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Sustainable Water Management in the City of the Future

Integrated Project
Global Change and Ecosystems

Deliverable 2.1.2. A design manual incorporating best practice guidelines for stormwater management options and treatment under extreme conditions
Part A: Review of design guidelines for stormwater management in selected countries

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SWITCH Briefing Note

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Audience: stakeholders involved in the planning, design, construction, operation and maintenance of BMPs/SUDS which includes site and consulting engineers, planners, landscape designers, developers, architects, environmental regulators, sewerage undertakers and BMP/SUDS practitioners.
Purpose: This deliverable reviews and compares the design guidelines which have been established for stormwater management in countries which are participating in SWITCH (UK, Switzerland, Brazil and Germany) as well as in selected countries not directly involved in SWITCH but where design procedures have been established to different levels of sophistication (Australia and Malaysia).
Background: The SWITCH project sets out to identify sustainable stormwater control options which are able to cope with the demands of the city of the future. With respect to the task with which this deliverable is associated, the project partners involved discussed a range of topics which they wished to see incorporated in the deliverable. This deliverable represents one part of the final report (Part A) and sets out to identify generic- and site- specific information, gaps and information/research needs following a review of existing stormwater BMP/SUDS design manuals. It is important to note that the research work carried out within SWITCH which complements this deliverable includes: • A review of BMPs/SUDS in relation to their potential to integrate with existing infrastructure (i.e. retro-fit/hybrid systems); this topic is fully reported in Deliverable 2.1.2b. • The development and application of stochastic rainfall series to determine the impact of climate change scenarios on urban hydrology (this represents part of a PhD research study at EPFLand will be reported elsewhere. • A review of BMPs/SUDS in relation to their potential to contribute to other sectors of the urban water cycle (this is currently being fully investigated as part of Task 2.2.5 of the SWITCH project).

Potential impact: The existing manuals have been supplemented, where relevant, by recent conference publications, to provide the latest advice available. Through the presentation of guidelines for different selected countries, consideration has been given to the design of BMPs/SUDS under a wide range of climatic conditions. A critique of the described design guidance manuals for the UK is presented in terms of criteria relating to hydraulic design, surface water runoff management and water quality design. Finally, the benefits and limitations of the different modelling approaches which can be used for predicting stormwater quality entering and, in some cases, leaving BMPs/SUDS are reviewed in an Appendix to the main report.
Recommendations: This review of design guidelines for SUDS/BMPs enables readers to assess the approaches which are most relevant to their situation in the quest to obtain the optimal environmental and long-term economic benefits associated with adapting existing drainage systems to environmentally sustainable design criteria.

EXECUTIVE SUMMARY

This document, representing Deliverable 2.1.2 of the SWITCH project, fulfils part of the requirements for Task 4 (also identified as Task 2.1.2) of WP 2.1 within Theme 2. It has therefore been labelled as Part A of the overall deliverable and complements Part B, which concentrates specifically on relevant aspects of the use of Best Management Practices (BMPs) for stormwater control in urban areas. Part A reviews and compares the design guidelines which have been established for stormwater management in countries which are participating in SWITCH (UK, Switzerland, Brazil and Germany) as well as in selected countries not directly involved in SWITCH but where design procedures have been established to different levels of sophistication (Australia and Malaysia).

Prior to the commencement of Task 4 (Task 2.1.2), the project partners involved in WP 2.1 fully discussed the range of topics which they wished to see in the associated deliverable. These topics are listed below:

1. A review of existing stormwater BMP/SUDS design manuals to include identification of generic- and site- specific information, gaps and information/research needs.
2. The development and application of stochastic rainfall series to determine the impact of climate change scenarios on urban hydrology
3. A review of BMPs/SUDS in relation to their potential to integrate with existing infrastructure (i.e. retro-fit/hybrid systems)
4. A review of BMPs/SUDS in relation to their potential to contribute to other sectors of the urban water cycle.

Item 2 represents part of the PhD research study of Xavier Beuchat at EPFL and is still under development with an estimated completion date of mid-2009. Items 3 and 4 are presented in Part B of Deliverable 2.1.2 which represents the companion volume to this document.

A wide range of guidance manuals is referred to in this report and these are available either as hard copy or in an electronic format. Different manuals are targeted at different user groups but collectively they provide relevant information on the planning, design, construction, operation and maintenance of BMPs/SUDS for site and consulting engineers, planners, landscape designers, developers, architects, environmental regulators, sewerage undertakers and BMP/SUDS practitioners. The existing manuals have been supplemented, where relevant by recent conference publications, to provide the latest advice available. By presenting information from the guidelines for different countries it could be argued that consideration has been given to the design of BMPs/SUDS under a wide range of climatic conditions, although the impact of prolonged very cold conditions may not be represented. A critique of the described design guidance manuals for the UK is presented in terms of criteria relating to hydraulic design, surface water runoff management and water quality design. Finally, the benefits and limitations of the different modelling approaches which can be used for predicting stormwater quality entering and, in some cases, leaving BMPs/SUDS are reviewed in an Appendix to the main report.

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A. UK DESIGN AND GUIDANCE MANUALS

A.1 CIRIA Sustainable Drainage System (SUDS) Design Manuals

There are now available in the UK a considerable number of design and guidance manuals for Sustainable Urban Drainage Systems (SUDS) of which the most commonly used are those developed by the private construction industry association CIRIA (Construction Industry Research & Information Association; www.ciria.org.uk). These manuals have been developed with sponsorship and authorship drawn from a combination of government, regulatory agencies, industry, water companies and academia. The manuals of "best practice" listed below in chronological order, have been developed under the oversight of an appointed Steering Group having experience and interest in the specific research theme.

2000. *Sustainable Urban Drainage Systems: Design Manual for Scotland and Northern Ireland.* P Martin et al. Report C521. CIRIA, London. ISBN 0-860175219.
(The Scottish Environment Protection Agency SEPA, produced an earlier brief guidance handbook on source control best practice intended as a primer for the Scottish water industry to such drainage techniques. 1996. Guide to Surface Water Best Management Practices. May 1996. SEPA, Erskine Court, Castle Business Park, Stirling, Scotland.)

2001 *Sustainable Urban Drainage Systems: Design Manual for England & Wales*. P Martin et al. Report C522. CIRIA, London. ISBN 0-860175227.

2001 *Best Practice Manual for England & Wales.* P Martin et al. Report C523. CIRIA, London. ISBN 0-860175235.

2004. *Sustainable Drainage Systems: Hydraulic, Structural and Water Quality Advice.* S Wilson, R Bray and P Cooper. Report C609. CIRIA, London. ISBN 0-86017-609-6.

The first three manuals listed above have also been compiled on to a single CD available from CIRIA as Report C599CD, ISBN 0-86017-599-5. However, all of these original design manuals have been largely superseded by a more recent update contained within the following two CIRIA manuals.

2007. *The SUDS Manual.* B Woods-Ballard, R Kellagher, P Martin, C. Jefferies, R. Bray and P. Schaffer. Report RP697. CIRIA, London. ISNB 0-86017-697-5.

2007. *Site Handbook for the Control of SUDS.* B.Woods-Ballard, R Kellagher et al. Report C698. CIRIA, London. ISBN 0-86017-698-3.

These two handbooks provide best practice guidance primarily aimed at site engineers and SUDS practitioners on the planning, design, construction, operation and

maintenance of Sustainable Drainage Systems (SUDS) to facilitate their effective implementation within developments.

A.2. General SUDS and Urban Surface Water Drainage Guidance

There are also available a number of general guidance manuals published by CIRIA, HR Wallingford and British Water which cover topics within the overall field of urban drainage which have relevance to surface water runoff drainage design and operational practice of which the following are probably of most significance.

2006. *Designing for Exceedance in Urban Drainage: Good Practice*. C Digman, D Balmforth, R Kellagher and D Butler. Report C635. CIRIA, London. ISBN 0-86017-635-0

This handbook aims to provide best practice advice for the design and management of urban sewerage and drainage systems to reduce the impacts that 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 appreciation of engineers, planners and designers of the risks associated with urban drainage systems and their understanding of how these risks may be mitigated. It provides guidance on how 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.

2005. *Use of SUDS in High Density Developments: Guidance Manual.* R Kellagher. Report SR666. Hydraulics Research, Wallingford, Berks.

This guide has been developed to assist developers, their professional advisors and local planning authorities with achieving drainage best practice on all new developments, with specific direction on achieving sustainable drainage solutions for high density sites. The document which is available from HR Wallingford (www.hrwallingford.co.uk) supports drainage infrastructure planning, conceptual design and construction.

2005. *Guidance to Proprietary Sustainable Drainage Systems and Components*. Technical Guidance Note, British Water, London. ISBN 1 9034810-4-10.

A briefing leaflet on types and acceptability of source control systems and components for surface water runoff control; intended as an introductory primer for suppliers to the UK water industry.

2004. *Drainage of Development Sites: A Guide.* R May and R Kellagher. Report X108. CIRIA, London. ISBN 0-86017-900-1

This guide is intended to assist all those involved with foul and surface water drainage of development sites. It is aimed specifically at developments in the UK based on national requirements and international best practice. The book provides guidance on

the approach needed to obtain Town and Country Planning Act consent and current good engineering practice for design of drainage and sewerage for new sites. In addition, issues affecting site drainage, hydraulic-related engineering issues and key industry documents are covered. Also included is a proposed new methodology for calculating site storage. It is intended that general engineering practitioners, developers and architects will use this book as a first point of reference for guidance and information on all aspects related to the hydraulics of site drainage. The sites discussed range from small suburban developments to large industrial estates, each having specific features that require particular attention.

2004. *Model Agreements for Sustainable Water Management Systems: Model Agreements for SUDS.* P Schaffer, C Elliott, J Reed, J Holmes and M Ward. Report C625. CIRIA, London. ISBN 0-86017-625-8.

This guide provides basic advice on the use and development of model operation and maintenance agreements for sustainable drainage systems together with simple guidance on their incorporation into developments. The aim of the model agreements is to facilitate uptake of SUDS by providing a mechanism for maintenance. The model agreements developed for use with this Interim Code of Practice achieve this through the planning process, either as a planning obligation under Section 106 of the UK Town and Country Planning Act 1990 or as a condition attached to planning permission. The handbook identifies maintenance considerations and provides an outline of ways in which the long-term responsibilities for the maintenance of the SUDS can be allocated. Provided with the book are three model agreement booklets and a CD containing electronic files of the model agreements.

2004. *Interim Code of Practice for Sustainable Drainage Systems.* National SUDS Working Group. CIRIA, London. ISBN 0-86017-904-4

This handbook aims to facilitate the implementation of sustainable drainage in developments in England and Wales by providing model maintenance agreements and advice on their use. It provides a set of agreements between those public organisations with statutory or regulatory responsibilities relating to SUDS. The specific objectives of the document are to:

- encourage the implementation of SUDS in new and existing developments
- provide basic guidance for practitioners on the implementation of SUDS in new developments
- make the adoption and allocation of maintenance for SUDS more straightforward.

2003/2004. *SUDS: Economic Incentives, Social Impacts and Ecological Benefits*

HR Wallingford (www.hrwallingford.co.uk) has published the outcomes of a UK Department of Trade & Industry (DTI) funded research project under the above title, which investigated the economic incentives, social impacts and ecological benefits of SUDS. The findings of this research have been brought together in four reports which are available from HR as a CD ROM compilation.

An Assessment of the Social Impacts of Sustainable Drainage Systems in the UK. Report SR622, This report assesses the perception and level of

understanding of people living close to seven different SUDS ponds in the UK. It draws conclusions on the impact of SUDS design and maintenance and of education in influencing the public's perception of SUDS ponds.

Maximising the Ecological Benefits of Sustainable Drainage Schemes. Report SR 625. This report reviews and provides guidance on the ecological benefits of sustainable drainage systems (SUDS) compared to conventional systems. The report also suggests designs and maintenance regimes that will maximise the ecological performance of a range of SUDS components.

2004. *The Operation and Maintenance of Sustainable Drainage Infrastructure*. Report SR626. This report describes a management strategy for the day to day care of SUDS, and applies current landscape maintenance practice to the problems of looking after a predominantly surface drainage infrastructure. Guidance on maintenance techniques is provided and two 'demonstration sites' are reviewed to try to gain an understanding of current cost implications associated with the operation and maintenance of SUDS features.

2004 *Whole Life Costing for Sustainable Drainage*. Report SR 627. This document provides guidance to the UK construction industry, on the assessment of whole life costs for sustainable drainage systems, and sets out a clear methodology for evaluating whole life costs for these systems. A case study of the application of whole life costing techniques for SUDS schemes in the UK is presented.

A.2.1.Recent Relevant Research Publications

2008. C Viavattene, L Scholes, D M Revitt and J B Ellis. A GIS based decision support system for the implementation of Stormwater Best Management Practices. In: CD of Proceedings of 11th International Conference on Urban Drainage, Scotland, UK, 31 August -5 September 2008.

A conference paper which demonstrates how methodologies designed to assist practitioners in the selection of BMPs/SUDS can be integrated into a decision support system based on a Geographic Information System (GIS) platform.

2008. C Jefferies, A Duffy, N Berwick, N McLean and A Hemingway. SUDS Treatment Train Assessment Tool. In: CD of Proceedings of 11th International Conference on Urban Drainage, Scotland, UK, 31 August -5 September 2008.

A conference paper which outlines a rationale and scoring system for the stormwater treatment train assessment tool (STTAT) which is a proposed regulatory tool for SUDS systems. STTAT provides guidance and regulatory consistency for developers about the requirements of planners and the Scottish Environmental Protection Agency (SEPA). The tool balances the risks of pollution to the receiving water-body with the treatment provided in a treatment train.

A.3. Specific SUDS Design Manuals

In addition to the general design manuals and guidance handbooks listed above, there are also available a number of manuals which cover specific stormwater source control devices and surface water runoff sources.

A.3.1 Infiltration Systems

1991. *Soakaway Design.* Report X254. Building Research Establishment, Garston, Watford, Herts. Digest 365 (DG365). ISBN 1-86081-604-5.

This digest guidance describes soakaway design and construction procedures, explains how to calculate rainfall design values and soil infiltration rates, and gives design examples.

1991. *The Hydraulic Design and Performance of Soakaways* DC Watkins. Report SR271. HR Wallingford, Oxon.

The existing guidelines, as of 1991, on soakaway design as well as field testing and site conditions are examined and the hydraulic analyses are reviewed and evaluated. The study includes a review of the hydraulic principles governing the groundwater infiltration process which controls the hydraulic behaviour of soakaways.

1996 I*nfiltration Drainage: Manual of Good Practice*. R Bettess. Report R156. CIRIA, London. ISBN 0-86017-457-3.

This handbook presents good practice for the design, construction and maintenance of infiltration systems for the on-site control and disposal of stormwater runoff from small-scale residential or commercial developments upstream of an area with existing sewers. It discusses the advantages and disadvantages of such systems and gives information to help determine whether, in given circumstances, infiltration techniques are appropriate. The manual provides information that will enable users to conduct field tests and relate the data to the design, and also to design a range of types of infiltration system. Guidance on pollution prevention is included.

2001. *Source Control Using Constructed Permeable Surfaces.* C Pratt, S Wilson and P Cooper. Report C582. CIRIA, London. ISBN 0-8697-582-0.

This handbook discusses the critical issues that should be considered when designing and constructing pervious pavements that are to be used as a technique for stormwater source control. It details the types of surfaces available and provides examples of developments that have used these techniques. It explores the issues needed to consider relating to the hydraulic, structural and water quality performance of pervious surfaces. The handbook also provides a design framework, which includes detailed recommendations for methods where necessary. This book is intended for use by developers, landscape architects, consulting engineers, local authorities, architects, highway authorities, environmental regulators, planners, sewerage

undertakers, contractors and other organisations involved in the provision or maintenance of surface water drainage to new and existing developments.

2002. *Hydraulic Design of Paved Areas.* M Escarameia. Report SR606. HR Wallingford, Oxon.

This report describes a 28-month long study carried out by HR Wallingford which had the following objectives:
- To determine acceptable design criteria for the design of drainage systems for large paved areas. These include maximum acceptable water depth and duration of ponding for the design storms.
-To develop a suitable design procedure.
-To promote adoption of the design procedure.

Design guidance was produced for 2-dimensional catchment lengths from 10 to 100m and slopes from 1/150 to 1/50, as these values constitute an envelope of the conditions for which paved areas are likely to be designed. In order to achieve the above objectives the study was divided into the following stages: (1) development of a numerical programme for calculation of water depths on pavements; (2) collection of site data to provide suitable resistance equations and enable the validation of the numerical programme; and (3) development of design guidance.

2007. *BRESOAK: Soakaway Design Software.* AP241. Building Research Establishment, Garston, Watford, Herts.

The BRESOAK software supports the 1991 DG365 handbook (see above) and will help soakaway designers plan in ways that are consistent with the advice given in BRE Digest 365 on design and construction procedures, and specifically the calculation of rainfall design values and soil infiltration rates. The digest (DG365) is also included as a pdf file on the CD ROM. The software runs on Windows (TM).

A.3.1.1. Recent Relevant Research Publications

2008. R. Kellagher and H.Udale-Clarke. Sustainability Criteria for the Design of Stormwater Drainage systems for the 21st Century. In: CD of Proceedings of 11th International Conference on Urban Drainage, Scotland, UK, 31 August – 5 September 2008.

Infiltration is highlighted as a new performance measure which has been mainly ignored to date. Greater emphasis is now being given to groundwater recharge and this should be added as a design criterion. Research has demonstrated that rainwater harvesting can significantly reduce the flow rate and volume of surface water runoff from a developed site and minimise the size of stormwater management control components at site and regional scales.

2008. G. Lemmen, F. Boogard, P. Schipper and R. Wentink. Maintenance of SUDS. In: CD of Proceedings of 11th International Conference on Urban Drainage, Scotland, UK, 31 August – 5 September 2008.

The importance of infiltration as a SUDS performance indicator in Holland (in contrast to the UK) is described. In response to the lack of management and maintenance of SUDS systems on new housing developments in Holland, the Dutch RIONED Foundation has introduced Guideline C3200 for management and maintenance of infiltration facilities. It includes a matrix of causes of impaired functioning of BMPs/SUDS providing advice to end-users including municipalities.

A.3.2. Ponds and Wetlands

1993. *Design of Flood Storage Reservoirs.* M J Hall, D L Hockin and J B Ellis. Report B014. CIRIA, London. ISBN 0-7506-1057-3.

This guidebook is intended primarily to assist the practising engineer with the detailed design of flood storage reservoirs for flood control in partly urbanised catchment areas. Individual sections deal with the causes and prevention of flooding in urbanised drainage areas, design flood estimation, flood routing, water quality, detailed engineering design and the operation and maintenance of reservoirs. The handbook contains a step-by-step methodology for a hydrological design procedure and describes two flood estimation methods. Details of statutory requirements and powers are also included.

1998. *Review of the Design and Management of Constructed Wetlands.* P M Nuttall, A G Boon and M P Rowell. Report R180. CIRIA, London. ISBN 0-86017-485-9.

A state-of-the-art review detailing the benefits and limitations of constructed wetlands to treat domestic, agricultural and industrial wastewater as well as urban and highway runoff. It also describes wetland operation, alternative design options, and management strategies, together with their economic and environmental considerations. It is relevant to a wide range of users, including those concerned with engineering, environmental considerations, planning, regulation, consulting and research. The review presents data which can be used effectively by the knowledgeable practitioner. This mainly relates to England, Wales and Scotland, but is also applicable to the international community. There are examples from 70 sites visited throughout the UK and an extensive reading list.

1998. Lagerberg, I., Barraud, V., Shutes, R B E., Revitt, D M and Smith, A. *Treatment of Highway Runoff Using Constructed Wetlands: An Interim Manual.* Environment Agency, Thames Region, Reading Berks.

Information is provided on the design, cost, operation and maintenance of constructed wetlands intended for the control and treatment of highway runoff. Detail on configuration, planting media, water levels and the type/extent of vegetation requirements are included as also are the preliminary results from the monitoring of a series of wetlands on the A34 Newbury-Bypass, SE England.

2002 J B Ellis, R B E Shutes and D M Revitt. G*uidance Manual for Constructed Wetlands.* R&D Tech. Report P2-159/TR2. Water Research Centre, Swindon. Wilts. ISBN 1-844-321185.

A practical guidance manual commissioned by the UK Environment Agency on the selection, design and management of constructed wetlands as sustainable drainage systems for surface runoff control and treatment. The manual includes a literature review and consideration of wetland design parameters together with kinetic approaches and worked examples for wetland sizing.

2003. J B Ellis, R B E Shutes and D M Revitt. *Constructed Wetlands and Links with Sustainable Drainage Systems.* R&D Tech. Report P2-159/TR1. Water Research Centre, Swindon Wilts. ISBN 1-8570-59182.

A technical report commissioned by the UK Environment Agency providing a review of the design and use of constructed wetlands for the treatment of stormwater runoff from impervious surfaces in urban areas and linkages between constructed wetlands and sustainable drainage systems. Primarily intended for training and awareness-raising of Environment Agency staff involved in urban drainage control and management.

A.3.3. Highway Runoff Control

A series of Advice Notes and design guidance documents for potential contractors have been produced by the Highways Agency (and its predecessor the Department of Transport) covering the design, operation and maintenance of surface water drainage systems for highway runoff. The documents comprise official standards and design criteria for highway construction drainage systems and constitute a total of 15 volumes which are available as pdf files for downloading from the Highways Agency website (www.standardsforhighways.co.uk). The material in the various volumes is regularly updated and revisions/amendments are noted on the website. The following list provides information on those volumes relevant to surface water runoff and its control.

> 1996 *Design of Outfalls for Surface Water Channels*. HA 78/96. Volume 4, Section 2. Gives guidance on suitable layouts for different types of surface water channels and provides methods for designing each type according to the flow rate in the channel.
>
> 1996 *Surface and Sub-surface Drainage Systems for Highways.* HD 33/96. Volume 4, Section 2. Gives guidance on the selection of the types of surface and sub-surface drainage for motorways and trunk roads. t also includes guidance on drainage of earthworks associated with highway schemes.
>
> 1999 *Pavement Design and Maintenance.* HD 23/99. Volume 7, Section 1, (Part 1; Preamble), Section 2, (Parts 2 and 3; Design of pavement foundations, roadbase and surfacing for new roads), Section 5 (Surfacing and surfacing materials including porous asphalt).
>
> 2006 *Water Quality and Drainage. (Road Drainage and the Water Environment)* HA216/06. Volume 11, Section 3. Gives guidance on the provision of predictive methods for the assessment of potential impacts of road runoff on the aquatic environment and advice on mitigation measures that

may be used to reduce any such pollutant impacts if and where required. Worked examples are provided for the predictive methodology.

An early review of the impacts of highway runoff on receiving waters and of source control measures for reducing these impacts is provided in the following volume which also includes design examples of infiltration and storage systems.

1991. J B Ellis, and D M Revitt. *Drainage From Roads: Control and Treatment of Highway Runoff.* Report 43804/MD012. September 1991. Tech. Services Admin., Thames National Rivers Authority, Reading, Berks.

A 1994 CIRIA book also provided practical guidelines for highway drainage designers and water quality regulators. The volume reviewed the pollutants likely to be present in highway drainage discharges, and assessed the impact that these can have on the receiving water. It also reviewed the legal framework within which the discharges are made, and the controls that can be imposed on these discharges. It described current drainage practice of the time and the operation of different types of drainage structure. Guidelines are presented for the planning and design of highway drainage systems in order to avoid pollution of receiving waters and recommendations for future work to reduce the environmental impact of drainage discharges are provided.

1994. M Luker and K. Montague. *Control of Pollution from Highway Drainage Discharges*. Report 142. CIRIA, London. ISBN: 0-86017-415-8

More recent overviews of the treatment methodologies available for highway runoff have been provided by:

D M Revitt and J B Ellis. Drainage, Runoff and groundwater. Chapter 4 in G Mudge (Edit): *Guidelines for the Environmental Management of Highways.* The Institution of Highways & Transportation, London. ISBN 0-902933-31-0.

D M Revitt. Water Pollution Impacts of Transport 81 – 109 in R E Hestor and R M Harrison (Edits): *Transport and the Environment.* Issues in Science and Technology, Vol.20. Royal Society of Chemistry, Cambridge. UK. ISBN 0-85404-295-4.

A.3.3.1.Recent Relevant Research Publications

2008. KV Heal, R Bray, SAJ Willingale, M Briers, F Napier, C Jefferies and P Fogg. Medium-term performance and maintenance of SUDS: a case-study of Hopwood Park Motorway Service Area, UK. In: CD of Proceedings of 11th International Conference on Urban Drainage, Scotland, UK, 31 August – 5 September 2008.

A conference paper which summarises studies conducted between 2000 and 2008 at Hopwood Park Motorway Service Area. The results demonstrate the benefits of a management train approach over individual SUDS units for flow attenuation, water treatment, spillage containment and maintenance. Of the current annual landscape budget of £15,000 for the whole site, the annual maintenance costs for SUDS were £2500 compared to £4000 for conventional drainage structures.

2008. F. Guz, K.Morrison, A. McKenzie, C.Aukerman and M. Ralph. Planning Construction, Operation & Maintenance of Sustainable Urban Drainage for Roads. In: CD of Proceedings of 11th International Conference on Urban Drainage, Scotland, UK, 31 August – 5 September 2008.

