018530 - SWITCH

Sustainable Water Management in the City of the Future

Integrated Project
Global Change and Ecosystems

Deliverable 2.1.1: Review of the adaptability and sensitivity of current stormwater control technologies to extreme environmental and socio-economic drivers

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SWITCH Deliverable Summary Sheet

SWITCH Document: REVIEW OF THE ADAPTABILITY AND SENSITIVITY OF CURRENT STORMWATER CONTROL TECHNOLOGIES TO EXTREME ENVIRONMENTAL AND SOCIO-ECONOMIC DRIVERS.
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Publication date: 16 November 2006
Audience: All stakeholders involved in planning stormwater management in future urban environments where changes in environmental and socio-economic conditions will need to be taken into account.
Purpose: This deliverable provides a comprehensive description of a range of stormwater control options and how the operation of these systems might be influenced by future changes in climatic conditions, land use changes and changes in existing socio-economic conditions.
Background: The SWITCH project sets out to identify, develop, apply and demonstrate a range of scientific approaches and solutions which will contribute to effective and sustainable urban water management. This involves tackling existing environmental, social and economic problems in order to establish coherent and integrated proactive solutions which are acceptable at local, regional, national and global scales. A principal objective in stormwater management is to identify control and treatment technologies which are appropriate for coping with the effects of different drivers whilst maintaining efficient levels of prevention/protection against flooding, receiving water pollution and water shortage. This report sets out to provide a review of the adaptability and sensitivity of current technologies for stormwater control when exposed to variations in environmental and socio-economic conditions. The report is divided into separate sections dealing with the different controlling influences on stormwater management followed by a final section which collates the individual findings and discusses the implications of current and predicted trends in identified drivers on the use of different stormwater control measures.
Potential Impact: The main drivers are dynamic making detailed and certain predictions difficult particularly at the local scale. It is also difficult to predict the future interactions between different drivers. Thus population dynamics influences

urbanization which has an impact on traffic densities etc. At a global scale, how society will respond to limitations in the world's oil reserves and hence traffic levels is uncertain. The unpredictability of these major drivers for urban stormwater management leads to a dilemma. Urban planners need to make long-lasting decisions but in many cases they cannot be sure that the basis for their decisions will not change during the lifetime of a proposed solution.
Recommendations: To respond to the dilemma proposed above, the best current solution is flexibility. Common approaches to assessing the benefits of different approaches have not considered flexibility as a criterion. To adapt to the future changes in identified drivers it is recommended that flexibility is adopted as a planning criterion with regard to the design and build of new stormwater control and treatment systems.

The authors of SWITCH Deliverable 2.1.1 (Review of the adaptability and sensitivity of current stormwater control technologies to extreme environmental and socio-economic drivers) are as follows:

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EXECUTIVE SUMMARY

A major goal of the SWITCH project is the identification, development, application and demonstration of a range of scientific approaches and solutions which will contribute to effective and sustainable urban water management (UWM). This involves tackling existing environmental, social and economic problems in order to establish coherent and integrated proactive solutions which are acceptable at local, regional, national and global scales. Theme 2 of the SWITCH project specifically addresses stormwater management and within Work Package 2.1 (Technological options for stormwater control under conditions of uncertainty) a principal objective is to identify control and treatment technologies, which are appropriate for coping with the effects of different identified drivers whilst still maintaining efficient levels of prevention/protection against flooding, receiving water pollution and water shortage. This report represents the first Deliverable produced within this Work Package and sets out to provide a review of the adaptability and sensitivity of current technologies for stormwater control when exposed to variations in environmental and socio-economic conditions.

This report is organised in three separate sections (identified as Sections A, B and C) dealing with different controlling influences on stormwater management followed by a final section which collates the individual findings. Section A focuses on the identification and application of innovative, structural and non-structural approaches and techniques for the control and management of urban stormwater runoff. The sustainable urban drainage approaches adopted by different countries throughout the world are described and compared in terms of their performance efficiencies. In addition, examples of primary national legislation which have influenced the development of stormwater management within different countries are discussed, providing a cross-section of the different policy approaches upon which various countries have based their stormwater regulatory practices.

Section B provides a comprehensive overview of the modelling procedures which exist for the global warming process and the uncertainties associated with them before going on to describe the possible impacts of different climate change predictions on stormwater management needs. In particular, the spatial scale resolutions of the different models are discussed and how these can be used to identify future stormwater management scenarios in terms of both flood risks and water quality effects. The emphasis switches in Section C, to a discussion of socio-economic and non-climate related environmental drivers for urban stormwater management systems. The relationships and interactions between many of these drivers are identified and the difficulties associated with making robust predictions for the future are described.

Section D represents a short concluding section in which the implications of current and predicted trends in the identified drivers on the use of various stormwater control measures are discussed. Ideally, planning for future stormwater management options needs confidence in long term predictions but where these are not available, adaptability may need to be a central criterion of stormwater management planning if the goal of long-term sustainability is to be achieved.

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A IDENTIFICATION OF STRUCTURAL AND NON-STRUCTURAL STORMWATER MANAGEMENT APPROACHES FROM AROUND THE WORLD

A.1 Introduction

Traditional urban water management (UWM) incorporates inherent risks and limited sustainability in the context of global environmental and urban changes. As change pressures increase, most cities throughout the world will experience difficulties in efficiently managing scarcer and less reliable water resources whilst at the same time being required to satisfy increasing numbers of water users/services and greater effluent disposal demands. Without a more sustainable approach, the likely consequences will be environmental, social and/or economic damage. The core objective of the SWITCH project is to address the paradigm shift in UWM needed to meet these challenges in order to convert current *ad-hoc* reactions (primarily problem and incident driven) into coherent and integrated proactive approaches which will be primarily sustainability driven.

The principal objectives of the SWITCH action-based research are the identification, development, application and demonstration of a range of proven scientific, technological and socio-economic approaches and solutions that will contribute to effective and sustainable UWM. The approaches should have a generic base and be capable of development within a globally acceptable planning and legislative framework. In addition, any innovative opportunities should also explicitly address the risks inherent in take-up.

A.1.1 Urban Stormwater Management (USWM)

A framework within which generic decision making processes which influence the identification and application of urban drainage controls can be made is illustrated in Figure 1. The primary objectives towards achieving sustainable USWM require the holistic integration of the control and treatment of:

- runoff flow quantity (runoff conveyance, capture and flow attenuation)
- runoff flow quality (for both surface and groundwaters)
- and the protection and/or enhancement of habitat/amenity uses within the receiving water channel and adjacent riparian corridor.

Table 1 identifies the different criteria that need to be assessed for each of these primary objectives and against which control practices must be evaluated. Such controls can be at source, on-site, in-pipe (i.e. during conveyance) or at the end-of-pipe and can include conventional gutter-gully/inlet-pipe sewer drainage systems. The main aim of traditional piped surface water drainage systems is to convey impermeable stormwater runoff from the development site as quickly as possible whilst using minimal flow control. In terms of preventing localised flooding this would initially appear to be beneficial, however the significantly increased peak flow rates and volumes generated in the receiving waters could potentially cause serious flooding and erosion downstream of the discharge point. Figure 2 depicts the main sources, runoff and pollution pathways and storage sinks associated with a separate stormwater sewer system in an urban catchment. Such separate drainage systems normally discharge directly to a receiving waterbody. As illustrated in Figure 2, wrong (illicit) connections and cross-connections from the sanitary sewer at various points (e.g. at dual manholes) can cause unintended mixing of the stormwater and wastewater in the separate sewer pipe.

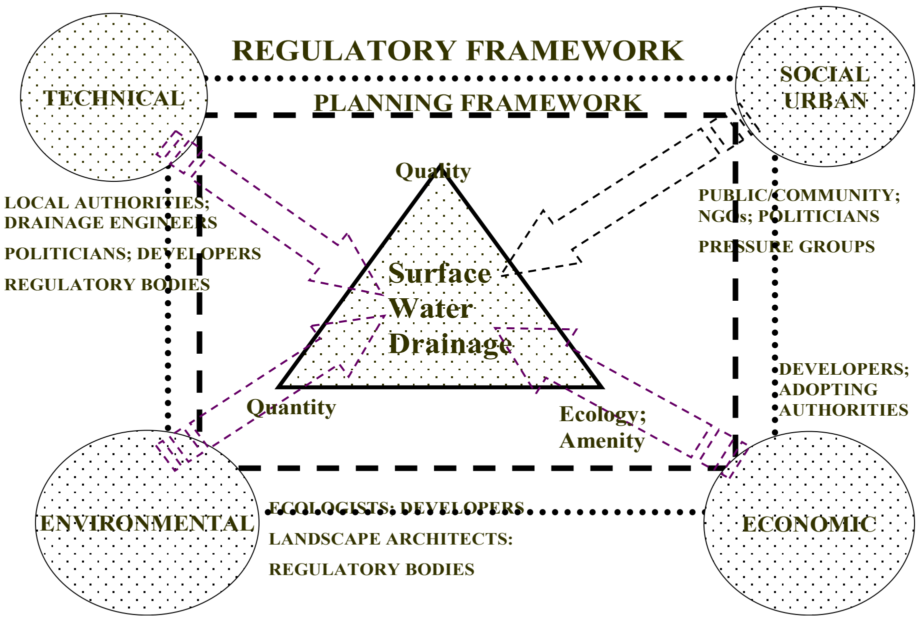


Figure 1. A Sustainable Framework for Urban Stormwater Management

Table 1. Objectives and Goals for Urban Stormwater Management Practices

Objectives	Criteria Category				
	Rainfall & Runoff Capture	Flow Attenuation	Water Quality Enhancement	Riparian Corridor Sustenance	Major & Minor Flow Conveyance
Achieve good ecological status	✓	✓	✓		✓
Reduce erosion & sedimentation impacts	✓	✓	✓	✓	✓
Maintain & re-establish “natural” hydrologic processes & encourage infiltration	✓	✓		✓	✓
Protect/enhance natural features		✓	✓		✓
Protect/enhance receiving waterbody quality			✓		
Minimise aesthetic nuisance			✓		✓
Reduce intra-urban flooding	✓	✓		✓	
Provide recreational, educational & aesthetic landscapes			✓		✓
Encourage re-use of stormwater	✓	✓	✓	✓	

In Wayne County, Indiana, USA, it has been estimated that a total of 1000kg of solids were prevented from entering the stormwater system over a four year period through elimination of misconnections.

Controls for both flow and quality can be located on most of the source and transport components shown in Figure 2 although conventional piped drainage systems would principally rely on the gully chamber and street sweeping to control pollution flows with limited end-of-pipe treatment such as catchpits/sediment traps and flood storage/balancing ponds.

Theme 2 of the SWITCH project is focussed on stormwater management with a principal aim of identifying and assessing the performance risks posed by alternative control and treatment technologies, which are appropriate for coping with the effects of different global change drivers whilst still maintaining efficient levels of prevention/protection against flooding, receiving waterbody pollution and water shortage. This SWITCH WP2.1 deliverable focuses on the global identification and application of innovative, structural and non-structural approaches and techniques for the control and management of urban stormwater runoff. The exact definitions of these two categories of Best Management Practices (BMPs) vary from country to country which can be the source of some confusion, but Section A of this report attempts to describe examples of individual national practice and conditions. Definitions and brief descriptions of adopted BMP approaches and techniques are given in Appendix F and further information and examples can be obtained from the EU 5th Framework DayWater Project website (www.daywater.org) and accessed via the ADSS Prototype to the BMP Catalogue tile window of Hydropolis. Brief definitions in English, French, German and Japanese can also be obtained from the IWA Urban Drainage Glossary (Ellis *et al*., 2004a). A review (Revitt *et al*., 2003) of the performance of European BMP systems can also be obtained from the publication listing on the DayWater website and the US EPA national BMP database (www.bmpdatabase.org) provides detailed statistical information and analysis of American treatment system performances. A more limited review of BMP performance and costing comparing US and UK storage, bioretention and infiltration systems is given in a recent UKWIR/WERF (2005) report.

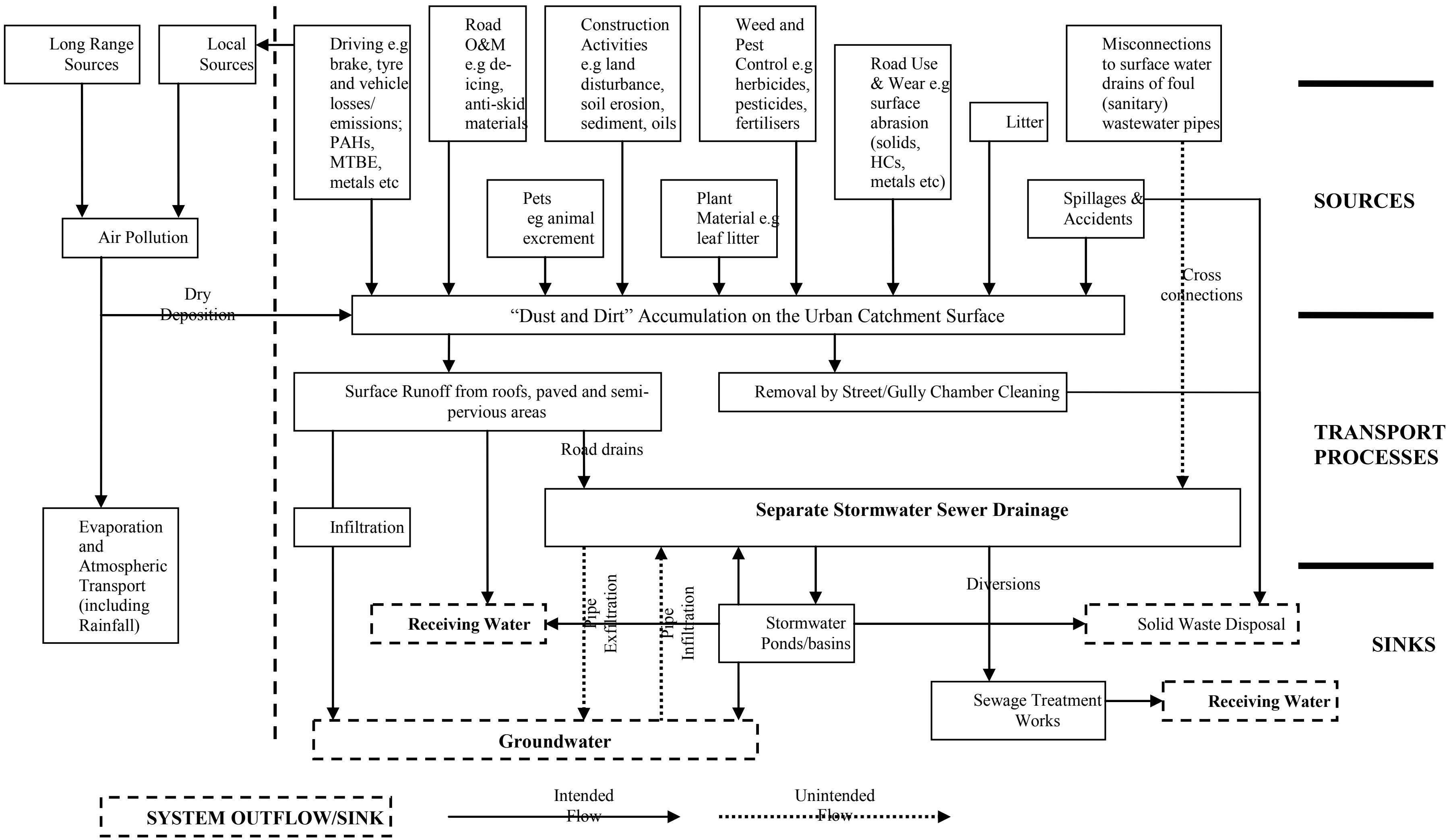


Figure 2. Flow diagram showing runoff and pollution pathways in a separate sewer system

A.2 National Best Practice for Stormwater Control

In this Section, the sustainable urban drainage approaches adopted by different countries throughout the world are described. These include representative countries from Europe (UK, France, Germany, The Netherlands, Scandanavia), N. America (USA), S. America (Brazil), Australasia (Australia and New Zealand) and Asia (Malaysia and Japan).

A.2.1 United States

The US Environmental Protection Agency (USEPA) has defined two basic types of Best Management Practices (BMPs) that can be used to reduce the threats of stormwater flooding and runoff pollution (WEF/ASCE, 1998). The two categories as defined by the US EPA are (i) non-structural or source control BMPs (which seek to minimise runoff generation and the introduction of pollutants) and (ii) structural or treatment BMPs (aimed at runoff storage and/or pollutant removal) (Tables 2 and 3). This categorisation has been accepted and applied by all US states in the various best practice management design manuals that have been produced over the past decade (see Appendix G) and has been replicated, to different extents, in a number of overseas countries including Canada, Japan, Australia/New Zealand and UK/Europe. The earliest and most influential US guidance manuals are those of Maryland (www. mde.state.md.us/Programs/Water Programs), which largely driven by the baseline work of Schueler (1987), and the best practice manual of Denver, Colorado (www.udfcd.org). Other notable design manuals are those of Washington state and Florida (www.ecy.wa.gov/programs/wq/stormater/manual.html,www.dep.state.fl.us/Water/nonpoint/ero_man.htm, respectively), which have been conceptually developed from the work of Horner *et al*., (1994). A comprehensive review of US BMP technologies and approaches is given in a recent report of a visit to the US by the UK water industry (DTI/British Water, 2006).

Structural controls not only provide treatment but can also be used for runoff capture and flow attenuation i.e. flood flow control with most US design manuals recommending the BMP capture of 90% runoff for the one year storm event with average retention times of 24 – 48 hours. Some of the listed non-structural practices in Table 2, such as green roofs, are regarded elsewhere as being structural BMPs. In addition, the so-called source controls include measures and strategies that can be applied at both source and end-of-pipe as well as on a regional, catchment scale.

Table 2. Non-structural BMPs for the control of urban stormwater runoff as defined by the US EPA.

CATEGORY	NON-STRUCTURAL PRACTICE
Public education/awareness	Public education; awareness and outreach campaigns
Planning & Management	Vehicle emission controls; Better site design; vegetation controls; reduction/disconnection of impervious areas; green roofs; Low Impact Design (LID) i.e combinations of non-structural and structural controls
Materials management	Alternative product substitution; housekeeping practices
Street/Storm drain O&M	Street cleaning; catchpit/gully cleaning; storm drain flushing; road and bridge maintenance; storm channel and ditch/creek maintenance
Spill prevention and clean-up	Tank spillage/leakage control; vehicle oil loss control
Illegal dumping and controls	Dumping controls; storm drain stencilling (labelling and/or signage); household hazardous waste collection; used oil collection and re-cycling
Illegal connection control	Illicit connection prevention, detection and removal; leaking sanitary sewer and septic tank control
Stormwater re-use	Landscape irrigation; aesthetic/recreational ponds; cooling water; toilet flushing.

Table 3. Structural BMPs for the control of urban stormwater runoff as defined by the US EPA.

CATEGORY	STRUCTURAL BMPs
Ponds	Dry retention ponds/basins Extended detention ponds/basins Wet detention ponds/basins
Wetlands	Constructed wetlands
Biofilters	Grass swales (wet/dry) Filter strips and buffers Bioretention cells
Infiltrations systems	Infiltration trenches Infiltration basins Porous Paving
Sand filters	Surface sand filters Organic and other media filters Perimeter filters
Other technology options	Water quality inlets/catchpits Vortex separator/continuous deflection systems Absorbent inserts Multi-chambered treatment trains

The basic objectives of BMP application—prevention, source control, site control and follow-up treatment control—are normally integrated in US designs into series to maximise stormwater quality benefits as illustrated in Figure 3. It is the use of BMPs in series that has become commonly termed as the surface water "treatment or management train" although the performance of in-series BMPs in comparison to individual, stand-alone BMP devices, has rarely been demonstrated. Most of the US design manuals assume that if the demonstrated performance of an individual specific structural BMP is recognised as being efficient, then any additional "bolt-on" BMP must only improve the performance effectiveness. Whilst this assumption has never been robustly tested, it is nevertheless the case that US best practice is to recommend a front-end sedimentation facility for any BMP. At its simplest this can be, for example, a retrofitted forebay in a wet detention basin or a sediment trap ahead of a grass swale. It is also the case that the focus of BMP use in the US is being increasingly placed on source/site construction controls, especially for solids runoff. The US has gone much further than most countries in the development and implementation of commercial or proprietary BMPs which include screens, vortex separators, up-flow clarifiers, hydrocarbon skimmers and absorbent filter inserts (so-called "smart sponges"). These latter devices are still largely in the field testing stage although they can play an important role as additional components in an effective treatment train approach.

A major new trend in US stormwater management is the application of Low Impact Development (LID) approaches (USEPA, 2001). LID approaches involve entire development sites and are broader in scope than BMP practices (Coffman, 2000).The approach emphasises the integration of site design and planning techniques that conserve natural systems and hydrologic functions on a site. LID utilises a combination of source controls and small scale, decentralised treatment practices to help maintain a hydrologically functional landscape and can include water recycling and re-use. LID practices include both preventative and mitigative measures; the latter may be more structural in implementation. They encompass an array of biofiltration and bioretention methods as well as roof disconnection, the use of rain gardens and minimisation of impervious cover. However there is some contention as to which BMP controls e.g. proprietary products such as vortex separators, are appropriate within LID drainage design. In addition, contemporary US views would consider urban surface water drainage as essentially comprising an integrated management train having a "toolbox" of drainage techniques that include "natural" and proprietary BMPs as well as conventional pipe drainage, but set within the context of LID.

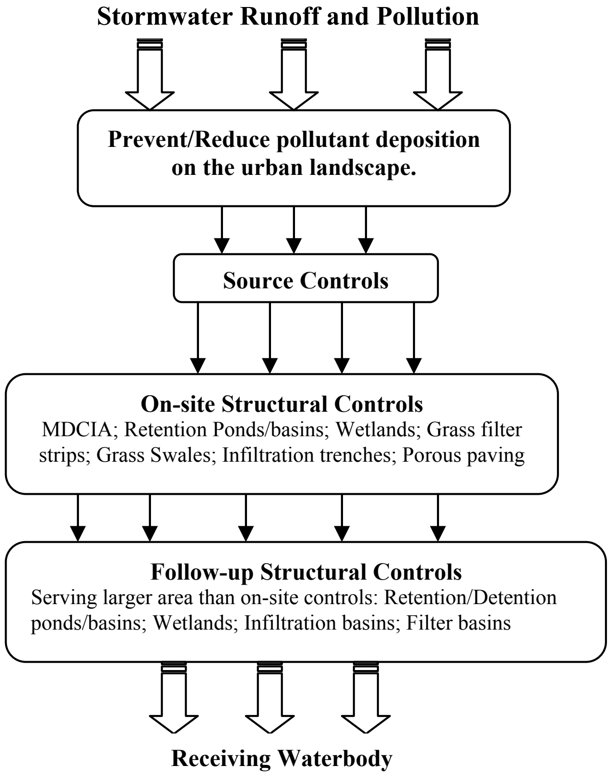


Figure 3. **Representation of the BMP in-series treatment train concept.**

A range of preventative non-structural measures can also be utilised including reduction of kerbing, routine maintenance, educational awareness campaigns, illicit connection removal etc. There is a growing conviction in the US within the context of the National Pollutant Discharge Elimination System (NPDES), that non-structural approaches which engage and involve stakeholders can be more effective than increased infrastructure. The use of site/lot clustering can free up land for the introduction of structural drainage controls and community open space to provide enhanced benefits. The effectiveness of LID practices can be measured through the hydrological effectiveness provided by runoff potential (as measured by the reduction in the runoff volumes (and Curve Number, CN), the time of runoff concentration (Tc), and by the amount of retention and detention provided (Table 4). As an example of the effectiveness that a LID approach can achieve, a 32 ha (80 acre), 199 dwelling development site at Somerset in Maryland saved over $30,000 and gained six additional 1,000 m^3 of dwelling units through its application. Such development gains provide a financial advantage (and incentive) to the developer and construction companies as well providing enhanced quality-of-life environments for the residents.

One major LID objective is to ensure a drainage design that maintains the post-development runoff volume as close as possible to the pre-development levels for the site. Limiting impervious cover by the introduction of the various LID practices itemised in Table 4, offers a range of techniques to accomplish this.

A.2.2 United Kingdom

In the UK, the term source control is commonly used to refer to on-site structural controls which can be applied at the point of rainfall as distinct from structural end-of-pipe controls, and "housekeeping" practices (which are essentially non-structural in nature). The

conventional design approach recommends the capture of the first 5mm of effective rainfall-runoff which is very much less than that included in US standards which approach the equivalent of 25 – 30 mm capture. The full suite of structural controls are collectively termed Sustainable Drainage Systems (SUDS) in the UK and are defined in Figure 4 as part of a surface water management train (CIRIA, 2001). Each type of SUDS unit has its own attributes in terms of catering for hydraulic and water quality drainage requirements. Their use should not be regarded as alternatives, but providing a suite of drainage tools in addition to conventional piped systems, for addressing the needs of a particular development site. What is not illustrated in Figure 4 is the potential significance of water re-use as many of the SUDS techniques involve storage and this provides opportunities to use these storage facilities as "tanks" for recycling and re-use.

Table 4. Low Impact Development (LID) hydrologic design components

LID Practice	Reduction in post-development runoff	Increase in Tc value	Provide Retention	Provide Detention
Flatten slopes		X		
Increase flow paths		X		
Increase roughness		X		
Minimise disturbance	X			
Flatten swale slopes		X		X
Infiltration swales	X		X	
Filter strips	X	X	X	
Disconnect impervious area	X	X		
Reduce kerb/gutter	X	X		
Rainwater barrels		X	X	
Green roof storage		X	X	X
Bioretention	X	X	X	
Re-vegetation	X	X	X	

Key: TC = Time of runoff concentration; CN = Curve Number

There is also an incipient interest in LID approaches for new developments given that the most recent national planning guidance relating to development and flood risk in Planning Policy Statement 25 (PPS25) (2005) is promoting the use of SUDS as well as influencing site layout and design to incorporate the basic principles of LID. In addition, the revised recommendations on housing in Planning Policy Statement 3 (PPS3) (2005) will recommend building densities of 25 – 30 dwellings per hectare, which should incorporate 30 – 40% social (or affordable) units. Such high densities will require LID clustering approaches to reduce the building "footprint" and leave intervening and adjoining land available for LID type drainage components and open space (Ellis *et al*, 2004b).

Although SUDS are recommended by the UK environment and highway regulatory agencies as appropriate surface water structural BMPs, and are also recommended in many local authority flood control regulations and planning development guidance, their actual take-up has been relatively slow, apart from in association with new greenfield developments. This is primarily because of concerns over long term adoption/ownership, responsibilities, long term operation and maintenance burdens, health and safety issues as well as doubts over performance and cost. However, in Scotland recent legislation has made SUDS mandatory for all new developments (see Section A.3.2.1.2).

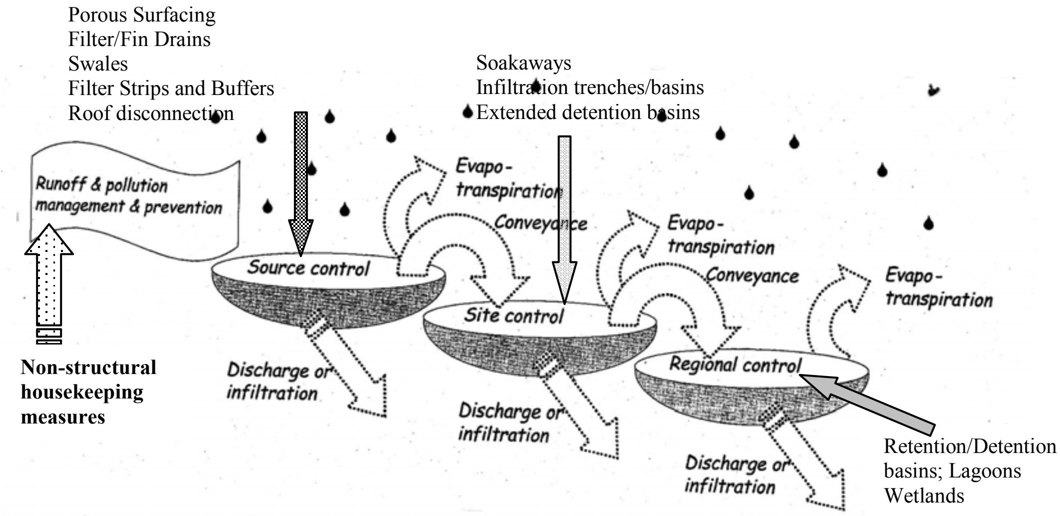


Figure 4. SUDS and the surface water management treatment train

A.2.3 France

In France all structural BMPs are collectively referred to as "*Techniques Alternatives*" which cover the full suite of structural source controls that would be equivalent to SUDS and BMPs in the UK and US respectively (IWA, 2004). In addition, storage controls are frequently referred to as "*Solutions Compensatoires*" which essentially refer to detention/retention and wetland facilities, although the latter are not popular devices for stormwater management in France (IWA, 2004). Source control (*Contrôle à la Source*) includes both structural and non-structural "housekeeping" measures as defined in the UK (Ellis *et al*, 2004b). Significant advances have been made in France with BMP infiltration facilities and various workers have played leading roles in the early pioneering and development of sub-base reservoir structures (Azzout *et al*., 1994; CEDTU, 1999).

A.2.4 Germany

The use of stormwater best management practices are well established in Germany where the approach is also known as 'near-natural stormwater management' (Gobel *et al.,* 2004). Although a variety of near-natural stormwater management options are found in Germany (e.g. detention basins and retention ponds), legislative changes in certain states, for example, the requirement in North Rhine-Westphalia for all new buildings and paved areas to have their own on-site stormwater treatment facilities (North Rhine-Westphalia SS51a), have focussed attention on local disposal of stormwater using infiltration options such as trough trench systems (also known as swales), as well as leading to the development of novel combined stormwater management options. An example of such an innovative design is the 'pocket wetland', a miniature trough-trench which incorporates a wetland system and was specifically designed to manage runoff in residential streets (Sommer, 2005). If appropriately located, the use of 'pocket wetlands' may also provide additional benefits through their potential to effectively act as traffic calming measures.

A.2.5 The Netherlands

With large areas of its land below sea level, including a considerable part of its capital city Amsterdam (van Luijtelaar and Baars, 2005), water management has always played a central role in the Netherlands. Recognition of the unsustainability of traditional combined drainage systems, together with increasing awareness of climate change issues, promoted the

development of a new national stormwater management strategy known as "hold-store-discharge" (Jacobs, 2002). In particular this strategy recognised that water needed space and that greater public awareness and acceptance of water and its natural behaviour was required. The strategy incorporates the use of a range of sustainable stormwater measures at both the basin-level (e.g. reforestation of slopes and building of dams) and household-level (for example, rainwater harvesting, green roofs and the disconnection of unpolluted stormwater flows from the sewerage system) effectively promoting the integration of sustainable stormwater management techniques over a range of scales.

A.2.6 Scandinavia

The use of sustainable urban drainage practices are well established in many Scandinavian countries, where they are referred to as best management practices (BMPs). This approach falls within the more general water management strategy 'daylighting', where stormwater is prevented from entering the drainage system (i.e. it is retained on the surface exposed to daylight) so that it may be used as a recreation/habitat resource. In cold climates the management of both the snow-pack and its subsequent melt-water can place great demands on municipalities. Swales and infiltration basins have been used to manage both stormwater and melt-water, with the use of swales offering an additional advantage as a potential deposit area for snow (Revitt *et al.,* 2003). A non-structural BMP approach to snow management is a snow handling strategy involving the zonation of towns and cities into white, grey and black zones on the basis of snow quality (Malmqvist, 1985; Swedish Environmental Protection Agency, 1990). White and black zones represent areas with clean and dirty snow respectively throughout the whole winter whereas grey zones have snow that is clean at the beginning of the winter but dirty at the end. The snow that is most polluted is transported to specific snow deposits that are designed and operated to minimise any negative environmental effects of the associated pollutant load. In contrast, clean snow can be dumped at stormwater outlets. The use of such a snow handling strategy results in a significant reduction in the volume of snow dumped at specific depot sites (Mikkelsen *et al.,* 2002).

A.2.7 Australia

Traditionally in Australia, the aim has been to channel the stormwater as rapidly and invisibly as possible from urban areas to the nearest waterway. However, best urban drainage practices are now encompassed in the concept of Water Sensitive Urban Design (WSUD), which is intended to define and describe an integrated urban water cycle management approach (Engineers Australia, 2006). Hence, WSUD is broader than dealing with stormwater alone and contains guiding principles which involve reducing potable water demand through water efficient appliances and seeking alternative sources of water such as rain water and treated wastewater reuse. It also advocates minimising wastewater generation and treatment of wastewater to a standard suitable for release to receiving waters and/or effluent reuse opportunities. Fundamental to the philosophy of WSUD is the integrated adoption of Best Planning Practices (BPPs) and Best Management Practices (BMPs). BPP refers to the site assessment, planning and design component of WSUD and is defined as the best planning approach for achieving urban water resource management objectives which may be implemented at the strategic or design levels. A BMP refers to the structural and non-structural elements of the design that perform the prevention, collection, treatment, conveyance, storage and re-use functions of a stormwater management scheme.

Different BMPs for managing water quality provide different levels of treatment as illustrated in Figure 5. In some cases, a particular BMP may overlap two or more treatment levels and in most situations, a combination of different BMPs acting as a treatment train will provide the best overall treatment. Source controls are here referred to as a mix of secondary level structural treatment systems and non-structural measures aimed at changing public/community behaviour through education, local government enforcement and planning strategies (CSIRO, 1999).

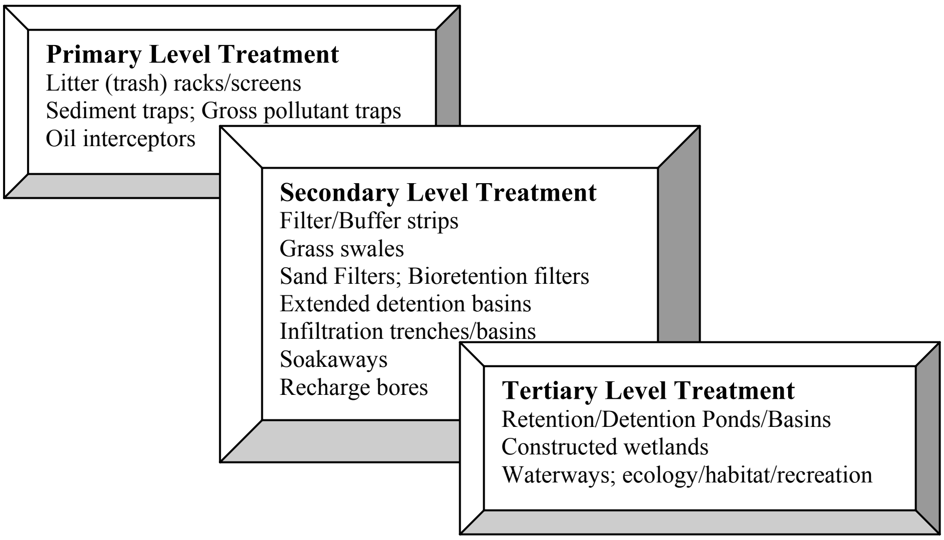


Figure 5. The different levels of treatment associated with Water Sensitive Urban Design (WSUD).

In addition to the recent stormwater runoff quality manual (Engineers Australia, 2006), there is also a detailed national engineering design manual for WSUD that has been recently published (Melbourne Water, 2005) and various states have worked up their own urban drainage manuals e.g. Queensland Government (2006).

A.2.8 New Zealand

New Zealand takes a similar approach to Australia in classifying their stormwater management practises although not specifically referring to them as WSUD concepts. Their national stormwater guideline manual (ARC, 2003) defines source control as approaches and management practices (i.e. non-structural approaches) which are intended to contain contaminants on-site or prevent them from contacting and being conveyed by stormwater runoff. These would include bunding, tank and spill containment, covering stock piles and work areas such as truck wash zones and oil changing bays as well as the diversion of "dirty" washwaters to the sanitary sewer. Management non-structural practices (or what might be termed "housekeeping" practices in the UK), include local authority initiatives such as street cleaning and gully/catchpit cleaning, re-cycling and education campaigns as well as industrial initiatives such as refuelling and chemical handling procedures, staff training and proper storage strategies etc.. Mitigation or treatment practices are regarded as structural BMP systems which are typically grouped as indicated in Table 5.

Table 5. New Zealand structural stormwater BMPs

BMP Category	BMP System
Storage Practices	Retention/detention ponds/basins Tanks and vaults Oil separators
Vegetative Practices	Grass sales Filter strips/buffers Wetlands
Infiltration Practices	Infiltration trenches/basins Soakaways Bores and tunnels Porous paving
Filtration Practices	Sand filters Compost and other organic filters Other bioretention filters

The trend is to combine the capabilities of two or more options through the establishment of treatment trains to achieve overall stormwater management benefits. In addition, the reduction of imperviousness at source combined with clustering configurations for new high density developments which have reduced “footprints” and source control drainage provides a Low Impact Design (LID) approach. Such LID approaches were first developed and applied in the US (USEPA, 2001) as noted in Section A.2.1 above, but have been also applied in New Zealand (Shaver, 2000).

A.2.9 Brazil

A number of cities in Brazil have developed urban drainage manuals since 1998/1999 to support municipal master-planning with the Sao Paulo, Curitiba and Porto Alegre manuals being the best known (Sao Paulo, 1999; SUDERHSA/CH2MHILL, 2002; Porto Alegre, 2002). They are principally based on US and UK design manual approaches with pre-programmed charts for source control device pre-design. Only the latter two city manuals give any real stress to alternative source control approaches and even here the emphasis is primarily placed on storage facilities. The adoption of a restriction flow equivalent to a pre-urbanisation condition (~ 20 l/s/ha) is recommended with a return period of 10 years used as the design threshold. The use of detention basins in Brazil has a longstanding engineering history, with Belo Horizonte being the first Brazilian city to install them in the early 1950s (Nascimento *et al*., 1999). However, the exclusive function of all stormwater control devices in Brazil is that of runoff capture and flow attenuation; little if any attention has been paid to the possibilities for water quality control and/or community amenity functions.

A.2.10 S.E. Asia and Malaysia

The majority of SE Asian countries have little experience or awareness of BMP drainage options for urban catchments although flood storage basins (balancing ponds) are fairly common flood control devices that have been traditionally adopted in most large Asian cities, based on standard European or American hydraulic design procedures. Stormwater drainage in most urban areas would generally consist of roadside drains and direct ground infiltration with the former discharging untreated runoff to adjacent receiving waters, with cross-connections from latrines and septic tank effluent being widespread and resulting in very poor water quality. The sewer system is also generally not adequately interconnected and does not form a recognisable network. In most Asian countries, stormwater management is thought of as being large scale flood control with enhanced sewer separation involving pumping and drainage works to accommodate the increased flows generated within urban areas. This is typified for example, by the June 2006 (Project No.37597) stormwater master-planning application submitted by Wuhan city, in central China to the Asian Development Bank for 125M US$. The investment plan for the 211 km^2 urban catchment with a population of 7.8M, is to provide entirely for separation of wastewater and stormwater flows based on conventional sewerpipe infrastructure. Records and data of stormwater quantity and quality as well as flow and pollution incidents are lacking in most SE Asian countries making it difficult to properly identify and design best management practices for stormwater runoff control.

In Malaysia, the potential environmental impacts of urban development on stormwater were first recognised in the early 1990s and pressure culminated in the production of an Urban Stormwater Management Manual for Malaysia in 2000 (JPS Malaysia, 2000), which was mandated for use in 2001. The goal of the manual was to provide guidance to all regulators, planners and designers involved in stormwater management in Malaysia. The process-based guidelines have been strongly influenced by the concepts of WSUD as developed and applied in Australia with a major focus on the prevention and control of sediment washoff to receiving waters. However, the guidance has been developed with little local data on and information of prevailing stormwater conditions.

The suite of best management measures (BMPs) for stormwater control and treatment recommended in the Malaysian manual are illustrated in Figure 6. The lightly shaded boxes comprise structural BMPs for use at site, community and regional levels, with source controls being those approaches and techniques applied at the on-site level. The community and regional level structural devices are regarded as comprising essentially "treatment" control BMPs with the off-stream regional ponds being sediment basins primarily intended to intercept solids and associated pollutants from construction sites. The three upper unshaded boxes of the post-construction group comprise non-structural "housekeeping" measures which include community education and public participation activities, land use planning and development control and operation and maintenance activities such as street sweeping and gully/catchpit cleaning.

It will not be easy to achieve the requisite directed and forward planning approaches and commitment from all key stakeholders in Malaysia. Transplanting of overseas approaches and techniques in the context of developing technologies will always lead to temporary spatial and procedural inconsistencies.

