on head losses through screens is provided in Section 7.16.14(c) of QUDM (2013).

b) Freeboard considerations

Where the inlet is contained within a pond formed by earth mounds or similar, freeboard should be 20% of the depth of the pond with a minimum of 50 mm under minor storm conditions. However, where overflow must be avoided, the design storm shall be the major storm event.

c) Minimum width of scour protection lip

The concrete lip formed around a field inlet should have sufficient width to:

- minimise the risk of grass growing over the grate or causing blockage of the grate
- prevent scour of an adjoining surface.

Unless otherwise supported by site-specific hydraulic calculations, the minimum recommended 'lip' width (Z) required to minimise the risk of scour within the adjoining grass may be determined from the following equation:

$$Z = 2.3 \times {A_g}/{L}$$

where Z = *minimum lip width for scour protection (m) (refer Figure 11.2.10.7(c))*

A_g = *effective 'clear' opening area of drop inlet (m²)*

L = *total internal circumference of drop inlet (m)*

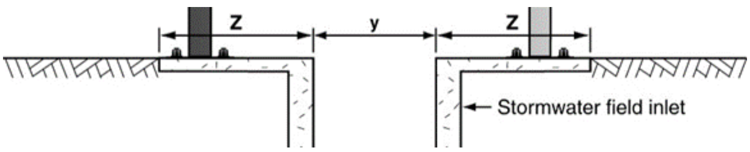
Thus, for square inlets ($A_g = y^2$ & $L = 4y$) and the minimum lip width: $Z = 0.57y$

where y = *internal side dimension of square drop inlet (m) (refer Figure 11.2.10.7(c))*

d) Safety issues

While inlet screens/grates shall comply with the requirements of AS 3996–2006, safety risks should be reviewed in circumstances where a field inlet is located within areas accessible to the public.

Figure 11.2.10.7(c) – Minimum lip width required for scour protection



The maximum spacing of bars must be in accordance with the following:

- horizontal inlet screens – maximum spacing is 125 mm; however, if there is a risk of a child being swept by stormwater towards the screen, then a maximum clear opening of 88 mm is required between bars. This spacing excludes the entry of the torso of child and is based on test procedures specified in AS 4685.1–2004
- vertical or inclined inlet screens – maximum spacing is 125 mm.

Other safety considerations include the following:

- possible tripping hazard of a horizontal grate/screen (for example, particularly if not set flush with the ground)
- flow velocity through the screen/grate should be sufficiently low enough to prevent a child from being held against the screen/grate by hydraulic pressure.

Raised, horizontal screens are generally not acceptable adjacent to footpaths, bikeways or public areas where significant numbers of people gather as these inlets may represent an unacceptable safety risk. In such circumstances, flush screens should be used, or possibly large dome screens if such screens are likely to be clearly visible and not represent a safety risk. Alternatively, marker posts or fencing may be used.

11.2.11 Access chambers

Section 6.6.12 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section with the following amendments.

Addition(s)

1. Standard departmental access chambers 1050 to 2100 mm in diameter are shown on Standard Drawings Nos. 1307 and 1308 (DMR 2009).

11.2.12 Access chamber tops

Where an access chamber is located within a carriageway, the chamber top, or access point, should be positioned to avoid wheel paths and should be finished with the top flush with the finished surface.

Elsewhere, access chambers should be finished 25 mm above natural surface with the topsoil or grassed surface around the chamber graded gently away. On playing fields, they may be finished 200 mm below the finished level, but only when located in a straight line between two permanently accessible chambers.

11.2.13 Reduction in pipe size

Section 6.6.12 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section.

11.2.14 Surcharge chambers

This section has been extracted from QUDM (2013).

Prior to incorporating a surcharge chamber into a drainage line, the following should be considered:

- the potential for a person (that has been swept into the upstream drainage system) being trapped inside the surcharge chamber unable to exit the chamber or the outlet pipe
- potential surcharge of the upstream system and flooding problems caused by debris blockage of the outlet screen
- structural integrity of the chamber, outlet screen, top slab and concrete coping, and its ability to withstand high outflow velocities and high 'pressure' forces caused by debris blockages. There is a need in many cases to ensure the surcharge screen is securely anchored to the top slab, and the slab to the chamber walls, to avoid displacement of the chamber lid/screen
- safe maintenance access to allow removal of debris trapped within the surcharge chamber.

The hydraulic analysis of surcharge chambers is presented in Section 7.16.14 of QUDM (2013).

11.2.15 Pipeline requirements

11.2.15.1 Pipe joint types

The description and requirements for types of pipe joints are detailed in Section 9.2.1 in Chapter 9.

11.2.15.2 Geometric tolerances and cover requirements

The geometric tolerances for cover requirements are detailed in Section 9.2.2.

11.2.15.3 Minimum pipe size

The minimum diameter of any pipe in a drainage system should be 375 mm.

11.2.15.4 Box sections

The requirements for use of box sections are detailed in Section 9.2.4.

Furthermore, where box culverts are constructed on a skew, special consideration is required where units join pits and access chambers.

11.2.15.5 Location in urban areas

This section has been extracted from QUDM (2013) with some modification and provides general guidance for the location of pipe networks in urban areas (local authorities would generally follow this guidance).

Minor pipes connecting one kerb inlet or pit directly to another are acceptable at the top of the drainage system and these pipes may be located under the kerb and channel.

For pipelines greater than 600 mm, it is recommended that the location for pipelines in the road pavement – other than a kerb inlet to kerb inlet connection – be 2.0 metres measured towards the road centreline from the invert of the kerb and channel; however, access chamber tops or access points should be located to avoid wheel paths.

Where sufficient verge width is available, stormwater pipes may be located in the verge to suit the services allocations of the relevant authorities/owners.

In divided roads, drainage pipelines may be located within the median, normally offset 1.5 m from the centreline (as street lighting poles are normally on the centreline).

11.2.16 Splay pipes

The use of splay pipe components to construct ‘bends’ in pipelines is not permitted, particularly between pits/access chambers.

Refer Section 9.2.11 for possible relaxation of this requirement when not between pits/access chambers.

11.2.17 Structural requirements of pipelines

The structural requirements for pipelines are detailed in Section 9.2.6. However, for pipe networks in urban areas, ‘trench installation’ is typical.

All other structural aspects should be referred to the department’s Bridge and Marine Engineering unit/Structures section, Engineering and Technology Branch or a suitably prequalified structural engineering consultant.

11.2.18 Flow velocity limits

Section 6.5.4 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section.

11.2.19 Pipe grade limits

Section 6.5.4 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section.

11.2.20 Discharge calculations

The following section has been extracted from QUDM (2013) with some minor modification.

The system objectives must seek to limit flooding and to ensure a reasonable level of pedestrian and vehicular traffic safety and accessibility. These objectives are met by ensuring that major and minor storm flows are managed within specified limits and by designing both major and minor system components in conjunction.

If the major (surface) system does not have the capacity to carry the difference between the design peak flow and the calculated pipe flow (based on normal AEPs), then additional inlets and, hence, larger pipes are required to ensure that the surface system operates within the specified limits.

The general principles or objectives are:

- the drainage system as a whole is provided to mitigate flooding and to ensure the safety and convenience of pedestrians and vehicles
- the minor drainage system comprising underground pipes and/or surface flowpaths is designed to provide for the safety and convenience of pedestrians and vehicles
- where flood immunity cannot be provided under major storm conditions via overland flowpaths, the capacity of the underground pipe system and the inlets leading to it need to be increased in order to reduce surface flows to acceptable levels.

Under normal conditions, the capacity of the underground pipe system should not be less than its minor storm flow conditions while the system is operating under major storm conditions. The exceptions would be when tailwater levels downstream have a significant effect on the system's HGL or the surface gradient is considerably flatter than the pipe gradient, thus causing the HGL to rise above the ground surface.

The underground system should be designed with a suitable allowance for blockage at kerb inlets as described in Section 11.2.10.1. In this way, the full design capacity of the underground system can be taken into account under both major and minor storm conditions.

11.2.21 General design procedure

A general design procedure is detailed in Section 7.15.3 of QUDM (2013) and provides a sound basis and understanding for the design of pipe networks required for departmental projects. It is recommended that designers should refer to this procedure for the initial design assessment.

11.2.22 Hydraulic calculations

The detailed HGL method is recommended for the analysis of underground stormwater pipe systems. It is further recommended that this be based on an analysis proceeding from downstream to upstream through the system.

Section 7.16 of QUDM (2013) provides guidance, understanding and the hydraulic calculations required to undertake the design of a pipe network for departmental projects. All subsections of Section 7.16 QUDM (2013) apply, except for Section 7.16.10 where Section 11.4.17 of this manual applies.

11.3 Aquaplaning

Section 4 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section.

11.3.1 What is aquaplaning?

Sections 4.1, 4.2 and 4.3 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section.

11.3.2 Causal factors

Section 4.4 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section.

11.3.3 Road surfacing

Section 4.5 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section.

11.3.3.1 Pavement surface types

Section 4.5.1 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section.

11.3.4 Tyres

Section 4.6 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section.

11.3.5 The road-tyre interface

Section 4.7 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section.

11.3.6 Skid resistance

Section 4.8 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section subject to the following amendments.

Addition(s)

1. The pavement surface is just one of a large number of contributory factors. The three main areas of control which relate to the pavement surface and which many road authorities use internationally to address the issue of skid resistance are:

a) in-service skid resistance (friction)

b) aggregate polishing resistance

c) surface texture depth.

11.3.7 Assessment – water film depth

Section 4.9 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section.

11.3.7.1 Adopted method

Section 4.9.1 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section.

11.3.7.2 Basis/limits

Section 4.9.2 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section subject to the following amendments.

Addition(s)

1. It should be noted that the Gallaway Method is one dimensional and only assesses depth of flow along a single (zero width) flow path. Flow velocity and width or spread of the flow over the pavement surface is not assessed. Some situations can occur where water runoff from off the road surface can flow onto the road and/or where runoff from one flow path crosses a boundary and joins another flow path. The Gallaway Formula is unable to assess these situations properly and cases such as these should be referred to the Director (Road Design), Engineering and Technology Branch.

11.3.7.3 Texture depth

Section 4.9.3 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section.

11.3.7.4 Drainage path

Section 4.9.4 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section.

11.3.7.5 Rainfall intensity

Section 4.9.5 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section.

11.3.8 Assessment – aquaplaning potential

Section 4.10 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section subject to the following amendments.

Addition(s)

1. In 1986, the National Association of Australian State Road Authorities (NAASRA) publication *Guide to the Design of Road Surface Drainage* stated that it is not completely possible to define recommended design limits for water depths, however:

- critical depth to cause hydroplaning occurs at about 4 mm and above
- partial hydroplaning may commence at depths of about 2.5 mm.

11.3.8.1 Assessment criteria

Section 4.10.1 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section.

11.3.8.2 Basis/limits

Section 4.10.2 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section.

11.3.9 Quick assessment

Section 4.11 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section.

11.3.10 Puddles/wheel ruts

Section 4.12 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section.

11.3.11 Guidance to reduce aquaplaning potential

Section 4.13 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section.

11.3.12 Worked example

Section 4.14 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section.

11.4 Subsurface drainage

Section 8.1 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section.

11.4.1 Moisture in roads

Some moisture is always present in the subgrade and unbound paving materials due to capillary moisture movement controlled by the environment. If this becomes excessive, the subgrade and pavement can be weakened appreciably. Consequently, it is important to minimise ingress of water into the pavement and subgrade.

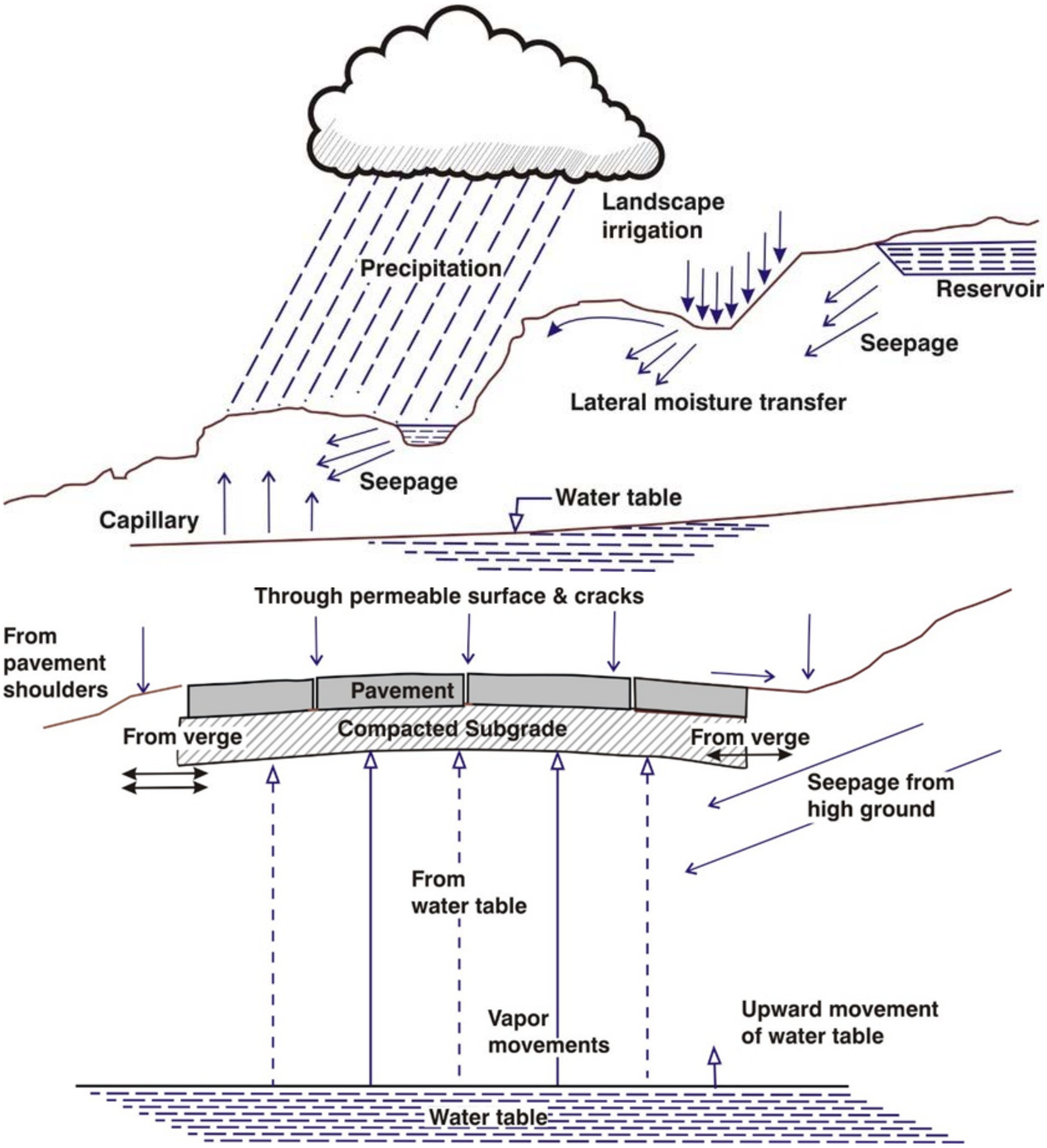
- Control of subsurface water is the key to longevity of the pavement.

