Journal of Environmental Planning and Management
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/cjep20

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Version of record first published: 11 Feb 2013.

To cite this article: Darla Nickel, Wenke Schoenfelder, Dale Medearis, David P. Dolowitz, Melissa Keeley & William Shuster (2013): German experience in managing stormwater with green infrastructure, Journal of Environmental Planning and Management, DOI:10.1080/09640568.2012.748652

To link to this article: http://dx.doi.org/10.1080/09640568.2012.748652

Journal of Environmental Planning and Management, 2013
http://dx.doi.org/10.1080/09640568.2012.748652

Routledge
Taylor & Francis Group

German experience in managing stormwater with green infrastructure

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(*Received 14 March 2012; final version received 7 November 2012*)

This paper identifies and describes experience with ‘green’ stormwater management practices in Germany. It provides the context in which developments took place and extracts lessons learned to inform efforts of other countries in confronting urban stormwater challenges. Our findings show that an integrated environmental planning approach helps to balance environmental and urban development. Further, the transformation to a mixed grey and green infrastructure necessitates both a quantifiable long-term goal and a suite of policies to incentivise green infrastructure and support implementation. Finally, public authorities must assume leadership while enabling the participation of stakeholder groups in the transformation process.

1. Introduction

To date, the management of stormwater in urban areas has tended to rely upon collecting and conveying urban stormwater runoff in combined or separate sewer networks – either to a wastewater treatment plant or directly into a receiving water body. Apart from their high initial capital costs and carbon footprint for operations and maintenance, these conventional ‘grey’ approaches are also associated with multiple negative hydrological effects. These include intermittent (i.e. storm) hydraulic stresses and high pollution loads to the receiving waters of stormwater discharges and combined sewerage overflows (CSO) following even small depths of rainfall or following periods of rapid thawing. Because of their intensive requirements, available end-of-the-pipe technologies such as stormwater retention basins, CSO structures and high-rate treatment plants are not always a feasible or sufficient solution. The significant expenditure and investment in wastewater and stormwater infrastructure makes this type of enterprise a candidate for an in-depth study of options that increase capacity or otherwise improve total system performance.

In North America, a number of European countries (e.g. Germany, Great Britain, and the Netherlands) and in Australia, water managers and policy makers

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are increasingly considering the use of 'green infrastructure' approaches to prevent, decelerate, and otherwise reduce stormwater runoff volume, with a long-term objective of complementing (e.g. reducing stormwater volume going into a combined system) or replacing some parts of current grey infrastructure (Brown 2005, Beenen and Boogaard 2007, Montalto *et al.* 2007, US EPA 2007, Environment Agency 2007, Boogaard *et al.* 2008, Roy *et al.* 2008, Roy and Shuster 2009). The term 'green infrastructure' (GI), which originated in the US in the 1990s, is used in this paper in its broadest form, to describe a strategic landscape approach to the conservation of open spaces in such a way that ecosystem processes and functions are maintained to the benefit of nature and human requirements (Benedict and McMahon 2002, Firehock 2010). With respect to stormwater management, the core concept of GI is that of harnessing the natural hydrologic cycle processes of infiltration, evapotranspiration and other losses to manage rainfall at its point of origin (US EPA *et al.* 2008). The term is also used to denote a wide range of potentially cost-effective practices that include the preservation or restoration of wetlands and river buffers on a larger scale to site-level, low-impact developments (LID) such as green roofs, swales, porous surfaces, rain gardens and rainwater harvesting. Such practices have the potential to reduce urban flooding, sewer overflows and pollution of receiving waters, help restore the hydrologic cycle, promote the replenishment of groundwater, mitigate the urban heat island effect through evaporative cooling, and provide habitat for wildlife (Bolund and Hunhammar 1999, Niemczynowicz 1999, Solecki *et al.* 2005, Nowak *et al.* 2006, Montalto *et al.* 2007, Matsuoka and Kaplan 2008). Investments in green approaches, particularly at the municipal level, can help to reduce capital investment needs during times of fiscal restraint and can provide redress for violations of environmental regulations through a comprehensive treatment of social equity, economic stabilisation, and environmental restoration and management (Bolund and Hunhammar 1999, Ngan 2004, Matsuoka and Kaplan 2008, Firehook 2010, US EPA 2007, 2011). This approach may also aid in the restoration of watersheds across geopolitical boundaries. However, while providing many advantages, the implementation of GI is anything but trivial. This is especially so considering the complexity of urban development and planning, the administrative fragmentation of responsibilities in the water sector, the variability of natural conditions, and the high operating costs and depreciable life of conventional water infrastructure (Brown 2005). If these factors are combined they are perceived to contribute to a climate of high risk adversity toward the planning, design, and implementation of GI (Brown 2005).