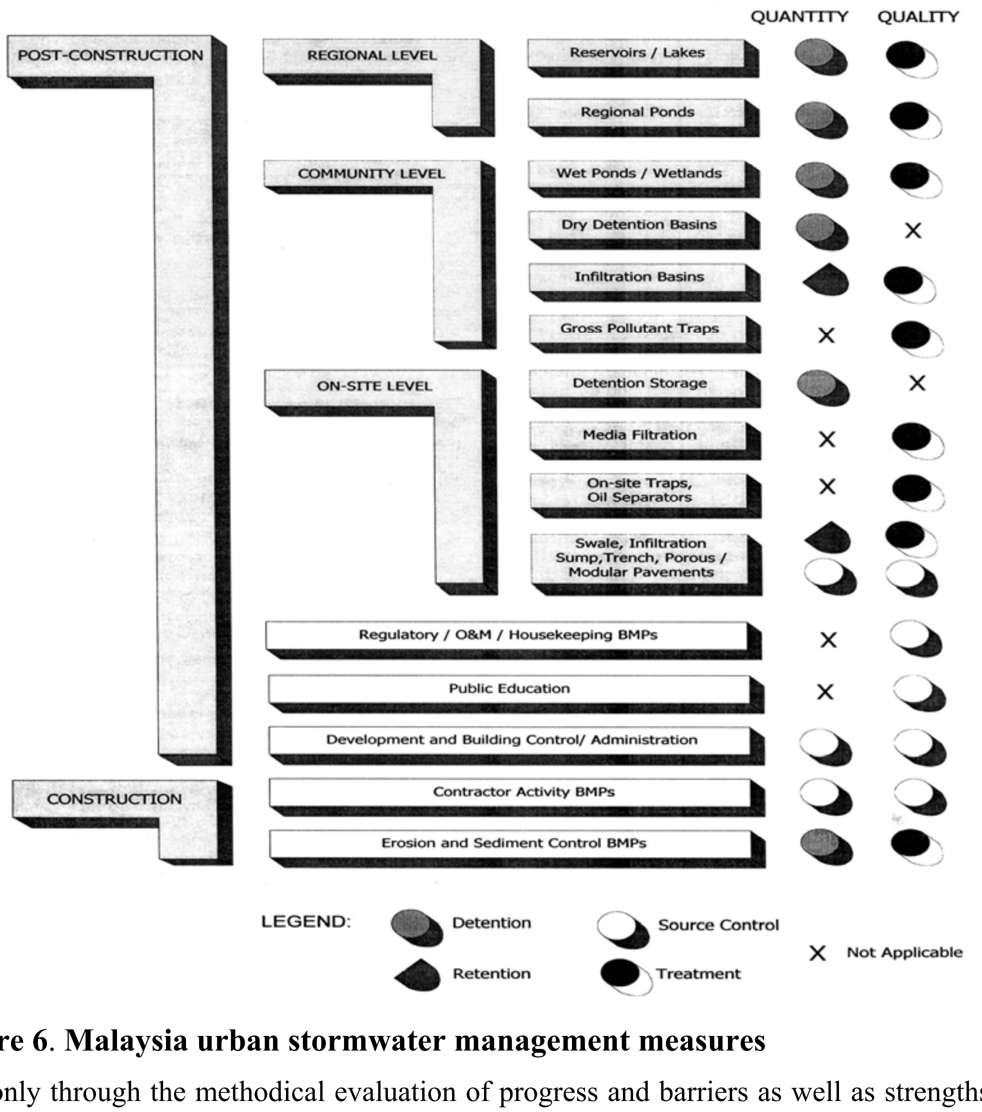


Figure 6. Malaysia urban stormwater management measures

It is only through the methodical evaluation of progress and barriers as well as strengths and weaknesses at the "grass-roots" level that valuable lessons will be learnt to implant truly sustainable drainage systems. The manual is still in its infancy but is serving as a catalyst for government, developers, consulting engineers and higher education institutions to undertake research into stormwater quality and in particular the application and performance of

constructed wetlands and detention /retention basins. The guidelines can be expected to be equally applicable in similar tropical environments elsewhere in the SE Asian region.

A.2.11 Japan

Japan has a long standing history of stormwater management and has been a pioneer and leader in the development and implementation of both structural and non-structural BMPs. Stormwater infiltration has been intensively practised since the early 1980s, with the introduction of the Experimental Sewer System (ESS) source control approach in the Nerima ward of western Tokyo between 1982 and 1994 being a typical example. Over 34,000 soakaways, 220 km of infiltration trenches (with perforated underdrainage), 70 km of grass filter strips and swale channels and over 0.65M m^2 of permeable pavements were introduced to this 1434 ha urban catchment during this 12 year period at a cost of nearly 500M US$. It has been estimated that these facilities eliminate 40% of the peak storm runoff and enable about 50% of the stormwater in the district to infiltrate into the ground. There is little if any evidence for contamination of the underlying groundwater since the inception of the ESS system. Figure 7 illustrates the source control ESS infrastructure layout for a typical residential area with Figure 8 showing the plan and section detail for the infiltration inlets used for disposal of impermeable street surface runoff. Wet weather solids loadings have been reduced by up to 25% and if the pollutants captured in the road inlet traps (Figure 8) are counted, the total solids loading from the catchment is reduced by nearly 47%.

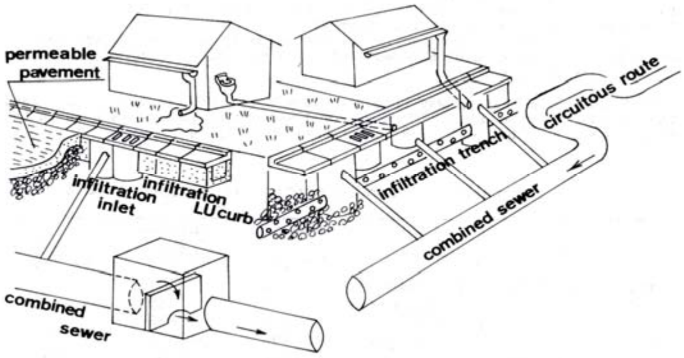


Figure 7. The Japanese Experimental Sewer design System (ESS)

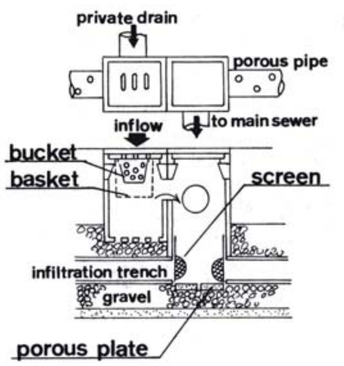


Figure 8. Infiltration inlet as part of the ESS system

Many Japanese cities have replicated the ESS approach which in its integrated, development site form is really a type of Low Impact Design (LID), but retrofitted into high-density urban areas. Porous surfacing received government mandate in April 2001 as an officially authorised road structure and it is estimated that there is some 4M m^2 of such paving in metropolitan Tokyo alone, representing 2.5% of the total road area. Most Japanese cities now have general rules and regulations for stormwater management to enforce city-wide stormwater runoff control measures. The use of a new approach to stormwater management, known as 'combined separate sewage system' (CSSS), has recently been proposed by Zaizen and Matsumoto (2005) for use in both new and existing developments. CSSS consists of a separate sewer system which is modified to capture and deliver the 'first flush' to sanitary sewer pipes where it is then transported to a sewage treatment plant. Following capture of the 'first flush', subsequent stormwater runoff is discharged to public water bodies or infiltration facilities. However, this approach is currently only a theoretical one and has yet to be tested using simulation models or in the field.

There is also a long history of water gardens, stormwater retention ponds and wetlands in Japan. In Fukoka city there are large scale rainwater collection systems covering 35,000 m^2 with tank volumes of 15,000 m^3 built into sports stadium facilities which provide low quality water for irrigation and toilet flushing. Similar large rainwater storage facilities have been built at the Ryoguku national sports stadium and city hall in Tokyo. Rainwater storage at the

household scale is also widely recognised as a practice that can contribute to flow-control as well as providing a valuable on-site multi-purpose resource. Recent research by Kawasaki *et al.,* (2005) investigated the potential of stored rainwater to meet water demand in a proposed new town development. On the basis of daily mass-balance calculations and cost-benefit analysis, the study concluded that stored rainwater could meet 8.5% of domestic water demand and reduce the total runoff discharged from the site by 67%.

A.2.12 Global approach to the use of BMPs

An outline perspective of the global uptake and application of structural BMPs, including LID approaches and proprietary technologies, is indicated by the information provided in Table 6. It is clear that the US and Canada lead the way in the implementation of structural BMP controls and in their integration with non-structural measures to provide a more holistic attitude to stormwater catchment management. The combination of planning and design strategies that also utilise ecological and conservation principles to reduce the impacts of site development has been principally driven by the Clean Water Act (CWA) and National Pollutant Discharge Elimination System (NPDES) regulations (see Section A.3.1). Australia, New Zealand and Japan have basically transplanted US design approaches and BMP technologies to new greenfield developments, but with appropriate modification in terms of climate, soil types and planning/institutional frameworks. They perhaps have also gone furthest in terms of community and stakeholder involvement in the BMP decision making process.

Table 6 National take-up and application of structural BMPs

COUNTRY	Infiltration Systems	Porous Surfacing	Dry/Wet Ponds and Basins	Constructed Wetlands	Grass Swales & Filter Strips	Other Bioretention BMPs	Other Control Technologies*	LID	Design Manuals
NW Europe	✓✓✓✓	✓✓✓✓	✓✓✓✓	✓✓✓✓	✓✓✓	✓✓	✓✓	✓	✓✓✓✓
S Europe	✓✓✓	✓✓	✓✓	✓✓	✓	✓	✓	-	✓✓
E Europe	✓	✓	✓✓	✓	✓	-	-	-	✓
Japan	✓✓✓✓	✓✓✓✓	✓✓✓	✓✓	✓✓	✓	✓✓✓		✓✓
US/Canada	✓✓✓✓✓	✓✓✓✓	✓✓✓✓✓	✓✓✓✓	✓✓✓✓✓	✓✓✓	✓✓✓✓	✓✓✓	✓✓✓✓✓
Australia & New Zealand	✓✓✓✓	✓✓✓	✓✓✓✓	✓✓✓✓	✓✓✓✓	✓✓✓	✓✓	✓✓	✓✓✓✓
S America	✓	-	✓✓✓	✓	-	-	-	-	✓✓
China	✓✓	-	✓✓✓	✓	-	-	-	-	✓
S Africa	✓✓	✓	✓✓✓	✓	✓	-	-	-	✓
SE Asia	✓	✓	✓✓	✓	✓	-	-	-	✓

KEY:

✓✓✓✓✓	Very frequent application
✓✓✓✓	Frequent application
✓✓✓	Quite frequently found
✓✓	Only occasionally found
✓	Rarely found
-	No information

* Including Vortex separators, up-flow clarifiers, absorbent filter inserts etc.

A.3 Policy and Institutional Drivers

In this Section some of the national legislation which has influenced the development of stormwater management in different countries is discussed. The examples chosen are representative of the different policy approaches which have been adopted and, in many cases, are those upon which other countries have based their stormwater regulatory structure. Information is provided for countries from four continents i.e. N America, Europe, Australasia and Asia.

A.3.1 USA

In the USA, increasing public awareness during the 1970s of the problems caused by water pollution led to the development of the Clean Water Act (CWA). This Act created a fundamental structure for regulating the discharges of pollutants into US waters by giving the Environmental Protection Agency (EPA) the authority to implement pollution control programmes such as setting wastewater standards for industry. In addition, the CWA required the setting of water quality standards for all contaminants in surface waters and made the discharge of any pollutant from a point source into navigable waters an unlawful act whilst recognising the need to address the serious problems posed by non-point source pollution.

The National Pollutant Discharge Elimination System (NPDES) was introduced by the EPA as a means of protecting receiving waters from contaminated stormwater discharges through the establishment of effluent guidelines for point discharges. An assessment of the water quality from separate storm sewers for different land uses was conducted between 1978 and 1983 under the auspices of the National Urban Runoff Program (NURP). This indicated that the task of issuing NPDES permits for each stormwater source in the US would be a daunting proposition and in an amendment to the CWA in 1987, 13 classes of stormwater discharges were identified including those from large (urban population > 250,000) and medium (urban population 100,000 - 250,000) Municipal Separate Storm Sewer Systems (MS4s). The NPDES permit programme is normally administered by authorised state governments and permits must be obtained by all facilities, including industrial and municipal, if their discharges go directly to surface waters. As part of the permitting process, a master drainage plan (MDP) is required, which for urban development proposals, generally follows a sequential 10-step process designed to facilitate approval with minimum time delays and hence costs. An important aspect in the implementation of the CWA at site level is via the definition of Total Maximum Daily Loads (TMDLs) for impaired water bodies. The establishment of a TMDL includes identifying the linkages between water quality problems and pollutant sources, estimating the total acceptable loading rate that achieves water quality standards, and allocating acceptable loading rates between point and non-point sources.

More recently, the implementation of the CWA has moved towards a more holistic watershed-based approach where equal emphasis is placed on protecting healthy waters and restoring those that are ‘impaired’. This fully involves a range of different stakeholder groups in the development and implementation of strategies for achieving and maintaining water quality and other environmental goals. An important leader in this since 1992 has been the Centre for Watershed Protection (CWP), a non-profit making organisation dedicated to protecting and restoring watersheds (i.e. river catchments) through effective land and water management including innovative stormwater treatments.

The CWA addresses public engagement issues by requiring the establishment of Stormwater Public Education Programmes (SPEPs) which are aimed at the various stakeholder groups engaged in activities relating to the target pollutants. These programmes may involve developing activities designed to reach and influence the behaviour of local residents and industries via printed leaflets and the internet. The major target pollutants for the SPEPs are identified in the NPDES permit requirements and include litter (particularly restaurants and customers of fast food outlets), indicator bacteria (advice to owners of pets and septic sewer systems), nutrients (advice to gardeners), pesticides (advice to pet owners, gardeners and DIY enthusiasts) and hydrocarbons (e.g. through oil recycling programmes addressed at DIY mechanics and the motor repair trade).

The EPA soon realised that the traditional end-of-pipe controls used for process discharges and treatment works did not represent the complete practical solutions for the control of stormwater pollution and that the use of creative approaches at the local level, known as Best Management Practices (BMPs) (see Section A.2.1), were more appropriate. The use of BMPs and LIDs (see |Section A.2.1) has been shown to be a much more cost-effective way of ensuring receiving water protection than the conventional use of drains and sewers for stormwater control. Local solutions also provide aesthetic and amenity benefits where the BMPs used have open surface water. The safety problems associated with such systems can be solved although in the USA there have been health concerns linked to mosquito breeding and the possible spread of West Nile virus.

The use of up-front construction bonds for BMPs and LIDs in some areas of the USA represents a payment to the permitting authority equivalent to the cost of the construction. This ensures that the construction regulations and standards are rigorously applied as the permitting authority has the power to retain this money to put right any sub-standard work. To ensure effective reductions in construction site pollution, legislation exists which establishes the minimum requirements regarding mitigation of any potential pollution and erosion created by construction site stormwater runoff. In addition to the regulatory aspects there are well developed systems of control and inspection, financing, incentives, permitting and penalties, all aimed at encouraging compliance by the use of stormwater management techniques which have been identified as being effective means of silt and erosion prevention.

The EPA has developed model ordinances for state/county decision makers and with respect to stormwater these specify responsibility for the long-term maintenance and implementation of regular inspection visits for BMPs. The objective is to ensure that stormwater BMPs perform efficiently over time and the ordinance may also address design guidelines that can help to ease the maintenance burden. The operation and maintenance services may be delegated to separate stormwater utilities, which because they do not need to own any assets, can also be effective at promoting the use of non-structural BMPs through local education and capacity building. The CWA positively encourages public participation in sustainable drainage systems through the provision of innovative service measures such as separate stormwater utilities, coupled with distinct charging systems for stormwater, which facilitates better engagement and responsibility. There is also the opportunity to use financial benefits (via rebates and special offers) to encourage those willing to take a more active role in stormwater management. In parts of the USA this has led to the disconnection of individual property stormwater inputs (downspout disconnection) from the main drainage network, allowing cheaper alternatives to be used to deal with downstream problems in combined sewer networks.

A.3.2 Europe

European legislation regarding urban water management is becoming increasingly influenced by the requirements of the Water Framework Directive. The impact with respect to policy implications for the UK and Germany are discussed in this section. The situation in the UK also illustrates how two closely related countries for many legislative processes (England/Wales and Scotland) can differ significantly with regard to stormwater management.

A.3.2.1 *UK*

As discussed in Section A.2.2, a variety of structural and non-structural control approaches are available for the local and on-site management of stormwater runoff which are collectively referred to throughout the UK as Sustainable Drainage Systems (SUDS). The majority of these systems have the ability to both attenuate water flows (preferably ensuring that the rate and volume of surface runoff from a post-development situation does not exceed the surface water discharge from the existing site) and to reduce the discharged pollutant levels (to receiving watercourse, to groundwater or to surface water sewer) as well as providing the opportunity to improve the existing ecological habitat and biodiversity and to aesthetically enhance the local urban environment. Hence benefits exist for both developer and the community from the adoption of sustainable drainage approaches for the control and management of urban runoff (CIRIA 2000a, 2000b). Throughout the UK, collaboration between the

England & Wales, Scotland and N Ireland regulatory authorities has focussed on providing guidance to local planning authorities regarding the benefits of alternative sustainable drainage systems (Scottish Environmental Protection Agency, Environment Agency and Environment & Heritage Service, 2000). Such an approach is compatible with the future demands of the EU Water Framework Directive which will place a regulatory emphasis on the identification and control of diffuse pollution including that generated from urban sources.

A.3.2.1.1 England and Wales

In England and Wales there is scope for a more extensive uptake of SUDS and to encourage this, the National SUDS Working Group (2004) produced an Interim Code of Practice for sustainable drainage systems following consultations with a wide range of stakeholders including central and local government, regulators, the water industry and developers. One objective of the Code of Practice has been to support planners, developers and practitioners by highlighting how current legislation can support the implementation of SUDS. It also sets out options for planning, maintenance and discharge through three model agreements which are aimed at those public organisations with statutory or regulatory responsibilities for SUDS and hence which will have a bearing on the required early interactions between practitioners, regulators and other stakeholders including local authorities, highway authorities and sewerage undertakers. At the planning stage, the implementation and maintenance of SUDS are seen as either an obligation under Section 106 of the Town and Country Planning Act, 1990 or as a condition attached to planning permission. A SUDS maintenance framework agreement is proposed as a legal entity defining which body takes over the routine maintenance. The model discharge agreement relates to owners of SUDS facilities granting sewerage undertakers rights in perpetuity to discharge, flood and maintain in default.

A.3.2.1.2 Scotland

The main legislation covering the regulation of surface water discharges is the Water Environment (Controlled Activities) (Scotland) Regulations 2005. These regulations, which are implemented by the Scottish Environmental Protection Agency (SEPA), identify certain categories of surface water discharge (e.g. housing developments >1,000 houses, car parks >1,000 spaces, industrial estates and motorways) as automatically requiring an application for a licence. All other discharges of surface water are required, as a minimum, to comply with the General Binding Rules (GBRs) for surface water discharges which specify a requirement to provide SUDS treatment or an equivalent. Inappropriately or wrongly designed SUDS found to be causing pollution, or pollution arising during the construction phase of development, may result in enforcement action and possible subsequent prosecution.

In Scotland, a partnership approach is employed to ensure that SUDS are designed effectively and are implemented consistently in new developments. Those involved in SUDS partnerships include developers and their designers (drainage engineers, architects, landscape architects), local authorities, SEPA, the water authorities, local people and certain non-governmental organisations. The use of SUDS is positively encouraged at the outset of a development proposal to allow full consideration of all influencing factors, including land take, in the decision-making process. Such a procedure also enables planners to co-ordinate consultation more efficiently with other statutory authorities hence facilitating the overall development process. It is a requirement that a maintenance schedule for the installed SUDS is produced and that there is a clearly identified person/body responsible for this. The responsibility for maintenance of road drains rests with the Roads Authorities with the Water Authorities having the responsibility to take the surface water drained from within the curtilage of a building i.e. roof water and areas of hard standing. There are many opportunities for SUDS to be designed to take both road drainage and curtilage drainage. Where a shared public SUDS exists the Water Authorities and Convention of Scotland Local Authorities have devised a Framework Agreement which allocates maintenance of above ground assets to the Unitary Authorities with the Water Authorities maintaining responsibility for below ground assets.

A.3.2.1.3 Impact of the Water Framework Directive

The EC Water Framework Directive (WFD), which came into force on 22 December 2000, establishes a new, integrated approach to the protection, improvement and sustainable use of Europe's rivers, lakes, estuaries, coastal waters and groundwater by introducing two key changes to the way the water environment must be managed across the European Community. The first relates to the types of environmental objectives that must be delivered. Previous European water legislation set objectives to protect particular uses of the water environment from the effects of pollution and to protect the water environment itself from especially dangerous chemical substances. These types of objectives are taken forward in the Directive's provisions for Protected Areas and Priority Substances respectively. The Directive also introduces new, broader ecological objectives, designed to protect and, where necessary, restore the structure and function of aquatic ecosystems themselves, and thereby safeguard the sustainable use of water resources. Future success in managing Europe's water environment will be judged principally by the achievement of these ecological goals.

The second key change is the introduction of a river basin management planning system. The planning system will provide the decision-making framework within which costs and benefits can be properly taken into account when setting environmental objectives and proportionate and cost-effective combinations of measures to achieve the objectives can be designed and implemented. It will be the key mechanism for ensuring integrated water management of groundwaters, rivers, canals, lakes, reservoirs, estuaries and other brackish waters, and coastal waters.

The UK Technical Advisory Group (UKTAG) is responsible for developing UK approaches to WFD implementation and, on behalf of the UK environment agencies, is developing the environmental standards and conditions to support delivery of the Directive. The initial work under article 5 of the Directive has involved a first broad characterisation of UK waters (including the typology of surface waters and the establishment of type specific reference conditions**)** and an analysis of the pressures and impacts that may put water bodies at risk. Under the WFD, the UK environmental agencies will continue to have the powers to control point source discharges, abstractions and impoundments, and adjacent engineering works but will also need to be fully aware of the potential problems posed to the receiving water environment by diffuse pollution.

A.3.2.2 *Germany*

The framework law of the German Federal Government relating to water resources management is the Federal Water Act 1996 which was most recently amended in 2001. It requires that waters are to be managed in such a way that they serve the public well-being and such that avoidable impairments of their ecological functions are prevented. All waters, including groundwaters and coastal waters, are subject to state control and to prevent pollution all uses of water are, in principle, subject to official authorisation. Authorisations for discharges are granted at the discretion of the competent water boards although in certain cases, this discretionary power is restricted in the interests of water protection. The minimum requirements are specified in more detail in the Federal Waste Water Ordinance (2001) which identifies the need for an official permit issued by state authorities with respect to the discharge of wastewater into a water body. Permits are normally only granted if the pollutant load of the discharged wastewater is kept as low as is possible through application of appropriate procedures using the best available technology.

The Federal Water Act provides a number of coordinated planning instruments, i.e. wastewater disposal plans, water pollution control regulations, management plans as well as water resources framework plans. In the course of implementation of the EC Water Framework Directive the focus will move towards overall river basin management plans for the entire catchment area which will substitute all the other plans mentioned above. Pollution of a water body without authority is liable to prosecution under regulations laid down in the Federal Water Act and the Environmental Liability Act 1990.

The Wastewater Charges Act 1994 was originally introduce in 1976 and stipulates that a charge shall be payable when wastewater is discharged directly into a body of water. The charge is the first eco-tax levied at the federal level and ensures that the polluter-pays principle is applied in practice. The charge is determined on the basis of the quantity and harmfulness of specific constituents discharged into the water, defined by a 'unit of noxiousness', and hence requires those responsible for discharges to bear at least some of the costs that their use of the water environment involves. The charge relates to a specific evaluated pollutant or group of pollutants and has increased incrementally since its inception in 1981. In the case of oxidisable substances, as defined by the Chemical Oxygen Demand (COD), a pollution unit equates to 50 kg of oxygen whereas for less abundant pollutants such as cadmium a pollution unit is represented by 100 g of the metal. In the case of the discharge of polluted rain water (stormwater), the number of 'units of noxiousness' of rain water discharged via a public sewerage system is defined to be 12 per cent of the number of inhabitants served by the system. If rain water from paved or asphalted commercial areas is discharged via a private sewerage system, the charges are calculated on the basis of 18 'units of noxiousness' per full hectare, if the paved or asphalted commercial areas are larger than 3 hectares. The number of the inhabitants served by the system and the size of the paved area may be estimated values.

Because the charge is intended to create an economic incentive to reduce wastewater discharges as far as possible, the Federal state may reduce the rate levied in cases where steps have been taken to limit the discharged pollutant load and in the case of rain water they may determine the conditions under which the discharges are exempt in whole or in part from wastewater charges. The revenue is earmarked for measures aimed at improving water quality, which in the case of stormwater may involve the construction of rain water retention basins or other BMPs for the control and treatment surface runoff.

Since the most important federal acts in the field of water resources management (Federal Water Act and Federal Wastewater Charges Act) are only framework statutes, the water resources regulations in the Federal States (state water acts, state wastewater acts and various statutory orders) also contain important provisions which supplement the federal regulations or define them in greater detail. For example, the Federal States regulate ownership of waters, monitoring of waters, maintenance of waters, licensing procedures for uses of waters, and indirect discharges (i.e. discharges via wastewater treatment plants) into waters. A number of states have also enacted provisions on charges payable for the abstraction of groundwater and surface water ("water use charges").

A.3.3 Australia and New Zealand

A.3.3.1 *Australia*

Water Sensitive Urban Design (WSUD) represents an alternative approach in which stormwater is treated as a resource that can bring environmental, economic and social benefits to urban environments and contribute to Ecological Sustainable Development (ESD). This has been defined as: "development that uses, conserves and enhances the community's resources so that ecological processes, on which life depends, are maintained and the total quality of life now and in the future can be increased".

In Australia the responsibility for managing urban stormwater rests mainly with local government. However, State and Territory governments have overall responsibility for land and water use planning and management. Collaboration between the different governmental levels is important if integrated approaches to water cycle management are to be successful. In South Australia, the existing significant stormwater issues are being addressed jointly by State and Local Government and a consultation document relating to a Draft Stormwater Management Bill and Stormwater Management Planning Guidelines has recently been published by the Local Government Association of South Australia (2006).

In many urban areas, drainage is the highest cost component of the water infrastructure. In February 1994, the Council of Australian Governments (COAG) agreed to the implementation of a strategic water reform framework which covers a range of areas including water pricing, institutional

arrangements, sustainable water resources management, and community consultation. This framework promotes innovation in stormwater storage and reuse as a supplement to existing water services with the proposed objective of eliminating the need for future new water supply reservoirs and their associated problems of infrastructure and environmental costs.

The Australian Guidelines for Urban Stormwater Management are incorporated within the National Water Quality Management Strategy (NWQMS) for which the objective is 'to protect and enhance the quality of water resources while maintaining economic and social development'. These guidelines recognise urban stormwater (together with treated wastewater) as important economic resources and support their use in a cost effective and environmentally sensitive manner for new urban developments. Ways of achieving this could be in potable water demand, through supplementing stream flows, and through the use of natural drainage corridors to provide landscaped and recreational areas and conservation benefits which increase the amenity of new urban developments (multiple use corridors).

Many city councils in Australia are required to develop a Stormwater Management Plan (SMP) to cover capital works, services, asset replacement programmes and activities aimed at protecting environmentally sensitive areas and promoting ecological sustainability. Typically, a SMP will identify the existing and future values of a catchment and the range of stormwater management objectives required to protect these values. The range of land use constraints will be established together with an identification of the range of corridor or drainage measures related to flow, interception of pollutants, provision of open space and recreation, conservation areas, urban stormwater reuse requirements and retention of the natural values of urban streams.

The holistic approach to water cycle management and regional natural resource management which is inherent in WSUD can be linked to catchment management networks and strategies, which, in turn, feed into planning by individual councils and then into their operational and works programmes and forward budget allocations. The application of water sensitive planning and management principles involves incorporating water resource issues early in the landuse planning process. It addresses water resource management at the catchment, suburban, precinct, cluster and allotment scale. WSUD makes the entire stormwater treatment network part of the urban fabric via multiple use corridors and best management practice (BMP) treatment trains. It maximises infiltration and on-site storage, treatment and reuse and utilises natural runoff channels where appropriate.

Best practice stormwater management for land development is implemented by the developer in harmony with the local council's stormwater management scheme and the catchment management plan. Land developers and builders are generally responsible for ensuring that their development does not result in significant worsening of existing stormwater management problems. Urban land developments should only occur in areas where a land capability assessment has indicated that stormwater management practices are capable of achieving this objective. Developers are encouraged to improve existing stormwater systems (eg. degraded creeks) and avoid using natural waterways or natural wetlands for stormwater treatment purposes. Alternatively, development using WSUD principles based on total water cycle management can be attractive to prospective purchasers, can increase the value of adjacent land, and may avoid expensive new infrastructure.

Stormwater runoff generated from Australian cities is equivalent to the current consumption of high quality imported water, about half of which is used for lower quality purposes, such as garden watering and toilet flushing. Stormwater represents an alternative source of water for non-drinking purposes but has not been exploited to any large extent in Australia despite the substantial environmental and economic benefits which could be gained through storage and reclamation. Currently only 3% of stormwater is reused compared to 11% of municipal wastewater due to the latter being a more reliable and consistent source of reclaimed water.

Examples of stormwater recycling include the use of rainwater tanks connected to roofs and underground stormwater storage below buildings. These can provide a valuable source of water for

gardens, toilet flushing, washing and hot water. Incentives can be promoted to developers and home owners to store and recycle stormwater, by providing rebates on their current water and sewer charges. Local Government can play a major role in encouraging this practice by establishing development consents which stipulate stormwater storage for toilet, garden, washing and hot water use. The use of storage gutters, acting as a linear tank, has produced a saving of 27% of the potable water supply to an average household in Sydney and when incorporated in new buildings the construction of this system is cost neutral. The system, known as 'Rainsaver', can also be applied to existing homes, as a replacement gutter system.

A.3.3.2 *New Zealand*

The top tiers of local government in New Zealand are known as regions of which there are 12, each governed by an elected regional council. In addition, four territorial authorities (representing the second tier of local government) also perform the functions of a regional council and thus are known as unitary authorities. The regional authorities are primarily responsible for environmental management, including water, contaminant discharge and coastal management, river and lake management including flood and drainage control, and regional land management. The territorial authorities are responsible for local-level land use management (urban and rural planning), network utility services such as water, sewerage, stormwater and solid waste management. There is often a high degree of co-operation between regional and territorial councils as they have complementary roles. Property rates (land taxes) are used to fund both regional and territorial government activities.

The core legislation relevant to stormwater discharges from development sites in New Zealand is represented by the Resource Management Act 1991 (RMA) [subsequently improved through the Resource Management Amendment Act 2005(RMAA)], the Local Government Act 2002 (LGA) and the Building Act 2004, which repeals the Building Act 1991. In addition, several current government initiatives influence the management of stormwater. Regional, district and city councils, and unitary authorities, all have functions under the RMA to control stormwater. Under regional plans, there are specific rules limiting the total impermeable area for a site (or total contributing catchment area) and the concentrations of contaminants in site stormwater discharges (rules are increasingly being set to achieve water quality standards which are specific for particular receiving water environments). These rules can also be incorporated in district plans and in situations where they are not complied with, resource consents can be required. Examples of resource consent applications are for stormwater outlets, culverts or pipes discharging contaminants to rivers, lakes and coastal waters unless exempted by a rule in a regional plan or regulations. Regional planning documents can recommend that comprehensive catchment management plans or integrated catchment management plans be completed by territorial local authorities (TLAs) for urban or urbanising catchments. These allow stormwater discharges to a council controlled drainage system provided they comply with conditions of the comprehensive consent.

The Local Government Act places an emphasis on local authorities to promote the social, economic, environmental and cultural well being of communities through the adoption of sustainability principles. Documents prepared by TLAs that should be consulted when considering on-site stormwater management issues include stormwater bylaws (e.g. those relevant to the management of overland flow paths) and water and sanitary assessments of how the levels of service for community stormwater systems may change as a result of community consultation and risk analysis. Section 36 of the current Building Act requires that all building work is adequately protected from flooding and that the results of the development do not make flooding worse. Developers are assisted by the approved New Zealand Building Code which addresses aspects such as estimation of runoff and the sizing of surface water systems. Proposed amendments to the Building Act and Code aim to promote sustainable development by the introduction of building standards in relation to among other things, water efficiency, and water conservation and the need to facilitate the efficient use of water and water conservation in buildings. On-site stormwater management measures may assist these goals to be met as well as meeting stormwater management goals.

There are several government initiatives relevant to stormwater management, including the Department of Prime Minister and Cabinet's January 2003 sustainable development programme of action, supported by the Ministry for the Environment's sustainable cities group. The former programme of action addresses (among other things) the maintenance of freshwater quality to meet all appropriate needs and has implications for the quality and quantity of stormwater discharges. Provisions relating to sustainable cities that are relevant to on site stormwater management include working collaboratively with local authorities to improve the legislative arrangements and statutory controls on planning, development and service delivery for urban areas with a focus on removing legislative impediments to sustainable medium and high density housing and infrastructure investment planning. The Ministry for the Environment (MfE) has formed a pilot group of government agencies that are seeking to take practical steps towards sustainability. In the international context, Agenda 21 is a comprehensive plan for management of all forms of human impact on the environment, developed principally by the United Nations and Governmental groups. This plan of action was adopted by 178 countries (including New Zealand) in 1992. The full implementation of Agenda 21 was strongly reaffirmed at the World Summit on Sustainable Development in Johannesburg, South Africa, in 2002.

A.3.4 Japan

The use of sustainable stormwater management practices has recently been greatly strengthened throughout Japan through the implementation of the Designated Urban River Inundation Act which came into force in 2004 (Okashita and Ogata, 2005). This Act brings together disparate legislation relating to rivers, sewage, flood prevention and town planning to support an integrated approach to urban water management at the river basin scale. In particular it promotes the use of water storage and infiltration in identified "water-retaining" areas (parts of the catchment in which the local geology permits the infiltration or temporary storage of stormwater) and enforces the steps needed to secure and/or further augment water retention functions through the installation of measures such as infiltration drains and permeable paving in both public and private buildings.

In contrast, areas in which stormwater tends to collect and rivers burst their banks are categorised as 'lowland areas', and in these areas stormwater retention systems, water-proof buildings and other inundation measures are heavily promoted. In relation to the financing of such measures, the Act states that the local authority implementing the measures may request financial support from other authorities which also benefit from the system. The aim of this provision is to ensure that costs do not prevent the implementation of basin-wide water management plans. Under the Act, local authorities may identify particular stormwater detention ponds as large stormwater detention facilities. Following this classification, landowners are obliged to maintain the pond's stormwater storage function and also to notify the local authority of any actions (e.g. land-filling) which may affect its performance. In addition, homeowners living in designated urban basins are also obliged to make efforts to provide facilities for the temporary storage and infiltration of stormwater.

A.4 Summary

The conventional approach to drainage in urban areas has been to remove surface water as rapidly as possible through a piped system to avoid flooding. However, this approach is becoming increasingly recognised as inappropriate and unsustainable for the control of stormwater as it may translocate rather than resolve storm flooding and it poses problems for receiving waters due to the direct discharge of pollutant loads as a consequence of surface wash-off processes. An alternative approach, which is being increasingly adopted throughout the world, is the use of stormwater best management practices (BMPs) as part of a multifunctional source control methodology. The two categories which have been identified are non-structural and structural BMPs. The former aim to minimise runoff and to reduce the availability of pollutants to stormwater through practices such as street cleaning, limitation of unauthorised dumping and illegal connections, public education and awareness campaigns, and stormwater re-use. Until recently, there has been less emphasis on the development of these processes but their importance is now being appreciated.

Structural BMPs include systems such as ponds, wetlands, biofilters, infiltration devices and sand filters and have the capacity to both store runoff and assist in pollutant removal. Different countries tend to place a different emphasis on which examples they prefer with sand filters being common in the USA but considerably less widely used in Europe although infiltration systems are popular in France. There are also different terminologies in use with the UK referring to these systems as Sustainable Drainage Systems (SUDS) and Australia and New Zealand adopting Water Sensitive Urban Design (WSUD) although this concept tends to be wider than just stormwater control and incorporates a full integrated water cycle management approach. A recent innovation in the USA has been Low Impact Development (LID) which tends to be broader than BMP practices and incorporates site design and planning techniques with the objective of conserving natural systems on a site and preserving the overall discharges at pre-development levels. The USA and Canada have lead the way with the implementation of structural BMPs and their more recent integration with non-structural measures to achieve a more holistic approach to stormwater catchment management. In the USA, this has been driven by the introduction of the Clean Water Act and the National Discharge Elimination System which have encouraged the combination of planning and design strategies based on ecological and conservation principles to reduce the impacts of site developments.

A major policy driver within Europe for the control of stormwater is the Water Framework Directive which focuses on the ecological structure and function of aquatic systems and by emphasising the need for an efficient management planning system at river basin level, identifies the importance of integrated water management with respect to the range of different receiving water systems. The ongoing analyses by European countries of the pressures and risks which are likely to put water bodies at risk will almost certainly identify the potential problems posed by diffuse pollution. In the urban environment, BMPs provide a possible solution and it will be interesting to see how different European countries address this situation. There are already large differences between the approaches adopted with regard to the installation and operation of these systems with, for example, Scotland being more advanced than England and Wales. This has been achieved by adopting a partnership approach (involving designers, local authorities, water authorities, the Scottish Environmental Protection Agency, local people and relevant non-governmental organisations) to ensure that BMPs are designed effectively and implemented consistently in new developments. The maintenance of the installed BMPs is supported by a Framework Agreement which allocates responsibility of above ground assets to the appropriate local authority with the water authority dealing with the below ground components. A novel approach which has been adopted in Germany is the introduction of an eco-tax directed at wastewaters discharged directly to a receiving water body. In the case of stormwater, the revenue generated is directed at the improvement of water quality involving, for example, the construction of BMPs. In Australia, urban stormwater is recognised as an important economic resource and the future emphasis will almost certainly be concentrated on storage and reclamation as part of comprehensive recycling procedures.

B THE IMPLICATIONS OF CLIMATE CHANGE ON URBAN STORMWATER MANAGEMENT: SCENARIO BUILDING

B.1 Introduction

The primary scope of this document is to provide the SWITCH project with a general common background to climate change assessments. A secondary important objective is to formulate some recommendations regarding how this climate change issue should be addressed within the investigations on stormwater management strategies in the SWITCH demo-cities.

"Climate Change 2001: The Scientific Basis", the review prepared by the Intergovernmental Panel on Climate Change (IPCC Working Group I, 2001), has concluded that globally averaged mean evaporation, precipitation, and rainfall intensity will very likely increase in response to increased concentrations of greenhouse gases in the atmosphere. One of the most challenging aspects of global change is the estimation of its potential impacts on the hydrological cycle and the human built environment. This is especially important in urban areas since world's population living in cities currently amounts to slightly less than 50% and is expected to rise to more than 60% in the next 30 years.

The methodologies used to address climate change impacts on hydrology and water resources systems have been addressed by many authors (e.g. Wood *et al*., 1997; Xu, 1999; Bronstert *et al*., 2002; Varis *et al*, 2004; Xu *et al*. 2005). They involve two major steps: (i) Determining the expected changes for different key meteorological variables such as precipitation, surface air temperature or other climatologic variables (e.g. evapotranspiration) associated with climate change and; (ii) Using these changes to determine in turn the resulting changes in surface and subsurface water behaviour (e.g. overland flow, streamflow, groundwater flow, etc.).

As for other climate change impacts' studies, the definition of an appropriate climate scenario1 is a central issue for climate change impacts on water management. The challenge becomes even tougher in urban hydrology because of the high spatial and temporal resolutions required (< 1km, minutes).

There are several methods for creating climate scenarios, which cover a considerable range of complexity, cost and time demand. Three main types of climate scenarios have been employed in impact assessments (IPCC, 2001): incremental scenarios, analogue scenarios and climate model-based scenarios (i.e. Global Climate Models or General Circulation Models, GCMs). This gradation reflects to a certain extent the history of climate change scenario construction since the construction methodology has developed in line with the type of data available. The simplest scenarios are synthetic, or arbitrary, whilst those derived from GCMs are the most complex. To date, even the simplest incremental scenarios are based upon GCM outputs.

The most common scenarios use outputs from coupled ocean-atmosphere global climate models (AOGCMs), often simply called GCMs. These models are considered to be the only credible tools currently available for simulating the response of the global climate system to increasing greenhouse gas concentrations. However, the climate change scenarios derived from GCM outputs are of insufficient spatial and temporal resolution for most regional and local applications (e.g. average grid spacing in the finest GCMs is in the order of magnitude of 300 x 300 km). Indeed, in most climate change impact studies, such as hydrological impacts of climate change, impact models are usually required to simulate sub-grid scale phenomenon and therefore require input data (such as precipitation

[1] A climate scenario is defined here as, a plausible future climate that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change (IPCC, 2001). We distinguish between a climate scenario, which refers to a plausible future climate, and a climate change scenario, which implies the difference between some plausible future climate and the present-day climate.

and temperature) at similar sub-grid scale. Moreover, continuous rainfall-runoff simulation at daily, hourly or even sub-hourly time steps is usually necessary to model the flood regime of a watershed correctly. Precipitation scenarios at such fine temporal and spatial resolution are needed in order to improve the design and to evaluate the future performance of urban drainage systems (Bronstert *et al.*, 2002).

A number of methodologies have been developed for deriving more detailed regional and site scenarios of climate change for hydrological impact studies. These are usually referred to as 'downscaling2' techniques and have been designed to bridge the gap between the information that the climate modelling community can currently provide (based on GCM outputs) and that required by the impacts' research community (Wilby and Wigley, 1997).