The main mechanisms by which moisture can enter a road subgrade and/or pavement are shown diagrammatically in Figure 11.4.1 and include:

- longitudinal seepage from higher ground, particularly in cuttings and in sag vertical curves
- rise and fall of water table level under a road
- rainfall infiltration through the road surfacing
- capillary moisture from the verges
- capillary water from a water table
- vapour movements from a water table
- lateral movement of moisture from pavement materials comprising the road shoulder
- water flowing or standing in table drains, in catch drains, in median areas, within raised traffic islands or adjacent to the road (not illustrated)
- leakage of water supply and drainage lines (not illustrated)
- passage of water through construction joints in pavements, and back and front of kerb and channel, between old and new pavements and behind bridge abutments (not illustrated).

It is important to note that, in some flood plains and low lying areas, a permanent, high-level water table may exist. Subsoil drains may be ineffective in such areas, particularly where it is difficult to provide an outlet. In some cases, such drains could act in reverse and provide a means of access for water to the pavement.

Figure 11.4.1 – Sources of moisture (Adapted from ARRB (1987))



In these circumstances, the most effective measure which can be taken to control subgrade moisture conditions is to raise the subgrade above the surface of the ground. A height of 1.2 m above the water table is suggested (Earley 1979). This is usually impossible in urban street construction, in which case the pavement design should take into consideration the soaked conditions. In some situations, a cement or bituminous stabilised sub-base and/or base may be used. Reference should be made to the department's *Supplement to 'Part 2: Pavement Structural Design' of the Austroads Guide to Pavement Technology.*

Roads on a thick layer of soft, compressible clay also need special consideration and geotechnical advice should be sought for requirements such as preloading and other possible drainage mechanisms.

11.4.2 Control of road moisture

Section 8.4 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section.

11.4.3 Types of subsurface drainage

Section 8.5 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section subject to the following amendments.

Addition(s)

1. Consideration of the permeability and capillary moisture characteristic of the material surrounding the pavement is a major factor in assessing the need and type of subsurface drainage required.

Suitable drainage systems for various conditions are presented below.

a) Drainage for surface infiltration

Figure 11.4.3(a) illustrates the type of subsoil drainage suitable for a permeable base and surface contained in relatively impermeable material.

Figure 11.4.3(b) illustrates an embankment with the permeable base and surface on a relatively impermeable subgrade. A free draining layer is provided in the shoulders below a low permeability material.

A variation is to carry the full permeable base course over the full width of the shoulders.

b) Groundwater

A static water table may be lowered by using either drainage trenches shown in Figure 11.4.3(c) or a horizontal filter blanket shown in Figure 11.4.3(d).

The horizontal filter blanket will also act as an intercepting barrier for capillary moisture in some situations.

If water flows along an inclined permeable layer, as shown in Figure 11.4.3(e), a trench should be constructed to divert the subsurface flow into a drainage pipe before it can enter the road structure. The trench should be excavated to at least the depth of the permeable strata.

Upward flow from a pervious aquifer is usually controlled by constructing a horizontal filter blanket in the base of the excavation as shown on Figure 11.4.3(f).

Figure 11.4.3(a) – Drainage for surface infiltration with subsoil drains

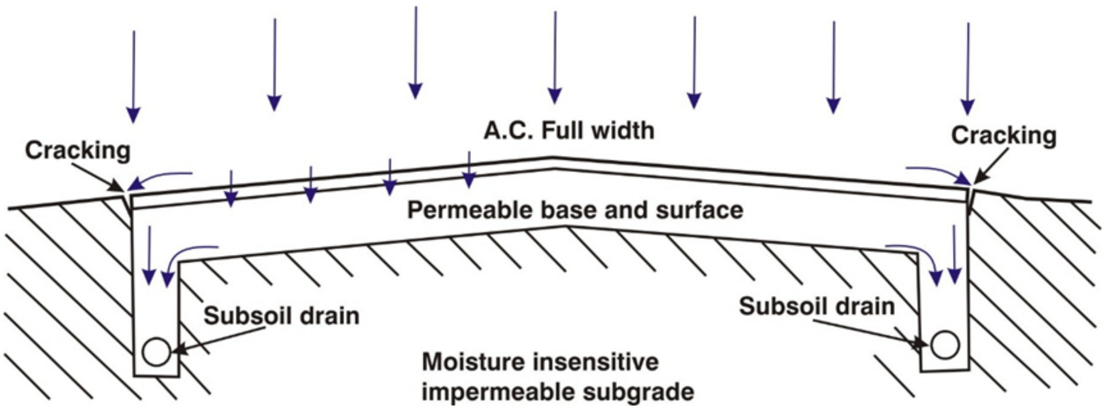


Figure 11.4.3(b) – Drainage for surface infiltration with free draining layer

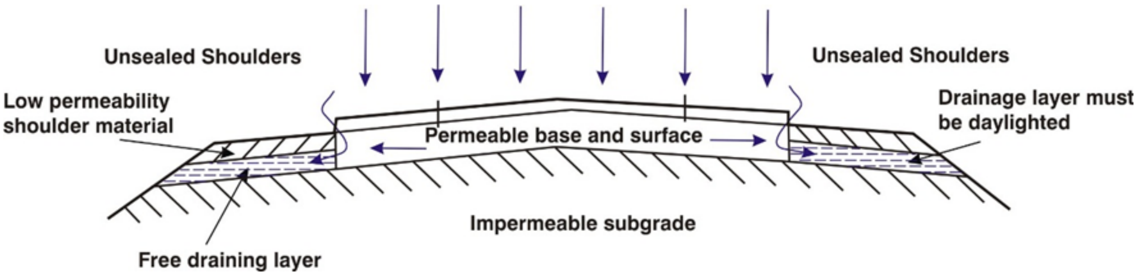


Figure 11.4.3(c) – Drainage trenches to lower water table

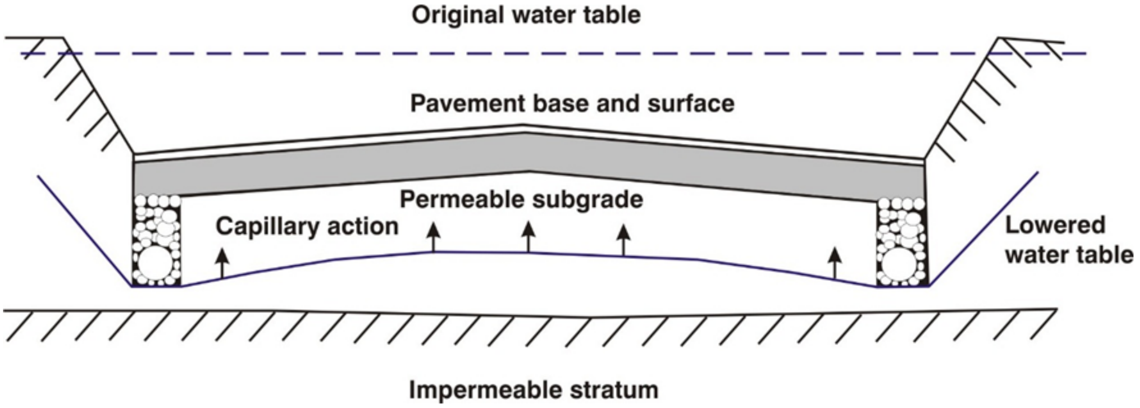


Figure 11.4.3(d) – Horizontal filter blanket to lower water table

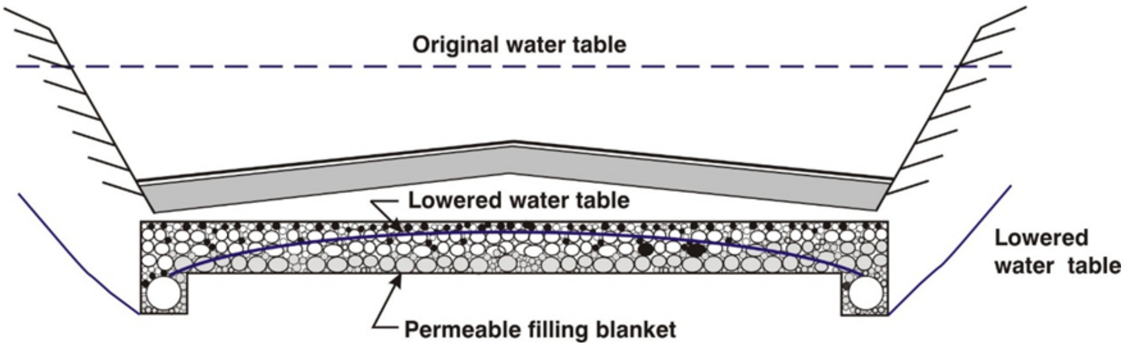


Figure 11.4.3(e) – Trenches to intercept flow through an inclined permeable layer

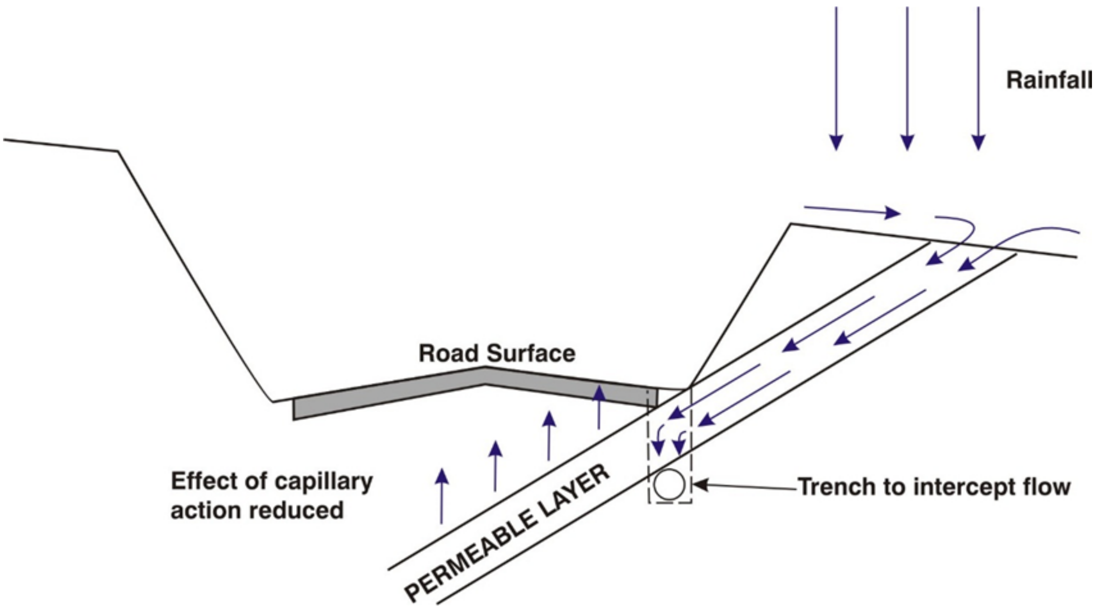
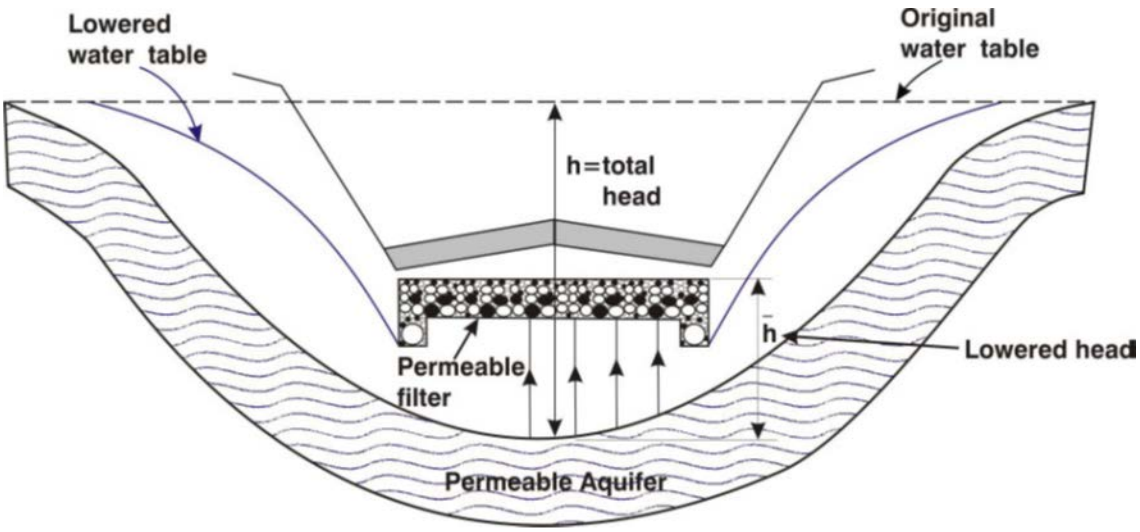


Figure 11.4.3(f) – Permeable filter to lower the effect of head from a permeable aquifer



c) Standard drains

Subsoil drains, described in MRTS03 (TMR 2015b), are shown in Figure 11.4.3(g). The depth of these drains may be increased to suit the particular installation.

Subsurface drain pipes may be surrounded by a single stage filter or by two-stage filters. Filter materials can consist of aggregates (ranging in size from sand to cobble size), geotextiles or combinations of aggregates and geotextiles. The level of filtering will be determined by the prevailing soil types and any environmental requirements on the discharge. In some cases, a second stage filtering may be required and this can take the form of a geotextile wrap either around the pipe or around all the filter material.

A more recent form is the geocomposite edge drain sometimes known as a ‘strip filter’ or ‘fin drain’. These are prefabricated with a polymer core wrapped in a geotextile. They can be installed in much narrower trenches than traditional pipe-based drains.

Material requirements are contained in MRTS03 (TMR 2015b) including those for sheet filter drains, trench backfill, fibre reinforced concrete pipes, corrugated steel pipes, polyvinylchloride pipes, and plastic pipes (perforated and unperforated). See also Section 11.4.4 on filter materials.

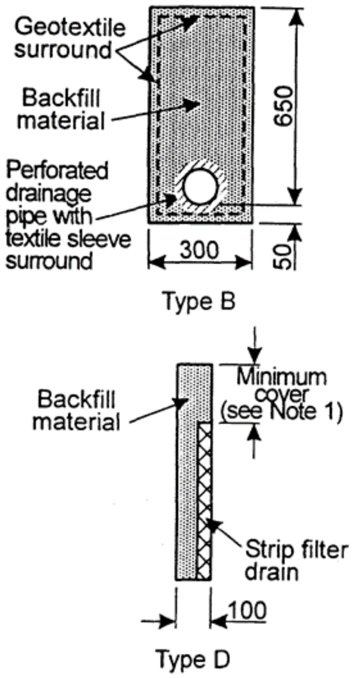
The department’s MRTS04 (TMR 2014d) is also relevant.

Figure 11.4.3(h) shows typical subsoil drain outlets and cleanouts in an urban environment. Standard Drawing No. 1116 (DMR 2009) provides further details including treatments for rural environments.

The outlets of subsoil drains discharging into gully pits, manholes, or culvert endwalls are preferred. Outlets discharging to natural surface should be made accessible for maintenance operations and a concrete headwall should be constructed together with a small area concreted or rockpitched around it as shown on the standard drawing. To aid finding the outlet a timber marker post should be maintained.

Accurate records of the position, depth and type of subsoil drains which are installed should be maintained.

