CIRIA C635 **London, 2006**

Designing for exceedance in urban drainage – good practice

David Balmforth	MWH
Christopher Digman	MWH
Richard Kellagher	HR Wallingford
David Butler	University of Exeter

CIRIA *sharing knowledge ▪ building best practice*

Classic House, 174–180 Old Street, London EC1V 9BP
TELEPHONE 020 7549 3300 FAX 020 7253 0523
EMAIL enquiries@ciria.org
WEBSITE www.ciria.org

Summary

This guidance provides good practice advice to drainage engineers, regulators, planners and the construction industry on the design and management of urban sewerage and drainage systems to reduce the impacts from drainage exceedance.

It includes information on the effective design of both underground systems and overland flood conveyance. It also provides advice on risk assessment procedures and planning to reduce the impacts that extreme events may have on people and property within the surrounding area.

This book constitutes Environment Agency R&D Report SC030219/TRI

Designing for exceedance in urban drainage – good practice

Balmforth, D; Digman, C; Kellagher, R; Butler, D

CIRIA

Publication C635 © CIRIA 2006 RP699 ISBN 0-86017-635-5 978-0-86017-635-0

British Library Cataloguing in Publication Data

A catalogue record is available for this book from the British Library

Keywords Urban drainage, flooding, housing, land use planning, rivers and waterways, sustainable construction		
Reader interest	**Classification**	
Developers, consulting engineers, local authorities, architects, highway authorities, environmental regulators, planners, sewerage undertakers and other organisations involved in the provision of surface water drainage involved in the provision of surface water drainage to new and existing developments	AVAILABILITY CONTENT STATUS USER	Unrestricted Technical guidance Committee-guided Planners, developers, engineers, regulators

Published by CIRIA, Classic House, 174–180 Old Street, London EC1V 9BP, UK

All rights reserved. No part of this publication may be reproduced or transmitted in any form or by any means, including photocopying and recording, without the written permission of the copyright-holder, application for which should be addressed to the publisher. Such written permission must also be obtained before any part of this publication is stored in a retrieval system of any nature.

This publication is designed to provide accurate and authoritative information in regard to the subject matter covered. It is sold and/or distributed with the understanding that neither the author(s) nor the publisher is thereby engaged in rendering a specific legal or any other professional service. While every effort has been made to ensure the accuracy and completeness of the publication, no warranty or fitness is provided or implied, and the author(s) and publisher shall have neither liability nor responsibility to any person or entity with respect to any loss or damage arising from its use.

Acknowledgements

Research contractor

This guidance has been produced as part of CIRIA Research Project 699. The detailed research was carried out by MWH, HR Wallingford Ltd, Imperial College, London.

Authors

David Balmforth BSc PhD CEng FICE FCIWEM

Prof. David Balmforth has been actively involved in research into urban drainage for over 25 years at Sheffield Hallam University where he was head of the Urban Drainage Research Unit. He joined MWH in June 1999 and is knowledge manager of sewerage design and construction for MWH's European operations. He is particularly noted for his work on the design and operation of combined sewer overflows, and for investigating the effects of climate change on sewer system performance. He is a past president of the engineering section of the British Association for the Advancement of Science, a director of CIRIA and a visiting professor in the Department of Civil and Environmental Engineering at Imperial College of Science, Technology and Medicine, London.

Christopher Digman BEng (Hons) PhD CEng MICE

Dr Chris Digman is a senior engineer at MWH and has worked in the water and wastewater industry for over nine years. He has primarily been involved in urban drainage research and design. He has particular expertise in sewer solids modelling, hydraulic modelling, sewerage design and urban flooding.

Richard Kellagher BSc MSc CEng MICE MCIWEM

Richard has been involved in drainage for most of his 28 years of professional life, the last 18 of which have been at HR Wallingford. He has been at the forefront of drainage modelling and SUDS research as well as having been involved in a number of European projects on drainage. More recently he has become involved in drainage issues relating to climate change. He has written a number of guidance documents on drainage engineering.

David Butler BSc, MSc, PhD, DIC, CEng, CEnv, MICE, FCIWEM, ILTM

David Butler is professor of water engineering and co-director of the Centre for Water Systems at the University of Exeter. He formerly headed the Urban Water Research Group at Imperial College London. He specialises in sustainable urban water management, water conservation and recycling, integrated modelling of urban water systems, spatial water management, operational management of stormwater runoff and urban flooding, in-sewer processes and decision support tool development. He is currently director of EPSRC's Sustainable Urban Environment Programme Water Cycle Management for New Developments (WaND) consortium, director of the WATERSAVE network, and is co-editor-in-chief of the Water and Environment Journal (CIWEM) and the Urban Water Journal.

Steering group Following CIRIA's usual practice, the research project was guided by a steering group, as listed below.

Chair	Martin Osborne	Ewan Group plc formerly Earth Tech Engineering Ltd
Attending members	Richard Allitt	Richard Allitt Associates
	William Apps	Morrison/Brown and Root
	Richard Ashley/John Blanksby	Sheffield University
	Mark Averill	County Surveyors' Society
	David Barraclough	RTPI
	Brian Cafferkey	WSP Development
	Paul Davies/David Bowen	Biwater plc plc
	Graham Fairhurst	Borough of Telford and Wrekin
	Ray Farrow	House Builder's Federation
	Phil Gelder	Severn Trent Water
	John Holmes	Pannone & Partners formerly Weightman Vizards
	Matthew Kean	Environment Agency
	John Malone	Ewan Group plc
	Russ Wolstenholme	WS Atkins (DTI representative)
	Barry Luck	Southern Water
	Aidan Millerick	Micro Drainage Ltd
	Alison Peters	EDAW
	Leighton Roberts	White Young and Green
	John Wickham	Norwich Union
	David Wilson	Scottish Water (now independent consultant)
	Phil Reaney	Yorkshire Water
Corresponding members	Peter Bide	ODPM
	Joe Howe	University of Manchester

Iain Macnab	Glasgow City Council
Christopher Mills	NHBC

CIRIA manager

CIRIA's project manager for the project was Paul Shaffer

Project funders

Department for Trade and Industry

Biwater plc

Environment Agency

Ewan Group plc

Micro Drainage Ltd

Morrison/Brown & Root

NHBC

Norwich Union

White Young and Green

WSP Development

Richard Allitt Associates

Scottish Water

Severn Trent Water

Southern Water

Contributors

CIRIA wishes to acknowledge the following individuals who attended a consultation workshop for the project.