After briefly reviewing some of the characteristics of current GCM experiments (Section B.2), this report focuses on some of the methods currently used to convert GCM outputs into meteorological variables appropriate for hydrological impact studies (Section B.3 on Downscaling Techniques and Section B.4 on Alternatives to Downscaling Techniques). The last section focuses on the methods currently used in urban stormwater applications (Section B.5 on Climate Scenarios for Stormwater Management Studies).

The IPCC Task Group on Scenarios for Climate Impacts Assessment (IPCC, 2001) provides an excellent and up-to-date scientific assessment of past, present and future climate change. The guidelines are available for download (pdf file) from:
http://grida.no/climate/ipcc_tar/wg1/index.htm.

[2] Downscaling is the translation of an estimate to a finer spatial or temporal resolution.

B.2 General Circulation Model experiments

Climate based computer models have been widely used by scientists to study the impacts of global warming. General Circulation Models (GCMs) are considered to be the only credible tools currently available to project the response of many climate variables – such as increases in global surface temperature and sea level – to various scenarios of greenhouse gas and other human-related emissions. This section describes several of the most important features of GCMs and how they are used to model the climate under global warming

B.2.1 General Circulation Models (GCMs)

GCMs are computer programs which use fundamental laws of physics, expressed as mathematical equations, to simulate at a field of grid points the behaviour of the climate system. They also contain parameterisations for processes - such as convection - that occur on scales too small to be resolved directly. To derive a solution, the planet is considered to be covered by a 3-dimensional grid to which the basic equations are applied and evaluated (see Figure 9). At each grid point, e.g. for the atmosphere, the motion of the air (winds), heat transfer (thermodynamics), radiation (solar and terrestrial), moisture content (relative humidity) and surface hydrology (precipitation, evaporation, snow melt and runoff) are calculated as well as the interactions of these processes with neighbouring points. The computations are stepped forward in time from seasons to centuries depending on the study requirements.

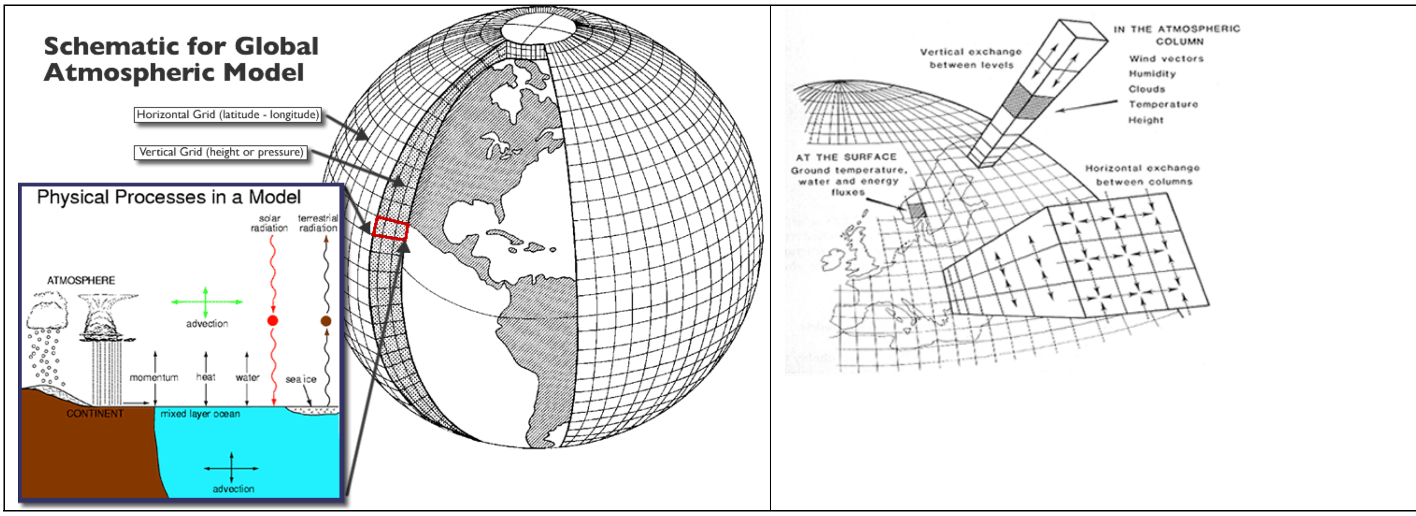


Figure 9. Grid structure for a general circulation model (from NOAA, 2006)

B.2.1.1 *Types of Climate Models*

There are many types of GCMs according to the individual components of the earth system that have been considered (Table 7). There are for example atmospheric GCMs (AGCMs) or ocean GCMs (OGCMs). An AGCM and an OGCM can be coupled together to form an atmosphere-ocean coupled general circulation model (AOGCM). With the addition of other components (such as a sea ice model or a land surface model), the AOGCM becomes the basis for a full climate model.

In coupled models, multiple components act individually to model different aspects of the total global climate. Each component is generally developed separately and operates with its own set of input and output parameters. A description of the model types and how they are developed is available at the Hadley Centre for Climate Prediction and Research (http://www.met-office.gov.uk/research/hadleycentre/index.html) or at the IPCC Data Distribution Centre (http://ipcc-ddc.cru.uea.ac.uk/ddc_gcm_guide.html).

Table 7. Type of climate models currently used

<table>
<tr><td>Component</td><td colspan="5">Types of model</td></tr>
<tr><td>Atmosphere</td><td rowspan="2">3D atmosphere model (AGCM)</td><td rowspan="3">AGCM plus 'slab' ocean</td><td>Atmospheric chemistry</td><td rowspan="3">Coupled atmosphere-ocean model (AOGCM) = AGCM plus OGCM</td><td rowspan="2">Regional climate model (RCM)</td></tr>
<tr><td>Land surface</td><td rowspan="2">Carbon cycle</td></tr>
<tr><td>Ocean</td><td>3D ocean model (OGCM)</td><td></td></tr>
</table>

Table 8 shows nine of the most commonly used GCMs (all are coupled GCMs) which are widely accepted by the scientific community for climate change modelling. The HadCM3 which is a coupled atmosphere-ocean general circulation model (AOGCM) developed at the Hadley Centre, is one of the major models used in the IPCC TAR (Third Assessment Report) in 2001.

B.2.1.2 *Resolution*

The physical phenomenon influencing atmospheric and ocean processes are calculated at a resolution defined by the cell size. Cells are described by their two dimensional projection on the earth, an area, and by their depth (as height) resulting in a three dimensional representation. Fluxes (exchanges of heat, air, and water) occur between adjacent cells. The resolution of a GCM typically refers to the size of the cells associated with the most important physical process. The spatial resolution of available GCMs ranges from 2.25 to 5.6 degrees (latitude or longitude) with between 9 and 30 layers for the atmosphere, and 0.67 to 5.6 degrees with 11 to 45 layers for the ocean). The highest resolution GCMs currently use 2.8° latitude × 2.8° longitude grids and represent global patterns well. The resolution at which a model simulates a phenomenon affects both the computational speed of a model run and the complexity of the modelling details. The time resolution of climate models varies substantially, from minutes to years depending on the nature of the models and the problem under investigation.

Table 8. Main characteristics of the GCMs (coupled GCMs).for which experiments have been commonly used for scenario construction

Current model name	Developing organization	Atmospheric GCMs (AGCM)		Ocean GCMs (OGCM)		Flux correction*	Starting and final year of simulation**
		Resolution °lat×°long	layers	Resolution °lat×°long	layers		
CCSR/NIES2	Centre for Climate Systems Research, University of Tokyo / National Institute for Environmental Studies.	5.6×5.6	20	2.8×2.8	17	Yes	1890-2100
CGCM2	Canadian Centre for Climate Modelling and Analysis	3.75×3.75	10	1.8×1.8	29	-	1990-2100
CSIRO mk2	Commonwealth Science and Industrial Research Organisation	3.2×5.6	9	3.2×5.6	21	Yes	1990-2100
CSM1.3	National Centre for Atmospheric Research	2.8×2.8	18	2×2.4	45	-	1870-2100
DOE OCM	National Centre for Atmospheric Research	2.8×2.8	18	0.67×0.67	32	-	1870-2100
ECHAM4	European Centre for Medium Range Weather Forecasts	2.8×2.8	19	2.8×2.8	11	Yes	1990-2100
GFDL_R30	Geophysical Fluid Dynamics Laboratory & NOAA	3.75×2.25	14	1.875× 2.25	18	Yes	1960-2090
HadCM3	Hadley Centre for Climate Prediction and Research	2.5×3.75	19	1.25×1.25	20	-	1990-2100
MRI2	Japanese Meteorological Research Institute	2.8×2.8	30	2×2.5	23	Yes	1990-2100

*Early generations of AOGCMs required a somewhat ad hoc process of "flux correction" to achieve a stable climate.
** Simulations under SRES scenarios

B.2.1.3 *Model inputs and outputs*

The inputs needed for the global circulation models are the boundary conditions for the atmosphere and the oceans, initial conditions to start the simulations, and a description of how important features would change with time (e.g., atmospheric carbon dioxide concentrations). Model outputs consist of climate data (including temperature, air pressure, humidity, wind speed, mean sea level pressure and vapour pressure) given for a network of grid points which cover the earth's surface. These data are generally available at a time scale as short as 15 minutes, but as there is little confidence in the predictions for time scales shorter than 1 month, especially for variables such as rainfall, only monthly data are usually provided for impact assessment studies.

B.2.2 Projections of Future Climate Change

The projections of future climate change are obtained using the previously described climate models in which changes in atmospheric composition are specified. The models "translate" these changes in composition into changes in climate, based on the physical processes governing the climate system as represented in the models. The simulated climate change depends, therefore, on projected changes in emissions (i.e. forcing scenario), the changes in atmospheric greenhouse gas and particulate (aerosol) concentrations that result, and the manner in which the models respond to these changes.

B.2.2.1 *Forcing scenarios*

Combinations of forcing scenarios have been compiled by the IPCC based on different "predictions" of the earth's future (see Table 9). The scenarios are described in the Special Report on Emission Scenarios (SRES)3. The SRES scenarios represent a standard set of forcings used by all GCMs (IPCC, 2001). The A2 scenario is the most well-studied of the SRES scenarios that assume no attempt to address global warming.

Table 9. GCM forcing scenario predictions (adapted from SRES, 2000).

Scenario	Key details
AIF1	Family A1 assumes rapid economic and population growth which peaks mid-century and declines thereafter. It also assumes introduction of new, more efficient technologies and declines in global economic disparities resulting in a more homogenized worldwide social and economic structure. The distinction F1 represents a continued reliance on fossil fuel sources.
A1T	Also in the A1 family, A1T assumes the same social and economic conditions as above; however, the T designation represents a shift to non-fossil fuel, non-carbon emitting fuel sources. A1T therefore has lower long term values for atmospheric forcings by greenhouse gases.
A1B	Another A1 scenario with the same social and economic conditions as above. The B designation represents a more balanced shift between fossil fuel and alternative energy sources. The atmospheric forcings represented are about halfway between those of A1F1 and A1T.
A2	Scenario A2 describes the development of a heterogeneous, insular and fragmented global population with greater regional disparities in fertility, economic development, and technological advancement. Overall there is a greater increase in global population. Energy sources are not globally uniform, resulting in some regions with high carbon emissions and others with low carbon emissions.
B1	B1 is similar to A1 in terms of global population patterns, but with rapid shifts towards service and information economies. There is a reduction of material consumption and shift towards resource efficient technologies. Greater global harmony and joint initiatives towards problem solving are assumed. This scenario represents the lowest rate of future total carbon emissions
B2	As in B1, B2 presents a shift towards more environmental technologies, but with the less global and more regionalized patterns. B2 represents greater social and economic heterogeneity similar to A2. Population growth is greater than that in B1, but less than A2. Total carbon emissions are greater than B1 and less than all of the A1 and A2 scenarios.

[3] The Special Report on Emission Scenarios was a report prepared by the Intergovernmental Panel on Climate Change (IPCC) for the Third Assessment Report, on future emission scenarios to be used for driving global circulation models to develop climate change scenarios. It was used to replace the IS92 scenarios used for the IPCC Second Assessment Report. The starting point for these is a number of 'storylines' describing the way in which the world (population, economies, etc.) will develop over the next 100 year. The 35 SRES scenarios represent a standard set of forcings used by all GCMs (IPCC, 2001).

B.2.2.2 *Climate change experiments*

Three types of climate change experiments have been undertaken using GCMs, which reflect the progress of research in this topic: equilibrium experiments, transient cold start experiments and transient warm start experiments (see Box 1). The construction of climate change scenarios differs according to the three types of GCM experiments. However, they all require a description of the current climate (the observed "baseline" climate) and future climate. It is the contrasting effects of these two climates on the exposure unit that determines the impact of the climate change. GCM experiments usually provide the difference or ratio, respectively in temperature and precipitation between the predicted future value and the modelled historic one (also known as the delta values; e.g. T for change in temperature).

The latest projections for global mean warming provided by the third assessment report of the IPCC (IPCC, 2001) are based on the SRES scenarios and warm start experiments. These projections are monthly time series from about 1900 to 2100 for most of the models and allow climate change scenarios to be built. Figure 10 shows how changes in climate are then obtained, i.e. how a climate change scenario may be constructed. In contrast to older experiments, only the climate change experiment is used for climate change integration in warm start experiments.

According to IPCC recommendations, 30 years of data are generally used from two time periods selected from the climate change simulation. One of these time periods represents the baseline climate (currently 1961-1990) and the other some period in the future, e.g., 2040-2069, to represent the 2050s. A 30-year mean field is calculated for each time period and the difference (or ratio) between the baseline and future time period is then calculated (i.e. $^{t2-t1}$ or $^{t2/t1}$).

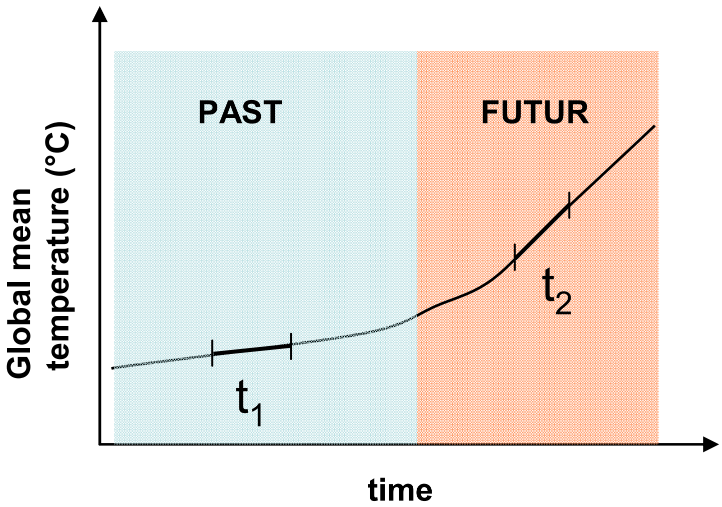


Figure 10. Climate change scenario from GCM warm start experiments.

Climate change scenarios are constructed by calculating the difference (or ratio) between a particular time period in the climate change simulation (^{t2}) and the model-simulated baseline period (^{t1}). A climate change scenario can be viewed as an interim step toward constructing a climate scenario. Usually a climate scenario requires combining the climate change scenario with a description of the current climate as represented by climate observations (see next Sections).

Results from GCM scenarios are frequently made available to the scientific community through data archives, accessible over the internet. The IPCC and the developing institutions maintain databases of output from the many different models over several different forcing scenarios (see main developing organization of GCMs in Table 8.

Box 1: GCM experiments to simulate the future climate

Three types of climate change experiments have been undertaken using global climate models, which reflect the progress of research in this topic:

- Equilibrium experiments. In earlier models, a three-dimensional atmospheric model was coupled to a very simple representation of the ocean (a 'swamp' or 'slab' ocean). Equilibrium experiments were undertaken with these GCMs and have examined the equilibrium response of the global climate following an abrupt increase in atmospheric CO2 concentration (i.e., 2xCO2). In equilibrium experiments, the step change in atmospheric composition is unrealistic. However these experiments are straightforward to conduct and useful for model diagnosis and development.
- Advances in computing technology resulted in the development of GCMs which could be run in 'transient' mode. In these AOGCMs a full 3D model of the ocean was coupled to that of the atmosphere and so the rate of change as well as the magnitude of the climate change could be modelled since the oceanic processes were well represented. Earlier transient experiments, in which no representation of historical forcing was included, are known as cold start experiments since there was a lag in the response of climate to the imposed forcing; it takes several decades after the start of the climate change experiment before there is any appreciable difference between the perturbed and control simulations. The experiments which do include a representation of historical forcing are known as warm start experiments. All of the models available from the IPCC Data Distribution Centre (http://ipccddc.cru.uea.ac.uk) are warm start transient experiments.

For more details about the GCMs experiment and the resulting projections see Chapter 9 of the IPCC Climate Change report (IPCC, 2001).

B.2.2.3 *Global projections: some results (IPCC, 2001)*

The charts in Figure 11 show: (a) the CO2 emissions for the six illustrative SRES scenarios summarised in Table 9, along with the earlier IS92a scenarios in the IPCC Second Assessment (SAR) for comparison purposes; (b) the projected CO2 concentrations; and (d) the projected temperature changes.

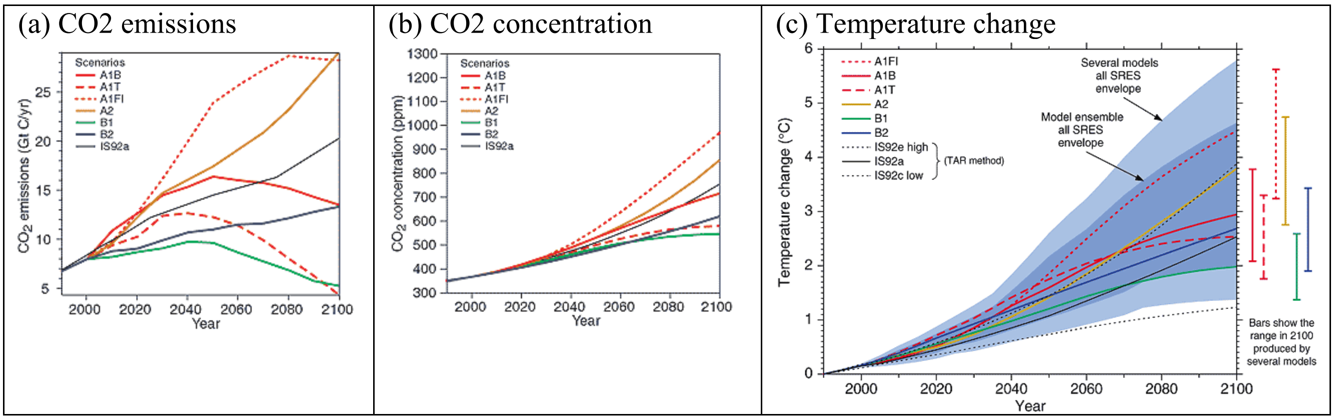


Figure 11. Range of temperature response to SRES emission scenarios (reproduced from IPCC, 2001)

As shown in Figure 11, the IPCC predicts, in its third assessment report, a global temperature change of 1.4-5.8°C due to global warming from 1990 to 2100 for the full range of the 35 SRES scenarios. The IPCC estimates also that sea levels could rise by as little as 9 cm to as much as 88 cm, by 2100 with continuing rises thereafter.

Figure 12 shows the climate responses to the SRES A2 scenario over the next 100 years for the nine GCMs. The trends in both temperature increases and precipitation changes are shown. The average temperature response for the 30-year average 2071 to 2100 relative to 1961 to 1990 is +3.0°C with a range of +1.3 to +4.5°C (Figure 12a). The average precipitation response for the 30-year average 2071 to 2100 compared with 1961 to 1990 is an increase of 3.9% with a range of 1.3 to 6.8% (Figure 12b).

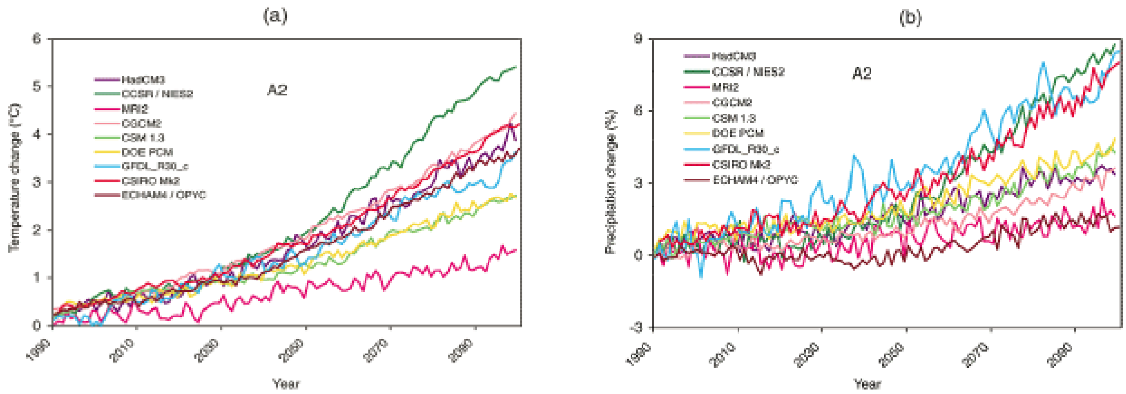


Figure 12. Predicted globally averaged temperature and precipitation changes from 1990 to 2100 under SRES simulations A2. Units are respectively in degrees Celsius and in percentage. (Reproduced from IPCC 2001)

As failures in urban drainage systems are triggered by extreme precipitations events, it is also interesting to see how climate models represent such extremes. Increased intensities for precipitation events in a future climate with increased greenhouse gases was one of the earliest model results regarding precipitation extremes, and remains a consistent result in a number of regions with improved, more detailed models (IPCC, 2001). However the climate models have not yet been sufficiently tested with regard to how realistically they represent such extremes for present conditions (Bronstert *et al*., 2002).

B.2.2.4 *Model evaluation: which GCM?*

There are many GCM experiments available from which climate scenarios can be constructed. As seen before, different state-of-the-art GCMs generally simulate different climate evolutions for the same emission scenario. Smith and Hulme (1998) have put forward a number of criteria which should be considered when selecting a GCM based on vintage, resolution, validity and representativeness of the results (see Box 2).

Box 2: Criteria which should be considered when selecting a GCM (Smith and Hulme,1998):
Vintage: it can be argued that only the most recent GCM experiments should be used, given the developments in the science and modelling of climate change which have occurred over the last 20 years. However, this is an arbitrary criterion to apply, since it is sometimes useful to consider the development history of different climate models. **Resolution:** the spatial resolution of GCMs has generally increased over time, with more recent GCMs operating at about 300 km resolution compared to the 800 km of earlier models. Although higher resolution means more spatial detail, it does not necessarily mean that more recent GCMs are superior to lower resolution versions, particularly in areas of complex terrain, e.g., mountainous regions. **Validity:** the ability of a GCM to simulate the present climate of the region in question is a stronger selection criterion than either vintage or resolution. It is assumed that if a GCM is better able to simulate the current climate of a particular region, then it will also yield a more accurate representation of the future regional climate, although this is not guaranteed. However, there is a caveat to this. A GCM may not successfully simulate the major features of the global circulation, but by some chance does manage to simulate the climate of a particular region in a reasonable manner. In this case, the user of the GCM information cannot be confident in using the future regional climate information from this particular GCM. It is advised that GCM selection should be based on an assessment of the model's ability to simulate current climate conditions at both the global and regional scales. Most modelling centres undertake analyses of the performance of their GCM in simulating current global climate and these results are published in the literature. It may be necessary for researchers interested in impacts to determine the GCM's ability to simulate regional climate for the study area in question. **Representativeness of results:** in order to meet the scenario construction condition that the scenarios should, to a reasonable extent, reflect the potential range of future regional climate change, it is necessary to consider the representativeness of each GCM's results. For example, if three GCMs are to be selected for scenario construction, then a GCM might be chosen which gives a magnitude of change fairly typical of the population of GCM experiments, together with GCM experiments which give results at the low and high end of the range of results. This may be particularly relevant when examining precipitation changes, since the climate change patterns of this variable show the greatest differences from model to model.

One of the criteria commonly used in selecting a GCM to be used in constructing regional climate scenarios for impact assessment is the performance of the GCM in simulating the present-day climate at both global and regional scales. This is evaluated by comparing the model outputs (from coupled GCM "control"4 run simulations) with a wide range of "observations". Often the most useful source for a particular variable is a product of one of the re-analysis projects (most commonly that of the National Centres for Environmental Prediction (NCEP) or from the European Centre for Medium-Range Weather Forecasts (ECMWF).

Several studies are published in the literature which present an inter-comparison of recent, readily available coupled-GCM simulations of present climate (IPCC, 2001; Covey *et al*. 2003). Further information is available concerning the inter-comparison project may be found on the Coupled Model Inter-comparison Project (CMIP) Web site at http://www-pcmdi.llnl.gov/cmip/diagsub.php. General information on the performance of coupled-GCMs can be found also in Ruosteenoja *et al*. (2003).

In general, coupled models provide credible simulations of climate, at least down to sub-continental scales and over temporal scales from seasonal to decadal (IPCC, 2001). However, comparisons and evaluations of the relative performance of coupled models is difficult. No single criterion exists to evaluate a model's overall performance. All models have strengths in some areas and weaknesses in others. No model has emerged as "the best" available to the scientific community and it is recommended that the results from a range of coupled models are utilised.

B.2.3 Representing uncertainty in Climate Scenarios

As evidenced in Figure 11, there are two key sources of uncertainty in projections of future climate that need to be considered in determining the impacts of climate change:

i) Uncertainties in future emissions (i.e. forcing scenario), which affect the radiative forcing5 of the climate system.

ii) Disagreement among climate models. Due to the different ways in which GCMs represent physical processes and feedbacks in the climate system, each climate model simulates a different global mean and regional pattern of change in climatic variables such as temperature, precipitation, cloudiness and atmospheric circulation.

An additional source of uncertainty relates to the natural variability of climate. Part of this variability is unforced, due to internal perturbations in the climate system. Another part is due to external forcing from natural phenomena such as variations in solar activity or volcanic eruptions. Uncertainties regarding future climate predictions are discussed extensively in the IPCC report (IPCC, 2001). The different approaches for representing each generic source of uncertainty are also presented. In the context of an evaluation of the full range of potential climate change impacts on a given water resources system, it is necessary to take into account the uncertainties due to different emission scenarios and due to the climate model structures and the corresponding parameterizations. The level of these uncertainties cannot be determined quantitatively and is essentially unknown; however, by using the range of predictions available from all current generation GCMs outputs, it should be possible to obtain some insight into the range of this uncertainty.

In recent years, the scientific community has focused on probabilistic approaches to the synthesis of climate projections from different GCMs, in order to produce probabilistic forecasts of climate change (e.g. Allen *et al*. 2000; Schneider, 2001; Wigley and Raper, 2001; Forest *et al*., 2002; Prudhomme *et al*., 2003; Tebaldi *et al*, 2005). This kind of approach needs a large number of GCM experiments with different emission scenarios. For instance, Wigley and Raper (2001) used 109 375 climate model simulations to produce probability density functions (PDFs) of global mean temperature change over the periods 1990 to 2030, 1990 to 2070 and 1990 to 2100 (Figure 13). Recent emphasis is given to

[4] In the control simulation, CO_2, solar brightness and other external climatic forcing is kept constant.
[5] Radiative forcing is the aggregate effect of greenhouse gas and aerosol concentrations on the radiation balance of the Earth.

quantifying regional uncertainty (e.g. Ruosteenoja *et al*., 2003, Tebaldi *et al*, 2004). For example, the National Centre for Atmospheric Research (NCAR) in the USA make available on their web site, detailed PDF representations of temperature and precipitation changes for all regions, under three SRES scenarios, based on model output from all the GCMs contributing data to the IPCC-AR4 archive. Ruosteenoja *et al*. (2003) provide also information on changes in temperature and precipitation for each season, time slice and region in the form of scatter diagrams. These diagrams are designed to provide a consistent overview of the range of coupled-GCM projections in different regions of the world (see example in Figure 14). Such a large-scale intercomparison may offer useful guidance on the selection of a representative range of climate scenarios for regional impact studies. This procedure often precedes a further "regionalization" exercise to obtain higher resolution scenarios at the scale of the impact study.

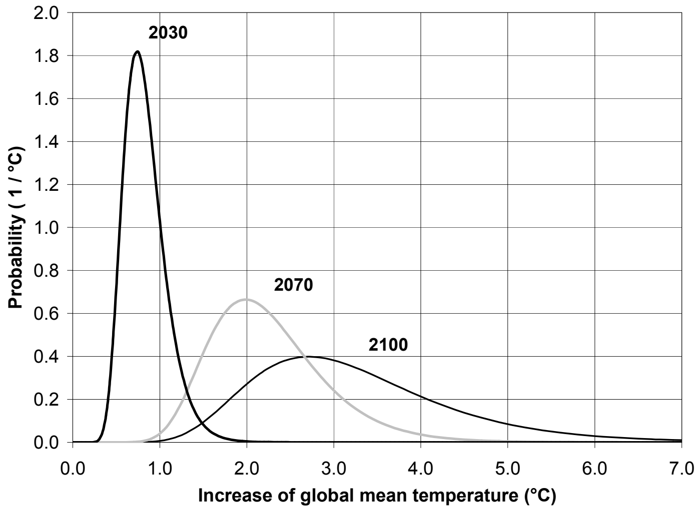


Figure 13. Evolution of uncertainties in global-mean warning (from Wigley and Raper (2001)

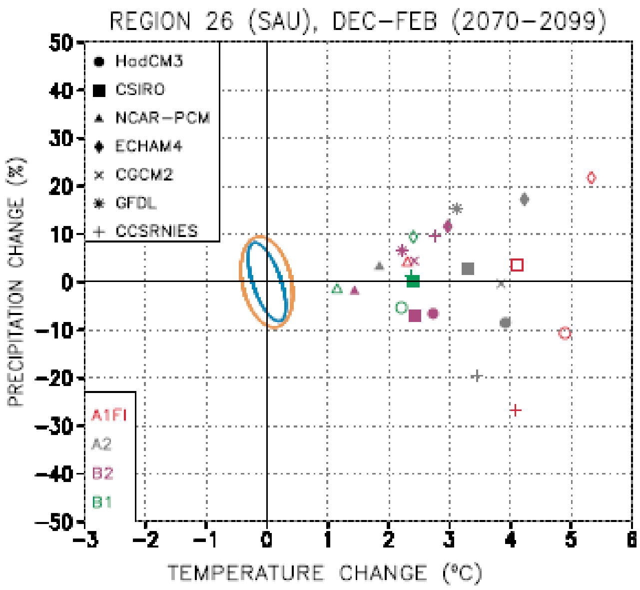


Figure 14. Projected climate change by 2070–2099 (relative to the baseline period 1961–1990) in the Southern Australia region (Reg. 26) during December-February.

Key: ovals centred on the origin are the 95% Gaussian contour ellipses of the natural tridecadal variability of temperature and precipitation, derived from the unforced 1000-year AOGCM runs performed by CGCM2 (orange) and HadCM3 (blue) (Ruosteenoja *et al*., 2003).

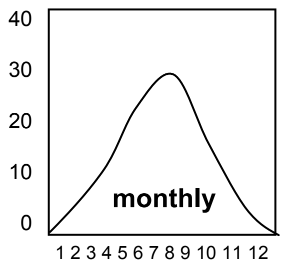
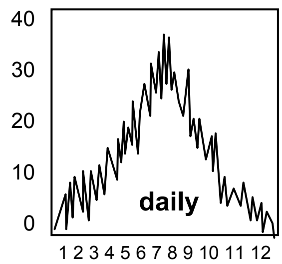
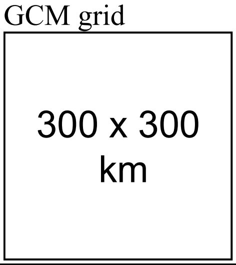
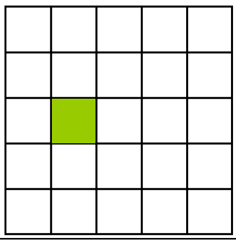
B.3 Downscaling techniques

As described in the previous section, a great deal of useful information can be derived directly from GCMs. However, reliable results are not yet available at the spatial and temporal resolutions required for many impact studies (e.g. IPCC, 2001; Xu, 1999; Bronstert *et al*., 2002; Varis *et al*. 2004). One reason for this is that GCMs were not primarily designed for climate-change impact studies, and therefore are not well suited to answering questions of primary interest to hydrologists concerning regional hydrologic variability (see Table 10).

A second reason is the high complexity of the atmospheric processes modeled by GCMs. Refining the spatial resolution would incur extremely heavy computational costs. However, GCMs are the only available tools for the detailed modeling of the future climate, and a key challenge to hydrologists is thus to express the GCM results at a scale more relevant to hydrological studies, i.e. to downscale GCM experiment outputs (Prudhomme *et al*, 2002).

There are a variety of downscaling or regionalization techniques reported in the literature (see the review papers of Wilby and Wigley, 1997; Xu, 1999; Prudhomme *et al*, 2002; Mearns *et al*. 2003). Downscaling is the term given to the process of deriving finer data (i.e. finer spatial or temporal resolution) from coarser resolution GCM data. This section presents the general principles behind the different types of downscaling techniques which are available.

Table 10. Temporal and spatial scales in GCMs and hydrological modelling.

	GCM Calculation	Available data from GCM simulations	Hydrological requirement
Time	~ 0.5h	daily, monthly 	5 min – year 
Space	300x300 km	GCM grid 	1 km2 – 500 km2 

B.3.1 Type of downscaling techniques

The downscaling techniques currently practiced are (e.g. IPCC, 2001; Mearns *et al* 2003): (i) High resolution and variable resolution “time-slice” Atmosphere GCM (AGCM) experiments, (ii) Nested limited area (or regional) climate models (RCMs), (iii) Empirical/statistical and statistical/dynamical downscaling.

The first two approaches are identified as “dynamic downscaling approaches” because they are process-based. They simulate the climate at a higher spatial resolution (15 - 50 km) using the time varying atmospheric conditions obtained from the GCMs. In contrast, the third approach uses statistical relationships between atmospheric variables given by the GCM and locally measured

climate variables. Since spatial and temporal scales in atmospheric phenomena are often related, approaches for increasing spatial resolution can also be expected to improve information at high-frequency temporal scales, such as daily or sub-daily (IPCC, 2001).

Various studies have evaluated downscaling methods, particularly in terms of their ability to reproduce surface temperature and precipitation fields (e.g. IPCC, 2001; Mearns *et al* 2003) and in terms of hydrologic implications (Wood *et al*, 2004). Table 11 provides a summary of the three previously described techniques together with an evaluation of their advantages and disadvantages. However, at the moment, there is no universal downscaling method for all situations, and all are still at the stage of development and testing (Xu *et al*. 2005).

Table 11. The role of some of climate scenarios and an evaluation of their advantages and disadvantages according to the five criteria described in the text (modified from IPCC, 2001)

Downscaling methods	Description/Use	Advantages [a]	Disadvantages [a]
High resolution/ stretched grid (AGCM)	Provide high resolution information at global/continental scales; (order of 100 km globally, or 50 km locally; accurate at monthly time step)	Provides highly resolved information (3); Information is derived from physically-based models (2); Many variables available (3); Globally consistent and allows for feedbacks (1,2)	Computationally expensive to derive multiple scenarios (4, 5); Problems in maintaining viable parametrizations across scales (1,2); High resolution is dependent on SSTs and sea ice margins from driving model (AOGCM) (2); Dependent on (usually biased) inputs from driving AOGCM (2)
Regional models	Provide high spatial/ temporal resolution information; (up to 10 to 20 km or less; accurate at daily time step)	Provides very highly resolved information (spatial and temporal) (3) Information is derived from physically-based models (2); any variables available (3); Better representation of some weather extremes than in GCMs (2, 4)	Computationally expensive, and thus few multiple scenarios (4, 5); Lack of two-way nesting may raise concern regarding completeness (2); Dependent on (usually biased) inputs from driving AOGCM (2)
Statistical downscaling	Provide point/high spatial resolution information	Can generate information on high resolution grids, or non-uniform regions (3); Potential,for some techniques, to address a diverse range of variables (3); Variables are (probably) internally consistent (2); Computationally (relatively) inexpensive (5); Suitable for locations with limited computational resources (5); Rapid application to multiple GCMs (4)	Assumes constancy of empirical relationships in the future (1, 2); Demands access to daily observational surface and/or upper air data that spans range of variability (5); Not many variables produced for some techniques (3, 5); Dependent on (usually biased) inputs from driving AOGCM (2)

Key: [a] Numbers in parentheses under Advantages and Disadvantages indicate that they are relevant to certain of the following five criteria:
(1) Consistency at regional level with global projections;
(2) Physical plausibility and realism, such that changes in different climatic variables are mutually consistent and credible, and spatial and temporal patterns of change are realistic;
(3) Appropriateness of information for impact assessments (i.e., resolution, time horizon, variables);
(4) Representativeness of the potential range of future regional climate change;
(5) Accessibility for use in impact assessments.
Note: In some applications a combination of methods may be used (e.g., regional modelling and a weather generator).

B.3.2 High resolution and variable resolution time-slice AGCM experiments

The primary factor preventing the use of higher resolutions in global scale coupled GCMs is the computing power required to generate, evaluate, and store the data produced. For many applications, it is not necessary to have a complete high resolution global data set covering thousands of years; several decades of model outputs for a small region may be sufficient. Over these time scales atmosphere global climate model (AGCM) simulations are feasible at resolutions of the order of 100 km globally, or 50 km locally with variable resolution models. This suggests identifying periods of interest (or "time-slices") within AOGCM transient simulations and modeling these with a higher resolution or variable resolution AGCM to provide additional spatial detail. The external forcings necessary to run the AGCM time slices, such as sea surface temperature (SST), sea ice distribution and greenhouse gas (GHG) and aerosol concentrations, are obtained from the corresponding periods in the AOGCM

simulation or a combination of observed and AOGCM predicted changes. Typically, a present day (e.g. 1960-1990) and a future climate (2070-2100) time slice are simulated to calculate changes in relevant climatic variables.

Use of high resolution and variable resolution global models is computationally very demanding, which poses limits on the increase in resolution obtainable with this method. This and the advantage of better atmospheric large-scale and land surface simulations suggest the use of high resolution AGCMs to obtain forcing fields for higher resolution regional model experiments (Hudson and Jones, 2002a,b cited by Mearns *et al*., 2003) or statistical downscaling, thus effectively providing an intermediate step between AOGCMs and regional and empirical models.

B.3.3 Regional climate models (RCMs)

What is commonly referred to as a nested regional climate modelling technique consists of using output from global model simulations to provide initial conditions and time-dependent lateral meteorological boundary conditions to drive high-resolution RCM simulations for selected time periods of the global model run (Mearns *et al*., 2003). To date, the nesting process is one-way with no feedback being provided to the GCM. The basic strategy underlying this one-way nesting approach is that the GCM is used to simulate the response of the global circulation to large scale forcings and the RCM is used 1) to account for sub-GCM grid scale forcings (e.g. complex topographical features and land cover inhomogeneity) in a physically-based way, and 2) to enhance the simulation of atmospheric circulations and climatic variables at fine spatial scales (up to 10 to 20 km or less). RCMs have a typical resolution in order of 50 km and run at a time scale as short as 15 min. Data is however usually provided on an hourly, six-hourly, or daily basis. As RCMs operate on some (high-resolution) grid-point scales, the results are in the form of spatial averages.

Most RCMs are based on numerical weather prediction models created for regional short-term weather forecasting (IPCC 2001). Recently, however, some research institutions have begun focusing on the creation of climate regional models capable of reaching high resolution (down to 10-20 km or less) and multi–decadal simulation times and capable of describing climate feedback mechanisms acting at the regional scale. The ability of RCMs to reproduce the present day climate has substantially improved (Varis *et al*., 2004). A number of widely used limited area modeling systems have been adapted to, or developed for, climate applications. For instance, the PRECIS program at the Hadley Centre is currently developing RCMs for three regions, Europe, the Indian subcontinent and southern Africa.

Even where significant improvements have been achieved in the areas of nested RCMs, the use of this technique is impaired by several theoretical limitations (e.g. Mearns *et al*., 2003; Varis *et al*., 2004; Xu *et al*., 2005). The principal difficulty with the use of RCMs for regional climate change impact studies is the intensive computing requirements, which have limited the length of many experiments to date. This limits, therefore, the number of scenarios which can be constructed using RCM data, with implications for the exploration of scenario uncertainty. The main benefit of RCMs is their ability to account for local topographic features or land surface conditions (e.g. land use) that may greatly influence regional weather, yet are too small to be accounted for by the coarser resolution GCMs. The spatial climate patterns produced by the RCMs are usually in better agreement with observations as compared to those of the GCMs (while the regional biases of the RCMs are not necessarily lower than those of the driving GCMs). There is also evidence that RCMs reproduce precipitation extemes well at scales not accessible to GCMs (Mearns *et al*., 2003). However, although RCMs tend to better capture the daily precipitation statistics than GCMs, the use of output data from RCM simulations directly as input to hydrologic models (or other energy balance models) in climate change research is still limited to studies at monthly and regional scales (i.e. for large watershed). This explains why, at present, RCM outputs are preferably used, when they are available, to downscale the results from such models to individual sites or localities in impact studies. It is important to note that high resolution GCMs and RCMs are subject to the same uncertainties as global scale GCMs.