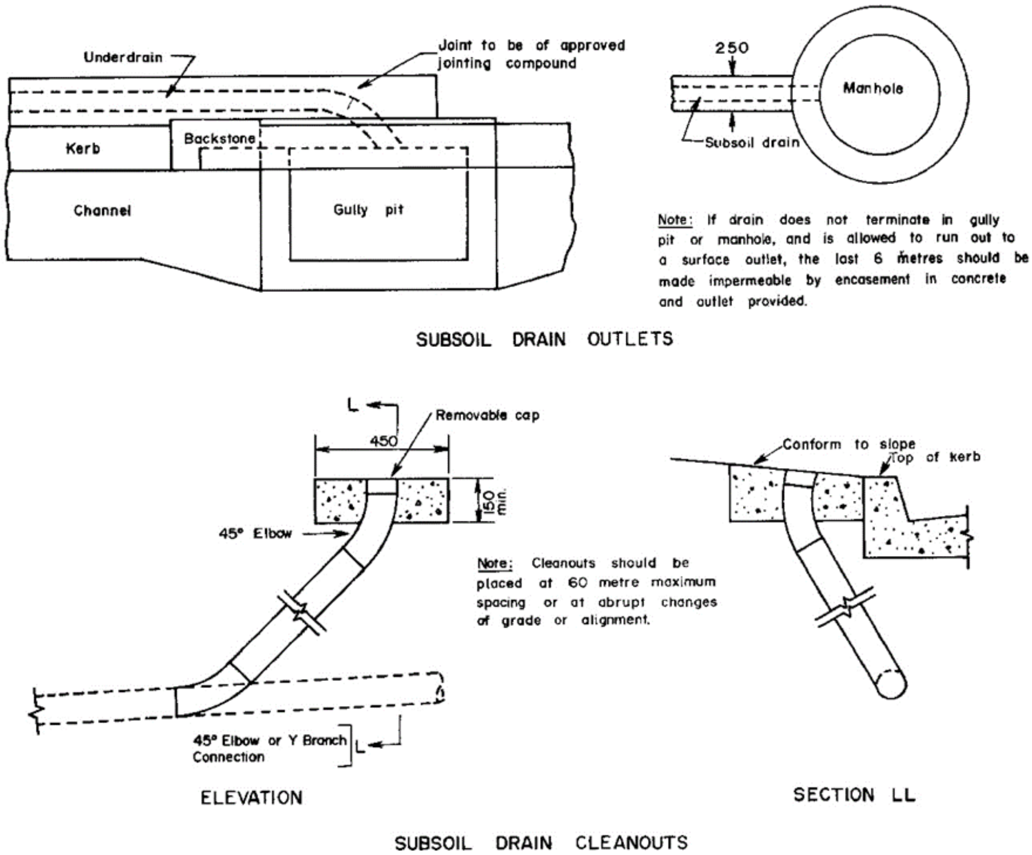
Figure 11.4.3(g) – Standard subsoil drains



Notes:

1. Minimum cover for various compactors unless approved otherwise:
   Hand held compactors –100 mm
   Compactors < 15 tonnes – 200 mm
   Compactors > 15 tonnes – 200 mm
2. All dimensions are in millimetres.

Figure 11.4.3(h) – Subsoil drain outlets and cleanouts



Notes:
The pavement base course may be more permeable than the sub-base.
Relative permeabilities should be considered in locating the drains.

11.4.4 Requirements of filter materials

This section contains extracts from the *Guide to the Control of Moisture in Roads* (NAASRA 1983) and applies to most drains.

A filter material is required in any permanent subsurface drainage system to prevent fine soil particles from washing into the system. For satisfactory performance, a filter material must be more permeable than the surrounding material but, at the same time, fine enough to keep that material in place.

In addition, the filter should be stable under flow situations and should itself be prevented from washing into perforations or joints in drainage pipes.

These requirements can be satisfied in various ways, usually by either granular materials or synthetic filter fabrics (geotextiles).

Filter materials are not usually necessary in temporary drainage systems or where the surrounding soil is known to be very stable. Examples of stable material are fractured rock, fissured or jointed heavy clays or other weathered materials, and naturally or artificially cemented materials. Care should be taken to determine whether fissured or jointed materials are sufficiently stable under adverse conditions to warrant dispensing with a filter material. Water flowing from joints should be examined for suspended particles and the susceptibility of the material to erosion in the disturbed or undisturbed state determined.

MRTS27 *Geotextiles (Separation and Filtration)* June 2009 (TMR 2009) describes the material requirements and work to be carried out for the relevant geotextiles in drains and trenches and drainage blankets, and geotextiles under or within embankments.

The design of granular filter material is described in *Subsurface Drainage of Road Structures* (ARRB 1987).

11.4.5 Design procedure

Section 8.8.2 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section.

11.4.6 Location of subsoil drains

Section 8.6 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section subject to the following amendments.

Addition(s)

1. Figure 11.4.6(a) shows typical locations of subsoil drains in a divided road in a cutting. The width and nature of the median determines the number of subsoil drains required.

Grassed medians can provide a means by which water can enter the pavement or subgrade. Medians should, therefore, be constructed of a material of low permeability (for example, a compacted soil aggregate as recommended for shoulders) except for 100 mm of topsoil to grow grass. Provision of an impermeable membrane under the median should be considered also.

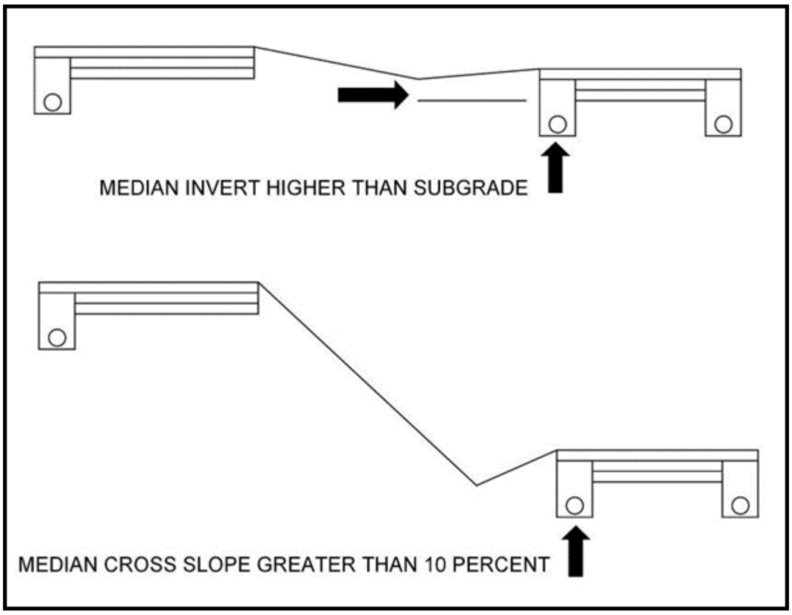
However, where median planting other than grass is required for aesthetic or headlight screening reasons, the low permeability material or impermeable membrane will inhibit growth and should not be used.

Longitudinal subsoil drainage should be provided where there is a possibility of entry of water from grassed medians, or where there is a significant difference in level between roadways, or where permeable subsoil surface strata exists.

Figure 11.4.6(b) shows typical locations of subsoil drains in a low embankment or transition zone from embankment to cut.

Figure 11.4.6(c) shows a typical example in a cutting where subsoil drains are often required.

Figure 11.4.6(a) – Location of subsoil drains (divided road)



Note:
If invert of median drain is not much lower than pavement layers and/or the possibility of seepage from median back under pavement exists, a subsoil drain should be considered here.

Figure 11.4.6(b) – Subsoil drains – Low embankment or transition from embankment to cut

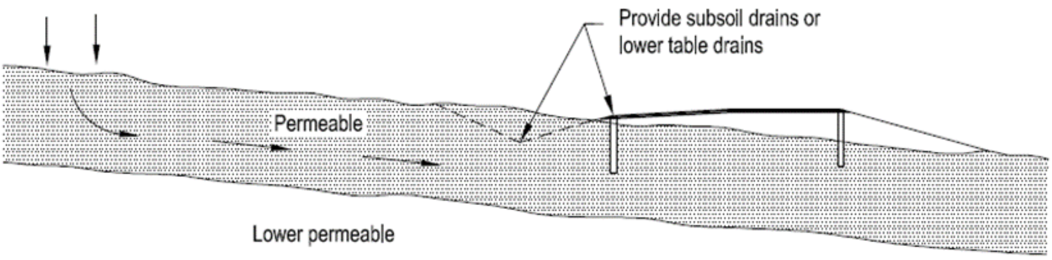


Figure 11.4.6(c) – Subsoil drains in cuttings

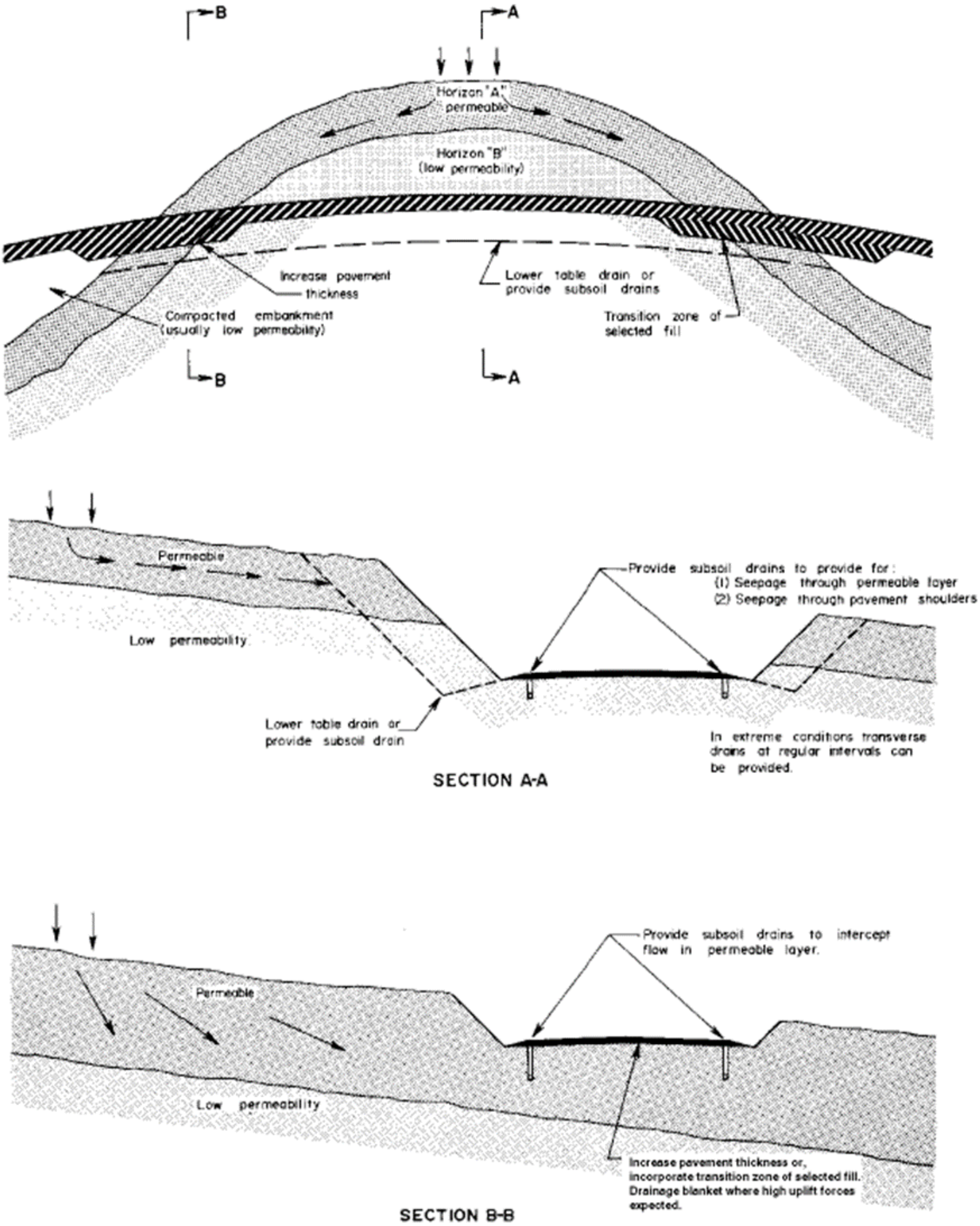
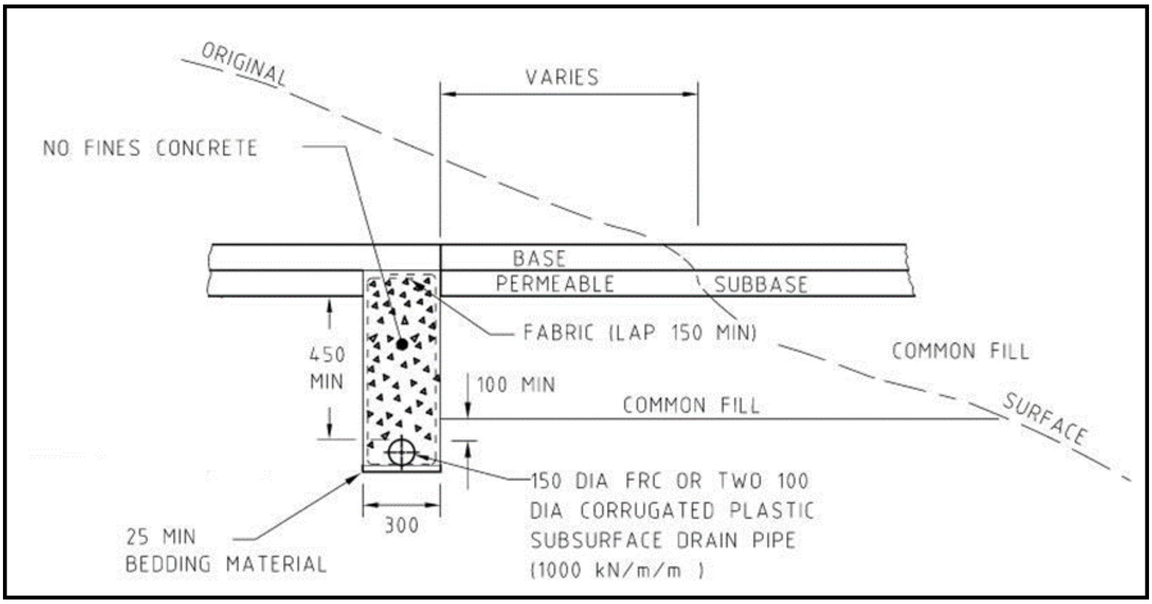


Figure 11.4.6(d) – Transverse, strip filter subsurface drain



11.4.7 Transverse subsurface drains

Section 8.6.1 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section.

11.4.8 Cut-off drains

Section 8.6.3 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section.

11.4.9 Design of cut-off drains

Section 8.9.5 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section.

11.4.10 Size of drain

Section 8.7.1 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section.

11.4.11 Materials

Section 8.7.2 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section.

11.4.12 Access to subsurface drains

Section 8.7.2 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section subject to the following amendments.

Addition(s)

1. Figure 11.4.3(h) shows typical subsoil drain outlets and cleanouts in an urban environment. Standard Drawing No. 1116 (DMR 2009) provides further details including treatments for rural environments.