Andrew Blake	Churchill Insurance Co ltd
Gail Cox	Yorkshire Water
Paul Davies	Independent Consultant
Sarah Davies	MWH
Steve Evans	Thames Water
Geoff Gibbs	Environment Agency
Renuka Gunasekara	Haskoning Ltd
James Hale	Charles Haswell & Partners Ltd
Celine Jackson	Weightman Vizards

Michael Johnson	Office of the Deputy Prime Minister
Matthew Kean	Environment Agency
James Lancaster	Arup
Kevin McAlpine	Fairview New Homes Plc
Clive Onions	Arup
Nick Orman	WRc Plc
John Packman	CEH Wallingford
Santi Santhalingam	Highways Agency
Andy Sharpe	Black and Veatch
Joe Whiteman	Countryside Properties plc

Contributors

CIRIA wishes to acknowledge the following individuals who provided substantial additional information for the case studies.

John Blanksby	Sheffield University
Steve Ball	English Partnerships
Duncan Clarke	Pell Frischmann
Aidan Millerick	Micro Drainage Ltd
John O'Leary	Severn Trent Water
John Taylor	Pell Frischmann
David Wilson	Independent consultant (formerly with Scottish Water)

Contents

Summary 2

Acknowledgments 3

List of figures 13

List of tables 18

List of boxes 19

1 Introduction to the guidance 21
- 1.1 Aims and objectives of the guidance 21
- 1.2 Limitations of this guidance 21
- 1.3 Structure of the guide 22
- 1.4 Sources of information 22
- 1.5 Associated publications 22
- 1.6 Background to drainage exceedance 23

Part A Overview 27

2 The process of exceedance and definitions 28

3 Stakeholder roles and drainage performance 31
- 3.1 Drainage stakeholders 31
- 3.2 Managing extreme events in existing urban areas 32
- 3.3 The role of the planner and developer in new developments 33
- 3.4 Drainage design and performance standards 33
- 3.5 Key stakeholder lessons 33

4 Effective management of exceedance 35
- 4.1 Identifying above ground flood pathways 35
- 4.2 The capacity of surface pathways 36
- 4.3 Providing surface storage 37
- 4.4 The effect of building layout 38
- 4.5 Impact on downstream systems 38
- 4.6 Post event clean up 39

Part B Detailed design 41

5 Managing stakeholder interaction 42
- 5.1 The planning process 42
- 5.2 Stakeholder responsibilities 43
  - 5.2.1 Local authorities 45
  - 5.2.2 Sewerage undertakers 46
  - 5.2.3 Environmental regulators 47
- 5.3 Stakeholder consultation process 47
  - 5.3.1 Initial stakeholder consultation phase 47

5.3.2 Stakeholder consultation phase 48
5.4 Good practice in stakeholder interaction 48
5.4.1 Glasgow East urban flooding 49
5.4.2 Yorkshire property flooding solutions 50
5.4.3 Flooding of residential area in Birmingham 51
5.5 Ownership and legal rights 53
5.6 Education – the public as stakeholders 53
5.7 Flood warning 54
5.8 Stakeholder collaboration 54

6 Runoff from natural catchments 55
6.1 Introduction 55
6.2 Natural drainage processes 55
6.3 Rainfall 56
6.3.1 Spatial rainfall 57
6.3.2 Seasonal rainfall. 58
6.4 Rural runoff 59
6.4.1 Characteristics of rainfall and rural runoff 59
6.5 Models for estimating rural runoff 60

7 Hydrological processes and the effects of urbanisation 65
7.1 Hydrological processes 65
7.1.1 Introduction 65
7.1.2 Interception. 65
7.1.3 Depression storage 65
7.1.4 Infiltration 66
7.1.5 Surface flow 66
7.1.6 Evaporation and evapo-transpiration. 66
7.2 Runoff 66
7.3 Stream network and channel morphology 68
7.4 Floods in natural catchments 68
7.5 The effects of urbanisation 69
7.6 Urban runoff behaviour 70
7.7 Urbanisation and Flooding 72

8 Runoff from urban catchments 73
8.1 Urban Runoff models 73
8.1.1 The constant (old UK) runoff model 73
8.1.2 The variable (new UK) runoff model. 77
8.1.3 The fixed percentage runoff model 80
8.2 Estimation of the difference between greenfield and development runoff 82

9 Interaction between major and minor systems 85
9.1 Principles of interaction 85
9.1.1 Flooding from manholes and other drainage connections . . 86
9.1.2 Limitation of inlet capacity 87

9.1.3 Surface run-off from pervious area 89

9.2 Calculating exceedance flow 89

9.3 Calculating flows in surface flood pathways 93

9.3.1 Surface run-off 93

9.3.2 Adding run-off from permeable areas 93

9.3.3 Surface conveyance 94

9.4 Calculating drainage inlet capacity and exceedance 97

9.4.1 Highway gullies 97

9.4.2 Roof drains 100

9.4.3 Yards and other paved area drainage gullies. 101

9.4.4 Applying limiting inlet capacity to calculate exceedance flows 102

9.5 Inlet capacity of SUDS systems 103

10 Developing a risk assessment 107

10.1 An introduction to exceedance flood risk assessment 107

10.2 Components of the EFRA 107

10.3 Determining the risk value 108

10.3.1 EFRA Process. 108

10.3.2 Selection of the appropriate EFRA level 112

10.3.3 Level 1 EFRA – simple small areas. 113

10.3.4 Level 2 EFRA – large or complex areas 114

10.3.5 Level 3 EFRA – large and complex areas. 114

10.4 Assessing the probability 115

10.5 Assessing the consequence 115

10.5.1 Consequence hierarchy for building types or land use as a result of flooding 116

10.5.2 Damage to property 116

10.5.3 Damage due to depth 117

10.5.4 Damage due to depth and velocity. 118

10.5.5 Health and Safety 119

10.5.6 Loss of facility/business 120

10.5.7 Emergency services 120

10.5.8 Social implications 121

10.6 Calculation of risk 121

11 Designing for surface conveyance 123

11.1 Principles of design 123

11.2 Identifying flood pathways 127

11.3 Designing flood channels 127

11.3.1 Channel conveyance 127

11.3.2 Velocity and depth of flow 129

11.3.3 Cross-section details 129

11.4 Channel transitions 130

11.4.1 General principles. 130

11.4.2 Transition between single channel reaches 131

11.4.3 Road junctions 131
11.4.4 Inlets 133
11.4.5 Outlets 134

12 Designing for surface storage 135
12.1 Principles of design 135
12.2 Storage area design process 135
12.2.1 Size 135
12.2.2 Health and safety 139
12.2.3 Maintenance 140
12.2.4 Outfall design 141
12.2.5 Diversion control design 142
12.3 Types of storage areas 143
12.3.1 Storage options hierarchy 143
12.3.2 Additional storage in SUDS 144
12.3.3 Car parks 144
12.3.4 Minor roads 146
12.3.5 Playing fields, recreational areas and parkland 148