B.3.4 Empirical/statistical and statistical/dynamical downscaling

Statistical downscaling regroups a wide range of techniques based on the same idea: the use of statistical relationships between atmospheric variables given by the GCM, also called "predictors" (such as the modelled sea-level pressure or geopotential height fields) and locally measured climate variables, also called "predictands" (e.g. temperature and precipitation at a certain location). In its most general form the downscaling model is:

$$Rt = F(XT) \text{ for } T<t$$

where Rt represents the local-scale predictand at single or multiple sites at time t; XT is the predictor set, and F represents the technique used to quantify the relationship between the two disparate spatial scales.

Statistical downscaling techniques differ substantially from RCMs or high resolution AGCMs in that they do not attempt to simulate atmospheric processes based on physical relationships. The main and fundamental assumption behind all these methods is that the statistical relationships derived using observed data will continue to be valid under future climate conditions (which may not be provable). Moreover, the following two implicit assumptions are made in order to use such types of downscaling methods for assessing regional climate change: (1) the predictors are variables of relevance and are realistically modeled by the GCM; (2) the predictors employed fully represent the climate change signal.

A variety of statistical downscaling techniques have been developed (e.g., Wilby *et al*., 1998a; Wilby *et al*., 1998b; Stehlik and Bardossy, 2002) and used in hydrological studies. There are three principal approaches to statistical downscaling (Wilby *et al*., 2004): 1) weather classification, 2) regression (transfer function) methods, and 3) weather generators. This categorization is similar to that used by IPCC TAR (IPCC, 2001).

B.3.4.1 *Weather classification schemes*

In weather classification schemes, statistical relationships are determined between particular atmospheric circulation types (e.g., anticyclonic or cyclonic conditions) and local weather.

The starting point of the methodology is the identification of the weather types, i.e., to group days into finite numbers of discrete weather types or "states" according to their synoptic similarity. This is typically done by applying cluster or principal components analysis to atmospheric fields or using subjective circulation classification schemes. In both cases, weather patterns are grouped according to their similarity with "nearest neighbours" or a reference set. Once the classification scheme has been selected and the weather types derived, relationships between the type and local weather variables (predictands) are calculated. For climate change studies, pressure fields from a GCM are used to drive the model. The weather types are calculated based on these pressure fields and the relationships derived using observed data are then implemented to derive site information for, say, temperature and precipitation for some point in the future.

Analogue approaches are examples of a weather classification method in which predictands are chosen by matching previous (i.e. analogous situations) to the current weather-state. Another approach is to classify spatial rainfall occurrence patterns using hidden Markov models, and then to infer corresponding synoptic weather patterns.

B.3.4.2 *Regression methods*

In the regression (transfer function) downscaling methods, statistical relationships are directly calculated between the local scale climate variable (predictand) and the variables containing the larger scale climate information (predictors).

The first step in this process is the definition of the statistical relationships based on observed climate data. This requires the identification of the large-scale climate variables (predictor variables) to be used in the transfer function(s): they must explain a high proportion of the variance in the predictand. These predictor variables may be large-scale variables, such as mean sea level pressure (MSLP) or geopotential heights, or it may be necessary to calculate area-average values for a region, roughly corresponding to the size of the relevant GCM grid box, using station data. Then a transfer function can be constructed between the identified suitable predictor variables and the local weather variables (e.g. temperature, precipitation) using an appropriate technique. Commonly applied methods include linear and non-linear regressions, canonical correlation analysis (CCA) and artificial neural networks.

To derive the predictand values under a future climate, the larger-scale predictors derived from GCM data are used to drive the transfer functions. Individual downscaling schemes differ according to the choice of the mathematical transfer function, the predictor variables or the statistical fitting procedure.

B.3.4.3 *Weather generators*

Stochastic weather time-series models ("weather generators") are statistical models that replicate the statistical attributes of a local climate variable (such as the mean and the variance) but not the observed sequences of events (Wilks and Wilby, 1999). There are two fundamental types of daily weather generators– referred to as 'Richardson' (which uses a Markov chain approach) (e.g. WGEN; Richardson, 1981) or 'serial' (e.g. LARS-WG; Semenov *et al*., 1997) types. An overview and the history of the weather generation approach can be found in Wilks and Wilby (1999).

The main use of stochastic weather generators is in the generation of synthetic daily weather data for a climate change scenario. They are adapted for statistical downscaling by conditioning their parameters on large-scale atmospheric predictors, weather states or rainfall properties (such as mean monthly rain and number of wet days in the month) derived from GCM or RCM experiments. This consists ideally of three steps (e.g. Semenov *et al*. 1997; Chen *et al*., 2006). Firstly, statistical models are established using observed daily weather data at each site, and then used to generate daily series (i.e. parameterization of the stochastic weather generator and validation). Secondly, a downscaling procedure is used to disaggregate model parameters from GCM-grid scale to local scale. Finally, daily series are generated using the weather generator with the downscaled parameters. This approach permits the incorporation of changes in the mean and variability of climate in a consistent and computationally non-expensive way. The second step (i.e. spatial downscaling procedure) is not necessary involved. If climate change scenarios are assumed to be known, these values may be used directly to perturb the parameters of the stochastic weather generator in order to simulate site-specific daily weather data (e.g. Szilagyi *et al*., 2002). Because, at present, there is little confidence in the daily data output by GCMs, particularly for use in impact applications, the GCM outputs are often in monthly rather than in daily intervals. It is hence very important to establish the parameter relationships between the daily and monthly scales.

As many hydrological rainfall-runoff models run on an hourly basis, procedures to derive a hourly precipitation generator were also developed in the context of climate change (e.g. Szilagyi *et al*., 2002). The use of a disaggregator from hourly to finer time-scales in conjunction with an hourly stochastic generator is emphasized as a useful tool for urban hydrological applications (Onof *et al*., 2005).

B.3.4.4 *Problems and challenges with Statistical Downscaling*

Statistical downscaling techniques are very flexible and their use is recommended by Wilby *et al.* (2004) for impact studies in heterogeneous environments (e.g. islands, mountains); whenever point-scale information is needed (e.g. localised flooding, soil erosion, urban drainage).

Compared with dynamic downscaling, statistical downscaling methods have the following advantages (von Storch *et al.*, 2000 cited in Xu *et al*. 2005): they are (1) based on standard and accepted statistical procedures, (2) computationally inexpensive, (3) may be flexibly crafted for specific purposes, (4) able to directly incorporate the observational record of the region. However, the following disadvantages have also been summarized by Goodess *et al*. (2001) as cited in Xu *et al*. 2005: they (1) assume that predictor/predictand relationships will be unchanged in the future, (2) require long/reliable observed data series, (3) are affected by biases in the underlying GCM.

Statistical downscaling techniques present limitations that are well identified in the literature (e.g. Wilby *et al*., 2004). A summary of their relative strengths and weaknesses is given in Table 12. All downscaling techniques suffer from the same degree of uncertainty because the basic assumptions of statistical downscaling are not verifiable (IPCC, 2001). Wilby *et al* (1998b) performed a comparison of six different downscaling techniques, applied to the same data set, and demonstrated significant variability in the prediction of daily precipitation. The implication to be had is that the selection of modelling techniques can have an equal or larger effect on predicted impacts of climate change than the predicted change itself. It is not possible to demonstrate one downscaling technique which is superior to the others (e.g. Wilby *et al*., 1998a and b; Wilby *et al*, 2004; Charles *et al*., 2004). The best approach is to examine a variety of techniques and determine which will better reproduce the variability and patterns of the region in question (IPCC 2001).

Among the statistical downscaling methods, stochastic weather generators seem to be fairly simple and computationally inexpensive tools for producing multiple-year climate change scenarios at the daily (or finer) timescale and incorporating changes in the mean and climate variability (e.g. Semenov and Barrow, 1997; Wilks, 1999).

Table 12. A summary of the strengths and weaknesses of the main statistical downscaling methods (Wilby *et al*., 2004)

Method	Strengths	Weaknesses
Weather typing (e.g. analogue method, hybrid approaches, fuzzy classification, self organizing maps, Monte Carlo methods)	Yields physically interpretable linkages to surface climates Versatile (e.g. can be applied to surface climate , air quality, flooding, erosion, etc.) Compositing for analysis of extreme events	Requires additional task of weather classification Circulation-based schemes can be insensitive to future climate forcing May not capture intra-type variations in surface climate
Regression methods (e.g. linear regression, neural network, canonical correlation analysis, kriging)	Relatively straightforward to apply Employs full range of available predictor variables “off-the-shelf” solutions and software available	Poor representation of observed variance May assume linearity and/or normality of data Poor representation of extreme events
Weather Generator (e.g. Markov chains, stochastic models, spell length methods, storm arrival times, mixture modelling)	Production of large ensembles for uncertainty analysis or long simulations for extremes Spatial interpolation of model parameters using landscape Can generate sub-daily information	Arbitrary adjustment of parameter for future climate Unanticipated effects to secondary variables of changing precipitation parameters

B.4 Alternative to down-scaling techniques

There are many alternative techniques for generating high-resolution climate scenarios other then the application of RCM and statistical downscaling schemes. It is important to mention that there exist almost as many different methods to produce climate scenarios as there are individuals conducting research on climate change impacts. The alternative approaches include the spatial interpolation of grid-point data to the required scale, the use of change factor (perturbation factor) to alter the present conditions (sometimes called "incremental scenarios") and the construction of spatial/temporal analogues. These techniques are discussed in more detail below and could be applied to downscaled (RCM) results as well as GCM results.

B.4.1 Linear Interpolation

The simplest method, adopted by hydrologists, is to interpolate the GCM outputs on to a finer grid, which is more appropriate for the proposed study. This retains the spatial pattern of the GCM without any correction to the absolute predictions. Disaggregation of the GCM rainfall pattern on a catchment can also be achieved using an empirical exponential model to distribute the rainfall intensity within the catchment (Wheater *et al*.,1999 cited in Prudhomme *et al*, 2002).

B.4.2 Incremental scenarios

The more direct and widely used approach is to use incremental scenarios where the existing conditions are altered or perturbed according to a climate change scenario. This approach regroups a wide variety of techniques, sometimes referred to as synthetic, arbitrary or hypothetical scenarios. The so-called perturbation method, which uses modelled changes within GCMs to alter time series, could be classified in these building scenario techniques. Within these approaches, the generation of climate scenarios consists of the following three stages: 1) Determination of the climate variables used as input to a hydrology model (e.g. temperature or precipitation time series, rainfall statistics); 2) Estimation of the "change factors" according to climate change scenarios (i.e. estimation of plausible changes in a particular climate variable) and 3) Perturbation of present conditions (uniform, non-uniform). Hence, as input the process requires a climate change scenario, and an actual historic record of the weather which has occurred in the studied area.

B.4.2.1 *Selection of climatic variables*

The selection of climatic variables that are to be used as inputs to the hydrological simulations is of paramount importance. The choice depends on the modelling approach and the relating data needs. With the incremental scenarios approach, it is possible to apply changes to any climate variable. Changes can be incorporated in variance as well as in means values or variable statistics. For instance, plausible changes in temperature or precipitation can be applied to observed time series.

B.4.2.2 *Estimation of plausible change (perturbation value)*

The challenge of the incremental approach is to produce relevant climate change scenarios (e.g. changes in temperature ΔT and precipitation ΔP) to perturb a particular variable. The simplest approach is to use arbitrary but plausible changes (e.g., +1, +2, +3, +4°C changes in temperature; ±15% changes in precipitation) based on expert judgement or historical measurement of change. Only a few studies have relied solely on this so called "synthetic scenarios" approach.

In most of the studies, changes in climate variables are predicted by GCM experiments (direct or downscaled GCM outputs – see previous sections). The scatter diagrams provided by Ruosteenoja *et al*. (2003) can be used for example to define the limits of temperature/ precipitation change to be employed in climate impact sensitivity studies. Average annual changes are usually calculated but it is also possible to estimate seasonal changes or monthly changes. The observed historic records are then altered according to

the modelled changes, for the GCM grid-box closest to the target site, in the so-called perturbation method.

B.4.2.3 *Perturbation method*

In practice, these changes were distributed during the year by various methods. The simple way is to adopt incremental scenarios of constant changes throughout the year (e.g. a difference of +2.5°C applied to each day in the long term series). Some studies have introduced seasonal and spatial variations in the changes and others have examined arbitrary changes in inter-annual, within-month and diurnal variability as well as changes in the mean (IPCC, 2001). For example the perturbation equation presented by Shabalova *et al*. (2003) takes into account a climate change scenario defined by the following statistics for different seasons: the absolute change of the mean temperature (XMTs) and the relative change of the mean precipitation (XMPs), of the standard deviation of daily temperature (XSDTs) and of the coefficient of variation of daily precipitation (XCVPs).

B.4.2.4 *Advantages / Disadvantages*

These methods of simple alteration of the present condition were widely used by hydrologists for rapid impact assessments at a local scale (e.g. Schreider *et al*., 2000; Etchevers *et al*., 2002; Shabalova *et al*., 2003). This is because they are simple to apply, they provide information on a range of possible changes and they can readily be applied in a consistent way to different studies and regions. In addition, because historic, observed daily values are used to generate the final values, local spatial and temporal variabilities are maintained and realistic weather sequences are generated. However, there are problems with these methods. Primarily, simple climate change scenarios seldom represent a realistic set of changes that are physically plausible; particularly if uniform changes are applied over a very large area (i.e. seasonal differences in climate change are not considered) or if assumed changes in variables are not physically consistent with each other. Unless the changes are derived from GCM results, these scenarios are not linked to greenhouse gas emissions and hence are unlikely to be consistent with the uncertainty range of global change. Moreover, the procedure assumes that the variability underlying the extreme events does not change, mainly because of the absence of reliable estimates from GCMs. Actually, the scaled and the base-line scenarios only differ in terms of their respective means, maxima and minima; all other properties of the data, such as range and variability remain unchanged (Wilby *et al*., 2004). However, it has to be admitted that changes in variability and intensity may well be more important than the changes in mean values, especially when dealing with extremes (McGuffie *et al*., 1999 cited by Prudhomme *et al*, 2002).

Another disadvantage to this approach is that it limits future weather patterns to those roughly similar past events. The temporal sequencing and spatial patterns of the historical records are unchanged (such as the sequences of storms and dry periods). Furthermore, the method does not easily apply to precipitation records because the addition (or multiplication) of observed precipitation by GCM precipitation changes cannot affect the number of rain days, the size of extreme events and may even result in negative precipitation amounts (Wilby *et al*, 2004). In brief, climate change effects of rain-day frequency and intensity are poorly captured. The main use of this approach is in the exploration of system sensitivity. Recent studies demonstrate the values of this approach, especially the use of response surfaces, for impact assessments in urban areas (Watt *et al* 2003; Semadeni-Davis, 2004). They can also be used to explore the sensitivities of different impact models by using the same synthetic scenarios in a number of different models.

B.4.3 Analogue scenarios

In analogue scenarios the fundamental assumption is that climate will respond in the same way to a unit change in forcing whatever its source or the boundary conditions in place at the time. Analogues can be either spatial or temporal - in both cases analogue scenario are constructed by identifying recorded climate regime which may resemble the future climate at the location in question.

Since the causes of changes in the analogue climate are generally not triggered by greenhouse gases, some have argued that these types of scenarios are of limited value in quantitative impact assessments of future climate change (Smith and Hulme, 1998).

B.5 Climate scenario for stormwater management studies

The designs of urban drainage systems are established on the basis of statistical recurrence criteria derived from available historical meteorological data. This procedure is therefore not well adapted to the expected changes in the return periods of major meteorological events, which could lead to increased frequencies of urban system overflows, sewer backups and flooding.

In recent years only a few studies have focused on the potential implications of climate change on the performance of existing urban drainage facilities (Schreider *et al*., 2000; Kije *et al*., 2001; Denault *et al*, 2002; Watt *et al*., 2003; Ashley *et al*., 2005; Duchesne *et al*., 2005; Denault *et al*, 2006; UKWIR, 2006). Research projects are also currently underway to develop tools and procedures for the assessment and mitigation of the effects of climate change on urban drainage systems (e.g. EPSRC 2006; OURANOS 2006; SWITCH, 2006).

As for the other real-world water systems, a quantitative analysis of the impacts of climate change on urban drainage conditions requires: (i) building climate scenarios and (ii) hydrological modeling. In the urban context, two approaches have been used to build these forcing scenarios: generation of “design storms” or generation of rainfall time series (and other climate variables). The use of one compared to the other depends on which method is used to analyze the drainage system (single-event hydrologic models or continuous simulation). The “design storm” approach is based on the modification or extrapolation of IDF (Intensity-Duration-Frequency) curves. The “rainfall time series” approach is based on either simple manipulation of current climate observations or stochastic modeling. Except for trend studies, all these climate scenarios are derived from GCM or RCM experiments. Downscaling techniques are hence usually used to convert GCM outputs into the local meteorological variables required for reliable hydrological modeling. Whatever method is used, climate scenarios remain the single greatest source of uncertainty in hydrological impact assessments.

This section presents the methods currently used to generate climate scenarios in the context of stormwater management.

B.5.1 Generation of “design storm”

Because the rational method and hydrograph methods are widely used by engineers to size drainage systems to carry runoff from urban catchments, several studies on climate change impact are based on the modification of IDF curves.

B.5.1.1 *Modifying or extrapolating historical IDF curves*

The changes in IDF curves are derived from GCM (or RCM) results, literature reviews or historical station rainfall analyses. For instance, Watt *et al*. (2003) assumed for the purposes of their studies on climate change and urban stormwater infrastructure in Canada that climate change will lead to a modest 15 percent increase in the magnitude of heavy rainfalls of the type that would normally be used in the design of urban stormwater infrastructure (here, the 10-year, 30 minute rainfall was chosen). The expected increase of 15 percent is based on a literature review. The design rainfall depth is simply increased by 15 percent. The same authors also provide results for increases in rainfall intensity of 5, 10, 15 and 20 percent. For the application of the rational method and the hydrograph model as well as the derivation of the design storm, Kije *et al*. (2001) also simply increase the existing 2 to 100 years Ottawa IDF curves by

5% to 20 % in increments of 5%. This arbitrary choice is derived from the results obtained for the station rainfall analyses and GCM modelling results.

Denault *et al*., 2002 and Denault *et al*., 2006 have developed another method to modify the IDF curves based on the nonstationarity analysis in rainfall records. Rainfall analyses are first conducted using maximum annual rainfall intensities recorded at the North Vancouver Municipal Hall rain gauge from 1964 to 1997 (Figure 15 a and b). The year 1975 is used as the baseline year for comparison because it lies at the midpoint of the period 1960-1990, which is commonly used as the baseline period in climate change studies.

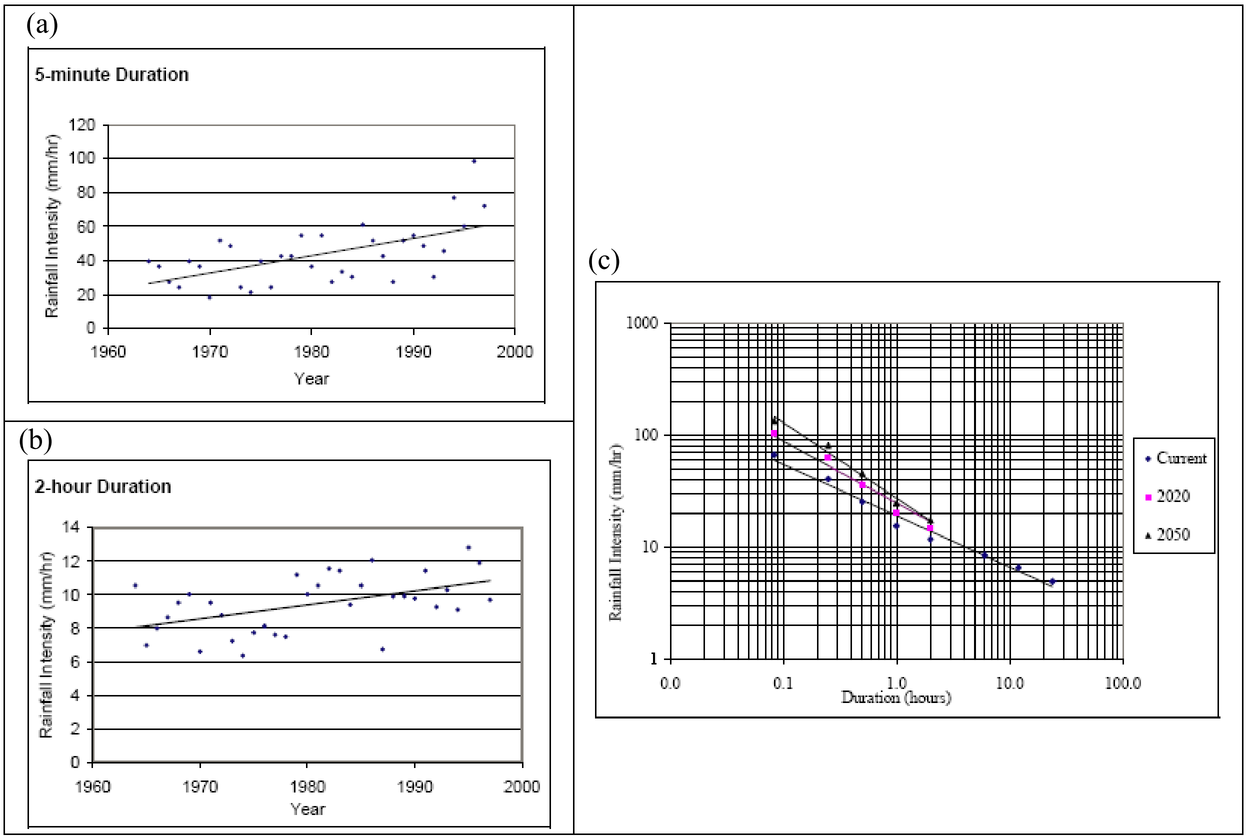


Figure 15. Temporal analysis of North Vancouver rainfall intensity trends for (a) the 5-minute and (b) 2-hour duration storms and (c) present and projected 10-year return period Intensity-Duration curves (modified from Denault *et al.*, 2002)

Statistically significant trends are obtained for the 5-minute, 15-minute, 30-minute, 1-hour and 2-hour series. The IDF curves are then modified assuming that the linear trends will persist in the future (although this is not guaranteed). The detected trends are extrapolated to build potential future rainfall scenarios. Future rainfall intensities are calculated for the years 2020 and 2050 using the method of moments where the mean is replaced by the projected future rainfall intensity from the regression line and the standard deviation is replaced by the standard error of the estimate. Extrapolations are performed only on the trends that are found to be statistically significant. Examples of temporal analysis of North Vancouver rainfall intensity trends for the 5-minute and 2-hour duration storms, as well as the resulting 10-year return period IDF are shown in Figure 15c.

B.5.1.2 *Direct use of RCM outputs*

The UK Water Industry Research sponsored project "Climate change and the hydraulic design of sewerage systems" (UKWIR, 2006) has examined the impact of future trends in rainfall on the design of new sewerage systems in the UK and on the capability of existing systems to cope with current and future rainfall. To carry out this work, the regional climate model which has been built and run by the UK Meteorological Office's Hadley Centre for Climate Prediction and Research, was used to determine likely changes in precipitation in the UK, based on scenarios of greenhouse gas emissions. This regional-scale model estimates climate change effects at 50 km resolution. Comparisons of future rainfall and current rainfall were then made, based on rainfall 'events' of a specific return period - for example, one in five years - and for specific event durations - such as 60 minutes. The comparisons were then mapped by the Meteorological Office for UKWIR and for drainage design engineers. Examples of the maps are given in Figure 16. These maps allow current design rainfall to be rescaled so that an engineer can predict the likely future effects of climate change on sewerage system performance (Spillet *et al.*, 2004).

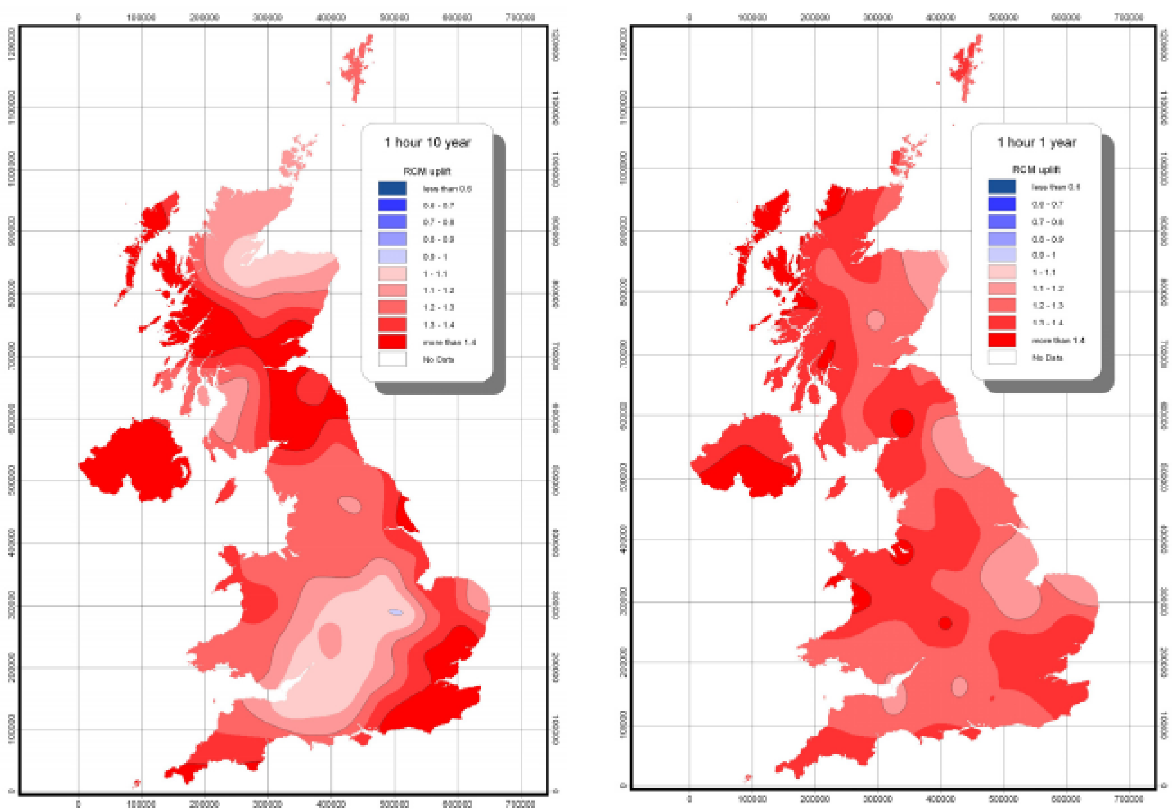


Figure 16. Ratio of 2080/present day 1 hour rainfall for 10 year and 1 year return periods

B.5.2 Generation of temperature and precipitation time series

It is accepted by hydrologists that continuous rainfall-runoff simulation at daily, hourly or even sub-hourly time steps is necessary to model the flood regime of a catchment correctly (e.g. Boughton and Droop, 2003). Two approaches have been used in urban hydrology studies to generate inputs to the rainfall-runoff models: incremental scenario approaches and approaches based on the use of a stochastic weather generator. A major disadvantage of time-series is that large amounts of data from recording rain gauges are required, and it is unlikely that these will be available for the particular site under consideration. However, this objection can be overcome to a limited extent by use of regional annual time-series.

B.5.2.1 *Incremental scenario approaches*

As seen in Section B.3, in the incremental scenario approach historical climatic time series (precipitation and temperature) are altered by either arbitrary or plausible changes derived from GCM (or RCM) experiments. The approaches are more or less complex according to each study. The easiest way is to alter systematically step-by-step the climate variables by arbitrary amounts (uniform perturbation over years). For example, Semadeni-Davies (2003, 2004) have altered incrementally daily average air temperature and precipitation data (1984–1993) between –5 and +15 ◦C and –10 and +40% respectively. These changed values drive a drainage transformation model to provide a seasonal output matrix (total of 1 000 points) where each point summarizes a transformation model run (see Figure 17; the matrix is summarized by isolines). Semadeni-Davies (2003, 2004) states that while simplistic, this method of developing climate scenarios is valuable for sensitivity analysis and lends itself to the construction of response surfaces to map the level of sensitivity. The range of climate changes that can be expected for the 2020s, 2050s and 2080s is superimposed in the form of an envelope to indicate the boundaries of possibility space. These envelopes are derived from GCM climate scenarios.

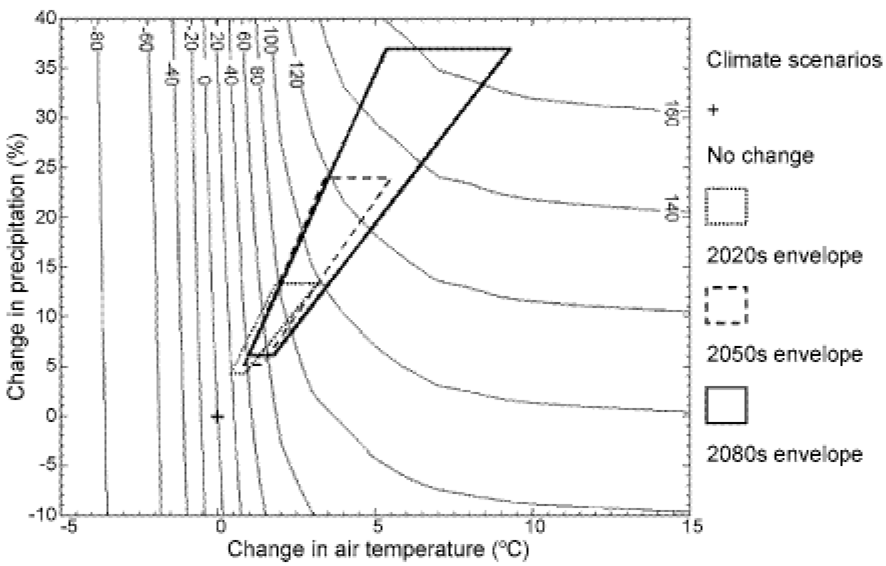


Figure 17. Response surface showing the sensitivity of winter waste water inflow (%) to incremental changes in air temperature and precipitation

To study the effects of increasing rainfall intensities caused by climatic change on drainage systems, Kije *et al*. (2001) modified thirty-nine years of hourly precipitation data on the basis of expected changes in rainfall intensities. This modification was based on a literature review in which i) increases in the frequencies of occurrence of heavy 24-hour rainfall intensities (greater than 6.4 mm/day) and ii) decreases in the frequencies of occurrence of light 24-hour rainfall intensities (less than 6.4 mm/day) compared to the climatic conditions that existed under the CO_2 concentrations observed in the early 1990s, were observed. Kije *et al*. (2001) used these results to perturb their thirty-nine years of hourly precipitation data in the following procedure: hourly rainfall intensities that were above the mean hourly rainfall intensity of 1.6 mm/hr (based on 39 years of record) were increased by 5% to 20% of the difference between the actual value and the threshold value. In order to maintain the same average rainfall volume over the period considered, rainfall intensities that were below the average value of 1.6 mm/hr were reduced by 5% to 20% of the difference between the actual value and the average.

Grum *et al*. (2005) used predictions from a regional climate model to look at the effects of climate change on extreme precipitation events. The results are presented in terms of point rainfall extremes. The analysis involved three steps. Firstly, hourly rainfall intensities from 16 point rain gauges were averaged to create a

rain gauge equivalent intensity for a 25 x 25 km square corresponding to one grid cell in the climate model. Secondly, the differences between present and future in the climate model were used to project the hourly extreme statistics of the rain gauge into the future. Thirdly, the future extremes of the square surface area were downscaled to give point rainfall extremes for the future.

B.5.2.2 *Stochastic weather generator*

As discussed earlier, a stochastic weather generator can serve as a computationally inexpensive tool to produce multiple-year climate change scenarios (most often at the daily scale) derived from GCM or RCM outputs which incorporate changes in both mean climate and in climate variability. However, only a few studies have used this approach in urban areas, even though it offers a viable route to the generation of sub-daily weather data series suitable for use in urban hydrological modelling. For example, Schreider *et al*. (2002) estimated changes in the potential damage caused by urban flood events due to increases in atmospheric CO_2 concentrations. The method employed was based on the use of a stochastic weather generator to generate a long term synthetic series (1000 years here) for 1 x CO_2 as well as for 2 x CO_2 conditions at daily scale. The double CO_2 parameters were derived from the changes observed from the CSIRO9 Global Climate Model runs using the method of Wilks (1992). The time interval, 2060–2100, was used to estimate when the doubling of CO_2 concentrations in the atmosphere will occur.

Within the previously cited UKWIR project, a stochastic rainfall generator tool was built by Imperial College (UKWIR, 2003; Onof *et al*, 2005) to generate 100 year five minute time series suitable for urban hydrological applications. To produce such fine (e.g. 5 minute) time-scale series, the method was based on the use of a disaggregator from hourly to finer (e.g. 5 minute) time-scales in conjunction with an hourly stochastic generator.

B.5.3 Future Climate Change and Flood Risk

Lehner *et al* (2006) have predicted changes within Europe for the recurrence interval (RI) of the 100 year flood between climate at present (averaged over 1961 – 1991), with expectations for 2070. As seen from Figure 18, the predictions range from "no change" predominantly in central/eastern Europe, to an order of magnitude (1:10) in N Europe. The changes in flood return period also reflect a strong gradient of change between N Europe (wetting as much as +2% per decade) and S Europe (drying by as much as -5% per decade).

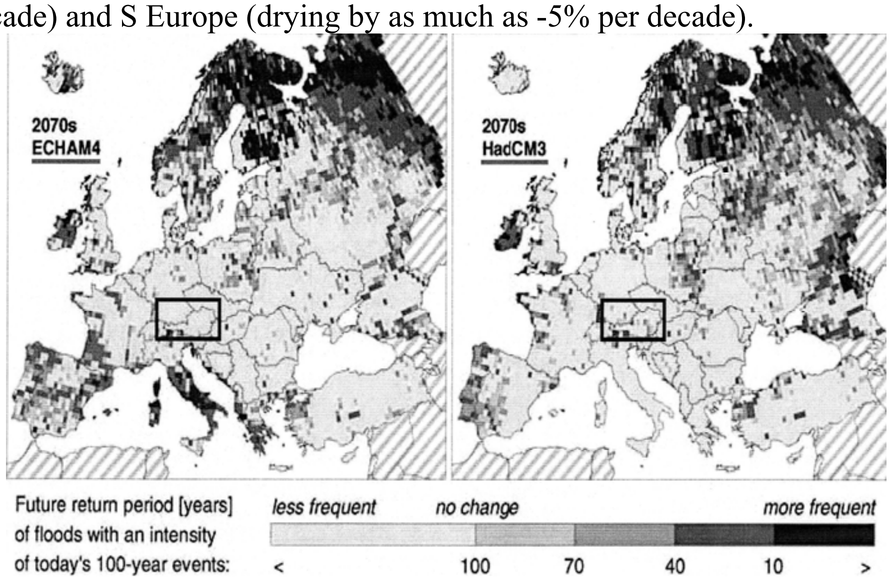


Figure 18. Predicted changes by 2070 to 100 RI flood events within Europe using two different models

However, Figure 18 also shows the considerable variability in the predictions based on which global model has been used. The ECHAM4 model suggests severe implications for most Mediterranean countries, in comparison to the HadCM3 model which only highlights Portugal as being particularly vulnerable. However the risk assessment approaches inherent in the modelling assume all scenarios are of equal probability for each exposure and/or vulnerability band e.g. a low risk bias is normally allocated to the 0°C - 2°C band. This leads to a general assumption that the 1961 – 1991 average 100 year event will become the future 2070 10 year event for freshwater runoff risk.

Very few studies have considered the incidence and impact of future extreme flows although there is some work available in the UK, German and Scandinavian although the outcomes differ and are uncertain. Figure 19, which is based on hydrological modelling, is a EU JRC analysis showing wide confidence bands for the prediction (JRC, 2005). The increase in extreme flows is shown to vary by three orders of magnitude but it is important to recognise that coarse modelling resolution precludes, to a large extent, the simulation of realistic extreme events or the detailed spatial structure of variables such as temperature and rainfall over heterogeneous surfaces.

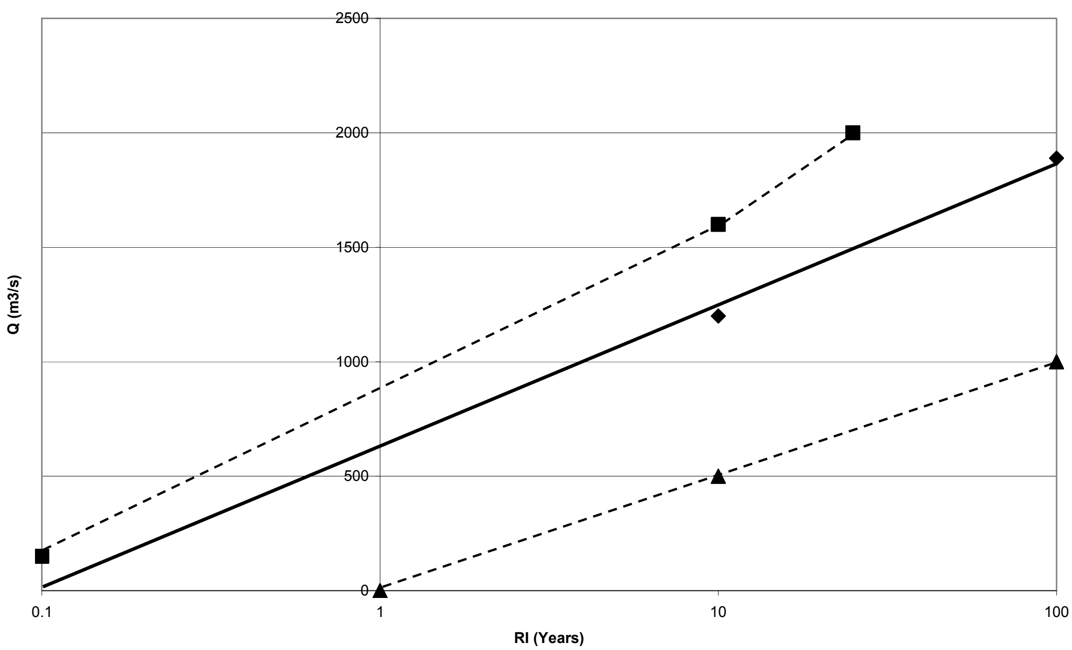


Figure 19. Extreme value analysis of peak flows.

The HadCM3 model suggests increases of up to 20% in the threshold values of a 1 day event across the UK for 2070 – 2100. The largest increases are predicted over Scotland, N Ireland and SE England with the smallest over NE England. For longer duration events (10 day), there are smaller increases in the threshold values of up to 10%. However, for the 50 year event, threshold values show a larger increase of 20% for Scotland, but a reduction of 10% for most of England. The outcome differs substantially from the previous HadRM2 and the ECHAM4 modelling approaches, both of which predicted large increases across the entire UK. Figure 20 shows a plot of the HadCM3 predictions for Lewes in SE England in respect of annual rainfall maxima and

flood return periods based on 30 day extreme rainfall statistics. Under this scenario, the 1:12 event of 1860 will become a 1:4 event by 2090.

These modelling estimates have major implications for the design of urban drainage structures. The threshold increase in the shorter duration events will have severe implications for control systems affected by such short duration intense rainfall, such as CSOs and stormwater outfalls. At the other end of the scale, an increase in longer duration event thresholds will have implications for fluvial flood defence schemes and retention/detention basins and associated spillways. Currently, the UK government spends in excess of £300M annually on flood defence. This is likely to rise by another £200M when also taking climate change impacts into account. DEFRA estimates that total capital value of assets currently at risk in the UK is some £222B with 50% lying within the Thames region; fluvial flooding representing 34% of this total value (DEFRA, 2001). To simply maintain present levels of protection from fluvial flooding would require an expenditure uplift by 2075 to over £1B (from £37M to £164M for the lower Thames region).

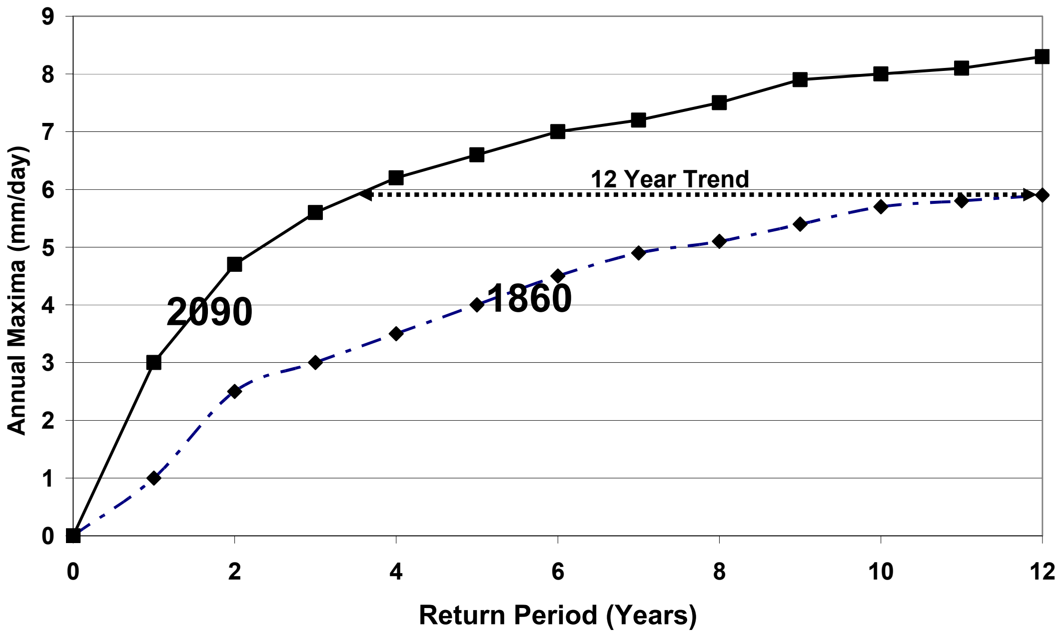


Figure 20. 30 day extreme rainfall and RIs for Lewes, Sussex, SE England

Recent floods in the UK winter period of 2000 – 2001 and in Europe during summer 2002, produced insurance claims of £1.45B and €19B, respectively. This has led the UK insurance industry (ABI) to re-evaluate its position in relation to flooding. Currently, the ABI is considering the withdrawal of flood insurance from the 10% of UK properties (worth some £200B), considered to have inadequate flood defences, and there has also been a similar global insurance response to future flood hazard. The ABI also estimate that the number of people at flood risk will double by 2080 assuming that no further mitigation measures are taken.

