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# Drivers for future urban stormwater management (USWM)

**Lian Scholes*, Bryan Ellis and Michael Revitt**

Urban Pollution Research Centre
Middlesex University
Queensway, Enfield, Middlesex, EN3 4SA, UK

**Abstract**
The use of structural and non-structural stormwater best management practices (BMPs) as part of a multifunctional source control approach for urban drainage is becoming increasingly supported. However, the impacts of progressively changing conditions on these approaches need to be carefully considered and planned for if the initial environmental and socio-economic gains are not to be lost. The effects of climate change are beginning to be predicted with increasing certainty and the factors and mechanisms underlying major socio-economic and environmental drivers are more fully understood. It is essential that the information generated from these future scenarios is incorporated into current urban planning decision-making practices and, as in the case of urban stormwater management (USWM) where there are long term design considerations, it is important that sufficient flexibility is built into the planning and dimensioning of control structures and approaches.

**Keywords:** climate change, environmental factors, socio-economic drivers, urban stormwater management.

## 1 Introduction

A major goal of the SWITCH project is the identification, 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 a principal objective of one of the work packages (Work Package 2.1) 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,

* Corresponding Author: l.scholes@mdx.ac.uk

receiving water pollution and water shortage. This paper relates closely to the first Deliverable (Ellis *et.al.*, 2006) produced within this Work Package and sets out to provide an overview of the adaptability of current technologies for stormwater control when exposed to variations in environmental and socio-economic conditions.

The key drivers for change in stormwater management 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. Our ability to understand and robustly predict the interlinked impacts of these changes is not fully developed, and this is particularly the case 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 population and urban dynamics as well as water usage and flood patterns are likely to change in contrary directions when viewed from differing spatial scales. The uncertainty associated with these aspects presents a particular problem for stormwater management as the current trend is towards the use of decentralised stormwater BMP approaches 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. However, a fundamental requirement for the successful application of these multi-benefit approaches is a detailed knowledge of specific catchment characteristics and future stakeholder acceptability. There is, then, a requirement to resolve the conflict between the need for site specific information and our current inability to robustly predict future environmental and socio-economic 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 is the approach which has been adopted in this paper and for which a discussion is provided in the following sections.

## 2 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 improving 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 (DTI/British Water, 2006; CIRIA, 2001). 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 (USEPA, 2001). In Australia and New Zealand, sustainable urban drainage is incorporated into Water Sensitive Urban Design which also includes water resource and wastewater treatment issues (Engineers Australia, 2006).

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 does not relate to the absence of stormwater runoff as an issue in certain countries but to the fact 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 as well as concerns over potential groundwater pollution.

# 3 Urban water management, the EU Water Framework Directive and climate change

The USA has been at the forefront of the development of non-point (diffuse) policy and associated 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 aquatic ecosystems in many developed countries. The negative impact of urban runoff is clearly recognised in the WFD in terms of both “heavily modified” receiving water status, as well as in specific reference to the need to tackle diffuse pollution to enable its ecologically-based targets to be achieved. 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 that 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 $km^2$ with a timescale in months/years whereas the identification of appropriate BMPs requires knowledge of short-term specific catchment conditions. Various downscaling approaches are available (Picouet and Soutter 2006) 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 1 outlines some of the major drivers for future flood drainage under prevailing climate change scenarios.

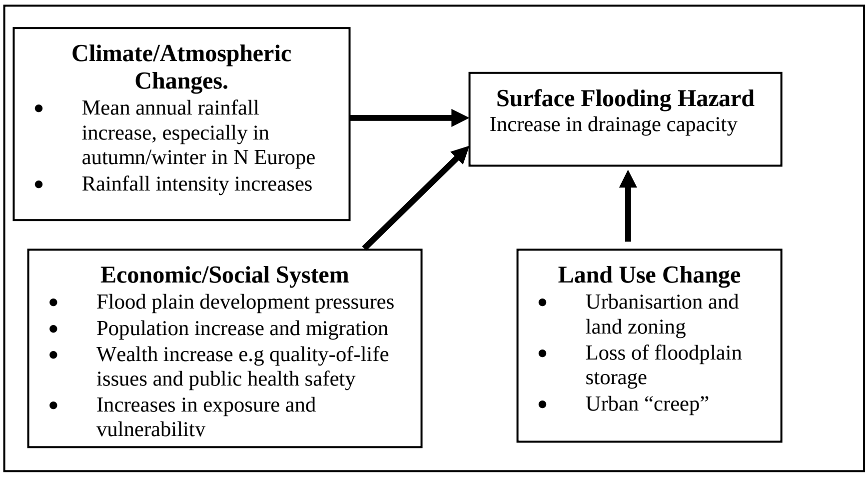


Figure 1. Identification of major drivers for future flood drainage under prevailing climate change scenarios

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 issues such as 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.

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). The same author (Wilby, 2004) has attempted to identify the potential ecological changes in receiving waters by giving separate consideration to physico-chemical, biological and hydro-morphological factors. 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.

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 on the grounds that flood management is indirectly addressed within the WFD.

# 4 Socio-economic and environmental drivers

A wide range of socio-economic and environmental conditions which have the potential to impact on stormwater management exist. 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 1. General information on many of the drivers presented in Table 1 is available but more detailed information on specific trends within selected locations tends to only be available on an '*ad hoc*' basis. Circumstances at a specific location can vary markedly from the general trends, and therefore even when a substantial data set may exist 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

Table 1. 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 | |
| | 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 urbanization; urban “creep” |
| | 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 |
| | Water consumption of industry | | Greatest use of water in high income countries (~59% of total water use) |
| | 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) |
| | Agricultural runoff and erosion | | Runoff of fertilisers and pesticides; erosion of soils blocking 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; but increasingly important driver for the water industry |
| | 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 |
| | 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 |
| | 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 |
| Water & energy costs | Water metering; water usage minimization; re-cycling; alternative energy sources | Europe, N.America, Australia | Rainwater harvesting; reduction in toilet flush volumes; dual piped systems; growth of wind turbines, solar panels etc.. |

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.

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. 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. The accumulative influence of urban "creep" through paving of gardens, driveways etc., is another influencing driver on impermeability and consequently on runoff rates. 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.

# 5 Conclusions

A major issue influencing the development of long-term urban drainage management plans is the limited availability of, and uncertainty associated with, detailed data on the drivers in many cities. In the absence of the availability of more robust predictions urban planners need support in embracing the complexity and dynamism of the urban environment in a holistic, rather than 'piecemeal', manner. The integration achieved by understanding the needs and demands of local populations with respect to their interactions with urban water and developing an appreciation of the relationships between various aspects of the urban water cycle will lead to greater resilience for urban water management developments. In addition, in making long-term decisions when the future is not absolutely clear, adaptability and flexibility must be key criteria in the identification and selection of stormwater control approaches. The SWITCH project provides an excellent opportunity for further benchmarking the adaptability of stormwater BMPs to the identified drivers through the global exchange of relevant information and data between urban agglomerations currently operating under different conditions, constraints and opportunities.

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