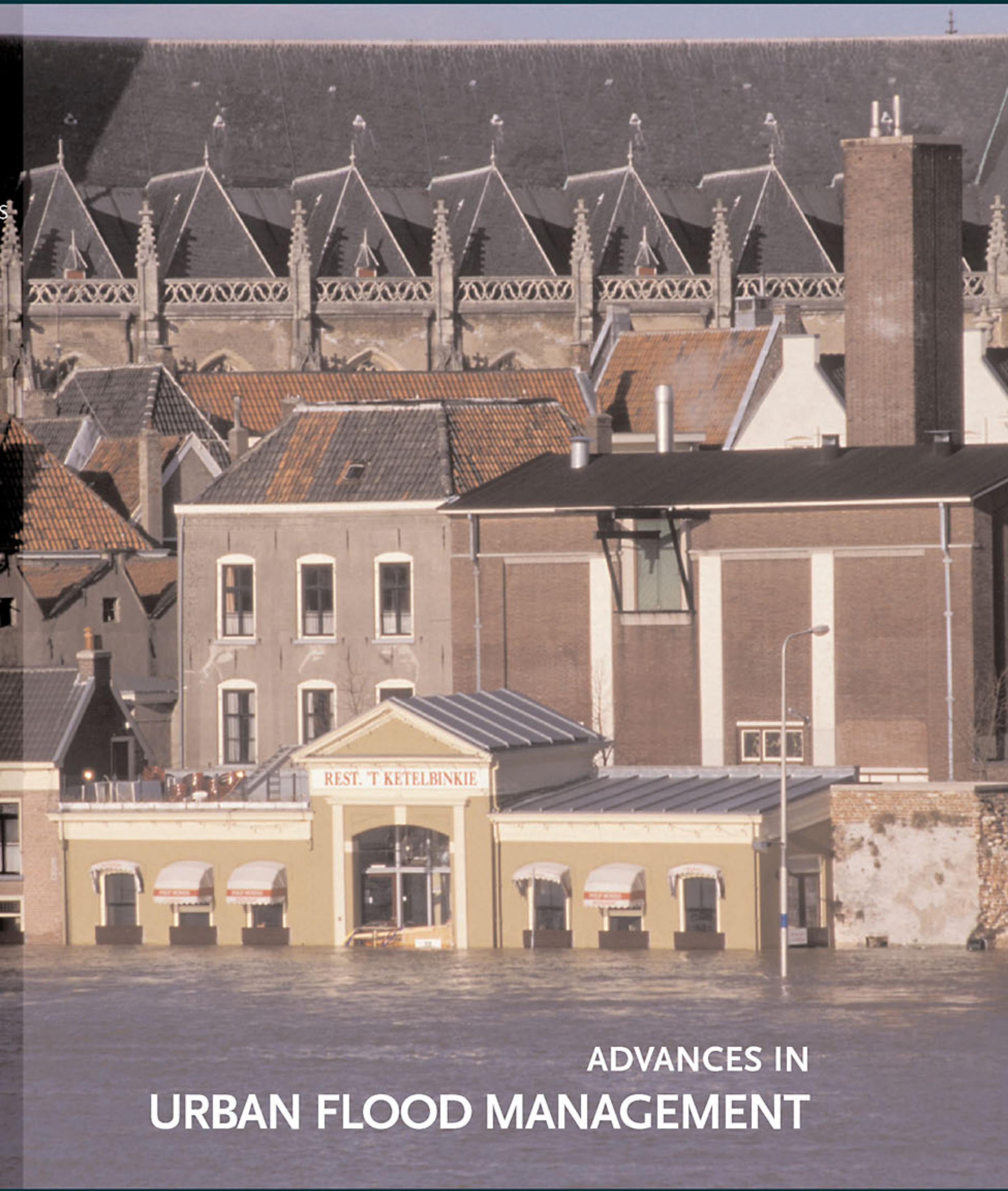


ADVANCES IN URBAN FLOOD MANAGEMENT

R. ASHLEY, S. GARVIN, E. PASCHE, A. VASSILOPOULOS AND C. ZEVENBERGEN
EDITORS

Advances in Urban Flood Management

BALKEMA – Proceedings and Monographs
in Engineering, Water and Earth Sciences

Advances in Urban Flood Management

Editors
R. Ashley
Department of Civil and Structural Engineering, Pennine Water Group, Sheffield, UK

S. Garvin
Building Research Establishment, East Kilbride, UK

E. Pasche
River and Coastel Engineering, Hamburg-Harburg University of Technology, Hamburg, Germany

A. Vassilopoulos
Geocultural Park of Eastern Aegean, Athens, Greece

C. Zevenbergen
UNESCO-IHE, Sustainable Urban Infrastructure, Delft, The Netherlands &
Dura Vermeer Group NV, Hoofddorp, The Netherlands

Taylor & Francis
Taylor & Francis Group
LONDON / LEIDEN / NEW YORK / PHILADELPHIA / SINGAPORE

Cover photo: Courtesy of Rob Lengkeek

COST is supported by the EU RTD Framework programme

ESF provides the COST Office through an EC contract

Taylor & Francis is an imprint of the Taylor & Francis Group, an informa business

This edition published in the Taylor & Francis e-Library, 2007.

"To purchase your own copy of this or any of Taylor & Francis or Routledge's
collection of thousands of eBooks please go to www.eBookstore.tandf.co.uk."

Published by: Taylor & Francis/Balkema
P.O. Box 447, 2300 AK Leiden, The Netherlands
e-mail: Pub.NL@tandf.co.uk
www.balkema.nl, www.taylorandfrancis.co.uk, www.crcpress.com

ISBN 0–203–94598–0 Master e-book ISBN

ISBN: 978-0-415-43662-5 (Hbk)
ISBN: 978-0-203-94598-8 (Ebook)

Table of Contents

Editors

Professor Richard Ashley
Departement of Civil and
Structural Engineering
Pennine Water Group
Mappin Street
S1 3 JD Sheffield
United Kingdom
Tel: +44 114 222 5766
Fax: +44 114 222 5700
Email: r.ashley@sheffield.ac.uk

Dr. Stephen Garvin
Building Research Establishment
Scotland
Kelvin Road
East Kilbride
G75 ORZ Glasgow
United Kingdom
Tel: +44 1355 576242
Fax: +44 1355 576210
Email: garvins@bre.co.uk

Professor Erik Pasche
River and Coastel Engineering
Hamburg University of Technology
Denickestraße 22
21073 Hamburg
Germany
Tel: +49 40 42878 3463
Fax: +49 40 42878 2802
Email: pasche@tu-harburg.de

Dr. Andreas Vassilopoulos
Geocultural Park of Eastern Aegean
Fliass 13 & V. Ipeirou,
151 25, Athens
Greece
Tel: +30 210 8056448
Fax: +30 210 8056091
Email: vassilopoulos@gcparks.com

Dr. Chris Zevenbergen
UNESCO-IHE
Sustainable Urban Infrastructure
PO Box 3015
2601 DA Delft
The Netherlands
Tel: +31 15 2151854
Fax: +31 15 2122921

and

Dura Vermeer Group NV,
PO Box 3098
2130 KB Hoofddorp
The Netherlands
Tel: +31 23 569 2380
Fax: +31 23 569 2332
Email: c.zevenbergen@duravermeerdiensten.nl

Foreword

Global climate change is increasing the variability of extreme flood events and cyclones. Current measures to mitigate flood impacts specifically for urban environments no longer provide optimal solutions for previously planned flood risk intervals. Being prepared for uncertain changes and extreme flood events requires a paradigm shift in current strategies to avoid and manage flood disasters. A major rethink of current planning and flood management policies and practices on different spatial and temporal scales is required to reverse the trend of increasing impacts of urban floods. In November 2004 an International Expert Meeting on Urban Flood Management was held to discuss these challenges. The outcome of this meeting resulted in a book on Urban Flood Management which was edited by A. Szöllösi-Nagy and C. Zevenbergen and published by A.A. Balkema Publishers in 2005. This International meeting also accompanied the launch of COST[1] action C22 on Urban Flood Management in March 2005. This European Concerted Action C22 brings together a large number of European research groups. Its main objective is to increase knowledge required for preventing and mitigating potential flood impacts in urban areas by exchanging experiences, developing integrated approaches, and by promoting the diffusion of best practices in Urban Flood Management. In the action, four working groups are active in the following areas:

Flood modelling and probability assessment: Computational methods to determine flood hydrographs of urban watercourses (hydrological models); flood propagation in storm water pipe and open channel networks (hydraulic models); and the assessment of the probability of extreme floods (statistical methods). Special reference is given to data management by making use of web-services, the modelling of flash floods; SUDS (sustainable drainage systems); the “daylighting” of urban streams by removing culverts and restoring open space for flood storage; and the assessment of climate change effects.

Flood risk assessment and mapping: Methods used to determine the impact of floods in urban environments. Special reference is given to the assessment and mapping of risk, and to methods to assess the impact of flood mitigation through structural and non-structural measures.

---

[1] Founded in 1971, COST is an intergovernmental framework for European Co-operation in the field of Scientific and Technical Research, allowing the co-ordination of nationally funded research on a European level. COST Actions cover basic and pre-competitive research as well as activities of public utility.

Flood resilience: Methods used to reduce flood damage for the built environment. Special reference is given to the techniques of flood resilient repair and dry and wet-proofing; the capacity building of residents and the prerequisites for efficient flood resilience.

Integrative concepts of urban flood management: Strategies to integrate technological and non-technological aspects into an holistic approach to flood risk management with special reference to non-structural solutions and the relevance of policy, insurance, risk awareness, communication, consistency management and the socio-cultural environments.

This book comprises initial results from C22 and aims to address the aforementioned issues by highlighting and analyzing the state of the art and best practices in this emerging field of urban flood management. Our thanks go to the contributing authors, whose efforts have made this book a useful reference in setting the direction for the future in urban flood management.

Chris Zevenbergen
Chair COST Action C22

Erik Pasche
Vice-chair COST Action C22

January 2007

1

Challenges in Urban Flood Management

Chris Zevenbergen[1,2] & Berry Gersonius[1]
[1] *UNESCO-IHE, SUIS, Delft, The Netherlands*
[2] *DuraVermeer Business Development BV, Hoofddorp, The Netherlands*

1.1 INTRODUCTION

Floods are the most common type of natural disaster in Europe (EEA, 2005). During the past five years floods have affected an estimated land area of one million square kilometres. According to CRED[1] in the period between 1900 and 2006 about 415 major damaging floods occurred in Europe. Over this period the number of flood events per year increased, while the number of deaths exhibited a decrease, although the economic losses increased substantially. The decreasing loss of life is likely to be due to improved warning and rescue systems. The dramatic and consecutive flood disasters in 2002 which occurred in countries such as Austria, the Czech Republic, Germany, Hungary and the Russian Federation have triggered several initiatives to improve preparedness and response to extreme weather events and enforced the need for a concerted European action (Barredo et al., 2005). The countries most affected by floods between 1998 and 2002 are in central and eastern Europe. Severe floods in 2005 further reinforced the need for concerted action.

In Europe, urban land expanded by 20% during the period 1980 to 2000, while the population increased by 6% (EEA, 2005). The building stock is mainly aging and there is much heritage, although overall, new building means the total stock is slowly increasing. Within 30 years, some one third of the European building stock will be renewed (ECTP, 2005). European cities are faced with a continuing demand for high quality, low density housing areas in the proximity of metropolitan areas. For example (re)development plans have been made for 12,000 new waterfront habitations (dwellings) in Hamburg Hafencity, Germany by 2010; there are allocations for 150,000 homes in the Thames Gateway, England by 2016, and 550,000 new houses are planned in the Randstad (The Netherlands) by 2010. Almost 80% of the original floodplains along the Elbe and Rhine rivers have been lost due to urban development and agricultural use. Both urban growth and the restructuring and transformation of existing urban areas result in an intensification of land use

[1] Centre for Research on the Epidemiology of Disasters, UCL, Belgium

and subsequently an increase of the level of investments in flood prone areas. Moreover, Europe has thousands of levees, dams and canal systems, some of which stem from Victorian times, in which the structural integrity is questionable and needs to be better understood.

For many centuries in most European countries, flood management policies have favoured engineering structural solutions over other complementary non-structural measures. The aim of these flood defence measures was to modify the flood and make it easier to cope with by eliminating the highest probability floods. Such measures gave a false sense of safety: the reduction in perceived vulnerability to flood loss was largely offset by the rapid growth of urban areas in flood-prone areas combined with an even larger increase in investment levels. In addition, the people in the cities were (and often still are) unaware of the risks associated with floods and accordingly the responses by individuals for reducing losses are limited. As a consequence of these policies, flood exposure and potential social and economic damage has increased substantially. In addition, reducing losses from high frequency floods has also caused a greater risk of disastrous consequences when more extreme events have occurred. The threat posed by climate change together with continuing urbanisation of flood plains has triggered many European countries to reconsider their flood management policies as part of their overall responses (Europa, 2006).