The analysis and communication of existing experience with using such approaches in response to urban stormwater challenges can contribute to a better understanding of the advantages of GI and help manage the real risks involved. This paper focuses on the German experience with GI during the past decades. Applications of GI for stormwater management are prevalent throughout Germany. Indeed, over the past 40 years, LID and LID-related technologies, such as green roofs, swales and constructed wetlands, have evolved from ecological experiments to common practice based on standards and norms (Koehler and Keeley 2005, SenStadt 2010, Buehler *et al.* 2011). The German experience is most notable with respect to innovative policy approaches to support and promote the use of GI. Indications or descriptions of individual German policies, technologies or projects can be found in current literature regarding stormwater management and on the complementary use of GI. Yet we find that to date no author has provided a comprehensive analysis of the wider policy, cultural and temporal contexts, which have been central to the outcome or success of these management approaches. We are convinced that such an understanding of context will provide a better basis for a goal-oriented and outcome-based policy transfer.

This paper aims to fill this identified gap. We first provide a brief introduction to stormwater management practices and a discussion of the general policy framework. We then delineate the specific context, challenges and approaches being used in the Emscher and Berlin regions. Finally, we extract important lessons that may serve as a basis for an exchange of experience with other countries confronted with similar urban stormwater management challenges.

2. Management and policy context in Germany

In Germany, responsibility for both urban stormwater and wastewater management is delegated to the municipalities. Continuous investment in maintenance and rehabilitation of the sewerage system has helped Germany avoid major investment gaps and price leaps. Investment costs are nearly fully covered by sewerage charges, which total an average annual per capita amount of €115.62, and the overall increase of charges remains below the national inflation rate (ATT *et al.* 2011). Since 1991, the wastewater sector alone has invested between €3.7 and €6.9 billion annually, so that currently 96% of the German population is connected to the public sewers, and 97% of the wastewater and combined sewerage collected is treated according to the highest European standards, including biological nutrient removal (ATT *et al.* 2011). Approximately 31% of the sewers are less than 25 years old and another 39% are between 25–50 years of age (DWA 2009).

Despite continuous investments, conventional systems for stormwater and wastewater management are challenged by issues similar to those confronting many developed countries. These include changing operating conditions (most notably demographic change leading to sharp decline or increase of population depending upon the region), and an increasing frequency and intensity of storm events. Rural areas of the Northeast, for example, have been widely affected by a population decline of 7% and more since the early 1990s following Reunification, and this trend is expected to continue (Hillenbrand *et al.* 2010). In many larger cities, particularly in the Southwest, population increase and high land-use rates necessitate an enlargement of capacity for stormwater and wastewater management. Increased flooding is a nationwide problem while CSO and stormwater discharge from separate systems remains a major source of concern for the quality of surface waters, both in terms of pollution and hydraulic stress (Zebisch *et al.* 2005).

In response, the use of stormwater policy instruments to promote GI, or more specifically LID, is widespread on a municipal level. Of 398 municipalities polled in a 2003 survey, 104 reported having such policy instruments in place. Approximately 18 localities provided direct financial subsidies, over 50 provided indirect financial subsidies and 36 mandated the use of LID for stormwater management under specific conditions (FBB 2003). More recently it was estimated that 106 m^2 of roof space is greened yearly, representing an estimated 10% of new private and commercial developments (SenStadt 2010).