A research paper which reports on the progress of the development of guidance for 'SUDS for Roads' which will remove many of the misconceptions around which current design practices are established and facilitate the adoption of a local roads hierarchy with associated SUDS by local roads authorities based on sound engineering judgement supported by academic study and scientific investigation.

A.4 On-Line SUDS Guidance and Training Materials

www.uwtc.tay.ac.uk

The Urban Water Technology Centre (UWTC) at the University of Abertay, Dundee offer a number of SUDS training opportunities which can be taken as 1/2 day short courses either at UWTC or in-house. A CD-ROM is available to provide a "stand-alone" information package on SUDS devices with information and advice on design, planning and maintenance to be used in conjunction with the CIRA C521 2000 design manual for Scotland. An on-line SUDS training course is also offered (at least once per year requiring 10 hours per week study over 12 weeks) providing SUDS design, planning and implementation guidance together with case studies, worked and self-test examples and supporting the full suite of CIRA design manuals. The on-line course provides support for the CIRA design manuals and includes a CD-ROM.

www.daywater.org

This website for the 5th EU Framework programme DayWater, provides access to full information and design guidance on source control BMPs. On entering the home site, the Reports and Publications portal enables free downloading of the following material relating to BMP design and operation.

August 2003. J B Ellis, D M Revitt, L Scholes, J-C Deutsch, H Seiker, M Viklander and E Eftias. *Review of the Use of Stormwater BMPs in Europe.* WP5 Task 5.1, Deliverable 5.1

November 2003. D M Revitt, J B Ellis and L Scholes. *Criteria Related to the Assessment of BMP Performance.* WP5 Task 5.2, Deliverable 5.2

The home page also allows access to the Adaptive Decision Support System, ADSS Prototype, by entering "guest" as the user name and password. The BMP panel widow can then be opened which provides full descriptions of structural and non-structural BMP systems including information and guidance on design, performance, O&M and costs. Links are also provided to specific design guidance information and to a case studies database.

www.microdrainage.co.uk

The home site of Microdrainage Ltd offers tailored urban drainage design and analysis as well as training services, case studies and sustainable drainage system presentations. WinDes software (EN BS ISOI 9001 certified) supports separate design modules for storage/attenuation systems and for infiltration/soakaway systems. SUDS and urban flood risk assessment training courses are offered in conjunction with the WinDes software. The technical portal on the website allows download of relevant publications and articles. A free interactive CD demonstrating the WinDes software is available on request.

www.ciria.org/SUDS

The CIRIA home site which provides general guidance on urban drainage best practice together with examples of SUDS infrastructure implemented within the UK. Further information of use to local authorities on surface water drainage issues and concerns is available from www.ciria.org/landform.

A.5. A Critique of UK Design Guidance Manuals

A.5.1 Hydraulic design criteria

5.1.1 Design criteria for SUDS have been rather slow in being developed. This is partly because the actual performance of SUDS units (both in terms of their water quality and hydraulic behaviour) have not been fully understood nor represented very well in drainage software to date. In addition, their introduction into the UK was championed by SEPA who have a remit for addressing only pollution issues and not flood control.

5.1.2 In the 1980s, the National Rivers Authority predecessor to the England & Wales Environment Agency started introducing hydraulic control stipulations on the discharge of stormwater drainage. These were set at a discharge rate (2 litres/sec/hectare) based on the peak rate of runoff from the site prior to development. It was felt that a controlled discharge would address both the scour and erosion aspects associated with the high rates of urban runoff and that the temporary storage of runoff also provided some flood protection. Traditional analytical approaches are based on the use of a critical duration design storm for the assessment of flood storage requirements. This essentially defines the storage volume needs for meeting a specified limit of discharge. The conventional wisdom in UK surface water design is to provide a 1:30 year flood protection as the appropriate design storm for pipe sizing.

5.1.3 Figure 1 provides a simple illustration of these hydraulic requirements. The figure shows that although the rate of runoff is limited to original greenfield conditions, much of the runoff is still discharged over the period when the receiving stream may be in flood.

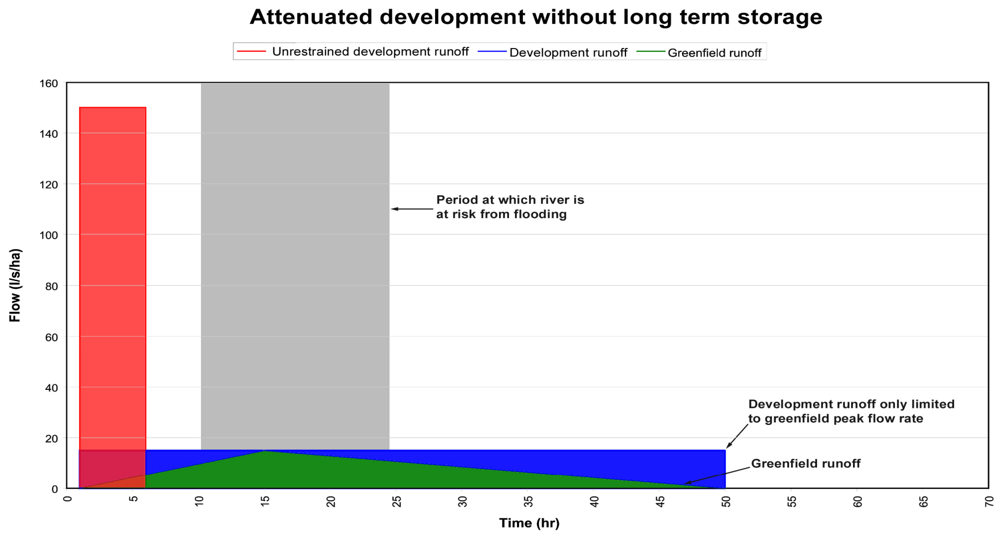


Figure 1 The use of only a greenfield discharge control

As the total volume of runoff has thus increased, the approach has therefore not addressed the potential exacerbation of flooding in the river. In addition the discharge rate was normally specified at a fixed rate and therefore runoff from the site would not show the variability of runoff which actually takes place from an undeveloped site. In this respect the hydraulic design approach can be considered to be flawed and lacking in rationale. The recent 2007 summer flooding has generated considerable attention on the hydraulic design of surface water systems given that the Pitt Review (cabinet Office, 2007) estimated that up to 65% of the urban flooding and subsequent damage could be attributed to surface water drainage. Increased rainfall intensities and increasing urbanisation are leading to more “flash floods” caused by overland flow from impermeable surfaces. Such high intensities not only induce sewer surcharging but also increase the likelihood of gully by-passing to exacerbate direct receiving water flooding. In addition, the Association of British Insurers (ABI) is proposing that property insurance should only be made available to developments having a minimum 1:75 RI level of protection. This may only be possible by fully containing the more frequent storm events (1:2/1:3 RI) totally within the property or curtilage boundaries using source control techniques. A limited number of pilot-scale studies applying this approach are being trialled in the Cambridge and Birmingham regions (EA, 2007; DEFRA, 2008a) as part of the DEFRA Integrated Urban Drainage (IUD) “Making Space for Water” initiative.

5.1.4 To address this fundamental issue, the concept of “long term” storage and variable rate of discharge has been recently introduced following research carried out by HR Wallingford into the requirements for development runoff attenuation (May and Kellagher, 2004). The HR Wallingford research is essentially underpinned by previous work developed in both the US and Australia which recognised the importance of flood volume and release rate as the prime driving criteria for design. This results in the requirements illustrated in Figure 2 where the criterion of a greenfield control rate are augmented by the need to provide long term storage to address extreme events which cause rare or extreme river flooding.

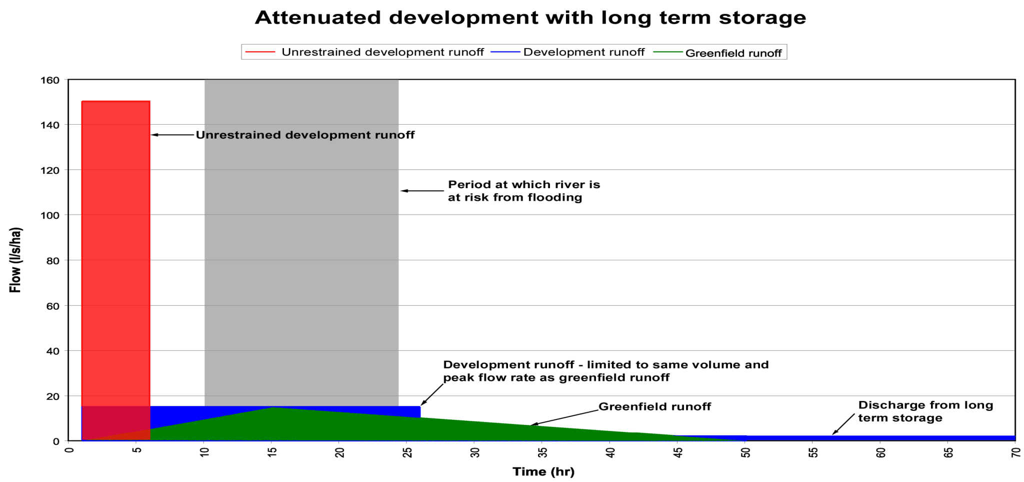


Figure 2 The use of a greenfield discharge control criterion together with long term storage

As this, by definition, is needed infrequently, this storage element need not necessarily be a traditional structure, but can be provided in the form of a temporary flooding area which would normally serve some other purpose, such as a park, football field or "hollow" within a residential cul-de-sac. It can be seen from the figure that this approach results in a reduced volume of runoff to the receiving water during the period when flooding may be an issue. However, such a solution also depends on the public and social acceptance of temporary flooding of "community-owned" riparian surfaces. Other criteria, such as interception storage at headwater sources, have also been suggested in the output from the same research carried out at HR Wallingford to try and move drainage design towards replicating greenfield behaviour more accurately.

5.1.5 The source storage approach philosophy to urban surface water drainage for greenfield development is to design on-site storage as a basic means of attempting to maintain the receiving river regime in its "natural state" by minimising the difference between the developed and undeveloped flood peak rates and volumes. Initial interception storage (between 5 to 10 mm) at headwater sources within the site would be followed by "permanent" surface storage for the 10 – 30 year event at the site outlet with provision for attenuation (peak shaving) of the high intensity 1:10 year event (Figure 3).

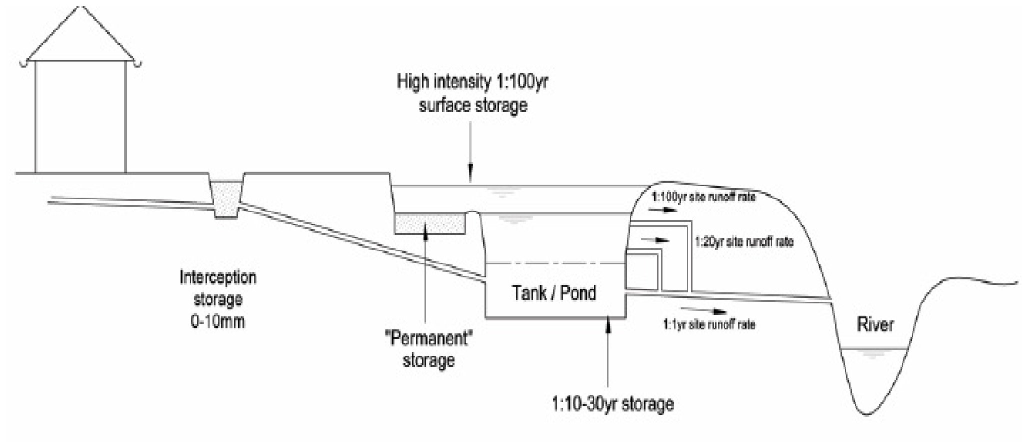


Figure 3 Interception and Permanent Site Storage

Recommendation was also made to move away from a single (2 litre/second per hectare) discharge or release rate to an increased volume with variable discharge rates (2 to 4 litres/second per hectare). [HR Wallingford, SP591; Storage Requirements for Rainfall-Runoff From Greenfield Development Sites). Design practice on the ground varies and there is a need for more consistent design criteria

5.1.6 The development of new runoff criteria has not yet resulted in new methods of design or even in further discussion of alternative approach philosophies within SUDS guidance manuals. This is despite the fact that the approach of running design storms of various durations, and determining the worst case has been used since the Wallingford Procedure was created in 1981. However the use of SUDS introduces various drainage features which have widely differing hydraulic behaviours. In addition, it is clear that their response to real storm events are significantly different to design storms. Figure 4 illustrates the outflow hydrograph for a 1 year event based on two drainage designs for a site. The red horizontal line represents the 1 year greenfield runoff rate while the green and pink lines represent the greenfield runoff as a hydrograph (each representing a calibration to a different greenfield formula). The blue lines represent the drainage system performance; one with the combined use of infiltration techniques and a pond, while the other is the pond only. It can be seen that although one has clearly less runoff volume, the other has a slightly lower peak discharge rate. These differences would vary depending on the design duration of the storm used. Thus although the critical duration storm provides the worst volumetric storage requirement, the actual performance against real rainfall will clearly vary depending on the event return period and duration.

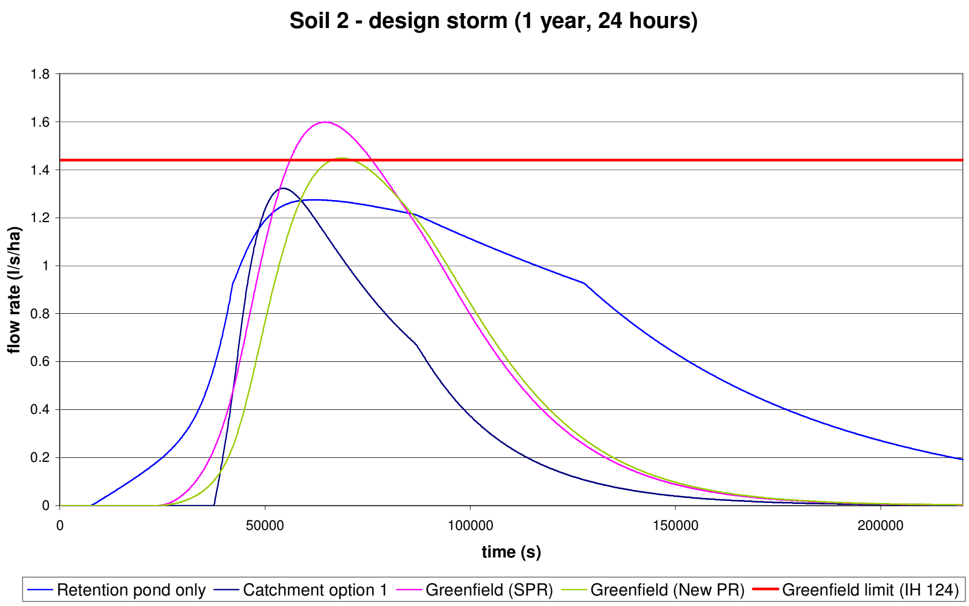


Figure 4 Outflow hydrographs for greenfield and two urban drainage systems

5.1.7 The difference in predicted performance between design storms and real events can be quite dramatic, as the design rainfall profile can sometimes heavily influence the outflow rate. Figure 5 illustrates the results for six recorded extreme events for a lined pervious paving system, where the return period of each was assessed and compared to the hydraulic results using design events. The differences are very revealing with the observed storm events not resulting in the hydraulic efficiencies predicted by the design storm approach. Similar results were produced from the analysis of retention pond design although the difference between observed and design storm outcomes was less dramatic. Much more research is needed to look into this aspect further, but it is clear that there may be significant limitations in using design storms for assessing the performance of SUDS systems. To date there appears to be relatively little urgency in research terms to undertake this work and certainly the issue is not incorporated or considered in the current UK design manual(s).

5.1.8 The same two simple drainage models have been applied using a 5 year time series of rainfall (split into summer and winter periods) and peak flows and volumes of runoff have then been assessed. These were similarly compared to the greenfield runoff predictions and the 1 year greenfield runoff rate. Figures 6 and 7 show the results of this analysis. The pond-only drainage system is now represented by the orange line. These graphs show that the ranking of events by one drainage system (represented by the dark blue line) is not the same ranking for the site drained by either the other drained system or the greenfield site models. It also shows the number of events that have no discharge and the general variation in performance against the greenfield condition with return period.

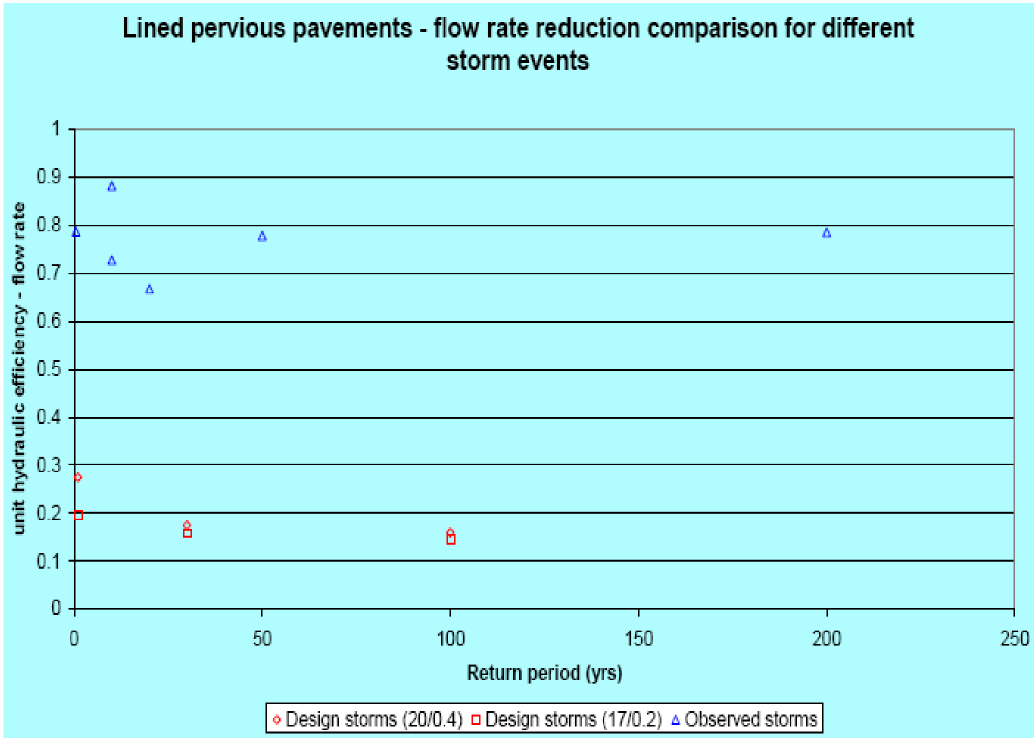


Figure 5 Hydraulic performance of pervious pavements using design storm events and recorded extreme events

5.1.9 Current SUDS design approaches do not sufficiently consider the importance of seasonality components to both hydraulic and water quality properties. This will become of increasing significance as climate change progresses. Research would suggest that infiltration systems typically show no outflows for up to 50% of summer storm events in comparison to less than 32% for winter events (see inset to Figure 8). In addition, it is already well recognised that increases in percentage runoff reduce substantially as storm rainfall depths increase above 100 mm (Figure 8). For infrequent and extreme events, the difference between the pre- and post- development storm hydrographs become minimal.

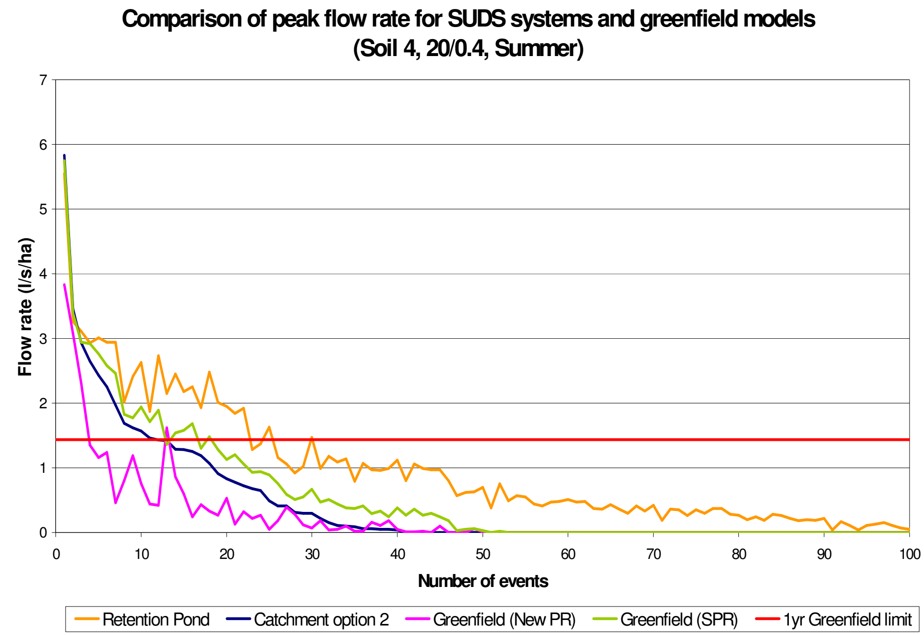


Figure 6 Peak flow rate outflow from a site using two calibrated greenfield models and two drainage models

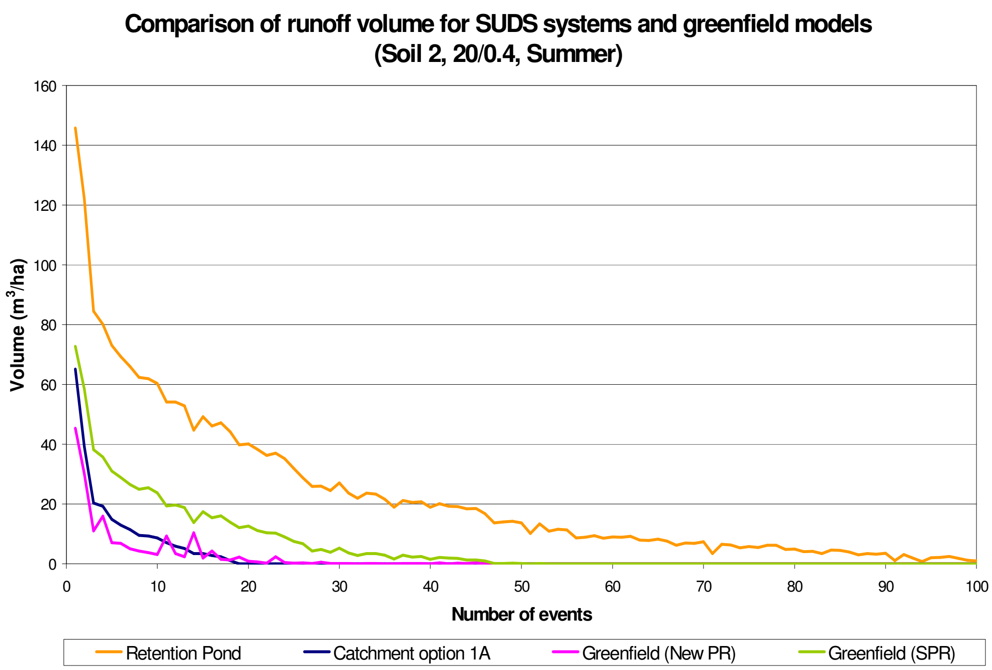


Figure 7 Volume of outflow from a site using two calibrated greenfield models and two drainage models

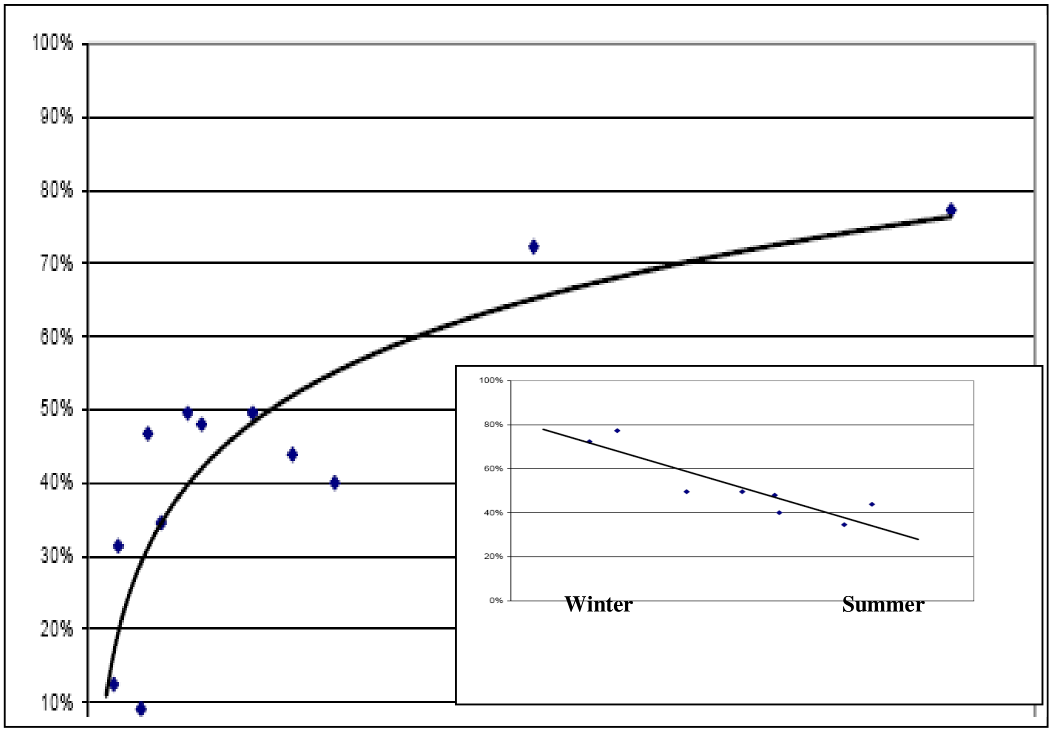


Figure 8 Percentage Runoff of Rainfall Events

The performances of SUDS in terms of flow control clearly reduce with more infrequent events and if climate change results in more intense, short duration summer storms, some of the expected benefits are not likely to be achievable. Design guidance currently also provides no advice or recommendations on linkages with larger regional catchment flood and water quality strategies or on likely consent requirements for discharges to receiving waterbodies.