13 Building layout and detail 149
13.1 Design principles 149
13.2 Building type and layout 149
13.2.1 Layout and flood pathways 149
13.2.2 Utilising existing features of the site 152
13.3 Building detail 153
13.3.1 Building in protection measures 153
13.3.2 Property elevation/threshold levels 154
13.3.3 Selection of the building materials 155
13.3.4 Venting 155
13.3.5 Entrance details 156
13.3.6 Driveways and curtilage 156
13.3.7 Siting of services 156
13.3.8 Inadvertent modifications to existing flood pathways . . . 156
13.3.9 Under building flood paths 157

14 Downstream impact assessment 158
14.1 Conveyance and storage 158
14.1.1 Flood conveyance impacts 158
14.1.2 Conveyance with storage 159
14.2 Procedure for assessing and mitigating impacts 159
14.3 Assessing the impact on downstream systems 159
14.4 Mitigating the effects of downstream impacts 162

Part C Case studies 165

15 Case study 1: Bishopbriggs South 166
15.1 Introduction 166
15.2 Stakeholder involvement 166

15.3 Calculating exceedance flow 167
    15.3.1 Collecting data. 167
    15.3.2 Using models to assess system performance 167
    15.3.3 Verifying against historic flooding 168
    15.3.4 Upgrading to a level 3 study 169
15.4 Exceedance risk assessment 172
15.5 Solution development 172
15.6 Impact on downstream systems 174

16 Case Study 2: Upton, Northampton 175
16.1 Introduction 175
16.2 Stakeholder involvement 175
16.3 Drainage of developed areas 177
16.4 Interaction between the minor and major systems 177
16.5 Risk assessment 178
    16.5.1 Collecting data and building a hydraulic model 178
    16.5.2 Assessing system performance (1 in 30 year return period – 0.033 annual probability) 178
    16.5.3 Assessing system performance (1 in 100 year return period – 0.01 annual probability) 179
    16.5.4 Assessment of risk outside school. 180
16.6 Building layout and detail 181
    16.6.1 Amending building layout and threshold levels 181
16.7 Impact on downstream system 182
16.8 Conclusions 183

Part D: Appendices 185

A1 Modelling exceedance 186
A1.1 Surface flood pathways 186
A1.2 Surface flooding 187
A1.3 Modelling inlet capacity 188
A1.4 Modelling flood risk 189
A1.5 Further guidance 190

A2 Exceedance flow at highway gully inlets 192

A3 Conveyance in surface flood pathways 198
A3.1 Introduction 198
A3.2 Flood pathway channels 198

A4 Assessment approach to determine flood volumes and rates from SUDS 201
A4.1 Assessment approach 201
A4.2 Hydrology 201
A4.3 Pervious pavement performance 202
    A4.3.1 Results 203
    A4.3.2 Application of results and conclusions 204
A4.4 Swale performance 204

A4.4.1 Contributing area 205
A4.4.2 Gradient of the swale 205
A4.4.3 Length of the swale 205
A4.4.4 Outflow control from the swale 206
A4.4.5 Application of results and conclusions 206
A4.5 Infiltration system performance 210
A4.5.1 Application of results and conclusions 210

A5 Generic guidance on assessing flood volumes and rates from SUDS . . . 212
A5.1 Assumptions 212
A5.1.1 Inflow 212
A5.1.2 Outflow 213
A5.1.3 Storage 213
A5.2 The principles of the flood estimation method 213
A5.3 Method of application 215
A5.4 Check against modelling results 217
A5.4.1 Pervious pavement 217
A5.4.2 Infiltration trench 218
A5.4.3 Swale 218

A6 Design example of a permeable pavement 226

A7 Methods of estimating rural runoff 228
A7.1 Rational Method 228
A7.2 The TRRL method (Young and Prudhoe, 1973) 229
A7.3 Flood studies report (FSR) – (NERC, 1975) 230
A7.4 FSSR 6 – flood prediction for small catchments 232
A7.5 Poots and Cochrane method, 1979 233
A7.6 The ADAS method (Agricultural Development and Advisory Service, 1980) 233
A7.7 The SCS method (Soil Conservation Service, 1985 – 1993) 234
A7.8 Institute of Hydrology Report No. 124 (1994) 234
A7.9 Flood Estimation Handbook, FEH, (1999) 235
A7.10 Statistical procedures for flood estimation 236
A7.11 Rainfall-runoff method for flood estimation 237
A7.12 Advantages and disadvantages of the flood estimation handbook techniques 239
A7.13 FSR and FSSR 5 and 16 percentage runoff estimation 239
A7.14 FEH runoff model – variable percentage runoff 240