More recently, GI has received additional support through national-level water policy. The German Federal Water Act (Wasserhaushaltsgesetz) (WHG 2009) and the State Water Laws together set the legal framework for wastewater and stormwater management. The Water Act generally requires that due care be exercised to maintain the functions of the natural hydrologic cycle and to avoid an increase of runoff and flow volumes. Following revision in 2008, the Water Act goes further to prioritise options for stormwater management. Preference is now given to stormwater infiltration near the source (§55, WHG 2009). In support of this, permission is generally not required for the infiltration of lightly polluted stormwater into groundwater (§46, WHG 2009). By comparison, stormwater collected from streets and from paved areas with heavy traffic requires treatment prior to percolation or direct discharge in to surface waters. Infiltration of any stormwater in designated water protection areas also requires permits. These regulations particularly affect new developments and pipeline rehabilitation projects in developed areas.

The Water Acts also implements the European Water Framework Directive (WFD), which regulates the protection, management and use of water resources in Europe, including rivers, lakes, coastal waters and groundwater (WFD 2000). Having come into force in 2000, this relatively young EU Directive is just now beginning to impact the use of GI. Fundamental to the WFD is the combined approach of emission limits and of quality standards for individual water bodies, not unlike the Total Maximum Daily Load approach in the US. The purpose is to remediate and otherwise protect all European water bodies by 2025 at the latest. Following a holistic approach, the WFD requires the establishment of integrated, catchment-based River Basin Management Plans and associated Programmes of Measures indicating how the good status of water bodies will be achieved. According to the first management plans from 2009, 137 out of 225 EU river basin planning units have included measures to decrease impacts of CSO and stormwater discharges to surface waters, including not only the renewal and expansion of retention and treatment capacities within the conventional sewerage system but also LID technologies (BMU 2010).

In compliance with equity and user-pay principles, prevailing German case-law calls for separate stormwater fees based upon estimates of the actual contribution of a parcel to the total stormwater burden (Tillmanns 2003, Keeley 2007). At present, two-thirds of all municipalities have introduced separate fees (ATT *et al.* 2011), suggesting that other local authorities will inevitably follow suit in the near future. Stormwater fees in Germany are based upon individual parcel assessments and are determined by the surface area which drains to the central conveyance system, with an average annual stormwater charge of €0.89/m^2 impermeable surface and an average wastewater charge of €1.95/m^2 (Keeley 2007, DWA 2009). Surface types and areas are typically determined based upon aerial photographs and satellite data. In many municipalities, on-site LID measures which help to restore the natural hydraulic cycle by increasing infiltration or evaporation reduce the stormwater fee, thus offsetting the costs for the installation of such technologies. For example, a greened roof is typically rewarded with a 50% discount off the stormwater fee (Ansel *et al.* 2011). Separate fees may therefore have the potential to provide incentives to implement LID (Keeley 2007). Although the introduction of such fees generally requires a substantial effort on behalf of the municipality, today they are considered an efficient form of incentive with some track record of successful implementation (FBB 2003).

Interestingly, innovative instruments for the promotion of green infrastructure can be found not only in water policy. Germany has developed a complex tiered system of spatial planning instruments that make use of GI for multiple benefits (stormwater management, but also habitat protection and urban climate control) on both a local and regional level to reconcile and align ecological conservation protection goals with those of economic and urban development. These instruments have their foundation in both nature protection and in building law. The Federal Nature Conservation Act (Bundesnaturschutzgesetz) establishes landscape planning as the central instrument for the conservation of natural resources (BNatSchG 2009). Landscape planning enables a municipality to devise a full-coverage strategy, tailored precisely to the municipality's interests. The approach to balancing tensions between conservation and municipal development is expedited through a local landscape plan (i.e. the Landschaftsplan), which is based upon specifications set out in regional and state-level landscape programmes. At the municipal level, landscape planning supports the search for mitigation sites and the determination of mitigation and environmental compensation measures required under nature conservation law for impacts or intrusions upon the natural environment. The local landscape plans are complemented by urban land-use plans, stipulated by the German Federal Building Code (Baugesetzbuch), specifically the preparatory and binding land-use plans (BauGB 1960). The preparatory plan shows the intended urban development for a municipality. Within this framework, the binding land-use plan then defines the use of the individual parcels. If impacts or intrusions upon the natural environment or landscape are to be expected as result of binding land-use plans, mitigation or compensation measures are required in compliance with the Federal Nature Conservation Act (Keeley 2004, Buehler *et al.* 2011). The creation of compensatory green spaces and LID technologies are acknowledged as candidates for both mitigation and compensation of such impacts. Areas or measures for avoidance and compensation of impacts upon nature are likewise included in the binding plan. Landscape and urban planning instruments therefore offer many possibilities to integrate stormwater management concerns and to promote green infrastructure on a range of spatial scales.