5.1.10 It is clear that hydraulic design is a function of the design criteria with the assessment ability being highly dependent on the availability and application of appropriate tools. A fundamental question for SUDS design guidance manuals is whether to advocate design storm or time series rainfall as the more appropriate approach for the definition and quantification of hydraulic performance. This is of particular importance given the need to identify more sustainable and innovative stormwater control options for the city of the future. There are a number of specific issues to this controversy which need addressing:

does SUDS analysis based on these two approaches arrive at the same answer and which is the most robust in terms of long term climate and land use change? There is undoubtedly a need to examine differences in SUDS unit performance between design events and real extreme events. Much more guidance is needed in respect of extreme event exceedance with more clarity on return periods such as the potential impact of a range of RIs and SUDS performance for events exceeding the design capacity, including recovery times. Advice also needs to be compatible with the 2006 6th edition of "Sewers for Adoption" (WRc Swindon, ISBN 1898920575) which includes in Section 2.15 general advice on surface water drainage management and recommends an interim code of practice for SUDS. There is a need for some

consistency of approach for the design of SUDS and piped systems. At present very little guidance is available on appropriate SUDS retrofitting for existing built-up zones.

which return period is most appropriate and/or significant for identifying SUDS performance; 100 year, 30 year, 1 year or "ordinary" short term (< 0.5) events? In addition, how do such return period designs affect the performance criteria and outputs when viewed from hydraulic and pollution control perspectives?

how should design criteria be developed to reflect and encourage the optimum use of space to meet hydraulic constraints?

how are infiltration systems (and reuse) to be evaluated given that seasonality is clearly a critical issue for design?

in terms of long term sustainability requirements, are frequent events more relevant than extreme events for both (or either) flow and quality control?

5.1.11 Time series analysis may probably prove necessary for assessing system design for water quality, reuse and (seasonal) volume balance, although design storm approaches are very likely to remain predominant for overall hydraulic volume determination and compliance to discharge requirements. They undoubtedly are appropriate for design of pipe systems and for determining attenuation storage volumes. However, the use of time series rainfall data is likely to become much more useful and important in evaluating system sustainability. Using a 24-hour rainfall analysis to set standards is problematic. Time series rainfall should be used to ensure that the 80%-ile retention times for either annual or summer events is less than 7 days. This is particularly important for SUDS having no regular baseflow or where low water depths and dense vegetation increase the risk of high nutrient concentrations in the permanent pool. When developments are being designed to carry a treatment train series, with each SUDS having very different critical duration characteristics, the composite response from the site (or from part of the site) will vary for different types of storms. It is also questionable as to whether long duration, low intensity events might constitute more critical design conditions than the relatively short duration, high intensity design events which currently comprise the predominant methodological approach.

5.1.12 Preliminary results from the United States EPA/ASCE National BMP database would also suggest that biofilters and (dry) detention basins can contribute significantly to volume reduction (30% - 40% less outflows compared to inflow volumes), even though they are normally not specifically designed to do so (Strecker et al., 2004). Design standards should account for the hydrologic losses that can occur with such SUDS types and perhaps give more encouragement to their use. In addition, the SUDS type and operational process needs consideration when setting standards. A storm depth or volume for example, is relatively meaningless for a vegetated swale. For such "flow-through" SUDS structures, an analysis of hourly (or 30/15 minute) data would be more appropriate. An over-reliance on infiltration systems, whilst achieving maximum reductions in runoff volume, can also result in substantial variations from the pre-development water balance. It is often the case that pre-development evapotranspiration can be as high as 80% or more of incident rainfall. If all runoff is infiltrated from the site, then clearly the original water balance will be disturbed. This can only be restored through increased site planting (trees, shrubs, grass etc), the use of ecoroofs and shallow, non-compacted soils.

5.1.13 The issue of design exceedance during short term, high intensity (>150 mm/hour) rainfall events has already been mentioned and is a fundamental concern underlying the Pitt Review of the UK 2007 summer floods. Under such conditions, overland flow contribution from normally permeable surface areas will occur as well as additional flows from surcharged roadside gullies and sewer pipes which are normally sized only to convey up to the 1:30 RI event. Current design manuals give little if any attention to approaches that can identify and predict areas at highest risk from excess surface water flooding. Whilst this issue can be regarded as principally falling within the purview of planning authorities and as such incorporated within the Critical Drainage Area PPS25 (2006 Planning Policy Statement) philosophy, SUDS design performance are nevertheless predicated by such exceedance flows. Information systems and local data registries of all flood risk management and drainage assets (above and below ground) need to be compiled by a competent authority as part of the design approach. This was a fundamental recommendation arising from the Pitt Review of the 2007 surface water flooding and will in any case be required as an integral part of future Stormwater Management Plans (SWMPs) under the PPS25 regulations. Similar recommendations are included in the DEFRA (2008b) consultation document "*Improving Surface Water Drainage*" (www.defra.gov.uk/environ/fcd/policy/surfacewaterdrainage.htm).

Mapping surface water flooding represents a considerable challenge as even small variations such as kerbs and street furniture can significantly affect water flows and the likelihood and scale of flooding. Thus for effective flood risk modelling, details on drainage and street infrastructure as well as exceedance flow velocities and routes need to be incorporated into hydraulic design predictions. This requires the independent development of appropriate real-time GIS visualisation tools. HR Wallingford (2007) is coordinating a DTI funded programme to develop new procedures and tools to enable such risk-based performance assessment of urban drainage systems. The work will utilise long term, 2D extreme rainfall series with 1-2 km radar resolution to derive probability distributions of flood damage risks and flood pathways. The modelling will be integrated into the InfoWorks CS engine and tested within sub-catchments in Bradford and Glasgow.

A further design issue associated with the derivation of exceedance flows is the accurate determination of impermeable surfaces. The likely overland runoff will be highly dependent on the extent, nature, age and condition of the surface component. The InfoWorks CS modelling routine allows for a total of 12 standard runoff surface types with only one category of "pervious" surface. Ellis and Revitt (2008) have identified up to 19 differing urban land use categories with three types of pervious surface. Such refinement is a pre-requisite for accurate flood visualisation mapping and for the hydraulic design of urban drainage infrastructure.

5.1.14 From this brief review of the SUDS hydraulic design included in current UK design manuals it can be suggested that an effective approach to assessment of the hydraulic performance of sustainable drainage systems requires the use of a sampled extreme time series rainfall as well as an annual series. As recorded data rarely exceeds 20 years, it is likely that this will need to be a stochastically generated series. Design storms will still serve a purpose in providing an initial estimate of drainage storage requirements and pipe sizing, but do not provide an adequate method of

evaluating a SUDS system performance against longer term sustainability criteria. Design solutions need to be:

technically appropriate and able to meet specified performance standards and output targets

institutionally viable such that the designed system can be safely adopted and regularly maintained

socially acceptable in that the designed SUDS unit(s) receive favourable community attitudes and achieve acceptable community cost-benefit-performance ratios

acceptable within the resource constraints prescribed by the environmental envelope considered from both short and long term sustainability indicators

A.5.2. Surface water runoff management

5.2.1 Surface water runoff from an undeveloped site compared to a development is illustrated by Figures 9 and 10. Figure 9 shows, in pictorial form, the various processes of runoff with the urban site being drained using a traditional pipe based system. Figure 10 simplistically illustrates the direct runoff portion of this process for a storm event with the post-development runoff being represented by both elevated and earlier peak flows relative to the pre-development situation. The prime intention of surface water runoff management is to reduce the peak flows shown in Figure 10 to a situation which mimics the original greenfield hydrograph. Thus SUDS design from a hydraulic viewpoint, is essentially concerned with determination of appropriate peak storage volumes and attenuation times as well as release rates, in order to minimise the hydraulic impacts on receiving waterbodies.

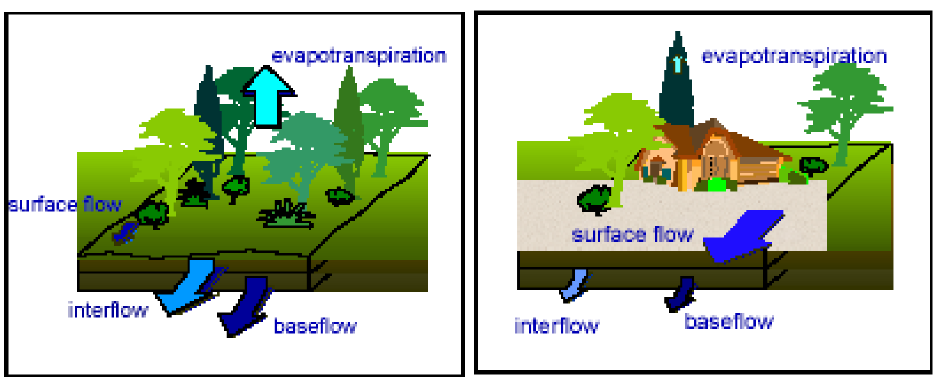


Figure 9 Pre and post-development rainfall-runoff characteristics. (From: Woods-Ballard et al., 2007)

5.2.2 Over the last decade the concept of SUDS has been introduced to try and replicate some of the natural runoff processes by using infiltration techniques and storage methods to reduce the rate of runoff. In addition there has also been a considerable emphasis over the past decade on addressing the pollution caused by stormwater, through the maximisation of physical as well as chemical and biological processes associated with differing SUDS control devices. These unit treatment

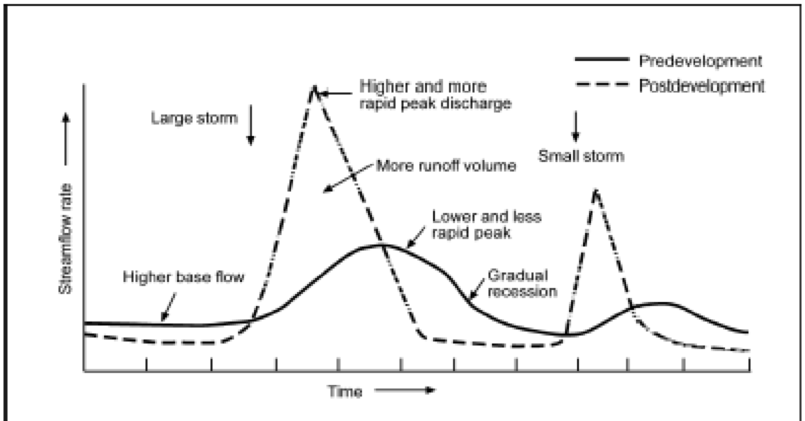


Figure 1.10-3 Changes in stream hydrology as a result of urbanization (Schueler, 1992)

Figure 10 Pre and post-development runoff hydrograph for a rainfall event (After Schueler, 1987)

processes essentially transpose traditional wastewater treatment approaches to SUDS devices for the removal of solids and solid-associated pollutants. Soluble contaminants still remain an issue for most SUDS designs. Each type of SUDS unit will inevitably have its own set of attributes in catering for hydraulic and water quality drainage requirements. The use of SUDS should not be regarded as simply providing drainage alternatives, but rather in providing a suite of drainage tools for addressing the needs of a particular site. Figure 11 outlines the fundamental basis used in the 2007 CIRIA Manual (Report RP697, The SUDS Manual: Updated Guidance on Technical Design and Construction) to illustrate the SUDS treatment mechanisms of encouraging infiltration and attenuation at each stage. Using a treatment train approach helps to address the inherent variability and uncertainties that are associated with individual SUDS performances and with treating the "cocktail" of pollutant types found in surface water runoff.

5.2.3 What is not illustrated in Figure 11 is the importance of water recycling and reuse. It is becoming ever more important given both climate change and increased

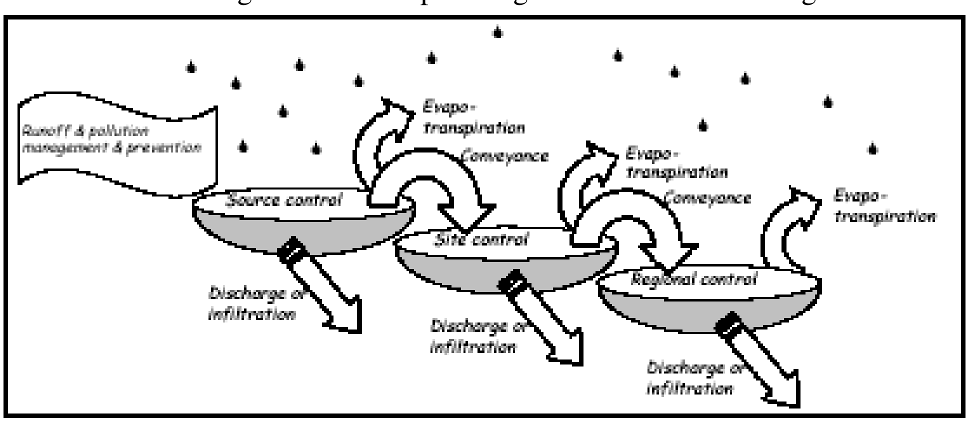


Figure 11 The SUDS water management train (From: The SUDS Manual. 2007. CIRIA, London.)

urbanisation as a means to minimise the use of water within urban catchments and to consider options for recycling and reuse. Many of the existing SUDS techniques involve storage and this provides the opportunity to use these as “tanks” from which water, after appropriate treatment, can be returned for toilet flushing and other uses such as garden irrigation etc. This aspect of stormwater runoff reuse was totally missing from the earlier UK SUDS design manuals but has been addressed in the most recent CIRIA SUDS Manual (Woods-Ballard et al., 2007).

5.2.4 In addition to stormwater re-use, there is very little in current SUDS guidance documentation on green roof design and performance or the suitability of materials (including recycled materials) in constructing SUDS devices although the most recent CIRIA SUDS manual does include a chapter on green roof design (Woods-Ballard et al., 2007). This could be an issue given the increasing use of proprietary products and materials particularly in below-ground infiltration (modular synthetic geocells), absorption media (polymer sponge inserts) and sediment centrifugation techniques. Specific detail in respect of proprietary products would clearly not be appropriate in design manuals as it could lead to a stifling of innovation. However, information on the general performance criteria of materials such as permeability, tensile strength etc. would be appropriate as well as general information on advanced “smart” solutions such as packaged multi-chambered treatment train units (MCTTs) suitable for small (0.1 – 1.0 ha) urban pollution “hotspots”. Modular upflow infiltration units and MCTTs are becoming increasingly popular in US municipal non-point control strategies and the retrofit of such small-scale packaged BMPs can offer some advantages in terms of space, advanced performance and control management for particular urban drainage situations. However, as yet such devices and the requirement for advanced BMP treatment has not been dealt within any design guidance documentation or manuals.

5.2.5 There is very little, if any, SUDS documentation guidance on the significance and implications of contaminated sediments arising from SUDS devices in terms of waste disposal standards and regulations. This could be a major future issue under recently introduced EU Waste Regulations. Ellis and Rowlands (2007) have provided some design guidance for the maintenance and disposal management of contaminated waste arisings associated with highway drainage BMP structures. However, to date no official stand-alone design documentation on this topic has been produced. In addition, most SUDS technical guidance provides little on the design and performance of SUDS devices to deal with accidental spillages.

A.5.3 Water quality design criteria

5.3.1 The performance of a SUDS unit varies between each system, between rainfall events and varies over time depending on the regularity of O&M as well as external variations such as changes in climate or urban land use activities. Whilst knowledge about SUDS performance and water quality is being steadily gained, it is unlikely that design criteria will be able to meet specific sediment, nutrient and other pollutant reduction standards over the short term e.g frequency and/or exposure exceedance for a specified concentration level. This is despite the fact that regulatory authorities may well expect SUDS devices to meet specific outflow performance levels in order to provide a sufficient level of protection to a receiving waterbody. Such regulatory

expectations can typically result in the overdesign of SUDS facilities in an attempt to make sure that compliance is achieved. It is much more likely that a minimum requirement for a certain SUDS unit (and combination of units) may be defined which will then be deemed to provide the required level of water quality treatment. There is for example, an increasing expectation that SUDS control devices should be capable of achieving a minimum of between 60% - 70% solids retention and an outlet BOD level of at least 10 mg/l. In addition, total heavy metal and hydrocarbon outflow concentrations should be maintained at levels below 3 - 5 mg/l for all storm events within the design envelope. However, it is far from certain that all SUDS devices are able to comply with even these general thresholds for every storm event, with below-ground devices being particularly prone to poor performance (Jefferies, 2004).

5.3.2 The UK does not possess a national SUDS performance database such as that compiled under the United States EPA/ASCE National BMP database (www.bmpdatabase.org) which has standardised monitoring, data collection and analytical protocols. The EPA/ASCE Steering Group argue that a standardised database is needed in order to establish quantifiable and statistically sound links between SUDS design parameters and their long term performance. The Scottish SUDS Working Party has undertaken a review of some 400 sites comprising over 4000 individual SUDS devices but did not provide any recommended monitoring or data collection protocols (Wild et al., 2002). A full listing of the monitored sites with details of flow rates and performances is provided in Part B (*SUDS Performance Data Summary Sheets*) of the 2004 Scottish SUDS Monitoring Group report (Jefferies, 2004). A database proposed by the Environment Agency for use in England & Wales (www.suds-sites.net) is still being considered.

5.3.3 The lack of recommended protocols for monitoring and sample collection presents a major problem for accurately defining SUDS performance and the controlling design parameters. The practitioner needs a firm statistical footing for design and implementation and it is therefore a valid question to ask how many samples are required to obtain statistical valid assessments of water quality. Four principal factors influence the probability of identifying significant temporal and/or spatial changes in water quality:

- variability in influent and effluent quality
- minimum detectable changes in water quality (difference in mean and the variability in concentration)
- number of influent and effluent samples collected
- the confidence level from which to draw conclusions

Performing a power analysis (an estimate of how many events need to be monitored to achieve a specified level of confidence for a particular conclusion), requires a knowledge of the magnitude of acceptable errors associated with these four factors to be known. In addition, very few studies are designed to quantify the errors introduced into SUDS performance data which result from flow measurement errors which are known to be very significant. This is particularly the case for small catchments having very peaky and flashy flows where flow rates can change very rapidly by up to three orders of magnitude. The largest source of errors however, results from inaccuracies related to low or unsteady flows.

5.3.4 The large majority of UK SUDS water quality performance data have been reported as Event Mean Concentrations (EMCs) and as percentage pollutant

removals. The Scottish 2004 monitoring programme also quotes time-based reductions in peak concentrations between inflow and outflow. What has been clearly demonstrated by the evaluation of the US National BMP database (Strecker et al., 2004) is that pollutant percentage removal reporting is not a valid indicator of performance unless treatability information and particularly settling velocity data is also provided. Percentage removal is essentially a function of how contaminated or "dirty" the incoming influent to the SUDS device is. Thus highly polluted inflows can still result in a low effluent quality even where the SUDS device achieves high retention efficiency. Low or poor performance may simply reflect a "cleaner" influent which may be close to the irreducible background concentration (IBC) for the control device. Most biochemical processes operating within SUDS will inevitably exhibit low percentage removal rates when the concentrations are low in the inflow and close to the IBC for the operational process(es).

5.3.5 The persistent characterisation of SUDS performance based on the quantification and comparison of percentage pollutant removal has undoubtedly led to some devices being characterised as "poor" performers. The effectiveness of (wet) retention basins and wetlands is particularly difficult to represent by percent removal as paired inflows and outflows are frequently not from the same event. If the wet pool volume is equal or less than the size of the storm event being monitored, the outgoing effluent will be primarily composed of "older" water which is displaced by fresh influent to the control device. For the majority of the time, effluent quality is pre-determined by the quality of the permanent pool volume.

5.3.6 There is undoubtedly a need for a consensus on the standardisation of SUDS performance measures. Performance and water quality effectiveness is essentially site specific with efficiency being a measure of how well a SUDS or SUDS system removes or controls pollutants. Such performance effectiveness therefore is a measure of how well the device meets its specific goals e.g. against a pre-determined effluent quality. Efficiency on the other hand is an absolute measure, independent of any effluent quality expectations. SUDS efficiency can be determined in various ways: as efficiency ratios (ER), summation of loads, load regression, (event) mean concentrations, individual storm loads etc. All of these measures have shortcomings given that most SUDS are effluent-limited with effluent concentrations being largely independent of the influent concentrations. Therefore efficiency calculations using influent concentrations tend to overestimate the SUDS efficiency when influent concentrations are high and underestimate when influent concentrations are low.

5.3.7 A comparison of SUDS effluent quality with receiving water quality standards together with biological/habitat assessments and downstream erosion impacts, may well provide a better gauge of long term SUDS effectiveness than pollutant removal efficiency. This alternative approach is advocated in the HR Wallingford report evaluating the performance of SUDS systems (Woods-Ballard et al., 2005). Identifying the frequency of potential exceedances of river water quality criteria and/or use-related standards would be a much more robust approach to measuring performance effectiveness. To date there is insufficient information to suggest which SUDS provide a better mitigation of urbanisation impacts on the receiving waterbody. The US EPA/ASCE National BMP database Project Team recommends the use of probability methods which statistically evaluate the influent and effluent EMCs to determine if differences in concentration are statistically significant. Trends are then

characterised by analysis of the concentration distribution function or standard parallel probability plots as illustrated in Figure 12.

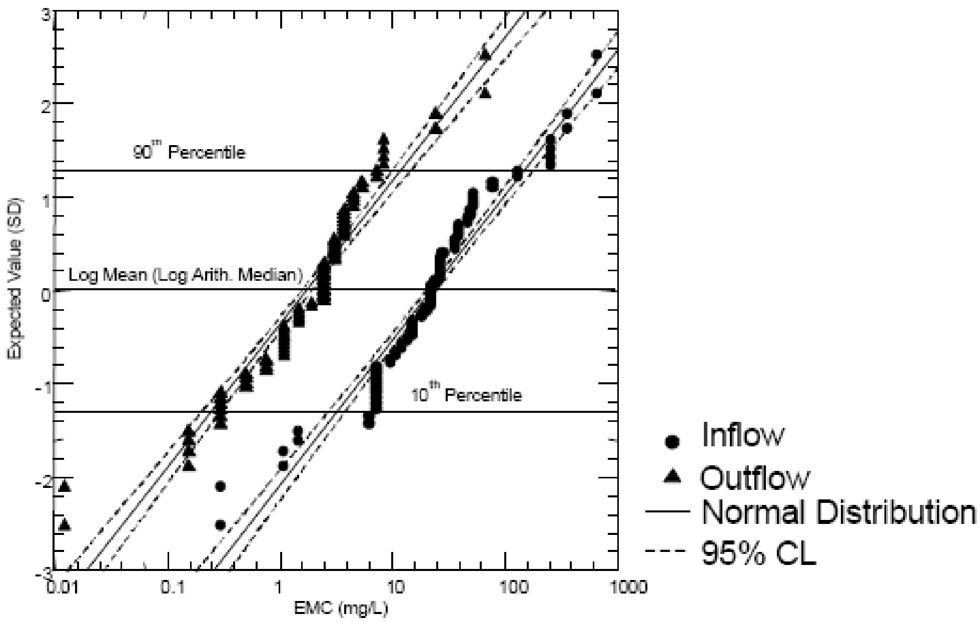


Figure 12 An Example of the Normal Probability Plots Used in the Analysis of the US EPA/ASCE National BMNP Database.

The method highlights ranges in influent values that yield the greatest percentage removal rates. This provides an innovative approach with potential to generate transferable data. To date no such similar analytical methodology has been developed or applied to UK SUDS data.

5.3.8 The US EPA/ASCE National BMP database shows that wet retention basins (flood storage ponds) and wetlands appear to achieve lower concentrations in outflow quality than dry detention basins and other hydrodynamic devices, although performance does vary depending on pollutant type. This conclusion is confirmed by the study of treatment train controls at a motorway service station at Junction 2 on the M42 undertaken by HR Wallingford (Woods-Ballard et al., 2005). In addition, the US evaluation shows that retention basins having a design ratio of 1 or greater between treatment volume and average storm event volume, achieve a much better overall effluent quality. Thus SUDS sizing relative to incoming stormwater volumes appear to be a statistically significant design parameter in terms of measuring their effectiveness. There is also some evidence that the ratio of basin area to impermeable catchment area should be at least 2.5%, as below this level higher outlet pollutant concentrations are consistently observed (Hall et al., 1993; Woods-Ballard et al., 2005).