References 242

British and international standards 248

UK Legislation and regulations 248

Legal rulings 248

Glossary 249

Abbreviations 253

List of figures

Figure 1.1 Highway acting as a flood pathway in an extreme rainfall event 24
Figure 1.2 Property flooding from overloaded sewerage system 24
Figure 1.3 Example of property damage due to storm sewage flooding 25
Figure 2.1 Interaction between the minor and major system during an extreme event 28
Figure 2.2 Conveyance of exceedance flow in surface flood pathways 29
Figure 2.3 Simplified representation of minor/major system flow 30
Figure 2.4 Runoff and exceedance flow for different return period events 30
Figure 3.1 Serious flooding in Glasgow in July 2002. In this case flooding was shown to be due to sewerage, highway and land drainage flooding combined 32
Figure 4.1 Exceedance flow generated by runoff from fields to rear of property . . 35
Figure 4.2 Above ground flood pathways identified during a site development study. Different shaded arrows refer to different types of above ground pathway 36
Figure 4.3 Unplanned ponding of surface flood flow at a low spot leading to property flooding 37
Figure 5.1 Recommended good practice for managing drainage in the development process 44
Figure 5.2 Flooding as a result of overland flow and sewer flooding on the 30 July in Glasgow 49
Figure 5.3 Discrete catchment flood volumes attributable to different sources for 30 July Glasgow floods 50
Figure 5.4 Cellar flooding from infiltration from a local watercourse 50
Figure 5.5 Property flooding by overland flow from the highway 51
Figure 5.6 Property location of flooding in a Birmingham suburb attributed to a number of sources 52
Figure 5.7 Plan showing overland flow paths for the flooding shown in Figure 5.6 52
Figure 6.1 Distribution of rainfall at three locations across the UK 56
Figure 6.2 100 year, 12 hour rainfall depths 57
Figure 6.3 Rainfall radar image Bracknell area 7 May 2000 (1 km resolution) . 58
Figure 6.4 Predicted peak flows for the catchment for various return periods . . 64
Figure 7.1 The hydrological process 65
Figure 7.2 Example of flood wave attenuation 69
Figure 7.3 The response of a traditional pipe system to one, 30 and 100 year events compared with a greenfield response 71
Figure 7.4 The response from two catchments (soil types 2 and 4) with a development proportion of 10 per cent, for the 100 year event 71
Figure 7.5 Urban area suffering from river flooding 72
Figure 8.1 Process of constructing a drainage model 74
Figure 8.2 PR as a function of SOIL and PIMP (old UK PR equation) 76
Figure 8.3 Volume of runoff from a 1 ha paved catchment with a variable amount of pervious area (constant and variable runoff models) . . . 79
Figure 8.4 Percentage runoff as a function of rainfall depth using the variable runoff model 79

Figure 8.5a Comparison of percentage runoff between the variable runoff model and fixed percentage model used in *Sewers for Adoption 5th Edition* (2001) for a one year return period storm of six hour duration 80
Figure 8.5b Comparison of percentage runoff between the variable runoff model and fixed percentage model used in *Sewers for Adoption 5th Edition* (2001) for a one year return period storm of 24 hour duration 81
Figure 8.5c Comparison of percentage runoff between the variable runoff model and fixed percentage model used in *Sewers for Adoption 5th Edition* (2001) for a 100 year return period storm of six hour duration 81
Figure 8.5d Comparison of percentage runoff between the variable runoff model and fixed percentage model used in *Sewers for Adoption 5th Edition* (2001) for a 100 year return period storm of 24 hour duration 81
Figure 8.6 Development plan of a modern high-density housing estate 83
Figure 8.7 Difference in runoff volume for developments where all pervious areas are assumed not to drain to the drainage network 84
Figure 8.8 Difference in runoff volume for developments where all pervious areas are assumed to drain to the drainage network 84
Figure 9.1 Urban flooding illustrating the difficulty of identifying the precise cause of flooding 86
Figure 9.2 Computing exceedance flows and volumes 87
Figure 9.3 Conceptual model of exceedance due to inlet capacity 88
Figure 9.4 Flowchart for computing exceedance flows and volumes 91
Figure 9.5 Road flood pathway represented by vee section channel 94
Figure 9.6 Conceptual representation of fully interactive major/minor system modelling 96
Figure 9.7 Flow pattern in highway channel at gully inlet information 97
Figure 9.8 Illustration of conveyance flows on a highway surface (see case study one for further information) 98
Figure 9.9a Flow characteristics of a gully inlet, maintenance factor = 1.0 98
Figure 9.9b Flow characteristics of a gully inlet, maintenance factor = 0.7 99
Figure 9.10 Flow of water from gutter into rainwater pipe 101
Figure 10.1 Summary of the inputs, processes and outputs in the exceedance flood risk assessment 108
Figure 10.2 Part 1 Generic EFRA process to determine the critical duration for the area being assessed 110
Figure 10.3 Part 2 – Generic EFRA process to determine the risk rating for different storm return periods 111
Figure 10.4 Showing the risk value depending on the probability and consequence value determined 112
Figure 10.5 Example of a possible risk band when there is low confidence in the probability and consequence values 121
Figure 11.1 Designing for surface conveyance 124
Figure 11.2 Flowchart for designing surface flood channels for extreme events . . 125
Figure 11.3 Flood wave caused by moving vehicle 129
Figure 11.4 Definitions of flows and slopes at four way road junction 132
Figure 11.5a Flow split at four way junction, subcritical flow 132
Figure 11.5b Flow split at four way junction, supercritical flow 133

Figure 11.6a Depth of ponding governed by discharge to a mild sloping flood channel . . . 133
Figure 11.6b Depth of ponding governed by discharge to a steep sloping flood channel . . . 134
Figure 12.1 Concept of how exceedance flows are managed . . . 135
Figure 12.2 Designing for surface storage . . . 136
Figure 12.3 Flowchart of the above ground storage design process . . . 138
Figure 12.4 Conceptual demonstration of the exceedance rainfall event hydrograph . . . 139
Figure 12.5 Conceptual process of diverting excess flow . . . 142
Figure 12.6 Cross-section through an infiltration or detention pond designed to accommodate exceedance . . . 144
Figure 12.7 Temporary ponding in car park showing the storage potential during an extreme event . . . 145
Figure 12.8 Example berm profile . . . 145
Figure 12.9 Conceptual arrangements to temporarily store exceedance runoff in a car park . . . 146
Figure 12.10 Example of the storage that can be achieved and examples of berms . . . 147
Figure 12.11 A dual-purpose recreational baseball pitch/storage area in Japan. This is significantly lower than the surrounding ground level . . . 148
Figure 13.1 Processes involved with designing building layout for exceedance events . . . 150
Figure 13.2 Flowchart showing the process of including building detail and layout in the design process when considering the exceedance flood pathways . . . 151
Figure 13.3 Example of major and minor systems in a site layout. Note the pathways created between housing clusters to allow overland flow to drain from undeveloped areas behind property . . . 152
Figure 13.4 Shows that increasing the ground level of the property can prevent flooding . . . 154
Figure 13.5 Theoretical position of property which has a high threshold level and therefore protection against flooding . . . 154
Figure 13.6 Periscope venting detail . . . 155
Figure 13.7 Plan view of how extensions to property can cause flooding by removing an existing flood pathway . . . 157
Figure 14.1 Procedure for assessing the impact of exceedance flow on receptor systems and developing appropriate mitigation measures . . . 16
Figure 15.1 Bishopbriggs South sewerage system . . . 167
Figure 15.2 Nodal flooding for the 30 year event, central area only . . . 168
Figure 15.3 Nodal flooding for the 100 year event, central area only . . . 169
Figure 15.4 Springfield Works: location of flooding in July 2002 . . . 169
Figure 15.5 Surface flood pathways identified by rolling ball model . . . 170
Figure 15.6 Flooding for the 30 year event with surface pathways modelled . . . 170
Figure 15.7 Flooding for the 100 year event with surface pathways modelled . . . 171
Figure 15.8 The Courtyard to Springfield Works showing the location of the most significant flooding in the drainage area . . . 171
Figure 15.9 Exceedance flood risk assessment for 100 year event . . . 173
Figure 15.10 Solutions model with 100 year event showing flood risk . . . 173