Within the UK, there is a current 1:30 standard (33% flood probability) operating under BS EN752, although the ABI state as a general principle, that this should be 1:75 (1.3% probability) for insurance purposes. Similarly, the existing 1:100 standard (1% probability) minimum level of

protection for new developments, is recommended by the ABI to be improved to 1:200 (0.5% probability). A 1:100 year standard requirement for piped flow systems may be considered to be unreasonable, but in any consideration of extreme event change, the routing and control of surcharged flows need to be clearly identified and covered in any risk assessment. Repeated (and increased) flood inundation would have the capacity to re-mobilise and re-distribute large amounts of pollutants from both urban surface and from in-pipe sources. This could cause much wider and extreme acute pollution effects to receiving waters and to contamination levels downstream. Increased winter rainfall could stimulate a variety of plant diseases and weed growth according to a UK government report (MAFF, 2000), which would require a greater use of pesticides. This would have runoff impacts for non-agricultural pesticide/herbicide applications given the known direct relationship between active ingredient applied and runoff loading, as well as due to enhanced application rates following increased tolerance. An increase of 2% in the loss rate of applied pesticide and associated increases in metabolite leaching (due to increased winter/spring soil wetting and hydraulic transport), would undoubtedly lead to increased pollutant loadings being delivered to receiving waters. With increased summer temperatures, there would also be a reduced period of effect, which would mean more than one application being required (Bloomfield *et al*., 2006).

Under such scenarios, urban floodplains are likely to become much more significant reservoirs of urban contaminants and hazardous substances. Figure 21 highlights some of the likely effects and deterioration directions in ecological status of what are in many cases already "highly modified" urban watercourses. Increases in late winter/spring discharge fluctuations might affect faunal life cycles and disturb breeding patterns, and thus impact on the success rates of sensitive species such as mayfly and caddisfly species. Restoration to "good ecological status" (even that defined under "heavily modified" status), will crucially depend on the interactions between climate change and recovery processes, which are as yet mainly speculative.

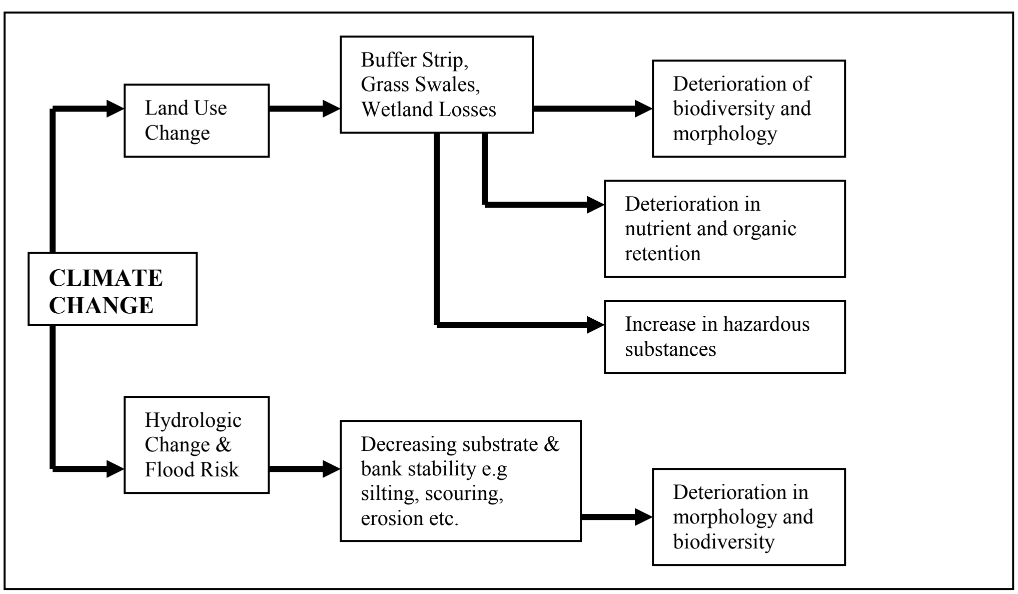


Figure 21. Climate change and possible impacts on aquatic fauna and flora.

B.6 Summary

The usual approach for assessing the impacts of climate change on urban drainage conditions is to force a hydrological transformation model with a changed climate scenario. Several factors distinguish the climate scenarios used in these studies such as the applied GCM, the downscaling methodology and the method used to characterize the uncertainty. The most important aspect is the choice of the method to analyse the drainage system (single-event hydrological models or continuous simulations) which implies the generation of either a "design storm" or a rainfall time series (and other variables).

It is accepted by the hydrology community that the single-event approach is outdated for the design and analysis of the urban stormwater infrastructure and that continuous rainfall-runoff simulation at daily, hourly or even sub-hourly time steps is necessary to model the flood regime of a catchment correctly (e.g. Boughton and Droop, 2003).

The first approaches used in urban hydrology studies to generate climatic time series (precipitation and temperature) were based on simple alteration of the present conditions according to climate change scenarios (i.e. incremental scenarios). Despite providing climatic estimates at a time step more or less relevant for urban hydrological studies, all the methods using these scaling techniques have assumed that the variability underlying the extreme events does not change. In other words, the methods allow the magnitude of events to change without adjusting the frequency; this could lead to an under-representation of low magnitude events (i.e. high return period events). A related assumption is that the number of days with precipitation will remain the same. This is the easiest type of scenario to apply, however, there is potential to create unrealistic scenarios neglecting the changes in the magnitude, character and spatial distribution of extreme rainfall events.

The approaches currently used in urban areas are based on the use of stochastic rainfall generator techniques where the parameters of the model are changed according to the changes in the mean and intensity of rainfall derived from GCM (or downscaled-GCM) climate projections. Weather generators produce daily rainfall estimates by stochastic models from data such as mean monthly rainfall and the number of wet days in the month, and may be calibrated at the site of interest. The main advantage of this downscaling procedure is that it incorporates changes in variability. Again, this procedure depends on the ability of the GCM to model correctly the changes in mean rainfall, rainfall intensity and number of wet–dry days, which is not satisfactorily achieved by current GCMs. Weather generators can also potentially improve the daily rainfall estimates, by adding more inter-daily variability in the daily series (e.g. generating hourly time-scale series). But the data they require are still not available from current GCMs, and it is not certain that they give satisfactory results (Prudhomme *et al*., 2002). The main challenge is that continuous hydrological modelling in urban areas requires even finer time step rainfall series (10 minute time steps or even shorter). This gap could be overcome using an appropriated rainfall disaggregation model in conjunction with a stochastic rainfall generator.

Finally, Figure 22 presents a schematic of the construction of climate change scenarios for urban area applications based on spatial regression downscaling, the use of a local stochastic weather generator and a disaggregation model. To date, it seems to be the most efficient procedure to obtain the desired rainfall information from the coarse resolution time series derived from climate models.

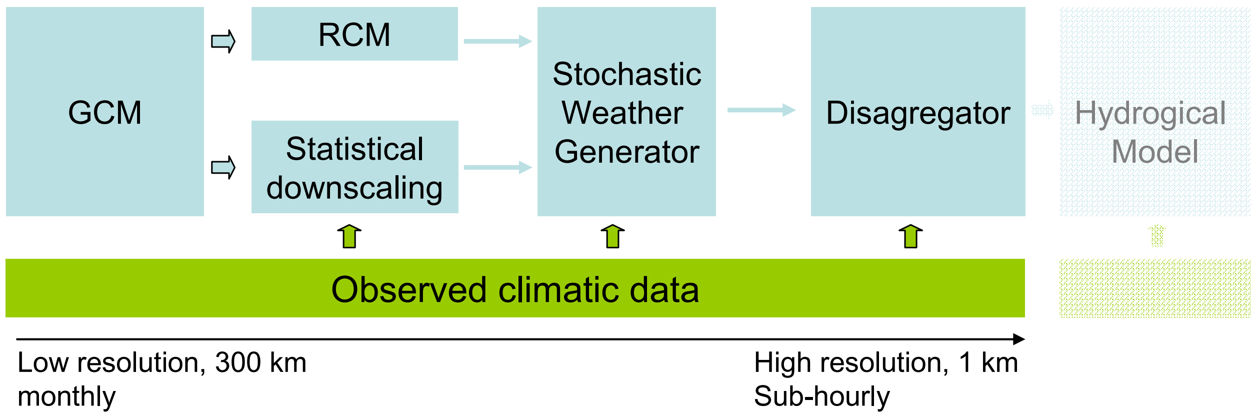


Figure 22. Schematic representation of the construction of climate change scenarios for urban area applications based on spatial regression downscaling, the use of a local stochastic weather generator and a disaggregation model.

It is not clear which method provides the most reliable estimates of daily, hourly or even sub-hourly time series of weather variables. In the light of this difficulty, the simple empirical approach described here where temperature and precipitation are changed incrementally over a range of values can be seen to be just as valid as a more sophisticated approach for a first assessment.

C THE IMPACT OF CHANGES IN ENVIRONMENTAL AND SOCIO-ECONOMIC CONDITIONS ON STORMWATER MANAGEMENT TECHNOLOGIES

C.1 Introduction

Cities and villages are dynamic systems. Larger urban agglomerations, in particular, are continually changing in terms of size and structure and constantly interact with their environments through expansion, consumption of natural resources, production of pollutants etc. This is demonstrated by the Ruhr-area which had 0.5 M inhabitants before industrialisation. Over a fifty year period the population increased to later 6 M living in the same area and the environment changed completely. Heavy air pollution, surface sealing and the conversion of natural rivers into open sewer channels were only some the consequences. Over the course of the last decade, the population has decreased again by several percent as a result of the decline of heavy industry. A further decrease of 7% has been forecast by 2015. Although at one time seen as a retrograde step, this structural change has nowadays led to high quality jobs, better life standards and a healthier environment. The revitalised River Emscher is a symbol for this process (see Figure 23).

Figure 23. Views of the River Emscher around 1890, 1960 and 2000.

Similar stories are available from all over the world, e.g. from Middle England, Detroit in Michigan, USA, and the former communist countries in Eastern Europe. Such examples show very clearly that development does not always mean beneficial growth. This is currently a major issue as most of the so-called mega-cities (generally defined as having a population >10 million) like Beijing; Mexico City and Sao Paulo, together with many smaller towns and settlements, are undergoing a process of rapid expansion. For example, in 1940 there was only one mega city (New York). However, there are now at least 20 mega-cities ranging from Lagos in Nigeria with a current population of 10 M to Tokyo, Japan, with 35 M inhabitants (Pearce, 2006).

It is well known that urban development has a strong impact on the water cycle. The following are often identified as being typical accompaniments of urbanization, although it is not the urbanization itself which causes these negative impacts but the approaches used to cope with the runoff from urban areas:

- Increases in flood peaks and volumes,
- Decreases of base flow,
- Hydraulic stresses and morphological damage,
- Water pollution.

Traditionally, stormwater is discharged as quickly as possible to the nearest receiving water by pipe systems or open ditches. Negative effects are compensated – if at all – by end of the pipe facilities such as retention ponds or clarifiers. In recent years, alternative strategies targeting the causes have become more

popular. These best management practices (BMP) – also called sustainable drainage systems (SUDs) provide the same drainage control as traditional sewer systems but also sustain the urban water cycle and control pollution at source.

It is obvious that changes in the urban development ("urban dynamics") will have an influence on the design and operation of urban stormwater management systems (USWMS) – whether traditional or source control approaches are utilised. For example, increases in the percentages of sealed surfaces due to urban sprawl result in more runoff requiring the hydraulic loads of sewers to be enlarged or new BMPs to be built. Another key impact is that the higher traffic loads associated with an expanding city will result in road runoff carrying a higher pollutant load.

With these influences in mind, strategies for design and operation of USWMS should include a detailed consideration of future urban development. This is particularly important in the case of USWMS as it usually involves long-term investments. Compared to other parts of a city's infrastructure, such as telecommunications or power supply systems, the average lifetime of a sewer system is relatively long. Major parts of an urban drainage system, for example the sewer system or retention tanks have typical life cycles of more than 50 years. In Germany, tax deduction for concrete sewer pipes has to be spread over a period of approximately 80 years (see Table 13). Many sewers in the centres of cities, such as London and Prague, are more than 100 years old.

Table 13. Average lifetime of different type of installations in urban drainage systems in years (LAWA, 2005)

Type of installation	Average life in years
Sewerage	
Urban drainage	
Sewers	
Sewers (new construction)	50 - 80 (100)
Sewers (reparation)	2 - 15
Sewers (renovation)	25 - 40 (50)
Manholes	50 - 80
Pressure pipes and culverts	30 - 50
Tanks (CSO-tanks, clarifiers)	
Construction part	(40) 50 - 70
Mechanical parts	5 - 20
Pumping stations	
Construction part	25 - 40
Mechanical parts	
Spiral pump	14 - 20
Other permanent pumps	8 - 12
Flood pumps	20 - 40
Connection pipes (properties)	50 - 80 (100)
Gully (inlet)	40 - 80
Other mechanical equipment (slide valve, gauge)	(15) 20 - 30 (40)
Infiltration systems	(15) 20 - 30
Special cars (e.g. for street cleaning)	7 - 10

The typical time horizon for an urban drainage master plan (UDMP) is usually between 25-30 years. A review of several UDMPs in Germany (Sieker, 1999) has shown that:

- Usually only increases in urban area and water consumption are taken into account as future changes. Other possible drivers such as changes in stormwater pollution, demands for higher security against flooding or new regulations are generally not considered.
- Even in cities where a decrease in population is already observed and further reduction is predicted, the urban drainage master plan may still assume an increase in surface sealing.
- Design storms are usually derived from historical recordings of rainfall. Future changes in rainfall pattern caused by climate change are not taken into account.
- Cost comparisons are done on the basis of life cycle cost assessments. With this tool, long lasting alternatives are generally preferred. Flexibility and ability to adaptive are not considered as decision criteria.

Several negative examples of this common practice can be observed in East Germany. Just after the fall of the iron curtain in the early nineties, most of the East German cities set up new UDMPs. With the euphoria of that time, enormous growth rates had been assumed which in reality did not take place. The consequences were over-sized drainage systems and treatment plants resulting in very high wastewater tariffs. An ideal UDMP would have attempted to base future scenarios for the socio-economic developments on expert knowledge. If a prediction for the socio-economic development is unclear or if the expression of caution is politically not opportune (which was the case in East Germany in the early nineties) then flexibility and the ability to adapt should be taken into account as decision criteria.

This paper identifies and describes the environmental and socio-economic drivers for urban stormwater management systems. Other drivers such as climate change are dealt with in Part B of this report with Part A identifying structural and non-structural stormwater management approaches from around the world.

C.2 Socio-economic drivers

C.2.1 Population dynamics

By July 2005, the world had 6.5 billion inhabitants, 380 million more than in 2000 representing a gain of 76 million annually (Figure 24). Despite the declining fertility levels projected over the 2005-2050 period (Figure 25), the world population is expected to reach 9.1 billion according to the medium variant and will still be adding 34 million people annually by the middle of the 21st century (United Nations, 2005).

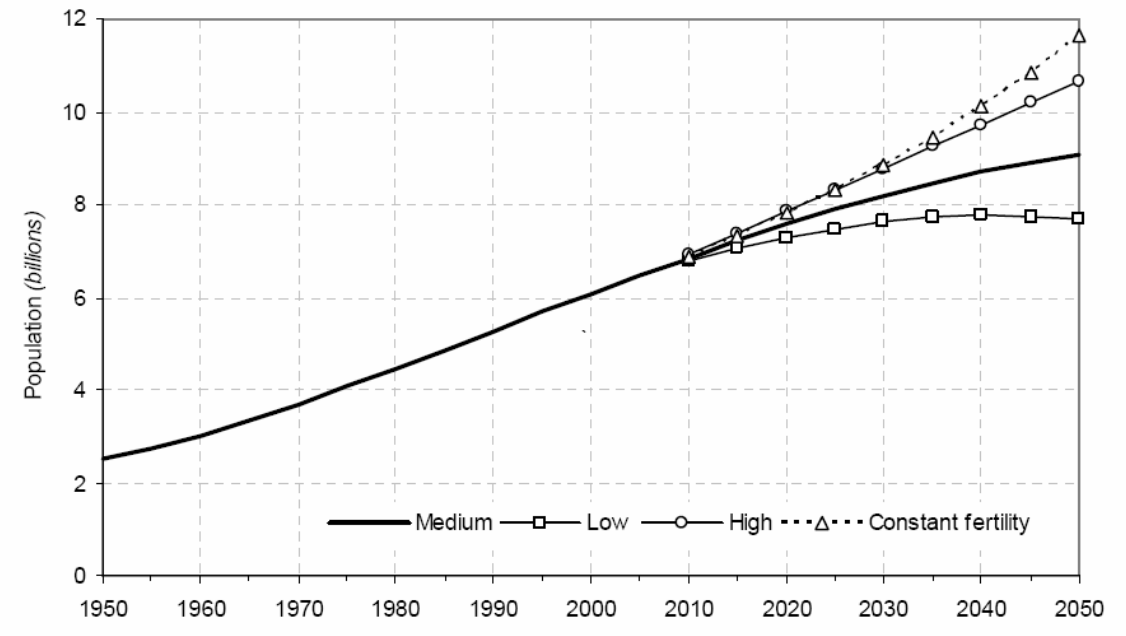


Figure 24. World population growths since 1950 and future predictions (United Nations, 2005)

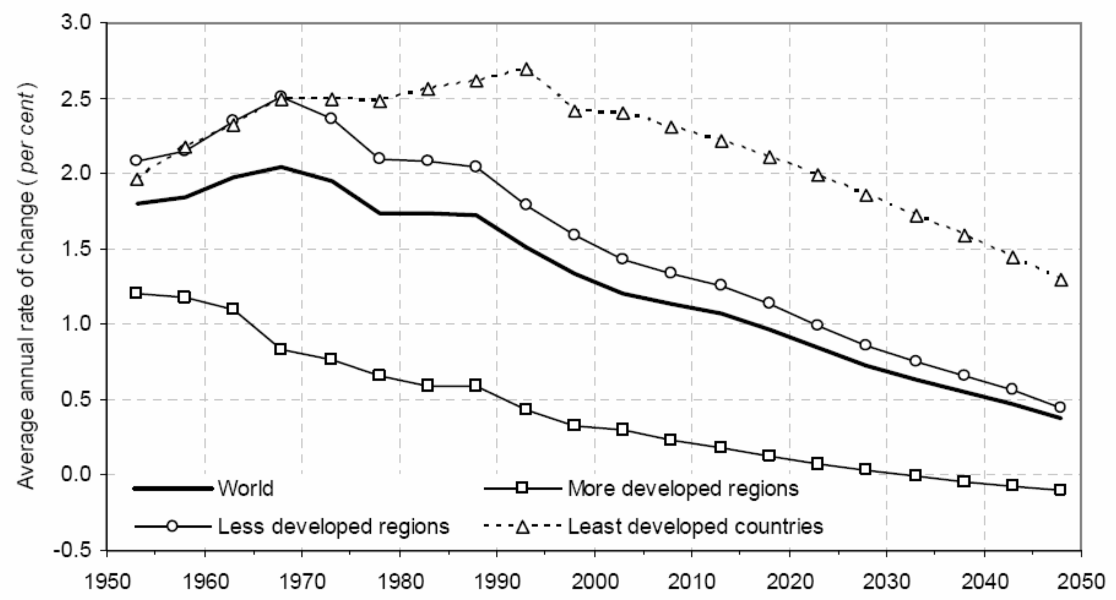


Figure 25. Fertility rates within different regions of the world since 1950 and future predictions (United Nations, 2005)

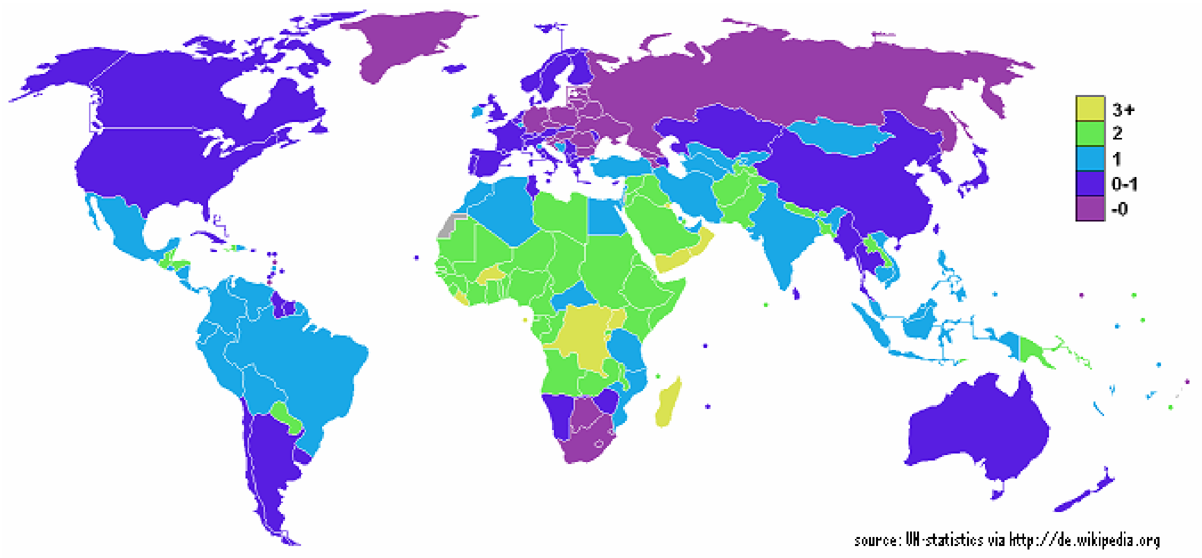


Figure 26 Alteration rates of the world population for 2006 (Wikipedia, 2006a)

However, the population development is strongly variable throughout the world. The chart presented in Figure 26 presents the changing patter for 2006 as forecast by UN Statistics Division. It can be seen, that there is a predicted decrease of population in Russia, Eastern and Central Europe, Southern Africa and parts of the Caribbean compared to a more or less stable situation in Western Europe, North America, Eastern Asia, most of Oceania and Southern South America. The regions of moderate growth include Northern South America, Central America, parts of the Caribbean, Southern, Southeastern and Central Asia. Accelerated growth is found in Central and Northern Africa, the Middle East and parts of Oceania. As the actual development is variable, the uncertainty of prediction is high. Influencing factors are e.g. existing social, political and economic frameworks, and events such as climatic changes and hazards.

For most countries a general tendency which can be observed is that populations, with or without general growth, tend to concentrate in certain locations so that inner as well as inter-regional differences increase. On the one hand this process results in the uncontrolled clustering of urban agglomerations (urban sprawl) and on the other side in relatively abandoned regions leading to difficulties in maintaining supply structures. A phenomenon that is gaining more and more importance is migration which leads to population change on regional, national or global levels. Reasons may be economic hardship, social conflicts or hazards due to natural changes.

All these factors are strongly inter-related and difficult to predict. Hence, prognosis scenarios show a wide range, as shown in Figure 24.

Population dynamics is a driver for USWM for several reasons:

- Growth or decrease of the population is causing a change in drinking water consumption, which leads to a change of wastewater flow. Consequently, problems with sedimentation or combined sewer overflows can occur.
- Population dynamics usually accompanies urbanization (see Section C.2.2) and the well-known effects of change in land use and traffic.
- Other than the direct effect mentioned above, population dynamics can also have an indirect influence on USWM, for example due to awareness for the environment or land prices.

C.2.1.1 *Increase of population*

Today, population increase is mainly an issue facing developing countries. It is often coupled with insufficient national structures, especially affecting the areas of social and medical care, education

programmes and economic security. These instabilities and insecurities often lead people to “invest” in their own family, rather than relying on the state system.

The consequences of population growth are strongly dependent on social and economic standards in the country. The main challenges are to keep medical, educational and other social structures efficient but also to provide basic needs such as drinking water and sanitation for the increasing population. Flexible structures are hence a pre-condition to meet this requirement.

C.2.1.2 *Decrease and ageing of population*

A problem that is much less common is population decrease. In industrialised countries, it is commonly induced by the social framework, economic considerations or private perspectives. Problems with sewer systems, which were planned based on population growth predictions occur regularly in these regions. In critical cases, there are problems maintaining the full function of the system for dry weather flows. While in rural regions of Western and South-western Europe the problem of depopulation has been known for some 30 years, it has become an urgent issue for Central and Eastern European regions after the fall of the iron curtain. Additional factors here are the losses of skilled workers and labourers, known as the “brain drain” with the possible loss of the full functionality of whole cities, with a wide range of consequences concerning and beyond urban water management.

More severe reasons for population reduction, often related to social or political mismanagement, are disease outbreaks, famines as consequence of bad harvests or local conflicts. Examples of these situations have been observed in Southern Africa, especially Zimbabwe and Botswana. The implications on population dynamics of the spread of AIDS, especially in third world countries, are unsure. Whilst some of these effects are considered – although not proved – to be stable, population decreases due to disasters showed historically to be overcompensated by growth afterwards.

In most industrialised societies, the ageing population poses a difficult challenge and often relates to enhanced medical services and a diminished number of progeny. There is little information about the impact of the age structure of a society on water demand and thus it is a source of uncertainty in planning USWM measures.

C.2.1.3 *Regional variation & migration*

There are various reasons for the migration of people and the results are essentially those described in the sections dealing with population increases and decreases. The different types of migration include:

- Commuting - a diurnal type of migration between place of work and place of residence. This type of migration is strongly related to sub-urbanisation.
- Seasonal migration - in accordance with a nomadic lifestyle or agricultural cycles.
- Permanent migration on regional, national or international scales - reasons may be the threat of social, economic or environmental hardship or religious, political or racial prosecution.
- Rural to urban - more common in developing countries as industrialisation takes effect or as a consequence of changes in social and / or environmental structures
- Urban to rural - more common in developed countries due to the higher costs and lower quality (space, nature) of living in urban centres (urban exodus).

Depending on the different temporal and spatial scale of migration, the effects on water resource and stormwater management will be different. Diurnal migration requires developed and increased use of traffic and transportation systems with accompanying higher levels of pollution due to combustion processes and the physical wear of transport systems and associated materials. Seasonal migration can be seen as a rather historical phenomenon, which is now mainly limited to a few regions of the world. Conflicts may arise from the difference between traditional ways of living and the demands of urban life e.g. conflicts relating to water resources and/or changed land use. A relatively new example is the "snowbird" migration of European and Northern American senior citizens towards the south during winter. The impact is, at the moment, concentrated locally but is increasingly becoming a global

phenomenon. Seasonal residents are difficult to consider, and thus provide a challenge when planning sewer and stormwater management systems.

Permanent migration is an effect of increasing importance. At the moment, 180 million people (3% of the world population) are first generation migrants. For some of the industrialized countries, immigration is a major source of population growth. Canada has an estimated population increase of 0.88% for 2006 with 0.59% of this figure being from immigration (Wikipedia, 2006b; cited from CIA World Fact Book). In the Gulf States, up to 90% of the labour force is provided by migrants. In Europe, immigration does not so much contribute to population growth, as to a reduction in population decline. The Republic of Ireland is the only EU country, where immigration contributes substantially to population growth. Figure 27 shows countries with negative (brown) balanced (green) and positive (blue) net migration balance. Note that the migration balance is not necessarily connected to the general population balance.

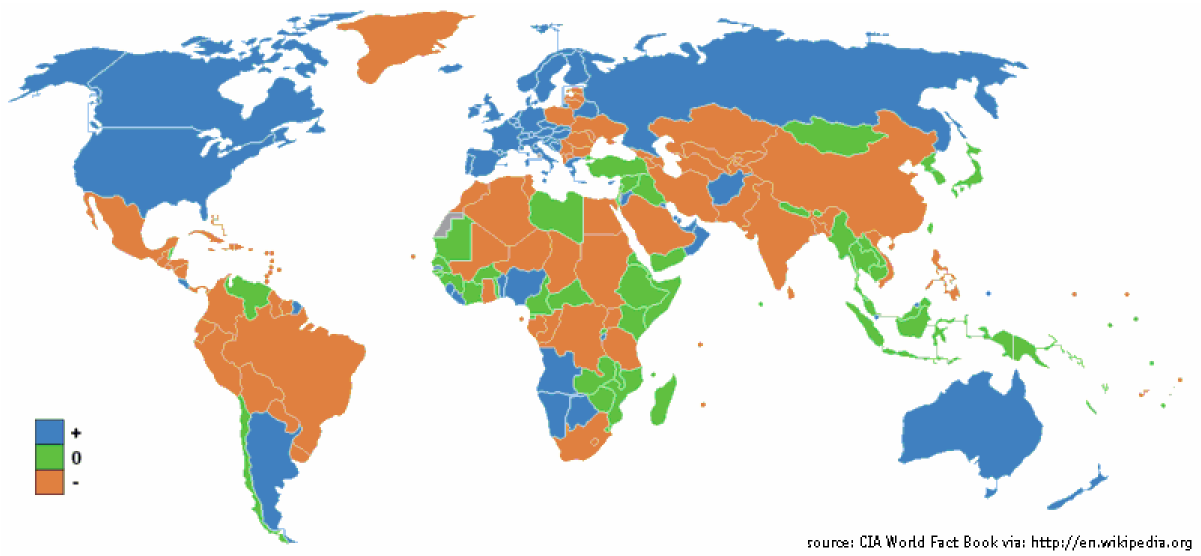


Figure 27 Countrywide migration balance of the world for 2006 (Wikipedia, 2006b)

Migrants contribute to the effects of urbanisation, as they tend to settle in urbanized regions. The impact on the sanitation and drainage systems is dependent on national immigration policies and the degree of integration into the receiving society.

C.2.2 Urbanization and urban development

An impact strongly associated with higher population density is urbanisation (United Nations, 2001), and this is demonstrated in Figure 28 where the different trends for industrialised and developing countries are shown.

There are two main characteristics of urban development. The first is the clustering of dwellings close to large urban areas in intended or uncontrolled ways, commonly known as 'urban sprawl'. Secondly, there is an increase in runoff-active surfaces due to the increased rates of sealing and compaction associated with increased levels of development. Both problems are relevant for industrialised as well as developing countries, although both the type and magnitude of their impacts may differ markedly. In the case of societies with diminishing population, the shrinkage of urban structures is imminent. In these cases, sustainable urban planning requires deconstruction of housing areas and structures to maintain efficiency.

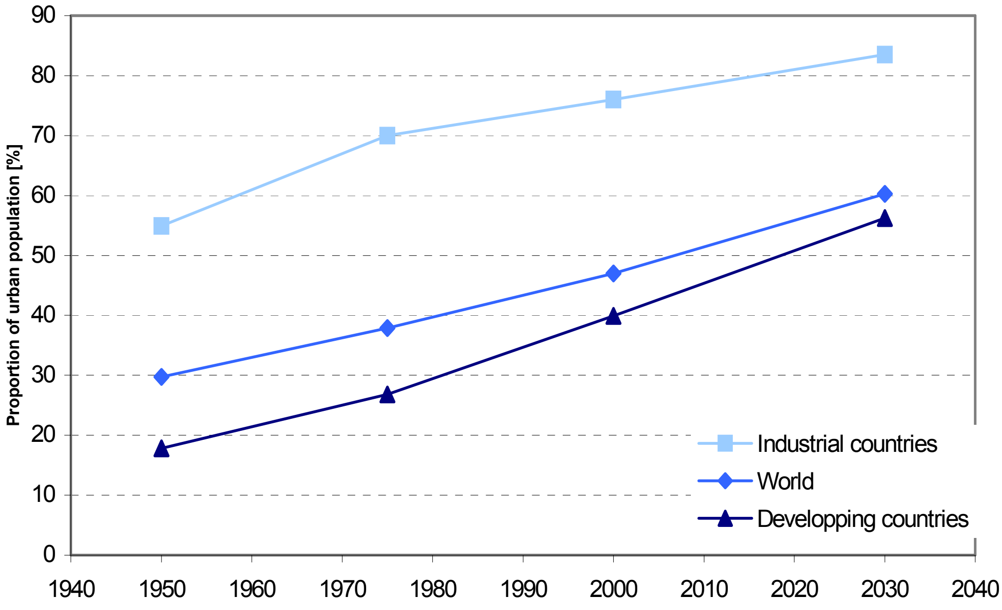


Figure 28. **Urbanisation since 1950 (United Nations, 2001)**

C.2.2.1 *Urban sprawl and re-densification*

There are two types of urban sprawl, depending on the economic conditions. In industrialized countries the consequences of concentrated urbanisation have resulted in increased technological development, leading to low transportation costs and reliability of remote communication/data transfer. In most of these countries controlled or even promoted sprawl (sub-urbanization) can be recognized, e. g. in Germany there was until 2005 the Eigenheimzulage (homestead bonus), which subsidized the construction of single household homes. At the moment, 90% of newly sealed surface in Germany consists of new or extended settlements or contributing infrastructure. In general, these dwelling units have a low population density. By 1990, it was estimated that more than 45% of the US population lived in suburban areas (Wikipedia, 2006) and the associated increase in petrol consumption due to daily commuting and other vehicle related activities, compared to European cities, is shown in Figure 29. A related problem is the restructuring of commerce from small shops in the urban centre to super- and mega- markets in suburban regions. Consequently, huge areas are covered by buildings, parking lots and supporting infrastructure, reducing heterogeneity and hence the retention capacity of the surface.

Urban sprawl consumes much more land than traditional urban developments because many new developments are of low density. One way to minimize the negative impacts of urban sprawl is re-densification. For example, encouraging land owners to split up properties and build more houses than there have been in an area previously is an approach promoted in Germany and most city planners now declare re-densification as a common goal. Such an approach was popular in the UK where a Government target of 60% of new homes to be built on brownfield sites (land that has been previously developed) was met 8 years ahead of target (Environment Agency, 2006). However, although re-densification leads towards more sustainable dwellings, it can cause difficult situations for stormwater management, especially if existing drainage systems are being overloaded.

In developing countries, urban sprawl appears basically as slums. Characteristically, they grow in an uncontrolled and often illegal way. While in the 1970s and 1980s most countries attempted to prevent the development of slums, they now appear to be tolerated, especially in newly industrializing countries as they provide a cheap labour force. A 2004 UN Habitat study reported that 1 billion people worldwide live in slums and predicted that that number may double over the next 30years (State of Our World, 2005). Problems relating to these uncontrolled dwellings include:

- no or insufficient sanitary sewer systems and hence problems with water quality in receiving water bodies, especially during storm events
- dwellings located in flood sensitive areas, as the urban planning process for these settlements is very limited and they tend to have close water access
- reduction of retention areas due to higher settlement densities in slums together with unplanned distribution
- influence on the local water cycle due to different effects connected with urbanization

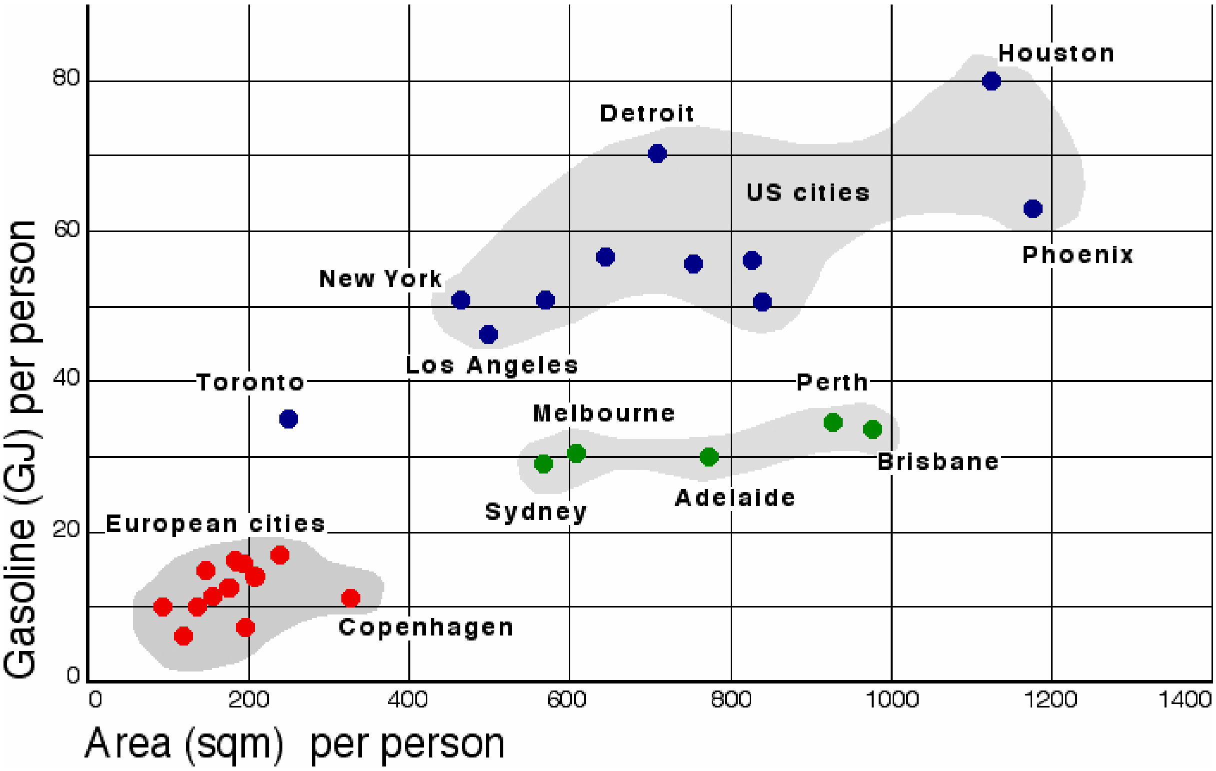


Figure 29. Relationship between urban densities and car use (Wikipedia, 2006c)

C.2.2.2 *Sealing and compaction*

Existing urban agglomerations are more compact, while the outskirts tend to spread. This type of development is not limited to so-called megacities.

At the present time it is estimated that 46,000 km² of land surface within Germany is categorized as urban, of which about 23,000 km² are paved or sealed, with buildings providing a 50% contribution to this (UBA, 2004). Whilst in 1997, the percentage of built and traffic areas was 11.7 %, this is expected to increase to 13.4 % by 2010 (BBR, 2001). Although the rate of increase is slowing down, the mean increment in these surfaces reaches nearly 1 km² each day and the main part of this increase is due to the extension of settlements with only 20 % accounted for by roads. Considering that half of these roads are contributory roads to new settlements, over 90 % of the surface use in Germany is invested in urban sprawl (UBA, 2004), despite the fact that the German population is expected to decrease.

Extended urbanization produces an impact on the local water balance. The sealing of surfaces increases the portion of runoff active areas, and compaction decreases infiltration capacity. As a result, volumes of surface runoff are increasing and due to the lower roughness of paved or constructed surfaces the concentration times are decreasing and peak discharges are rising. The consequence of this is that the water has a shorter detention time on surfaces and thus evaporation and groundwater recharge are diminishing (Figure 30).

Compaction is usually a side effect of sealing and occurs due to activities such as parking on unauthorized areas. It results in a reduced soil permeability constricting plant growth and hence an increase in erosion and a changed urban microclimate. The effect on surface runoff is similar to the effects of sealing.