In response to the 2002 floods, the European Commission developed in 2005 a proposal for a Directive on flood risk management. On 18 January 2006, after extensive consultations with stakeholders and the public the Commission adopted its proposal for a Directive of the European Parliament and of the Council on the assessment and management of floods. Its aim is to reduce and manage the risks that floods pose to human health, the environment, infrastructure and property. Under the Directive member states first need to carry out a preliminary assessment to identify the river basins and associated coastal areas at risk of flooding. For such zones they then require drawing up flood risk maps and then flood risk management plans focused on prevention, protection and preparedness. Since most of Europe's river basins are shared by more than one country, concerted action at a European level is expected to enhance effective management of flood risks. A binding legal instrument will ensure flood risks are properly assessed, coordinated protection measures taken and the public properly informed. Some European countries such as The Netherlands and Germany are already taking initiatives in further developing their flood risk maps and the UK has them already implemented.

1.2 TOWARDS A BETTER UNDERSTANDING OF URBAN FLOOD GENERATION AND IMPACTS

With this book, COST action C22 intends to support this new legal framework of flood risk management by presenting a review of best practice of flood risk management for urban environments. Due to the special nature of the flood regime, watercourses in urban catchments need special consideration and their own particular strategies for flood risk management. Currently, each city or district embarks on its own mitigation strategy – with some being more successful than others. For this reason there is a strong need to share current approaches to flood risk management for these urban catchments at a European level and to identify which are the good solutions in practice, and also highlight improved ways of managing and coping with urban water courses.

1.3 FLOOD MODELLING AND PROBABILITY ASSESSMENT

This book has selected this issue as a key topic. It begins with a characterisation of urban streams and urban flooding (paper by Douglas *et al.*). The impact of the contribution of runoff to flood risk in urban areas is described and how imprudent management practices and climate change are exacerbating urban flooding.

As flood risk is the product of probability of occurrence multiplied by its impact, the procedure for flood risk assessments is composed of three tasks: the determination of the inundation areas, the exploration of the vulnerability, and the assessment of probable damage. The determination of inundation areas (flood analysis) must include a hydrological and a hydraulic analysis. The former gives the design hydrographs and flood probability of occurrence. The latter determines the flooded areas for these design hydrographs. The paper by Pasche gives a state-of-the-art in hydrological and hydraulic modelling for urban environments. It concludes that for hydrological modelling, deterministic rainfall-runoff models, based on semi-distributive lumped approaches are appropriate when combined with hydraulic modelling that is 1- and 2-dimensional hydrodynamic water surface models. Together these may be used for the determination of the flood plains and the flood-prone areas requested by the EC Water Directive. It shows that within the hydraulic models the traditional roughness approach of Manning and a constant eddy assumption in the presence of vegetation, could lead to considerable errors in predictive mode, despite a good calibration using historical data. This deficiency can be avoided by using the Darcy-Weisbach-Equation and by applying special routines for modelling the effect of woodlands.

The paper by Oberle and Merkel addresses the modelling techniques of decision support systems. It concludes that for operational applications, in which a fast response and reliable numerical results are most relevant, 1-dimensional hydraulic models are still state-of-the-art. But they also show, that by integrating the models in a GIS and simplifying the theoretical approaches, 2-dimensional modelling techniques combined with 1-dimensional models can achieve a level of robustness and performance that allow a real-time simulation to be provided in time scales which are appropriate for disaster management, even for large rivers liker the Elbe.

The relevance of good knowledge of the spatial and temporal distribution of precipitation in storm events is shown by Kobold. She demonstrates the sensitivity of hydrological models for these input data and that the type of rainfall model has only minor relevance to the quality of the results as long as sufficient calibration events are available. Statistical models are needed to evaluate the probability of flooding. The paper by Frances gives an overview of the state-of-the-art in flood frequency analysis. It concludes that non-systematic information characterising the observed flood events is preferable to the present practice of annual maximum floods as input data. Hence, historical and paleo-flood information can be used for flood frequency analysis, which is of great use in the assessment of flood probability. Only few statistical concepts consider the non-stationarity of the long term flooding process, which is necessary for a better estimation of future flood hazards in a changing climate. Frequency analysis of precipitation data is highlighted by Koutsoyiannis. He demonstrates that the Extreme Value Type 2 distribution should replace the Gumbel distribution for probabilistic modelling of extreme rainfall.

The two papers by Koutsoyiannis and Jovanovic deal with sustainable measures to reduce the probability of flooding. The paper by Tourbier and White shows that sustainable urban drainage systems (SUDS) reduce the flood volume and peak flow only for minor storms. However, by expanding SUDS to include exceedence conveyance systems, which route the excess flood flow, the efficiency of SUDS can be extended to help cope with extreme floods. In his paper Jovanovic gives examples of technical solutions, which ensure the preservation of the riparian wildlife and the ambient quality of the stream corridor in addition to efficient flood attenuation.

Despite the high standard of the available mathematical methods to model and assess flood probability, some major deficiencies and gaps of knowledge have still been detected which should be addressed in the near future. Further experimental studies are required on hill slope hydrology in order to gain a better understanding of the contribution of subsurface flow to flood flows. This knowledge will support on-going research activities dealing with the coupling of hydrological (rainfall-runoff models) and hydraulic models (riverine flow models and groundwater models) by providing the necessary empirical input to model the mass and momentum transfer between the different flow regimes. The runoff models should be directly coupled with meteorological models to study, at a global scale, the effect of changes in evapotranspiration, which is a result of climate change caused by warmer periods with less rain. Floods in urban areas result from interaction between the storm water pipe network, the overland flow and flow in small watercourses (the minor and the major systems respectively). These can result in flash floods with extreme spatial and temporal variability. The modelling capabilities need to be extended by coupling pipe flow models with 2-dimensional (at least) overland flow models and developing robust numerical schemes for discontinuous and transient flow. In these flow domains erosion has a strong impact on flood damage.

Thus modelling techniques should be able to simulate any sheet erosion on green areas, scouring at buildings and the transportation and deposition of sediment in the drainage system and in the urban environment. They can then be used to help to develop efficient erosion-sediment-control plans.

Inputs to and the results from all modelling tools used in flood risk assessment and management are still of great uncertainty. Probabilistic methods should be included in deterministic models to estimate the ranges of uncertainty. Paleo-hydrologic and paleo-climatic data should be included in the frequency analysis of extreme events. However, the methods used to derive the flood characteristics of these historic events need further improvement.

Due to the deficiencies of today's meteorological models in forecasting small-scale storm events, radar data should be further analyzed to explore the possible predictability of precipitation. However, with climate changing the traditional view of what may be predictable held in the past will have to be revised.

Sustainable drainage systems need to be extended in their capacity to attenuate extreme floods. The possibilities to convey excess water through open space (e.g. parks, green areas, roads) should be further explored and methods to better evaluate the attenuation flood waves in such areas should be developed.

Decision support tools need a standardisation of the pre- and post-processing information stages. This would create the possibility of switching easily between different mathematical models allowing a direct comparison of the model qualities and an assessment of the uncertainty of the numerical results. The complexity of the flow in urban environments needs high spatial and temporal resolutions of models. These requirements cannot be fulfilled with current operational models. Performance improvements making use of parallel computing and grid technology can help to overcome these limitations.

A prerequisite for the reliable application of hydrological and hydraulic models is the availability of topographic, geomorphologic and hydrometeorological data of good quality and appropriate spatial and temporal resolution. The technological advancements in geo-data sampling by remote sensing (LIDAR-technology, satellite imaging) should be used to develop a geo-processing service which provides digital terrain models, numerical grids and the spatial distribution of vegetation and surface texture structured in hydraulic roughness classes for flood plains.

1.4 FLOOD RISK ASSESSMENT AND MAPPING

In order to establish a well defined theoretical and practical framework on flood resilience, it is vital to address the concept of vulnerability in flood prone areas. Although flood impact assessment methods have been around for many years (e.g. Penning-Rowsell, 1976), rapid changes in the contemporary urban environment require the continuous adaptation and development of theory, methods and applications in vulnerability assessment. Although, the concept of vulnerability is strongly related to susceptibility (e.g. the protection level provided by primary flood defence systems), quantitative assessment starts with impact estimation. Due to the increasing availability of data this holds true not only for retrospective assessment but to a large extent also for prospective cases in which potential flood impact assessment can address disruption of society's socio-economic backbones and their effects on regional, national and even trans-national networks. This applies especially to methods used to evaluate the indirect effects of flood impact, which are a relatively new research area in which econometric models are used to measure the effect local impacts have on a larger scale. While many of the models used have originated as methods of assessing impacts of policy changes (e.g. taxation), their adaptation for use within the hazard impact domain offers exciting new prospects that will put a new perspective on impact assessment, economic vulnerability and ultimately the implementation of design methods to improve resilience.

Increasing precision and the estimation of both direct and indirect flood impacts is vital for the evaluation (e.g. cost-benefit analysis) of impact reduction measures and flood risk management. The potentially large impact of extreme events caused by climate change further increases the urgency for further development of assessment models and the need for vulnerability indicators and localization of 'hotspots' of vulnerability. Furthermore, flood risk maps indicating direct and indirect damage can be used to raise awareness of both policy makers and citizens to influence preparation for flooding and adaptive responses. An essential factor in successful application is therefore, the accessibility of information for various groups of stakeholders. This puts emphasis on the development of a better presentation of the often complex results now only accessible for experts.

In addressing the theoretical framework of direct- and indirect flood loss estimation, Veerbeek describes the state-of-the-art in indirect flood loss estimation models. The paper covers Unit-Loss models, Input-Output Analysis models and the increasingly popular Computable General Equilibrium models within the flood impact domain. Computable General Equilibrium models in particular, provide a rich framework in which dependencies, individual agent behaviour as well as various multiplier effects can be modelled to closely resemble the behavioural response of economic systems as a result of local disruptions. Due to the relative novelty and complexity, the use of these models within actual case studies is so far limited. Veerbeek adds that further modifications by implementing GIS within the statistical framework of these models might further increase their application value and predictive qualities.

The paper by Kron deals with requirements for flood and flood risk mapping in the context of the shift from classical flood protection to flood risk management. Flood risk maps can support stakeholders in prioritising their investments and increase the awareness level of both authorities and citizens, possibly resulting in a more effective response. The increasing level of detail in flood risk maps results in better flood impact and risk assessments, and paves the way for a flood resilient planning approach. Models include assessment for direct and indirect damage for the whole range of flood events from the occurrence of first damage to catastrophic events with a low recurrence probability (10^{-3} or lower). Kron also acknowledges that with the coupling of hydraulic (hazard) simulation models and Flood Damage Estimation tools, risk assessment can be derived with a high level of detail. However, the paper concludes by questioning the effectiveness of detailed risk assessment, given the inherent uncertainties in integrated flood risk management.

1.5 INCREASED COMPLEXITY AND UNCERTAINTY

The challenges caused by climate change and the potential increase in the likelihood of extreme events are now widely recognized as a major challenge and risk for flood management approaches. Although research on climate change impacts has improved knowledge about certain variables, with increasing certainty, such as for the likely rise in sea level – in many situations the projections are still rather uncertain. These impacts include peak flows, extreme rainfall, extreme waves and winds. Here, there is a need for further evidence and research to reduce local and regional variations and variations between impact models. The uncertainties resulting from these projected changes imply that conventional risk-centered approaches can no longer be maintained as a robust strategy to ensure future safety and development. This means that seeking optimal solutions, in a cost-benefit approach based on statistical analysis of flood frequency, is no longer sufficient or feasible. In New Orleans, for example, a decision has been made as to the level of flood protection (to withstand storm surges from category 4 or 5 hurricanes) based on a cost-benefit analysis taking into account climate change and other human related disruptions of the environment and second order impacts: Here, two evaluations reached opposite conclusions (Hallegatte, 2005). This illustrates the deficiencies associated with decision making based on a cost-benefit analysis, which in turn is based on assumptions underlying a probability distribution.

Furthermore, the problems facing the future of urban flood management are set within the whole sphere of human activity. They are as much the result of planning and development, stakeholder and actor behaviour, and economic systems as they are of physical factors. Many challenges have to do with the complexity of the system to be managed and the uncertainties in socio-economic developments influencing the performance of future responses. The paper by Ashley et al. describes these challenges and recognizes that 'compared with entire river basins, urban areas are more complex in terms of the physical, institutional and scale dimensions'.