In many instances, European and national-level policies have combined with innovative policies on a regional or local level so as to stimulate the application of GI to manage stormwater at the source. We provide two instructive examples by analysing the developments in the Emscher area and in Berlin over the past 20 years. We have chosen these case studies because both have utilised green infrastructure and developed robust stormwater management policies in the face of both economic difficulties and disadvantageous population developments during transition to a more mixed, post-industrial economy. These case studies provide examples for other developed countries or regions undergoing similar transitions.

3. The Emscher case

3.1. History and drivers

Coal mining and heavy industry distinctively shaped the Emscher region in Mid-western Germany and eroded the quality of the Emscher river basin water resources during the last centuries. As early as 1899, the Emscher Public Water Management Association (Emschergenossenschaft) was voluntarily founded and financed by the surrounding municipalities, mining companies and industry to deal with increasing hygiene and flooding problems. Since it was founded, the overall objective of the Emschergenossenschaft has been to balance the demands of the different users (i.e.

humans, the economy and nature), and the association has taken on tasks covering wastewater and stormwater management, flood protection and groundwater management. Yet whereas its mission has remained the same over time, the means for achieving it have changed quite dramatically.

Early on, confronted by widespread occurrences of land subsidence due to mining, the Emschergenossenschaft straightened, deepened and embanked the Emscher River and canalised its tributaries, thereby essentially creating a combined surface sewer. The coal crisis of 1957 led to a radical structural change in the region and to a transition away from the heavy mining industry to a post-industrial economy based on high-tech and service industries. This transition also sparked a large-scale project to restore the Emscher River, which began in the early 1990s and will be completed during the next two to three decades (Stemplewsi and Raasch 2002). Central to this infrastructure project is a 51 km long sewer main running parallel to the Emscher River. By redirecting wastewater to treatment plants through a new subsurface sewer system, the goal is then to re-naturalise the surface hydrology of the Emscher catchment and its tributaries, converting many former industrial sites to green spaces in the process. The size and costs of the new sewer system were kept as low as possible by reducing the stormwater burden to the system through the widespread and concerted use of GI.

3.2. Policies and pilot projects

Initially administrators, politicians and the public were sceptical regarding the feasibility of utilising GI to achieve the separate management of stormwater and sewerage within the Emscher watershed (Becker and Raasch 2005). In 1992, in order to address doubts, the Emschergenossenschaft undertook a pilot project in the City of Gelsenkirchen. LID technologies were applied to decouple a large portion of the settlement from the central conveyance system. These included measures such as swales with French drains (Mulden-Rigolen Systems) for water from roofs and gardens, and open channels and swales for street water. To incentivise the implementation of further stormwater projects in the Emscher region, the Emschergenossenschaft set up a grant programme with a budget of approx. €5 million (10 million DM). The programme subsidised the disconnection of surface area from the sewer system with €5/m^2 (10 DM/m^2) on average between 1994 and 1999 (Spengler 2011). As most projects were completed on private parcels and later maintained by the landowners themselves, robust technologies and simple maintenance were of major importance. The programme successfully incentivised the implementation of GI projects and was found to be useful for demonstrating the effectiveness of LID. It also increased involvement and support of citizens and turned the public into partners in stormwater management (Becker and Raasch 2005). By enhancing citizen engagement, the programme fostered acceptance for subsequent, larger-scaled projects in the region. It was also soon discovered that the effort needed to implement stormwater management on small plots was high in relation to the achieved disconnection rate of surface areas.