5.3.9 Work on already well-studied SUDS types such as ponds, wetlands and swales needs to be re-directed to investigating internal design factors influencing pollutant removal performance e.g. geometry, bathymetry, hydraulic retention times, sediment-water column interactions, which are the fundamental causes of variability in pollutant removal rates. In particular, the role of sedimentation on effluent quality

needs to be explored more fully under varying storm conditions, SUDS configurations and treatment train designs. More information is also needed on specific pollutants such as bacteria/viruses, dissolved organic carbon (DOC) as well as soluble hydrocarbons and metal species, all of which have implications for both aquatic and human health. Such data would be of considerable value in developing better and more reliable design criteria and help to reduce pollutant removal variability. In addition, further work is needed to show how SUDS work as total systems within a catchment (or sub-catchment) in terms of receiving water protection otherwise their reliability and performance will always be in question. Such information will in any case be supportive of catchment management plans required under the Water Framework Directive.

5.3.10 One particular contentious SUDS design issue is that relating to the determination of treatment volume required for pollutant removal under varying hydraulic retention times. Various methods have been advocated to determine such treatment volumes (Vt), mainly based on particle settling characteristics. The earlier CIRIA design manuals [C521 (2000) and C522 (2001)] adopted the somewhat conservative Volume 3 Wallingford Procedure approach:

Vt (m3/total area, ha) = 9.D(SOIL/2 + (1 - SOIL/2). I

where SOIL = WRAP (winter rain acceptance potential) soil index i.e 1 to 5

D = M5 – 60 rainfall depth (mm)

I = Impervious decimal fraction (0.0 – 1.0)

Typically this relates to a treatment volume of 70 – 100 m3/ha for an average residential development and for a wet retention basin on a 370 ha development in SE Scotland would equate to an overall volume of 26,000 – 37,000 m3. The CIRIA "Design of Flood Storage Reservoirs" volume (Hall et al., 1993) suggests a treatment volume based on the first 12 – 15 mm of storm runoff distributed over the catchment area which would amount to 150 m3/ha for a wet retention basin on the same Scottish urban catchment. The most recent CIRIA SUDS design manual (Woods-Ballard et al., 2007) also recommends that the treatment volume (Vt) should be equal to 12 – 15 mm of rainfall on the impermeable area, which is equivalent to the total effective runoff depth. The Environment Agency volume "Constructed Wetlands and Links with Sustainable Drainage Systems" (Ellis et al., 2003) publication makes a similar recommendation with capture volume based on the first 10 – 15 mm of effective runoff and using local hourly rainfall time series. An alternative suggestion is to utilize time series rainfall data to derive the capture volume of all runoff from 90% of storm events or the runoff volume generated by 25 mm of rainfall over the catchment and to use the larger of these two depths as the design rainfall. The treatment volume can be calculated assuming all runoff from the impervious areas will drain to the treatment system and none from the pervious areas. If the 25 mm design rainfall is used, the volume (in m^3) is thus 0.025 x catchment area (in m^2). If the impermeable percentage is extremely high or low, this estimation may be inaccurate.

Based on the above approaches:

The design rainfall (R) should be the larger of:

10 – 15 mm of effective rainfall runoff (based on local hourly rainfall series analysis)

the one day, twice per year rainfall volume
rainfall volume from 90% of all storm events
25 mm rainfall volume distributed over the entire catchment

The treatment volume (Vt; m^3) is then calculated using:

Vt = (R x I x A) / 1000
where R = Design rainfall (mm)
I = Impermeability index
A = Catchment area (m^2)

The CIRIA 2001 (C522) design manual recommends that a satisfactory standard of service for water quality should be a permanent pond volume (m3) equal to 4Vt. The WRc volume "Reed Beds and Constructed Wetlands for Wastewater Treatment" (Cooper et al., 1996) gives guidance for the surface area of a treatment pond of between 1% to 5% of the total catchment area.There is similar design guidance provided in US handbooks with the US Corp of Engineers STORM model being perhaps the most widely used. This is based on:
Vt = 10890.Sd.I
where Sd = mean storm depth
and for the 370ha Scottish development receiving an average rainfall depth of 12.5 mm, this equates to a total volume for wetlands and ponds of 380 m^3 for each ha of impervious surface .

However, it should be remembered that "standard" SUDS design guidelines for the calculation of required storage volumes such as BRE (1991) or CIRIA (1996) are only acceptable if local conditions (e.g. rainfall, infiltration etc.) are fully taken into account and/or high safety factors are applied (Scholz, 2003). Finally, it is highly likely that in the future, small events and extended dry periods will assume much greater importance than they do now and this will also have an impact upon SUDS effluent quality.

B. DESIGN AND GUIDANCE MANUALS FOR SWITZERLAND

The traditional approach in Switzerland to the control of wet weather urban discharges from both CSOs and surface water outfalls (SWOs), has been the application of end-of-pipe emissions which framed standards in terms of the intended receiving water use (OFPE, 1977). This approach was changed following the enactment of the 1998 Water Protection Ordinance and the 1991 Water Protection Law which based the regulations on "immision" based standards demandins knowledge of cause-effect relationships and associated receiving water impacts. Article 6 of the Swiss Water Protection Law ("Loi Federale sur le Protection des Eaux"; RS814.20 enacted in January 1991) prohibited direct pollution of receiving waterbodies, with "non-polluting" effluents such as urban stormwater being required under Article 7 to be infiltrated with retention storage recommended for excess storm event discharges. Where infiltration capacity is insufficient or deemed inappropriate, additional or alternative control measures are required. Local cantonal (municipal) authorities are required to identify water protection zones (surface and groundwater) for urban developments and to oversee and enforce permitting arrangements. The permit (or license) is based on the assumed properties and composition of the effluent and the sensitivity of the receiving waterbody. Cantons can receive indemnities in respect of the installation of stormwater basins under the Law.

The October 1998 Water Protection Ordinance further specified regulations relating to receiving water quality and ecological status in urban areas. Under Article 3 of the Ordinance, runoff from impermeable urban surfaces would normally be considered a "non-polluting" effluent and cantons are required to develop and implement both regional and general drainage plans (RDPs and GDPs respectively) for surface water discharges. The 1989 guidelines provided by the Swiss water Pollution Control federation (VSA, 1989), recommend the use of 1:2 year RI rainfall data for urban sewer design with a temporal resolution varying between 1 – 15 minutes. The temporal resolution for sewer dimensioning is for example, much higher than needed for retention basin design. The guidelines also recommended a spectrum of analytical methods depending on the desired accuracy and size of the urban catchment such that form large catchments and high accuracy, historical rain series with complex modelling would be necessary for analysis of detailed receiving water impacts. Thus a new conceptual planning strategy was introduced based on the new regulations and on general national master planning guidance for urban drainage (VSA, 1989). The focus was thus placed on integrated management approaches to the urban hydrological cycle with public involvement in the decision making process.

The basic design criteria for residential and industrial/commercial areas is the 1:100 RI storm event for which appropriate drainage controls should be set although some limited flooding within the 1:50 to 1:100 range is expected. However, it is not clear whether this 1:100 RI criteria is intended for regional intra-urban flooding rather than inter-urban flooding associated with more limited storm sewer surcharging for which the design criteria are set at rather lower return periods of 1:20 – 1:30 years. The 1989 guidelines provided by the Swiss Water Pollution Control Federation (VSA, 1989), recommended the use of 1:2 year RI rainfall data for urban sewer design with a

temporal resolution varying between 1 – 15 minutes; the resolution for sewer dimensioning being much higher for example, than needed for retention basins. The guidelines also recommended a spectrum of analytical methods depending on the desired accuracy and size of the urban catchment such that for large catchment sand high accuracy, historical rain series with complex modelling would be required for analysis of detailed receiving water impacts. Overall guiding principles recommend the application of source control approaches whenever and wherever feasible in order to support sustainable environmental objectives.

The new Swiss guidelines (termed STORM) utilise a pre-evaluation matrix for the assessment of wet weather impacts on receiving waters based on frequency and exposure duration of discharge or spillage. Long term rainfall series are used with the REBEKA model (Fankhauser et al., 2004) to generate stochastic cumulative distribution functions representing the probability of complying with differing hydraulic requirements for varying control scenarios. The technical solutions can range from source control to end-of-pipe measures, with planners and developers (or other stakeholders) left to select a specific detailed solution for site implementation. The final version of the wet weather guidelines (VSA, 2007) are still being field tested with percentage imperviousness, initial losses and the validity of impact criteria being major sources of uncertainty and contention. Irrespective of these reservations, the regulations, methodological approach and analytical tools are firmly based on the objective of integrated sustainable urban stormwater managment.

General guidance to best management practice and source control for the management and control of urban stormwater is given in a practical handbook (OFEFP, 2000), which also illustrates various examples of infiltration, storage and re-use at the individual house plot, residential, highway and service road, administrative/industrial/commercial, and commercial city centre scales. As a first principle, impermeable runoff from all paved surfaces should be infiltrated as long as there is no danger of prejudicing or interacting with groundwater quality and thus the presence of a permanent unsaturated zone is required of at least 0.5 m. Excess runoff must be stored to provide appropriate peak flow attenuation and pre-treatment prior to discharge. Such flow attenuation should provide peak shaving to match pre-development discharge levels. Excess flows should be diverted such that the initial storm flush flow (effectively equivalent to the first 10 mm of rainfall-runoff) is retained and treated. Design examples given in the guidance handbook suggest that for larger developments exceeding 8 – 10 hectares, retention and sedimentation p0re-treatment for flow volumes up to the 1:10 RI design is provided with further 24 hour storage provided for the maximum design (1:20 to 1: 30 RI). Roof runoff can be directly infiltrated via soakaways or used to irrigate raingardens, otherwise overland flow should be directed across grass filter strips and/or swale channels. The use of extended detention and retention basins (with and without infiltration capacity or wetland vegetation), is recommended for paved discharges with open water channels (ditches) preferred to traditional kerb-gully-piped systems. Permeable paving systems for car parks and low trafficked residential areas are also recommended as appropriate source control approaches.

The guidance handbook suggests that BMP approaches are not necessarily more expensive than traditional piped systems in terms of either installation or maintenance costs. Local cantons are additionally allowed to raise stormwater taxes to encourage

infiltration and other source control measures for both new and retrofit development. A more detailed guidance document for the planning of wet weather stormwater discharges in urban catchments was published in 2007 (VSA, 2007), which provides information on basic requirements for flow and quality control and alternative source control BMP measures. Specific directives recommending infiltration and retention facilities for the control and management of urban stormwater were given in an earlier document (VSA, 2000). This handbook provided planning and legislative detail together with basic information on rainfall-runoff quality and case examples.

C. AUSTRALIAN DESIGN AND GUIDANCE MANUALS

C.1. National Design Manuals and Guidance Documents

1987. *Australian Rainfall and Runoff: A Guide to Flood Estimation*. Editor-in-Chief: D H Pilgrim. ISBN 0 858 25436 0 and CD-ROM Version. ISBN 0 858 25746 7 (pdf on CD-ROM). National Committee for Water Engineering, Engineers Australia, Barton.

This volume presents information necessary for the application of the procedures (Vol. 1) and contains design rainfall maps and diagrams (Vol.2) for key durations and average recurrence intervals (ARI). In addition, there are skewness and short duration parameter maps, interpolation diagrams and figures related to the derivation of design intensity-frequency-duration (IFD), rainfall tables and figures showing design temporal patterns, design runoff coefficient maps for NSW and Victoria, and an average annual rainfall map for Western Australia.

1996. Australian & New Zealand Environment and Conservation Council. *Draft Guidelines for Urban Stormwater Management*. Australian & New Zealand Environment and Conservation Council, Canberra, ACT. Australia. ISBN 0 642 19560 9.

These draft guidelines, which comprise part of the national water quality management strategy documents have an emphasis on quality management rather than flow control. They provide a national framework designed for the management of urban stormwater in an ecologically sustainable manner. The aim is to facilitate community participation, incorporate catchment-wide implications in decision-making and help to co-ordinate land use, drainage planning and management across the catchment. Limitations to stormwater management practices are outlined and organisational structures/procedures for integrated functional management are highlighted.

1999. *Australian Rainfall and Runoff: A Guide to Flood Estimation.* Volume 1. (3rd Edition) National Committee for Water Engineering, Engineers Australia, Barton. ISBN 1 858 25687 8 (Electronic edition also available)

This is the official standard Australian design guide manual for estimating peak flows associated with design storm events with the major emphasis throughout the document being on the estimation of design floods. It evaluates available design procedures extending from 3 months to probable maximum flood levels and provides separate design information for individual regions where possible. It also provides more specific guidance to designers on procedures and design values to be used, on the concepts involved in the procedures and their application, and on likely accuracies. Detailed hydraulic design for urban drainage systems including Water Sensitive Urban Drainage (WSUD) controls, where the hydraulic and hydrologic aspects of design are mutually dependent, is included in Book VIII. This section of the manual provides a background introduction to urban stormwater and the hydrologic management of stormwater and urban sewer systems together with

estimation procedures for both short term design and long term simulated flows. The design hydraulics of typical drainage structures and WSUD controls are developed in detail and advice provided on the selection of appropriate parameters, inputs etc., including those for event-based and continuous series. The implications of extreme events in both small and large urban catchments are also discussed together with the need for continuous simulation to develop appropriate estimates of failure probabilities. The 4th Edition of this volume is being currently developed by a National Committee on Water Engineering of Engineers Australia (www.arq.org.au).

2002. *Introduction to Urban Stormwater Management in Australia.* Department of Environment & Heritage, Environment Australia. Canberra, ACT. ISBN 0 642 598 323.

An overview of urban stormwater flooding and pollution and their impacts and management strategies for control and treatment are presented. WSUD source and site controls and measures are outlined together with sediment and erosion controls. Re-use and aquifer storage are briefly introduced and future management options and stakeholder participation policies are reviewed.

2004. *WSUD: Basic Procedures for Source Control of Stormwater- Handbook for Australian Practice*. J R Argue (Editor). Australian Water Association, Artaricon, NSW.

This handbook provides basic but detailed procedures for practitioners, academics and drainage engineers to assist turning planning goals into dimensioned installations. The recommendations and procedures have a strong municipal and catchment-wide orientation. Design storm and continuous simulation modelling respectively are used for determining flood and water quality control procedures. Dimensioning principles and procedures for a range of WSUD devices are given in detail.

2006. *Australian Runoff Quality: A Guide to Water Sensitive Urban Design*. National Committee on Water Engineering. Institution of Engineers, Barton, Australia. ISBN 0-858-25860-9

A detailed overview of current best practice for the management of urban stormwater in Australia providing procedures for estimating pollutant yields, WSUD design specifications, performance estimation techniques and advice on integrated urban water cycle management practices.

C.2. General Stormwater Management Guidelines

1993. *Better Drainage: Guidelines for the Multiple Use of Drainage Systems*. Land Systems EBC Pty Ltd. Department of Planning, New South Wales Government. NSW. Australia. ISBN 0 7305 7188 2.

Guidelines which support local district councils with the planning, design and management of open space in association with urban drainage. Principles, techniques and examples of drainage systems for the control of urban surface water and water quality are outlined with the emphasis on planning and policy frameworks, recreation requirements and landscape development.

2004. *Water Sensitive Urban Design Guidelines*. City of Melbourne. City of Melbourne, 90-120 Swaston Street, Melbourne 3000, Victoria, Australia.

This document is aimed at residents, business and local district councils as a basic guidance and educational "tool" to help increase awareness and appreciation of water sensitive urban design (WSUD) and to inform and guide urban water management decision-making processes. Innovative examples are described and water re-use and best practice management structures are included. Part 1 covers ecologically sustainable development with the focus on integrated water cycle management and a "toolkit" of appropriate WSUD. Part 2 essentially consists of case studies and Part 3 provides guidance on WSUD design measures and methods. The documentation is available as 4 pdf files (including fact/case sheets) and hardcopies can be obtained on request from enquiries@melbourne.vic.gov.au.

2005. *Water Sensitive Urban Design Engineering Procedures*. Melbourne Water. CSIRO Publishing, Collingwood VIC, Australia. ISBN 0-643-09092-4

This manual is designed to give practical engineering solutions to engineers who need to implement Water Sensitive Urban Design (WSUD) Guidelines. It is specifically aimed at the engineer who is given the task of implementing conceptual designs, referral agencies who assess these designs and local government who will be responsible for the maintenance of the systems. The manual includes a review of existing documents, design procedures for construction and maintenance, and checking tools, as well as worked examples and engineering plans for commonly used treatment elements including:
Sediment basins; On-site retention (infiltration); Swale/bioretention combinations; Bioretention basins; Buffer strips; Swale systems; Constructed wetlands; Ponds/lakes; Rainwater tanks (sizing for demand); Sand filters; Aquifer storage and recovery.

C.3. State Design Manuals and Documents

1999. *Urban Stormwater: Best Practise Environment Management Manual*. Victoria Stormwater Committee. CSIRO Publishing, Collingwood, Victoria, Australia. ISBN 0-643-06453-2

Guidelines to assist Victoria state urban catchment managers to protect and improve urban stormwater quality in terms of enhanced performance, methodological tools, best practice controls and management planning. Essentially aimed at urban planners, developers and drainage engineers within state/local government and consultancy/ industry. Advice on the selection of WSUD components is provided although detailed design guidance is not included. A 2006 electronic edition of the guidance manual is available on–line.

2001. *Model Urban Stormwater Quality Management Plans and Guidelines*. Environment Protection Agency, Quedensland Government, Albert Street, Brisbane 4002. Queensland.

A step-by-step approach is provided to assist Queensland local councils to develop master plans to manage stormwater runoff impacts on receiving waterbodies. The guidelines cover the preparation of local district stormwater plans and their monitoring and performance assessment.

2002. *Guidelines for Urban Stormwater Management*. Patawalonga and Torrens Catchment Water Management Boards & Planning SA. Government of S Australia.

A general overview of best management practises for stormwater control within South Australia based on integration of hydraulic, water quality and ecological criteria and multi-functional use. Integration of WSUD design into an urban stormwater master plan (USMP) is emphasised. The background legislative framework to stormwater control in S Australia is provided together with a consideration of the role of WSUD within catchment-wide objectives. Performance guidelines for various control types are presented in an Appendix.

2004. *Stormwater Management for Western Australia*. L Chalmers and S Gray Department of the Environment. Perth, Western Australia. ISBN 1-92084-954-8.

This Manual provides higher level policies and planning principles, as well as practical on-ground best practice advice. It supports and provides information to enable implementation of WA planning policies and EPA environmental policies. The Manual emphasises the use of a combination of stormwater management methods, including 'at source' controls and infiltration, non-structural methods, use of more natural water body systems, and structural methods. It was developed for engineers, planners, scientists and managers throughout local government, the development industry, environmental and planning consultants, state government agencies and water resource managers. Information in the manual is generic and needs to be adapted to suit particular sites and circumstances. It recommends that urban drainage and stormwater control techniques should not be implemented in isolation, but as part of an overall management plan.

The manual can be downloaded as pdf files from the state website (www.water.wa.gov.au) with Chapters 1 and 2 being dated 2004 and Chapters 3-11 dated 2007.

2004. *WSUD: Technical Guidelines for Western Sydney*. URS Australia PTY Ltd. 116 Miller Street, North Sydney, NSW, Australia. ISBN 0 7347 6114 7.

WSUD design specifications are provided at subdivision and site scales with the focus on the achievement of in-stream quality and quantity targets. Planning, selection and design specifications as well as O&M and life cycle costs are covered. Developed by local councils in Western Sydney to explain how best to incorporate and design WSUD measures into urban developments. Guidance relevant to councils, master planners, developers and builders is available through the provision of best management practice design specifications for differing WSUD measures. Pdf files available to download from www.wsud.org/tech.htm.

2004. *Urban Stormwater Management Policy for South Australia*. Urban Stormwater Initiative Executive Group, Local Government Association, South Australia.

Policy statement and planning guidance is provided on urban stormwater management for local councils, planning authorities and developers with an emphasis on governance, funding and risk minimisation issues. Key policy goals in terms of background rationale and strategic target directions are provided.

C.4. WSUD Systems and Component Design

1992 *Gross Pollutant Trap Guidelines.* Willing & Partners. Department of Urban Services, ACT Planning Authority. Canberra, ACT. Australia.

Design guidelines are presented for the construction and sizing of gross pollutant traps (GTPs) to act as initial sediment traps in the stormwater runoff drainage system. The GTPs are intended to intercept and retain coarse sediment, litter and debris to protect the aesthetic and environmental quality of in-line ponds, wetlands and waterways.

1998. *Design Guidelines: Stormwater Pollution Control Ponds and Wetlands*. Lawrence, I and Breen, P. Cooperative Research Centre (CRC) for Freshwater Ecology, University of Canberra, Canberra, ACT. Australia. ISBN 1-876144 20 3.

The guidelines summarise research findings to provide background information for stormwater managers to support the design and selection of stormwater treatment ponds and wetlands. The guidelines describe how a range of ponding and plant treatment zones can best intercept pollutants and discuss the selection and arrangement of treatment zones that respond best to specific pollutant forms and discharge conditions. Decision support tools and in-pond sedimentation rate modelling approaches are included together with case studies and pond/wetland sizing procedures.

1998. *Managing Stormwater Using Constructed Wetlands*. Wong, T H F., Breen, P F., Somes, N L G and Lloyd, S D. Cooperative Research Centre (CRC) for Catchment Hydrology. Monash University, Clayton, Victoria, Australia. ISBN 1 876006 36 6.

This booklet provides an overview of the design and management issues related to the use of constructed wetlands for the management of urban stormwater. It considers the role of wetland vegetation in pollutant removal and presents hydraulic, vegetative and water quality design criteria for achieving optimum performance. A multi-disciplinary approach is stressed with operation and maintenance being a major criterion for successful long term performance.

2003. *Guidelines for the Treatment of Stormwater Runoff from Road Infrastructure*. Report AP-R232/03. Austroads. 287 Elizabeth Street, Sydney. ISBN 0-85588-664-1.
This guideline handbook has been developed to assist road drainage practitioners with the selection and design of road runoff treatment measures, hydrologic design standards and design computations for selected treatment measures. The guideline

contains a series of worked examples to present the range of stormwater treatment measures suitable for use in road construction.

C.5. On-Line Guidance and Training Manuals.

www.clearwater.asn.au
This is a stormwater information exchange platform providing an extensive and useful resource library access covering a range of stormwater management guidance, technical guidelines, case studies, training manuals and research reports/articles.

www.toolkit.net.au/music
Provides access to the official website portal for the MUSIC v3.1 urban water quality model manual (published by eWater Ltd., University of Canberra, ACT). Requires access and licence registration but a full list of free worked examples for various WSUD components is available on the site.

C.6. Recent research publications

NA Keath and RR Brown. 2008. Are extreme events a crisis or catalyst for sustainable urban water management? The case of two Australian cities. In: CD of Proceedings of 11th International Conference on Urban Drainage, Edinburgh, Scotland, UK, 31 August – 5 September 2008.

This case study of Brisbane and Melbourne showed that, despite evidence of significant progress towards sustainable urban water management (SUWM) in both cities, extreme water scarcity acted to reinforce traditional practices at the expense of emerging sustainability niches.

RR Brown and MA Farrelly. 2008. Sustainable urban stormwater management in Australia: professional perceptions on institutional drivers and barriers. In: CD of Proceedings of 11th International Conference on Urban Drainage, Edinburgh, Scotland, UK, 31 August – 5 September 2008.

This paper documents one component of a larger research project available at www.urbanwatergovernment.com. Brisbane, Melbourne and Perth were selected for a comparative case study involving 800 urban water professionals completing an online questionnaire survey in order to understand what drives and limits treatment technology for stormwater management. Significant acquisition barriers within each city, including institutional arrangements, costs, responsibilities and regulations and approval processes were all identified as constraining more sustainable practices.

C.7 Critique of Australian Design Guidance Manuals.

The probability application of the Rational Method requires the estimation of probability runoff coefficients from the analysis of flood frequency characteristics in order to estimate peak flows for a range of probability. The methodology depends on using regional information for extrapolation to ungauged catchments with a 10 year

ARI being used as a probability reference base. This approach thus expresses the runoff coefficient as the ratio of peak flow to rainfall intensity and as such has no physical interpretation; it is quite possible (and not that uncommon in Australia) for areas to have very high runoff coefficients (even >1.0). In most cases only the catchment area is included in the formula used for computing the time of concentration (tc) and the method also assumes that the skew of the flood frequency curves will be similar from region to region which is not always the case. It is therefore not surprising that the expected range of uncertainty of the design peak discharge derived from the methodology is between 25% and 75%.

The existing methodology does not consider the over-attenuation of the design flood wave due to most flood routing channels starting as "dry" conveyance channels. This means that substantial storage capacity exists within the channel form (and larger platform) in comparison to the total volume generated by the critical 60 – 90 minute duration storm event. This rainfall "burst" as termed in Australian drainage literature, is not considered in the current design manual although it is planned to incorporate the phenomena into the forthcoming 2009 revisions to the design manual. However, it is uncertain whether this embedded approach will provide a more realistic design outcome than the traditional stand-alone (isolated) design storm burst method. It also implies that the potential storage volumes of detention basins are probably being significantly under-estimated within the current design recommendations.

There are various issues relating to the rainfall generation background for locations having little or no historical rainfall data or storm monitoring. Stochastic PDF rainfall generation can be either parametric or non-parametric in approach depending on sample type and availability. The latter PDF form requires substantial data lengths to ensure appropriate representation of the underlying PDF distribution and regionalisation is not possible, although it is still possible to provide simple estimates for ungauged locations. For a parametric definition, the estimation becomes much more difficult when data is limited. In addition, the representation of temporal persistence (i.e. follow-on rainfall events) and seasonality components in stochastic rainfall generation is prone to errors.