Pits for subsurface drainage should be spaced not further than 150 m apart for ease of inspection and cleaning of the pipes. Maximum spacing between a cleanout and an outlet should generally not exceed 120 m to facilitate inspection and flushing. In cuttings where groundwater is not present, the distance to the outlet of a pavement drain may be much greater, but intermediate pits should generally be placed at a maximum spacing of 120 m.

Where groundwater occurs in a cutting, the seepage should be conveyed from the subsurface drain into an impervious collector pipe to minimise water penetration of pavement remote from the problem area.

Outlets should be in areas that are easily accessible and, where possible, visible to personnel standing on the road surface. An outlet should not hinder road maintenance activities, such as cleaning unlined table drains or grass cutting.

Outlets should be provided with some form of erosion protection commonly referred to as a splash zone. Typically, this consists of either:

- a masonry or concrete apron, or
- an area of large aggregate to dissipate the outflow energy.

11.4.13 Lowering of ground water table

Section 8.9.1 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section.

11.4.14 Schilfgaarde's Method

Section 8.9.2 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section.

11.4.15 Draining an inclined aquifer

Section 8.9.3 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section.

11.4.16 Design of a filter blanket to lower a water table

Section 8.9.4 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section.

11.4.17 Capillary rise in soils

Section 8.9.6 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section.

12 Basins

12.1 Overview

In the context of this chapter, design guidance is provided for basin systems, which include detention, extended detention and sediment basins.

Generally:

- detention basins and extended detention basins are designed to reduce and delay peak flood flows
- sediment basins are designed to trap and retain a range of sediment particle sizes, thereby reducing both coarse sediment and turbidity values from the inflow
- retention basins are designed to retain some or all of the flow, allowing it to infiltrate into the soil.

Retention basins are rarely used on departmental projects and their design is specialised, therefore they are not covered in detail in this manual. However, where retention basins are deemed necessary reference should be made to the Austroads *Guide to Road Design* – Part 5A Section 7.4 and/or Water by Design *Bioretention Technical Design Guidelines* (October 2014 – refer to Water by Design website – http://waterbydesign.com.au/).

12.2 Detention basins

12.2.1 Introduction

Sections 7.2.1 and 7.2.2 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section.

12.2.2 Advantages and disadvantages of detention basins

Section 7.2.3 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section.

12.2.3 Initial design and feasibility

Section 7.2.7 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section. Consideration should also be given to the Sections 7.2.4, Design Principles – Detention Basins, and Section 7.2.6, Design Procedures for a Detention Basin, of the Austroads *Guide to Road Design* – Part 5A.

12.2.4 Simple hydrologic method of routing

Section 7.2.8 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section.

12.2.5 Other design considerations

Section 7.2.9 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section.

12.3 Extended detention basin

12.3.1 Description

Section 7.3.1 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section.

12.3.2 Design guidelines

Section 7.3.2 of the Austroads *Guide to Road Design* – Part 5A is accepted for this section subject to amendments.

Addition(s)

1. Design references

   Additional design information may be obtained from Best Practice Erosion and Sediment Control (IECA 2008).

12.4 Sediment basins

12.4.1 Description

Sediment basins are designed as part of a treatment train to improve the water quality of stormwater prior to discharge to the natural environment.

During the construction phase of projects sediment basins are used with drainage, erosion control and other sediment control strategies to manage erosion and sediment. Further information on effective erosion and sediment control is found in Chapter 13 of this manual and/or IECA Australasia *Best Practice Erosion and Sediment Control* guidelines.

During the operational phase, sediment basins are used in conjunction with other water sensitive design tools and techniques such as swale drainage to reduce the loads of sediment, nitrogen and phosphorus to the receiving environment. Further information on drainage design to improve water quality is found in Chapter 7 of this manual.

12.4.2 Design procedure – Sediment basin for temporary erosion and sediment control

Appendix B of IECA Australasia *Best Practice Erosion and Sediment Control*, November 2008 is accepted for this section.

12.4.3 Design procedure – Sediment basin for permanent stormwater treatment

For guidance on designing sediment basins for permanent stormwater treatment the following documents are recommended:

- *Water Sensitive Urban Design: Technical Design Guidelines for South East Queensland* (Healthy Waterways, 2006)
- *Australian Runoff Quality – A Guide to Water Sensitive Urban Design* (Engineers Australia, 2006)

Alternative basin designs (such as high efficiency basins) are acceptable for temporary or permanent stormwater treatment provided it is demonstrated that the discharge criteria (temporary) or minimum reductions in mean annual load (permanent) requirements will be met.

13 Erosion and sediment control

13.1 Introduction

The content previously contained within this chapter on temporary erosion and sediment control has been removed from this version of the *Road Drainage Manual*.

It is now expected that temporary erosion and sediment controls to manage construction impacts should be implemented in line with the guidance and requirements found within:

- *Best Practice Erosion and Sediment Control*, (IECA Australasia, 2008)
- the department's Technical Specification and Specification (Measurement) 52 *Erosion and Sediment Control* January 2015 (TMR 2015a)
- the department's *Soil & Revegetation Management Guideline* – State Wide Edition. Departmental employees can access this document via the Environmental Management System SharePoint site. External parties can request a copy from the department.

In particular:

- Information on field dispersion testing and erosion properties of TMR Soil Groups can be found within the department's *Soil & Revegetation Management Guideline*, – State Wide Edition (Chapter 3). This manual also contains design, construction and maintenance practices suitable for standard and specialised environments.
- Methods for determining erosion risk using Revised Universal Soil Loss Equation (RUSLE) including R values can be found in Book 2 – Appendix E of *Best Practice Erosion and Sediment Control*, (IECA Australasia, 2008).
- Control selection criteria is available in Chapter 4 of *Best Practice Erosion and Sediment Control*, (IECA Australasia, 2008). Detailed design fact sheets and standard drawings are also available in this manual (Book 4 and Book 6 respectively). This material can be accessed from the IECA website (http://www.austieca.com.au/publications/publications). Departmental employees can get login details from the Environmental Management System SharePoint site. External parties will need to arrange for their own access.
- Erosion and Sediment Control Plan requirements and design Annual Exceedance Probability (AEP)/Average Recurrence Interval (ARI) requirements are outlined in the department's Technical Specification MRTS52 *Erosion and Sediment Control*, (TMR, 2015a). For further assistance in preparing an Erosion and Sediment Control Plan please refer to Construction Administration System (CAS) standard checklist: CAC057M – *Erosion and Sediment Control Plan Checklist*. This is available on the department's website (http://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Contract-administration-system/CAS-Standard-Checklist.aspx).
- For assistance in the inspection of erosion and sediment controls please refer to the Construction Administration System (CAS) standard checklist: CAC005M – *Erosion and Sediment Control (Site Inspection)*. This is available on the departmental website (http://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Contract-administration-system/CAS-Standard-Checklist.aspx).

The Department of Transport and Main Roads strongly encourages the early installation of permanent water quality treatment systems and use of these permanent devices during

construction phase where appropriate. Information on permanent water quality treatment can be found in Chapter 7 of this manual.

14 Operation, maintenance and remediation

14.1 Introduction

Section 5.0 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section subject to the following amendments. Consideration should also be given to Section 5.1 of the Austroads *Guide to Road Design* – Part 5, Maintenance Access and Location.

Addition(s)

1. Reference should also be made to the Road Maintenance Performance Contracts Manual, Volumes 1 to 3 and Part 8 of the *Asset Maintenance Guidelines* (DMR 2002a).
2. The philosophy of this chapter is to use the maintenance process for identifying failures in the drainage system and to assist learning from these failures to prevent future failures.

14.2 Legal aspects

Applicable requirements of key legislation, such as the *Workplace Health and Safety Act 2011*, *Environmental Protection Act 1994* and *Environment Protection and Biodiversity Conservation Act 1999* (Commonwealth Act), apply to the department's operation and maintenance activities with respect to road drainage (refer Section 1.4 in Chapter 1). Furthermore, the department has a legal responsibility/duty of care to ensure that the road under its jurisdiction is maintained to provide an acceptable level of safety to the public, road users and to protect the environment from harm. It is important that supervisory staff overseeing these activities understand the applicable requirements of the legislation to ensure compliance.

To ensure appropriate and timely maintenance, it is important that regular inspections, followed by appropriate remediation works (where required), be conducted. With respect to road drainage, it is recommended that inspection of this infrastructure should be conducted shortly after significant rainfall/flood events when failures are more likely to occur. Any remediation work would depend on the severity of any damage/failure identified.

Furthermore, the department must also ensure prompt response to emergency situations (such as water over the road or subsidence of the roadway occurs) where rapid remediation works are required.

In both situations presented above, failure to act appropriately exposes the department, and its officers, to increased risk of investigation and/or legal action.

14.3 Operation

Section 5.2 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section.

14.3.1 Period of inspection

Section 5.2.1 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section.

14.3.2 Performance

Section 5.2.2 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section.

14.3.3 Reporting of deficiencies

It is important that deficiencies in the drainage system (when compared to design intent) be identified, investigated and corrected. In particular, remedial works should be considered for sites where recurring issues are identified.

14.4 Maintenance

14.4.1 The maintenance process

Section 5.3.1 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section subject to the following amendments.

Addition(s)

1. The Department of Transport and Main Roads is the steward of the state-controlled road network. Part of this role is to maintain the road network to a standard which ensures the safety and efficiency of the travelling public and protection of the environment.

14.4.2 Types of maintenance

With respect to drainage, the RMPC covers predominantly two maintenance types. The first, and most dominate type, is routine maintenance.

Routine maintenance work includes those activities that keep the road corridor in good order, such as the cleaning and repair of drainage systems (refer RMPC Vol. 3 (DMR 2004)).

Emergency maintenance work relates primarily to work performed immediately following an emergency (e.g. vehicle accident, natural event) to ensure the safety of motorists and/or pedestrians using the corridor. Other routine maintenance work may be necessary after making the situation safe.

14.4.3 Metal culverts

The maintenance of metal culverts can be difficult and specialised, therefore maintenance engineers are referred to the latest version of the department’s manual, *Design Criteria for Rehabilitation of Circular Corrugated Metal Culverts*, for further guidance.

14.5 Drainage failures

14.5.1 Introduction

Section 5.4 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section.

14.5.2 Causes of failure

Section 5.4.1 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section.

14.5.3 Types of failure

Section 5.4.2 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section.

14.5.4 Environmental impacts of failures

Section 5.4.3 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section.

14.5.5 Identifying failures

Section 5.4.4 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section.

14.5.6 Reporting of failures

Section 5.4.5 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section.

14.6 Remediation

14.6.1 Introduction

Section 5.5.1 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section.

14.6.2 Remediation options

Section 5.5.2 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section.

14.6.3 Evaluation

Section 5.5.3 of the Austroads *Guide to Road Design* – Part 5 is accepted for this section.

14.6.4 Metal culverts

The remediation/rehabilitation of metal culverts can be difficult and specialised, therefore maintenance engineers are referred to the latest version of the department's manual, *Design Criteria for Rehabilitation of Circular Corrugated Metal Culverts*, for further guidance.

Glossary

Glossary based on:

1. AS 1348–2002 *Australian Standard for Road and Traffic Engineering*
2. *Queensland Urban Drainage Manual* (QUDM) 2008
3. American Association of State Highway and Transportation Officials, *Model Drainage Manual 1991*
4. *Queensland Water Act 2000*.

Term	Definition
Afflux	The rise in water level on the upstream side of a constriction, such as a road, weir or bridge in a stream or channel relative to the water level at that point without the constriction.
Aggregate	A soil aggregate consists of a cluster of primary soil particles bound together into a clearly defined unit by electrostatic forces, such as charges on clay particles, cementing substances from organic matter or hydroxides of iron, or binding strands of roots.
Allotment drainage	A system of field gullies, manhole chambers and underground pipes constructed within private property to convey flows through and from allotments.
Alluvial plain	A landform with extremely low relief formed by the accumulation of alluvium from overbank stream flow over a considerable period of time. This accumulation may still be occurring (flood plain) or may have ceased (terrace).
Amelioration	Refers to efforts made to minimise adverse effects of an activity (e.g. road construction) after the event.
Anabranch	A branch of a stream which leaves and later re-enters the stream.
Annual Exceedance Probability (AEP)	The probability that a given condition, such as rainfall total accumulated over a given duration or flow rate, will be exceeded in any one year
Annual flood	The highest peak discharge in a water year consisting of 1 September to 31 August.
Apron	A floor or lining at either the inlet or outlet of a hydraulic structure, such as a culvert, to protect the waterway channel from erosion.
Asphalt	A mixture of bituminous binder and aggregate with or without mineral filler produced hot in a mixing plant. It is delivered, spread and compacted while hot.
Australian Height Datum (AHD)	A level datum, uniform throughout Australia, based on an origin determined from observations of mean sea level at tide gauge stations, located at more than 30 points along the Australian coastline.
Australian Height Datum Derived (AHDD)	The level datum based on a direct connection to the Australian height datum.
Average Annual Time of Closure (AATOC)	The expected average time per year of closure of the road caused by flooding. It is expressed as time per year.

Term	Definition
Average Annual Time of Submergence (AATOS)	The expected average time per year of submergence of the road caused by flooding. It is expressed as time per year.
Average Recurrence Interval (ARI)	The average or expected value of the period between exceedances of a given rainfall intensity or discharge.
Backwater	That part of a stream, the water level of which is kept above normal due to some controlling influence downstream.
Backwater Curve Analysis	A procedure for determining water surface levels in open channels under gradually varied flow conditions.
Basin	A hollow or depression within which water can be contained.
Batter	The side slope of an embankment or cutting.
Batter chute	A temporary or permanent structure designed to convey concentrated storm runoff down a cut or fill embankment, or over a change in grade, without causing erosion.
Bed and bank	With reference to a watercourse or lake, means land over which the water of that watercourse or lake normally flows or that is normally covered by the water whether permanently or intermittently, but does not include land adjoining or adjacent to the bed or banks that is from time to time covered by floodwater (*Water Act 2002*, Queensland).
Bench (benching)	1. A ledge cut or formed in the batter of a cutting or bank to provide greater security against slips. 2. A ledge constructed in a batter or natural slope to segment the slope length to reduce erosion potential.
Berm	Typically used in reference to slope barrier measures designed to break the continuity of slopes to reduce runoff velocities.
Biodiversity	(Short for biological diversity) Number of species of vegetation and wildlife in a given habitat; e.g. rainforests (which typically have a large number of different plant and animal species) are said to be 'high' in biodiversity.
Borrow pit	An excavation outside the formation limits for obtaining fill.
Broadcast seeding	Any method of planting seed which scatters the seed in random pattern on the surface of the soil.
Buffer zone	Zone adjoining a sensitive area that is required for protecting stream banks from erosion, providing habitat along stream corridors and treating overland flow before it enters the drainage network.
Building	A habitable room; retail or commercial space; factory or warehouse; basement providing carparking space, building services or equipment; or enclosed carpark or enclosed garage.
Bypass flow	That portion of the flow in a road or in a channel which is not collected by a gully inlet or field inlet and which is redirected out of the system or to another inlet in the system.
Capillary water	Water drawn upwards into soil pores and held by surface tension.
Catch bank	A small levee constructed to intercept and divert runoff away from cut slopes, embankments, disturbed areas and stockpiles. An alternative to, or can be combined with, a catch drain. See also Standard Drawing 1178.