1.6 BUILDING FLOOD RESILIENT URBAN AREAS

To deal with the challenges of increased uncertainty and complexity, efforts have to be made to increase the resilience of the urban environment both before and after disasters occur. Resilience reflects the amount of change a system can undergo and still retain the same control on function and structure, the degree to which a system is capable of self-organisation and the ability to build and increase the capacity for learning and adaptation (Holling, 1973 cited in Pahl-Wostl et al., 2005). Hence, the concept of resilience represents a profound shift in conventional perspectives, which attempt to control system changes that are assumed to be stable, to a more realistic viewpoint aimed at sustaining and enhancing the capacity of complex systems to adapt to uncertainty and surprise (Adger et al., 2005).

It should be noted that the delivery of resilient urban areas is not only a technical exercise. Flood resilient planning and building has two dimensions; on one hand it is a technical approach, and on the other it has to do with many other aspects, including policy, regulation, decision making and engagement. It has therefore become increasingly necessary to engage with stakeholders and communities in general so that these are better prepared for flooding, but so that they can also take an active role in decision making for where, when and how investments and measures are taken. The papers by Ashley et al. and Tippett & Griffiths recognize that resilience in a 'soft' sense can only be developed by creating the conditions within which resilience will emerge – and that resilience cannot as yet be provided (in a non-structural sense).

In addition, the challenge of building resilience will involve multiple scales, and hence the overall performance is dependent on the ability to understand and take advantage of different initiatives at different levels (Allenby, 2005). For example, designing a flood-proofed building is useful, and a number of such buildings in the urban environment will enhance the area's overall resilience against floods. But flood-proofing will not substitute for an early warning system, and neither for the flood relief effort that the city as a whole will need to mount.

This multi-dimensional nature of the concept of resilience makes it difficult to put into operation. What constitutes resilience in a complex system, such as flood risk management, is as yet poorly defined and the concept seems to remain elusive other than as an aspirational concept or principle, although ecological theories and principles of resilience have been around for a long time. How urban areas should be planned, designed or managed to contribute to resilience, however, has not yet been defined. The results of the work done so far by COST C22 support the adoption of more resilient approaches to urban flood management by presenting the current state-of-the-art in technological and non-technological measures to increase the resilience of the urban environment.

1.7 TECHNOLOGICAL MEASURES TO INCREASE FLOOD RESILIENCE

The technological dimension of resilience refers to the ability of physical systems (including components, their interconnections and interactions, and entire systems) to perform to acceptable levels when subject to floods, as well as developing and implementing, to the maximum extent possible, dual-use measures that offer societal benefits even if anticipated disasters never occur (Bruneau et al., 2003; Allenby and Fink, 2005).

The book also discusses means of improving the performance of buildings in a flood. Current guidance on flood resilient repairs involves not just the use of materials or a change of design, but the whole process of investigating the extent of flood damage to a building, the drying and decontamination process and the use of risk assessment to set the standard of repair required. It is clear from recent repair standards that many of the issues regarding building technology and flood protection products are already well known, but the scope for further research to enhance flood resilience of the urban fabric is also identified. Areas in which research and innovation are required include, for instance, performance of material related to flood conditions, the role of planning and building regulations, and knowledge of the benefits of improved flood resilience.

The lack of information on the economics of using flood proofing measures for domestic buildings has also been identified in this book. The paper by Zevenbergen et al. illustrates a benefit-cost analysis carried out to enhance knowledge about application of these technologies. The three flood proofing techniques that have been investigated are dry flood proofing, wet flood proofing and building an elevated structure. For this study, functional relations between hypothetical flood damage and inundation depth were established for different types of flood proofing of newly built dwellings and buildings under construction.

In addition to taking measures at the building level, (residual) flood risk can only be sensibly managed through adopting a holistic approach, aimed at creating robustness and redundancy. In this sense, technical measures within the urban area and the wider catchment involve building permanent and semi-permanent flood protection structures. Some of these measures are highlighted in the papers by Salagnac and Bjerkholt and Lindholm, respectively.

The paper by Brilly provides an overview of local flood defence measures in the urban environment. The local flood defence systems are closely connected to the urban drainage system and the related pollution this leads to. These systems have specific characteristics, contrary to the regional and national systems. The local authority usually carries out maintenance of local systems and often these systems are not integrated into the national system. Due to these arrangements information on the performance of these local systems is generally lacking. This paper provides a useful insight describing the policies in local flood protection in a number of countries.

Notwithstanding advances in flood protection measures, urban planning as part of a holistic approach needs to avoid residential developments in areas of particularly high residual risk. Particular caution should be exercised in allocating essential infrastructure, vulnerable uses and developments that attract large numbers of people. In this respect, the move from a strategy of flood defence to one of flood risk management is very significant. The paper by Kelly and Garvin deals with new approaches which focus on managing floods in a more sustainable manner. These include 'making space for water' and creating areas which can be used to accommodate flood water during and after an event.

1.8 OUTLOOK

There is growing recognition in Europe that flood management strategies need to change. This particularly holds true for the urban environment. Living with Flood, Space for Water and 'resilience' are becoming key issues in national and European policies. Support for this is based on a general trend towards sustainable development in urban society. Climate change has become an additional incentive. We must recognize that increasing climate variability is now unavoidable so we need to start adapting to the potential impacts. If we succeed in coping with current extreme flood events, it will help us to deal better with gradual changes associated with climate change.

For the future, a twin approach should be adopted in which (i) precautionary investments need to be made in responding to the changes we think we can predict reasonably well and (ii) an adaptive and incremental approach in which we are less certain about future changes. Such an approach has recently been specified for the different aspects of flood risk management in the UK (Defra, 2006). To achieve this, governments must have access to relevant information and they must involve stakeholders more effectively and be as open as possible about the flood risks involved. The scientific community should develop proper analytical instruments and more cooperation is needed between various disciplines such as (urban) planners and water managers. The private sector and more specifically the building industry has little understanding of the challenges and threats at stake and consequently their participation in research and development in this domain is still much too limited. Ultimately, integrated water management approaches will emerge, but this seems a long way off at the moment, with barriers at each stage: governance, policy, private sector, institutions, and communities (Ashley, 2006). It is expected that this book will not only encourage further relevant research and development in urban flood management, but also help to inform and engage stakeholders in promoting integrated and cooperative approaches in water management in general.

REFERENCES

Adger W.N., Hughes T.P., Folke C., 3 Carpenter S.R., Rockström J. (2005) Viewpoint: Social-Ecological Resilience to Coastal Disasters. Science Vol. 309. no. 5737, pp 1036–1039

Allenby B., Fink J. (2005) Viewpoint: Toward Inherently Secure and Resilient Societies. Science Vol. 309. no. 5737, pp 1034–1036

Ashley R. (2006) The future for water and flood risk management in highly susceptible urban areas; 9th Inter-Regional Conference on Environment-Water, EnviroWater 2006, Delft, the Netherlands

Barredo J.I., Lavalle C., De Roo A. (2005) European flood risk mapping. European Commission, DG-Joint Research Centre, Ispra, Italy

Bruneau M., Chang S.E., Eguchi R.T., Lee G.C., O'Rourke T.D., Reinhorn A.M., Shinozuka M., Tierney K., Wallace W.A., von Winterfeldt D. (2003) A Framework to Quantitatively Assess and Enhance the Seismic Resilience of Communities, Earthquake Spectra, Vol. 19, no. 4, pp 733–752, Earthquake Engineering Research Institute

Cumming G.S., Barnes G., Perz S., Schmink M., Sieving K.E., Southworth J., Binford M., Holt R.D., Stickler C., Van Holt T. (2005) An Exploratory Framework for the Empirical Measurement of Resilience. Ecosystems (2005) 8: 975–987

Defra (2006) Flood and Coastal Defence Appraisal Guidance FCDPAG3 Economic Appraisal. Supplementary Note to Operating Authorities – Climate Change Impacts. October

Europa (2006) Climate Change and the EU's response. Europa press release. 6th November 2006 (MEMO/06/406)

European Construction Technology Platform (ECTP), *Strategic Research Agenda for the European Construction Sector* (2005)

EEA. Climate change and river flooding in Europe. EEA Briefing 2005/01, European Environment Agency, Copenhagen

Hallegatte, S. "The Cost-Benefit Analysis of the New Orleans Flood Protection System" (Center for Environmental Sciences and Policy, Stanford University, and Centre International de Recherche sur l'Environnement et le Développement, Ecole Nationale des Ponts-et-Chaussées, 2006)

Pahl-Wostl C., Downing T., Kabat P., Magnuszewski P., Meigh J., Schlueter M., Sendzimir J., Werners S. (2005) Transition to Adaptive Water Management; The NeWater project. Water Policy. NeWater Working Paper X., Institute of Environmental Systems Research, University of Osnabrücklimate change and river flooding in Europe. EEA Briefing 2005/01, European Environment Agency, Copenhagen

Pahl-Wostl C., Möltgen J., Sendzimir J., Kabat P. (2005) New methods for adaptive water management under uncertainty – The NeWater project. Paper accepted for the EWRA 2005 conference

Penning-Rowsell E.C. (1976) The effects of flood damage on land use planning, Geographica Polonica, Vol. 34, pp 135–153

2

Sustainable Measures for Flood Attenuation: Sustainable Drainage and Conveyance Systems SUDACS

Joachim T. Tourbier
Dresden University of Technology, Dresden, Germany

Iain White
Centre for Urban and Regional Ecology (CURE), School of Environment and Development, University of Manchester, UK

ABSTRACT: On-site stormwater management, or sustainable drainage systems (SUDS) have been conceived to satisfy the ecologic, social and economic aspects of sustainability. In certain European countries SUDS are supported by institutional arrangements, covering aspects of runoff attenuation, quality improvement, infiltration, and detention. It is being shown that SUDS often only control the volumes and peaks of minor storms and only reduce flood risk to a limited extent. This situation can be improved if SUDS include conveyance systems for the routing of drainage that exceeds the capacity of measures traditionally considered to be part of the "treatment train". It is recommended to expand the concept of SUDS to make them "Sustainable Drainage and Conveyance Systems" (SUDACS) to fully include routing of exceedance flows. With such an expansion SUDS could more adequately address the needs of flood management in Europe, which needs to cover the prevention, protection, preparedness, emergency response and recovery from floods.

2.1 INTRODUCTION

In the United States a first manual on Best Management Practices for on-site stormwater management was issued under the Clean Water Act (WPCA, 1972) in the mid-nineteen-seventies (Tourbier and Westmacott, 1974) and ordinances have been passed for water quality control, infiltration and on-site detention up to the 100 year frequency storm (Tourbier and Walmsley, 1994). "Low Impact Development" (LID) in stormwater management is being widely advocated on the east coast of the US (www.lid-stormwater, 2006). In Germany the IBA Emscherpark International

Construction Exhibit (1989–99) sparked off an approach of "Near Natural" stormwater management, including infiltration that is being advocated by the "Emscher-Lippe Verband" in the Ruhr Valley (Sieker, Kaiser, Sieker 2006). In the United Kingdom there has been a considerable initiative through (CIRIA), the "Construction and Industry Research and Information Association" (www.ciria.org, 2006) advocating Sustainable Drainage Systems (SUDS). In 2001 a first planning advisory note on SUDS was published in Scotland, to be followed by the consultation document *Framework for Sustainable Urban Drainage Systems (SUDS) in England and Wales* in 2003 (NSWG, 2003). In 2004 an *Interim Code of Practice for Sustainable Drainage Systems* (NSWG, 2004), was published by the National SUDS Working Group. It lead up to the *SUDS Best Practice* manuals as well as documents to aid implementation. CIRIA has now published "Designing for Exceedance in Urban Drainage – Good Practice" (CIRIA C635) considering floods that exceed system capacity. The ongoing UK project *AUDACIOUS* will be modelling such drainage exceedance www.eng.brad.ac.uk/audacious (2006). Despite the potential benefits, on-site stormwater conveyance of major storms is not yet a standard approach in the UK, nor is the practice of SUDS yet generally accepted on the European Continent.