The aspects of uncertainty associated with the estimation of the time of concentration and parameter input selection within the probabilistic rational method approach have been recognised and a national consultation stage is currently in progress to refine and extend the design guidance. These revisions will appear in the forthcoming 2009 update to the design manual.

D. URBAN STORMWATER MANAGEMENT MANUAL FOR MALAYSIA. A REVIEW.

D.1. Introduction

The Urban Stormwater Management Manual for Malaysia or Manual Saliran Mesra Alam (MSMA) published by the Department of Irrigation and Drainage (DID) www.water.gov.my in 2000, replaces the first urban drainage manual ‘Planning and design Procedure No. 1: Urban Drainage Standards and Procedure for Malaysia,’ which was published by DID in 1975. The first manual advised on conventional drainage systems to provide rapid transport of stormwater runoff from catchments to receiving waters. However, these systems have led to an increase in the occurrence of flash floods and levels of water pollution downstream of the catchments. The increase in the urban population of Malaysia from 26.8% in 1970 to 50.7% in 1991 and a projected rise to 65% by 2020 has exacerbated the problem of flash flooding. Many urban water bodies in Malaysia are overloaded with non-point source pollutants and an evaluation of river water quality showed that 60% are failing (W Mokhtar, 1998). ‘Urban drainage practices in Malaysia relied on slight adaptation or even direct use of temperate region–based urban rainfall/runoff design procedures and computer models’ based on the 1975 manual (Zakaria et al., 2004). From 1 January 2001, all new development in Malaysia has been required to comply with new guidelines that require the application of Best Management Practices (BMPs) to control the quantity and quality of stormwater to achieve a zero impact of development. The introduction of BMPs is intended to preserve the natural river flow carrying capacity (Zakaria et al., 2004).

The information in the 2000 manual is transferred from US, Australian and New Zealand sources including the American Society of Civil Engineers (ASCE) (1992, 1998), United States Department of Agriculture (USDA) (1986), United States Environment Protection Agency (USEPA) (1983), United States Federal Highway Administration (USFHA) (1997), New South Wales EPA (1996; 1997) and Auckland Regional Council (1992). There are no references to stormwater management guidelines for other countries in the south east and east Asia region which may not have been available in the year of the manual’s publication. The authors acknowledge that ‘the concept of stormwater management is relatively new to Malaysia and that a paradigm shift would be required to turn around the traditional concept of drainage engineering practices based on rapid disposal towards this new Stormwater Management (SWM) concept’. It is specifically stated that it is not a training manual and it acknowledges the limitation that it may be lacking in the ‘peculiarities’ of the stormwater processes/practices occurring in Malaysia. Furthermore, due largely to the recent introduction of the SWM concept in Malaysia, there are relatively few examples in the text of its application to specific urban locations or developments, although there are some worked examples focussing on local sites in the Appendices.

D.2. Structure of the Manual

The manual is composed of 20 softback volumes and is sub-divided into 9 parts (A-I) and 48 chapters (Table 1) subdivided into sections. ‘The first three parts (A-C) contain background information on environmental processes and stormwater

management, administration aspects and planning processes. The remaining parts (D-I) contain detailed information on hydrology and hydraulics, runoff quantity control and conveyance, source and treatment runoff quality controls, runoff quality controls during construction, and special stormwater applications'.

'Introduction to the Manual' (Vol 1; Chapter (Ch.) 1), provides a Malaysian perspective of the consequences of development and increasing urbanisation. The stormwater-associated problems being encountered in Malaysia include among others;

construction activities and mud flows
flash flooding
urban slope failures
sedimentation

The need to augment water supplies with stormwater is recognised in the manual although it is was rarely applied in Malaysia when the manual was written. Two examples, the use of stormwater for irrigation at Kuala Lumpur International Airport (KLIA) and the new Putrajaya city wetland and lake stormwater management and pollution control system are mentioned but the latter is not described in the manual (see Section C.3.4 of this review).

The manual indicates the need for specific Malaysian requirements for the design and management of the stormwater systems described in the manual and which are used in developed countries. Research is frequently recommended in the manual in order to gain a better understanding of the design, operation and management requirements of stormwater systems in Malaysia There is no apparent procedure in place for providing the results of such research in printed or online updates.

The publication of the Malaysian SWM manual is a significant achievement for a developing country and will undoubtedly result in major changes in urban drainage practices in this country. It is an exemplary synthesis of information on SWM derived from a number of published sources from economically developed countries. The following chapters and sections of the manual have been selected for comment to indicate their sources, the adaptation of the source material to local conditions and climate and the problems of transferring and editing material from different sources. The comments are both positive and negative and are intended for consideration for both future editions of the manual and for the preparation of stormwater management manuals in other economically less developed countries and climates.

D.2.1 Introduction to the Manual (Vol.1)

Ch.1 Malaysian perspective.
Section 4. Guide to users. The relevance of each chapter to different authorities including the Department of Irrigation and Drainage (DID), the Department of the Environment (DOE) and the Town and Country Planning Department (TPCD) and users including urban planners and civil engineers and (Table 1) and to different SWM activities (Table 2) including preparing a strategy plan and designing a new drainage system provides an accessible visual summary to complement the introductory description of each chapter and enhances understanding of the structure of the manual.

D.2.2 Regulatory criteria and requirements (Vol. 2)

Ch. 4 Design acceptance criteria.
Section 4.1 Practical limitations including funding are recognized as constraints to the adoption and upgrading of the stormwater management systems in Malaysia.

Ch. 5 Institutional and legal framework
Section 5.3.2 (e) Environmental Management
The manual states that there is no direct reference to the control and regulation of environmental pollution in Malaysian legislation.

D.2.3 Planning processes (Vol. 3)

Ch. 7 Planning framework
Section 7.3 Planning Principles are based on ASCE, 1992.
Ch. 8 Strategy Planning is based on NSW, EPA, 1996.
Ch. 9 Master Planning is based on Walesh, 1989.
The different sources for the chapters in this volume indicate the authors' careful selection and integration of material that would be appropriate for application in Malaysia.
Figure 9.2 provides a matrix of objectives versus alternative solutions to managing stormwater and relates to the previous point related to Volume 2 concerning funding limitations (Walesh, 1989).
Ch. 10 Choice of management options.
Section 10.4.6. General BMP selection guidance is based on Auckland Regional Council, 1992.

D.2.4. Design fundamentals (Vol. 4)

Ch. 11 Hydrologic design concepts.
Section 11.6. The concept of major and minor drainage systems in relation to major and minor storms is developed with illustrative designs. The major design storm standard recommended for urban areas is 100 year ARI which should be reviewed in the context of Malaysian rainfall volumes.

The manual states that 'the standards set out in Ch. 4 are typical of the latest practices in urban areas in developed countries. Because of differences in climatic and other factors, it would be appropriate to review the standards of application under Malaysian conditions from time to time.'

Ch. 13. Design rainfall.
Section 13.1. Design methods have been adjusted in this manual to suit Malaysian conditions. The manual recommends an updating of the Malaysian DID intensity-duration-frequency (IDF) curves and a review of standard temporal rainfall patterns following a research study.

Table 1 Relevance of each Chapter to different authorities and users

Table 1 Relevance of Each Chapter to Different Authorities and Users	Administration, Operations & Maintenance					Planning & Design				Construction		Education			
		State Level													
	Federal Authorities (TPCD, DID, DOE)	TPCD	DID	DOE	Local Authority	Urban Planners	Civil Engineers/Designers	Environmental Engineers / Environmental Scientists	Landscape Architects	Developers	Contractors	Urban Planning	Hydrology and Hydraulics	Water Quality / Environment	Landscape Architecture
Part A Introduction															
1. Malaysian Perspective	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
2. Environmental Processes	■	▒	■	■	■	▒	■	■	▒	▒	▒	▒	■	■	▒
3. Stormwater Management	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Part B Administration															
4. Design Acceptance Criteria	▒	■	■	■	■	▒	■	■	▒	▒	▒	▒	■	■	▒
5. Institutional and Legal Framework	■	■	■	■	■	▒	▒	▒	▒	■	▒	▒	▒	▒	▒
6. Authority Requirements and Documentation	▒	■	■	■	■	■	■	■	■	■	■				■
Part C Planning															
7. Planning Framework	▒	■	■	■	■	■	▒	▒	▒	▒		■			▒
8. Strategic Planning	■	■	■	■	▒	■	■	■	▒			▒		▒	▒
9. Master Planning		▒	▒	▒	■	■	▒	▒	▒	■		■			▒
10. Choice of Management Options		▒	▒	■	■	▒	■	■	▒	▒		▒		▒	
Part D Hydrology and Hydraulics															
11. Hydrologic Design Concepts			▒			▒	■					▒	■	▒	
12. Hydraulic Fundamentals			▒			▒	■		▒			▒	■		▒
13. Design Rainfall			▒	▒			■	▒					■	▒	
14. Flow Estimation and Routing			▒	▒			■	▒					■	▒	
15. Pollutant Estimation, Transport and Retention			▒	■			▒	■					▒	■	
16. Stormwater System Design			▒	▒	■		■	▒		▒					
17. Computer Models and Software			▒	▒	▒		■	■					■	■	
Part E Runoff Quantity Control															
18. Principles of Quantity Control		▒	▒		■	▒	■			▒		▒	■		
19. On-site Detention					▒		■			■			■		
20. Community and Regional Detention			▒		■		■			▒			■		
21. On-site and Community Retention					▒		■			■			■		
22. Regional Retention			▒		■		■			▒			■		
Part F Runoff Conveyance															
23. Roof and Property Drainage					■		■						■		
24. Stormwater Inlets					■		■						■		
25. Pipe Drains					■		■						■		
26. Open Drains					■		■						■		
27. Culverts					■		■						■		
28. Engineered Waterways			■	▒	■		■	■	▒	▒			■	▒	▒
29. Hydraulic Structures			■		■		■						■		
Part G Post-construction Runoff Quality Controls															
30. Stormwater Quality Monitoring				■			▒	■				▒		■	
31. Filtration				▒	■		■	▒					■	▒	
32. Infiltration				▒	■		■	▒					■	▒	
33. Oil Separators				▒	■		■	▒					■	▒	
34. Gross Pollutants Traps				▒	■		■	▒					■	▒	
35. Constructed Ponds and Wetlands				■	■		▒						▒	■	
36. Housekeeping Activities			▒	▒	■		■	■					■	■	
37. Community Education	▒		▒	▒	■	▒		▒				▒			
Part H Construction Runoff Quality Controls															
38. Actions to Control Erosion and Sediment				■	■			▒			■			▒	
39. Erosion and Sediment Control Measures				■	■			▒			■			▒	
40. Contractor Activity Control Measures				▒	■			▒			■			▒	
41. Erosion and Sediment Control Plans		▒		▒	■			▒		▒	■	▒		▒	
Part I Special Applications															
42. Landscaping				▒	■	▒	▒	▒	■			▒	▒	■	■
43. Riparian Vegetation and Watercourse Management	▒		■	■	■	▒	■	■				▒	■	■	
44. Subsoil Drainage					■		■						■		
45. Pumped Drainage			▒		■	▒	■			■		▒	■		
46. Lowland, Tidal and Small Island Drainage			▒	▒	■	▒	■	▒		■		▒	■	▒	
47. Hillside Drainage			▒		■	▒	■		▒	■		▒	■		▒
48. Wet Weather Wastewater Overflows	▒			■	■		▒	■					■	■	

■ An Understanding of the Issue/Activity is Necessary
▒ An Appreciation of the Issue/Activity is Advantageous

Table 2 Relevance of each Chapter to different activities.

Table 2 Relevance of Each Chapter to Different Activities

	Planning		Investigations, Design and Submissions											On-Going Activities	
Chapter	Preparing a Strategy Plan	Preparing a Master Plan	Surveys and Information Collection	Design Requirements or Procedures	Existing Drainage System Investigation (Flooding)	Design a New Drainage System (Quantity Only)	Designing Runoff Quantity Controls	Sizing or Designing Water Quality Controls	Water Sensitive New Urban Development	Development on Hillsides	Development of Lowland Areas	Redevelopment of an Existing Site	Documentation and Submission Requirements	Community Consultation/ Education	Operating and Maintaining Stormwater Systems
Part A Introduction															
1. Malaysian Perspective	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
2. Environmental Processes	■	░	■				■	■	■	░	░	░		░	■
3. Stormwater Management	■	■	■		■	■	■	■	■	■	■	■		■	■
Part B Administration															
4. Design Acceptance Criteria	■	■		■	■	■	■	■	■	■	■	■	■	■	░
5. Institutional and Legal Framework	■	■		■	░	░	░	░	░	░	░	░	■	■	░
6. Authority Requirements and Documentation			░	░		■	■	■	■	■	■	■	■		
Part C Planning															
7. Planning Framework	■	■													
8. Strategic Planning	■		░						░					░	
9. Master Planning		■	░						■	■	■	■		░	
10. Choice of Management Options	■	■				░	░	░	░						
Part D Hydrology and Hydraulics															
11. Hydrologic Design Concepts	░	░		░	░	░	░	░	░	░	░	░		░	
12. Hydraulic Fundamentals					■	■	░	░	░	■	░	░			
13. Design Rainfall	░	░		░	■	░	░	░	░	░	░	░			
14. Flow Estimation and Routing	░	░		░	■				■						
15. Pollutant Estimation, Transport and Retention	░	░		░				■	■						
16. Stormwater System Design	░	░		■											
17. Computer Models and Software	░	░		░	■	■	■	■	■	░	░	░			
Part E Runoff Quantity Control															
18. Principles of Quantity Control	░	░		░		■	■		■	■	■	■			
19. On-site Detention				■		■	■		░	░	░	■			■
20. Community and Regional Detention				■		░	■		■	░	░				■
21. On-site and Community Retention				■		■	■		░	░	░	■			■
22. Regional Retention				■		░	■		■	░	░				■
Part F Runoff Conveyance															
23. Roof and Property Drainage				■		■			■	■	■	■			
24. Stormwater Inlets				■		■			■	■	■	■			
25. Pipe Drains				■		■			■	■	■	■			
26. Open Drains				■		■			■	■	■	■			
27. Culverts				■		■			■	■	■	■			
28. Engineered Waterways	░			■		■			■						░
29. Hydraulic Structures				■		■			■	■	■	■			
Part G Post-construction Runoff Quality Controls															
30. Stormwater Quality Monitoring	░	░	■	░				■	■						░
31. Filtration				■				■	■	░	░	░			■
32. Infiltration				■				■	■			░			■
33. Oil Separators				■				■	■	░	░	░			
34. Gross Pollutants Traps				■				■	■	░	░	░			■
35. Constructed Ponds and Wetlands				■				■			░				■
36. Housekeeping Activities				░		░	░	░	░	░	░	░			■
37. Community Education	■	░												■	■
Part H Construction Runoff Quality Controls															
38. Actions to Control Erosion and Sediment				■					■	■	■	■			
39. Erosion and Sediment Control Measures				■				■	■	■	■	■			░
40. Contractor Activity Control Measures				■					■	■	■	■			░
41. Erosion and Sediment Control Plans				■					■	■	■	■	■		
Part I Special Applications															
42. Landscaping	░	░		■					■	░	░	░			░
43. Riparian Vegetation and Watercourse Management	░			■				░	■						░
44. Subsoil Drainage				■			░		■	■		░			
45. Pumped Drainage	░	░		■					■		■	░			
46. Lowland, Tidal and Small Island Drainage	░	░		■					■		■				
47. Hillside Drainage	░	░		■					■	■					
48. Wet Weather Wastewater Overflows	■	░							■					░	

■ An Understanding of the Issue/Activity is Necessary
░ An Appreciation of the Issue/Activity is Advantageous

D.2.5. Runoff estimation (Vol. 5)

Ch. 14 Flow estimation and routing.
The Rational Formula is one of the most frequently used urban hydrology methods in Malaysia. It gives satisfactory estimates of peak discharge in small catchments up to 80 ha. For large catchments a hydrograph method is required usually with computer programmes to generate runoff hydrographs. Since the Malaysian SWM manual was published, rainfall- runoff characteristics have been determined in Sungai Kerayong, a typical urban catchment with an area of 48.3 km^2 of which 77% is impervious (Abustan et al., 2008a). A total of 90 independent storm events, selected randomly for a period of 5 years, were analysed. The average value of the time of concentration t_c obtained from the analysed hydrographs is 139 minutes and the results indicated that Yen and Chow's Simplified Formula gives the best estimation of t_c. Analysis of rainfall and runoff data from 1996 to 2004 for the Sungai Kayu Ara catchment, with an area of 22.33 km^2 of which 61% is impervious, in Damansara, Kuala Lumpur, showed that the correlation between runoff coefficients and rainfall intensities in the Malaysian SWM manual Design chart (14.3) corresponded quite well with the degree of land cover (Abustan et al., 2008b).

Appendix 14B has a worked example to determine the design peak for flow generated from a residential area of 10 ha in Kuala Lumpur. Although the manual is not intended for training, a further example to be worked by the reader would be useful in this and the appendices of other chapters.

Ch. 15 Pollutant estimation, transport and retention.
Section 15.5 Pollution load estimates. There is very little measured data on stormwater pollution loads in Malaysia. The manual recommends detailed long-term studies in order to derive reliable estimates of pollutant exports.
Table 15.2 shows typical Event Mean Concentrations (EMC) for selected pollutants in Malaysia derived from several sources including Auckland regional Council (1992) and NSW, EPA, 1997.

D.2.6. Network system and computation (Vol. 6)

Ch. 16 Stormwater system design.
Section 16.4 Flow charts 1 and 2. 'Stormwater system design procedures' summarise and simplify the procedure. However, since the manual was published, computer presentation of such procedures and the development of decision support systems has both complemented and replaced the printed format. For example, the EC DayWater project provides an adaptive decision support system for stormwater management at www.daywater.org. User name: guest and password: guest.

Appendix 17A. List of Computer Modelling Software.
This list requires regular updating of programmes available in the public domain which are very useful for less economically developed countries as well as details of commercial suppliers.

D.2.7. Detention (Vol.7)

Ch. 18 Principles of quantity control.
Section 18.4.1 (b) Catchment- based methods.

The Swinburne Method (Swinburne University of Technology, Melbourne, Australia) based on the Rational Method is recommended for on-site detention (OSD) in preference to more sophisticated modelling techniques.

Ch. 20 Community and regional detention.
Section 20.10.4. Operation and management of grassed areas and embankments near secondary outlets. 'Regular mowing (at least twice a year) is required to keep the grass sward in good condition and discourage woody growth.' The recommended minimum frequency needs to be increased for Malaysian tropical conditions.

D.2.8. Retention (Vol. 8)

Ch. 21 On-site and community retention.
Section 21.1.3 Feasibility Analysis. This section states that infiltration systems on fill material are not permitted on sloping sites which are common in Malaysia and may use extensive cut and fill operations,
Ch. 22 Regional retention.
Section 22.2.4 (c) paragraph 3 System Operation and Management of recharge basins. 'When the basin is kept full of water over an extended period of time, algae and aquatic weed growth may occur.' This growth will undoubtedly occur in Malaysia and require frequent O&M. The relatively low cost of labour enables the manual removal of aquatic weeds to be the favoured option.

D.2.9. Property drainage and inlets (Vol. 9)

Ch. 23 Roof and property drainage
Section 23.1 Roof Drainage systems. 'The methods described in this section are based on the Australian and New Zealand Standard AS/NZS 3500:3 (1998) adapted for Malaysian conditions.' However, the authors then point out that there is relatively little experience of designing roof systems in Malaysia and that the chapter will be reviewed in the future following further research.

Section 23.3 Rainwater Tanks. 'The design of rainwater tanks is not covered in this manual.'
This omission will no doubt be rectified in a future edition in view of the current global focus on rainwater harvesting. However, 'The design of on-site detention storage is covered in Chapter 19 '

D.2.10. Drains (Vol. 10)

Ch. 26 Open drains
Section 26.2.6. This section recommends five permanent grasses for seed mixes suitable for swales but should be replaced by the more extensive list of 21 local grass species suitable for swales with both scientific and Malay names presented in Ch. 42 table 42.10. Only two of the recommended species listed in Section 26.2.6, Axonophus compressus (Cow grass or rumput pahit) and Cynodon virgatum (Bermuda grass or rumput Bermuda) are listed in table 42.10

D.2.11 Culvert and waterway (Vol.11)

Ch. 27 Culvert

Section 27.6 notes that there is a 'very high risk of debris blockage in all urban areas in Malaysia' and that precautions therefore need to be taken ranging from providing freeboards to elaborate debris control structures.

Ch. 28 Engineered waterways

Section 28.10.7 Advisory signs. The example given in Standard Drawing SD-F43 is in English rather than Malay and needs to be abbreviated and simplified in translation.

D.2.12 Source control BMPs (Vol. 12)

Ch. 30 Stormwater Quality Monitoring.

Section 30.1.3. The manual acknowledges that benchmark concentrations or target levels and realistic values for parameters monitored in stormwater need to be developed by the Malaysian Department of the Environment (DOE).

Section 30.2.3. The need to indicate detection limits for the laboratory analysis of water quality parameters is mentioned but quality control including inter-laboratory calibration should be considered.

Section 30.2.4. Biological monitoring is 'currently evolving in Malaysia', and is considered 'outside the scope of this manual' and regrettably no examples of hydrobiological indices suitable for use in Malaysia are given.

Section 30.4. Biological hazards of sampling. 3Rs- roaches, rodents and reptiles are appropriate to Malaysia but there is no advice to personnel to sample in pairs.

Ch. 31 Filtration

Section 31.2.1 refers to design criteria being at the development stage in Malaysia and the need for research. There is clearly a need to provide updates, possibly online, to this and other relevant chapters when the results of research are published.

Section 31.2.4. Maintenance of biofilters. A reference to 'at the end of the growing season' for grasses is inappropriate for Malaysia where there is a continuous plant growing period.

D.2.13. Treatment control BMPs (Vol. 13)

Ch 34 Gross pollutant traps.

The manual acknowledges that 'no information is available on construction and operating costs of most structural devices under Malaysian conditions.' An example of the use of booms in the river Klang is given. However, the frequent impact of flash flooding on the river Klang in the capital Kuala Lumpur is not considered in relation to the BMP options that are feasible for future application (Fig.13). Furthermore, the sediment load to the river Klang and its tributaries is estimated at 3300 tones per day and 20 tonnes per day of garbage is collected from the river to maintain flow conditions (Zakaria et al., 2004). (See Section C.3.2 of this report).

Figure 133 River Klang (right) merging with the river Gombak (left), Kuala Lumpur.

Ch. 35 Constructed ponds and wetlands
Section 35.1 'a lack of experience with ponds and wetlands' is acknowledged and requires recent examples of their successful design and operation to be made available online.

Section 35.8.1 Constructed wetlands. The manual refers to the Guidelines for the Putrajaya wetlands focusing 'to a large extent on the wetland only' whereas ponds should also be considered. However, each of 24 wetland cells at Putrajaya contains a significant area of open water at the inlet and outlet of each cell. An opportunity to provide more information on this prestigious national project has been missed.

Section 35.9.2. A statement on the need for research into the possible use of harvesting of plants in constructed wetlands in Malaysian conditions is appropriate.

D.2.14. Housekeeping and Education BMPs (Volume 14)

Ch. 36. Housekeeping practices
Section 36.5.19. Wet Markets, stalls and night markets. The problem of waste disposal directly to street storm drains from hawker food stalls in Malaysia should be addressed in this section and in the following Chapter in section 37.2.3, because it is a significant cause of blockage and odour nuisance.

Ch. 37 Community education.
Section 37.2.3 'Know your target group'. Hawker street food stall owners are not included in this section. An education programme should be developed as a priority for this target group who have defied a system of fines.

Section 37.2.5 (ii) the 'Love Our Rivers' programme developed by the Malaysian DID is a good example of a local environmental education programme. Its use of simple visual material and the targeting of schools has been very successful.

D.2.15. Construction sediment BMPs (Vol. 15)

Ch. 38 Actions to control erosion and sediment. Rapid urban development has caused the excessive loss of soil from construction sites and the deterioration in receiving watercourses due to severe siltation.

Section 38.1.1 Local experience with construction sites is addressed in this section.

Section 38.1.2 A summary of guidelines for the layout and management of construction sites published by DID and DOE in Malaysia from 1975 -1996 is presented. Unfortunately, these guidelines, especially for soil erosion control, tend to be ignored by sub-contractors on large construction sites.

Ch. 39 Erosion and sediment control measures.
Section 39.1. Introduction. Sub-section (c) Approach. 'Avoid rainy periods' for major soil grading operations. This is difficult in Malaysia where rainfall occurs throughout the year.

D.2.16. Construction BMPs and plans (Vol. 16)

Ch 41 Erosion and sediment control plans.
Section 41.1.1 A list of 16 items of statutory legislation by Malaysian government agencies from 1933-1999 is presented in this section which indicates the importance of this issue. The section refers to the regulatory framework for stormwater management, addressed in Ch.5.where it was emphasized that the traditional approach that SWM is a local problem should be replaced by 'a new approach which looks at drainage and pollution abatement in the context of integrated management of water resources.'

D.2.17. Bioengineering measures (Vol.17)

Ch. 42 Landscaping. Detailed lists and photographs of suitable and locally available plants for planting in and around swales, wetlands and ponds with both English and Malay are presented.

Section 42.3.2. Wild collection. The importance of collecting wild plants from a range of sources and the need to avoid intense collection from any one source to protect its species diversity, should be mentioned in this section.