Figure 16.1 Overview of catchment D including details of the outfall from the surface water drainage system . . . 176
Figure 16.2 Plan and section of ground model including the position of the highways, swales and surface water pipe system . . . 179
Figure 16.3 3D view of ground model with conceptual view of the school and some housing (for illustrative purposes) . . . 179
Figure 16.4 Flood flow paths for 100 year event with additional flooding due to climate change indicated by the lighter colour . . . 180
Figure 16.5 3D view of the modelling of surface flood paths and the inter-connections with the below ground sewerage system, in the vicinity of the school . . . 181
Figure 16.6 Modification to building layout with school threshold levels raised and ground re-profiling adjacent to housing . . . 182
Figure A1.1 3D graphical representation of surface flooding . . . 187
Figure A1.2 Overland flow paths identified with "rolling ball" algorithm . . . 188
Figure A1.3 Model of gully inlet . . . 189
Figure A1.4 Property below level of minor system, showing flooding due to sewer surcharging . . . 190
Figure A1.5 Property with cellar, showing flooding due to sewer surcharging . . . 190
Figure A1.6 Property above level of minor system showing flooding due to local surface flooding . . . 190
Figure A1.7 Flood risk scoring at the level of individual property . . . 191
Figure A2.1 Flow split at highway gully inlet . . . 192
Figure A2.2 Effective area contributing to flow in channel – note that ç is calculated at the design flow . . . 193
Figure A2.3 Cross-section of flow in the channel . . . 194
Figure A3.1 Typical cross-section of flood pathway in a minor highway, showing surface conveyance for non-extreme events . . . 198
Figure A3.2 As Figure A3.1 but with exceedance flow contained within the highway channel . . . 198
Figure A3.3 As Figure A3.2 but with exceedance flow above top of kerb level . . . 199
Figure A3.4 As Figure A3.3 but showing dropped kerb detail on right hand side . . . 199
Figure A3.5 Flood pathway on footpath between walls . . . 199
Figure A3.6 Flood pathway on footpath between grass banks . . . 200
Figure A3.7 Flood pathway in rough cut ditch . . . 200
Figure A3.8 Flood pathway in lined ditch . . . 200
Figure A4.1 FSR regions across the UK . . . 202
Figure A4.2 Swale cross-section . . . 205
Figure A5.1 Estimation of storage required . . . 214
Figure A5.2 Estimation of flood volumes . . . 215
Figure A5.3 Flowchart for estimating flood volumes and flood flow rates . . . 216
Figure A5.4 Estimation of storage/flood volume for different return period events (no lag) . . . 219
Figure A5.5 Estimation of storage/flood volume for different return period events (six hour lag) . . . 219
Figure A5.6 Flood volume for different levels of storage provision for 10 year return period events (no lag) . . . 220

Figure A5.7 Flood volume for different levels of storage provision for 30 year return period events (no lag) 220
Figure A5.8 Flood volume for different levels of storage provision for 100 year return period events (no lag) 220
Figure A5.9 Flood volume for different levels of storage provision for 200 year return period events (no lag) 221
Figure A5.10 Flood volume for different levels of storage provision for 10 year return period events (six hour lag) 221
Figure A5.11 Flood volume for different levels of storage provision for 30 year return period events (six hour lag) 221
Figure A5.12 Flood volume for different levels of storage provision for 100 year return period events (six hour lag) 222
Figure A5.13 Flood volume for different levels of storage provision for 200 year return period events (six hour lag) 222
Figure A5.14 Flood flow rate for different levels of storage provision for 10 year return period events (no lag) 222
Figure A5.15 Flood flow rate for different levels of storage provision for 30 year return period events (no lag) 223
Figure A5.16 Flood flow rate for different levels of storage provision for 100 year return period events (no lag) 223
Figure A5.17 Flood flow rate for different levels of storage provision for 200 year return period events (no lag) 223
Figure A5.18 Flood flow rate for different levels of storage provision for 10 year return period events (six hour lag) 224
Figure A5.19 Flood flow rate for different levels of storage provision for 30 year return period events (six hour lag) 224
Figure A5.20 Flood flow rate for different levels of storage provision for 100 year return period events (six hour lag) 224
Figure A5.21 Flood flow rate for different levels of storage provision for 200 year return period events (six hour lag) 225
Figure A6.1 Flood flow rate from pervious pavement system – north 227
Figure A6.2 Flood volume from pervious pavement system – north 227
Figure A7.1 Growth curve factors for UK hydrological regions 231
Figure A7.2 The growth curve regions of UK 231
Figure A7.3 WRAP map of SOIL type for UK 232
Figure A7.4 FSR/FEH rainfall depth ratios for the one hour 25 year event 238
Figure A7.5 CWI vs SAAR – flood studies report 240

List of tables

Table 3.1 Drainage design and performance standards 34

Table 5.1 Stakeholders responsible for drainage in England and Wales 45

Table 6.1 Rainfall runoff characteristics for undeveloped areas 59

Table 6.2 Probability of an extreme event happening 60

Table 6.3 Summary of the methods that can be used to estimate the peak rate and runoff volume (the preferred method is shown in bold) . . . 61

Table 6.4 Catchment characteristics 63

Table 6.5 Regional growth curve for the catchment 63

Table 6.6 Peak runoff (m^3/s) assessment for the catchment (the preferred method is shown in bold) 64

Table 8.1 Recommended values of IF 77

Table 8.2 Relationship between soil type and CP 78

Table 9.1 Overflow rate (l/s) from pervious pavement system – south 103

Table 9.2 Overflow rate (l/s) from pervious pavement system – north 104

Table 9.3 Overflow volume (m^3) from pervious pavement system – south . . . 104

Table 9.4 Overflow volume (m^3) from pervious pavement system – north . . . 104

Table 9.5 Overflow rate (l/s) from 100m long swale system – south 105

Table 9.6 Overflow rate (l/s) from 100m long swale system – north 105

Table 9.7 Overflow rate (l/s) from an infiltration system designed to a 10 year return period – south 105

Table 9.8 Overflow volume (m^3) from an infiltration system designed to a 10 year return period – south 105