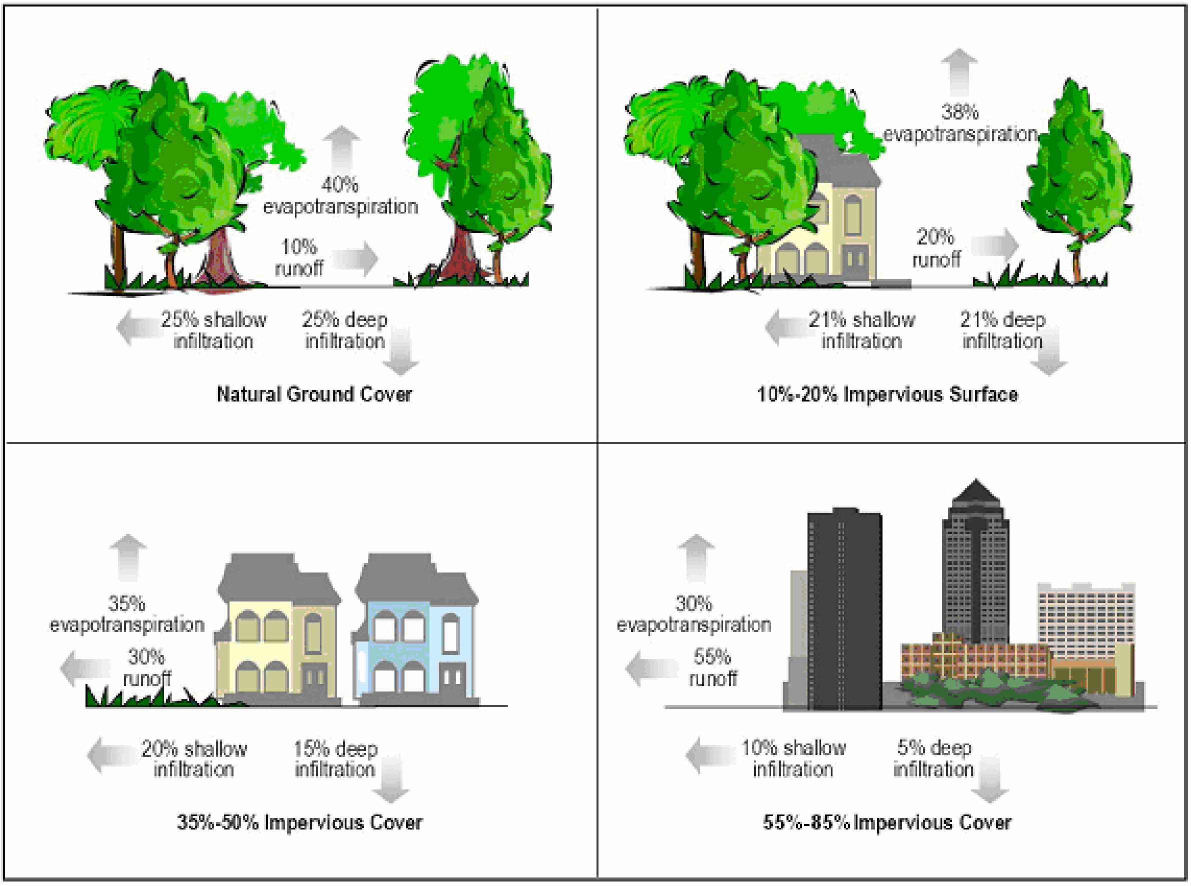


Figure 30. Effects of sealing and compaction on the local water balance (adapted from (US-EPA, 2005)

C.2.2.3 *Shrinkage and deconstruction*

While migration into the cities is commonly known in many countries e.g. Western and Southern Europe or Latin America, the shrinkage of towns is a relatively new phenomenon. It is a consequence of emigration due to economic factors and population decrease, occurring mainly in Central and Eastern Europe, but in future, it may be relevant for other regions, as well. The effect of diminishing population is difficult to cope with, especially as most infrastructures are constructed for an increasing population. Instead of uncontrolled shrinkage, there are several scenarios for the transformation into so-called lean cities. Approaches which have been realized in various Eastern German towns like Magdeburg, Halle/Neustadt or Hoyerswerda, are the tendency to concentrate maintaining structures and settlements in order to maximize utilization and to adopt a long term perspective in planning the deconstruction. Shrinking is coupled with the demolition of houses and associated supply infrastructure providing increased open spaces, which can benefit the quality of life for the remaining town.

The main challenges for the water management of shrinking towns are:

- oversized systems: longer times of residence within supply/sewer networks and hence increased potential for biochemical reactions within the transported matter; lower transport velocities and higher sedimentation rates due to lower discharges
- reductions in the efficiencies of sewage treatment plants
- higher maintenance costs per capita in less densely settled areas

- the control of surface runoff in deconstructed areas and projection of decentralized retention for stormwater.

C.2.3 Agricultural development

Water saving and land conserving technologies have valuable roles to play in enhancing water management in relation to quantity and quality aspects.

C.2.3.1 *Use of stormwater for farming*

As the population grows and society progresses, there is a rising demand for more and better quality food. This requirement can be met by expanding agricultural land use or enhancing effectiveness of cultivation e.g. through irrigation. In both cases there is a need for higher water usage. The increased consumption of meat that can be observed in connection with a rising standard of living additionally increases the demand for water substantially. For example, the amount of water consumed to supply 10g of protein is 67 L in the case of potatoes rising to 303 L for poultry with it taking 1000 L of water to produce 10g of protein from beef (State of the World, 2004). Particularly in highly urbanized regions, e.g. Central America with up to 80% urbanization, and in regions of strong year-to-year or season-to-season climatic variation, e.g. Western and Southern Asian countries, the storage of urban stormwater represents a possible solution to the increased demand.

C.2.3.2 *Agricultural runoff and erosion*

The intensification of conventional agriculture causes an increased erosion rate at field level. Among the various reasons are tillage (plough) operations into deeper lying layers, the spatial and temporal interaction of compaction and loosening of the ground, and periods of denudation between the cultivation phases. Consequently, soil particles are washed out, and transported e.g. into sewer systems or receiving water bodies. The washed out material may sediment out, depending on the soil type and the hydraulic properties of the receiving channel, in sections of low flow velocities. As well as reducing the flow capacity of the receiving system, the washed out material may cause problems in water treatment processes and increase costs as a result of the larger amounts of solids to be removed. Another effect is the impact on the load and nutrient balances of ecosystems, e. g. in rivers the hyporheic zone (interstitial) may become blocked or the sedimentation rate of algae in lakes increased. The consequences of erosion listed above are of ascending importance for urban stormwater management. On the one hand, in connection with urban sprawl, the impact on urban sewer systems gets bigger, while on the other side, the fertility of eroded fields decreases and hence the capacity to nourish people diminishes.

The effects of unsustainable cultivation methods in the vicinity of urban environments can be observed in many German viticultural regions. Their location on steep slopes in combination with gradient directed cultivation practices, which are advantageous for the farming and harvesting processes, leads to strongly increased erosion rates. As most of the viticultural regions are densely settled, and dwellings are often situated at the foot of the hills or in valleys, the eroded load enters USWMS via surface runoff. There are two strategies to cope with the challenge of increasing erosion loads from agricultural surfaces. One is lowering the release of sediments from the fields, e.g. by changing cultivation practices such as conservational tillage (Schmidt *et al.*, 2001); the other way could be to establish sand traps in the environment of the fields.

C.2.4 Wastewater production

Combined sewer systems, although no longer state of the art (Sieker *et al*., 2004), are still common in European cities. In Germany, approx. 60% of all municipalities have combined sewer systems (DWA, 2006). The overflows of combined systems (CSOs) do not only depend on stormwater runoff but also on the base flow, which is a mixture of wastewater and water infiltrating from other sources. Wastewater base flow depends on the number of people and industries connected to the sewer system and their specific wastewater production. In London (UK), there are currently 57 CSOs which discharge into the River Thames, some as many as 60 times per year, which between them discharge an annual average of 20 million cubic metres of storm sewage directly into the river ecosystem (Thames Tideway Strategic Study, 2004). In conventional urban water systems, wastewater production

is more or less related to water consumption. Therefore, specific water consumption is a driver for USWM.

C.2.4.1 *Specific water consumption per capita*

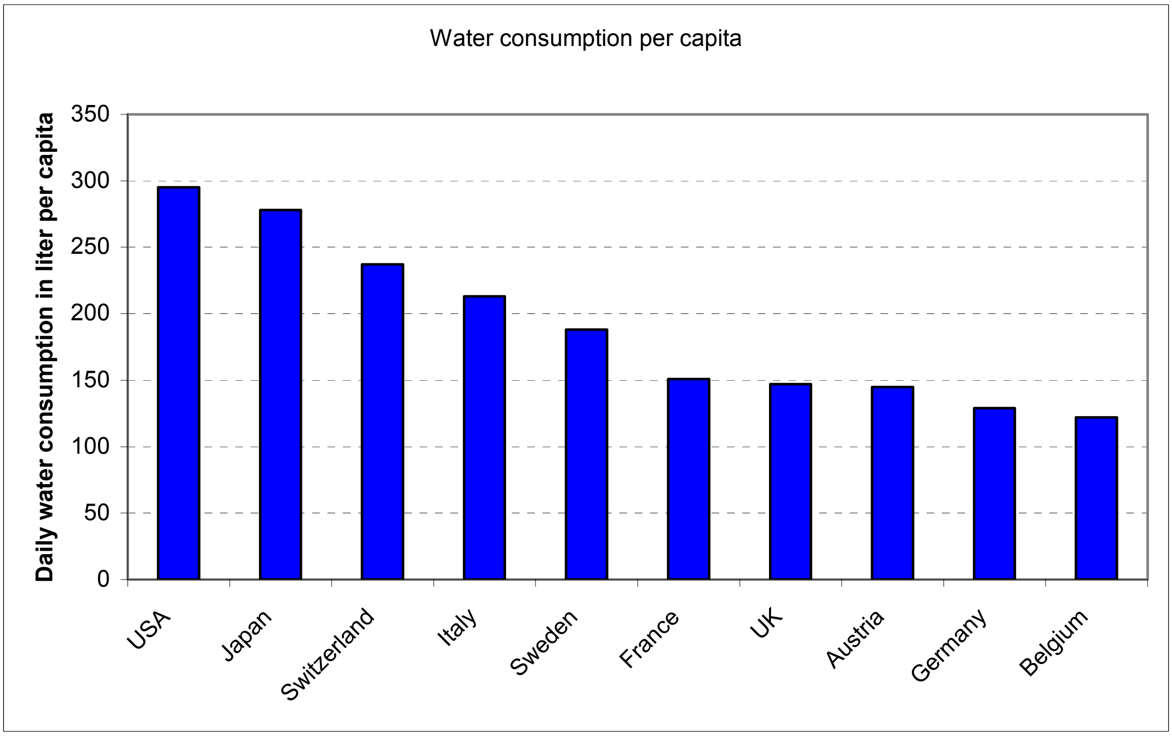


Figure 31. Daily water consumption (litre per capita) for different countries in 2006

Water consumption in private households varies considerably throughout the world with, for example, the typical consumption in the USA being over twice the amount used in Belgium (Figure 31). Figure 32 shows the water consumption in private households in Germany (West) from 1975 until 2004 together with different earlier predictions for how water consumption could increase between 1975 and 2000. This example demonstrates very clearly the difficulty of forecasting socio-economic drivers such as this.

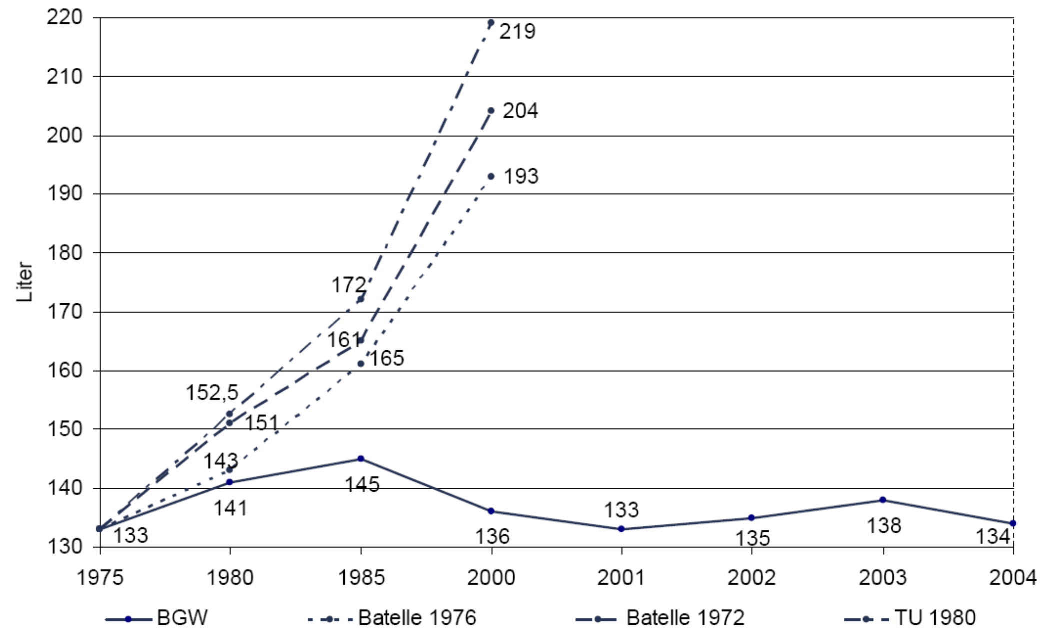


Figure 32. Water consumption (prognoses and real) per capita in Germany (West) (BGW, 2006)

C.2.4.2 *Water consumption of industry*

Water consumption in the industrial sector depends very much on the techniques used for production. In recent years, far-reaching developments have been achieved in this field, which in Germany have resulted in a reduction of water consumption for industrial production (Figure 33). However, on a global level, the trends in industrial consumption are somewhat different (Figure 34).

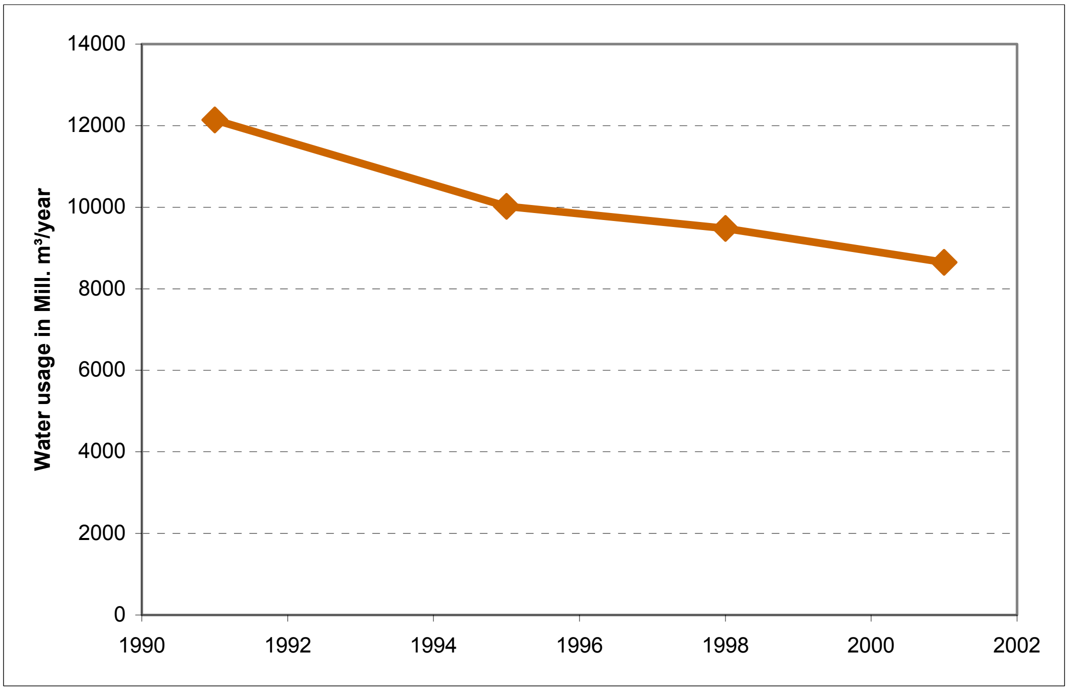


Figure 33. Water usage for industrial production in Germany (UBA, 2006a)

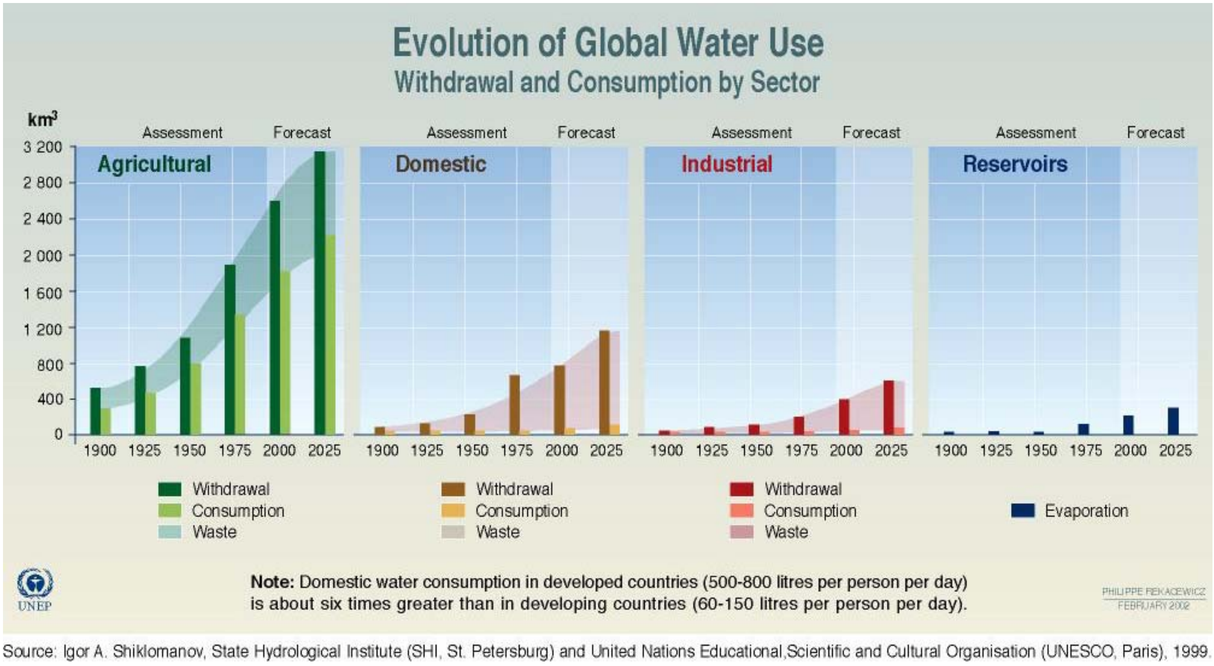


Figure 34. Global water use (UNEP, 2006)

C.2.4.3 *Wastewater production*

Although in conventional urban water systems, wastewater flow is related to water consumption, there are other influencing factors such as leakage, stormwater drainage and the degree of connection.

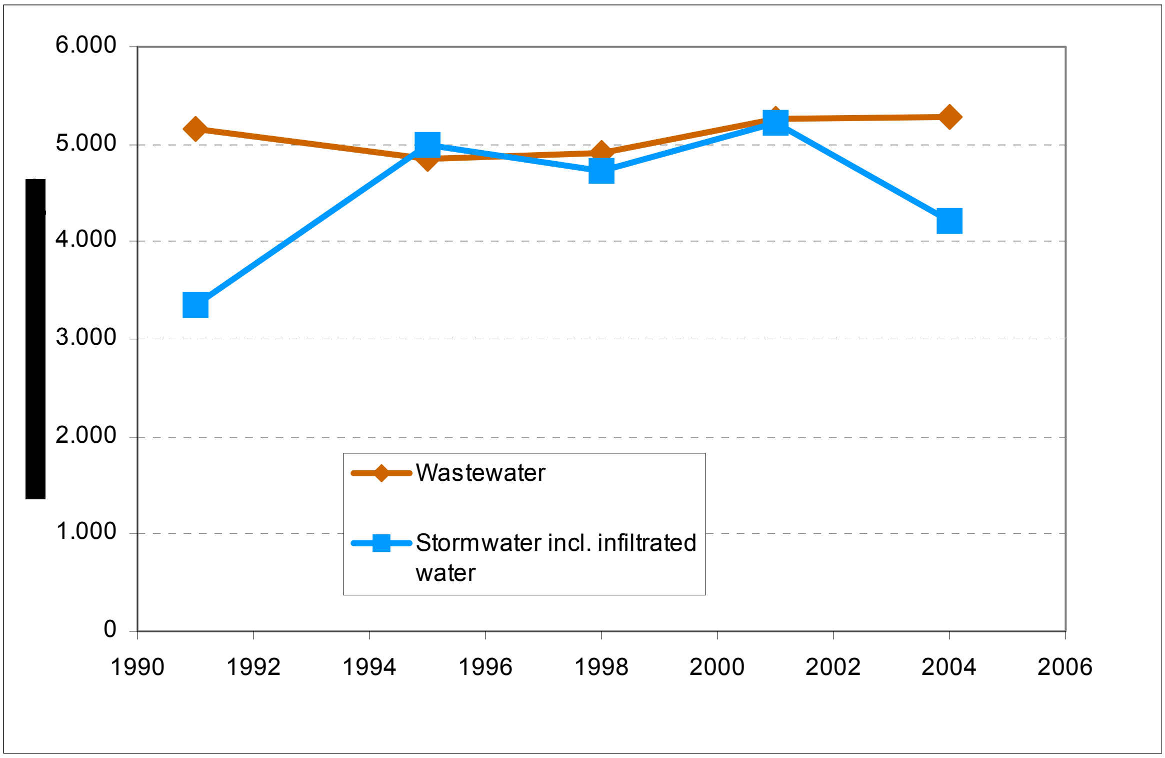


Figure 35. Treated wastewater in million m /year in Germany (Destatis, 2006)

Although Figure 32 and Figure 33 show a decrease of water consumption for households and industry, Figure 35 illustrates a slight increase in wastewater production for Germany. This can be explained by the increased degree of connection.

C.2.4.4 *Wastewater recycling*

The degree of wastewater recycling determines the volume of waste flow and therefore is a driver for USWM. In many fields of industry, wastewater recycling is already common practice and one reason for the decreasing water consumption in this sector. On the other hand, wastewater recycling in private households is still very uncommon.

C.2.5 Economic aspects

Economical aspects are a clear driving force in the planning of stormwater drainage systems. Apart from the effectiveness of the actual construction process, aspects of vulnerability, adaptability and sustainability have to be considered.

C.2.5.1 *Economic development and income structure*

In western countries, approximately 1-2% of the gross domestic product (GDP) is spent on urban water management. Table 14 shows the mean annual costs per household for drinking water supply and wastewater disposal in selected western countries (Schönbäck *et al*., 2002).

Table 14. Annual cost in Euro per household for drinking water supply and wastewater disposal (Schönbäck *et al*., 2002) in selected countries

	Austria	France	England and Wales
	Household with consumption of 150 m³	Household with consumption of 120 m³	Real household
Drinking water	60,70	63,14	70,67
Wastewater	83,87	69,19	79,59
Total cost per household	144,57	132,33	150,24

In most countries, the fees citizens have to pay for drinking water supply and urban drainage do not cover the real cost. It is one goal of the European Water Framework Directive to establish fair price policies (Water Framework Directive, 2000). The share of the cost for USWM is not well documented but the cost for stormwater drainage can reach 50% of the total cost of wastewater disposal. With higher standards for stormwater treatment in combined and separated systems, the share will probably increase in the future. In Germany, many cities have introduced a separate fee only for stormwater drainage (see Figure 36). The average annual cost per square metre is about 0.82 € (BGW, 2003) but it is much higher in Berlin at 1.53 €/m²/year. For a typical one-family-house in this city with an impervious area of 150 m², the annual charge for stormwater drainage would be 225 €. In Dresden, an increase in the stormwater fee to 1.69 €/m²/year has already been fixed for 2010. The costs for stormwater drainage from public areas (roads, schools, pedestrian zones, etc.) have to be paid by the municipalities from taxes.

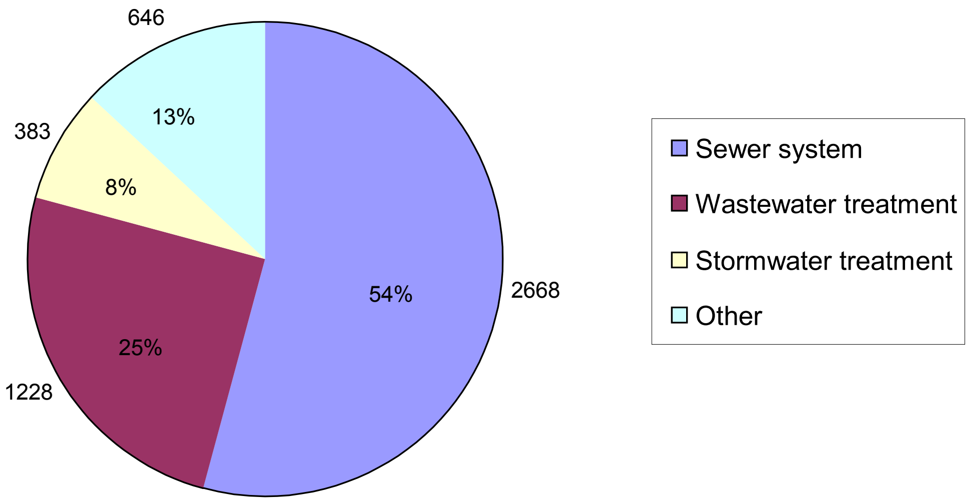


Figure 36. Investment for wastewater disposal in Germany 2003 (BWB, 2006)

Given that even in western countries people complain about the high prices for urban drainage and that the present situation regarding stormwater treatment is far from ideal, it is obvious that an application of the current technologies and standards of urban drainage would be overtaxing for many poorer countries and not only in those in the third world. Figure 37 shows the gross national income per capita for a range of selected countries from which it is clear that countries like China and Ghana simply could not afford current western practices.

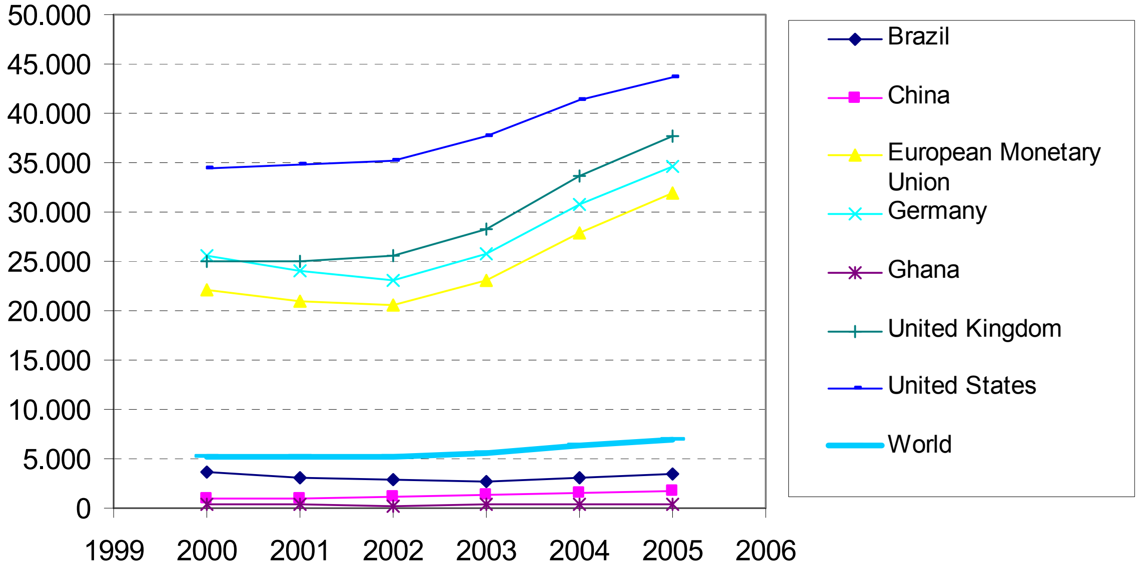


Figure 37. GNI (gross national income) per capita in US$/year (Eurostat, 2006)

The industrialized countries have started discussing the current practices of urban drainage in general (Wilderer, 2002; Schertenleib, 1999) and stormwater drainage in particular (Sieker, 1998). In those countries that face economic problems e.g. Germany (see Figure 38) some experts report that conventional systems with end-of-pipe treatment are not economically sustainable.

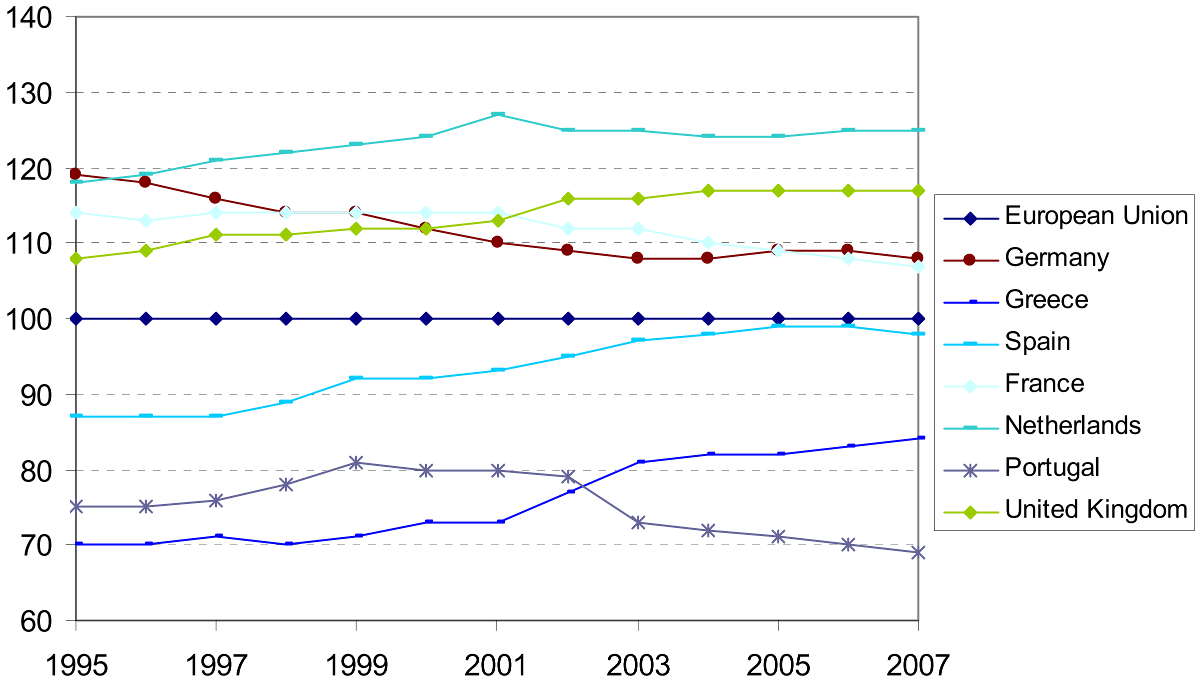


Figure 38. GNI (gross national income) relative to the EU average (Eurostat, 2006)

C.2.5.2 *Energy prices*

Energy is needed for the construction and maintenance of all structural stormwater management measures (SWMM). Examples are the production of concrete for sewer pipes, pumping of wastewater or fuel consumption during grass cutting in infiltration swales. It has to be expected that energy prices will rise significantly in the next decades, particularly the price of energy from fossil fuel resources, although it is not possible to quantify the expected trend.

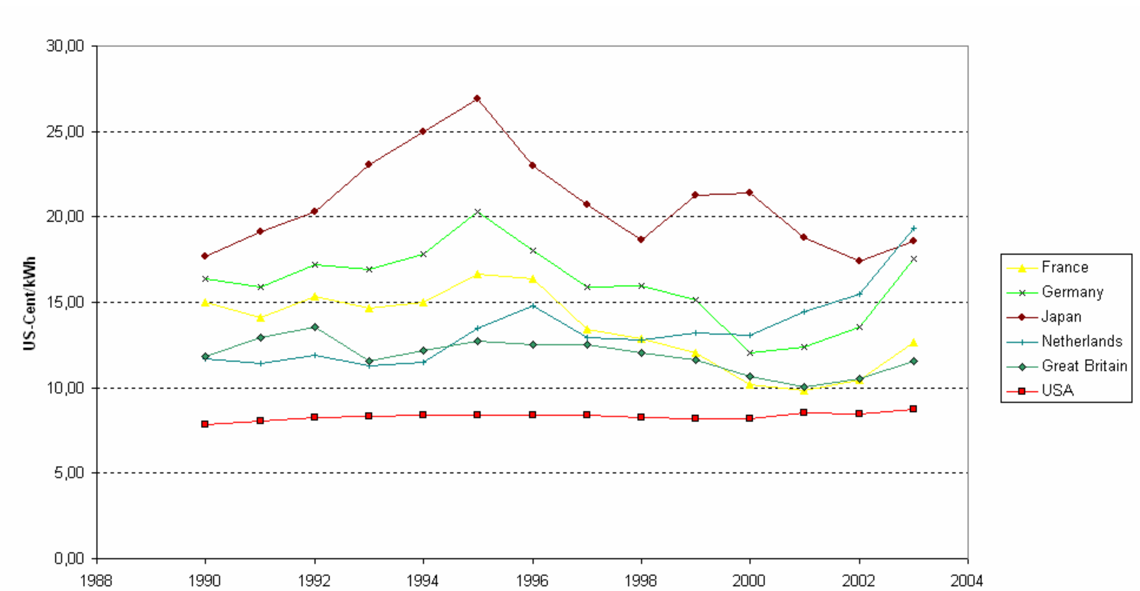


Figure 39. Price for electricity in US-Cent/kWh for a range of different countries (German Ministry of Economics, 2006)

Figure 39 shows the variation in electricity prices over the 16 year period between 1998 and 2004. The prices are highly variable for most of the countries and there are few general trends. Therefore a prediction of future energy prices at a national level is not feasible.

Nevertheless, compared to other fields of infrastructure like transportation or heating, energy prices are of minor importance for stormwater management. Even for the more energy consuming tasks of drinking water supply or waste water treatment, energy prices are not very important (Table 15).

Table 15. Proportion of energy on the water price (Jacoby, 2004)

	Energy required (kWh/m³)	Energy price (€/m³)	Water price (€/m³)	Proportion (%)
Drinking water supply	0.50	0.075	1.80	4.2%
Waste water treatment	0.38	0.057	2.30	2.5%

A simple calculation demonstrates the minor importance of energy prices in the field of urban stormwater management. To pump the annual rainfall of e.g. 600 mm (=600 kg/m2/year) up to 5 m (typical pressure height needed for a filter device) an amount of work equivalent to 0.016 kWh has to be done (pump efficiency of 0.50). With an average price of 0.13 €/kWh this would cost only 0.2 cents. Compared to the total cost for stormwater drainage (e.g. in Berlin 1.50 €/m²/year), energy prices are negligible.

C.2.5.3 *Land prices*

For the implementation of storm water management measures (SWMM), whether end-of-pipe or decentralized, a certain amount of land take is required. Table 16 shows the area demand under German rainfall conditions for different SWMM expressed in m² per hectare of drainage area.

Table 16. Land area needed for different USWM measures in m /hectare (Sieker, 1999)

BMP	Space required in m²/hectare
Infiltration areas	5,000
Infiltration swale	2,000
Infiltration trenches	1,200
Swale-trench-system	1,000
Retention pond (300m³/hectare)	700
Sewer system	450
Tank for stormwater harvesting	400
Ditches	300
Infiltration shaft	100
Sand filter	100
Soil filter pond	100
Retention tank (100m³/hectare)	50
Stormwater clarifier	27
Storage pipe	15
CSO Tank	10

Some types of SWMM can be built underground, for example storage tanks or pipes. In addition, the space needed for some BMPs like infiltration swales or green roofs can be used in multiple ways. Figure 40 shows the joint use of an infiltration area as a children's playground. Nevertheless, the price for land has to be taken into account when planning a stormwater management system. This is complicated by the fact that land prices vary considerably over time and from area to area even at a national level.

Figure 41 shows the variability in the average land prices for the federal states of Germany in 2004. The variation becomes much larger when major cities (e.g. Munich, Stuttgart, Hamburg, Berlin) are considered as land price can be multiples of the mean value and the countryside value. In other

countries, e.g. UK, the variation is even greater. A prediction for future land prices is very difficult. Current values for land prices are usually available from the statistical agencies or private providers.

Figure 40. Use of an infiltration area as a playground

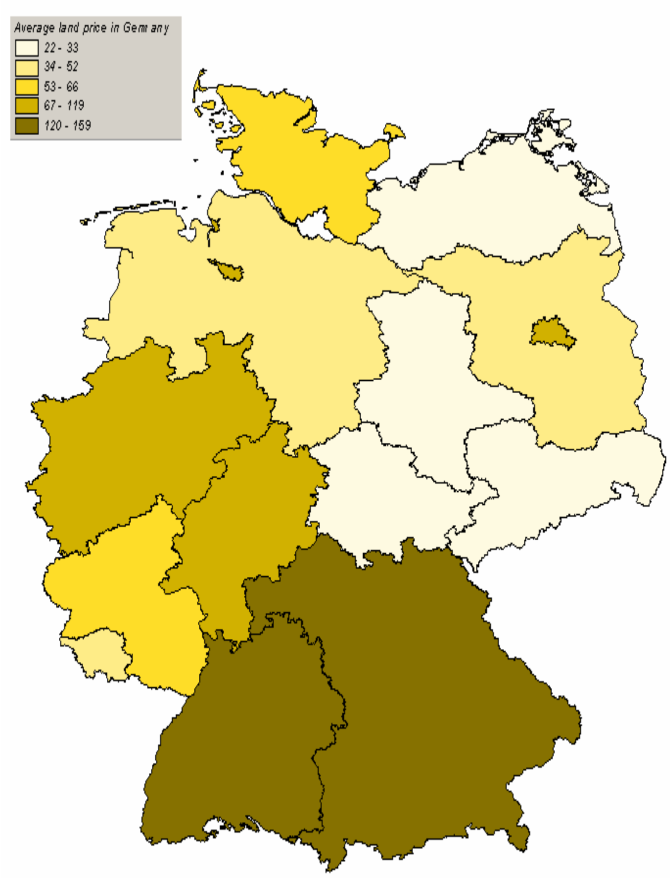


Figure 41. Average land prices in Germany in 2004 in €/m (Destat, 2005).

C.2.5.4 *Privatization and liberalisation*

Privatisation of water related services is a hot topic in the countries of the EU. Like in other sectors (energy, gas, telecommunication), private companies and their associations are searching for an entry into the market. Their arguments for privatization of the water industry are an increased efficiency, more competitiveness on the world market and better possibilities for making the huge investments, which are undoubtedly necessary in the coming years (Heymann, 2000). On the other hand, many public institutions, political movements like the Association for the Taxation of Financial Transactions for the Aid of Citizens (ATTAC) and other groups are stressing that (drinking) water is not ‘a goods’ which can be directly compared to other products in daily use. In their opinion, a public service should assure a high quality, the continued protection of natural resources, and stable/moderate prices.

Privatisation of water and wastewater services in the UK dates from 1989 with the core business now being more of a ‘contracted out’ delivery rather than being ‘service orientated’. Sewage undertakers are essentially reactive rather than proactive but are strongly motivated to invest under the prevailing centralisation regulatory system, with strategic policy oversight being vested in OFWAT (define). However, the companies are relatively weak players in the decision as to what types of work should be operationally supported for an investment. In the current (2005-2010) and last (200-2005) price rounds associated with asset management plans (AMP), other major stakeholders such as the EA, English Nature, and RSPB were successful in directing the primary investment towards environmental benefits rather than in upgrading/rehabilitation of the sewer system. Despite the evident problems of sewer surcharging and persistent flooding, the privatised companies have not been that successful in bringing the capacity of the sewer system to centre stage. In addition, they have resisted attempts to accept any responsibility for source control drainage as these are still not classified as being official drains or sewers for adoption.

Although it is not the task of this paper to assess benefits and disadvantages, privatisation is without doubt an important driver for urban stormwater management. First of all, privatization and liberalisation have to be distinguished (Kluge *et al*., 2003). Liberalisation means the introduction of a market mechanism while privatization means a shift of responsibilities from the public to private sector. Many examples of privatization have nothing to do with liberalisation as public monopolies have simply converted into private ones. In these cases, the benefits of privatization have to be questioned.

Many studies have come to the conclusion that privatization is not beneficial because a true liberalisation in a network based system is not possible or, at least, is very difficult ((Schönbäck *et al*., 2002). All these studies are based on the unspoken assumption, that water supply and wastewater disposal necessarily have to be network based. This is not the case in the field of USWM which needs to be distinguished from water supply and wastewater disposal. Especially for source control measures, a liberalised market can develop if the legal and financial framework is suitable. Maintenance of on-site infiltration or retention devices is certainly not a task which has to be done necessarily by a public service. Compliance with environmental standards can be guaranteed by supervision of water authorities. The possibility for liberalisation is one reason for the resistance of the currently dominating monopolies, regardless of public or private, against stormwater source control.

C.2.5.5 *Fees and taxes*

Policies for fees or taxes are also a driver for USWM. A cause-oriented fee is always a strong motivation for avoidance-oriented measures. For example, the stormwater fee in many German cities (see Section C.2.5.1) has lead to the disconnection of impervious areas. Another example is the motivation for rainwater harvesting due to rising water prices.

C.2.6 Traffic

Traffic is an important driver for stormwater management for two reasons:

- The volume of traffic, based on the current societal demand for individual car transport, determines the need for roads and other sealed surfaces like parking lots.
- Traffic is one of the major sources of stormwater runoff pollution.

C.2.6.1 *Volume of Traffic*

The changes in employment structures as well as in recreational behaviour have a strong influence on the demand of mobility. Especially in developed countries, there is a noticeable continuous rise in driven kilometres per year and capita, as well as an increase of the number of vehicles per capita. Both circumstances result in space requirements for moving and parked vehicles.