2.2 THE CONCEPT OF SUSTAINABLE DRAINAGE

Throughout Europe there has been an increase in the frequency and depth of flooding with the related property damage and loss of life. The causes are the spread of urbanisation and the affiliated impervious surfaces exacerbated by climate change, which affects the intensity and frequency of precipitation. In Germany for example, built up urban areas have more than doubled in the last 70 years, from 5.1% to 12.3% (Kaiser, 2005). Land use changes through urbanisation cause substantial changes in the volume and peak flows of stormwater runoff. The volume of runoff generated by impervious surfaces can be as much as 20 times that of an undeveloped site (Lampe, 2005). Fig. 2.1 shows typical hydrograph changes for both an urban area and one with natural ground cover. In an undeveloped environment 10% of rainfall forms runoff, 40% evapotranspirates and 50% infiltrates into the ground, whereas in a site with 75–100% paved surfaces 55% of the rainfall runs off, 30% evaporates and only 15% infiltrates.

Since the nineteen-seventies on-site stormwater management follows the approach to internalise the responsibility for stormwater control, by charging those who cause problems with the responsibility of solving them, rather than to have all taxpayers pay for corrective actions (Heaney *et al.*, 1975). However, despite the construction of ever larger and more expensive federally funded flood control dams in the US flood losses were mounting. Progressive municipalities there started to implement ordinances that require post-development stormwater

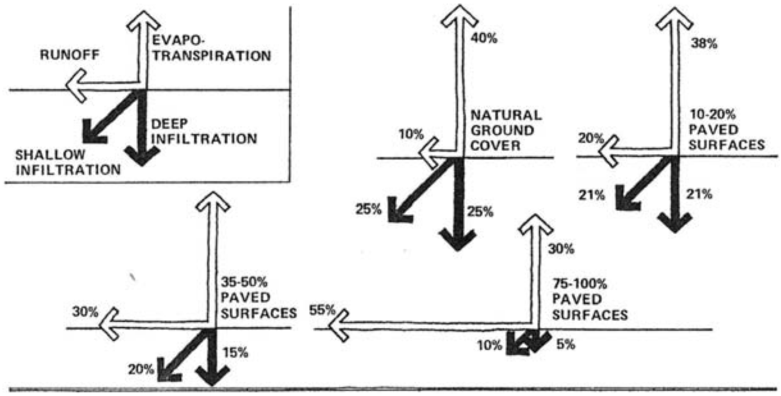


Figure 2.1. Typical hydrograph changes due to increases in impervious surface areas (*Source*: Tourbier and Westmacott, 1981).

discharge peaks not to exceed pre-development peaks. The 1992 Earth Summit in Rio, which produced Agenda 21, also internalised responsibilities by encouraging participating countries to develop sustainable development strategies at local and national government levels.

In the UK the Office of the Deputy Prime Minister put forth the *Planning Policy Guidance Note 25: Development and Flood Risk* (DTLR, 2001), for application in England. It requires that runoff from development should not increase flood risks elsewhere in a catchment area and that sustainable drainage systems be incorporated wherever practicable. It is also being argued in Britain that Integrated Urban Water Resources Management (IUWRM) should be practiced as part of Integrated Catchment Management, as set forth in the EU Water Framework Directive. In the UK, there is also widespread encouragement for SUDS and to modify the current right of connection of piped surface water drainage into the existing sewer (Tyson, 2004).

In Germany there are several legal provisions with implications on SUDS. A new law for improved preventive flood protection (GVVH, 2005) as well as the federal working commission on water (LAWA, 1995) hold, among others, that it is advantageous to detain and to infiltrate floodwater where it is generated. Many German cities charge separate stormwater fees in an effort to make the determination of water and sewer fees more transparent. The city of Berlin charges land users app. 1.30 Euro/year per square meter of impervious surface, unless there is an on-site disposal for runoff, such as infiltration practices. This provides a substantial incentive for the implementation of SUDS.

SUDS are a range of flexible drainage techniques that alter the focus of drainage design, practice, construction and maintenance to facilitate a higher consideration for society in general and the receiving environment (CIRIA, 2000a). There are

Preventative measures	The first stage of the SUDS approach is to prevent or reduce pollution and runoff. This may include good housekeeping, to prevent spills and leaks, storage in water butts, rainwater harvesting systems, and alternative roofs (i.e. green and brown roofs).
Pervious surfaces	Surfaces that allow inflow of rainwater into the underlying construction or soil.
Green roofs	Vegetated roofs that reduce the volume and rate of runoff and remove pollution.
Filter drains	Linear drains consisting of trenches filled with a permeable material, often with a perforated pipe in the base of the trench to assist drainage, to store and conduct water; they may also permit infiltration.
Filter strips	Vegetated areas of gently sloping ground designed to drain water evenly off impermeable areas and to filter out silt and other particulates.
Swales	Shallow vegetated channels that conduct and retain water, and may also permit infiltration; the vegetation filters particulate matter.
Basins, ponds and wetland	Areas that may be utilised for surface runoff storage.
Infiltration devices	Sub-surface structures to promote the infiltration of surface water to ground. They can be trenches, basins or soakaways.
Bioretention areas	Vegetated areas designed to collect and treat water before discharge via a piped system or infiltration to the ground.
Filters	Engineered sand filters designed to remove pollutants from runoff.
Pipes and accessories	A series of conduits and their accessories normally laid underground that convey surface water to a suitable location for treatment and/or disposal. (Although sustainable, these techniques should be considered where other SUDS techniques are not practicable.)

Figure 2.2. Summary of SUDS components (National SUDS Working Group, 2004).

a number of different types of SUDS, which can be used either as an individual system or an integrated network of techniques. Whilst each SUDS measure might only bring a small amount of benefit, the cumulative effects over an entire catchment can be significant. Fig. 2.2 provides an overview of the most popular SUDS components[1].

[1] Note that although SUDS use predominately "soft" engineering techniques, they can also use hard engineering solutions.

SUDS are more sustainable than conventional drainage techniques, offering the following benefits:

Flood related benefits:
Attenuation of runoff prior to concentration
- Reduction of runoff peaks
- Reduction of runoff volumes
- Reduction of flood related erosion and deposition in channels and reservoirs

Water quality benefits:
- Through a passive level of treatment the quality of runoff is improved (CIRIA, 2000a; SEPA and EA, 1999)

Groundwater benefits:
- Pre-development groundwater recharge rates can be maintained through infiltration

River related benefits:
- Reduction in Floodwater flows that cause channel degradation through erosion of stream bed and banks
- Minimization of adverse flood impacts on the environment

Social and economic benefits:
- Reduction of flood damage to property
- Reduction of flood related public health and safety problems
- Creation of visual enhancement and amenity
- Passive recreation
- Employment opportunities in construction and maintenance

The storage of stormwater has been identified as one of the key mechanisms to protect against damaging floods (Defra, 2004; Evans *et al*., 2004). Yet, in practice there are a number of significant barriers inhibiting the widespread use of SUDS (White and Howe, 2004b). White (2005) demonstrated that the impact of seemingly robust SUDS planning policies is severely undermined by a lack of wider information and guidance, as many developers continue to manage runoff using conventional engineering approaches.

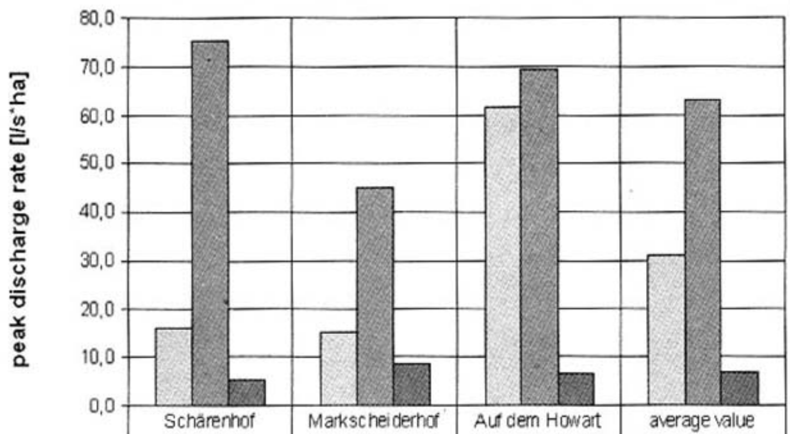
Detention or retention basins can store precipitation and so increase the level of rainfall needed before flash flooding occurs. Utilisation of SUDS may also reduce the volume of surface water that the drainage infrastructure has to manage and so lessen the possibility of sewer flooding due to storm events. A higher utilisation of basins in a catchment also reduces the demand on flood defenses downstream, changing the emphasis from a protectionist to preventionist outlook and help to adapt to the challenges of climate change (Evans *et al*., 2004; White and Howe, 2002).

Finally, on the EU level the "Directive of the European Parliament and of the Council on the Assessment and Management of Floods" {SEC 92006 66} was published in 2006. It covers the steps of "prevention, protection, preparedness, emergency response, recovery and review". SUDS, when expanded to include conveyance systems will help to meet those demands.

2.3 DESIGN AND PLANNING APPROACHES

A range of studies has been conducted to address a widespread concern about the performance of SUDS. A comparison of pre- and post development discharge peaks of newly constructed residential sites in Germany (Kaiser, 2005) show that SUDS consistently bring a reduction of peak flows. The comparison to peaks generated by conventional drainage is substantial (see Fig. 2.3).

In a recent study US and UK researchers conducted *Post-Project Monitoring of BMP's/SUDS to determine Performance and Whole-Life Costs* (Lampe, 2005). The relative hydrologic performance of individual facilities was determined through computer modelling for observed events, design storms, and five years of stochastically generated rainfall data. The study also provided valuable data on maintenance costs.



	Schärenhof	Markscheiderhof	Auf dem Howart	average value
before built-up	16,2	15,1	61,7	31,0
conventional dewatering	75,4	45,0	69,4	63,3
rainwater-managemnt	5,3	8,5	6,7	6,8

Figure 2.3. Pre- and post development runoff peaks of four residential developments in comparison to conventional drainage (*Source*: Kaiser, 2005).

Design criteria for the sizing of on-site stormwater management facilities can vary. In the US many municipalities that have adopted a view that stormwater management ordinance requires that post-development discharge peaks for the 2, 5, 10, 20, 50 and 100-year frequency storms should be equal to the predevelopment peak. However, in areas adjacent to large bodies of water such detention may not be meaningful. There also is a trend in the US to primarily control the 25- to 50-year storm, and to create flood routing depressions and passages to handle larger storms (Tourbier, 2003). A further concern in the US, where on-site detention is routinely used, is that delayed releases may contribute to flooding when the longer duration discharges from detention basins coincide with discharges of upstream sub areas. This point reinforces the need for integrated catchment management.

2.4 A PLANNING PROCESS FOR SUSTAINABLE DRAINAGE AND CONVEYANCE SYSTEMS (SUDACS)

The concerns associated with the current concept of SUDS provides a strong argument that their remit should be expanded to include both Sustainable Drainage and Conveyance Systems (SUDACS) to increase their potential to mitigate flood risk. In practice SUDS are rarely designed to detain runoff volumes and peaks that exceed the 30-year frequency storm. This means that facilities overflow during exceedance of these storms, not protecting against flood potential. Fig. 2.4 below shows a "treatment train" of SUDS, addressing the runoff volume generated by a design storm. Volume reduction can occur through attenuation, quality improvement measures, infiltration and detention. The 30, 50, 100, and 200-year frequency storms will generate exceedance flows. Their management should become an integrated component of SUDS.

Figure 2.5 shows stormwater conveyance measures for channel stabilisation through transverse and flow parallel structures, point protection, stabilisation of upper bank areas, and measures for emergency floodways and flood damage control, providing benefits in addition to conventional SUDS.

The planning procedure for such systems should start with (1) an analysis of predevelopment condition and should consider (2) goals and objectives to be defined

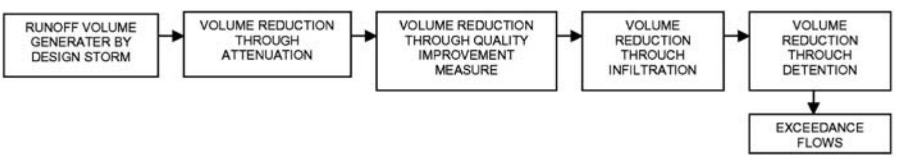


Figure 2.4. The sustainable urban drainage and conveyance system.