Table 10.1 Summary of the phases used to undertake each level of study 113

Table 10.2 Probability rating for a storm event 115

Table 10.3 Type of consequence considered for each EFRA level 115

Table 10.4 Initial hierarchy of the consequences of flooding certain properties/locations 116

Table 10.5 Flood damage for a typical residential property 117

Table 10.6 Consequence ratings for property dependent upon flood depth . . 118

Table 10.7 Consequence rating when velocity and depth are considered 118

Table 10.8 Consequence rating for pedestrians in flood water. For children and the elderly, increase the consequence rating by one 119

Table 10.9 Description of the two condition extremes for pedestrians 120

Table 10.10 Consequence rating for humans in cars and damage to the car itself 120

Table 11.1 Values of Manning roughness coefficient ‘n’ for use with Equation 9.3 128

Table 12.1 Key health and safety areas that should be considered in the design of exceedance storage areas 140

Table 12.2 Key maintenance considerations required in the design of exceedance storage areas 141

Table 12.3 Summary of different storage options available 143

Table 15.1 Summary of maximum surface velocities and depths for the 100 year event 172

Table A2.1 Values of K1 197

Table A4.1 Pervious pavements – modelling assumptions 203
Table A4.2 Swale – modelling assumptions 206
Table A4.3 Overflow rate (l/s) from 20 m long swale system – south 207
Table A4.4 Overflow rate (l/s) from 20 m long swale system – north 207
Table A4.5 Overflow rate (l/s) from 50 m long swale system – south 207
Table A4.6 Overflow rate (l/s) from 50 m long swale system – north 207
Table A4.7 Overflow rate (l/s) from 100 m long swale system – south 208
Table A4.8 Overflow rate (l/s) from 100 m long swale system – north 208
Table A4.9 Overflow volume (m^3) from 20 m long swale system – south 208
Table A4.10 Overflow volume (m^3) from 20 m long swale system – north 208
Table A4.11 Overflow volume (m^3) from 50 m long swale system – south 209
Table A4.12 Overflow volume (m^3) from 50 m long swale system – north 209
Table A4.13 Overflow volume (m^3) from 100 m long swale system – south 209
Table A4.14 Overflow volume (m^3) from 100 m long swale system – north 209
Table A4.15 Infiltration system – test characteristics 210
Table A4.16 Overflow rate (l/s) from infiltration system 211
Table A4.17 Overflow volume (m^3) from infiltration system 211
Table A6.1 Example of design data 226

List of boxes

Box 6.1 Example of calculating the peak runoff 63
Box 9.1 Levels of detail for calculating exceedance flow 90

1 Introduction to the guidance

1.1 Aims and objectives of the guidance

This guidance aims to provide best practice advice for the design and management of urban sewerage and drainage systems in order to reduce the problems which arise when flows occur that exceed their capacity. It includes information on the effective design of both underground systems and overland flood conveyance. It also provides advice on risk assessment procedures and planning to reduce the impacts that extreme events may have on people and property within the surrounding area.

The broad objective of the guidance is to improve the engineers, planners and designers' appreciation of the risks associated with urban drainage systems and their understanding of how these risks may be mitigated. It provides guidance so that systems can be designed to safely and sustainably accommodate periods when the design capacity of drainage systems are exceeded during extreme events. The guidance will be relevant to areas drained by piped systems or SUDS.

PPG25 *Development and flood risk* (DTLR, 2001) identifies that flooding can occur on a local scale due to runoff exceeding the capacity of the minor system during extreme events and it can only be addressed on a site-specific basis. *Sewers for adoption 5th edition* (Water UK and WRc, 2001) states that properties should be protected against flooding from extreme events and that flood pathways are identified when the drainage system is exceeded. Yet there is no standard way to meet these challenges. This guidance aims to address this anomaly. It complements CIRIA publication C624 *Development and flood risk* (Lancaster *et al,* 2004) by focusing on those extreme events which are as a result of flooding in the urban environment.

The specific objectives of the guidance are to:

- address the key issue of designing urban drainage systems that can cope with periods of exceedance
- provide guidance on risk assessment procedures to determine the likelihood and impacts of drainage exceedance
- provide guidance on planning and layout to reduce the impacts of exceedance in drainage systems
- offer best practice guidance for the design of urban drainage systems that can sustainably accommodate periods of exceedance.

1.2 Limitations of this guidance

This guidance presents information which will enable a variety of stakeholders to identify risks and subsequently design mitigation measures. The publication focuses on extreme events, and considers the water quantity aspects of volume, depth, velocity and duration. Water quality issues are not considered in this document.

This guidance document is applicable across the UK. However different regional and national planning policies, stakeholder interactions and legislation must be taken into account when applying the guidance to each case. The guide is based on the planning guidance and legislation in place from January 2005. The reader should ensure that designs and processes are consistent with current regulatory and legislative frameworks.

1.3 Structure of the guide

The guidance is divided into four sections:

- **Part A Overview** is a strategic overview of the guidance. It covers the main issues in general, and will be useful to planners, developers, regulators and other stakeholders who wish to understand the principles, and obtain an overview of the processes, but do not require an in depth understanding of detailed design.
- **Part B Detailed design** offers detailed risk assessment and design, and is aimed at practitioners with a day-to-day responsibility for drainage design.
- **Part C Case studies** includes case studies demonstrating the important stages of the design and risk assessment process covered in Part B.
- **Part D Appendices** give important supplemental information and details of further information that the user can refer to.

1.4 Sources of information

This guide has been compiled following a worldwide literature review. There is significant information available for flooding and its consequences, however information regarding designing for exceedance events is less common. The guidance identifies good practice from around the world and applies it to the UK.

A consultation workshop was held to gather information and opinions from representatives of the various interested parties including water companies, planners, local authorities, drainage engineers and regulators.

1.5 Associated publications

The work provides good practice guidance on assessing the risk from flooding in extreme events and how to design mitigation measures which can prevent or limit flooding through conveyance and storage. It can be used in conjunction with a variety of other publications and sources of information, which are listed below:

Book 14 *Design of flood storage reservoirs* (Hall *et al,* 1993). Guidance to assist the practising engineer with the detailed design of flood storage reservoirs for flood control in partly urbanised catchment areas.

C523 *Sustainable urban drainage systems – best practice manual for England, Scotland, Wales and Northern Ireland* (Martin *et al*, 2001). This publication provides guidance on employing sustainable methods for surface water drainage and implementing sustainable development into practice.