Section 42.3.3. Habitat creation. Malaysian species of wildlife are appropriately included in this section, adapted from US and NZ sources.

Section 42.4 General planting. Point 24. BMPs are unlikely to receive excessive amounts of de-icing salts in Malaysia!

D.2.18.Special Drainage (Vol.18)

Ch. 44 Subsoil drainage.
This chapter is based on ASCE, 1998. Subsoil drainage is particularly important in hillside areas, commonly being developed in Malaysia, due to the potential to create land instability.

Ch. 45 Pumped drainage.
Gravity systems are the preferred option owing to the high cost of pumped systems in low lying and coastal areas which are commonly developed in Malaysia.

D.2.19. Special environment (Vol. 19)

Ch. 46 Lowland, tidal and small island drainage.
Section 46.1 The Tsunami of December 2005 has highlighted the importance of retaining mangrove systems and coastal vegetation as a protection against incursion by tidal waves, and reviewing the practice of developing of land in tidal zones mentioned in this section.

Section 46.2.3. Integrated measures for small islands refer to three islands situated off the east coast of Malaysia where the rapid development of tourism and absence of adequate planning has caused water supply problems and saline groundwater intrusion due to its excessive abstraction.

Ch. 47 Hillside drainage.
Further research is recommended to establish design rainfall intensities on hillsides. Hillside development is common in certain areas of Malaysia where land is scarce, for example the island of Penang (Fig.14). The experience and information on hillside drainage and construction in Hong Kong could be utilized in Malaysia and in this manual. (See Section D.3.2 of this report).

Figure 14 Hillside cutting on the island of Penang

Ch. 48 Wet weather wastewater overflows.
Although Malaysia has a separate sewer system, the problem and sources of stormwater contamination by wastewater from sewer overflows during wet weather and cross-connections are referred to.

D.3. Examples of stormwater management in Malaysia using the manual guidelines

D.3.1. Stormwater management and road tunnel (SMART tunnel)

This stormwater bypass tunnel which is 9.7 km long and was constructed from 2003-2007, is both a storm drainage and road structure in Kuala Lumpur. There is also a double-deck motorway 4 km long within the stormwater tunnel (Rieker, 2006). The main objective of the stormwater bypass tunnel is to solve the problem of flash floods in Kuala Lumpur. It begins at Kampung Berembang lake near the Klang River and ends at Taman Desa lake near the Kerayong River. The project has been led by the government, including the Malaysian Highway Authority and the DID and a joint venture between two companies. The SMART system is activated by moderate storms and flood water is diverted into the bypass tunnel in the lower channel of the motorway tunnel while the motorway section remains open to traffic. During major storms the motorways will be closed to traffic. Sufficient time will be allocated to allow the last vehicle to exit the motorway before the automated water tight gates are opened to allow the flood water to pass through the tunnel. The motorway will be reopened to traffic within 48 hours of the closure.

D.3.2. Erosion control in highway and urban construction

Soil erosion is difficult to control in the tropics owing to the complex climate and high rainfall, erodible lateritic soils or highly-weathered rocks and the hilly terrain. Construction practices often result in steep ‘cut and fill’ embankments and the stripping of local vegetation. Leong et al., (2006) describe three recent case histories on slope rehabilitation and revegetation in Malaysia and Singapore exemplifying sustainable construction best management practices using geosynthetics such as Erosion Control Mattresses (ECM) to reinforce bioengineering techniques.

D.3.3. Bio-ecological drainage system (BIOECODS)

The Engineering Campus of University of Science, Malaysia has implemented a stormwater management system with a source control approach, following the guidelines outlined in the SWM Manual. The concept of BIOECODS is to integrate the drainage components (i.e. ecological swales, on-line sub-surface detention and dry ponds) with the ecological pond components (i.e. a wet pond, a detention pond, a constructed wetland, a wading stream and a recreational pond) for further treatment of the stormwater runoff (Zakaria et al., 2003). The combination of these treatment systems increases runoff lag time and pollutant removal from settling, biofiltration and biodegradation and reduces the rate and volume of runoff by enhanced infiltration due to the increased area of impermeable soils. The vegetated ecological systems also provide an opportunity to enhance the landscape and provide habitats for wildlife within the university campus. The final discharge will significantly reduce the risk of pollution of the receiving river and of flooding downstream. Surface volumes are predicted to be reduced by 65% and solids, nutrients and heavy metal loads by 85% to 100%. There will also be substantial cost benefits to developers and river management authorities.

A BIOECODS drainage system has recently been introduced at the Taiping Health Clinic. A grassed swale receives the flow from pervious and impermeable surfaces and excess stormwater is stored in subsurface detention modules and temporarily in a dry pond or detention basin (Ghani et al., 2008). Two former tin mining ponds and an existing wetland near Ipoh are being rehabilitated by the BIOECODS team as a stormwater management facility with multi-functional uses, which include recreation, water reuse and stormwater retention (Ghani et al., 2008) The ex-mining ponds will be designed for stormwater quantity and quality control for a storm event of 10 year ARI (minor) and 50 year ARI (major). A wetland will be constructed to cater for flows of 3 months ARI to 10 years ARI from a catchment area of 53.54 hectares.

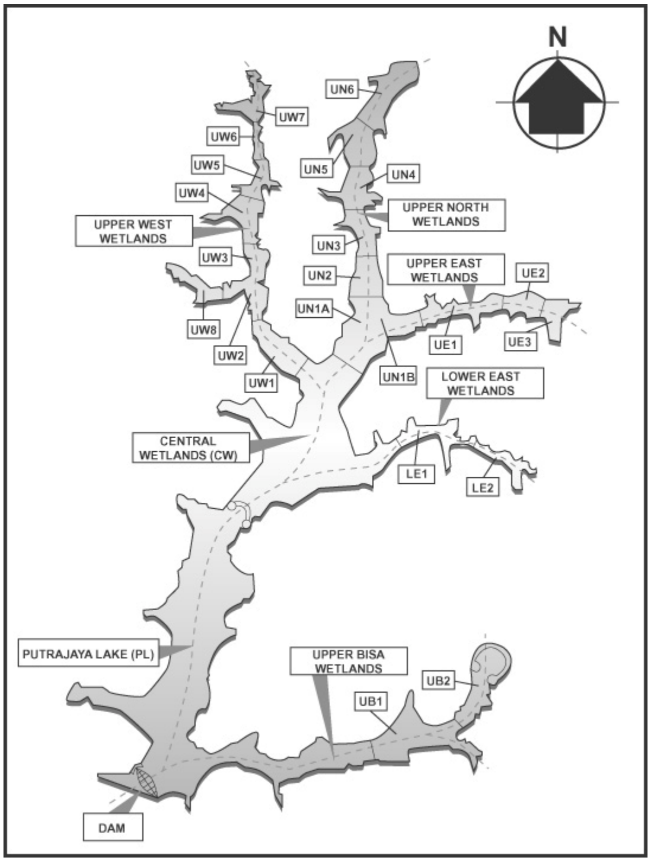
Although this project was partly funded by the DID, information about the system is not available on the DID website and there will be limited access of developers and local authorities to scientific journals and conference proceedings where the details are published.

D.3.4. Putrajaya Wetland: the first Constructed Wetland in Malaysia

The Putrajaya wetland system, consisting of 24 constructed wetlands (200 ha) and a downstream lake (400 ha), is located in Putrajaya, the new Federal Government Administrative Centre in Malaysia (Figures 15 and 16). It is the first example of wetland creation to restore polluted river systems, as well as for treating stormwater in the catchment area and flood control and demonstrates the concept of sustainable development in an urban area (Shutes, 2001; Sim, 2007; Sim et al., 2008).

Putrajaya Wetland was created in the valleys of the Chuau and Bisa Rivers and was completed within a period of 17.5 months in August 1998. The 400 ha Putrajaya Lake was created by constructing a dam at the lower reaches of the Chuau River. The wetland cells are designed using the multi-cell-multi-stage approach, with different water levels in each cell. The water flows through these wetland cells, which decrease in depth downstream toward the lake and finally flow into Putrajaya Lake. The wetland is currently treating 60% of the catchment runoff before it enters the lake.

Each wetland cell has an inlet zone that feeds into a primary sedimentation basin and finally into the wetland. Weirs or riffle rocks separate each cell area. Each wetland cell has a range of functional zones including wetland zones (divided into the macrophytic, 0-1.0 m deep and intermittently inundated zones, up to 1.5 m in depth) and open water ponds (1.0-3.0 m deep). Some ornamental ponds and vegetated islands were constructed in the open water ponds of some cells. A total of 12.3 million individual plants of 62 wetland species were planted in the wetland zone. Out of these, 27 species were emergent marsh species include Phragmites karka, Typha angustifolia, Lepironia articulata, Eleocharis dulcis and Scirpus grossus. This planted marsh area covers about 40% of the wetland area.



Map 1: **Location of wetland cells at Putrajaya Wetlands**

Figure 15 Location of wetland cells at Putrajaya Wetland

Figure 16 Putrajaya wetland cell vegetated and open water areas above outlet

Putrajaya Wetland with its high diversity of plants and fishes has attracted various types of wildlife (including waterbirds, amphibians, reptiles, insects) and hence has

enhanced the biological diversity in the area. The wildlife includes 110 species of birds, 122 species of insects, 3 species of snakes, 6 species of amphibians, and 11 species of mammals.

3.4.1 Putrajaya Lake: It is the vision of the Putrajaya Corporation to manage the lake in order to sustain its aesthetics and good water quality while providing different recreational uses, including primary and secondary water contact activities. Lake water quality is of paramount importance to the development of Putrajaya. The lake water quality is designed to comply with the Putrajaya Lake Water Quality Standard (Table 3), for swimming and other related water recreational activities. The lake is also designed for multi-functional uses, including stormwater treatment, flood control, recreation, fishing, canoeing and water transport, whilst maintaining high standards of water quality and aesthetics as well as creating wildlife habitats.

Table 3 Putrajaya Lake Water Quality Standard

Water quality parameter	Putrajaya Lake Water Quality Standard
In-situ parameter	
pH	6.5-9
Conductivity (S cm-1)	1000
Dissolved Oxygen (mg l-1)	5-7
Water transparency (m)	0.6
Water depth (m)	-
Turbidity (Nephelometric Turbidity Unit)	50
Laboratory analysis	
Ammoniacal-Nitrogen (mg l-1)	0.3
Nitrate-Nitrogen (mg l-1)	7
Phosphate (mg l-1)	0.05
Total Suspended Solids (mg l-1)	50
Total Dissolved Solids (mg l-1)	-
Chemical Oxygen Demand (mg l-1)	25
Biological Oxygen Demand (mg l-1)	3

3.4.2 Wetland treatment performance: The management of the lake and wetlands is being implemented through the Lake Management Division, City Planning Department of Putrajaya Corporation. The division is managing and supervising the works of the contractors and the experts that are involved in the maintenance and implementing a monitoring exercise in the wetland. It also oversees the operators of activities in the wetland and lake as well as enforcing rules and regulations of the water body. Within Putrajaya, which constitutes about 70% of the Lake catchment area, developments are controlled by the Putrajaya masterplan and stringent regulatory controls by Putrajaya Corporation. However, the Federal Government is

concerned about the uncontrolled developments in the 30% upstream areas of the catchment, outside Putrajaya. In order to achieve and maintain the high water quality objective set for Putrajaya Lake, a comprehensive Catchment Development and Management Guidelines for the Putrajaya Lake Catchment have been prepared. The guidelines have defined the land-use, drainage and sewerage masterplans for areas outside Putrajaya to integrate them to the pertinent masterplans for Putrajaya (Akashah, 2003).

Water quality is monitored on a daily, weekly, monthly, and yearly basis according to the parameters requirement in the Putrajaya Lake Water Quality Standard. The Putrajaya Lake and Wetlands Management & Operational System (PLWMOS) initiated in August 2000, an environmental monitoring and environmental decision support system that would serve as the main environmental database and spatial analytical tool for the current survey of hydrological, physico-chemical, and biotic parameters of Putrajaya wetlands and lake (Nazari et al., 2003).

The primary objective of the current ecological monitoring programme is to assess the overall health of Putrajaya Lake and Wetlands through the changes in the hydrological, physicochemical and biotic factors. The programme also provides for the early detection of potential pollution problems hence allowing for rapid remedial and preventive measures. In addition, the suitability of the lake to perform its function for recreational purposes could also be ascertained.

The monitoring programme includes the studies of water quality, phytoplankton, zooplankton, benthic macroinvertebrates, mosquitoes, waterborne pathogens, fish, plants and wildlife. In addition, the programme is also part of research to study the movement of contaminants in the biotic system, bio-accumulation studies on macrobenthos, plankton, fish,amphibians, molluscs, and macrophytes.

The wetlands have shown good water quality improvement along the flow length along Upper North (UN 6) to UN 1 wetland cells (Figure 16). However, silt runoff from surrounding development land has resulted in low pollutant removal in some months especially during the wet seasons. Siltation has resulted in the wetland bed becoming shallower and terrestrial weeds have invaded the wetland cells. Dredging has been carried out to desilt the wetland cells by Putrajaya Corporation.

To ensure the sustainability of the wetland system, Putrajaya Corporation has implemented the Polluters Pay Principle where developers who cause siltation in one wetland cell will be responsible for the desilting work and wetland plant replacement, as stated in the Catchment Development Management Plan for Putrajaya Lake. For further information on Putrajaya Wetland, please see http://www.ppj.gov.my

D.4. Conclusions

The manual represents a laudable means of introducing the concept of stormwater management to Malaysia and changing the concept of drainage engineering practices based on rapid disposal. However, there are lessons to be learnt from this first edition which could lead to its improvement and the transferability of stormwater

management systems from developed to less economically developed countries in the future.

(i) Stormwater management manuals should indicate the local requirements including climatic factors, for the design and operation of stormwater management systems and describe, where available, local examples of stormwater management systems using BMPs.

(ii) If research is recommended in order to gain a better understanding of the design, operation and management requirements of local stormwater systems, the results of the research, e.g. BIOECODS and the implementation of BMPs e.g the SMART stormwater diversion tunnel and erosion control should be provided in printed or online updates in a more accessible format than conference papers.

(iii) Practical limitations, including funding, should be identified as constraints to the adoption and upgrading of stormwater management systems in an economically less developed country and a list of alternative solutions provided.

(iv) Benchmark concentrations or target levels and realistic values for parameters monitored in stormwater need to be developed for the specific country. Biological monitoring should also be applied.

(v) Local community and environmental education programmes are an important component of the successful implementation of stormwater management.

E. BRAZILIAN DESIGN AND GUIDANCE MANUALS

E.1. National and State Design Manuals and Guidance Documents

In Brazil, a national design manual on urban drainage or on urban best management practices (BMPs) does not exist. However there is an increasing imperative to address the urgent problems of urban flooding in an effective and sustainable manner. To date there has been a prediliction for post-hoc reparative solutions to flooding and water quality problems rather than preventative measures (Silveira and Goldenfum, 2004). Nevertheless, a certain number of publications have appeared which contribute to the growing improvement in urban stormwater hydrology methods and to the progressive adoption of stormwater management best practices. In general, these publications are strongly based on overseas technical literature, as there is only limited domestic knowledge and experience of BMPs and source control approaches. The reliance on foreign design guidance, drawn principally from North America and Europe, has meant there has been little adaptation to local soil, climate and urban conditions. The clear need nevertheless, is for the development of simple and technically consistent analytical procedures that can help identify appropriate and effective measures for long term, sustainable urban stormwater management
In the present report, a listing of the main documents, reports and books published in this urban drainage domain is firstly given. Then follows a critique of best practice guidelines for stormwater management in Brazil, where relevant comment and discussion on, and quotations from, some of the research publications are also given. The municipalities of Sao Paulo, Porto Alegre, Curitiba and Belo Horizonte stand out amongst Brazilian cities that have been in the forefront of urban drainage design and in the development of stormwater management guidelines and thus their contributions dominate the literature as well as practice on the ground.

1957. *Chuvas Intensas no Brasil (Intense Rainfall in Brazil).* Author: O. Pfasfstetter. Departamento Nacional de Obras de Saneamento, Rio de Janeiro, 1982 (2nd edition), 426 p.

This is the first Brazilian study on rainfall intensity, duration and frequency (IDF) published in 1957 (1st edition) with the purpose of furnishing relevant information and methods for calculating design storm events for different regions of the national territory. It presents curves and IDF equations for 98 urban areas, distributed throughout the then inhabited territory. It is quoted here mainly considering its historical value, although its equations are still in use for many towns where no other updated information on storms exists. It is also mentioned to acknowledge the remarkable effort of Mr. Pfasfstetter in developing so many rainfall IDF studies during a time when computer facilities were not available.

1978. *Engenharia de Dremagem Superficial (Urban Drainage Engineering).* Author: P S Wilken, Companhia de Technolgia de Saneamento Ambiental (CETESB), Secretary of State for Envrionment, São Paulo, 477 p.

This volume presents the theoretical basis of applied hydrology within the urban context as well as detailed procedures and guidelines for practitioners to help develop IDF equations, event design storms and hydrograph estimations. The three chapters

dealing with these subjects contain detailed information about the measurement of hydrological variables and data treatment, statistical methods for rainfall and flood frequency analysis as well as traditional methods for estimating peak discharges and event urban hydrographs. These are based on the estimation of losses from rainfall and time of concentration, and the application of methods such as the rational method and the unit hydrograph concept. The design of typical urban drainage structures is also covered, including gutters, culverts, channels and detention basins. Other BMPs are not mentioned in the book. The book also contains a chapter on catchment studies, dealing with catchment geomorphology, soil types, vegetation cover, land use and estimation of impervious coefficients.

1980. *Drenagem Urbana: Manual de Projeto* (Urban Drainage: Design Manual). Compamhia de Tecnolgia de Saneamento Ambiental/Dept.de Aguas e Energia Electra (CETESB/DAEE) São Paulo, 468 p.

This work basically presents the same contents of the Wilken's book previously described. Nevertheless, it is more focused on design methods than on basic urban stormwater hydrology. In this sense, desk top methods on urban hydrology are described in detail, e.g.: rainfall design storms, peak discharges and event based hydrograph calculations. The manual contains also detailed guidelines for designing urban hydraulic structures, e.g.: gutters, inlets, storm sewers, manholes, canals, culverts, energy dissipation structures, bridges, and others. With the exception of the design of detention basins for flood control, no other BMPs typically employed in urban drainage nowadays are mentioned in the manual. The manual also reproduces Pfasfstetter's rainfall IDF curves in table form and quotes updated IDF equations for big cities in Brazil. Finally, an extended part of the manual is dedicated to stormwater management planning and its interaction with urban development planning, planning of the road system and other urban policies. This is possibly one the first Brazilian documents on urban drainage which stresses the planning aspects of stormwater management in a comprehensive way, although for present times it seems outdated given recent concepts on sustainability, integrated urban water management, wet weather diffuse pollution issues, best management practices etc..

1995. *Drenagem Urbana (Urban Drainage*). Editors: C Tucci, R Porto, M T Barros, ABRH e Editora da Universidade, Porto Alegre, 428 p. ISBN 85-7025-364-8

This volume combines updated theoretical aspects on urban hydrology and urban hydraulics with general guidelines and design examples that may be useful for undergraduate students and drainage engineers in dealing with modern concepts and methods on urban drainage. In its first part, the book presents a detailed description of the main impacts of urbanisation on hydrologic processes, including quantitative (rainfall, floods) and water quality aspects (e.g.: erosion processes in urban areas, wet weather diffuse pollution). The following chapters deal with more conventional subjects of urban drainage: rainfall IDF curves and design storms, rainfall-runoff relationships, peak flows and event hydrographs, conventional urban drainage hydraulic structures (design methods and construction). Basic theoretical aspects and methods are updated in respect to the CETESB/DAEE manual previously described, particularly concerning unsteady flow and flood routing, as well as hydrologic and hydraulic modelling in urban areas. Two chapters develop in detail questions related to erosion processes and wet weather diffuse pollution in urban areas. The final part to

the work is dedicated to alternatives for reducing the environmental impacts of urbanisation. Chapters in this part deal with erosion control methods, a wide general description of BMPs focused on runoff control (e.g.: infiltration trenches, pervious pavement, infiltration basins, swales, detention basins etc.), and institutional aspects mainly stressing the need of stormwater master plans and methods for developing them. In spite of presenting some inequalities in the treatment of different subjects, the book has strongly contributed to disseminating new concepts on urban drainage in Brazil and presents the advantage of always taking into account typical Brazilian conditions (climate, urban development, institutional development). It is therefore not a simple compilation of international experiences in the urban drainage domain.

Prefeitura do Municio de Sao Paulo. 1999. *Diretrizes Basicas para Projetos de Drenagem Urbana no Municipio de Sao Paulo.* Fundacao Centro Tecnologico de Hidraulica, Universidade de Sao Paulo. (CTH/USP), Sao Paulo, Brazil.

The Sao Paulo drainage manual dates from the end of the 1990s and is essentially concerned with conventional sewered urban drainage design but does place emphasis on the importance of macro-scale detention basins as part of the drainage system. In the period 1999 – 2002, nine flood storage (wet detention) basins were constructed varying in size between 25, 000 to 365, 000 m3 and such basins are now mandatorily required for impermeable lots larger than 500 m2. Although the manual does list alternative source control devices, the strong emphasis on large detention basins has had a lasting effect on subsequent design approaches for stormwater control.

2000. *Avaliação e Controle da Drenagem Urbana* (Urban Drainage: evaluation and control). Editors: C E M Tucci & D M L M Marques, ABRH and Editora da Universidade, vol. 1, Porto Alegre, 558 p. ISBN 85-7025-544-6.

2001. *Avaliação e Controle da Drenagem Urban*a (Urban Drainage: evaluation and control). Editors: C E M Tucci & D M L M Marques, ABRH and Editora da Universidade, vol. 2, Porto Alegre, 548 p. ISBN 85-88686-04-X.

These two volumes present a collection of papers issued from a long-term research project on urban drainage lead by the Hydraulic Research Institute (IPH) of the Federal University of Rio Grande do Sul (IPH-UFRGS). The publication is far from being a manual. Nevertheless by the fact of gathering in two books papers produced in the context of a specific and multidisciplinary research project, it presents a particular interest in terms of the dissemination of new tendencies and approaches on stormwater management in Brazil. In both volumes there is a wide range of subjects presented and discussed. They are organised according to subdivisions as follows: monitoring water quantity and water quality in urban areas; environmental impacts of urbanisation; wet weather diffuse pollution; hydrologic and hydraulic modelling of urban catchments, BMPs for runoff control and water pollution abatement; urban planning; integrated urban water management; case studies.

2002. *Plano Diretor de Drenagem para a Bacia do Rio Iguacu na Regiao Metropolitana de Curitiba; Manual de Drenagem Urban*a. CH2MHILL, Superintendence for Hydraulic Resources and Environmental Sanitation Development (SUDERHSA), Governo do Estado do Parana, Curitiba.

This manual follows closely the guidance outlines of the Porto Alegre 2000 drainage design manual with a variety of source control approaches being advocated mainly based on the works of Schueler (1987), Urbonas and Stahre (1993) and Azzout et al (1994). Definitions for each device are introduced and applications under differing soil and urban space conditions are developed. Pre-design procedures based on explicit methods are coupled with rainfall-envelope methods and Talbot-type IDF curves. Pre-development volumes and flow rates are recommended for design with a 1:10 year return interval and maximum outflow rates of 27.1 l/ha

2003. *Inundações Urbanas na América do Sul* (Floods in South American Urban Areas). Editors: C Tucci & J C Bertoni, ABRH, Global Water Partnership and WMO, Porto Alegre, 471 p. ISBN 85-88686-07-4.

This book gathers contributions by 22 authors from different South American countries on flooding in this region. General concepts about urbanization processes in South America and resulting environmental impacts as well as the need for integrated management of urban water are developed in the first part of the work. In its second part, experiences of floods and flood control measures are described for Argentina, Bolivia, Brazil, Paraguay, Peru and Uruguay. The third and last part of the book describes a series of workshops addressed to decision makers on floods and flood control alternatives. These workshops, supported by the GWP – Global Water Partnership and by the World Meteorological Organisation (WMO) were organised in five South America countries (Argentina, Brazil, Chile, Colombia and Peru), having as their main objectives: (i) dissemination amongst decision makers modern concepts on flood control approaches; (ii) identifying the main flood problems existing in those regions where the case studies were developed in the context of the workshop preparation; (iii) elaborating propositions for flood mitigation and for the development of future projects on flood control to be funded by national and international organisations.

2005....*Manual de Drenagem Urbana* (Urban Drainage Manual). Project Coordinator: C Tucci, Porto Alegre Municipality and IPH-UFRGS, 159 p.