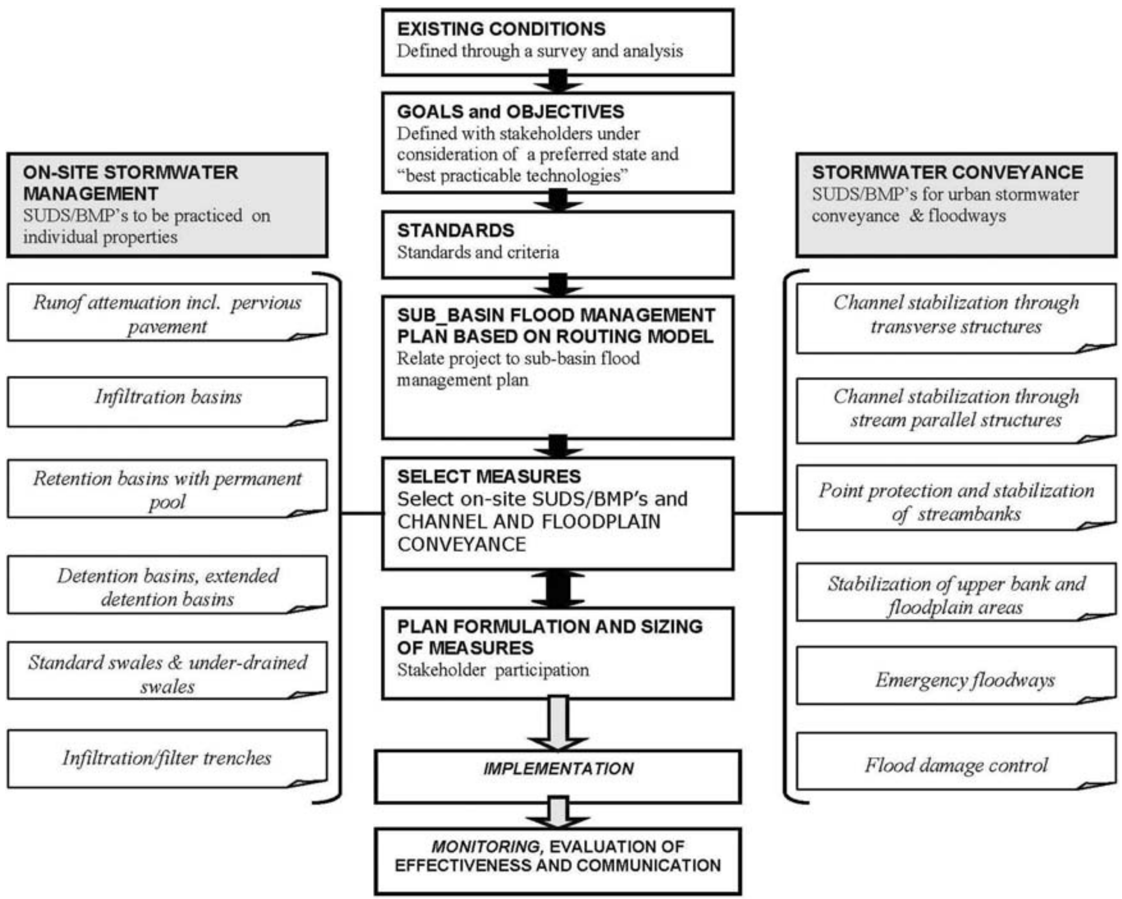


Figure 2.5. Flow diagram SUDACS planning procedure (*Source*: Tourbier, URBEM, 2005).

under stakeholder participation, leading to the definition of (3) standards, criteria and performance controls. A site concept should then be related to a (4) sub-basin flood management plan that includes a flood routing model. Steps 1–4 should be completed before (5) on-site SUDS and stormwater conveyance measures are defined. The plan (6) to be formulated should also provide for exceedance flows, leading to (7) implementation and (8) monitoring and evaluation of effectiveness and the communication of results.

2.5 DESCRIPTION OF MEASURES

Section 6 describes and discusses the various measures that could be employed for on-site stormwater management and conveyance. It is anticipated that this description will enable the SUDACS process to be understood in more depth.

2.5.1 Runoff attenuation including pervious pavement

The differing aspects of surface cover have a substantial effect on the rate and volume of runoff. Porous pavement, gravel road surfaces and modular porous pavers can all provide for infiltration where precipitation falls, whilst extensive roof covers and evaporation through landscaped areas can both intercept precipitation and allow evapotranspiration back to the atmosphere (Fig. 2.6). Furthermore, exceedance flows can be directed to additional measures. Evapotranspiration is being increasingly considered as important mechanism in reducing runoff rates. The Bagrov-Glugla model (Glugla *et al.*, 2003), as recommended by Harlass and Herz (2006) can be used to calculate the water balance in urban areas with consideration to evapotranspiration losses. It considers the following:

$$\frac{d\overline{ET_a}}{d\overline{P_{korr}}} = 1 - \left(\frac{\overline{ET_a}}{\overline{ET_{\max}}}\right)^n$$

P_{korr} Precipitation (mm/a) after correcting systematic errors of measurement
ET_a Actual Evapotranspiration
n Bagrov Parameter of Effectiveness
$ET_{\max}$ Maximum Evapotranspiration

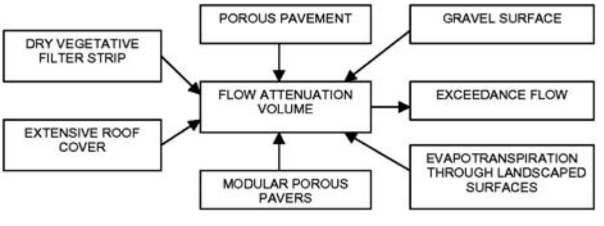


Figure 2.6. Runoff attenuation measures.

$$\overline{ET}_{\max} = \overline{ET}_0 * f_I$$

with ET_0 Evapotranspiration of Standard Gras (mm/a)
f_I Factor Depending on Type of Land Use, Slope and Exposure

Another example of runoff attenuation is pervious pavement, which can be installed to include a reservoir course with a void ratio designed for runoff detention. A sample cross section is shown in Fig. 2.7 below.

2.5.2 Water quality improvement

Runoff pollution can be defined by the type of surface that the runoff is generated from. Treatment can be achieved through biological treatment ponds, extended detention basins, constructed wetlands, or dry vegetative filter strips. The 2 year or 5 year frequency storm is usually used as the standard design, after which exceedance flows will be passed on.

2.5.3 Infiltration

Distance to groundwater table, infiltration rates of soil and the consideration of hazardous wastes in soil can all influence the selection of below ground or above

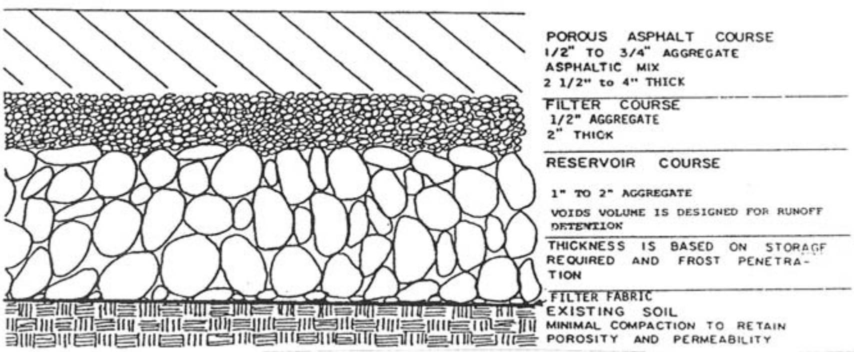


Figure 2.7. Pervious asphalt (*Source*: Tourbier, 2003).

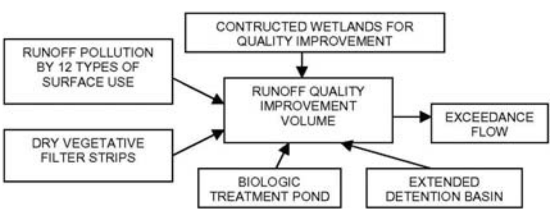


Figure 2.8. Water quality improvement measures.

ground infiltration measures and their respective infiltration volumes. It is considered that infiltration from a two-year frequency storm may be sufficient to maintain pre-development base flow of streams. However, although infiltration devices can divert runoff there may still be exceedance flows during major storm events. An example of measures with limited recharge potential are infiltration swales, shown in Fig. 2.10 below, while infiltration basins, shown in Fig. 2.11, have the benefit of considerable storage, but tend to have problems with clogging over time and need regular inspection (ASCE, 1992).

2.5.4 Detention

Detention basins and detention areas hold back, and slowly release runoff. They may be wet – or dry detention basins. Surface area, spillways and dam width have

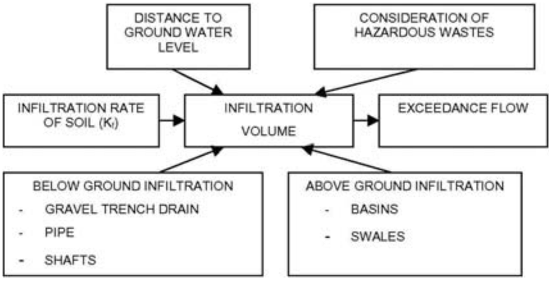


Figure 2.9. Infiltration measures.

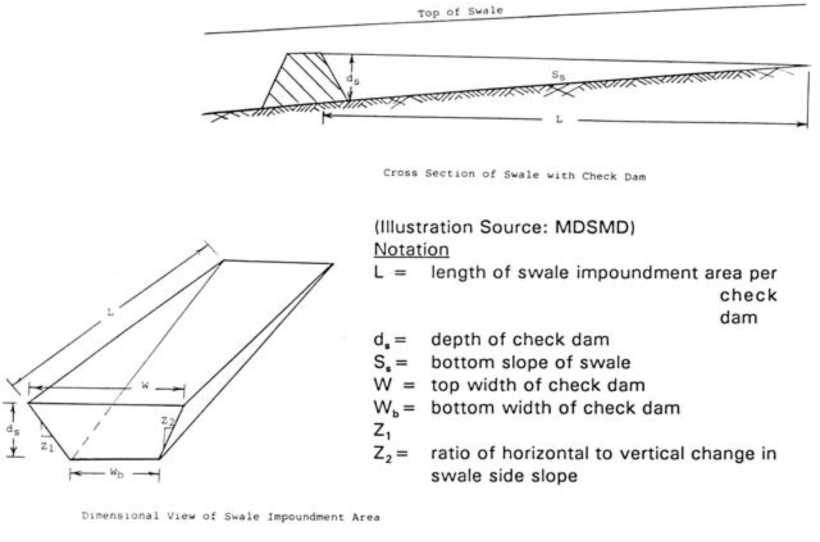


Figure 2.10. Infiltration swales (*Source*: Tourbier, 2003).

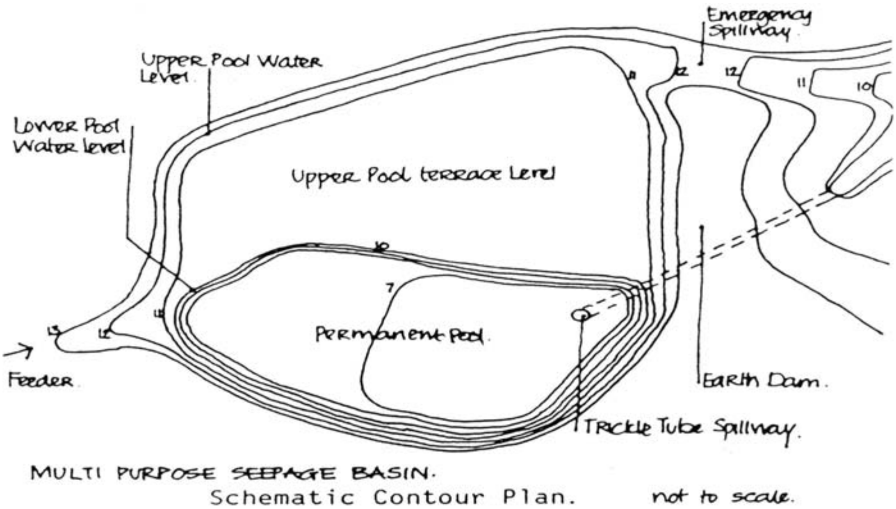


Figure 2.11. Infiltration basin (*Source*: Tourbier & Westmacott, 1981).

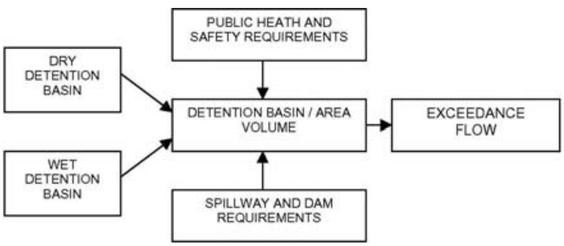


Figure 2.12. Detention facilities.

considerable space requirements. There also are public health and safety concerns, limiting the steepness of side slopes and affecting the size of basins in urban areas where space is at a premium. Although detention basins can hold back precipitation, dependant upon design of the mechanism there may also be exceedance flows during a major storm event.