C521 *Sustainable urban drainage systems – design manual for Scotland and Northern Ireland* (Martin *et al,* 2000a). Like C522 this manual describes good practice in Scotland and Northern Ireland.

C522 *Sustainable urban drainage systems – design manual for England and Wales* (Martin *et al,* 2000b). This manual describes current good practice in England and Wales, and sets out the technical and planning considerations for designing SUDS.

C609 *Sustainable drainage systems. Hydraulic, structural and water quality advice* (Wilson *et al,* 2004). This technical report summarises current knowledge on the best approaches to design and construction of sustainable drainage systems.

C623 *Standards for the repair of buildings following flooding* (Garvin *et al,* 2005).

C624 *Development and flood risk – guidance for the construction industry* (Lancaster *et al,* 2004). This book offers practical guidance when assessing flood risk as part of the development process.

X108 *Drainage of development sites – a guide* (Kellagher, 2004). This guidance is intended to assist all those involved with foul and surface water drainage of development sites.

Information can also be found on CIRIA's flooding and SUDS websites at <www.ciria.org/flooding> and <www.ciria.org/sud>

1.6 Background to drainage exceedance

It is inevitable that as a result of extreme rainfall the capacities of sewers, covered watercourses and other drainage systems will be exceeded on occasion. Periods of exceedance occur when the rate of surface runoff exceeds the drainage system inlet capacity, when the pipe system becomes overloaded, or when the outfall becomes restricted due to flood levels in the receiving water.

Underground conveyance cannot economically or sustainably be built large enough for the most extreme events and, as a result, there will be occasions when surface water runoff will exceed the design capacity of drains. This is especially problematic where the drain is a combined sewer and sewage flooding can result. When drainage system capacity is exceeded the excess water (exceedance flow) is conveyed above ground, and will travel along streets and paths, between and through buildings and across open space (Figure 1.1). Indiscriminate flooding of property can occur (Figure 1.2) when this flow of water is not controlled.

Flooding can have huge social, economic and environmental impact (ICE, 2001). The Ofwat consultation on sewer flooding (Ofwat, 2002) highlighted that the damage to property is a small element of the human impact of floods. This is evident if there is internal flooding of property, as the impacts are a lot more severe and difficult to cope with (Figure 1.3). The stress associated with losing personal belongings, living in temporary accommodation, in addition to the trauma of the clean up and restoration process can be considerable.

Figure 1.1 *Highway acting as a flood pathway in an extreme rainfall event (courtesy Scottish Water)*

Figure 1.2 *Property flooding from overloaded sewerage system (courtesy Scottish Water)*

Figure 1.3 *Example of property damage due to storm sewage flooding (courtesy Pennine Water Group)*

Current climate change predictions indicate that severe weather events will become more frequent. Rainfall could increase by 40 per cent leading to at least a 40 per cent increase in surface runoff and a 100 per cent increase in flood volumes (UKWIR, 2004). This may affect 130 per cent more properties leading to a 200 per cent increase in flood damage (Evans *et al,* 2004). These values although theoretical have been produced using models verified on past performance to predict future changes and are by no way, the most extreme of all the climate change predictions.

Although designers of drainage in new developments are now required to consider the effects of extreme wet weather in their designs, there is no obligation to properly manage the consequence of such events. *Sewers for adoption 5th edition* (Water UK and WRc, 2001) identifies that overland flood pathways should be considered, but no recommendation of the level of protection is given. BS EN 752-4:1998 (BSI, 1997) identifies areas where a level of service check should be undertaken and to what return period, but there is no guidance for dealing with extreme events.

Experience has shown that much of the recorded flooding in urban areas is attributable to the passage of above ground surface flow. However, this above ground conveyance is essential in allowing runoff from extreme events to drain from developed areas effectively. It is clear that much can be done to mitigate the effects if surface flood flow is managed proactively. Recognising the importance of flood pathways along highways and other routes, and the storage of water in low spots, is the first step to better management. Through good design, a second important step is to direct flood flows along routes where the risk of property flooding and the risk to health and safety is minimal. Options to achieve this are available, and explored within this guidance.

Defra's consultation document *Making space for water* (Defra, 2004) has suggested that highways can be used to facilitate the management of extreme events. If highways and other urban features are to be effectively used to convey exceedance flow, then careful design will be essential. Relatively minor features of the urban landscape, such as kerb heights, traffic calming and property threshold details can significantly affect flood risk.

Engaging stakeholders to collectively manage and maintain flood routes, and designing buildings to be more flood resistant, is another important factor in the equation. The Building Regulations (2000) do not take into account property flooding and flood resistance, however in Approved Document C (ODPM, 2004b) which came into force in December 2004, provides advice on flood risk. It states that "*…when local considerations necessitate building in flood prone areas the buildings can be constructed to mitigate some effects of flooding…*"

A greater understanding of the mechanisms of drainage in extreme events and improved guidance on how above-ground flood pathways can be effectively managed can assist in reducing the risk of urban flooding. This guidance aims to address these issues.

Part A Overview

2 The process of exceedance and definitions

Traditionally, urban drainage systems are designed to meet a particular and specified **level of service**, known as the **target level**. This is normally expressed as a frequency of property flooding. A **level of protection** of one in 100 years (annual probability of 0.01 being equalled or exceeded) might be defined for internal property flooding as a suitable target for a new development. This can be delivered using a conventional below ground piped drainage system, designed to a pipe full capacity using a one in two year return period rainfall (annual probability of 0.5 being equalled or exceeded), and then checking the performance for flood protection using a suitable sewer simulation tool. Alternatively SUDS (sustainable (urban) drainage system) might be specified. Its performance may be checked in a similar way. Following such checks, the design may be amended to ensure that the desired level of protection is achieved across the drainage area.

Existing drainage systems typically do not achieve the same level of service as that required for new systems. This is in part due to the structural deterioration and siltation of the existing network. More often, it is due to the network carrying increased flows from expanding urban areas. Once system performance falls below an acceptable level, known as the **trigger level**, early rehabilitation will be planned. This will then raise system performance to an agreed target level. The performance target of a rehabilitated system will of course be higher than the trigger level, but may be less than the performance level for a new system. Further information on performance levels is given in Table 3.1.

The formal or designed drainage system (piped or SUDS) is referred to in this guidance as the **minor system** (Figure 2.1). For a piped system, the **conveyance capacity** will normally be greater than the pipe full capacity, since additional conveyance can be generated as flow backs up in manholes causing surcharging. The resulting slope of the hydraulic gradient can be greater than the gradient of the pipes themselves, forcing more flow through the system. A similar effect can occur with SUDS.