Following the initial programme, the Emschergenossenschaft and the Environment Ministry of the Land North Rhine-Westfalia (MNULV) launched a joint grant-contest in 1998 called ‘Route de Regenwasser’ (rainwater route). Of 46 initial applications, 17 projects, intentionally of various sizes and design, were awarded a grant – one representative project in each city of the Emscher region. The grant

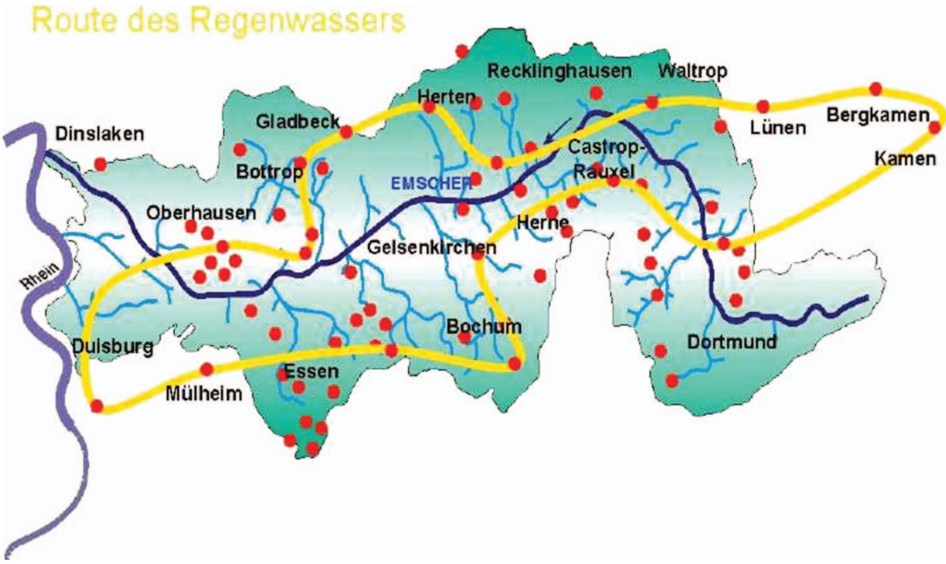

Figure 1. Stormwater management through green infrastructure in the Emscher region; the (yellow) line connects the 17 projects of the grant contest ‘Rainwater Route’. Source: Stemplewski and Raasch (2002). See online colour version for full interpretation.

covered 80% of the investment costs of each project, totalling nearly €6.25 million (12.5 million DM). The projects effectively disconnected 275,000 m^2 of impervious surface area from the combined sewer system by 2001 (Stemplewski and Raasch 2002). To increase public awareness, maps showing the location of the projects were made available (Figure 1), and the projects were connected via bike routes.

3.3. Strategy and commitment

The successful implementation of these first projects demonstrated the overall feasibility of applying green infrastructure to manage stormwater. Thereafter, a comprehensive strategy was designed to identify and link smaller-scale stormwater projects with an ecological and economic advantage for the overall Emscher restoration (Becker and Raasch 2005). This entailed a detailed assessment of the available potential for decoupling within the Boye basin, an 80 km^2 wide sub-basin of the Emscher. The outcome of this assessment was that between 12–18% of impervious surfaces in this basin could be decoupled within 7–12 years. Further, this assessment demonstrated that LID, installed in the right locations, could substantially reduce the necessary dimensions of the sewer system and the amount of stormwater needing treatment (Becker and Raasch 2005). Extrapolated to the entire Emscher watershed, the results showed that a 15% reduction of impervious areas draining to the sewer system would cost €250 million yet would reduce the investment costs in the central system by €270 million. As private investment was to cover GI implementation costs – at least in part – these were costs of major importance (Becker and Raasch 2005). The same authors demonstrated the possible economic impacts for both investors and municipalities, using the hydraulic sewer rehabilitation project in Recklinghausen as an example: 19 reaches of the sewer with a total length of 700 m were to be enlarged at a cost of €700,000 (Becker and Raasch 2005). The application of LID technologies to reduce the stormwater runoff of a hospital into the sewer resulted in a required rehabilitation for only two reaches, reducing the necessary investment to €67,000. The investment costs for decoupling the 4.15 hectares of developed area were approximately €450,000 and were shared nearly equally by the Emschergenossenschaft and the hospital. As the sewerage fees of the hospital were reduced annually by approximately €33,000, the private investment was amortised within seven years (Becker and Raasch 2005). Such results demonstrated the feasibility of implementing stormwater projects that resulted in economic win-win situations for all parties, but also pointed to the need to specifically target and prioritise appropriate locations. To this end, in 2003 the Emschergenossenschaft and the planning and building departments of the 17 Emscher municipalities developed the 'Management Information System Rainwater BIS/RW' (''Bewirtschaftungsinformationssystem Regenwasser) (Becker and Raasch 2005). This system provides online accessible information on both stormwater management options, based upon geological, morphological, topographical, soil types and geohydrologic information, and on the potential to reduce stormwater impact on the sewerage in a specific area as a function of current settlement structures and space availability. It also links potential measures to the state of the sewage system in the particular area in order to help prioritise projects in line with system rehabilitation needs. The BIS/RW information system verified that sufficient space was available to achieve the desired decoupling of 15%. Yet to overcome remaining doubts, an additional 'catalogue of measures' was developed to further persuade decision makers. Based on the BIS/RW information system, the Emschergenossenschaft identified nearly 4000 specific measures within the Emscher watershed that could be taken, validated the decoupling potential using aerial photos, and verified a considerable number of measures via site visits. According to Becker and Raasch (2005), the following criteria were used to select project measures:

- Settlement structure: row apartment housing, industry, trade and public ownership were preferred, as only a small number of owners needed to be persuaded to take part. Concepts were elaborated for publicly-owned facilities such as churches, kindergartens, schools and sports facilities.
- Decoupling potential according to the BIS/RW.
- Type of possible measures according to the geomorphologic conditions, the possible measures and their related costs; for example, installing a swale-spall drain system (Mulden-Rigolen System) is approximately 5–10 times more expensive than a swale (Emschergenossenschaft 2008). Simpler and potentially cheaper measures were preferred.
- Enforceability: including the interdependence with other activities such as city development but also the better enforceability on public grounds.
- Possible synergies with other water management or urban development measures in the area.

The Emschergenossenschaft then went as far as completing the conceptual planning for numerous projects, thus facilitating actual implementation (Becker and Raasch 2005). The measures proposed are now being pursued and co-ordinated with the construction and rehabilitation of sewers and with river restoration measures.

In 2005, the mayors of the 17 member cities of the Emschergenossenschaft, the (MNULV), and the Emschergenossenschaft signed a joint political commitment which obligates each signatory to promote and support the green infrastructure approach to stormwater management in order to reduce stormwater drainage through the sewer systems by 15% within 15 years (by 2020), or '15 in 15' (MUNLV and Emschergenossenschaft 2005). No such commitment setting a defined water management goal can be found elsewhere in Germany. Although not legally binding, this agreement has proved to be a very important element for promoting the GI approach.

3.4. Instruments and implementation

Through to the present day, the Emschergenossenschaft, the member municipalities, and the State of North-Rhine Westphalia continue to support the execution of GI projects through a set of managerial, financial and informational instruments.

The majority of the 17 Emscher municipalities have designated 'stormwater managers', who collaborate with the stormwater team of the Emschergenossenschaft and inform the mayors concerning the implementation progress (Spengler 2011). To promote maintenance and assure that stormwater management performance is achieved over time, the Emschergenossenschaft offers free inspections of stormwater facilities for property owners. Approximately 400 facilities have been inspected repeatedly in the last few years by external evaluators with very good results (Spengler 2011).

As to be expected, financial instruments continue to play a central role. All 17 municipalities introduced separated fees for stormwater, which are based on the impervious surface area, and lowered the sewerage charge. On average, disconnected surfaces generate annual savings of €1/m^2. In addition, in 2005, the Emschergenossenschaft established a grant programme to support GI-based stormwater projects with a total budget of €70 million, which is generated through the decreased costs for the grey infrastructure system resulting from stormwater management at the source. MUNLV also contributed €35 million from the revenues of the wastewater levy. Municipalities apply for the grants (for themselves or on behalf of landowners) and the Emschergenossenschaft decides on funding based mainly upon the criteria cost-effectiveness, economic advantage and size (Spengler 2011). Funding up to 80% of the investment costs was possible until 2008, but since then has been reduced annually by 5%. The programme favours the implementation of larger stormwater projects (e.g. streets, schools, churches, warehouses, industrial sites and housing blocks). Public housing societies have been particularly active. Such societies typically manage larger housing blocks, often for lower-income families. In a region experiencing population decline, the housing market is under less pressure and the housing societies must expend more effort to enhance the attractiveness of larger housing blocks (Spengler 2011). In an effort to accelerate the implementation of projects, earlier project starts are rewarded with higher grants (Figure 2) (Spengler 2011).