Term	Definition
Catch drain	A small surface channel constructed to intercept and divert runoff away from cut slopes, embankments, disturbed areas and stockpiles. See also Standard Drawing 1178.
Catchment area	That area determined by topographical or equivalent features, upon any part of which rain falling will contribute to the discharge of the stream at the point under consideration.
Causeway	A raised carriageway across wet or low areas or across tidal water.
Channel	1. The bed of a stream or river. 2. A course or passage through which something may move or be directed.
Channel freeboard	Vertical distance between the design water surface elevation in an open channel and the level of the top of the channel bank.
Channel lining	Material placed on the surface of a channel or chute to protect it from erosion. Materials include grass and turf, reinforced grass, erosion control mats, rock lining, rock mattress, cellular confinement and impervious liners.
Channel stabilisation	Materials used to stabilise the channel surface. Examples include soil retention blankets (with appropriate seeding mixture) for non-structural cover and concrete or riprap (rock) for structural cover.
Check dam	Check dams are typically used in channels conveying concentrated flows to control flow velocity and minor gully erosion. They may be constructed from semi-pervious or impervious materials, such as medium-size rock or sand and gravel-filled bags.
Chute	Used to convey water down slopes and are constructed with materials suited to the expected life of the chute (i.e. concrete for permanent chutes).
Clearing	The removal of vegetation, structures or other objects.
Coastal plain	A complex, level to very gently inclined, landform pattern adjacent to the coast. The plain was formed by the deposition of material from overbank stream flow, overland sheet flow and marine inundation.
Coefficient of runoff (discharge)	Dimensionless coefficient used in the Rational Method for the calculation of peak runoff discharge.
Coefficient of runoff (volumetric)	The ratio of the amount of water that runs off to the amount that falls in a catchment area.
Cofferdam	A temporary enclosure formed to exclude water from an area in which construction is to take place. Cofferdams can take a variety of forms and are constructed from materials, such as driven sheet piling, rock, earth or concrete.
Concentrated flow	Water, usually storm runoff, flowing in a confined feature such as a channel, ditch, swale, river, etc.
Contour ploughing	Ploughing horizontally along the contour.
Cover crop	Plants, particularly cereals, grown mainly to protect the soil on a temporary basis during or prior to the establishment of more protective plant cover.
Cover ground	Any vegetation producing a mat on or just above the soil surface. In forests, this may be formed by low-growing shrubs, vines and herbaceous plants under the trees.
Crest	The summit or top edge.
Critical depth	The depth occurring in a channel or conduit at a condition of flow such that the specific energy is a minimum for the particular flow. Froude number equals 1.

Term	Definition
Critical flow	Flow condition such that the specific energy (of the mean flow) is minimum. Froude number equals 1. When the flow is critical, small changes in specific energy cause large changes in flow depth. In practice, critical flow over a long reach of a channel is unstable, resulting in a wavy or undulating surface.
Critical velocity	The average velocity of flow in a section of a channel or conduit when the flow is at critical depth.
Cross-drainage	A system of pipes or culverts which convey storm flows transversely across or under a roadway.
Crossfall	The slope, at right angles to the alignment, of the surface of any part of a carriageway.
Crown	1. The highest part of an arch. 2. The highest point on the cross-section of a carriageway with a two-way crossfall.
Culvert	One or more adjacent pipes or enclosed channels for conveying a watercourse or stream below formation level.
Dam	A barrier or embankment which confines water.
Design discharge	The volume of water in cubic metres passing during one second, through a drainage section to be designed, which determines the size the drainage section needs to be.
Detention basin (retention/retarding/ compensating basin)	A storage pond, basin or tank used to reduce and attenuate the peak discharge within a drainage system. In Australia, detention basins may have an outlet pipe and/or a spillway and the term is interchangeable with ‘retention basin’. It is also interchangeable with ‘sedimentation basin’ when ‘sediment control’ is the main purpose of the basin.
Development category	Refers to land use within a catchment (see ‘Land use’).
Diversion block	A small block constructed for the purpose of diverting water from the table drain to a culvert or side drain. Can be combined with a ‘diversion drain’ to divert water out of the table drain and away from the road formation. See also Standard Drawing 1178.
Diversion channel	A hydraulically designed, open channel that diverts or redirects a given water flow from its current, natural flow path.
Diversion drain	A drain leading water away from an existing small channel (for example, a table drain). See also Standard Drawing 1178.
Drainage	Natural or artificial means of intercepting and removing surface or subsurface water (usually by gravity).
Drainage catchment	The area of land contributing stormwater runoff to the point under consideration.
Drainage system	A system of gully inlets, pipes, overland flow paths, open channels, culverts and detention basins used to convey runoff to its receiving waters.
Dyke	See ‘Levee’.
Ecologically Sustainable Development (ESD)	‘Protection of the environment while allowing for the development that improves the total quality of life, both now and in the future, in a way that maintains the ecological processes on which life depends.’
Ecology	The interrelationships between plants, animals and humans, which compete and depend on each other for existence in the physical environment.

Term	Definition
Event Mean Concentration (EMC)	Pollutant load washed off by a storm event divided by the runoff volume.
Energy dissipator	Any means to reduce the total energy of flowing water, especially high-velocity flows. In stormwater design, they are usually mechanisms that reduce velocity prior to, or at, discharge from an outfall in order to prevent erosion. Materials used include gabions, concrete splash pads, drop structures, riprap and boulders.
Environment	Refers to the conditions in which an organism lives and survives or the conditions in which an object or organism resides. These conditions can be described as aspects of a 'physical', 'social' or an 'economic' environment, depending on the perspective perceived by the observer. The *Environmental Protection Act* (1994) describes the environment as including: a) ecosystems and their constituent parts, including people and communities b) all natural and physical resources c) the qualities and characteristics of locations, places and areas, however large or small that contribute to their biological diversity and integrity, intrinsic or attributed scientific value or interest, amenity, harmony and sense of community d) the social, economic, aesthetic and cultural conditions that affect, or are affected by things mentioned in paragraphs a) to c).
Environmental Design Report (EDR)	Outlines the ways in which environmental requirements outlined in the EMP (Planning) have been incorporated into the detailed design and contract documentation. It is an audit report and not a contract document.
Environmental Management Plan (EMP) (Construction)	Prepared by the Construction Contractor, considering the management of environmental impacts of activities in a given road project during the construction period. It identifies risks to the environment for the project and the environmental requirements contained within the contract documentation and outlines key strategies for managing these risks and minimising undesirable environmental impacts.
Environmental Management Plan (EMP) (Maintenance)	Prepared by the Maintenance Contractor. It considers the management of environmental impacts of activities in a given maintenance project, as well as environmental requirements contained within the contract documentation. It focuses on the minimisation of adverse effects (and the management of these effects) on the environment by maintenance activities required.
Environmental Management Plan (EMP) (Planning)	Sets out the overall requirements, outcomes and performance indicators for the design, construction and maintenance of a road project.
Environmental Monitoring	Includes activities which gather and evaluate information used for the assessment of environmental performance.
Erosion	1. The wearing away of the land surface by moving water, wind, ice or other geological agents, including such processes as gravitational creep. 2. Detachment and movement of soil or rock fragments by water, wind, ice or gravity (i.e. accelerated, geological, gully, natural, rill, sheet, splash, or impact, etc.).
Erosion control	Includes the protection of soil from dislocation by water, wind or other agents.
Erosivity	The erosive potential of rainfall expressed as the product of total storm energy and the maximum 30-minute intensity of each storm.

Term	Definition
Exceedances per Year (EY)	Used for events with an Annual Exceedance Probability (AEP) more frequent than 50%, the number of times a given condition is exceeded in any year.
Extreme flood	The rare flood event for which the performance of a detention basin or similar structure should be checked in order to assess the economic and social risk that could be associated with overtopping or failure of that structure.
Fan	A level to very gently inclined landform associated with rapidly migrating stream channels. The landform occurs as a typical fan shape below uplands on hard rock and is formed by deposition of alluvial material through overbank stream flow and overland sheet flow.
Filter fabrics	See 'Geotextile'.
Filter material	Granular material with the grading selected so that it will allow water to pass through it while retarding the movement of soil particles.
Filter strip	Typically a long, relatively narrow area of undisturbed or planted vegetation used to retard or filter sediment for the protection of watercourses, drainage basins, diversions, reservoirs or adjacent properties.
Flocculant	A chemical agent used to enhance the flocculation process (see 'Flocculation').
Flocculation	The process of combining individual soil particles to form larger aggregates to facilitate settling.
Flood boundary line	A line defining the edge of the area submerged at the height of a flood. Usually related to a given recurrence interval.
Floodgate	1. A gate placed in a channel, drain or culvert to control the passage of flood or tidal water. 2. A gate placed in a fence where it crosses a watercourse or drain, which permits the passage of stormwater or floodwater but acts otherwise as an integral part of the fence.
Floodplain	The relatively flat area adjoining the channel of a natural stream which has been or may be inundated with flood waters.
Floodway	Longitudinal depression in a carriageway specially constructed to allow the passage of floodwater across it without damage.
Fraction impervious	That part of a catchment which is impervious, expressed as a decimal or percentage.
Freeboard	The height between a given water level and the underside of a bridge, top of a channel or embankment, or floor of a building to give a factor of safety against calculated design flood levels.
Friction slope	Sometimes referred to as the 'hydraulic gradient' or 'pressure gradient' and is the slope of the line representing the pressure head or piezometric head in a pipeline.
Froude number	Froude number is proportional to the square root of the ratio of the inertial forces over the weight of fluid. For an irregular section $F = V \Big/ \sqrt{g \frac{A}{B}}$ Where V is the mean velocity, A is the cross-sectional area, B is the free surface width and g is acceleration due to gravity. When Fr < 1, then flow is subcritical, when Fr = 1, flow is critical and when Fr > 1, flow is supercritical.

Term	Definition
Gabion (reno mattress)	1. Wire mesh basket or cage filled with rock and used to retain earth or as a protecting agent against erosion. Used as energy dissipators, channel liners, steep slope protectors, and retaining walls. 2. Geotextiles filled with soil, in which cuttings (brush) are placed used for streambank stabilisation and termed soft gabions.
Geofabric	See 'Geotextile'
Geotextile (filter fabric, geofabric)	1. A synthetic fabric, woven or non-woven, used for various purposes, including embankment reinforcing and stabilisation as a filter layer between dissimilar materials and as a strain alleviating membrane. 2. Channel lining – to protect channels against erosion and to filter fine particles from runoff.
Grading	Any stripping, cutting, filling, stockpiling, or combination thereof which modifies the land surface.
Ground water	The water below the water table.
Grubbing	The removal of roots and stumps below ground level.
Head	The difference in water level upstream and downstream of a structure.
Headloss coefficient (pressure)	A dimensionless coefficient which, when multiplied by the velocity head in the outlet pipe, gives the difference in the level of the hydraulic grade line (HGL) between the inlet and outlet pipes. It may be positive (indicating that the HGL rises upstream) or negative (indicating that the HGL is less upstream).
Headwater	The height of water above the invert of a culvert measured at the inlet of the culvert.
High level basin outlet	The outlet of a detention/retention basin from which flows greater than those handled by the low level outlet will be discharged (usually a weir type or glory hole spillway).
Hydraulic design	In relation to stormwater drainage, this involves the determination of velocities, the hydraulic grade line and water levels as storm runoff passes through the drainage system.
Hydraulic Grade Line (HGL)	A line representing the pressure head along a pipeline, corresponding to the effective water surface elevation in the piped portions of the stormwater drainage systems.
Hydraulic gradient	The slope of the hydraulic grade line – see also 'Friction slope'.
Hydrograph	A graph of stream height or volume rate of flow past a specific point against time.
Hydrology	Prediction of runoff based on an assessment of rainfall.
Hydromulching	A mechanical method of applying seed, lime, fertiliser and mulch in a water slurry to which has been added fixatives for soil stabilisation.
Immunity / Flood immunity	The probability of the storm event for which flood extents do not exceed above or encroach beyond defined limits. Used as a design criterion for road drainage elements. Expressed in terms of either an Annual Exceedance Probability (AEP) or a number of Exceedances per Year (EY).
Impact Assessment Study (IAS)	A detailed study of the likely effects (both positive and negative) on the environment and of the ameliorative strategies proposed for a particular project.
Impermeable	Cannot be penetrated by a fluid such as air or water, but commonly refers to water penetration.

Term	Definition
Impervious area	The area within a drainage catchment that is impermeable.
Infiltration	The slow movement of water into or through a soil or drainage system.
Inlet control	A condition where discharge through a culvert is dictated by the depth of headwater and entrance geometry at the inlet.
Intensity–Frequency–Duration Data (IFD)	Rainfall data used in the calculation of rainfall runoff rates.
Invert	The lowest portion of the internal surface of a drain or culvert.
Junction structure	A pit or chamber constructed at the junction of two or more pipes, or at a change of grade.
Lake	Includes 1. A lagoon, swamp, or other natural collection of water, whether permanent or intermittent 2. The bed and banks, and any other element, confining or containing the water (*Water Act 2002*, Queensland).
Land use (development category)	The particular use or uses of land within a catchment, such as central business, commercial, industrial, residential, open space and parks, major and minor roads.
Leaching	The removal of soluble material and colloids by percolating water.
Legal point of discharge	A point of discharge which is either under the control of a local authority or statutory authority, or at which discharge rights have been granted by registered easement in favour of the local authority or statutory authority, and at which discharge from a development will not create a worse situation for downstream property owners than that which existed prior to the development.
Levee	An earth or rock embankment constructed to prevent flooding of low lying land (for example, along the banks of a stream or river) or control the level or direction of flow of water at or into a structure.
Level spreader	A device to convert channel or pipe flow to sheet flow to prevent concentrated, erosive flows from occurring, and to enhance filtration.
Loss rate	The rate at which rainfall is lost through processes such as infiltration, evaporation and local storage and, therefore, does not contribute to surface runoff.
Major drainage system	The major drainage system is that part of the overall drainage system which is designed to convey a specified rare flood event. This system may comprise: a) open space floodway channels, road reserves, pavement expanses and other flow paths that can act as overland flow paths for flows in excess of the capacity of the minor drainage system b) detention basins and lagoons c) major underground piped systems installed where overland flow is either impractical or unacceptable.
Major road	A road to which is assigned a permanent priority for traffic movement over that of other roads.
Major storm	The design storm with an average recurrence interval selected on the basis of satisfying requirements for flood immunity and safety. Design may vary in accordance with local authority guidelines. For most development in Queensland, the major storm has an ARI of 100 years.