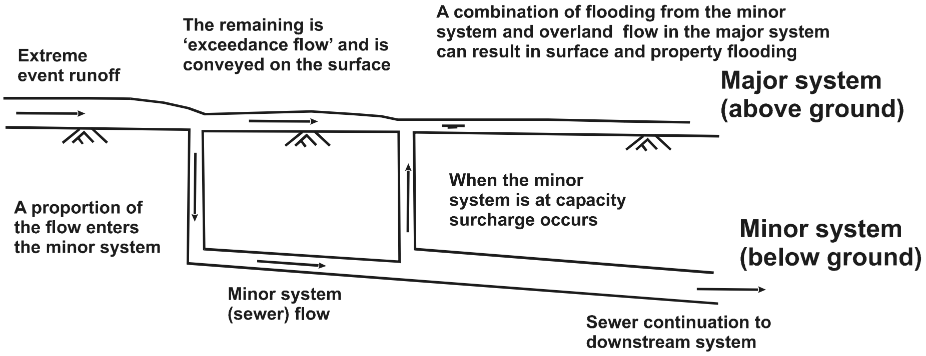

Figure 2.1 *Interaction between the minor and major system during an extreme event*

Once the conveyance capacity of the minor system is exceeded, surface flooding will occur. The excess flow that appears on the surface is known as the exceedance flow. The rainfall events that result in **exceedance flow** are known as **extreme events.** Exceedance flow will be conveyed on the ground by **surface flood pathways**. These may be roads, paths or depressions in the surface (Figure 2.2). Where they have not been specifically designed as flood pathways, they are known as **default pathways**. Otherwise they are know as **designed pathways**. The system of above ground flood pathways, including both open and culverted watercourses, is known as the **major system**.

Even within the target level of service, often there will be some above ground flood flow. Equally, there can be flooding of property before the capacity of the minor system is exceeded. This may occur when the level of property is below the level of the hydraulic gradient in the drainage pipes, especially where there is a direct drainage connection. The connection between the minor and major systems is extremely complex and can only be properly represented by a computer simulation model of both systems. Even then, current capability of modelling above ground flood pathways is limited. A simplified graphical representation of the interaction between the minor and major system is given in Figure 2.3.

Figure 2.2 *Conveyance of exceedance flow in surface flood pathways (courtesy Pennine Water Group)*

The magnitude of surface flooding and the exceedance flow will depend on the return period of the extreme event and the capacity of the minor system. Assuming that the latter is equivalent to the runoff from a 10 year return period storm, Figure 2.4 illustrates typical relative magnitudes for different return periods.

It can be seen from Figure 2.4 (based upon data from a real catchment) that the increase in runoff is by no means proportional to the increase in return period. For example the 100 year runoff is only 1.54 × the 10 year amount. Additionally for the 100 year event, the exceedance flow to be conveyed by the major system is only 1.24 m^3/s compared with the minor system flow (capacity) of 2.34 m^3/s. The minor system capacity is the difference between the exceedance flow of 0 m^3/s and the runoff at approximately the 10 year return period, assuming that all the runoff is drained to the minor system. However, existing sewerage systems rarely convey the full 30 year flow without some surface flooding, so that the surface conveyance can be expected to be greater than this.

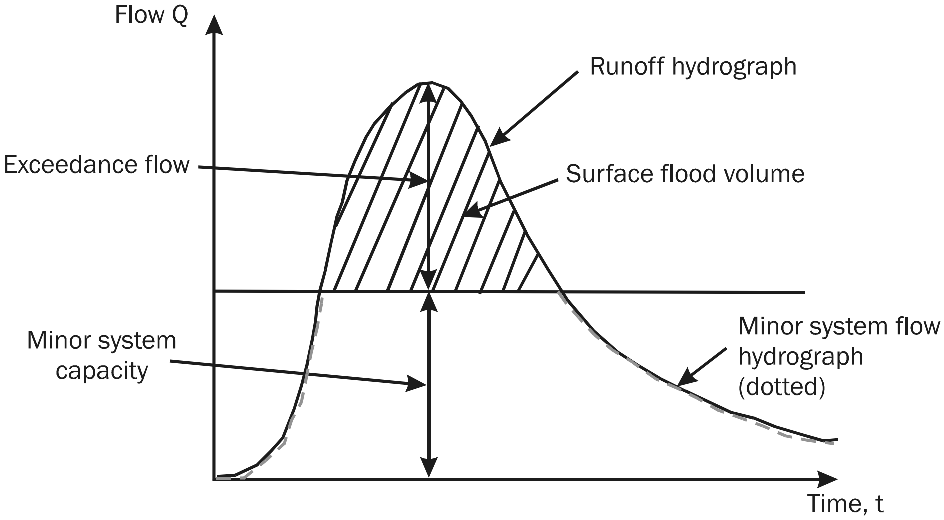

Figure 2.3 *Simplified representation of minor/major system flow*

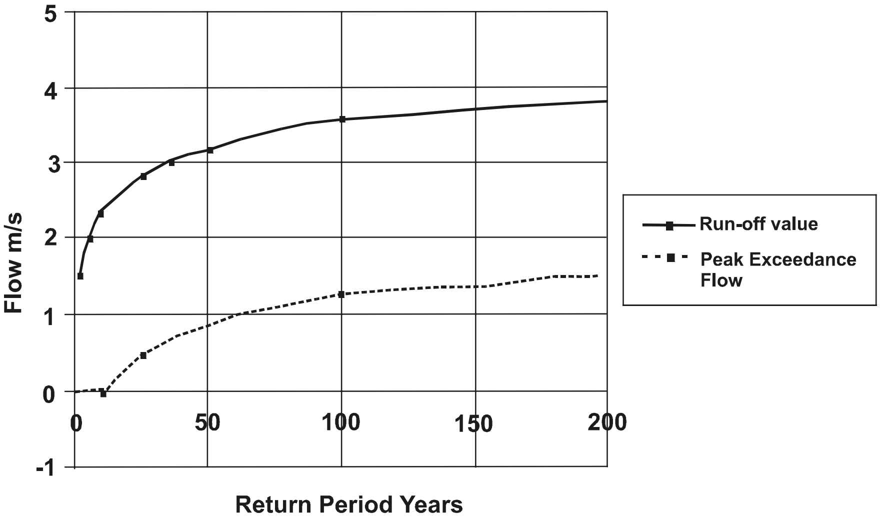

Figure 2.4 *Runoff and exceedance flow for different return period events*