The Urban Drainage Manual prepared by a team of the Institute for Hydraulic Research of the Federal University of Rio Grande do Sul (IPH-UFRGS) is part of the Porto Alegre Municipal Stormwater Master Plan (www.portoalegre.rs.gov.br). The current manual represents a further development of the original 2000 urban drainage manual (Plano Diretor de Drenagem Urbana; Vol. 6. Manual de Drenagem Urbana) worked up for the DEP/PMPA (Department of Pluvial Drainage of Porto Alegre) by IPH-UFRGS (Instituto de Pesquisas Hidrailicas of the Universidade Federal do Rio Grande do Sul). Both the original 2000 and the current 2005 manuals place considerable emphasis on source control management approaches

The 2005 manual covers the main topics concerning stormwater management, with a focus on quantitative aspects (runoff control, flood control). Basic principles and concepts of urban drainage are given in the first chapters: notions on urban hydrology, risk analysis, impacts of urbanisation on hydrologic processes and so on. Then, stormwater source control techniques and other BMPs are presented together with design methods as well as design recommendations. This part contains reference to detention and infiltration basins, infiltration trenches and detention trenches; swales;

permeable paving, infiltration wells etc.. Urbonas and Stahre (1993), CIRIA (1996) and ASCE (e.g: ASCE, 1992)1 figure among the main references for the design methods with different studies and publications specifically developed by the IPH-UFRGS. The manual also presents many examples on the use of BMPs and on design methods. It adopts a layout similar to the US manuals, such as that of Denver, Colorado offering pre-programmed charts for source control device pre-design. The manual recommends the adoption of a restriction flow equivalent to the pre-urbanised flow conditions with a return period of 10 years as a compromise between cost and hydraulic efficiency; with a 2 year return period being encouraged for micro-drainage source control with a maximum outflow value of 20.8 l/ha. Where this outflow value is exceeded, local bye-laws require the introduction of source control devices within the curtilage of the property.

2005....*Técnicas Compensatórias em Drenagem Urbana* (BMPs in Urban Drainage). Authors: M Baptista, N Nascimento, S Barraud, ABRH, Porto Alegre, 266 p. ISBN 85-88686-15-5.

This book is, so far, the sole Brazilian publication centred on the use of BMPs for stormwater management. It is an issue of the long-term co-operation between the Federal University of Minas Gerais (UFMG) and the French Institut National des Sciences Appliquées de Lyon (INSA-Lyon). Although not organized as a manual, the publication contains basic guidelines and design examples that facilitate the practitioner in the conception and design of stormwater systems employing BMPs in urban areas. The book is divided in three main parts. In the first part, general concepts of stormwater systems, environmental impacts of urbanisation and institutional issues are addressed. The second part deals with storage and infiltration processes centred on process description and modelling, which is the base for the presentation of general BMP design guidelines developed at the and of this part. The third part contains a series of chapters on different types of BMPs, including detention and infiltration basins; infiltration trenches and detention trenches; swales; permeable paving, infiltration wells; green roofs and so on. For each one of the BMPs a description of the structure is given and how it works, guidelines for conception and design, information on construction materials, construction guidelines and advice, maintenance requirements as well as costs for implantation and maintenance. Pictures, diagrams and examples of application, presenting all the conception and design steps, are also furnished for each BMP discussed in the book.

E.2. Comments on best practice guidelines for stormwater management in Brazil

The use of BMP/SUDS as urban drainage controls in Brazil is still relatively restricted although there is a long-standing experience in using detention basins for flood control. Nascimento et al (2000) presents a comparative assessment of the use of

[1] Quoted references in the Manual:
CIRIA (1996). *Infiltration drainage - Manual of good practice*. R Bettes Bsc PhD MCIWEM. CIRIA Report 156
ASCE, 1992. Design and construction of stormwater management systems. The urban water resources research council of the American Society of Civil Engineers (ASCE) and the Water Environmental Federation. New York.
URBONAS, B.; STAHRE, P., 1993. *Stormwater Best Management Practices and Detetion,* Prentice Hall, Englewood Cliffs, New Jersey. 450p.

detention basins in Belo Horizonte, with international experience gained in the same domain. In large Brazilian cities, such as São Paulo and Porto Alegre, municipalities have employed detention basins as a focus for flood control since the 1980's. Some examples can be find on the home pages of the Department of Water Resources and Electrical Energy (DAEE – www.daee.sp.gov.br) for the São Paulo State, and of the Department of Stormwater Management (www.portoalegre.rs.gov.br) for the Porto Alegre Municipality.

It can be argued that the emphasis on large macro-storage detention basins simply represents the most obvious engineering solution to high magnitude large-scale urban flooding. Such basins are relatively easy and cheap (median costs about US$20 – 30/ m3) to construct and have a high public visibility. However, they have "sidelined" alternative smaller scale storage and source control approaches and fail to recognise that flooding is only a part of wider environmental problems. It may also reflect the reluctance of public authorities and drainage engineers to embrace multi-disciplinary approaches and joint stakeholder actions in order to achieve a more sustainable management of the urban hydrological cycle. The problems of rapid sedimentation, vandalism and lack of maintenance of urban detention basins in Brazil have been highlighted in Nascimento et al (2000). Such basins require upstream sediment control on new construction sites as well as pre-sedimentation traps. It is debateable however, whether a shift to smaller, dispersed detention facilities would offer any better solution given the serious issues of regulation and maintenance.

There is considerable inherent semi-autonomy within the various sectors of municipal administration which are severally responsible for urban stormwater management. In addition, the lack of local knowledge and technical expertise in alternative source control approaches provides a serious barrier to their introduction. This is exacerbated by a lack of consistent technical standards for urban stprmwater drainage. Nevertheless, the use of other types of BMPs (e.g.: source control techniques) is progressing in Brazil although, in most cases, these solutions are mainly employed in new developments with wealthy urban neighbourhoods. There is also a growing general interest for rainwater reuse and green roof alternatives in urban areas. On the other hand, a few works have been done on the conception and adaptation of BMPs to poor neighbourhoods where urban drainage presents particular challenges such as: very dense occupation, high impervious rates, steep slopes and landslide risk in the case of shantytowns located on hillsides, flood risk and high groundwater levels in the case of shantytowns located in valley bottoms, as well as poor environmental sanitation services e.g. lack of wastewater and solid waste collection.

Another possible difficulty that prevents a wider spread of the use of BMPs in Brazil is the feeble exchange of experience amongst Brazilian municipalities on these matters. Furthermore, there is a lack of monitoring of hydrologic processes and therefore, a lack of hydrologic data in urban areas, including monitoring of the functioning and efficiency of existing BMPs. This is a factor which not only prevents progress in modelling hydrologic processes in urban areas, but also the development of design methods in stormwater management.

Nevertheless, the context described above is quickly changing. This acceleration is in part due to the recognition by Brazilian municipalities of the pressing needs to promote institutional and technical development on stormwater management. With

the rapid urban growth experienced during the 1970's and 1980's, traditional solutions proved to be very ineffective and expensive, with frequent failures in flood control and huge environmental impacts. Porto Alegre, Curitiba, São Paulo, Goiânia, Rio de Janeiro and Belo Horizonte are examples of Brazilian state capitals which are developing or have recently concluded stormwater master plans, trying to promote the required updates on stormwater management.

In the case of Belo Horizonte (BH), the on-going Stormwater Strategic Plan and the Water Supply and Sanitation Strategic Plan focus on the following programmes:
the DRENURBS programme: creek restoration within the urban area, which involves not only the restoration of polluted creeks but also complete sanitation, risk management (risk of flooding, risk to public health etc,.), and a housing programme addressed at people living in risk prone areas (improvement of housing conditions, removing people from flood risk areas);

- the stormwater monitoring programme: establishing and operating a rainfall, discharge and water quality measurement network to allow the identification of BH stormwater problems at the present time and to contribute to the future evaluation of the efficiency of control measures that will be implemented according to the stormwater plan. This programme will also contribute to impact assessment of urbanisation on water resources and to the statement of land use regulatory measures aimed at the mitigation of impacts.
- a rainfall-runoff and hydraulic modelling programme: data generated by the monitoring programme will feed models that will be employed to diagnose the functioning of the storm water system in order to devise the main causes of system operational problems and to simulate different control measure scenarios. The first phase of this programme will start in 2006. In this phase, modelling will be performed prior to the monitoring programme, using data from the existing rainfall measurement network and from detailed surveys on land use and on the stormwater sewerage system characteristics. Modelling results from this phase will be useful in devising actions to deal with critical and urgent problems and in designing the monitoring network.
- a research and technological development programme: the main programme goal here is the development of stormwater management technologies to solve the main stormwater problems. Although the final scope of the programme has not yet been concluded, the following themes will certainly be part of it:
  - physical modelling of specific hydraulic structures, like gutters, culvert entrances and confluences with the purpose of efficiency evaluation under particular conditions that prevail in BH (steep channels, high flow velocities, frequent changes in water flow regimes etc.) and design criteria statements;
  - evaluation of the volume of solid waste transported by the stormwater system during storms and assessment of the waste typology (this is a common problem in many Brazilian towns, due to failures in solid waste management);
  - experimental investigation through pilot experiments of the efficiency of source control devices (BMPs: infiltration trench, pervious pavement, detention facilities etc..) in terms of runoff and pollution abatement, maintenance requirements, building and operational costs, design criteria statement, etc. Although there is important literature available on this subject, local particularities need to be considered

(e.g. rainfall intensity, sediments and solid waste, public acceptance, maintenance requirements, costs etc..).

- o assessment of the benefits of flood control measures by an economic evaluation of direct and indirect flood damages.
- o an institutional and managerial development programme: this programme aims to provide a statement of legal, economic, institutional and managerial measures in order to improve storm water management in the BH municipality.

At the Federal Level, the Ministry of Cities is leading a national training programme called 'The National Network on Environmental Sanitation Training – ReCESA' conceived as a means of contributing to reduce the low qualification level of practitioners in sanitation companies throughout the country. It consists of a network of Brazilian institutions that work in the sanitation sector (water, wastewater, municipal solid waste and urban drainage), involving universities, technological centres, state and municipal sanitation companies, among others. The network integration is guaranteed by four regional nuclei constituted in the south, southeast, northeast and central regions of Brazil (congregating 13 federative states in total), under the leadership of four previously qualified universities (one in each nucleus). The main objectives of the project are to develop appropriate training material and to qualify around 5,000 workers during the period 2007-2008.

Regarding research activities, for the first time the Brazilian Programme on Environmental Sanitation (PROSAB) included the theme of stormwater management, in its 5th version covering the period 2006-2008. PROSAB is a long-term multidisciplinary research and development programme covering the domains of drinking water, sanitation, urban drainage and solid waste management. It is nowadays funded by the Brazilian Science and Technology Fund on Water Resources and managed by FINEP (Research and Project Financing) and CNPq (National Council for Scientific and Technological Development). The on-going programme on stormwater management gathers 5 federal universities (Rio Grande do Norte, Pernambuco, Minas Gerais, Brasília and Rio Grande do Sul) as well as the University of São Paulo, in a research network with a focus on characterising diffuse pollution in urban areas, testing different types of source control devices (detention trenches, infiltration trenches, pervious pavement, green roofs etc..), extended detention ponds and artificial wetlands. Concerning source control devices and other BMPs, research efforts are directed at assessing environmental risks (e.g.: soil and groundwater contamination), efficiency on runoff control and pollution abatement, maintenance requirements and construction and maintenance costs. The research team is now preparing a book aiming to disseminate the main research issues for an academic and technical public.

In the following paragraphs, some comments are given about selected papers on stormwater management which have been recently published as examples of methodological developments on this domain for the Brazilian context.

Pinheiro, M. G. ; Naghettini, M (1998). *Frequency and Time Distribution Of Rainfall in Heavy Storms over the Metropolitan Region of Belo Horizonte, Brazil*. 297 – 306 In: Wheater H. & C. Kirby (Editors). (Org.). Hydrology in a Changing Environment. Vol.1, John Wiley & Sons. Chichester, UK

The method of regional L-Moments, along with the index-flood concept, have been applied to 11 rainfall recording gauging stations located in the metropolitan region of Belo Horizonte (MRBH), with the purpose of defining a IDF-type curve valid within the peri-urban area. Locally, the IDF curve depends only on the average annual precipitation, which indirectly accounts for the combined effects of dominant direction of winds and the pronounced regional relief, on short-duration rainfalls. The resulting equation is given by:

$$i_{T,d,j} = 0.76542 d^{-0.7059} P_{annual}^{0.536} \;\; _{T,t}$$

where:

iT,d,j: rainfall intensity for a particular return period (T), duration (d) and at a location (j) in the MRBH [mm/h];

d: rainfall duration [h];

Pannual: annual precipitation at location (j) in the MRBH [mm];

T,d: dimensionless quantile of regional frequency analysis associated to a rainfall duration (d) and return period (T).

In addition, the paper proposes a time distribution of short-duration rainfall on the basis of a simple empirical frequency analysis of dimensionless quantities, similar to the conventional Huff method used to deduce standard hyetographs (Figure 17). Davis and Naghetini (2001) applied the same methodology on regional rainfall studies for the Rio de Janeiro State.

Regarding standard design return periods, in Brazil there is no national standard level of service for urban drainage. This is mainly due to the fact that urban drainage is under municipal responsibility and each municipality tends to state its own standards in this domain. Nevertheless, some publications contain general recommendations on design return period that have been broadly adopted by the majority of municipalities. One example is the design return periods proposed by the DAEE/CETESB Urban Drainage: Design Manual (Table 1). Table 2 presents the design return period recommended by the Porto Alegre Municipality according to its Urban Drainage Manual. The Porto Alegre Urban Drainage Manual also adopts a design criteria based on a pre-development peak flow not to be exceeded by the design peak flow after the development.

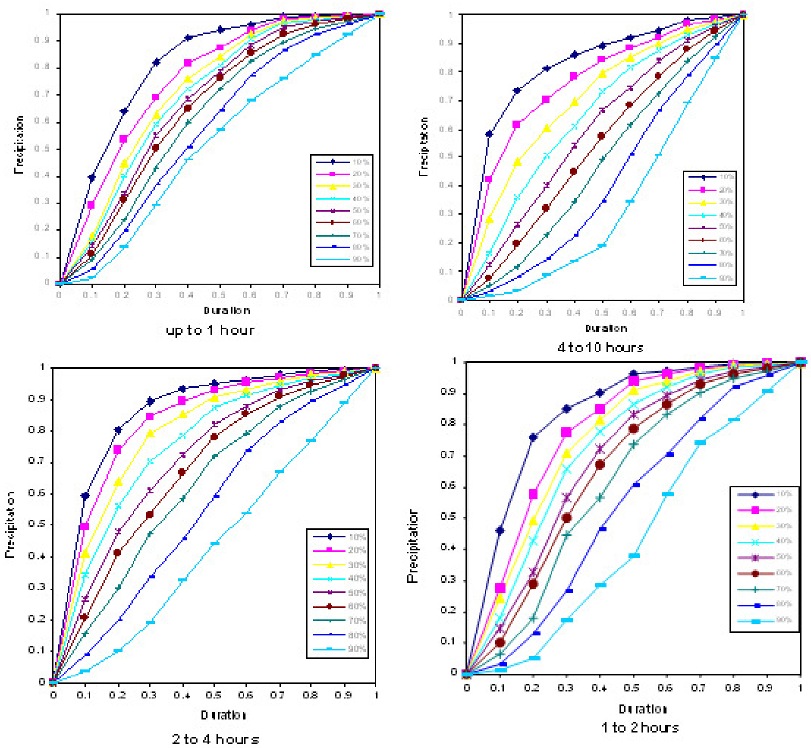


Figure 17 Dimensionless Hyetographs for Different Exceedance Probabilities and Duration

Table 4 Design return periods for urban drainage structures according to land use (DAEE/CETESB, 1960)

Type of structure	Land use	Return periods (y)
Micro-drainage structures	Residential	2
(gutters, inlets, storm drains)	Commercial	5
	public service buildings	5
	Airports	2-5
	central areas and main roads	5-10
Macro-drainage structures	residential and commercial areas	50-100
(main channels, detention basins, …)	areas presenting particular relevance	500

In the case of Belo Horizonte, the municipality adopts a 10-year return period for micro-drainage structures (gutters, inlets, storm drains etc..). In the case of macro-drainage structures, return periods are adopted according to the stream classification in the two main catchments where the urban area is located, the Arrudas and the Onça stream catchments.

Table 5 Design return periods for urban drainage structures according to land use (Porto Alegre Urban Drainage Manual, 2005)

System	Characteristics	Interval for the design return period (y)	Design return period frequently adopted (y)
Micro-drainage	Residential	2-5	2
	Commercial	2-5	5
	Public service buildings	2-5	5
	Airports	5-10	5
	Commercial areas and main roads	5-10	10
Macro-drainage		10-25	10
Flood risk zoning on flood prone areas		5-100	100

If the drainage structure is to be built on the main streams (Arrudas or Onça), the return period will be 100 or 200 years. Interventions on direct tributaries to the Arrudas or Onça are designed for the event with a 50-year return period. A 25-year return period is adopted in the case of interventions on the head tributaries to the direct tributaries to the mentioned main streams. Emergency detention basin spillways are typically designed for 1000-year return period and verified for the maximum probable discharge.

In Belo Horizonte, return period standards for flood risk zoning in flood prone areas are not available. Nevertheless, zoning is currently stated for events with return periods of 5, 10, 25, 50 and 100 years.

Urban drainage design methods currently employed in Brazil essentially adopt event-based simulations. In the case of the design of macro-drainage structures, it is relatively common to perform simulations of design rainfalls having different duration in order to define the critical duration for the design storm. Rainfall time series are rarely employed in urban drainage design in Brazil, although this approach has had its relevance highlighted by various research issues. One example is a research project developed at the Federal University of Minas Gerais which focused on the assessment of the probability of failure of a stormwater system containing 5 associated detention basins (Diniz, 2002; Nascimento et al, 2001). In this work, a 10-year rainfall time series plus a 50-year synthetic rainfall time series obtained with a stochastic rainfall generator were employed to estimate the probability of failure of the detention basins in controlling floods in a urban catchment with a surface of 50 km2. This research also includes the identification of the main causes of failures and on the flood characteristics (e.g.: duration, depth, flooded area). Another example was presented and discussed by Souza and Goldenfum (Souza & Goldenfum, 2004) for an infiltration trench experiment; a paper briefly described in the forthcoming

paragraphs. In both cases, the initial state of the catchment area and of flood control devices proved to play a major role on the device failure probability, even for events presenting estimated return periods lower than that adopted for the design of those devices.

Some progress has been obtained in flood damage assessment (Nascimento et al, 2005) which can be useful for stating design return periods by means of cost-benefit analysis. Nevertheless, this is an approach rarely adopted in Brazil, with possibly the exception of flood control measures funded by international banks (e.g.: World Bank, Inter-American Development Bank) that require benefit analysis usually based on willingness to pay methods.

Cruz, M A S & Tucci, C E M (2007). *Otimização de obras de controle de cheias em uma bacia urbana* (Flood control devices optimisation in a urban basin). Rev. Bras. de Recursos Hídricos, vol. 12, n.2, ABRH, p. 63-80.

This paper presents the development of a hydrologic-hydraulic simulation model associated with optimisation of genetic algorithms having the purpose of optimising flood control alternatives in a catchment. The model takes into account, as flood control alternatives, detention basins and channels that may be considered according to different layouts of the catchment. Therefore, different possible associations of both alternatives can be evaluated by the model. The optimisation process adopts as an objective function the lowest cost of alternatives combining detention basins and channels. This is an interesting tool allowing the evaluation of low cost solutions as well as the impact on flood control of the use of many detention basins at the catchment scale.

Baptista, M. B. ; Barraud, S ; Alfakih, E ; Nascimento, N O ; Fernandes, W S ; Moura, P M ; Castro, L M A (2005). *Evaluation system for urban storm drainage.* Water Science and Technology, v. 51, n. 2, p. 99-107.

This paper presents a simple decision aid methodology and associated software (AvDren) concerning urban stormwater systems devoted to the evaluation and the comparison of drainage scenarios using BMPs according to different technical, sanitary, social environmental and economical criteria. This kind of tool is particularly interesting to help decision makers in selecting appropriate alternatives and to plan investments especially for developing countries having important sanitary problems and severe budget restrictions. The software can be downloaded from www.ehr.ufmg.br.

Nascimento, N, Cançado, V, Cabral, J R (2005). *Taxing for stormwater drainage system,* Water Science and Technology, vol. 52, n. 9, p 251-258.

This article evaluates the possibility of creating a tax for urban drainage in order to make the system self-financing and to promote either the growth of impervious surfaces or the use of source control technique. Average costs of implementation and maintenance of the services were used to individualize the charges and definition of the tax. The conventional drainage system was evaluated along with a source control

alternative comprising water detention in tanks on the property lot. The magnitude of the values being charged varies as a function of the impermeable surface and the density of the urban area. Preserving creeks in natural conditions and using source control approach, are all options having the advantages of lower investment and smaller financial burden for the users.

Souza, V C B and Goldenfum, J A (2004). *Critical analysis of data from two infiltration trenches under subtropical climate conditions*. 1501 – 1508 In: Proceedings 5th International Conference on Sustainable Techniques and Strategies in Urban Water Management, NOVATECH04, GRAIE, Lyon. France.

The paper presents and discusses issues of an experimental study developed at IPH-UFRGS (Institute for Hydraulic Research of the Federal University of Rio Grande do Sul) on infiltration trenches. This is one of the first experiments on source control techniques developed in Brazil. The first paper mainly describes monitoring issues associated with two infiltration trenches, covering a total period of 30 months. Both trenches presented good performance during the monitoring period. As expected, the highest infiltration rates were observed with very dry soil moisture conditions. Initial conditions played a major role on the trenches performance. One observed event presented rainfall recurrence times bigger than the design return period of 5 years: 10 years for a 30 minutes duration and 25 years for durations smaller than 15 minutes (event 28/11/2001). However, the most critical events, corresponding to the maximum observed depths, were not due to the rainfall having the biggest return period, but rather due to wet soil moisture conditions before the events. Destructive sampling showed that the trench's top layer is of great importance for clogging control. The presence of a geotextile can protect the inner layers of the trench, significantly reducing clogging. The device's lifetime can also be extended by a correct maintenance or even by the substitution of this top layer (Caramori and Goldenfum, 2004).

Nascimento, N.O., Machado, M., Baptista, M.B., Silva, A. (2007), *The assessment of damages caused by floods in the Brazilian context,* Urban Water, vol. 4, n. 3, p. 195-210.

This paper describes theoretical aspects and the main results from the development of a methodology for the global evaluation of direct damage caused by floods. This methodology is based on the use of standard flood-damage curves (FDCs) versus depth of inundation on dwelling, commerce and service sectors (Figure 18). The research was developed based on field surveys in the city of Itajubá, located in the valley of the Sapucaí River, in Minas Gerais state, in the Southeast region of Brazil. In January 2000, this city suffered severe floods where more than 70% of the urban area was affected; with depths of inundation higher than three metres in certain areas. The empirical data was obtained through questionnaires applied during 2002 in the ravaged area. The questionnaires allowed the characterization of the dwellings and their content, as well as the different categories of commercial and service activities. The generic curves obtained from the data in the survey were used at the same site to evaluate the amount of potential flood damage in relation to different hydrologic risks.

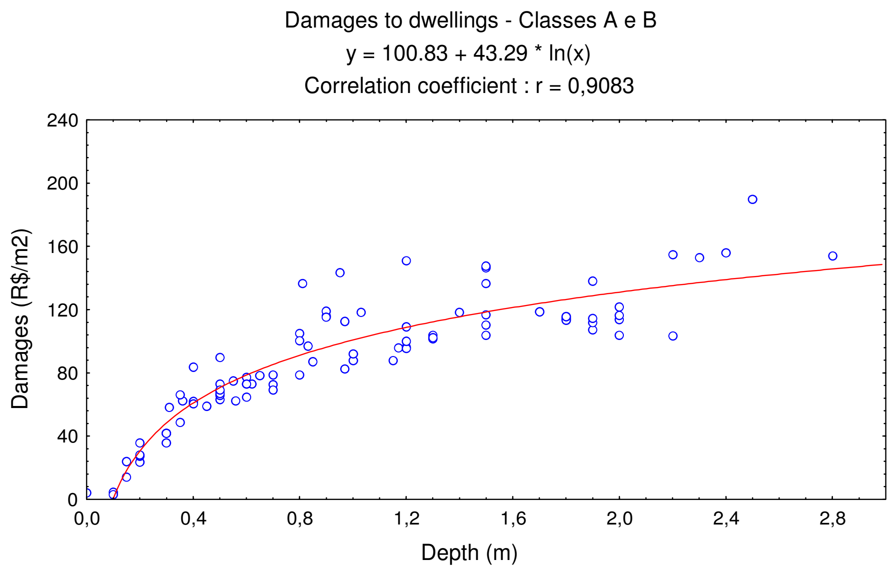


Figure 18 FDC for Socioeconomic Classes A and B (R$/Euro rate: 1.85, January, 2000)

E.3. Conclusions

Despite the growing awareness in Brazil of sustainable principles, there is still only limited technical information and design guidance to urban drainage controls and associated BMP measures. A generic outline for state (federal) urban drainage manuals within Brazil has been suggested (Tucci, 2001) which recommends the following sections:

Principles and Conceptions: source control; peak flow attenuation; initial flow treatment; receiving water impacts; land user development controls

Regulation: flow limits; return periods; storage and impermeable area limits; urban densities; stormwater taxes; building construction

Design: alternatives for flow and quality control; design parameters; design and performance limitations; maintenance

Such recommendations represent a real challenge for future Brazilian urban drainage and a new paradigm compared to traditional drainage practice.

Differing criteria and approaches are currently being practiced for the design of urban stormwater drainage facilities across Brazilian municipalities. Furthermore, the application of overseas design procedures without recognition of local conditions also limits the effectiveness and efficiency of the limited source control approaches which are being introduced. The historical subservience to the use of macro-storage detention basins within Brazilian engineering practice also distorts the focus of more sustainable small-scale solutions. There remains a need to adopt a more dispersed source control approach which can address the flow and quality problems associated with more frequent storm events. There is an incipient but growing interest in such source control approaches and undoubtedly significant future advances can be expected towards the achievement of more sustainable integrated urban stormwater management.