2.5.5 Surface conveyance

Fig. 2.13 above shows how a digital terrain model and runoff model that subtracts storage in SUDS will yield above ground excedence volumes and flows that need to be conveyed through a site. Conveyance may be accommodated in vegetation areas, on pedestrian ways, roads and parking lots. The objective of this conveyance

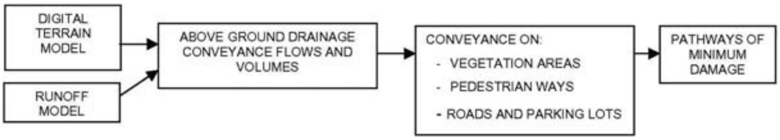


Figure 2.13. Surface conveyance systems.

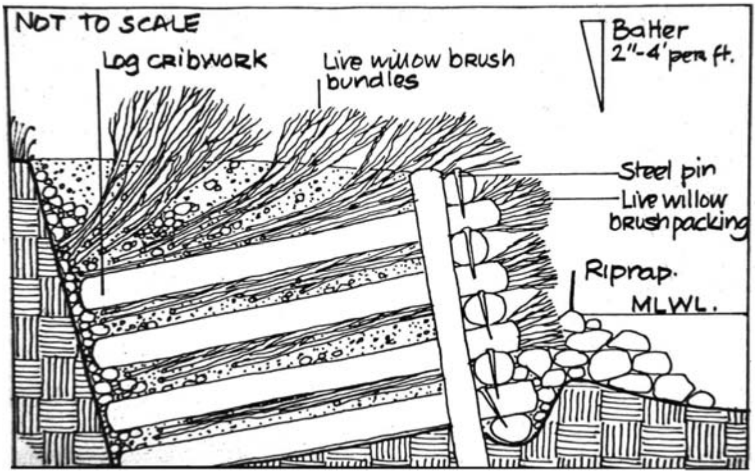


Figure 2.14. Life cribwall for point protection of emergency floodways in parks (*Source*: Tourbier and Westmacott, 1981).

method is to define a pathway of minimum potential damage. Channel conveyance can be calculated by using the Manning Equation:

$$Q = \frac{1}{n} A_C R^{\frac{2}{3}} s^{\frac{1}{2}}$$

where
Q = discharge, m^3/s
N = Manning roughness value
R = hydraulic radius = NP
S = slope (decimal)
A_C = cross-sectional area of flow, m^2
P = wetted parameter

Surface channels for exceedance storm flows should have non-erosive surfaces. Soil-bioengineering techniques that combine mechanical and vegetative techniques to protect critical areas on banks against erosion can included vegetated brush packing, wing deflectors, brush matrices and life crib walls (Fig. 2.14) that can be integrated into the landscaping of emergency flood channels.

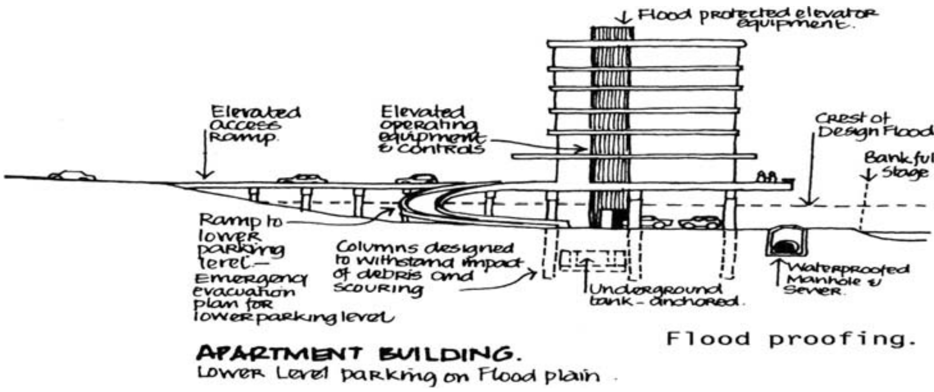


Figure 2.15. Flood proofing and emergency access on floodplains (*Source*: Tourbier and Westmacott, 1981).

Prevention, protection and preparedness, can be achieved through the careful routing of emergency foodways through urban areas, while response, recovery and being prepared for emergencies are aided through flood proofing and emergency access provisions (Fig. 2.15). All of these components should be part of stormwater management planning efforts.

In summary, we argue that the potential of future problems caused by conventional drainage could be increased due to the impact of climate change and the rising demand for housing, presenting environmental planning and society in general with considerable challenges. Therefore, alternative approaches to managing surface water can help to mitigate these impacts and achieve a more sustainable outcome, a view supported by recent research (DEFRA, 2004; Evans *et al*., 2004).

Sustainable Drainage Systems as a drainage approach are inspired by natural processes and gaining in sophistication (CIRIA, 1992, 1996, 2000a, 2000b), having the potential to prevent stormwater from having a negative influence on society (CIRIA, 2000a; Howe and White, 2001). Yet, their benefits to flood mitigation could be improved. We recommend that the conveyance of exceedance flows needs to become an integrated component of sustainable drainage systems (SUDACS) and that this new emerging method should become an integrated component of both, city planning and urban design.

REFERENCES

ASCE, American Society of Civil Engineer, *Design and Construction of Stormwater Management Systems*, New York NY, 1992

CIRIA, Construction Industry Research and Information Association, *Scope for Control of Urban Runoff*, Report 124, Vol. 1,2,3, Construction Industry Research and Information Association, London, 1992

CIRIA, Construction Industry Research and Information Association (2000a) *Sustainable Urban Drainage Systems – Design Manual for England and Wales*, London, 2000

CIRIA, Construction Industry Research and Information Association (2000b) *Sustainable Urban Drainage Systems – Best Practice Manual*, London, 2000

CIRIA, Construction Industry Research and Information Association (1996) *Infiltration Drainage – manual of good practice*, London, 1996

CIRIA Construction Industry Research and Information Association, C635 Balmforth D., Digman C., Kellagher R.B.B., Butler D., Designing for Exceedance in Urban Drainage – Good Practice. ISBN 0-86017-635-5, 2006

COST, Memorandum of Understanding, Technical Annex, March 2000

DTLR (2001) *Planning Policy Guidance Note 25: Development and Flood Risk*, DTLR, London

Geiger, W., Dreiseitl, H. *Neue Wege für das Regenwasser.* IBA Emscherpark GmbH. 2001

GVVH (2005) Gesetz für einen verbesserten vorbeugenden Hochwasserschutz der Bundesrepublik Deutschland, 2005

Glugla, G., Jankiewicz, P., Rachimow, Lojek, K., Richter, K., Fürtig, G., Krahe, P. *Wasserhaushaltsverfahren zur Berechnung vieljähriger Mittelwerte der tatsächlichen Verdunstung und des Gesamtabflusses* – BFG Bericht 1342. Koblenz, Bundesanstalt für Gewässerkunde, 2003

Harlass, R., Herz, R. *Water Balance in Urban Development – Accounting for Evapotranspiration.* Paper presented at the COST C13 End of Action Conference on "Sustainable Urban Development" in Bergen, Norway, Aug. 24/25, 2006

Heaney, J.P. *et al. Urban Stormwater Management Modelling And Decision Making*, Gainesville, FL: University of Florida, 1975

Kaiser, M. *Near Natural Stormwater Management as a Model in the Sustainable Development of Settlements*, in Tourbier, J.T., Schanze, J. (Eds.) *Urban River Rehabilitation Proceedings – International Conference on Urban River Rehabilitation.* Technische Universität Dresden & Leibniz Institute of Ecological and Regional Development, Dresden, ISBN 3-933053-29-3, 2005

Lampe, L. *et al. Post-Project Monitoring of BMP's/SUDS to Determine Performance and Whole-Life Costs.* Alexandria, VA: Water Environment Federation, 2005

LAWA (1995) Länderarbeitsgemeinschaft Wasser und Abfall, 1995

National SUDS Working Group (2003) *Framework for Sustainable Drainage Systems (SUDS) in England and Wales.* Copy available from www.environment-agency.gov.uk/yourenv/consultations/

National SUDS Working Group, *Interim Code of Practice for Sustainable Drainage Systems.* ISBN 0-86017-904. Copy available from www.ciria.org/suds/, 2004

Office of the Deputy Prime Minister (2005) *Consultation on Planning Policy Statement 25:Development and Flood Risk* ODPM, London

Department of the Environment, Food and Rural Affairs (2004) *Making space for water: developing a new Government strategy for flood and coastal erosion risk management in England*, Department of the Environment, Food and Rural Affairs, London

Sieker, F., Kaiser, M., Sieker, H. Dezentrale Regenwasserbewirtschaftung im privaten, gewerblichen und kommunalen Bereich. Stuttgart, Fraunhofer IRB Verlag, 2006

Tourbier, J., Westmacott, R. *Water Resources Protection Measures in Land Development – A Handbook.* For the Office of Water Resources Research of the U.S. Department of the Interior. University of Delaware Water Resources Center. Recommended reading in EPA's "Section 208 Guidelines for Area Wide Waste Treatment Planning" 1974

Tourbier, J.T. Westmacott, R. *Water Resources ProtectionTechnology*, Washington, DC: Urban Land Institute, 1981

Tourbier, J.T. in *Urban River Basin Enhancement Methods (URBEM), Work Package 8, New Techniques for Urban River Rehabilitation*, 2006

Tourbier, J.T. *Blue Green Technologies, Integrated Practices to Manage Stormwater as an Asset*, Geraldine R. Dodge Foundation, USA, Madison, NJ: Great Swamp Watershed Association, 2003

Tourbier & Walmsley, London, *Grove Township Stormwater Management Ordinance*, Avongrove, Pa., 1994

Tyson, J.M. *A Review of Current Knowledge – Urban Drainage & the Water Environment: a Sustainable Future?* Marlow: Foundation for Water Research, 2004

WPCA 1972, Water Pollution Control Act Amendment of 1972, PL 92–500

www.lid-stormwater.net/intro/background.htm, 30.10.2006

www.cira.org/suds/background.html, 30.10.2006

www.eng.brad.ac.uk/audacious/, 30.10.2006

3

Characterisation of Urban Streams and Urban Flooding

Ian Douglas[1], Mira Kobold[2], Nigel Lawson[1], Erik Pasche[3] &
Iain White[1]

[1] *University of Manchester, UK*
[2] *University of Ljubljana, Slovenia*
[3] *Technical University Hamburg-Harburg, Germany*

ABSTRACT: This chapter explores a number of issues concerned with urban flooding. It firstly examines the broad problems of rural and urban flooding before focusing on the classification of the different types of urban watercourse, from major rivers to sewers to minor streams, found in urban areas. Secondly, the paper explores in depth the impact of runoff in contributing to flood risk in urban areas, providing both a broad discussion and a specific investigation of flow processes in water bodies. Section four expands on the issue of runoff by providing on overview of the influence of land use on urban flood risk. Sections five and six attempt to link the information discussed thus far by examining the different types of flood event that these runoff regimes, flow processes and land uses may create and introduces two brief case studies describing how cities in the UK have suffered from flooding. It concludes that unwise management practices and climate change are exacerbating urban flooding and that there is a need for a holistic approach towards improving our understanding of the complexities of urban flood risk.

3.1 INTRODUCTION

Floods are natural recurring hydrological phenomena that have been affecting human lives from time immemorial. They become disasters because of their impacts on people and ecosystems, particularly in terms of human life and property damage (Smith and Ward, 1998; WMO, 2004). Munich Reinsurance data (Bruen, 1999) show that floods cause nearly one third of natural catastrophes. With rivers providing water for human use and industrial production and valley-floor alluvium often producing best agricultural land, urban settlements grew on river banks. They gradually organised protection against flooding by building dikes and embankments. However, streams carrying eroded material from the upper parts of the watershed deposited some of their load, gradually raising the natural riverbed. Eventually levees develop along the river raising the height of the banks, but leaving lower land further away from the river liable to flooding.

Floods are associated with extreme natural events that happen on a geographical area, such as a river basin, a catchment area or a watershed. These areas can be rural and urban, the former commonly being much larger than the latter. Hence, flooding can be rural and urban. An extreme natural event only becomes a disaster when it has an impact on human settlements and activities. At the European scale, 5 types of urban rivers and watercourses can be envisaged, each causing differing problems associated with flooding:

1. Major rivers, such as the Danube, Elbe and Rhine, adjacent to which urban areas have developed;
2. Rivers rising in adjacent mountains or uplands, such as the Drava and Mura in Slovenia and the Ribble and Mersey in England, which descend relatively steep courses from the highlands and then enter urban areas;
3. Streams whose entire catchment area, or watershed, lies totally within the built-up area, such as the Irk in Manchester and the Brent or Wandle in London;
4. Small urban streams, that an adult can jump across, that have been totally or partially culverted, such as the Cornbrook and Baguley Brook in Greater Manchester.
5. Sewers and the total artificial urban drainage network.