Through 2011, half of the grant budget had been spent and a 4% reduction of stormwater discharge into the sewer was achieved. This value is just slightly below the 2010 target of 5%, and the majority of municipalities have elaborated concepts to achieve the mid-term goal of 7.5% by 2013 (Spengler 2011). Although it was estimated that municipalities of the region could save a total of €200 million by implementing '15 in 15', a number of municipalities still struggle with designating the

Figure 2. Application of GI for stormwater management on property of public housing in the Emscher region. © Authors.

initial funds necessary from the public budget. Here, the prognoses and balances of the smaller municipalities are generally better because the decision-making process is more simple and direct, and also because the implementation of a single large project can have a significant impact on the balance for the entire municipality, as demonstrated by the Recklinghausen example above.

Finally, information has been a powerful tool in the progress toward stated management targets. The Emschergenossenschaft provides extensive information to the public in the form of brochures and a manual on decentralised stormwater management (Geiger *et al*. 2010). In addition, a travelling exhibition demonstrating LID technologies and a comprehensive website about regional stormwater management were designed to continue public outreach and keep citizens abreast of progress (Spengler 2011, Emschergenossenschaft 2012).

4. The Berlin case study

4.1. History and drivers

Berlin's unique history, especially the period of its division following the Second World War and the 20 years following reunification in 1990, have driven the city's evolution and implementation of sustainable water management practices, including the utilisation of green infrastructure. There is a historical precedent for water conservation and efficiency in Berlin. For 40 years, West Berlin functioned as an urban island entirely surrounded by East Germany. During this period of isolation, the city strove to close its water cycle and become self-sufficient, thereby relying solely upon groundwater resources, mainly river bank infiltrate, extracted within the limits of the city (Salian and Anton 2010). Wastewater and stormwater were discharged to these same surface waters, thus necessitating high standards for wastewater treatment. Water extraction exceeded natural groundwater replenishment and artificial groundwater recharge was carried out on a large scale, complemented by decentralised rainwater infiltration.

Berlin's isolation from the surrounding countryside simultaneously generated a high demand for inner-city green spaces for recreation, urban climate, air quality control and wildlife, and increased the receptiveness of both the administration and the general public to water and urban ecology issues. Therefore, the 'island' situation of West Berlin essentially prepared the ground for the successful implementation of integrated and at times unique policies for the creation and protection of green spaces on both a small and large scale. Although new options for water supply were available following Reunification in 1990, reunited Berlin opted to retain the closed-water-cycle paradigm and to fortify the system ensuring the sustainability of the city's water. In particular, the necessity for groundwater replenishment has promoted decentralised forms of stormwater management (Salian and Anton 2010).

Despite specific conditions that favour green infrastructure utilisation, Berlin faces serious barriers in its attempts to continue to expand usage of this technique. The ongoing redevelopment of infrastructure in the former East Berlin has been a formidable challenge since Reunification. Specifically, finances have been strained by the need to revitalise and harmonise infrastructure of all types and to redevelop vast expanses of fallow land, including the former city centre. Early expectations for substantial population growth in the new national capital did not materialise. Instead, the population has remained more or less stable and water demand has decreased by over 40% since 1989 as a result of a loss of water-intensive industries (SenGuv 2007). The lack of demand for water resources, value placed on natural green spaces, continued degradation of and reduced environmental effectiveness of older combined systems, and climate change have jointly called for increased consideration, if not implementation, of green infrastructure.

4.2. Evolution of financial incentives

In general, while direct financial subsidies were preferred in the early years of promoting green infrastructure, planning instruments, non-financial incentives, fees and regulations have played the dominant role since Reunification (Ngan 2004, Buehler *et al*. 2011). In the early years of promoting GI (1983–95), the Berlin Senate provided direct subsidies to increase green spaces, decrease impervious cover in the dense city centre and improve evapotranspiration through measures such as greened courtyards, green facades and green roofs (Koehler and Keeley 2005, Keeley 2004, Reichmann 2009). Total subsidies of €16.5 million resulted in 740,000 m^2 of courtyards and facades and 65,000 m^2 of green roofs, mainly on private property (Ngan 2004, Reichmann 2009). The programme ended due to a lack of funds; however, some inner-city districts continue to run similar programmes today. It is noteworthy that financing is generally coupled to predefined spatially-differentiated nature protection goals (see Green Area Ratio – GAR – below) to maximise the positive impact of a limited budget. Because decreasing CSO was not the main motivation of these programmes, their impact upon CSO has never been estimated.