Term	Definition
Manning's roughness coefficient	A measure of the surface roughness of a conduit or channel to be applied in Manning's Equation.
Minor drainage system	The minor drainage system includes kerbs and channels, roadside channels, inlets, underground drainage, junction pits or access chambers and outlets designed to fully contain and convey a design minor stormwater flow of specified Average Recurrence Interval (ARI). This arrangement may also include: a) field gully inlet pits installed to collect surface runoff from within allotments, as well as the roofwater drainage provisions for buildings b) cross-drainage under minor roads where delay or inconvenience during major flows is acceptable. This also includes low flow pipes or box culverts installed under floodways c) low flow pipes installed under drainage reserves or park areas.
Minor road	A road whose primary function is to provide access to individual properties.
Minor storm	The design storm with an average recurrence interval selected on the basis of satisfying requirements for convenience and safety of pedestrians and vehicles. Design may vary in accordance with local authority guidelines. For most development in Queensland, the minor storm has an Average Recurrence Interval (ARI) of between two and 10 years.
Mulch anchoring	A method used to increase the effectiveness of mulch against surface erosion by water and wind. Binding agents, referred to as 'tackifiers', are mixed with the mulch in a water slurry prior to application.
Mulching	The application of plant residues or other suitable material to the land surface to conserve moisture, hold the soil in place, aid in establishing plant cover, increase infiltration and minimise temperature fluctuations.
Normal flow conditions	A condition in open channel flow where the depth and velocity of flow achieved is consistent with the prevailing channel shape, slope and roughness.
Obvert	The highest portion of the internal surface of a culvert or arch.
Open graded asphalt	A bituminous mix using aggregate containing only small amounts of fine material and providing a high percentage of air voids.
Outlet	The point at which water discharges from a stream, river, lake, tidewater, or artificial drain.
Outlet control	The situation where factors downstream of the culvert entry, such as high water level at the outlet, govern the discharge characteristics.
Outlet protection	Scour protection placed downstream of a pipe or culvert outlet to complete the transition between pipe flow and open channel flow. Pipe outlet protection may be provided by energy dissipaters, channel protection (non-structural and structural methods), or a combination of the two. See also 'Apron'.
Overland flow path	Open space floodway channels, road reserves, pavement expanses and other flow paths that convey flows typically in excess of the capacity of the minor drainage system.
Permeability	The property of a material by virtue of which a fluid, such as water, can pass through it.
Pervious surface (pervious area)	A surface or area within a drainage catchment where some of the rainfall will infiltrate, thus resulting in a reduced volume and rate of runoff, e.g. grassed playing fields, lawns, etc.

Term	Definition
Piping	Refer to 'Tunnel erosion'.
Pressure change coefficient	Refers to 'Headloss coefficient (pressure)'.
Probable maximum flood	The theoretically greatest runoff event from a catchment.
Probable maximum precipitation	The greatest theoretical depth of precipitation for a given duration that is physically possible over a catchment.
Rainfall intensity	The rate of rainfall in millimetres per hour.
Reach	A section or length of stream/channel/river over which the physical characteristics are similar.
Retention basin	See 'Detention basin'
Revetment	A facing of stone or other material laid on a sloping face of earth to maintain the slope in position or to protect it from erosion.
Review of Environmental Factors (REF) (concept)	Broadly identifies, describes and assesses environmental advantages, disadvantages and constraints associated with particular broadly defined routes or corridors during the concept phase of the Roads Delivery Program.
Review of Environmental Factors (REF) (planning)	Identifies, describes and assesses the environmental advantages, disadvantages and constraints associated with chosen route options during the Planning and Preliminary Design Phase.
Riprap	Medium to large size rock protection applied (usually by dumping) to the face of an embankment in a waterway or as an outlet protection from a storage.
Road	A route trafficable by motor vehicles – in law, the public right of way between boundaries of adjoining property.
Rock Sediment Trap	Barriers consisting of rock placed in a channel to trap sediment through the temporary detention of water.
Runoff	That portion of the water precipitated onto a catchment area which flows as surface discharge from the catchment area past a specified point.
Run-on	Water that accumulates at a site (compared with runoff water that exits a site).
Scour	A term commonly used to mean localised erosion of a bank or channel which typically occurs due to excessive slope, turbulence or flow velocity.
Sediment basin	A basin or tank in which stormwater containing settleable solids is retained to remove by gravity or filtration a part of the suspended matter.
Sediment curtain	A piece of material, typically geotextile, attached to floats and weights and extending from the floor of a water body (e.g. sea, lake, river) to the surface and used to trap sediments. Also referred to as 'silt curtain'.
Sediment fence	A barrier typically consisting of permeable material stretched between and attached to supporting posts and entrenched in the earth.
Sediment trap	Generally, sediment traps are smaller versions of sediment basins.
Sedimentation	Deposition of material of varying size, both mineral and organic, away from its site of origin by the action of water, wind, gravity or ice.
Seeding	Refers to the establishment of perennial warm season grasses for the stabilisation of disturbed soils.

Term	Definition
Sheet flow	Water, usually storm runoff, flowing in a thin layer over the ground surface. Also referred to as 'overland flow'.
Silt	An alluvial material intermediate in particle size between sand and clay (0.002–0.02 mm). It is usually non-plastic.
Sodicity	A measure of the exchangeable sodium percentage (ESP) of soil material. Soil material with an ESP of < 6 is referred to as 'non-sodi'c. Soil material with an ESP of 6–15 is referred to as 'sodic'. Soil material with an ESP > 15 is referred to as 'strongly sodi'c.
Soil dispersion	The process by which soil aggregates disperse into individual particles (clay, silt and sand) in water.
Specific energy	The measure of the total energy of water flow at a particular location. It is the combination of static, velocity and pressure heads and is measured as a height with the channel bottom as the datum and expressed in metres of water. For any cross-sectional shape, the specific energy 'E' at a particular section is defined as: $E = y + \alpha V^2/2g + P/\rho g$ where V is the mean velocity, P is the pressure, r is the density of water, y is the flow depth, g is acceleration due to gravity and α is the kinetic energy correction factor which accounts for velocity variations across the section.
Spillway	An open or closed outlet used to convey water from a reservoir or basin. Usually used to convey a given design runoff.
Sprayed Seal (flush seal)	A thin layer of binder sprayed onto a pavement surface with a layer of aggregate incorporated and which is impervious to water.
Stabilisation (soil)	The provision of adequate measures (vegetation, mulches, geotextiles, riprap and other structural measures) to prevent erosion from occurring.
Stabilised construction exit	Stabilisation of exposed soil at construction exits to reduce or eliminate sediment from leaving the construction site. Common materials or controls include gravel, aggregate cover and timber, and cattle grids.
Stabilised material (soil)	A natural material which has been modified to improve or maintain its load carrying capacity or reduce erosion. Modification may be by the addition of other natural materials such as sand, loam or clay or of manufactured materials such as bitumen, lime and cement.
Stream bank protection	Measures used to protect existing stream banks from eroding. Measures may include loose or anchored materials, such as large boulders, brush mats, geotextiles, logs or concrete.
Structure	Soil structure refers to the size, shape and arrangement of particles and aggregates, and the size, shape and arrangement of voids or spaces separating the particles and aggregates.
Subcritical flow	Flow in a channel or conduit which has a Froude number less than 1, a depth greater than the critical depth and a velocity less than the critical velocity. In practice, subcritical flows are controlled by the downstream flow conditions.
Subsoil drain	A drain below the ground surface, which collects subsurface water throughout its length.
Supercritical flow	Flow in a channel or conduit which has a Froude number greater than 1, a depth less than the critical depth and a velocity greater than the critical velocity. In practice, supercritical flows are controlled from upstream.

Term	Definition
Superelevation	1. The continuous transverse slope normally given to the carriageway at horizontal curves. 2. The phenomenon where flow around a horizontal curve in an open channel is at a higher level at the outer edge than at the inner edge of the curve.
Surcharge overflow	That portion of the flow which is forced out of a piped system at a gully inlet, manhole or surcharge structure when the downstream pipe system capacity is exceeded.
Surface condition	Surface condition refers to the characteristic appearance of the surface soil when dry. Conditions including cracking, firm, loose and soft.
Swale	A shallow constructed channel, often grass-lined, which is used as an alternative to kerb and channel or as a pre-treatment to other measures. Swales are generally characterised by a broad top width to depth ratio and gentle grades.
Table drain	The side drain of a road adjacent to the shoulders, having its invert lower than the subgrade level and being part of the formation.
Temporary seeding	Refers to the use of soil stabilisation with grasses that will establish quickly and have longevity of one year or less.
Terrace	A former flood plain on which alluvial deposition and erosion are barely active or inactive.
Terracing	Grading technique which reduces slope length through the creation of benches.
Tidal definitions	a) Highest Astronomical Tide (HAT) – Highest tide level which can be predicted to occur under average meteorological conditions and under any combination of astronomical conditions. b) Lowest Astronomical Tide (LAT) – Lowest tide level which can be predicted to occur under average meteorological conditions and under any combination of astronomical conditions. c) Mean High Water Springs (MHWS) – The long-term average of the heights of two successive high tides when the range of tide is greatest, at full moon and new moon. d) Mean Low Water Springs (MLWS) – The long-term average of the heights of two successive low tides when the range of tide is greatest, at full moon and new moon. e) Mean High Water Neaps (MHWN) – The long-term average of the heights of two successive high tides when the range of tide is the least, at the time of the first and last quarter of the moon. f) Mean Low Water Neaps (MLWN) – The long-term average of the heights of two successive low tides when the range of tide is the least, at the time of the first and last quarter of the moon. g) Mean Sea Level (MSL) – The average level of the sea over a long period. h) Storm Surge – The increase in sea level occurring during a cyclone resulting from the combines effect of reduced atmospheric pressure and the buildup of water against the shore caused by onshore wind (wind stress). i) Wave Setup – The raising of sea level inside the surf zone resulting from the momentum flux of broken waves.
Time of concentration	The shortest time necessary for all points on a catchment to contribute simultaneously to runoff past a specified point.

Term	Definition
Trafficability	A road is defined as trafficable when the total head (static plus velocity) across a carriageway is less than or equal to 300 mm.
Transition loss coefficient	Coefficient associated with headlosses at open channel transitions.
Tunnel erosion	The removal of subsoil by water while the surface remains relatively intact – also referred to as 'piping'.
Vegetative protection	Stabilisation of erodible areas through covering with vegetation.
Velocity head	A measure of the kinetic energy of flow in a pipe or channel and equal to V2/2g where V is the average velocity of flow.
Water surface elevation	The elevation of the water surface reached in a gully inlet, manhole, junction structure or open channel.
Water table	1. In an aquifer, the upper limit of the portion of ground saturated with water. 2. The natural level at which water stands in a borehole or well under conditions of equilibrium.
Watercourse	A river, creek or stream in which water flows permanently or intermittently in a natural or artificial channel. For legal definition, refer *Water Act 2000* (Qld).
Waterway	1. A channel or stream. 2. The area available for water to pass through or under a structure.

References

The following lists the references used (either cited or consulted) in compiling this manual.

American Association of State Highway and Transportation Officials (AASHTO). 1991. *Model Drainage Manual*. Washington: unknown.

American Society of Civil Engineers (ASCE). 1992. *Design and Construction of Urban Stormwater Management Systems. Engineering Practice No 77.* New York: American Society of Civil Engineers.

Australian National Committee On Large Dams (ANCOLD). 2000. *Guidelines on Selection of Acceptable Flood Capacity for Dams*.

Argue, J. R. 1960. *New Structure for Roadway Pipe Culverts*. The Journal of the Institution of Engineers, Australia. Sydney: Institution of Engineers, Australia.

Argue, J. R. 1986. *Special Report No 34. Storm Drainage Design in Small Urban Catchments*. Australia: Australian Road Research Board.

Australian and New Zealand Environment and Conservation Council (ANZECC). 2000. *Australian and New Zealand Guidelines for fresh and marine water quality*. Australia: unknown.

Australian Road Research Board (ARRB). 1987. *Special Report No 35. Subsurface Drainage of Road Structures*. Australia: Australian Road Research Board.

Australian Road Research Board (ARRB). 1998. *Part I Biodiversity and Road Drainage Issues, Part II Practical Rules to Reduce Impacts of Drainage on Ecosystems and Part III Applications of Improved Drainage Management*. Draft. Australia: Australian Road Research Board.

Australian Standard (AS) 1348. 2002. *Glossary of terms – Roads and traffic engineering*. Australia: Standards Australia.

Australian Standard (AS) 1726. 1993. *Geotechnical site investigations*. Australia: Standards Australia.

Australian Standard (AS) 1761. 1985. *Helical lock-seam corrugated steel pipes*. Australia: Standards Australia.

Australian Standard (AS) 1762. 1984. *Helical lock-seam corrugated steel pipes – Design and installation*. Australia: Standards Australia.

Australian Standard (AS) 2041. 1998. *Buried corrugated metal structures*. Australia: Standards Australia.

Australian Standard (AS) 3725. 1989. *Loads on Buried Concrete Pipes*. Australia: Standards Australia.

Australian Standard (AS) 3996. 2006. *Access covers and grates*. Australia: Standards Australia.

Australian Standard (AS) 4058. 2007. *Precast concrete pipes (pressure and non-pressure)*. Australia: Standards Australia.

Australian Standard (AS) 4685.1. 2004. *Playground equipment*. Australia: Standards Australia.

Australian Water and Coastal Studies (AWACS). 1990. *Smeaton Grange Industrial Development – Hydraulic Model Testing of Drop Structure*. Report 90/15. Sydney: unknown.

Austroads. 1994. Waterway Design – *A guide to the hydraulic design of bridges, culverts and floodways*. Sydney: Austroads.

Austroads. 2005. *Guidelines for the management of road surface skid resistance*. Sydney: Austroads Inc.

Austroads. 2010. *Guide to Road Design. Part 5: Drainage Design*. Sydney: Austroads Inc.

Austroads. 2008b. *Guide to Road Design, Part 7: Geotechnical Investigation and Design*. Sydney: Austroads Inc.

Ball, J.E., Jenks, R. and Aubourg, D. 1998. *An assessment of the availability of pollutant constituents on road surfaces*. The Science of the Total Environment, 209: 243–254.

Barnes, D., P. J. Bliss, B. W. Gould, and H. R. Vallentine. 1981. *Water and Wastewater Engineering Systems*. Great Britain: Pitman.

Beecham, S. C. and S. J. Sablatnig. 1994. Hydraulic modelling of stormwater trash racks. *Proceeding of the International Conference on Hydraulics in Civil Engineering, NCP 94/1*, 97–104.

Blaisdell, F. W. 1948. *Development and Hydraulic Design, The SAF Stilling Basin. Report SCS-TP-79*. United States of America: US Soil Conservation Service.

Blaisdell, F. W. 1948. *Development and Hydraulic Design, Saint Antony Falls Stilling Basin. Transactions of the American Society of Civil Engineers*, Volume 113. United States of America: ASCE.

Blaisdell, F. W. 1949. *The SAF Stilling Basin. Technical Bulletin No 79*. United States of America: US Soil Conservation Service.

BMT WBM 2007. *State-wide Review of the Use of Road Runoff Treatment Devices and Water Monitoring Programs*. Brisbane: Queensland Department of Main Roads & BMT WBM Pty Ltd.

Bohan, J. P. 1970. *Erosion and Riprap Requirements at Culvert and Storm-Drain Outlets. US Army Engineer Waterways Experiment Station, Research Report H-70-2*. Vicksburg, Mississippi: US Army.

Brater, E. F., H. W. King, J. E. Lindell and C. Y. Wei. 1996. *Handbook of Hydraulics* (Seventh Edition). USA: McGraw-Hill.

Brisbane City Council (BCC). 1996. *Environmental Best Management Practice (Volume 1) for Erosion and Sediment Control and for Waterways and Wetlands*. Brisbane: Brisbane City Council.

Brisbane City Council (BCC). 2001. *Sediment Basin Design, Construction and Maintenance Guidelines*. Brisbane: Brisbane City Council.

Bureau of Meteorology (2013) *Intensity-Frequency-Duration Data Report and Release*. http://www.bom.gov.au/water/designRainfalls/ifd/index.shtml.