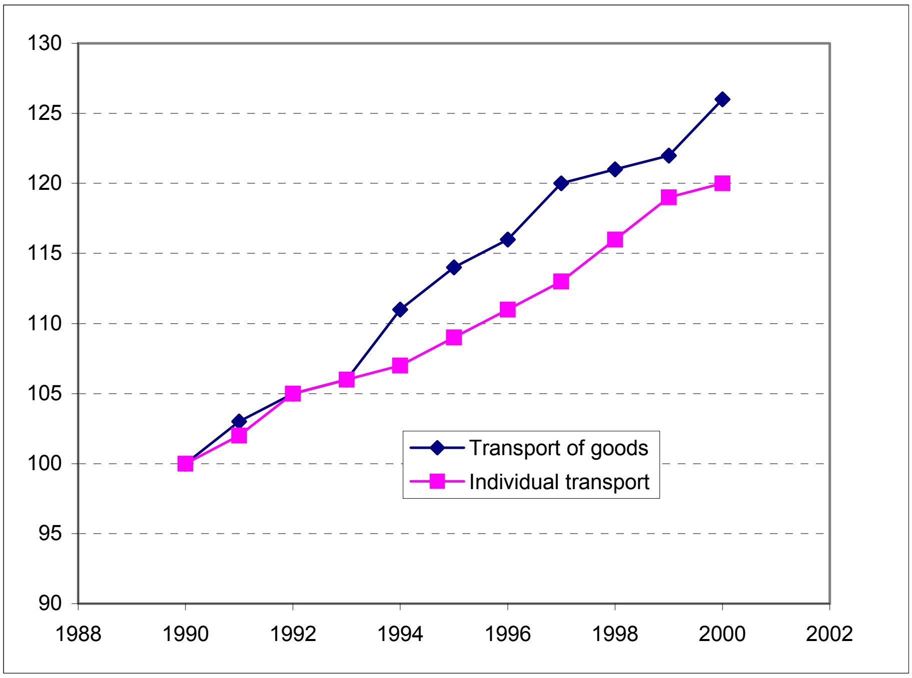


Figure 42. Increasing volumes of transport in the EU (1990=100) (Eurostat, 2006)

Globalization, low fuel costs and advantages in flexibility and mobility ("Just in Time Strategies") have lead to a strong increase in commercial road transport within the last 20 years (Eurostat, 2006). How traffic volume will develop in the future is hard to predict. With respect to the developments over the last few years, a continuing increase seems probable. On the other hand, a shortage of fossil fuels (see Section C.2.5.2) and rising energy prices may act as a moderating influence, causing other technologies like hybrid cars or hydrogen fuel cells to dominate traffic scenarios over the next fifty years.

C.2.6.2 *Pollutants*

Traffic is one of the major sources of stormwater runoff pollution. Table 17 shows the results of a German literature review on stormwater pollution comparing pollutant concentrations in street and roof runoff. Despite the variability in the results it can be seen that runoff from streets or roads is usually more polluted than roof runoff.

Due to enhanced combustion technology and changes in fuel composition, the gaseous emissions from cars have been reduced but the advantages gained have in many cases been compensated by traffic increases. With rising energy prices (see Section C.2.5.2) caused by a shortage of fossil fuels, the pollution characteristics of road runoff may change over the coming decades. Nevertheless, even for today it is difficult to predict or to model the extent of stormwater runoff pollution (Ahlman *et al.*, 2005). A detailed prediction of this driver for the next 50 years is not possible.

Table 17. Literature review on measurement in stormwater runoff in Germany

		streets				roofs			
	unit	count	Medium	Minimum	Maximum	count	Medium	min	max
pH		4	7,0	6,4	7,6	3	6,1	5,9	6,3
conductifity	µS/cm	8	136,6	69,2	342,5	3	91,7	66,0	129,0
AFS	mg/l	11	210,2	37,5	980,0	2	51,6	43,2	60,0
TOC	mg/l	2	17,2	6,6	27,8	0	n.v.	n.v.	n.v.
COD	mg O_2/l	17	88,1	13,2	260,0	3	30,8	22,0	37,0
chloride	mg/l	3	30,0	12,0	47,0	0	n.v.	n.v.	n.v.
AOX	µg/l	6	136,5	12,8	600,0	0	n.v.	n.v.	n.v.
Ptot	mg/l	8	0,9	0,1	3,0	1	0,1	0,1	0,1
PO4P	mg/l	6	0,1	0,0	0,2	0	n.v.	n.v.	n.v.
Ntot	mg/l	3	2,8	1,8	4,1	1	9,0	9,0	9,0
NO3-N	mg/l	11	0,8	0,4	1,5	1	0,2	0,2	0,2
NH4N	mg/l	11	1,0	0,2	2,4	1	4,0	4,0	4,0
HC	mg/l	8	0,3	0,0	0,7	0	n.v.	n.v.	n.v.
BOD5	mg/l	11	15,0	1,1	28,0	0	n.v.	n.v.	n.v.
PAC	µg/l	5	1,9	0,6	3,1	1	0,5	0,5	0,5
Cd	µg/l	10	5,2	0,0	20,0	1	1,0	1,0	1,0
Zn	µg/l	14	687,9	80,0	1950,0	1	24,0	24,0	24,0
Cu	µg/l	11	76,0	6,0	380,0	1	35,0	35,0	35,0
Pb	µg/l	14	180,2	9,4	980,0	1	104,0	104,0	104,0

Sommer and Sieker, 2004

C.2.7 Demands (for amenities)

In this section, the ‘softer’ aspects which complement the factors normally considered to influence USWM (e.g. increase in urban area, economic factors) are discussed. These specifically take into account ‘quality of life’ issues which people increasingly expect to be achieved and which can have a strong impact on the design of stormwater management measures.

C.2.7.1 *Requirements for flood security*

Urban drainage systems are usually designed for a certain overflow frequency. For sewer systems, a Europe-wide standard is available (DIN-EN 752-4, 1997) which prescribes tolerable overflow frequencies depending on the damage potential in the area (Table 18). The overflow frequency for sewer systems is determined by using either a ‘design storm’ or a long-term simulation. Stormwater treatment systems such as infiltration devices can be designed in a similar way.

Table 18. Overflow frequencies for urban drainage systems (DIN-EN 752-4, 1997)

Type of area	Frequency of design storm	Overflow frequency for new designs or restored systems	Flood frequency
	(overflows in “n“years)		
Rural areas	1 in 1	1 in 2	1 in 10
Housing areas	1 in 2	1 in 3	1 in 20
City centres, Commercial areas	1 in 2 1 in 5	1 in 5	1 in 30
Underground crossings	1 in 10	1 in 10	1 in 50

The frequencies listed in EN 752 have a strong impact on the cost of a drainage system. However, these design criteria represent fairly arbitrary values and it is ultimately a decision for society regarding the level of security required balanced by the financial costs. It is entirely possible, that in future years the level of security against flooding defined by regulations will be different from those existing today.

C.2.7.2 *Requirements for water quality*

The Water Framework Directive (WFD) sets new standards regarding water quality in Europe. By 2015, all water bodies should have a good ecological status. This goal is not only valid for watercourses with a catchment larger than 10 km², which is a common misunderstanding. The WFD is a driver for USWM from a legal point of view and it has also been developed as the consequence of an increased awareness regarding water quality over previous decades. Clean watercourses are seen as an important aspect of quality of life today. People want to enjoy walking along natural rivers and the

ability to swim safely in rivers is an objective. In 2005, the first European River Swimming Day known as “BIG JUMP 2005” was celebrated in 31 rivers in 22 countries. A further tightening of water quality regulations cannot be ruled out. However, if economic problems take priority it is possible that the demands for improved water quality will be lowered again.

C.2.7.3 *Demands for water in urban space*

In former times, it was common practice to get rid of stormwater as quickly as possible. Stormwater was seen as a type of waste rather than a resource. Under German law (WHG, 2002) and in some European regulations (e.g. Urban Wastewater Treatment Directive, 1991) it is still defined as a type of wastewater. However, in association with increases in environmental awareness, there is renewed emphasis on increasing the visibility of water in urban spaces and architects and landscape planners are enthusiastic about the implementation of ponds, wetlands or open ditches into their designs (Geiger and Dreiseitl, 1995) (see Figure 43 for an example).

Figure 43. Integration of USWM in urban space (Berlin-Karow)

C.2.7.4 *Tourism*

Tourism can indirectly influence USWM in many ways. First of all, tourism is a strong factor for the general economic development of a region (see Section C 2.5). Pressure exerted by visitors from the industrialized world supports the demand for better water quality in developing countries. Polluted beaches keep tourists away. Tourist businesses and responsible institutions (hotels, etc.) are becoming increasingly aware of the importance of a clean environment.

In contrast, tourism can be compatible with a certain type of urbanization. New hotels and the corresponding infrastructure are built and have the same resulting influence on USWM as previously described in Section C.2.2 (surface sealing). An associated increase in traffic can also be expected (see Section C 2.6). Tourism also has a special impact, which can be seasonal, on water consumption and therefore on wastewater production. The water consumption per hotel guest is usually much higher than per capita. Tourist resorts incorporating golf courses exhibit particularly high water consumption rates.

C.2.8 Innovation

Looking 50 years into the future, technological innovation is an important aspect. 50 years ago, many of the techniques used today e.g. for treatment of wastewater were unknown and it is probable that new and more efficient technologies will be available in the future. Innovations are not easy to predict but new developments in fields related to USWM are almost certain. The introduction of non-fossil based fuels, new surface and construction materials and the recycling of wastewater at a household level are three possible innovations which are discussed below.

C.2.8.1 *Non-fossil fuels*

The limited available resources of fossil fuels are well established (see also Section C.2.5.2.on energy prices and Section C.2.6 on traffic). Both the car industry and research institutions are intensively working on new technologies for transportation in particular and energy supply in general. The combustion of fossil fuels contributes to the pollution of road runoff and this would be substantially reduced by the advent of hydrogen fuel cells as a major vehicular power source. Alternatively, rising energy prices and the introduction of more efficient public transport systems could lead to a significant reduction in individual vehicle use.

C.2.8.2 *New materials*

An important characteristic of stormwater runoff, compared with domestic wastewater, is the high concentration of heavy metals. This pollution is partly caused by the erosion of uncoated metal surfaces such as those found on rooftops (copper, zinc) or crash barriers.

Innovations can also be expected with regard to road and pavement construction. Today, most surfaces used for traffic, parking or pedestrians are sealed with asphalt, concrete or paving stones. New materials for pavements allowing at least a partial infiltration have been developed in recent years. Problems have been encountered with these permeable pavements due to clogging and/or the winter use of salt but further improvements can be expected.

C.2.8.3 *Recycling of wastewater on household level*

The industrial sector has shown that recycling of wastewater is possible. For domestic wastewater, recycling is currently not very common although the technologies are available (see SWITCH Work Package 4). It is a realistic scenario, that in the future recycling of wastewater at household level becomes common practice. Such developments would have implications for USWM. Historically, combined sewer systems have been built to facilitate the flushing of sediments by storm runoff. By reducing wastewater flows this requirement and hence the need for discharging stormwater would diminish.

C.2.9 Responsibilities

C.2.9.1 *Stakeholder engagement and citizen involvement*

Traditionally, the design of urban drainage systems is a role carried out by technical planners. Citizens and stakeholders like NGOs - contrary to other environment related planning processes – are not involved. With the new EU directive on the assessment of the effects of certain environmental plans and programmes on the environment (commonly known as the Strategic Environmental Assessment Directive (2001)), the nature of the planning process can be expected to change in the near future. The directive demands an environmental assessment not only for new plants (e.g. wastewater plants) but also for plans that provide a framework for such plants. For urban drainage master plans, this will usually be the case. This will usually be the case and an environmental assessment, as prescribed by the EU directive, will include the examination of variants and the involvement of the public. Hence, the need for public participation can be a driver for USWM.

C.2.9.2 *Education, awareness and self responsibility*

New concepts for stormwater management e.g. infiltration or re-use are dependent on a close involvement of the people (van Beurden and Geldof, 2005). Homeowners and companies cannot be

forced to implement source control techniques against their will. Therefore, education is an important component of a modern stormwater management strategy (Geldof, 2005). The willingness to take over responsibility for stormwater source control measures depends very much on the social situation in a community. Motivation in stable neighbourhoods will be higher than in areas with social problems. On the other hand, urban water management in combination with landscape development can help to improve the social situation (Kaiser, 2004).

C.2.10 Legislation

Legislation as a driver for USWM usually arises as a consequence of other aspects e.g. demands for stronger requirements regarding flood security or water quality leading to new regulations for the design of BMPs. However, sometimes legislation itself becomes a strong driver for USWM. The EU Water Framework Directive (EU-WFD) is a good example of such a situation.

C.2.10.1 *EU Water Framework Directive*

The EU Water Framework Directive (2000) will have a strong impact on USWM planning and management in the near future. Many reports (Article 5 WFD) have shown the negative impact of untreated stormwater discharges on the ecological status of surface water bodies. Most of the European member states have traditionally used emission-based standards. The WFD advocates a combined approach and this has resulted in new emission-based regulations for stormwater discharges, e.g. the BWK-M3 guideline in Germany (BWK-M 3, 2001).

C.2.10.2 *Shift of competences*

A shift of legislative competence can also be an important driver for USWM. In Germany for instance, water legislation was until 2006 a responsibility of the federal states. With a change of the constitution in 2006, the competence for emission standards now lies at the national level. This will eventually lead to new homogenous, nationwide standards.

C.3 Environmental drivers

C.3.1 Air pollution

Major sources of anthropogenic air pollution are combustion processes and enhanced organic decomposition. Combustion derived sources include those involved in the generation of energy for transport, electric power and/or heat supply. The amount and composition of exhaust gas emissions depends on the source of energy, the type of combustion and the post-process treatment. The main contaminants are CO_x, NO_x, SO_x hydrocarbons, and organic matter particles (OMP). Enhanced organic decomposition takes place on agricultural land areas and waste disposal sites, especially under reducing conditions. The main contaminants are CH_4, NH_3 and H_2S.

Within the atmosphere, the emitted compounds may change due to chemical, biochemical or photochemical reactions and their impacts can vary. The concentrations of the pollutants and their metabolites are normally higher in urban environments, due to increased human activity. According to Landsberg (1981) the proportion of particulates is 50 times higher and that of gaseous contaminants up to 25 times higher in urban environments. The situation in most western countries has been improved in recent years (Figure 44) but in other regions of the world, air pollution is still a big problem. Figure 45 shows the diurnal variation for 3 air pollutants derived from traffic combustion processes and identifies peak concentrations corresponding to the morning ‘rush hour’ (Sturm, 1995).

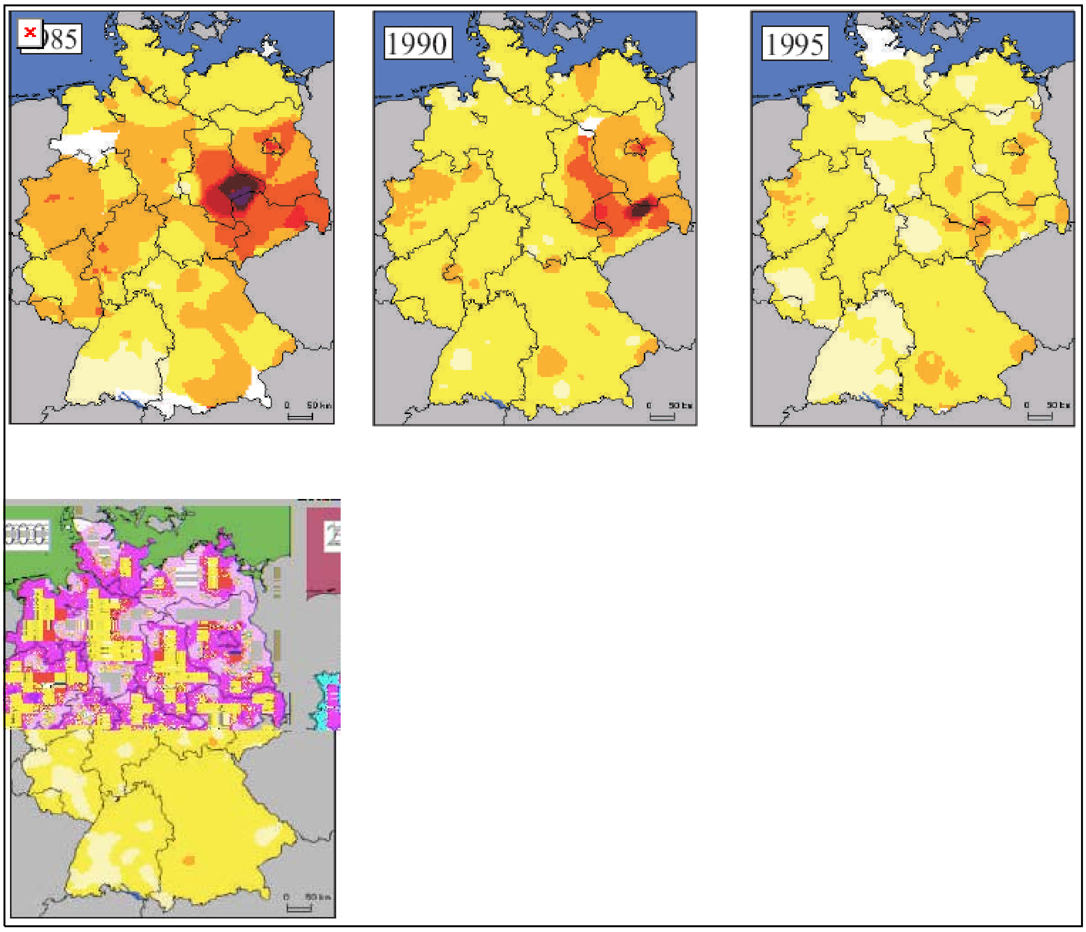


Figure 44. Temporal changes in atmospheric particulate matter pollution in Germany between 1985 and 2004 (UBA, 2006b)

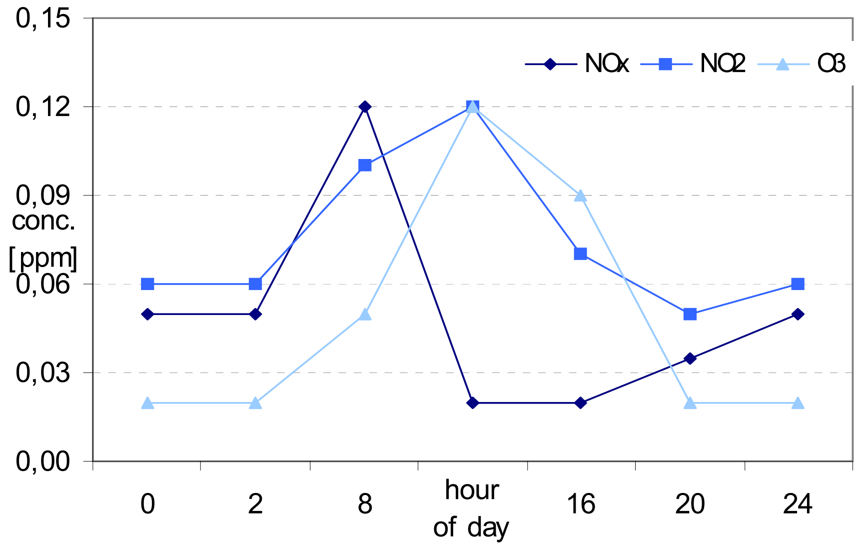


Figure 45. Diurnal variations for 3 gaseous pollutants in an urban environment (Sturm, 1995)

Another source of air pollution is aeolian erosion of soil particles and dust, caused by denudation and degradation of inappropriately used surfaces.

Among the various effects of air pollution there are some which are especially relevant for USWM:

- Wet deposition and input into the USWM system - soluble and dissociating compounds such as SOx contribute to the phenomenon known as acid rain; in contrast the presence of NH3 would have a neutralising effect.
- Dry deposition on runoff active surfaces and subsequent wash-off; cumulative accumulations occur during extended dry periods and can be particularly relevant for OMPs and soil particles
- Local impacts on climate can arise due to particles and ions acting as condensation nuclei for rain droplets and hence increasing the frequency of rainfall events.

Changes in air pollution concentrations and trends can act as a driver for USWM due to the influence on the quality and quantity of stormwater runoff requiring treatment.

C.3.2 Groundwater

Groundwater storage systems are connected with urban environments by in- and ex-filtration, interfaces with surface water bodies and both authorised and unauthorised groundwater exploitation. Aquifers store and provide water and due to the retention times can support chemical transformations. The factors which influence the interaction between groundwater and stormwater management are the nature of the receiving waterbody, the presence of ex - and in-filtration into urban drainage systems and the transmission of pollution in either direction. Climate change and mining activities are both processes which can affect the groundwater regime making it an important driver for USWM.

C.3.2.1 *Quantitative aspects*

Where surface water is polluted or limited in terms of availability e.g. in arid or highly urbanized regions, groundwater and fossil water are major sources for drinking water. At the present time overexploitation of groundwater is common in many regions of the world, e.g. in Beijing (see Figure 46) and in Mexico where depletion of the aquifer has caused a shifting of land to the extent that Mexico City is now sinking.

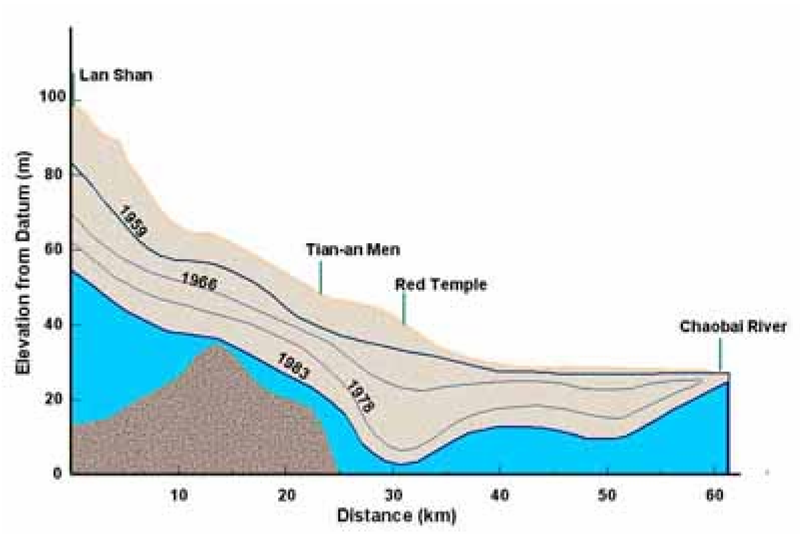


Figure 46. Decline of ground-water table in the City of Beijing, China (Scientists, 2006)

Groundwater resources can be stressed by urbanisation in two ways:

- By extraction for drinking water supply and irrigation
- Indirectly by surface sealing, which leads to a reduced groundwater renewal

Both aspects have implications for USWM. In addition to improved water efficiency regarding industrial, domestic and agriculture uses, rainwater harvesting can reduce the need for groundwater extraction. Groundwater renewal can be enhanced by stormwater infiltration.

In many lowland areas, high groundwater tables are causing problems such as damage to existing building foundations and even flooding of basements. Under these conditions, reductions in groundwater extractions or the supplementing of groundwater through stormwater infiltration can aggravate the situation. Combined stormwater and groundwater management can be a solution (Bandermann, 2006). An example for an infiltration-drainage-system is given in the report on USWM demonstration projects in the Emscher region.

Leaky sewer systems can also have a quantitative impact on groundwater resources. In the presence of a high groundwater table, sewer systems can have the same effect as drainage pipes producing a high dry weather flow, which has to be dealt with at the wastewater treatment plant.

C.3.2.2 *Qualitative aspects*

Urbanisation and USWM in particular may impose a qualitative burden on groundwater resources. In Germany there are about 250,000 contaminated sites which are within the process of registration, observation, examination or decontamination. Abandoned or still in use industrial sites and associated infrastructure are places with an increased potential of contamination. Within the unsaturated soil zone and the groundwater body, the contaminants may remain inert, be transported (diffusive and/or dispersive) or react (through metabolization or degradation). The influence of infiltrating stormwater on pollutant transport to groundwater has to be considered when planning decentralized detention. In addition to assisting the transmission of existing sub-surface pollutants, infiltrating water acts also as a pollutant source depending on the level of contamination for the surface runoff. Possible inputs are OMPs and hydrocarbons from street runoff, heavy metals from streets and roofs, nutrients and pesticides from green spaces and agricultural surfaces, and microbiological loads from interfaces with the sewer system or stock farming sites. The awareness of microbiological contamination is relatively new, although Ellis and Revitt (2002) found in a literature study, that sewer leakage could cause remarkable numbers of coliforms in shallow urban groundwaters in the Nottingham, UK area. In regions with longer snowfall periods, salt, used for de-icing, becomes an important contaminant.

C.3.3 Soil protection

In contrast to groundwater which is defined as a water-saturated layer, soil usually represents the unsaturated zone. Soil generation is a very long-term process (average soil generation rate in Central Europe is only 1 mm/year) and soil is now acknowledged as an important resource which needs to be protected Germany recently introduced new soil protection legislation (BBodSchG, 1998).

USWM is connected to the "soil compartment" in different ways:

- Soil erosion results in sediment loads which can cause problems in urban drainage systems.
- USWM measures have an impact on the natural soil water balance due to infiltration or drainage processes.
- Stormwater infiltration or leaking sewer systems can cause soil contamination

C.3.3.1 *Erosion control*

As already mentioned in Section C.2.3 on agricultural development, eroded sediments qualitatively influence stormwater management due to inputs of nutrients, pesticides and herbicides, and quantitatively due to obstruction by sedimentation and decreases in infiltration capacity. Other important erosion sources include construction yards, badly planned urban landscapes (e.g. involving steep or unsecured slopes) and denuded surfaces as a consequence of changed land use.

The impacts of erosion can be controlled by either lowering the removal of sediment from affected surfaces or by increasing the USWM capability to cope with incoming sediments. An efficient measure for erosion control on farmland is conservation tillage (Schmidt *et al*., 2000) as shown in Figure 47.

Figure 47. Erosion control with conservational tillage

C.3.3.2 *Soil contamination*

The distribution processes and pathways for soil contaminants are similar to those exhibited by groundwater contaminants with the main difference being that soil systems normally have a much longer retention time and thus exchange rates are much lower. The resulting accumulation of pollutants may result in contaminated soils which are not only a threat for ecosystems but through the food chain also for human health.

Heavy metal contamination of soils can result from stormwater infiltration (Boller, 1997) due to the metal ions being absorbed by clay particles and organic matter. As the metals accumulate they reach toxic levels for the organisms which are present and may be incorporated by plants and inhibit biological functions.

In Germany the artificial soil layer in infiltration devices is not regarded as "natural soil" as defined in the soil protection legislation. As for the soil layer in botanical sewage treatment plants or soil filter ponds it is seen as a part of a technical device. If heavy metals or other pollutants accumulate in such a filter this is not seen as a disadvantage. In contrary, the fixing of pollutants in a defined compartment, which can be removed and treated if necessary, is seen as an advantage compared to the uncontrolled distribution in the environment. Threshold values have been established for the lower level of the artificial soil layer such that for typical stormwater runoff from roofs or residential roads, a 30 cm layer of activated soil is seen as a sufficient treatment (DWA-A 138, 2005).

C.3.4 Surface water bodies

In classical urban drainage systems, surface water bodies are usually the receiving water bodies:

- In separate systems directly with or without treatment
- In combined systems either directly by combined sewer overflows (CSO) or indirectly in the effluent from a wastewater treatment plant (WWTP).

New requirements for the flow regime and quality aspects of surface water bodies are a major driver for USWM, as retention and treatment systems can be very costly.

C.3.4.1 *Quantitative aspects*

The impact of urban stormwater on the flow regime of a receiving water is clearly evident, as the concept of classical systems has been to fully discharge the stormwater as fast as possible in order to prevent flooding, wetting or unhygienic conditions (Sieker, 1998). Negative consequences of this approach are:

- Hydraulic stress: during storm events the runoff arrives faster, and a with higher peak discharge, causing increased shear stress and erosion potential
- Water balance: as a consequence of faster runoff, the wetting period of surfaces and the soil moisture content are diminished, leading to a reduced evaporation rate which could be of benefit for the runoff.
- Natural flow regime: while the direct runoff is increased, base flow is reduced. Hence, over a long-time perspective, flow peaks are more intense and low flow periods are prolonged.

The identified effects threaten the natural development and function of aqueous and other ecosystems (see Figure 48). It is clear that hydraulic loads from urban drainage system are a major cause for hydro-morphological damage to river catchments possessing a high degree of urbanization (MUNLV, 2005).

Figure 48. Drift of macro invertebrates due to hydraulic stress (source: P. Podraza)

C.3.4.2 *Qualitative aspects*

The qualitative impacts of urban stormwater including physical, chemical and biological aspects are identified in Table 19. They are of concern, given that surface water bodies are an important part of the water cycle, function as a source for water supply and food, support valuable ecosystems, and utilised for leisure activities.

Table 19. Potential dangers of stormwater discharges for receiving waters

Time scale	Important parameter
Acute Hours	Hydraulic effects: Flow velocities at river bed Shear stress at river bed Pollutants: Toxic effects (especially NH_3) Sedimentation of particles Pathogenic bacteria in the sediment
Delayed Several hours to days	Pollutants: Dissolved oxygen depletion Suspended solids Toxicity Pathogenic bacteria
Long-term Month to years	Pollutants: Organic, persistent substances Metals, inorganic and organic sediments Eutrophic substances

C.3.4.2.1 Chemical aspects

Stormwater runoff contains pollutants including nutrients such as nitrogen and phosphorus; organic carbon; trace metals such as copper, zinc, and lead; petroleum hydrocarbons; and pesticides (Schueler and Holland, 2000). Nitrogen is typically the limiting factor for aquatic plant growth and its sources are mainly diffuse and difficult to control. The primary sources of nitrogen in most developed watersheds are fertilizer runoff from lawns and golf courses, automobile exhaust, and municipal wastewater treatment plant effluent.

The effects of heavy metals e.g. those washed off from roads and roofs have been previously discussed (see Section 3.3 on soil protection). Copper is a serious threat for aquatic ecosystems as it is highly toxic for microorganisms and molluscs. Doses as low as 0.32 µg/l have been found to be toxic for some green algae (West, 2003) which is a factor of particular concern when this value is compared to recently monitored mean copper concentrations in the River Rhine (Figure 49). According to the WFD-report for the river Rhine (MUNLV, 2005), urban stormwater discharges are a major source of copper.

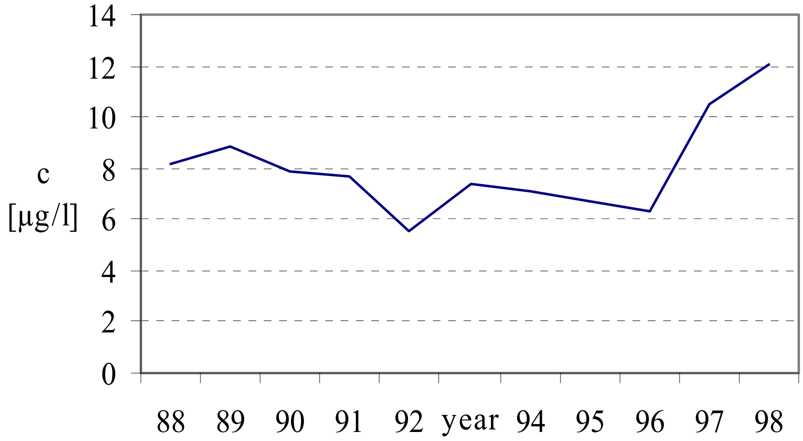


Figure 49. Concentrations of copper in the Rhine at the Kleve Bimmen gauging station for the years 1988 – 1998

C.3.4.2.2 Habitat quality

Increased runoff from impervious surfaces to streams, rivers, and estuaries has a substantial impact on the associated habitats. This is illustrated by the fact that a one hectare parking lot produces about 16 times the runoff volume typically associated with a one hectare meadow. The resulting magnified "pulses" of runoff alter the stream flow patterns and consequently, the shape of the stream channel. Streams in watersheds with more than 10 percent impervious surfaces become physically unstable, causing erosion and sedimentation (Booth, 1991). In addition, there is a decline in natural habitats, such as pools, woody debris, and the wetted perimeter of the streambed. Overall, habitat quality falls below the level necessary to sustain a broad diversity of aquatic life.

Under confined conditions, it is possible to establish a good ecological status in urban rivers using compensatory habitat structures (Figure 50). However, the use of such structures requires a steady water flow regime and the ‘flash flood' nature of many urban stormwater discharges would rapidly flush away the introduced compensatory structures.

C.3.4.2.3 Water Temperature

As runoff flows across paved roads and parking lots the water temperature rises. The higher the degree of imperviousness in the watershed, the warmer the water becomes (Galli, 1991). This poses a particular problem in areas that are often naturally low in dissolved oxygen, as further increases in temperature can push oxygen levels toward zero, especially in the summer. This is the case in small tidal creeks and marshes and because their upper reaches serve as nursery grounds for many fish and shellfish that inhabit coastal waters, the dissolved oxygen balance has important implications for the future health of the marine environment.

C.3.4.2.4 Other impacts

In addition to the chemical substances and fine particles that cause water pollution, combined sewer overflows and separate storm sewer systems emit gross pollutants including toilet paper and other sanitary products (Figure 51). Although these materials are usually harmless with regard to the chemical and biological status of the watercourse, they create a disturbing visual impression which is a particular problem when the watercourse is part of a recreation area.

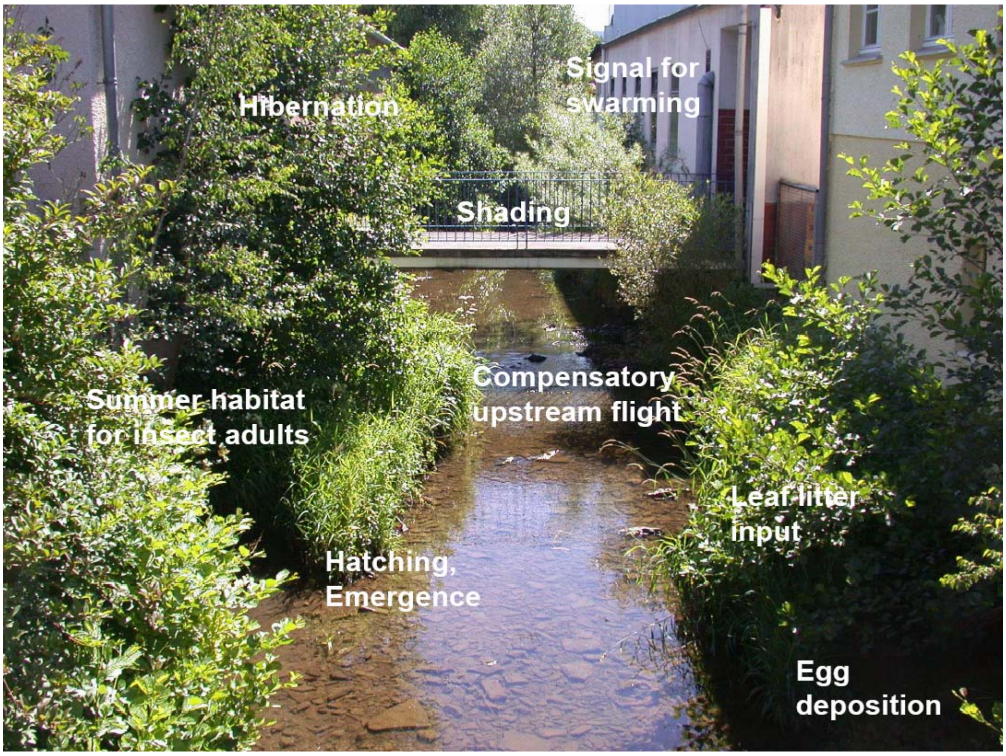


Figure 50. Urban river with compensatory habitat structures (Source: P. Podraza)

Figure 51. Water pollution resulting from debris discharged by combined sewer overflows

C.3.5 Urban environments

C.3.5.1 *Urban landscapes*

High quality recreation areas are an increasingly important goal of spatial planning in large urban areas and mega cities. In this context, the restoration of natural watercourses is not only of benefit to the ecology but also to the enhancement of living standards. Open water bodies are of special value and the sound of flowing water is appreciated (Kaiser, 2005).

C.3.5.2 *Anthropogenic sediments*

In separated systems, particles washed from urban surfaces usually directly enter receiving waters without any treatment. In parts of the river system with low velocities, these particles settle and attached pollutants quickly accumulate. To ensure that the hydraulic capacity is maintained and to provide the necessary flood protection, regular removal of sediments is required. If the sediments are contaminated e.g. with heavy metals, the common practice of disposal next to the riverbank may be prohibited. Deposition in landfill sites is much more expensive and increases the operational cost.

C.3.5.3 *Micro-climate*

As described in Section C.2.2.2, the sealing and compaction associated with urbanisation not only causes an increase in runoff volumes and peaks, but also a reduction in groundwater recharge and a reduction in evapotranspiration (see Figure 30). Together with the heating effect of sealed surfaces, this can cause a change in microclimate which on hot summer days can make life in urban areas uncomfortable. Green roofs and infiltration devices can help to improve the situation.

Another climatic aspect associated with urbanisation is a changing rainfall pattern. For example, in Berlin the annual rainfall in the east part of the city is approximately 100 mm or 20% lower than in the western part. This effect can be explained by the ascending heat due to surface sealing similar to that which would be observed as the lee-effect in mountainous regions.

C.4 Summary

An overview of the major influences on stormwater management is shown in Figure 52 which summarises the discussions in the preceding two chapters on ‘Socio economic drivers’ and ‘Environmental drivers’. A review of their past development has shown that most of the drivers are dynamic and it is very likely that they will continue to be so in the future. The problem is that for most of the drivers a detailed prediction is not possible. Although global trends are obvious, e.g. growth of population or urbanization, it is more difficult to forecast the consequences on local scale. Another problem affecting the predictive process is the interaction between different drivers. Population dynamics for example, is influencing urbanisation which has an impact on traffic densities and so on.

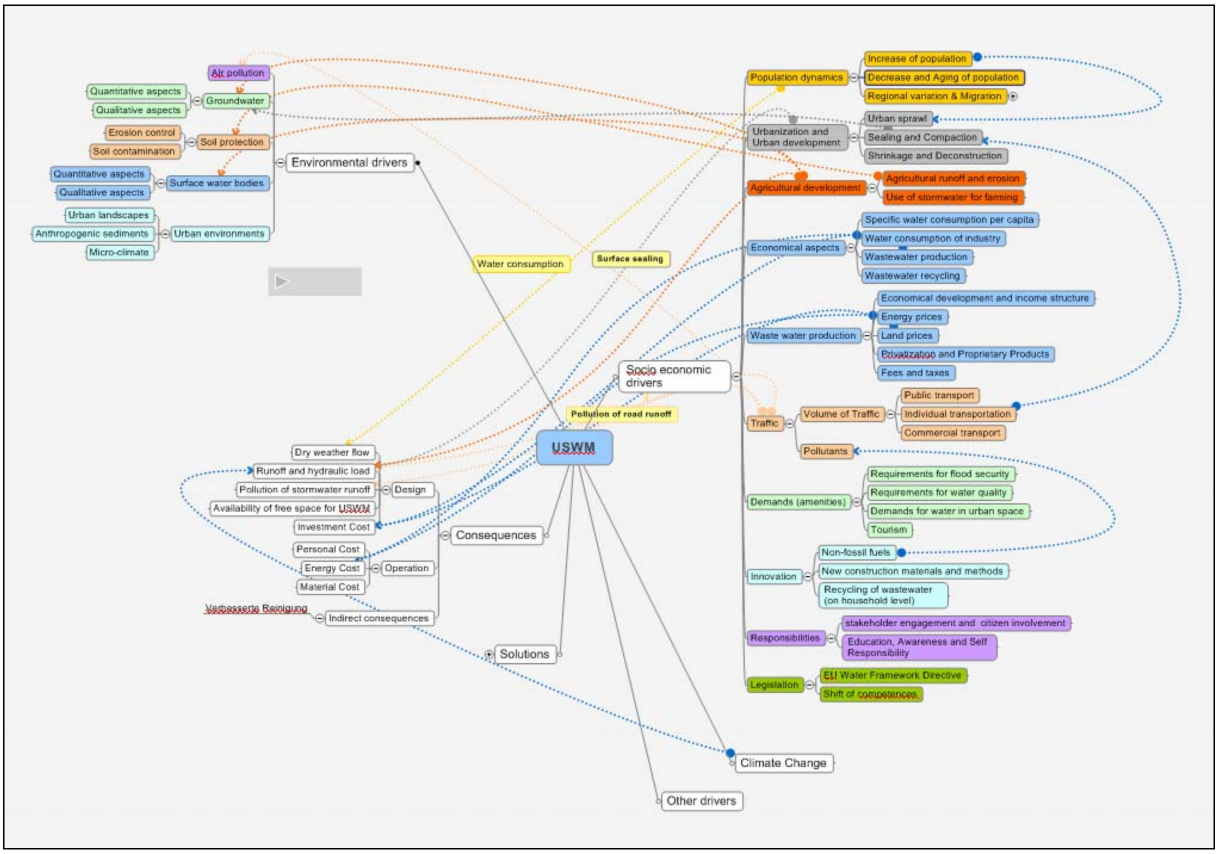


Figure 52. Overview chart of socio-economic and environmental drivers and their interactions

It is difficult to predict how society will react to changes in global trends. For example, the limitation of the world’s oil resources and the potential implications for today’s traffic levels are well known, but how the world will react to such a shortage in the future is not predictable. Therefore, a forecast of the directly influencing factors for stormwater management e.g. the demand for road areas and the pollution contribution of vehicles to stormwater runoff cannot currently be achieved with a high degree of accuracy. The unpredictability of major drivers for USWM produces a clear dilemma: Planners have to make long-lasting decisions at the present time although they know that the basis for their decisions will change during the lifetime of the possible solutions. The only solution for this dilemma is flexibility. Common methods for the comparison of alternatives do not consider flexibility as a criterion. In the traditional cost comparison method, investment and operation costs for the whole lifecycle are compared. Long-lasting solutions are generally preferred by the utilization of this method. However, this approach leads to good decisions only if the boundary conditions do not change during the lifecycle. For example, if a treatment plant is not needed anymore or new emission standards require different treatment methods, the decision to select a long-lasting solution in relation to initial conditions may ultimately be unfavourable. To overcome this problem, the introduction of flexibility as a planning criterion is necessary.