These five broad types of watercourses can cause flooding in both rural and urban areas. The basic cause of rural or river basin flooding is heavy rainfall or rainfall combined with snowmelt, followed by slow development of flood flows, which exceed the capacity of natural waterways. Other causes of rural floods are:

- surcharge in water levels due to natural or man-made obstructions in the flood path (bridges, gated spillways, weirs)
- sudden dam failure
- landslide
- mud flow
- inappropriate urban development (excessive encroachment in the floodway)
- ice jam
- rapid snowmelt
- deforestation of the catchment basin

Rural floods are river-basin events, whereas urban floods can have both area-wide and local origin, and can be accompanied by water pollution problems. As the proportion of the stream catchment area that is urbanized increases, and as the degree of management, modification and channelisation increases, so the flashiness of floods tends to increase.

From an urban perspective, flooding has become increasingly severe in most cities and usually occur in built-up areas as a result of heavy rain and the large amount of rain water that subsequent runoff. Rivers overflowing do not always cause floods; they can also be caused by high rain intensities over the city combined with inappropriate sewer systems and diverse urban land cover. However, generally, flooding in cities originates from extreme high flows and stages in major neighbouring rivers as a result of severe regional meteorological disturbances, or from local high intensity thunderstorms occurring over parts of the urban area. Thus, management of urban floods requires both the knowledge of physical characteristics of specific flood events and understanding of urban hydrometeorological issues. Urban flooding therefore requires special attention due to its sheer complexity incorporating a host of social, economic, institutional and technical factors within both rural and urban environments.

Furthermore, it should be noted that flood occurrences are not bound by local administrative areas because storm water drainage and protection facilities are part of an environmental system that is usually larger than an incorporated city territory (Andjelkovic, 2001). Thus, effective management of risk can present difficulties due to the disparity between natural and administrative boundaries and also between the differing strategies in place within neighbouring local, regional or national areas (White and Howe, 2002, 2004a). This is especially the case within urban areas as the policy framework becomes increasingly complex and strategies to research and mitigate flooding need to understand the broader drivers of risk, such as runoff, discussed in section 2.

3.2 THE IMPACT OF RUNOFF

3.2.1 Processes acting on the formation of surface runoff

In an urban area the management of surface runoff has been highlighted as a key driver on flood risk (White and Howe, 2004b). Horton's well-known concept (Horton, 1933) has been used widely to explain the surface runoff in terms of the precipitation water that exceeded the infiltration capacity of the topsoil layer (infiltration-excess water). This concept has been subsequently been developed and we now understand the surface runoff generation process in much more depth. Surface runoff (Figure 3.1) is not only generated by infiltration excess flow but also on saturated topsoil layers, and on water bodies (lakes, rivers and streams) as saturation flow (Dunne, 1978). Subsurface runoff can be generated by rapid throughflow of newly infiltrated storm water within macropores and soil pipes feeding directly into the stream flow. In case of saturation of the soil matrix (micropores) and the macropores pre-storm soil water returns to the surface through the additional water pressure created by the blocked runoff within the macropores at the depression zones. Thus this return runoff mainly occurs close to rivers and is significant on concave hillslopes and in wide, flat river valleys (Dunne *et al*., 1975; Tanaka *et al*., 1988). Furthermore, surface crusts can develop on loamy soils by the direct impact of heavy rain drops on the surface. The raindrop impact creates a sealing effect

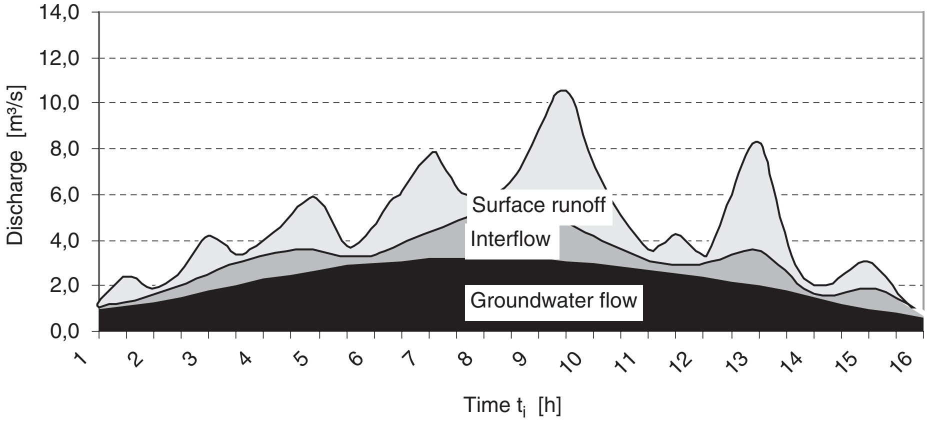


Figure 3.1. Runoff components of a flood hydrograph.

on the soil surface. Water can only infiltrate through the remaining cracks (Roth, 1992). Such situations commonly arise on farm land that lacks a vegetation cover.

3.2.2 Processes acting on the formation of subsurface flow

Interflow, or hypodermic flow, (Figure 3.1) forms in the unsaturated soil layer and flows more or less directly through this soil layer to the river. It can be divided into slow and fast interflow. While slow interflow results from long flow paths in the soil layer, fast interflow occurs in areas with a distinct topographic gradient close to rivers and in unsaturated soil zones with decreasing permeability with depth, or a layered soil profile in which the permeability of the lower layer is much less than the upper one (by power of 2 to 3 for sandy soil and power of 1 for loamy soil (Peschke *et al.*, 1999)). Zuidema (1985) showed that the interflow can occur in the network of macropores, soil pipes and cracks or through porous medium along an impervious layer (piston-flow). In steep regions (e.g. at hillsides) gravity can drive free soil water through the soil matrix, called matrix-throughflow (Kirkby and Chorley, 1967). Groundwater ridges can block interflow draining into wide flat valleys and direct the groundwater into the river by lifting the groundwater table (Blowes and Gillham, 1988).

In urban areas interflow is reduced by various people-made environmental changes. First, because the sealing of the surface reduces the infiltration of the precipitation, less free water is available in the unsaturated soil layer. Furthermore, much of the original natural soil layer may have been removed or have been consolidated by construction activities. These processes reduce the number and size of macro- and micropores, so decreasing the formation of interflow.

Because urban soils are often developed on composite materials derived from previous uses and exogenous sources, spatial heterogeneity is a typical feature. Their evolution is controlled almost exclusively by humans, who impose very rapid transformation cycles compared with those occurring in less disturbed areas. However, there is a continuum from the natural soils to the extensively disturbed soils, and their basic functions are essentially the same. As a result of their origin and uses, urban soils may contain pollutants that can find their way into interflow and groundwater and thus into rivers.

3.2.3 Processes acting on the formation of groundwater flow

Groundwater is subsurface water which fills totally the pores and cavities of the lithosphere (saturated zone). It comprises about 97% of the fresh water on earth. Although the groundwater aquifers can be regarded as huge water reservoirs, the groundwater table shows a distinct pressure gradient through which the water in these reservoirs is subjected to continuous flow and exchange processes with rivers, lakes and the unsaturated zone. Between 60 and 80% of the long-term flow volume in rivers is a result of groundwater discharge. Compared to interflow and surface runoff this flow process is much slower and can take years before the infiltrated precipitation water can reach the river. Due to these hysteresis effects, the outflow of groundwater into rivers persists even during long periods of no rain. Thus the groundwater is responsible for the dry-period flow in rivers (also named baseflow). However, during floods, rapid changes in groundwater outflow can be observed, which are not due to lateral flow processes through the aquifer. In confined aquifers a distant rise of the groundwater table through infiltrated precipitation water can increase the groundwater pressure close to the river, similar to the principle of communicating tubes in hydraulics. This process is often called piston flow, because the new water pushes out the old water. Old groundwater outflows along the river, while new groundwater enters distant aquifer regions.

Like interflow, groundwater in urban areas is affected by land surface changes. Surface sealing reduces groundwater recharge. The overall amount of groundwater in urban watersheds declines and the groundwater table is lowered, reducing the groundwater discharge to rivers. In dry periods, rivers draining urban catchments have lower runoff than rural streams of comparable size and at times may become totally dry.

The characteristics of groundwater baseflow may have a significant influence on the quality of urban surface watercourses. Transport of dissolved phase contaminants from the aquifer to the river will take place across the groundwater/surface water interface where processes are governed by the rapid change in physical and chemical conditions. Mixing of groundwater and surface water occurs at variable depths below the riverbed within the hyporheic zone where sorption and degradation may be significant with high levels of organic matter and microbial activity. The spatial distribution of flux through the riverbed is complex and sudden changes in river water levels may lead to reversals in flux direction.

Research to assess the impact of groundwater on the quality of the River Tame draining an urban catchment (408 km^2) containing the industrial city of Birmingham above an underlying Triassic Sandstone Aquifer found the river to be typically 8–12 m wide, 0.2–2 m deep with average dry weather flow velocities of 0.1–0.8 $m\,s^{-1}$. The river more than doubles its mean discharge across the 24 km study reach between the gauging stations at Bescot, 182 mega litres per day ($Ml\,d^{-1}$) and Water Orton 397 $Ml\,d^{-1}$. Work on a 7.4 km section receiving $\sim$6% of its total baseflow (60% of which is groundwater) from the underlying Triassic Sandstone aquifer and flood-plain sediments provided surface water and groundwater flow, head and physical/chemical data. Field data and supporting computer modelling indicated positive piezometric heads in the riverbed and the convergence of groundwater flows from the sandstone/drift deposits and variable discharge to the river (0.06 to 10.7 $m^3\,d^{-1}\,m^{-1}$, mean 3.6 $m^3\,d^{-1}\,m^{-1}$). The data reveal the discharge of organic (chlorinated solvents) and inorganic groundwater contaminant plumes through the bed of the river (Ellis *et al.*, 2000).

3.3 FLOW PROCESSES ACTING ON FLOOD PROPAGATION IN WATER BODIES

The concentration and formation of runoff ends in rivers, storm water pipes, channels or any other water body. Within these transport elements, the runoff is subjected to translation and retention. The translation corresponds to the travel time of the water, which is dependent on the flow velocity and the length of the water course (Figure 3.2). The flow velocity is influenced by the gradient of the bed of the water course, the water depth and the flow resistance.

Retention, the second process contributing to flood propagation in water bodies, is caused by temporary storage of water within the water course. This occurs either on the rising stage, when the river itself is filled with water, or when overbank flow occurs inundating flood plains. Especially in natural rivers the retention has a strong effect on the propagation of the flood wave. Here wide flood plains, meandering river beds and wooden vegetation cause high flow resistance and vast areas of inundation. They have a positive effect on the retention at flood by dampening the flood wave and attenuating its peak. However they are very complex and not fully understood. Retention is strongly influenced, not only by the size of the flooded water body, but also the variation of the flow velocity along the wetted perimeter within this water body. If the velocity is nearly constant, all water particles reach the downstream end of the river section at the same time. In this case no retention occurs. The more the velocity profile varies over the cross-section the more the water will be retained in the slower sections of the river. For no flow in inundation areas the retention can be easily assessed. But in general on flood plains flow still occurs and returns back to the river through momentum exchange or transverse flow

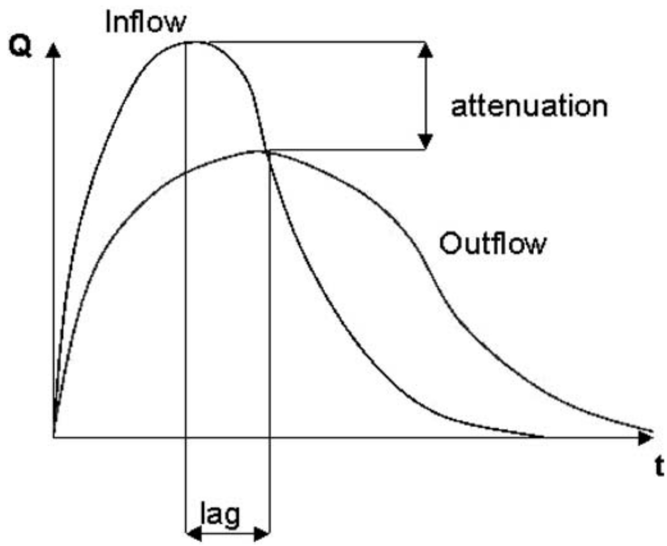


Figure 3.2. Inflow/outflow hydrograph of a flood wave.

at converging flood plains. As the flow velocity varies considerably in space and time, the retention effect can not be easily evaluated or determined for natural rivers. Often the retention effect in natural rivers is overestimated. Pasche and Plöger (2004) demonstrated that merely widening flood plains and the meandering of the main channel does not give a substantial attenuation of the flood peak, although these measures have led to higher water depth and larger inundation volume.