Bureau of Public Roads. 1965. *Hydraulic Charts for the Selection of Highway Culverts*. Washington DC: US Department of Commerce.

Bureau of Reclamation. 1960. *Design of Small Dams*. Washington DC: US Department of the Interior.

Bureau of Reclamation. 1964. *Hydraulic Design of Stilling Basins and Energy Dissipaters, Engineering Monograph No.25*. Washington DC: US Department of the Interior.

Cameron and McNamara. 1966. *Report on Model Investigation of Causeway Design for Commonwealth Department of Works, Darwin and Queensland Main Roads Department*. Unknown.

Camp, Dresser and McKee. 1993, *California Storm Water Best Management Practice Handbooks: Municipal*. (prepared for California Stormwater Quality Task Force). Unknown.

Chiew, F. H. S., L. B. Mudgway, H. P. Duncan, and T. A. McMahon. 1997. *Urban stormwater pollution. Industry Report 97/5*. Australia: CRC for Catchment Hydrology.

Chiu, A and W. R. Rahmann. 1980. *Drainage Design and Outlet Protection*. Brisbane: Department of Main Roads.

Chow, V. T. 1959. *Open Channel Hydraulics*. New York: McGraw-Hill Book Company Inc.

Cotterell, E. 1998. *Fish Passage in Streams: Fisheries guidelines for design of stream crossings*. Brisbane: Department of Primary Industries.

Cottman, N. H., and G. R. Mackay. 1990. *Bridges and Culverts Reduced in Size and Cost by Use of Critical Flow Transitions*. Proceedings Institution Civil Engineers (London), Part 1, Volume 88.

Commonwealth Scientific and Industrial Research Organisation CSIRO. 1989. *Greenhouse: Planning for Climate Change*. Melbourne: CSIRO Publishing.

Commonwealth Scientific and Industrial Research Organisation CSIRO. 2006. *Urban Stormwater Best Practice Environmental Management Guidelines*. Melbourne: CSIRO Publishing.

Commonwealth Scientific and Industrial Research Organisation CSIRO. 2013. “Sea level Rise: Understanding the past – Improving projections for the future” http://www.cmar.csiro.au/sealevel/sl_proj_21st.html.

Dash, D. M. 1977. *Life Cycle Study F3 Sydney to Newcastle Highway, Surface Characteristics*. Australia: Roads and Transport Technology.

Dash, D. 2006. *Aquaplaning literature review*. Sydney: Roads and Traffic Authority (NSW).

Department of Agricultural and Biological Engineering. 1996. *Reducing Sediment Discharge from Sedimentation Basins with Barriers and a Skimmer*. Pennsylvania: Pennsylvania State University.

Department of Agricultural and Biological Engineering. 1996. *Sedimentation Basins Evaluation and Design Improvements*. Pennsylvania: Pennsylvania State University.

Department of Agriculture, Soil Conservation Service (USA). 1975. *Standards and Specifications for Soil Erosion and Sediment Control in Developing Areas*. Maryland.

Department of Conservation and Land Management (NSW). 1992. *Urban Erosion and Sediment Control*. Sydney.

Department of Energy and Water Supply (QLD) (DEWS). 2013 (provisional) *Queensland Urban Drainage Manual* (QUDM) 3rd Edition. Brisbane: Department of Natural Resources & Water.

Department of Environment (QLD). 1997. *A User's Guide to Queensland Environmental Protection (Water) Policy*. Brisbane.

Department of Environment and Heritage Protection (QLD). 2009. *Queensland Water Quality Guidelines (QWQG)*. Brisbane: EPA.

Department of Environment and Heritage Protection (QLD). 2012. ‘*Queensland Coastal Plan*’.

Department of Employment, Economic Development and Innovation (QLD). 2009. *Fish Habitat Management Operational Policy (FHMOP 008) – Waterway barrier works development approvals*. Brisbane: Queensland Fisheries.

Department of Housing (NSW). 1998. *Managing Urban Stormwater – Soils and Construction (Third Edition*). Sydney.

Department of Land and Water Conservation (NSW). 1998. *The constructed wetlands manual, Volume 1 and 2 Department of Land and Water Conservation*. Sydney.

Department of Main Roads (QLD) (DMR). 1997a. *Erosion and Sediment Control Manual*. Brisbane: Queensland Department of Main Roads.

Department of Main Roads (QLD) (DMR). 1997b. *Roads in the Wet Tropics – Planning, Design, Construction, Maintenance and Operation Best Practice Manual*. Brisbane: Queensland Department of Main Roads.

Department of Main Roads (QLD) (DMR). 1998. *Cultural Heritage Manual*. Brisbane: Queensland Department of Main Roads.

Department of Main Roads (QLD) (DMR). 2000. *Fauna Sensitive Road Design, Volume 1 – Past and Existing Practices*. Brisbane: Queensland Department of Main Roads.

Department of Main Roads (QLD) (DMR). 2001a. *Queensland Environmental Legislation Register, 2nd edition*. Brisbane: Queensland Department of Main Roads.

Department of Main Roads (QLD) (DMR). 2001b. *Road Maintenance Contracts, Volume 2: Open Competition*. Brisbane: Queensland Department of Main Roads.

Department of Main Roads (QLD) (DMR). 2002a. *Asset Maintenance Guidelines*. Brisbane: Queensland Department of Main Roads.

Department of Main Roads (QLD) (DMR). 2002b *Road Drainage and Design Manual*. Brisbane: Queensland Department of Main Roads.

Department of Main Roads (QLD) (DMR). 2004. *Road Maintenance Contracts, Volume 3: Guidelines for undertaking maintenance*. Brisbane: Queensland Department of Main Roads.

Department of Main Roads (QLD) (DMR). 2005a. *Preconstruction Processes Manual*. Brisbane: Queensland Department of Main Roads.

Department of Main Roads (QLD) (DMR). 2005b. *Road construction erosion & sediment control workshop*. Brisbane: Queensland Department of Main Roads.

Department of Main Roads (QLD) (DMR). 2006. *Road Planning & Design Manual (RPDM) Bridges and Retaining Walls* (Chapter 22). Brisbane: Queensland Department of Main Roads.

Department of Main Roads (QLD) (DMR). 2007. *Road Maintenance Contracts, Volume 1: Sole Invitee*. Brisbane: Queensland Department of Main Roads.

Department of Main Roads (QLD) (DMR). 2008a. *Guidelines for Strategic Road Network Planning.* Brisbane: Queensland Department of Main Roads.

Department of Main Roads (QLD) (DMR). 2008b. *Macrotexture and Microtexture for Road Surfacings – Development of Interim Initial Standards*. Brisbane: Queensland Department of Main Roads.

Department of Main Roads (QLD) (DMR). 2009 *Standard Drawings (Roads) Manual*. Brisbane: Queensland Department of Main Roads.

Department of Natural Resources & Water (QLD) (NR&W). 2007. *Guidelines on Acceptable Flood Capacity for Dams*. Brisbane: Department of Natural Resources & Water.

Department of Natural Resources & Water (QLD) (NR&W). 2008. *Queensland Urban Drainage Manual* (QUDM) 2nd Edition. Brisbane: Department of Natural Resources & Water.

Department of Primary Industries (DPI) (QLD). 1978. *Soil Conservation Handbook*. Brisbane.

Department of Primary Industries (DPI) (QLD). 1992. *Soil Conservation Handbook Part 9 – Design of Structures*. Brisbane.

Department of Primary Industries (DPI) (QLD). 1998. *Fisheries, Fish Passage in Streams – Fisheries Guidelines for Design of Stream Crossings*. Brisbane.

Department of Transport (QLD). 1975. *Urban Road Design Manual – Volume 2*. Brisbane.

Department of Transport. (QLD). 1978. *Charts for the Hydraulic Design of Channels and Pipes*. London, UK: HMSO.

Department of Transport and Main Roads (QLD) (TMR). 2009. MRTS27 *Geotextiles (Separation and Filtration)* June 2009. Brisbane: Queensland Department of Transport and Main Roads.

Department of Transport and Main Roads (QLD) (TMR). 2012. *Project Cost Estimating Manual*. Brisbane: Queensland Department of Main Roads.

Department of Transport and Main Roads (QLD) (TMR). 2013. *Design Criteria for Rehabilitation of Circular Corrugated Metal Culverts*. Brisbane: Queensland Department of Main Roads.

Department of Transport and Main Roads (QLD) (TMR). 2013. *Road Planning & Design Manual – Queensland Practice*. Brisbane: Queensland Department of Transport and Main Roads.

Department of Transport and Main Roads (QLD) (TMR). 2013a. *Road Landscape Manual*. Brisbane: Queensland Department of Main Roads.

Department of Transport and Main Roads (QLD) (TMR). 2013b. *Road Traffic Noise Management: Code of Practice*. Brisbane: Queensland Department of Main Roads.

Department of Transport and Main Roads (QLD) (TMR). 2013c. *Road Project Environmental Processes Manual*. Brisbane: Queensland Department of Main Roads.

Department of Transport and Main Roads (QLD) (TMR). 2013d. *Road Planning and Design Manual.* Brisbane: Queensland Department of Main Roads.

Department of Transport and Main Roads (QLD) (TMR). 2014. *Design Criteria for Bridges and Other Structures*. Brisbane: Queensland Department of Main Roads.

Department of Transport and Main Roads (QLD) (TMR). 2014a. MRTS26 *Manufacture of Fibre Reinforced Concrete Drainage Pipes* September 2014. Brisbane: Queensland Department of Transport and Main Roads.

Department of Transport and Main Roads (QLD) (TMR) 2014b MRTS 25 *Manufacture of Precast Concrete Pipes* September 2014. Brisbane: Queensland Department of Transport and Main Roads.

Department of Transport and Main Roads (QLD) (TMR) 2014c MRTS16 *Landscape and Revegetation Works* October 2014. Brisbane: Queensland Department of Transport and Main Roads.

Department of Transport and Main Roads (QLD) (TMR): 2014d MRTS04 *General Earthworks* October 2014. Brisbane: Queensland Department of Transport and Main Roads.

Department of Transport and Main Roads (QLD) (TMR): 2014e Guideline *Storm Tide – Issues for Design of Road Infrastructure in Coastal Areas.* 2014. Brisbane: Queensland Department of Transport and Main Roads.

Department of Transport and Main Roads (QLD) (TMR). 2015a *Technical Specification and Specification (Measurement) 52 Erosion and Sediment Control* January 2015. Brisbane: Queensland Department of Transport and Main Roads.

Department of Transport and Main Roads (QLD) (TMR). 2015b MRTS03 *Drainage, Retaining Structures and Protective Treatments* April 2015. Brisbane: Queensland Department of Transport and Main Roads.

Department of Transport and Main Roads (QLD) (TMR). 2015c MRTS01 *Introduction to Technical Specifications* January 2015. Brisbane: Queensland Department of Transport and Main Roads.

Department of Transport and Main Roads (QLD) (TMR) 2015d MRTS24 *Manufacture of Precast Concrete Culverts* January 2015. Brisbane: Queensland Department of Transport and Main Roads.

Department of Transport (USA). 1972. *Hydraulic Design of Improved Inlets for Culverts, Hydraulic Engineering Circular No.13*. Washington DC.

Department of Transport (USA). 1983. *Hydraulic Design of Energy Dissipaters for Culverts and Channels. Hydraulic Engineering Circular No.14*. Washington DC.

Department of Transportation (USA). 1995. *Best Management Practices of Erosion and Sediment Control*. Washington DC.

Department of Urban Services (ACT). 1994. *Urban Stormwater: Standard Engineering Practices*. Canberra.

Drapper, D., A. Bell, and R. Tomlinson. 1997. *Analysing Runoff from Road Surfaces; Formulating a Baseline for the Queensland Department of Main Roads*. Storm Water and Soil Erosion 97 Conference, Brisbane.

Earley, P. C. 1979. *Gully Inlet Spacing Design*. Australia: University of Western Australia.

Emerson, W. W. 1967. *A classification of soil aggregates based on their coherence in water*. Australian Journal of Soil Research No.5, 47–57.

Emerson, W. W. 1977. *Determination of the contents of clay sized particles in soils*. Journal of Soil Science No.22, 50–59.

Engineers Australia. 2006. *The Australian Runoff Quality – A guide to Water Sensitive Urban Design*. Australia: Engineers Australia.

Environmental Protection Agency (NSW). 1997. *Treatment techniques, Managing urban stormwater series*. Sydney.

Environmental Protection Agency (QLD). 2008. *Best Practice Urban Stormwater Management – Erosion and Sediment Control Guideline*. Brisbane: EPA.

eWater (2008). *Catchment Modelling Toolkit*, (http://www.toolkit.net.au/music). Canberra: eWater Cooperative Research Centre (CRC).

Frankcombe, M. and R. Coventry. 2001. Townsville City Council, *Revegetation Contractors, Natural Resource Assessment, Catchments & Creeks. Erosion and Sediment Control Planning for North Queensland*. Unknown.

Franzini, J. B. and E. J. Finnemore. 1997. *Fluid Mechanics with Engineering Applications* (Ninth Edition). USA: WCB McGraw-Hill.

Freeman, G and L. Howells. 1995. *Saline Flocculation in Stormwater Quality Management*. Proceedings of the 3rd Annual Conference on Soil and Water Management for Urban Development. Sydney: International Erosion Control Association of Australasia.

Foucard, J. 2005. *Role of tires in the skid resistance phenomenon*. France.

Gallaway, B. M, R. E. Schiller Jr and J. G. Rose. 1971. *The Effects of Rainfall Intensity, Pavement Cross Slope, Surface Texture and Drainage Length on Pavement Water Depths*. Texas: Texas Transportation Institute.

Gallaway, B. M., G. G. Hayes, D. L. Ivey, W. B. Ledbetter, R. M. Olsen, H. E. Ross Jr, R. E. Schiller Jr, and D. L. Woods. 1979. *Pavement and Geometric Design Criteria for Minimising Hydroplaning*. Washington, DC: Federal Highway Administration.

Gillespie, T.D. 1992. *Fundamentals of Vehicle Dynamics*. Warrendale, PA: Society of Automotive Engineers, Inc.

Goldrick, D. A., I. Yassini, and B. G. Jones. 1996. *Flocculation Behaviour of West Dapto and Albion Park Soils Types in Urban Runoff Treatments*. Proceedings of the 4th Annual Conference on Soil and Water Management for Urban Development. Sydney: International Erosion Control Association of Australasia.

Gothié, M. 2005. *Water Influence on Skid Resistance*, Surface Friction: Roads & Runways Conference, 1–4 May 2005, New Zealand.

Griffith University and RUST PPK. 1997. *Erosion Treatment for Urban Creeks, Guidelines for Selecting Remedial Works Guidelines for Brisbane* City. Brisbane.

Hare, C. M. 1983. *Magnitude of Hydraulic Losses at Junctions in Piped Drainage Systems. Australian Transactions, Volume CE25*. Australia: Institution of Engineers.

Hee, M. 1969. *Hydraulics of Culvert Design Including the Constant Energy Concept*. Queensland Local Government Engineers' Conference, Brisbane.

Hee, M. 1978a. *Hydraulic Calculations for Bridges and Culverts*. 2nd Conference, Road Engineering Association of Asia and Australasia. Manila, Philippines.