F. GERMAN DESIGN AND GUIDANCE MANUALS

F.1. Introduction

German design and guidance manuals have been developed by several associations of experts and practitioners e.g.: DWA (German Association for Water, Wastewater and Waste, former ATV and DVWK), BWK (Association of Water Resources, Waste Management and Land Reclamation Engineers), DVGW (German Technical and Scientific Association for Gas and Water), FGSV (Research Association for Roads and Traffic). In addition there are the DIN standards. The guidelines by these associations generally comply with the DIN (German Institute for Standardization) standards and refer to them. They are usually more elaborate, comprehensive and fully explained than the DIN standards. Surface water quality issues are also tackled by the LAWA, an expert group of the German federal states that, for example, have issued river and lake quality classifications.

There are guidelines for almost every issue dealing with urban drainage with respect to dimensioning, design and operation. All of them are available in German, but are being gradually translated into English and also other languages such as Polish, Spanish, French and even Arabic.

In principle, the application of the guidelines is not mandatory. However, in some federal states administrative regulations, laws or the client require compliance with some of them.

In the past the principle behind the guidelines was to require a uniform minimal technical standard for all facilities (e.g. COD discharges through CSOs). With this philosophy, the guidelines led to remarkable improvements in river quality. However, some guidelines were pushing a certain technology, such as the ATV-A128 [ATV-A 128 1992; ATV-A 128E 1992] for detention tanks. This is currently making the shift to other innovative BMPs (where the same associations provide excellent guidelines) more difficult.

Without abandoning the philosophy of minimal requirements, there is today also consideration of discharge based requirements (BWK M3 [BWK-M 3 2001] and M7 [WK-M 7 2007]).

F.2. Design and Guidance Manuals

DWA-A 138*: Planning, Construction and Operation of Facilities for the Percolation of Precipitation Water* [DWA-A 138 2005 (German); DWA-A 138E 2005 (English)]

This guideline provides information on the planning, construction and operation of facilities for the infiltration, treatment and attenuated drainage of stormwater. It provides a description of the systems, as well as recommendations with respect to which system is appropriate under different boundary conditions e.g. source of runoff (roof, roads with different traffic loads, etc.), soil properties and space availability. It gives recommendations for the conceptual planning and on the data required for this.

It provides equations for the design calculations (e.g. infiltration rate) as well as recommendations on the design procedure depending on the boundary conditions ranging from simple manual calculations to long term simulations. It also provides several design examples.

Information on legal issues and other relevant technical rules is provided.

The facilities described include:

- Surface percolation
- Swale (shallow decentral infiltration basin) infiltration
- Swale infiltration trench element
- Infiltration trench and pipe-infiltration trench element
- Percolation shaft
- Infiltration basin
- Swale infiltration trench system

There is already a substantial amount of experience available on the facilities described in the guidelines. However some of the facilities are still almost unknown in the UK and other countries. An example is the frequently applied swale infiltration trench system shown in Figure 19. The stormwater is drained into a vegetated swale and filtration through the vegetated soil layer provides treatment. If the permeability of the sub-soil is sufficiently high the other facilities shown in the figure are not required. If the permeability of the sub-soil is low, a trench can be added. The water that infiltrates rapidly through the swale is stored in the trench and then slowly infiltrates into the sub-soil. If further capacity is required, a throttled outflow can be introduced. The water that reaches the outflow is treated (soil filtration) and attenuated and can be drained to a receiving surface water system without causing problems or to an existing conventional drainage system. Because of the attenuation only small pipe diameters are needed.

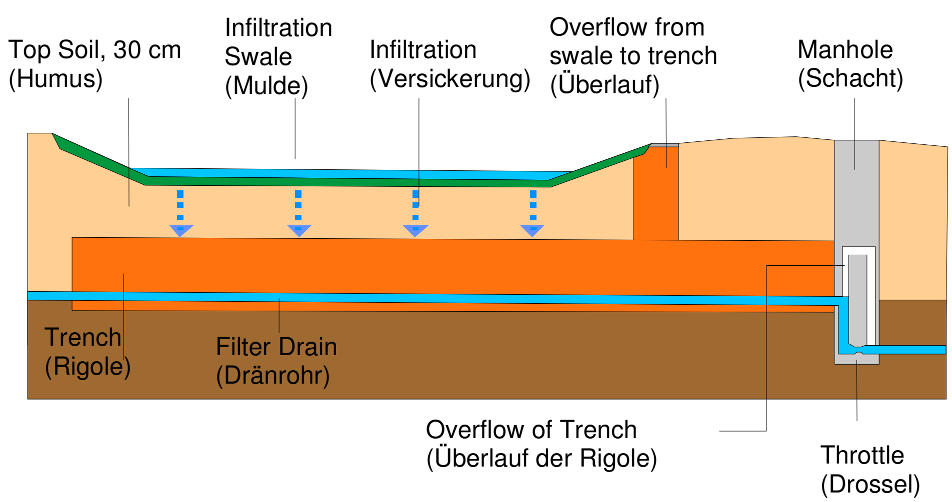


Figure 19. Swale infiltration trench system

It also must be stated that compared to the UK point of view, groundwater protection in given more attention. Direct infiltration (e.g. through an infiltration trench or shaft)

is generally not recommended/permitted except for very low polluted sources (e.g. green roofs, non-metal covered roofs, terraces in residential areas). For all other sources infiltration through a vegetated soil layer is recommended/required for filtration of the water. Direct infiltration of road runoff into an infiltration trench for example would not be allowed. The vegetated soil layer has another important advantage in that it avoids clogging problems.

DWA-A 117: *Standards for the Dimensioning, Design and Operation of Detention Tanks* [ATV-DVWK-A 117E 2001 (English); DWA-A 117 2006 (German)]

This guideline provides procedures for the volume calculation of detention basins. It contains a simple manual calculation procedure as well as a procedure using long-term simulation and information on when which procedure is applicable.

RAS-EW: *Guidelines for Road Constructions, Part: Drainage* [RAS-Ew 2005 (German)]

This Guideline contains information on the drainage of roads such as:

Choice of the drainage system
Procedure for runoff calculation,
Dimensioning of facilities, e.g. pipes, bridges, swales, ditches, soil filters, infiltration swales, settling ponds (in some aspects referring to A 117 or A 138)
Suitable vegetation
Maintenance
Example drawings

The guideline includes a CD with dimensioning tools.

DIN 1998: *Rainwater harvesting systems - Part 1: Planning, installation, operation and maintenance* [DIN 1998-1 2002b (German); DIN 1998-1 2002a (English); DIN 1998-1 2002c (French)]

This DIN standard covers the following aspects:

Requirements to source
Treatment
Storage Tanks
Pumps
Filling with drinking water in dry period
Control
Pipes and Labelling, two separate networks mandatory, no connection between drinking water pipes and rainwater pipes
Example technical drawings
Dimensioning of storage tank volume
Operation
Maintenance

BWK-M 3: *Requirements on stormwater discharges and combined sewer overflows taking into account the local situation.* [BWK-M 3 2001 (German); BWK-M 7 2007 (German)]

Stormwater and combined sewer overflow emissions are judged based on criteria such as hydraulic stress, O2, NH3 and TSS concentrations in the river.

The Guideline provides a simple procedure for the (static) calculation of the hydraulic stress and the (extreme) concentrations in the river and their judgement according to the guideline. An EXCEL-tool for the procedure is provided, as well as guidance, when the simple procedure is applicable. If the simple procedure is not applicable, a detailed procedure, which is documented in BWK-M 7, has to be applied.

A slightly modified version of the BWK-M 3 became mandatory for the permission of CSOs and stormwater discharges in the German federal state of Hessen.

BWK-M 7: *Detailed procedure for the immission based judgement of stormwater discharges and combined sewer overflow according to BWM-M 3*

The described detailed procedure contains river-type specific matrixes of 3x3-limit values for the criteria dissolved oxygen, NH3 and TSS. The limit values depend on the duration of an event and the frequency with which it occurs. For example for a short and infrequent event higher concentrations are allowed then for a long and frequent one.

(The rainfall runoff model STORM presented in the appendix contains a simple river water quality model and allows dynamic calculations of the concentrations of O2, NH3 and TSS using the equations of BWK-M 3)

ATV-A 128: *Standards for the Dimensioning and Design of Stormwater Overflows in Combined Wastewater Sewers* [ATV-A 128 1992 (German); ATV-A 128E 1992 (English)]

This standard provides guidelines for the dimensioning of combined sewer overflow tanks. Compliance with this guideline is still mandatory in some German federal states. As stated in the introduction, this guideline lead in the past to significant improvements in river quality. However it is facing critics today, because:

- The only criterion considered is the annual mean COD load into the river. Acute effects from CSOs (oxygen depletion, NH3 toxicity, hydraulic stress) that pose a major threat to the river are not considered.
- The allowed COD load is calculated using a very rough procedure, leading sometimes to inappropriate results.
- It focuses on tank solutions

In spite of the stated criticism, the guideline also contains information on detail planning and operation of CSOs and CSO-tanks.

DWA-M 153 *Recommendations for the handling of Stormwater* [DWA-M 153 2007 (German)]

A scoring system is presented to assist the decision-making regarding stormwater management measures

DWA-A 100*: Guideline for integrated urban drainage planning* [DWA-A 100 2006 (German)]

A methodology is proposed for integrated urban drainage planning which forms a framework for all other guidelines

DWA-M 178: *Recommendations for planning, construction and operation of retention soil filters for enhanced stormwater treatment in combined and separate systems* [DWA-M 178 2005 (German)]

Stormwater or CSO-water flows vertically through the soil filter. As the filtration rate is usually lower than the hydraulic load of the facility, the water level increases on top of the filter (retention). The filter is vegetated with reeds and is usually dry. Vegetation and drying phases prevent clogging. Nutrients are removed biologically and through adsorption.

ATV-A 166: *Facilities for central stormwater treatment and retention*
ATV-DVWK-M 176: *Information and examples for detail planning and technical equipment of facilities for central stormwater treatment and retention*
ATV-A 156: *Rules for sewer operation, stormwater tanks and combined sewer overflows* [ATV-A 166 1999 (German); ATV-DVWK-A 156 2000 (German); ATV-DVWK-M 176 2001 (German)]

Information on construction, detailed planning of equipment and operation of central storage and stormwater treatment facilities.

DWA-A 110: *Hydraulic Dimensioning and Performance Verification of Sewers and Drains* [ATV-DVWK-A 110E 2001 (English); DWA-A 110 2006 (German)]

ATV-A 111: *Hydraulic Dimensioning and the Performance Verification of Stormwater Overflow Installations in Sewers and Drains* [ATV-A 111 1994 (German); ATV-A 111E 1994 (English)]
ATV-A 118: *Hydraulic Dimensioning and Verification of Drainage Systems*. [ATV-A 118E 1999 (English); DWA-A 118 2006 (German)]

ATV-DVWK-M 165: *Requirements on rainfall runoff calculations in urban drainage* [ATV-DVWK-M 165 2004 (German)]

DVGW-W 101: *Guidelines for drinking water protection areas, part 1: protection areas for groundwater*
DVGW-W 102: *Guidelines for drinking water protection areas, part 2: protection areas for drinking water dams.* [DVGW-W 101 1995 (Spanish); DVGW-W 101 2006 (German); DVGW-W 102 2006 (German)]

2008 . H. Sieker, B. Helm, P. Krebs, P Schlottmann and J. Trankner. Flexibility- a planning criterion for stormwater management. In: CD of Proceedings of 11th International Conference on Urban Drainage, Scotland, UK, 31 August – 5 September 2008.

This research paper describes a methodology which enabled the flexibility of different BMP options to be identified and described. The COFAS (comparing the flexibility of alternative solutions) method is based on classical utility value analysis (UVA) using a hierarchy of indicators for environmental, economic and social aspects. The COFAS method applies statistical methods to the level of variation associated with the utility values under different conditions.

F.3. Conclusions

In Germany, there is much available technical experience as well as design and guidance manuals on stormwater management. This refers both to the conventional piped systems as well as to innovative SUDS/BMPs such as for example decentralised infiltration. In the past the principle behind the guidelines was to require a uniform minimal technical standard for all facilities (e.g. COD emissions through CSOs). With this philosophy, the guidelines led to remarkable improvements in river quality. However these uniform requirements do not suit the river in all situations. Therefore today, without abandoning the philosophy of minimal requirements, also site specific immission based requirements are considered (BWK M3 and M7).

The SUDS/BMP measures most commonly implemented in Germany differ from the UK and other countries. They represent valuable additional tools for planners in these countries. Especially, the content of DWA-A 138 is recommended to all non-German readers of this chapter.

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APPENDIX H WATER QUALITY MODELLING

H.1. Introduction

There has been considerable application of statistical techniques to the presentation and analysis of monitored water quality data of diffuse urban surface water runoff and in data interpretation. The use of probability distribution functions, standardised parallel plots and regression functions in the US EPA/ASCE national BMP database illustrates such applications. However, the mathematical modelling of the water quality processes and associated characteristics of surface water drainage systems and BMP source control devices has been largely confined to the analysis of pollution variability within selected systems such as ponds and wetlands. In addition there have been some modelling applications of the diffusion of pollution plumes from infiltration devices.

Over the last five years however, there has been a growing interest in the development of generic modelling techniques for the analysis and prediction of BMP/SUDS/WSUD water quality. This is partly related to the criticisms arising from lack of long term performance data, potential impacts upon receiving waterbody quality targets as well as a need to extend knowledge of dominant interactive processes such as water-sediment reactions. In response to such demands, a number of proprietary models are appearing, most of which are still under development or remain largely untested to any great extent. Three major dynamic modelling software packages which are becoming widely known within the urban stormwater quality field are briefly reviewed below. Most of the established modelling techniques, "force-fit" due to in-built inflexibilities in the pre-calibrated runoff algorithm. Making a model "agree" with measured field data encourages user changes to input data which often conflict with flow survey information. It could be argued that the verification process may not be so critical these days given it is much easier to obtain catchment data and input areas can be supplied in digital form for direct use in models. None of the modelling approaches consider the interactive processes of flocculation or biochemical transformation preferring to use fixed potency factors and/or partitioning coefficients.

One major issue relates to the high number of parameters used in most water quality models for which only limited data is available. Whilst the modelling procedures do provide default values for various parameters, these must be used with extreme caution as differing models derive vastly different outcomes for the same parameter input values (Bouteligier et al., 2004). In addition, water quality modelling is highly dependent on the initial conditions prior to the storm as well as to the model input data. Therefore, long tome series data is required to obtain acceptable results, which is normally in conflict with the event-based framework on which these modelling approaches are constructed. Whilst design storms are a very useful basis for hydraulic design, their application for water quality modelling purposes is much more fragile.

H.2. Software Packages

H.2.1. InfoWorks SD

This is a recent product of HR Wallingford in the UK (www. wallingfordsoftware.com) and provides a fully dynamic, network hydraulic modelling solution designed specifically for the analysis and prediction of surface water flooding. There are options for event-based or real time continuous simulation. Modelling of SUDS structures (soakaways, infiltration trenches, swales, permeable paving) and integrated flood mapping to visualise flood depths and velocities are incorporated into the software. The SD modules include SUDS/BMP design, construction and maintenance practices and primary criteria for stormwater control facilities.

The 1D profiling version makes assumptions about flow directions within conveyance routes and is also limited where detailed information on overland flow velocities are required. This presents a particular problem where flow paths are persistently obstructed by urban buildings, street "furniture" and other protruding infrastructure. A 2D version (v8.5; 2007) is available which is better suited to modelling complex geometries such as street intersections and buildings. The modelling analysis is also complicated by the exacerbating presence in urban areas of sewer networks and foul surcharging mixing with the surface derived stormwater flows. Under such conditions, flows can both enter and exit the surface drainage system during a flood event and modelling such complex scenarios is beyond the capability of the 1D approach.

The stormwater component has only recently been added to the InfoWorks CS software package and although calibration and beta testing has been conducted, the modelling capability and accuracy remains to be fully and comprehensively tested. However, there are known problems with the InfoWorks model principally related to the derivation of runoff volumes which in turn will generate uncertainties with pollutant loadings. The first issue relates to the assignment and contribution of urban surface types where both uniform and composite surfaces drain to more than one drainage system such as combined, separate, soakaways, SUDS etc. The concept of "total area" adopted by the model creates difficulties for catchments drained by more than one system. Sub-catchment definition within the modelling does not represent all contributions adequately and frequently requires the addition of large "unaccounted for" impermeable areas during the verification process. There is an assumption that non-road and roof surfaces will be pervious and thus non-contributing, which is unrealistic for heavily trafficked urban areas where parks, open spaces etc., can have compacted surfaces which contribute to effective runoff especially during extreme events. There is also undoubtedly a need to take a more realistic and proper account of formal road inlets and gullies to the below-ground drainage system. In addition, there is a need for the model to include separately, areas which could deliver runoff during extreme (or longer) storm events. At present the modelling routine does not allow for runoff contributions from remote and unconnected surfaces during extreme events.

A further issue arises from the incapability of the model to take account of changing conditions related to depression storage and initial losses, both of which can have substantial impact on the modelling outcomes. Traditionally default values have been

used to represent initial losses, but modelling predictions are extremely sensitive to evaporation and depression storage and antecedent wetness conditions, all of which can vary considerably across different types of urban surfaces. For example, the meso-topography variation and surface roughness encountered on a typical paved surface can account for up to 1.8 – 2.2 mm ponding which can substantially affect the surface depression storage volumes. Thus differing runoff surface types can have very different rates of runoff, depression storage and percentage contribution.

The PR equation is difficult to apply in continuous simulation and particularly where permeable, impermeable and semi-permeable surfaces need to be considered within the modelling routine. InfoWorks CS proposes a new API index (NAPI) to try to counter this problem but may need a "capping" rate to prevent continued filling of the depression storage capacity as otherwise it will lead to massive over-estimation of flows. The Wallingford model also becomes inappropriate for areas having low PIMP values.

H.2.2. Mike Urban CS

This is a GIS- based model data management software package developed by the Danish Hydraulic Institute (www dhigroup.com) with the stormwater module powered by the fully dynamic SWMM5 software. A pollution and sediment transport module is incorporated into the main package and simulation provides analysis of return periods, sewer loadings, sediment deposition rates and locations and peak outflow concentrations. Supporting "webinars" and client training are offered with on-line presentations to provide information on the modelling software architecture and capabilities.

H.2.3. MUSIC

The Model of Urban Storrmwater Improvement Conceptualisation (MUSIC) is a widely used software package developed in Australia by CRC for Catchment Hydrology (now eWater CRC). Version 3.0.1 was issued in 2005 with Patch 3.0.2 added in August 2007 and is available via the eWater Ltd product website (www.toolkit.net.au). It is essentially a decision-support system to evaluate the conceptual design of stormwater management drainage systems in terms of water quality outflows and receiving water objectives. It is applicable at a range of temporal and spatial scales and for catchments varying between 0.1 km^2 to 100 km^2 with modelling time steps ranging from 6 minutes to 24 hours. Outputs include time series cumulative frequency graphs and a life cycle costing module is also available in the software. The modelling capability extends to water re-use analysis of treatment facilities having a permanent pool allowing simulation of stored stormwater for household uses such as garden irrigation or toilet flushing.

MUSIC does not have capabilities for detailed sizing of stormwater facilities and omits any hydraulic or ecosystem response analysis. A number of assumptions are built into the algorithms including in particular those relating to the rationale for selecting default parameters. The modelling routine depends on default mean and standard deviation values to derive stochastic pollutant concentration distributions, and thus there is a need for independent calibration of the results based on local flow and pollution concentration data. This becomes a particular issue when considering

extreme storm events. The 3.0.2 Patch to v.3.0.1 allows the application of time steps less than 6 minutes for flow routing to control devices having small storage volumes and subject to rapidly varying flows.

One issue is that the use of average statistics means that inflow concentrations will always be lower than outflows due to the background concentration C* value, despite new default C* and k (treatment or decay rate) values being added to v.3 in May 2005. There is also a need for users to remove all zero flow time periods from the analysis and only include effective storm flows to achieve a more appropriate measurement of concentration reductions across the WSUD facility. The observations of settling rates in WSUD/BMP facilities are typically much less than theoretically predicted by the model. Thus, smaller devices where the k factor dominates, predict less treatment efficiency. Background C* concentration values are also frequently lower than theoretically predicted, thus apportioning better treatment efficiency to larger devices where C* is the dominant factor. These differences appear to be applicable to all structural WSUD/BMP devices and the revised May 2005 defaults to v.3 were applied on this basis. It should be noted that filtration systems do not use k or C* values, so modelling depends on multiple regression of detention time against filter particle size. However, this relationship can be highly variable both between devices and between storm events. In addition, the modelling analysis does not consider the effects of evaporation/transpiration losses from pond/wetland systems which can be significant over protracted dry weather conditions. A further problem in the analysis is that no initial or exfiltration losses are considered.

The use of a first-order kinetic decay (or treatment) k rate implies that the rate of change of pollutant concentration with time is proportional to the concentration and plug flow implies that stomwater entering the pond/wetland "reactor", flows as a coherent body along the length of the device. The change in concentration during the retention time is therefore dependent solely on processes occurring within the plug flow. Therefore k is a lumped parameter representing a deposition rate in the case of solids and bacteria, a biodegradation rate for organics (BOD) and a reaction rate in the case of nutrients, metals and hydrocarbons. Thus the value of k really depends on the relevant operating "treatment" process and is normally expressed as a synthesised index value combining the different removal processes. Any factor such as hydraulic retention time which influences these processes can indirectly affect the final k value. Rainfall will cause dilution and shorten retention times and such "augmentation" can lead to errors by as much as a factor of four in the determination of rate constants for a first-order reaction. The k-C* two-parameter model also does not account for adaptation trends in a wetland system as it matures or the effects of pH and dissolved oxygen as well as other factors which are known to affect the fate of pollutants in treatment systems.

H.3. Other Modelling Approaches

H.3.1 SFM (STORM & SEWSYS)

SFM (Sources and Flux Model) is a modelling tool to simulate different scenarios of stormwater source control practices developed under the EU 5th Framework programme DayWater project. This modelling package can be accessed via the DayWater website (www.daywater.org) by clicking on the Access to ADSS Prototype

portal and then entering “guest” as user name and password to access the Hydropolis Modelling Tools window. It can also be downloaded from www.sieker.de. The SFM application allows employment of either standard pollutant concentration distributions or an in-built, integrated pollutant yield generated from the SEWSYS model. This calculates pollutant loads or site mean concentrations, with the load displayed as a function of source category e.g. roads, roofs, wet/dry deposition, building material etc. An essentially Scandinavian database is used as the basis for deriving emission factors.

Using the quality parameters derived from SEWSYS, the STORM model then generates water balances, pollutant fluxes and BMP performance. STORM uses design storm criteria to compute necessary storage volumes with rainfall-runoff transformation conceptualised using either linear cascade storages or time-surface functions. A time step of between 5 to 15 minutes is used in the analysis, and like MUSIC this raises problems for small storage devices subject to high and/or rapidly varying flows. Long term simulation requires a measured rainfall time series as input data.

Non-road/roof runoff is considered to be essentially pervious in nature and STORM can calculate the runoff from these areas in two different ways, as shown below:

a) Runoff coefficient: the user can define the maximum runoff coefficient for the pervious area. After the initial losses, the runoff increases from an initial runoff coefficient to the maximum (depression storage) one. Initial losses and depression storage are filled during rainfall and empty through evaporation. If two storm-events occur shortly after each other, these storages are still full and the maximal runoff will occur almost immediately.

b) Detailed soil water balance: the soil is modelled in a detailed way with different layers. Only if the rainfall is higher than the infiltration capacity, a surface runoff is generated. Soil parameters like water content etc. change with the time, e.g. the soil dries through percolation into deeper layers and through evaporation after the rainfall event so that the initial conditions for each storm-event vary depending on the history. With the detailed soil water balance, it is possible to connect areas to the model that normally do not generate runoff, except under extreme conditions.

H.3.2. UK Highway Agency Model

The official UK HMSO 2006 Design Manual for Roads and Bridges (DMRB) Volume 11, Section , Part 10 provides an assessment methodology for the prediction of impact risks from highway discharges to receiving water ecology. This methodology was based on the Wallingford runoff procedure as developed in the 1994 CIRIA Report 142, Control of Pollution from Highway Discharges. Annex III of the DMRB volume provides worked examples of the assessment method in respect of soluble pollutants which are regarded as the most damaging in terms of potential risk.

Work is now in progress to develop this modelling approach further to predict pollutant concentrations in highway runoff for performance assessment against ecological-based receiving water standards, particularly to control the impact of

soluble pollutants (Crabtree et al., 2007). The modelling input is based on storm flow and EMC data collected from 24 highway locations across England, within four defined climatic regions based on average annual rainfall and annual average daily traffic (AADT) flow bands. Runoff specific thresholds (RSTs) define potential ecological impact of the EMCs on receiving water status expressed as discharge emission standards. The model development is focussing on a statistical approach using multiple regression analysis to assess the relative importance of differing driving factors e.g AADT, ADWP, maximum hourly rainfall intensity etc. The approach will develop a stochastic solution based on long term rainfall time series to predict EMCs, rather than deterministic modelling of build up-washoff as contained within the SFM modelling routine.