However, for flooding it is not merely a case of evaluating land cover, it is important to characterise hydraulic constraints and obstacles to stormwater flows. Yu and Lane (2005) have used high-resolution data obtained from airborne remote sensing to represent small-scale structural elements (e.g. walls, buildings) in complex floodplain systems using two-dimensional (2D) models of flood inundation. and to determine patterns of fluvial flood inundation in urban areas. Their model shows that even relatively small changes in model resolution have considerable effects on the predicted inundation extent and the timing of flood inundation. Timing sensitivity would be expected, given the relatively poor representation of inertial processes in a diffusion-wave model. Sensitivity to inundation extent is more surprising, but is associated with: (1) the smoothing effect of mesh coarsening upon input topographical data; (2) poorer representation of both cell blockage and surface routing processes as the mesh is coarsened, where the flow routing is especially complex; and (3) the effects of (1) and (2) upon water levels and velocities, which in turn determine which parts of the floodplain the flow can actually travel to. The combined effects of wetting and roughness parameters can compensate in part for a coarser mesh resolution. Nevertheless, the coarser the resolution, the poorer the ability to control the inundation process, as these parameters not only affect the speed, but also the direction of wetting. Thus, high-resolution data will have to be coupled to a more sophisticated representation of the inundation process in order to obtain effective predictions of flood inundation extent. Using roughness parameters to represent sub-grid-scale topography inadequately reflects the effects of structural elements on the floodplain (e.g. buildings, walls), as such elements not only act as momentum sinks, but also have mass blockage effects. These can be extremely important in floodplains within built-up areas. By using high-resolution topographic data to precisely represent sub-grid-scale topographic variability in terms of the volume of a grid cell that can be occupied by the flow and the effect of that variability upon the timing and direction of the lateral fluxes, significantly better prediction of fluvial flood inundation in urban areas than traditional calibration of sub-grid-scale effects using Manning's *n* can be obtained.

In addition to built topographic elements, vegetation affects flows in many urban channels. Davenport *et al.* (2004) have developed an urban river survey (URS), from the River Habitat Survey (RHS) which is applied routinely to UK rivers. The URS recognizes that most urban channels have been engineered and that management decision-making has to take account of previous "channel improvements". Urban river stretches are identified for survey according to their engineering type (a combination of planform, cross-sectional form and level of reinforcement). The URS is then applied to stretches of a single engineering type and incorporates recording of (i) additional variables to the RHS that are particularly relevant to urban channels (e.g. indicators of pollution); (ii) improved resolution in the recording of some variables in comparison with the RHS (e.g. habitat features); and (iii) separation of layers of information that relate to the engineered (e.g. artificially introduced materials) and more natural (e.g. bank materials and morphological features) channel properties so that the interaction between these properties can be identified. The URS has the potential to improve channel characterization and to enable dynamic vegetation communities to be incorporated into flood flow monitoring.

Retention is only of minor relevance in stormwater pipes and drainage channels, where compact cross sections produce a nearly constant flow velocity. In addition, the travel time of the water is reduced by a straight channel and a smooth surface along the wetted perimeter. This acceleration of flow reduces the translation time with the effect that flood waves, especially in storm water pipe networks and channels, reach the downstream end of their system without attenuation and much faster than flood waves in natural rivers. The more catchments are developed and drained by sewers and channels the more the flood waves will overlap with the negative effect of increasing the flood peaks in the central draining rivers. But this wave interference can be very complex especially in rivers where the flood waves from sewers and natural drains come together. Figures 3.3a and 3.3b show a flood wave separated into a slow moving part coming from the natural watershed and a fast one from an urban area released through the sewer pipe network. They show all

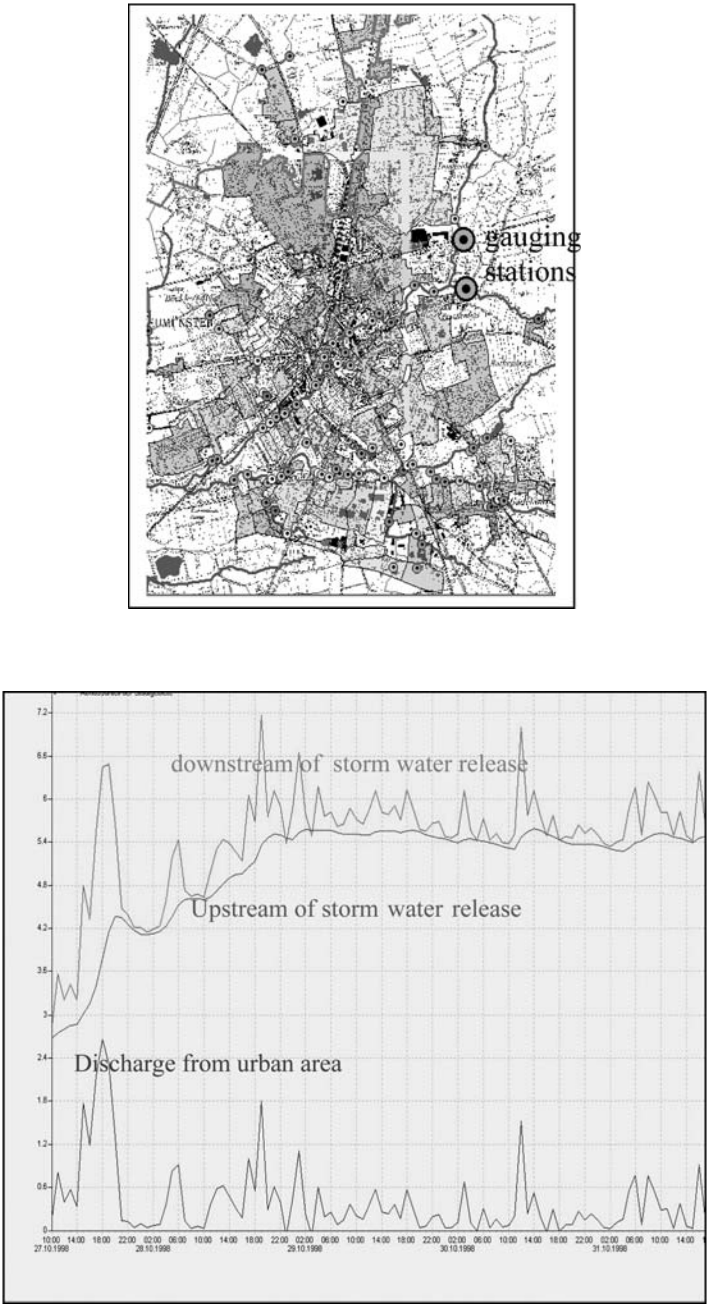


Figure 3.3. (a) Urban area draining into a stream. (b) Calculated discharge hydrograph upstream and downstream of an stormwater outlet.

the characteristics and differences between flood waves from natural watersheds and urban areas. They overload the pipe networks, flooding streets, cellars and the low-lying parts of urban areas. The flooded area however is restricted to the surrounding of the pipes and seldom comprises extensive urban areas. In natural watersheds, long lasting rain events with high total precipitation volumes but relatively low intensity cause the most critical floods. The larger the river basin, the longer the flood wave lasts. For large rivers the floods can last several weeks as observed at the Elbe flood and Danube flood in 2006.

Due to these distinctive differences in the flood waves, their accumulation in the river is hard to determine. Therefore it is difficult to assess effect on flood attenuation in the receiving urban rivers of retention measures in urban drainage networks, such as detention in green roofs, ponds and reservoirs, and infiltration to the subsurface through drains, porous pavements and ponds. Pasche *et al*. (2004) showed that for increasing flood events the attenuation effect of sustainable retention measures in urban areas is decreasing. In extreme floods, only reservoirs that retain large volumes of flood water clearly exhibit an impact on flood magnitude.

3.4 THE INFLUENCE OF LAND USE

3.4.1 The influence of land cover

The great variety of ground cover in urban areas leads to far greater complexity than the simple characterization of urban surfaces as permeable or impermeable suggests. Attention has now been paid to detailed multiple land-cover mapping. However, despite the value of this approach, many are attracted by a single "index" variable that characterizes the magnitude of urban development in a watershed. Patterns can be readily displayed, correlations are simplified, and communication between scientists and planners is enhanced. Yet urban development comes in many styles, occurs on many different types of landscapes, and is accompanied by a variety of mitigation measures designed to reduce its negative consequences on downstream watercourses. So any simple correlation between any single measure of urbanization and aquatic-system condition are unlikely to be precise. Past efforts to quantify the degree of urban development have not been consistent. Thus, the green infrastructure can be viewed as consisting of corridors, patches, and the overall matrix (Figure 3.4) (Gill *et al*., 2006).

Vegetated areas are not actually examined closely in urban flood hydrology. However, the components of the green infrastructure play varying roles in influencing runoff. For example, flood storage is especially important in corridors, but also has some importance as SUDS in the patches. In Greater Manchester, for example, green spaces (golf courses, nature reserves, etc.) alongside the River Mersey are used as flood storage basins at times of high river flow. On the other hand, the matrix is especially important when it comes to rainwater infiltration, as

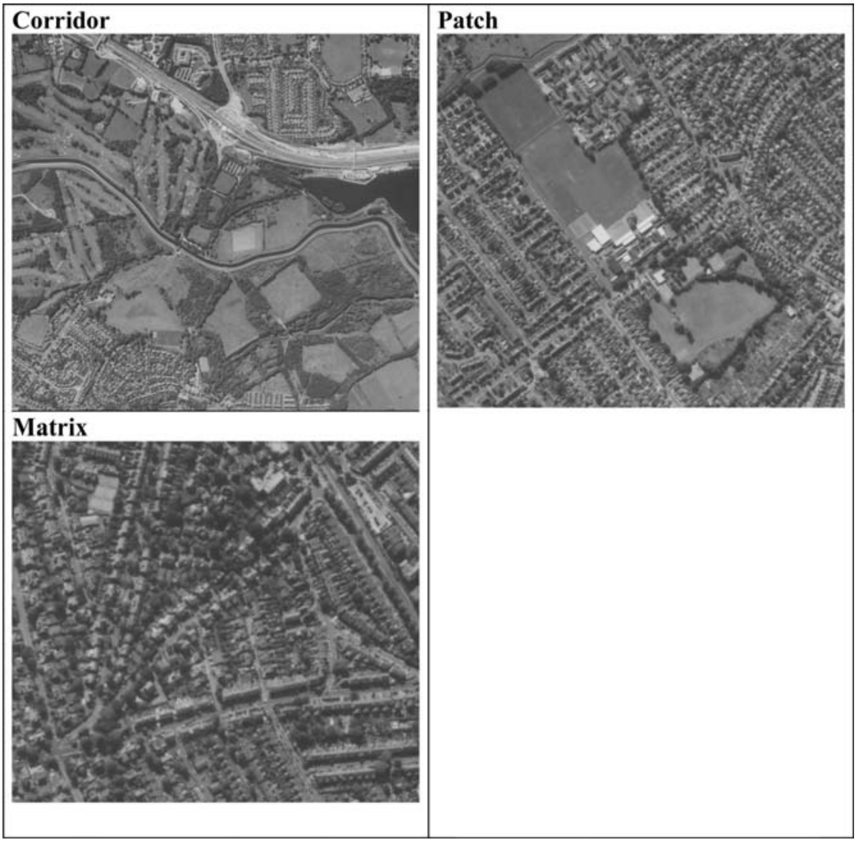


Figure 3.4. Green corridor, patch and matrix.

are patches (linking back to the work on surface runoff modelling). There may be a case for restricting infill development in lower density residential areas with high infiltration capacity.

The key element in urban runoff is the sealing of the ground surface, or the extent of the impermeable area. The extent of sealing of the surface varies considerably within urban areas. Although nearly 100% of precipitation, less that lost by evaporation, will runoff from impermeable areas, many sealed areas are not connected to a storm water pipe drainage network. The more they are surrounded by gardens and green spaces, the more the sealed areas shed rainwater laterally into depressions, hollows or drains where it can infiltrate into the ground (Sieker, 1999). Therefore Pasche *et al*. (2004) distinguish the sealing rate of urban areas in term of both the total sealed area and the proportion connected to drainage pipes. This has been expressed by Schueler (1995) as the distinction between the *total impervious area* (TIA) and the *effective impervious area* (EIA).