Hee, M. 1978b. *Selected Case Histories. Workshop on Minimum Energy Design of Culvert and Bridge Waterways*. Australian Road Research Board.

Hee, M. 1993. *Practical and Legal Aspects of Floodway Design*. First Annual Conference, the Institution of Municipal Engineers, Queensland Division.

Henderson, F. M. 1970. *Open Channel Flow*. United States of America: Prentice Hall.

Higgins, R. G. and R. J. Campbell. 1997. *Pacific Motorway (Logan to Nerang) – Case Study: Management of Water Quality Impacts*. Brisbane: Department of Main Roads.

Highway Department. 1962. *Hydraulic Manual*. Texas.

Highway Research Board. 1971. *Design of Culverts, Energy Dissipaters and Filter Systems, Record No.373*. Washington DC.

Horner, R. R., J. J. Skupien, E. H. Livingston, and H. E. Shaver. 1994. *Fundamentals of urban runoff management*. Washington DC: Terrene Institute.

Horne, W. B. 1968. *Tire Hydroplaning and its Effects on Tire Traction*. HRR. No. 214.

Hunt, J. S. 1992. *Urban Erosion and Sediment Control. (revised edition).* Sydney: Department of Conservation and Land Management.

Ibrahim, A and F. Hall. 1994. *Effect of Adverse Weather Conditions on Speed-Flow-Occupancy Relationships*. TRR No. 1457.

IECA (Australasia) 2008. *Best practice erosion and sediment control*. International Erosion Control Association (Australasia).

Institution of Engineers, Australia (IEAust). 1977. *Australian Rainfall and Runoff – Flood Analysis and Design*. Barton, ACT: Institution of Engineers, Australia.

Institution of Engineers, Australia (IEAust). 1985. *Guidelines for the Design of Detention Basins and Grassed Waterways for Urban Drainage Systems*. Sydney.

Institution of Engineers, Australia (IEAust). 1987a. *Australian Rainfall and Runoff – Guide to Flood Estimation, Vol 1*. Barton, ACT: Institution of Engineers, Australia.

Institution of Engineers, Australia (IEAust). 1987b. *Australian Rainfall and Runoff – Guide to Flood Estimation, Vol 2*. Barton, ACT: Institution of Engineers, Australia.

Institution of Engineers, Australia (IEAust). 1996. *Soil Erosion and Sediment Control Engineering Guidelines for Queensland Construction Sites*. (prepared by G. Witheridge and R. Walker). Brisbane.

Institution of Engineers, Australia (IEAust). 2001. *Australian Rainfall and Runoff – Guide to Flood Estimation, Vol 1*. Barton, ACT: Institution of Engineers, Australia.

IPCC (2007) *"Climate Change 2007: Synthesis Report, Contributions of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change".*

IPCC (2013) *"Working Group I Contribution to the IPCC Fifth Assessment Report, Chapter 13 – Sea Level Change – Final Draft Underlying Scientific Technical Assessment".*

Isbell, R.F. 2002. *The Australian soil classification.* Revised edition, CSIRO Publishing.

Ishak, EH, Rahman, A, Westra, S, Sharma, A and Kuczera, G (2013) *"Evaluating the Non-Stationarity of Australian Annual Maximum Flood",* Journal of Hydrology, Vol 494, pp 14–145.

James Cook University of North Queensland (JCU). 1977. *Numerical Simulation of Tropical Cyclone Storm Surge Along the Queensland Coast, Parts I to X.* (prepared for Beach Protection Authority, Department of Environment and Heritage). Townsville.

Keim, S. R. 1962. *The Contra Costa Energy Dissipater*. Journal of the Hydraulic Division, Proceedings of the American Society of Civil Engineers, Vol 188, No.HY2.

Korom, S. F., S. Sarikelle and A. L. Simon. 1990. *Design of Hydraulic Jump Chamber.* Journal of the Hydraulic Division, Proceedings of the American Society of Civil Engineers, Vol 116, No.HY2.

Lawrence, I. and Breen, P. 1998. *Design Guidelines: Stormwater Pollution Control Ponds and Wetlands*. Canberra: Cooperative Research Centre (CRC) for Freshwater Ecology.

Landcom 2004. Managing urban stormwater: *Soils and construction*. (Fourth edition). Landcom NSW.

Local Government and Shires Association (NSW). 1982. *Residential Standards Manual*. Sydney.

Loch, R. J., B. K. Slater, and C. Devoil. 1998. *Soil erodibility (Km) values for some Australian soils*. Australian Journal of Soil Research.

Maccaferri Gabions (London). 1973. *River and Sea Gabions*, London.

MacDonald, T. C. 1969. *Energy Dissipaters for Large Culverts*. Journal of the Hydraulic Division, Proceedings of the American Society of Civil Engineers, Vol 95, No.HY6.

Matthews, M. 2007. *Manual for Erosion and Sediment Control Version 1.1*. Maroochy Shire Council, Qld.

McDonald, R. C., R. F. Isbell, J. G. Speight, J. Walker, and M. S. Hopkins. 1990. *Australian soil and land survey field handbook*. (Second edition). Australia: Inkata Press.

McDonald, R. C., R. F. Isbell, J. G. Speight, J. Walker, M. S. Hopkins, L. J. Gregory, R. J. Hnatiuk and R. Thackway. 2009. *Australian Soil and Land Survey Field Handbook*. (Third edition). Australia: CSIRO Publishing.

Meredith, D.D. 1975. *Model Study of Culvert Energy Dissipater*. Journal of the Hydraulic Division, Proceedings of the American Society of Civil Engineers, Vol 101, No.HY3.

Ministry of Works and Development (NZ). 1978. *Culvert Manual*. Christchurch.

Mockmore, C. E. 1944. *Flow Round Bends in Stable Channels. Transactions of the American Society of Civil Engineers*, Volume 109. United States of America: ASCE.

Moore, D. F. 1975. *The friction of pneumatic tyres*. Amsterdam: Elsevier Scientific Publishing Company.

Moreton Bay Waterways and Catchments Partnership (MBWCP). 2006. *Water Sensitive Urban Design – Technical Design Guidelines for South East Queensland*. Brisbane: Moreton Bay Waterways and Catchments Partnership.

Morse, McVey and Associates. 1993. *Soil and Water Management for Urban Development*. (prepared for New South Wales Department of Housing). Sydney.

Mudgway, L. B., H. P. Duncan, T. A. McMahon and F. H. S. Chiew. 1997. *Best Practice Environment Management Guidelines for Urban Stormwater*. Australia: CRC for Catchment Hydrology.

National Association of Australian State Road Authorities (NAASRA). 1983. *Guide to the Control of Moisture in Roads*. Sydney: NAASRA.

National Association of Australian State Road Authorities (NAASRA). 1986. *Guide to the design of Road Surface Drainage*. Sydney: NAASRA.

National Association of Australian State Road Authorities (NAASRA). 1989. *Bridge Waterways Hydrology and Design*. Sydney: NAASRA.

National Capital Development Commission. 1988. *Design Manual for Urban Erosion and Sediment Control*. Unknown.

Neill, C. R. 1973. *Guide to Bridge Hydraulics*. Canada: Roads and Transportation Association of Canada.

New South Wales Soil Conservation Service. 1998. *Construction Site Erosion and Sediment Control Course Notes*. Sydney: (authors: A. King, D. Greentree and D. Height).

North Carolina Department of Transportation. 1992. *Erosion and Sediment Control Guidelines for Division Maintenance Operations*. Raleigh, North Carolina.

North Carolina Department of Transportation. 1995. *Erosion and Sediment Control Guidelines for Contract Construction*. Raleigh, North Carolina.

North Carolina Sediment Control Commission. 1992. *Erosion and Sediment Control – Inspector's Guide*. Raleigh, North Carolina.

North Carolina Sediment Control Commission. 1993. *Erosion and Sediment Control Planning and Design Manual*, 1993. Raleigh, North Carolina.

O'Loughlin, E. M. 1960. *Culvert Investigations by Hydraulic Models, Harbours and Marines Branch, Hydraulic Laboratory*. Sydney: Department of Public Works.

Oliver, J. W. H. 1979. *Surface Drainage of Road Pavements, the Problem*. Australia: ARRB.

Orange County Planning Department. 1989. *Soil Erosion and Sediment Control Manual*. Hillsborough, North Carolina.

Peterka, A.J. 1984. *Hydraulic Design of Stilling Basins and Energy Dissipaters*. USBR Engineering Monograph 25. Denver: US Bureau of Reclamation.

Premier's Department (QLD). 1989. *The Greenhouse Effect: Implications for Queensland A Discussion Paper*. Brisbane.

Queensland Fisheries (QF). 2009. *Fish Habitat Management Operational Policy (FHMOP 008) – Waterway barrier works development approvals*. Brisbane: Queensland Fisheries (part of Department of Employment, Economic Development and Innovation).

Queensland Government (QG). 2003. *Manual of Uniform Traffic Control Devices*. Brisbane: Queensland Government.

Queensland Government (QG). 2010. *Fauna Sensitive Road Design Manual Volume 2.*Brisbane.

Rand, W. 1955. *Flow Geometry at Straight Drop Spillways*, Transactions of the American Society of Civil Engineers. Volume 81, No 791. United States of America: ASCE.

Rice, C. E. and K. C Kadavy. 1991. *HGL Elevation at Pipe Exit of USBR Type VI Impact Basin*. Journal of the Hydraulic Division, Proceedings of the American Society of Civil Engineers, Volume 117, No.HY7.

Ritchie, J.A. 1963. *Earthwork Tunnelling and the Application of Soil Testing Procedures*. Journal of the Soil Conservation Service of New South Wales, No.19, 111–129.

Roads and Traffic Authority (NSW). 1993. *Road Design Guide – Section 8 "Erosion and Sedimentation*". Sydney.

Roads and Traffic Authority (NSW). 1994. *Draft Guidelines for Limiting the Risk of Aquaplaning on Roads*. Sydney.

Roads and Traffic Authority (NSW). 1995. *Water Quality Management*. Sydney.

Roads and Traffic Authority (NSW). 1996. *Road Design Guidelines*. Sydney.

Roads and Transportation Association of Canada. 1982. *Drainage Manual, Volume 1*. Canada.

Rosenthal, K. M. and B. J. White. 1980. *Distribution of a rainfall erosion index in Queensland. Land Utilisation Report 80/8*. Australia: Queensland Department of Primary Industries.

Rosewell, C. J. and J. B. Turner. 1992. *Rainfall Erosivity in New South Wales*. CaLM Technical Report No.20, NSW. Department of Soil Conservation and Land Management. Sydney.

Rosewell, C. J. and R. J. Loch. 2002. *Estimation of the RUSLE soil erodibility factor, in soil physical measurement and interpretation for land evaluation*. (McKenzie, N., Coughlan, K. and Cresswell, H.) of CSIRO Publishing.

Ross, N. F. and K. Russam. 1968. *The Depth of Rain Water on Road Surfaces*. Berkshire: Road Research Laboratory.

Rouven, N., R-M. Li and D. B. Simons. 1981. *Flow Resistance in Vegetated Waterways*. United States of America: American Society of Agricultural Engineers.

Sangster, W. M., H. W. Wood, E. T. Smerdon and H. G. S. Bossy. 1958. *Pressure Changes at Storm Drain Junctions, Engineering Series Bulletin No 41, Engineering Experimental Station*. United States of America: University of Missouri.

Schueler, T. R., P. A. Kumble and M. A. Heraty. 1992. *A Current Assessment of Urban Best Management Practices: Techniques for Reducing Non-point Source Pollution in the Coastal Zone.* United States of America: US Environment Protection Authority.

SMEC 2008. *Literature Review: Road Runoff Quality and Treatment Technologies*. Queensland Department of Main Roads & SMEC.

Smith, C. D. and J. Yu. 1966. *Use of Baffles in Open Channel Expansions*. Journal of the Hydraulic Division, Proceedings of the American Society of Civil Engineers, Vol 92, No.HY2, plus various discussions: Skogerboe, G. V., M. Leon Hyatt and M. M. Soliman. 1966. ASCE No.HY5, 255–261; Rao, B. V., V. J. Galay and W. H. R. Nimmo. 1966. ASCE No.HY6, 212–215; Dake, J. M. K., S. Kar, S. Raghunathan, V. C. Kulandaiswamy and M. Narayanan. 1967. ASCE No.HYl, 78–85; Smith, C. D. and J. Yu. 1967. ASCE No.HY4, 273–275.

Speight, J. G. S. 1990. *Landform, in Australian soil and land survey field handbook (second edition)*. Australia: Inkata Press.

Vallentine, H. R., R. T. Hattersley and B. A.Cornish. 1961. *Low Cost Scour Control at Culvert Outlets Reports 48 and 62*. Sydney: University of New South Wales.

VicRoads. 1995. *Road Design Guidelines, Part 7, Drainage*. Melbourne: VicRoads.

Victoria Parliament Standing Committee on Rivers and Catchments. 1991. *Guidelines for stabilising waterways*. Armadale: Rural Water Commission of Victoria.

Water Resources Commission. 1998. *A Manual for Managing Urban Stormwater Quality in Western Australia*. Perth: Water Resources Commission.

Westra, S (2011) *"Implications of Climate Change on Flood Estimation: Discussion Paper for the Australian Rainfall and Runoff Climate Change Workshop No 2"*, Engineers Australia Water Engineering, http://www.arr.org.au/wp-content/uploads/2013/Projects/CC_Workshop_DiscussionPaper_Final.pdf.

Willing and Partners Pty Ltd. 1992. *Design guidelines for gross pollutant traps*. (prepared for ACT Department of Environment, Land and Planning and the Department of Urban Services). Canberra.

Wischmeier, W. H. and D. D. Smith. 1978. *Predicting rainfall erosion losses, a guide to conservation planning, USDA Agriculture Handbook Number 537*. United States of America: unknown.

Witheridge, G. M. and R. B. Tomlinson. 1995. *Water Under the Bridge, Engineering Update, Institution of Engineers, Australia, Queensland Division, Technical Papers*. Brisbane: IEAust.

Witheridge, G. M. 1997a. *Design of Energy Dissipators: Engineering Update Volume 5 No.2*. Brisbane: IEAust.

Witheridge, G. M. 1997b. *Design of Energy Dissipators. Technical Paper 3, Engineering Update, Institution of Engineers, Australia, Queensland Division, pp.3–10*. Brisbane: IEAust.

Witheridge, G. S. 1997c. *Erosion and Sediment Control in Road Design and Construction.*

Wong, T. H. F. 2000. *Improving Urban Stormwater Quality – From Theory to Implementation. Water –* Journal of the Australian Water Association, Vol. 27 No. 6, November/December, 2000, pp. 28–31.

Wong, T., T. Fletcher, H. Duncan, J. Coleman, and G. Jenkins. 2002. *A Model for Urban Stormwater Improvement Conceptualisation (MUSIC) (Version 1.00)*. Melbourne: CRC for Catchment Hydrology.

Wright, I, Davis, P., Jonasson, J., Findlay, S. 2010. *Impact on runoff quality by the concrete drainage system.* Proceedings of Stormwater 2010, 1st National Conference of the Stormwater Industry Association of Australia, November, 2010. Sydney.

Wright-McLaughlin Engineers. 1969. *Urban Storm Drainage – Criteria Manual, Volume 2*. Denver.

Yeager, R. W. 1974. *Tire Hydroplaning: Testing, Analysis and Design.* Plenum Press.