D CONCLUDING REMARKS

In common with many sectors across Europe (e.g. industry, construction and farming), the adopted approaches to stormwater management have seen several major changes over the last 20 years. The key drivers for change include the increasing awareness of sustainability issues and man's detrimental impact on the environment, as well as the general desire to enhance quality of life indicators. Many of these changes have been directed at improving performance within a specific field in relation to current or near-future conditions where both the problem and the measure required to address it could be determined with reasonable precision e.g. the introduction of Integrated Pollution Prevention Control (IPPC) regulations to tackle industrial emissions. However, the increasing awareness and legislative requirements to operate sustainability are clearly linked to long-term planning and accountability and appear to coincide with a growing realisation that the planet is undergoing major man-mediated climatic changes. In addition, our ability to understand and robustly predict the interlinked impacts of these changes are at best highly generic, and particularly so in terms of the resolution of impacts at either a local spatial or temporal scale. However, not only is the climate changing in ways which are difficult to predict, but populations are increasing and decreasing, urban agglomerations are growing and shrinking, industrial water use is increasing and decreasing, rivers are drying out and flooding more frequently. This leads to a number of difficult questions with perhaps the most pertinent being how can this uncertainty be managed?

Such uncertainty presents a particular problem for stormwater management as the current trend is towards the use of decentralised approaches involving stormwater management BMPs which can directly fulfil or contribute to the achievement of a variety of sustainability-associated targets such as stormwater quality and quantity control, low energy use, habitat provision and socio-amenity enhancement (see Section A). However, a fundamental requirement for the successful application of these multi-benefit approaches is a detailed knowledge of specific catchment characteristics. There is, then, a requirement to resolve the conflict between the need for site specific information and our current inability to robustly predict future scenarios.

There is no easy answer to this complex issue but a first stage is to gather the available data together to enable the current level of understanding and uncertainty associated with a wide range of stormwater management drivers and their impacts to be assessed. This report aims to address this initial stage through its provision of:

- a detailed description of current stormwater best management practices (BMPs) and overview of the legislation that has been used to promote their use within a variety of countries (Section A)
- a review of current 'state-of the art' downscaling techniques and levels of uncertainty associated with climate change modelling and its application to stormwater management scenarios (Section B)
- the identification and description of further environmental and socio-economic drivers which may impact on stormwater management needs (Section C).

D.1 The use of stormwater BMPs

Sustainable urban drainage approaches for stormwater quality and quantity control are becoming an increasingly established technology which can also contribute to increasing the productivity of water through their potential to offer additional benefits such as the re-use of stormwater stored in ponds for irrigation and the multi-purpose value of stormwater wetlands as wildlife and recreational areas. In most countries these methodologies are referred to as Best Management Practices (BMPs) although the UK is unique in using Sustainable Drainage Systems (SUDS) as the descriptor. These control systems which can be identified as either structural or non-structural in nature, may be used in association with conventional piped systems. Non-structural approaches are primarily directed at reducing pollutant levels at source and include practices such as street cleaning, spill prevention and

dumping controls, and education/awareness campaigns, and are hence often refereed to as 'good house-keeping practices'. A wide variety of structural control systems exists which are typically directed either at source control (e.g. porous surfacing, swales, filter strips), at site control (e.g. ponds/basins, wetlands, infiltration trenches/basins) or off-site/regional control (larger versions of site control systems) with combinations of systems (treatment trains) utilised across a variety of scales being used to improve overall performance as necessitated by the site conditions. This multi-scale technique plays an important role within an approach developed in the US known as Low Impact Development (LID) where the objective is to maintain a site's natural drainage so as to preserve it as closely as possible to the pre-development runoff characteristics. In Australia and New Zealand, sustainable urban drainage is incorporated into Water Sensitive Urban Design which also includes water resource and wastewater treatment issues.

The use of stormwater BMPs varies greatly between countries (Revitt *et al.,* 2003), with developed countries generally demonstrating greatest usage. An important factor in this differential uptake of use is not that stormwater runoff is not an issue in certain countries but that in developing countries the impacts of diffuse pollution tend to be 'masked' by the more immediate effects of the direct discharge of raw sewage into water courses. As a result, the awareness of the potential pollutant load associated with stormwater runoff tends to be lowered (Nascimento, 2006). However, even within European countries the use of stormwater BMPs are not widespread due to concerns over their long-term operation and maintenance requirements and an apparent 'inertia' by municipalities and water companies to adopt new technologies.

D.2 Urban water management, the EU Water Framework Directive and climate change

The USA has been at the forefront of the development of policy and institutional drivers with the introduction of the National Pollutant Discharge Elimination System (NPDES) and the concept of Total Maximum Daily Loads (TMDLs) for the protection of impaired water bodies. However, the European Community has recently introduced a fundamental change to all water management practices with its development and ratification of the EU Water Framework Directive (WFD, 2000) which focuses attention on catchment-scale issues (through the requirement to develop integrated River Basin Management Plans (RBMPs)) and the overall objective of achieving 'good ecological status' in all surface waters. EU Member States are required to implement the WFD with a programme of measures (POMs) to be in place by 2012 in order to achieve the following identified objectives by 2015:

- prevention of further deterioration, protection and enhancement of the status of aquatic ecosystems and the water needs of terrestrial and wetland ecosystems
- promotion of sustainable water use based on the long term protection of available water resources
- enhancement of the protection and improvement of the aquatic environment
- ensuring the progressive reduction of pollution of groundwater
- contribution to mitigating the effects of floods and droughts.

The quality of urban runoff is increasingly recognised as one of the key factors suppressing the aquatic ecosystems in many developed countries. The negative impact of urban runoff is clearly recognised in the WFD, which specifically refers to the need to tackle diffuse pollution, and it is therefore likely that stormwater management will become a key focus of the introduced POMs. Importantly, as well as focussing attention on diffuse pollution, the WFD also offers the opportunity and legislative support for a move away from the more traditional hard engineering approaches to stormwater control through its promotion of integrated approaches to water management, such as the use of stormwater BMPs.

In achieving the goals of the WFD, some of the most significant issues or 'risks' needing to be addressed are those posed by climate change. The Directive clearly requires variability to be taken into account and stipulates this should include climatic effects if many of the benefits from the

stipulated POMs are not to be negated. Although the general consensus of the scientific community is that there is a reasonable likelihood of a progressive warming and increased rainfall intensities over much of Europe in the future, there is considerable debate at present concerning whether climate modelling is sufficiently advanced to be able to provide clearly reliable predictions. Most European member states have developed global and regional climate models for different future scenarios. However, the resolution of these models is generally not sufficient for urban drainage planning e.g. minimum areas of 300 km2 with a timescale in months/years whereas the identification of appropriate BMPs requires knowledge of specific catchment conditions. Various downscaling approaches are available (see Section B) but these are not yet reliable. There is therefore a risk that individual POMs will be based on a limited process understanding which really needs to reflect possible climate adaptation changes. It is highly unlikely that climate change driven variability will be taken into account in the first 2009 – 2015 RBMP cycle of the WFD. It is also the case that such potential adaptation considerations have not been clearly taken into account in the context of current EU water planning strategies and policy. Figure 53 outlines some of the major drivers for future flood drainage under prevailing climate change scenarios.

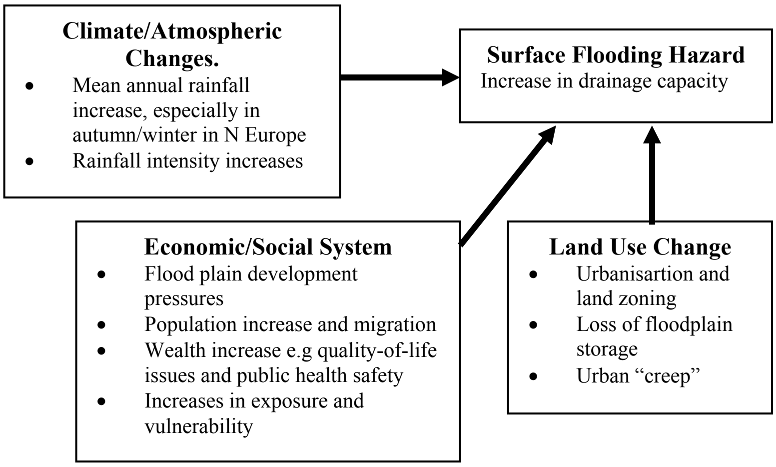


Figure 53. Identification of major drivers for future flood drainage under prevailing climate change scenarios

Of particular importance within the context of the WFD, is the relationships between climate change and ecological responses which are often poorly understood and this is typified by the expected direct and indirect impacts of climate change on freshwater ecosystems (Harrison *et al,* 2001). However, Wilby (2004) has attempted to identify the potential climate change impacts which may impede the establishment of good ecological status by giving separate consideration to physico-chemical, biological and hydro-morphological factors (Table 20).

From a political and strategic land-use planning perspective, it is not clear whether climate change constitutes a true driver for future urban drainage management and flood policy or simply represents a lever with which to introduce adaptation, uncertainty and change into the policy arena. An UK consultation document on "Making Space for Water" (DEFRA, 2005) contains few legislative proposals for addressing climate change, despite an acknowledgement that it will be a major cause of flooding. Nevertheless, it supports the view that, as mitigation measures may have a response time of up to 50 years, action must take place soon, and this is also the outcome of the recently released Stern Report (Stern, 2006). Placing emphasis on the 'worst case scenario' conditions, this report identifies the increasing costs of flooding in Europe due to extreme weather events unless flood management is strengthened in line with the rising risk. In the UK, annual flood losses could increase from around 0.1% of GDP today to 0.2 – 0.4% of GDP once global temperature increases reach 3 to 4°C. Developing countries are identified as being especially vulnerable to climate change because of their geographic exposure, low incomes, and greater reliance on climate sensitive sectors such as agriculture. There are also foreseen to be problems with the application of Western practices regarding

USWM to developing countries as the typically expensive infrastructure of these systems makes them unattractive.

Table 20. Potential climate change impacts on good ecological status

Parameters	Potential impacts
Physico-chemical	Changes in water temperature and dissolved oxygen
	Decreased dilution capacity of receiving waters
	Increased erosion and diffuse pollution
	More frequent flushing of combined sewer overflows
	Photoactivation of toxicants
	Exceedence of water quality standards
Biological	Changing metabolic rates of organisms
	Changing ecosystem productivity and biodiversity
	Climate space of plant and animal distributions
	Fish migration patterns and animal distributions
	Increased eutrophication and prevalence of algal blooms
	Changes in aquatic fauna and flora
	Changes in species assemblages in designated areas
Hydro-morphological	Changing river flows and sea levels lead to coastal erosion
	Indirect impacts from land-use practices and agriculture
	Hydrological connectivity of slopes, channels, and coastal zones
	Diffuse and point sources of sediment
	Long term bed-load and channel change
	Geomorphological processes creating dynamic/diverse habitats
	Channel changes

Source: Wilby (2004).

The UK Government, Office of Science and Technology, Foresight programme on climate change and associated flooding (Evans et al, 2004) showed that, in the context of the usual uncertainty associated with climate predictions, severe rainfall intensities in the UK may increase by up to 30% - 40% by 2080. This in turn could lead to a 40% increase in urban flood flows, a 100% increase in flood volumes, a 130% increase in the number of properties affected and a 200% increase in flood damage. The report also suggested that traditional approaches to resolving urban flooding are more likely to become unsustainable in the longer term. This conclusion alone provides a major driver for change in urban flood risk management strategies and hence has implications for stormwater management. Climate change is likely to influence both point and diffuse sources of pollution through increased flushing of pollutants during peak flows and/or reduced dilution during low flows (Wilby et al., 2006). Many urban pollutants are bound to particulates which may collect as contaminated surface sediments or as deposited sewer sediments. Urban drainage systems will be highly sensitive to increases in summer convective storms due to a direct flushing of toxic materials to receiving waters via separate sewers and capacity exceedence in combined sewers will result in contamination by CSOs. However, a recent UK Water Industry Research (UKWIR) report (Ashley *et al,* 2006) has suggested that in the short term up to 2020, both environmental legislation and energy use will be more important drivers for urban drainage than climate change. It is only post 2080 that climate change is likely to become the prime driver, although this conclusion runs counter to that of the Stern report (Stern, 2006) which argues for urgency in terms of financial and economic responses to climate change.

A further consideration is that every European Member State is committed to cutting greenhouse gas emissions, which should mitigate to some extent the impacts of climate change and contribute to reducing the magnitude of the flooding problem. However, there is a need to take explicit account of climate change in flood management policy, and hence stormwater management policy, in line with the precautionary principle and include adequate allowances for impacts in design against storm peaks/surges, the categorisation of flood zones for planning purposes and the capacity of storm drains to cope with increased rainfall intensities. Current urban drainage master plans/systems have been designed using historic rainfall data but as a result of predicted changes in rainfall frequency, intensity and duration (although the precise direction and magnitude of these changes are uncertain), this

approach will no longer be reliable in the long term. Guo (2006) has demonstrated the need for updating rainfall intensity-duration-frequency relationships to reflect changing environmental conditions through a quantification of the impact of an increase in heavy rainfall events on the design and performance of urban drainage systems in Chicago. Also in North America, Denault *et al.,* (2006) have developed a framework for examining the impacts of future increases in short duration rainfall intensities on urban infrastructure and natural ecosystems using a watershed in British Colombia as an example. The EU Action Programme on Flood Risk Management includes a proposal for a future Directive on the assessment and management of flood risk although a number of Member States have questioned the need for further legislation. It is argued that requirements on flood management are clear within the WFD and that further elaboration is not necessary. The counter argument is that the new Floods Directive will stipulate that the potential effects of future climate change will need to be considered in Member State river basin management plans and that it will provide a valuable and needed link with the WFD. However, it is not clear whether the Directive will specifically cover the problem of inter-urban flooding caused by surface water drainage being compromised when combined systems are unable to deal with heavy runoff events. Flood risk management should also consider the protection of water infrastructure from a public health perspective and their impacts on urban drainage systems. Raised river levels during heavy rainfall may mean that runoff drainage cannot discharge to a watercourse and increasing impervious areas within cities can only exacerbate this problem. It is not clear whether the EU will encourage sustainable urban drainage practices within any future EU Action Programme.

D.3 Socio-economic and environmental drivers

In Section C of this report, a wide range of socio-economic and environmental conditions with the potential to impact on stormwater management are identified and discussed. An overview of these drivers, together with examples of locations or areas where particular trends have been observed together with further supporting information, is provided in Table 21.

In common with the information on climate change predictions (Section B), general information on many of the drivers presented in Table 21 is available whereas more detailed information on specific trends within selected locations tend to only be available on an '*ad hoc*' basis. One factor that does clearly emerge from the data compiled within this report is that it is essential to appreciate how markedly circumstances at a specific location can vary from the general trends, even when a substantial data set may exist and how the question of scale may be critical. Perhaps one of the clearest examples of variations in trends around a specific driver is the data available on population dynamics. For example, on a global scale the human population is increasing. However, these increases are not consistent across the world and nor are they are predicted to be so in the future. The current global population is estimated to be 6.5 billion with a predicted increase to 8.9 billion people by 2050 (United Nations, 2005). Over the past century, the number of people living in cities has increased dramatically from 13% in 1900 to 29% in 1950, reaching 49% in 2005 with an estimated urban population of 60% by 2030 (UN Population Division, 2005). This urban population growth is predicted to be proportionately greater in less developed regions with an average increase of 2.2% per annum compared to an annual urban average increase of 1.1% for the population as a whole. This is due to factors such as elevated rural to urban migration and the greater transformation of rural into urban areas. Based on these population trends, it might be assumed that reliable population growth predictions are possible for any urban area. However, a city-by-city break down of data for the SWITCH demonstration cities for which comparable UN data is available shows that predicted growth at an individual city-scale can vary considerably from 0% over the period 2005-2015 in the case of Birmingham to a 35% increase over the same time period for Accra (Table 22).

Table 21. Overview of identified socio-economic and environmental drivers with potential to impact on USWM practices

Driver	Trends observed	Example town/country/ area	Further information
Population dynamics	Increase of population	Accra	See Table 22
	Decrease population	Emscher region	Associated with decline of local industry
	Migration	Gulf States	90% of work force provided by migrants
Urbanisation	Urban sprawl and re-densification	Birmingham	Eastside Development an example of redensification[1]
	Sealing and compaction		General impact of urbanisation
	Shrinkage and deconstruction	East Germany	Overestimation of population growth following the fall of the 'Iron Curtain'.
Wastewater production	Daily water consumption per capita		Estimates range from 300L/day in the USA to 140L/day in Belgium, to 4.5L/day in the Gambia[2]
	Water consumption of industry		Greatest use of water in high income countries (~59% of total water use)[2]
	Wastewater production		Varies in relation to water consumption
	Wastewater recycling		Generally under-utilised source of water
Agricultural development	Irrigation		Greatest water use in all regions except Europe and North America (~69% of total water use) [2]
	Agricultural runoff and erosion		Runoff of fertilisers and pesticides; erosion of soils block drainage
Economic aspects	Cost of urban drainage	Europe	Full costs of urban drainage generally not met by citizens
	Energy prices	Europe	Energy costs of USWM typically low
	Land prices		Can vary greatly even within a single city
	Fees and taxes	Germany	Use of stormwater tax led to significant increase in household disconnections
Traffic	Volume of traffic	Global increase	In 2003, number of private cars in China increased by an average of 11,000/day[3]
	Pollutants	Global increase	Traffic is a major sources of stormwater pollutants
Demands for amenities	Flood security	EU	EU standard prescribes tolerable overflow frequencies but values arbitrary and should be societal decision.
	Water quality	EU	EU WFD is a strong driver for USWM
	Water in urban spaces	Global	Increased demand associated with increasing environmental awareness
	Tourism		Tourism supports demand for better water quality, clean beaches etc
Innovation	Non-fossil fuels		Use of hydrogen fuel cells in cars would reduce pollutant load of road runoff
	New materials		Enhancement in the functioning of permeable/filtration materials expected.
	Domestic recycling of stormwater	Australia	Widely practised in Australia; predicted to become common practice elsewhere
Responsibilities	Citizen involvement	Europe	Now a requirement under the SEA and WFD directives
	Education / self responsibility	Global	Important elements in the success of certain BMPs
	Legislation	EU WFD	Increasingly stringent environmental standards likely to increase USWM costs
	Shift of competences	Belo Horizonte	Shift of water supply and sanitation provision from state to municipal level initiated review of USWM practices
Environmental drivers	Air pollution	Global	Enforcement of emission standards in western countries has led to improvement but a big issue in other regions
	Groundwater	Birmingham	Rising groundwater levels associated with industrial decline means stormwater infiltration not advisible[4]
	Soil protection	Global	Soil erosion can block drainage structures
	Surface water bodies	Europe	Often receiving water bodies for storm flows; legislation to improve their quality is an important USWM driver

Additional sources:
1 = Birmingham City Council (2006)
2 = People and Planet (2003)
3 = State of the World (2004)
4 = Birmingham project sheet (2006)

Table 22. Population data for selected SWITCH demonstration cities

	Population (millions)*		
	1975	2005	2015
Accra	0.7	2.0	2.7
Alexandria	2.2	3.8	4.5
Beijing	6.0	10.7	12.9
Belo Horizonte	1.9	5.3	6.4
Birmingham	2.4	2.3	2.3
Hamburg	1.7	1.7	1.8
Tel Aviv	1.2	3.0	3.5

*UN Population Division (2005)

However, even data collated at the city level may not be sufficiently sensitive for urban drainage planning needs. For example, although the population of Birmingham is predicted to remain stable over the next 10 years, on an intra-city scale a substantial part of Birmingham (an area of 420 acres known as 'the Eastside Development') is currently undergoing massive redevelopment and investment in an effort to transform an under-used and derelict area into a vibrant centre of cultural and economic growth providing thousands of new jobs (Birmingham City Council, 2006). The on-going implementation of this plan will obviously have an impact on local population dynamics as well as a significant impact on the drainage characteristics of the local area. This level of information and data is critical for developing an integrated urban water management policy, but is only available at the relatively detailed individual city-scale.

D.4 Role of SWITCH

This review identifies the complex and dynamic nature of the urban environment and addresses the issue of USWM within the wider context of climate change and socio-economic and environmental drivers. One of the issues influencing the development of long-term urban drainage management plans (i.e. robust predictions on a local or catchment scale) is the limited availability of detailed data on many of the drivers in many cities. However, it is not possible to delay urban planning decisions until scientists have collected and analysed sufficient data to enable more robust predictions to be made. Many urban populations are growing and urban planners around the world are required to make major long-term decisions on a daily basis. What support can be offered to those having to make these difficult and complex decisions?

Based on the findings of this review, two primary conclusions are made which can contribute to addressing this question. Firstly, just as the capabilities of climate change models are continually improving as different layers are gradually built up by scientists from different disciplines working in a co-ordinated approach, so urban planners need support in embracing the complexity and dynamism of the urban environment in a holistic, rather than 'piecemeal', manner. The more the needs and demands of local populations are understood with respect to their interactions with urban water, as well as the relationships between various aspects of the urban water cycle, the resulting integration will lead to greater resilience for urban water management developments.

Secondly, in making long-term decisions when the future is not clear, adaptability and flexibility must be key criteria in the identification and selection of stormwater control approaches. Some initial theoretical work has been done in benchmarking the adaptability of structural stormwater BMPs to trends predicted for various drivers such as increasing urban growth and decreasing soil moisture content as a result of global warming predictions. These aspects have been considered within the Multi-Criteria Comparator component of the Adaptive Decision Support System (ADSS) developed as part of the EC funded Framework 5 project, DayWater (www.daywater.cz). This work needs to be further expanded and tested within the field. As an individual research project this objective would be extremely challenging to achieve in anything but an extremely long-term time-frame which is

unfortunately not compatible with the need to support urban decision-makers at the present time. However, this type of project is exactly the sort of ambitious target which is facilitated by the global consortium bought together through SWITCH. Data on the impacts of a single city experiencing rapidly changing conditions may not be immediately available but through SWITCH there is the opportunity for the exchange of information and data between urban agglomerations currently operating under different conditions, constraints and opportunities. This opportunity is further supported by the development of Learning Alliances in each of the SWITCH demonstration cities, bringing together a variety of stakeholders from a range of public, private and civil sectors with the aim of breaking down barriers and facilitating the take-up of innovation through integration. The implementation of the SWITCH project offers a real opportunity to take forward urban water management planning at a range of scales.

E ACKNOWLEDGEMENTS

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G APPENDIX F: GUIDE TO STORMWATER BEST MANAGEMENT PRACTICES (BMPS)

Stormwater BMPs are divided into two main types as follows:

- structural BMPs (which involve the physical construction of a system for urban stormwater management)
- non-structural BMPs (which involve either the introduction of a new management practice or the modification of an existing management practice).

The following sections give a brief overview of the most common structural (Section F.1) and non-structural (section 1.2) stormwater best management practices. Further information and data, including photographs and case studies, on many of the BMP measures described in the following sections are available in the on-line DayWater BMP catalogue.

To access this catalogue:

- go to www.daywater.cz
- enter the word ' guest ' as both the username and the password
- click on the tile entitled 'BMP'.

This takes you to the 'front page' of the catalogue which gives an overview of its contents. Clicking on the hyperlink 'list of BMPs' takes you to a page which lists all the BMPs contained in the database and clicking on a particular BMP enables you to access further information on each of the measures listed.

G.1 Structural BMPs.

Detention Ponds/Basins (Dry Ponds): depressed basins which are normally dry but which temporarily store and attenuate a portion of stormwater runoff following a storm event and may consist of a berm or dam-encased area. Water is controlled by means of a hydraulic control structure to restrict outlet discharge according to the required detention time. Such dry basins offer public open space for recreational uses but are of limited habitat value.

Extended detention basin (EDB): a two-stage design providing a dry upper level and a smaller lower stage containing permanent water and/or a shallow marsh of about 0.25–0.35 m depth to facilitate the biological removal of colloidal and soluble pollutants. Pollutant removal rates range from 10% to 90%, depending on the constituent and geometry of the installation. For similarly sized EDBs, removal rates for total suspended solids, lead and other less soluble contaminants are only marginally less than observed for retention ponds and wetlands. To serve as an effective BMP, EDBs need to hold stormwater in the lower stage basin for relatively long periods e.g. in the USA, an emptying time of 40 hours is recommended for the one year runoff volume.

Filter (French) drain: a perforated or slotted drain pipe placed in a backfill aggregate material which is normally wrapped with a geotextile of fabric filter although some French drains may consist solely of aggregate materials. Such drains are primarily used to lower the water table and drain stormwater runoff from a highway surface.

Filter (buffer) strips: vegetative buffer strips similar to grass swales except they are essentially flat with very low slopes and are designed to promote sheet flow of the incoming stormwater runoff. The grassed strip intercepts suspended solids and associated pollutants using lateral runoff from land adjacent to streams, drains and basins and may be located along streets and highways. Buffer strips can remove coarse particulates effectively provided the flow is kept shallow and slow. As for grass swale channels, they are commonly used as a pre-treatment device to protect downstream BMPs.

Fin drain: a vertical, small diameter porous or perforated drain used in the UK at the edge of the highway pavement to assist sub-base drainage. They normally have the same internal structure as a filter (French) drain with aggregate backfill and geotextile liner. The ability of fin drains with regard to pollutant removal is limited by their design criteria which is based on dealing solely with subgrade drainage water.

Green/brown roofs: roofs planted with vegetation or vegetated sections. Green roofs use clean substrates whereas brown roofs incorporate the use of recycled aggregates which may have originated on-site. Green/brown roofs can be classified as intensive (substantial depth of growing medium supporting trees/shrubs) or extensive (shallower depth of growing medium utilising plants such as sedum). Such roofs are reported to retain from 25 to 80% of rainfall as well as reducing the rate of flow of any stormwater which does discharge from the roof. They are also reported to provide a variety of further benefits ranging from thermal insulation to evaporative cooling.

Gross Pollutant Traps; Sedimentation basins: these are structures intended to intercept and retain coarse sediment and litter carried in stormwater runoff by means of a bed load mechanism and are often located at the front end of a treatment train system.

Gullypots (Inlets, Catchbasins): a roadside chamber designed to collect stormwater runoff washed from the carriageway or paved surface and to trap grit and litter prior to entry to the below-ground sewer network. In North America, the term catchbasin is taken to mean the whole structure i.e. the inlet grate and sediment trap or chamber underneath, connected to the sewer system through a water lock. In other cases, the inflow structure is referred to as a sewer inlet (or gutter inlet) whilst the catchbasin refers to the sediment trap or chamber below the inlet grate. There are no volume standards for gully chambers or catchbasins although they generally vary between 40 – 100 litres in UK/Europe but in Canada and the US, their volume can be up to 2.2 m^3. However, this volume can be substantially reduced by a large quantity of solids trapped in the sump or gully chamber with the consequence that they become subject to surcharging during storm events. By trapping solids and associated pollutants, often retained under a small reservoir of standing water, the gully chamber can act as biochemical reactors often becoming anaerobic in dry weather. This results in poor quality supernatant liquor and contaminated interstitial porewaters being flushed out during the following storm event releasing oxygen demanding soluble organics, metals, bacteria and ammonium into the sewer pipe.

Infiltration basin: similar, in principle, to infiltration trenches, except that they are generally used for larger drainage areas and water is temporarily stored in a visible pond. A normal design would involve capturing, at least, the "first-flush" volume. As for detention basins, infiltration basins are frequently dual-purpose areas being used for stormwater runoff control and disposal under wet weather conditions, and recreational amenity use during dry weather. Although pollutant removal rates as high as 70% to 90% have been frequently reported, there are again many reports of basin failure from the USA and Europe due to surface sealing/clogging with groundwater mounding developing under basins.

An **infiltration ditch** is a narrow, steep sided open channel within which stormwater is stored and/or conveyed and from which the waters infiltrate into the adjacent soil as part of a planned method of disposal. When properly operating, infiltration trenches can remove up to 90% of particulates but there are many reported failures in the USA.

Infiltration trench: an excavated trench lined with a filter fabric and backfilled with stone. Runoff is diverted to the trench and either exfiltrates into the soil (a complete trench) or enters a perforated under-drain pipe (partial trench) with any excess flow being routed to an outflow.

Interceptors (separators): commonly known as oil and grit separators (USA) or interceptors (UK/Europe) and typically comprise two or three-chambered structures designed to remove oil and

grease as well as solid materials. They consist of a stilling tank (usually below grade) configured to separate lighter oily matter, scum and hydrocarbons from incoming stormwater runoff. The lighter oil rises and remains at the surface as a layer until it is withdrawn. Oil/water separation is accomplished by baffling the effluent orifice to block the surface layer from escaping with the effluent. Baffles are usually comprised of boards, inverted vertical pipes or metal hoods. The term "oil trap" refers to a small oil separator situated close to the source of oil and/or grease in an industrial plant or commercial building.

Kerb-cuts (water turnouts): a kerb (or curb) cut is a cut in a kerb block which allows stormwater runoff to discharge to a stable vegetated area or treatment basin. Water turnouts are stable channels connected to the road or kerb-cut. Normally lined with rip-rap, they are configured in such a way as to receive stormwater from the road to the stable treatment area.

Lagoons: small, permanent water bodies which are constructed by excavating natural earth basins. They may be lined to prevent infiltration and for safety reasons a fencing surround is often provided. Vegetation may be introduced to assist with the pollutant removal process.

Porous paving: an asphalt or concrete-based paving material that allows stormwater to rapidly infiltrate the surface pavement layer and enter into a high-void aggregate sub-base reservoir composed of gravel, crushed stone/rock or natural soil. Examples of such surfacing are porous macadam and no-fines concrete block paving or pavoirs. Some forms of permeable pavement use grass-concrete blocks which provide an open area for water flow of around 80% of the top surface area. The captured runoff is stored in this reservoir until it either infiltrates into the underlying soil, or excess flow is routed through a perforated underdrain system to a conventional outfall. Estimates of pollutant removals for modular porous paving systems range from as low as 10% up to 95% depending on the pollutant and site conditions. In the UK and Europe an increasing trend is to utilise polythene cellular blocks for the sub-base reservoir structure to provide increased void space and storage.

Retention Ponds/Basins (Wet Ponds): possess a permanent pool of water incorporated into the design and are also known as balancing ponds or flood storage basins. Principally function as sedimentation facilities with soluble pollutants being removed by biological processes which can be enhanced by marginal planting. Such wet ponds/basins can have substantial aesthetic, amenity and ecological benefits in addition to their flood and water quality control benefits.

Sand filters: designed to remove sediment and other adsorbed pollutants from the "first-flush" volume of impervious surface runoff with the filtration of nutrients, organics, metals and bacteria being facilitated and enhanced by a slime mat. There are various types of such filter which can include a variety of organic media such as peat or peat-sand mixes as well as various synthetic media. Filters can be very effective (although expensive) BMPs where land area is at a premium, but need regular operation and maintenance to ensure continuous satisfactory working. Average removal efficiencies of between 40% and 80% for total suspended solids, BOD, Total P, TOC, COD and dissolved zinc have been reported. However, concentrations of dissolved solids and nutrients in the outgoing effluent can be elevated compared to the incoming influent.

Soakaway: a stone or rubble-filled pit covered by soil into which a storm drain discharges runoff from roofs and paved areas. Although soakaways (or infiltration pits) may be some tens of square metres in plan area where they receive stormwater from a large impermeable catchment, they are frequently much smaller in area (<4 m^2 in plan area), serving only one household and being constructed in the private grounds surrounding the property. Often constructed no more than 2 m deep and with the storm drain discharging to the pit around 1m below ground surface, the resulting volume of water storage in the pit is only some 1 m^3 (assuming 30% void space in the stone or rubble fill). Recent design recommendations suggest that the pit should be lined with a geotextile fabric in order to separate the surrounding soil from the fill material and prevent the loss of storage volume due to soil migration and slippage into the pit.

Swales: shallow vegetated channels used to convey stormwater runoff. Pollutants are removed by settling, filtration through the grass sward and by infiltration into the underlying soil. Removal rates exceeding 80% of total suspended solids are commonly quoted for swales having flow velocities less than 0.15 m/s and with high soil infiltration rates. Runoff volume may also be reduced through infiltration. Ideally, swales require shallow slopes and soils that drain well and are often used as a pre-treatment measure for downstream BMPs. They can utilise check dams to increase storage, settling and infiltration and to reduce the channel gradient.

Vortex Separators: suspended solids separation units which use the force of influent stormwater into a cylindrical chamber to impart a rotational force that aids the separation of entrained solids. There are many types of vortex separator designs including the Fluidsep, Storm King and Grit King as well as the USEPA swirl regulator/concentrator. A significant design difference between the swirl and Fluidsep and Storm/Grit King devices is that the former uses baffles to impede vortex flow, whereas the latter promote free-vortex flow. In operation, most of these devices have a continuous foul underflow (containing concentrated solids) that can be directed to the sanitary sewer with the clear effluent passing on to further BMP treatment or to discharge.

Wetlands: a generic term for an area that is regularly saturated by surface and/or groundwater and subsequently is characterised by a prevalence of vascular vegetative species that is adapted for life in saturated soil conditions. Any standing water is generally less than 1m deep and both emergent and submergent plants can be used. These support a significant biomass of benthic algae and macrophytic epiphytes or biofilm which can take-up dissolved nutrients with organic colloid material being adsorbed onto the biofilm. Constructed wetlands are artificial, designed complex vegetative waterbodies that can provide treatment (and re-cycling) of both wastewater effluent and stormwater runoff. Most constructed wetlands are horizontal flow systems with the influent being directed either through the substrate (sub-surface flow systems) or across the surface of the substrate (surface flow systems). The majority of urban stormwater wetlands are surface flow systems.

G.2 Non-Structural BMPs

Chemical storage: certain materials need to be protected from exposure to rainfall and runoff in order to prevent leaching of contaminants and discharge to surface waters. Vehicle maintenance and storage areas, fuelling areas and petrol/gas stations, parking areas, weighing stations, food service outlets as well as road surfaces can contribute petroleum and other contaminants to runoff. Of particular concern for transportation and highway facilities are de-icing chemicals, fuels, oils, solvents, cleaning solutions, paints and pesticides.

Illicit connection controls: separate stormwater surface water drains are often used as an inexpensive or convenient alternative to proper disposal of wastewater and other effluents. Illicit discharges typically occur as illicit connections to storm sewers or from illicit dumping into storm drains. Controls for the former include close inspection during sewer construction, routine outfall inspection (including use of CCTV), interior pipe inspection (perhaps using wire strands to detect sewage), and interior building inspection. Illicit dumping controls include storm drain stencilling (signage), personnel training and public awareness campaigns, encouragement of complaint and dumping reporting.

Landscaping and vegetative practices: vegetation increases surface roughness, helping to control both the quantity and quality of stormwater runoff. Not normally used as "stand-alone" measures, vegetative practices are effective means of pre-treatment to reduce the size, cost, operation and maintenance of other BMPs and also enhance the aesthetic quality of facilities and urban landscapes.

Land-use and site planning: widely viewed as the most cost-effective control approach for stormwater quantity and quality, this BMP involves the prevention of impacts rather than retrofitting additional controls or conducting restoration projects downstream. Existing or potential water quality and flooding problems are identified and goals and measures are defined for preventing, reducing or

reversing receiving water degradation. It is an essential component of Low Impact Development (LID) and is a core process underpinning the Programme of Measures (PoMs) for River Basin Management Plans (RBMPs) contained in the EU Water Framework Directive. Site planning which introduces a minimisation of directly connected impervious areas (MDCIA), can almost completely eliminate runoff from storms of between 13 – 25 mm rainfall depths.

Litter and debris controls; Street sweeping: kerb accumulations of "dust and dirt" are normally controlled by street sweeping and/or vacuuming operations. Most studies would suggest that street sweeping is only effective at removing coarse litter and provides essentially an aesthetic function rather than any pollution control benefit.

Pesticide and fertiliser management: stormwater runoff quality may be improved by reducing the amounts of pesticides and herbicides applied for weed and pest control by local authorities and transport agencies as well as reducing garden and golf course fertiliser applications. Management issues include applying the chemicals at the right time, applying only the types and amounts necessary and considering the specific environmental conditions and hazards at the application site. Other control options include optimising low maintenance vegetation and integrated pest management approaches.

Public education and awareness campaigns: to be effective, it is necessary to modify how each individual uses and disposes of fertilisers, pesticides, herbicides, paints, solvents, oils, antifreeze etc.. To what degree, and in what numbers changes in behaviour can be achieved have yet to be fully answered. The more aggressive and re-iterative the public education process and campaign, the more effective it becomes as is evident from the UK national Oil Care Campaign. Local authority programmes that also facilitate the disposal of unwanted household products, such as used oil and paints, are also likely to increase public participation.

Rain gardens are a combination of infiltration/filtration devices where runoff from an impervious surface such as a road, is directed to a local hollow where it is allowed to soak into an organic filter medium such as topsoil or compost. Some water soaks into the ground while the remainder can be collected and piped to the stormwater drainage system. Such devices are regarded as being structural BMPs in New Zealand and Australia.

H APPENDIX G: USA AND CANADA BEST MANAGEMENT PRACTICE MANUALS

H.1 USA WEBSITES

www.epa.gov/waterscience/stormwater
Provides linkage through the "STORMWATER" search menu facility to over 220 documents, reports and manuals covering stormwater best practice design, management and operation.

www.epa.gov/npdes/menuofbmps/menu.htm
Provides full detail of the US Environment Protection Agency NPDES (National Pollutant Discharge Elimination System) programme. Information, design guidance and stormwater management manuals can be downloaded free from the site with fact sheets explaining US stormwater regulations and rules. A regular NPDES NewsSheet covers both structural and non-structural approaches and methods to stormwater control.

www.dot.ca.gov/hq/env/stormwater
The Californian Department of Transportation (CALTRANS) website on stormwater highway drainage issues and themes including regular bulletins and newsletters.

www.georgiastormwater.com
Access to free download of the Georgia State stormwater management manual covering Policy (Vol.1) and Technical detail (Vol.2).

www.mde.state.md.us/Programs/WaterPrograms
Access to download (at cost) of the Maryland State stormwater design manual and other information on stormwater management planning and policies.

www.dec.state.ny.us/website/dow/swmanual/swmanual.html
Access to free downloading of the state of New York Stormwater Management Design Manual covering design, operation and maintenance of stormwater source control BMPs and other guidelines on urban erosion control. Division of Water window provides additional, access to further information on NPDES permitting, stormwater management and related urban catchment issues.

www.txnpsbook.org
Stormwater information for public works professionals and developers on non-point diffuse source discharges within the state of Texas. Site includes free downloadable design guidance manuals and factsheets covering all aspects of non-point (rural and urban) stormwater discharges. Comprehensive interactive links to related US website services.

www.metrocouncil.org/environment/watershed/bmp/manual.htm
Website of twin cities Minneapolis/St Paul, Minnesota with free downloadable manual on Urban Small Sites BMPs covering design and performance evaluation.

www.swrcb.ca.gov/stormwtr/index.html
Website of the California EPA, State Water Resources Control Board providing access to free downloadable manuals on stormwater control and management, BMPs and urban runoff pollution and modelling. Links to individual County urban runoff management programmes and to public and outreach information and projects.

www.sacto.org/cleanwater

City of Sacramento stormwater management website with information, leaflets and basic manuals on urban BMP approaches. Downloadable resource materials for both public awareness and educational programmes.

www.udfcd.org
Access to website of the Denver, Colorado Urban Drainage and Flood Control District with (at cost) downloadable Urban Storm Drainage Criteria Manual but free Volume 3 on Urban Stormwater Quality BMPs. Regular newsletters on urban drainage and BMPs/SUDS approaches, case examples; publication listing and useful link addresses.

www.ecy.wa.gov/programs/wq/stormwater/manual.html
Provides access to revised 2005 update to the Stormwater Management Manual for western Washington which can be downloaded free or a CD/printed version can be ordered. Other publications on stormwater controls and practice can also be obtained.

www.dep.state.fl.us/Water/nonpoint/ero_man.htm
Free access to download the Florida Stormwater, Erosion and Sediment Control Manual primarily intended for BMP inspectors under the non-point discharge consent program. Other relevant documentation can also be obtained from the site.

www.portlandonline.com/bes/index.cfm?c=35122
Free download of the City of Portland *Stormwater Management Manual* (2002) available from the city Environmental Services. A free CD version of the manual can be obtained by contacting **robin.smith@bes.ci.portland.or.us** or a hardcopy obtained for $35.

H.2 CANADIAN WEBSITES AND SOURCES

http://wlapwww.gov.bc.ca/epd/epdpa/mpp/stormwater/stormwater.html
Access to free download of the British Columbia Stormwater Planning guidebook.

www.ene.gov.on.ca/envision/gp/4329eindex.htm
Access to free download of the Ontario Ministry of Environment (MOE) Stormwater Management Planning and Design Manual.