In the late 1980s, Berlin also initiated a programme to specifically support experimental ecological building and urban development projects ('Pilot projects in urban ecology'). Sustained for two full decades, one of the thematic areas was 'integral building concepts', which placed a strong focus upon LID for stormwater management and long-term trials and optimisation of new technologies in a typical local setting, supported through scientific investigation and analysis (SenStadt 2011a). The strategy of the Berlin programme was to demonstrate the cost-effectiveness of the measures and to generate a publicly-available knowledge base, guidance on planning, implementing and maintaining GI installations and regulatory standards (SenStadt 2010, Reichmann 2011). Ultimately, the city published compulsory rainwater management and ecological construction guidelines for all public construction projects (schools, administration offices, etc.) and projects receiving public support from Berlin, thereby placing the public sector intentionally in the role model position and securing the transfer of research knowledge to practice (SenStadt 2011b).

4.3. *Integrated planning and strategies*

Early on, Berlin made extensive use of available planning instruments to support GI on both a large and a small scale. Required by Nature Protection Law (see Section 2 Management and policy context in Germany), the first 'Landscape Programme including Nature Conservation' (Landschaftsprogramm – LaPro) was enacted in 1988 and provided Berlin with a city-wide, strategic and binding planning instrument to ensure that ecological concerns, such as the preservation of natural habitats and open green space, are incorporated into urban development (Cloos 2004, SenStadt 2011c). In conjunction with the urban land-use planning, the LaPro provides the basis for future urban development and the creation of binding Land-use and Landscape Plans for specific city sections. The introduction of the Green Area Ratio (Biotopflaechenfaktor) (GAR) in Berlin starting in 1994 was a novel application of Landscape Plans to realise inner-city 'greening' goals of the LaPro by incentivising GI on a smaller scale (Keeley 2011). The GAR is a binding value (between 0.3 and 0.6) for the portion of a specific plot of land under development that must serve a function for the ecosystem (SenStadt 2011c). To calculate the GAR, surface types are weighted according to the ability of that cover type to store, evaporate or infiltrate rainwater and provide other environmental services. Weighting factors range between 0 (impervious surfaces) and 1 (vegetated surfaces connected to soil below) per m^2. Green roofs, to provide just one example, are weighted with a factor of 0.7. Unlike general 'open space' requirements, the GAR incorporates various LID techniques, an innovation which provides more flexibility for architects and property owners in meeting requirements (Becker *et al.* 1990, Keeley 2011). City planners have received positive feedback from architects and property owners about the GAR, as it is easy to use which results in immediate visual improvements and can provide other benefits, such as energy savings. City planners appreciate that the GAR calculation logic is similar to other planning indices and ratios, rendering the training of staff easier (Ngan 2004, Keeley 2011). They also value access to the GAR administrations, which provide information about how to meet GAR requirements and reduce stormwater fees (Keeley 2011). Currently, 12 of Berlin's 28 binding Landscape Plans contain GAR goals. Fourteen additional plans with GAR have been introduced and await approval. From a political perspective then, the GAR can be deemed a successful policy approach. However, its environmental impacts are much more difficult to assess; because of its dependence upon cycles of urban renewal, the GAR is slow to yield its positive impact.

Environmental goals defined in the LaPro can also be directly mandated in the binding Land-use Plans for new urban development. This instrument is used in Berlin to directly stipulate the use of LID for stormwater management, although not as extensively as in other cities, such as in Stuttgart, where this strictly regulatory approach is common practice today (Ansel *et al*. 2011). Indeed, urban planners and architects have demonstrated considerable resistance to such binding provisions which allow less flexibility than the GAR approach described above (Rehfeld-Klein 2011).

More recently, the implementation of the EU Water Framework Directive (see Section 2 Management and policy context in Germany) and river basin planning has provided increased impetus for the use of green infrastructure for stormwater management in Berlin, as the most significant pressures to Berliner water bodies relate to stormwater. Berlin and the State of Brandenburg, which encircles the city, have agreed upon strategic nutrient reduction goals on a sub-catchment level, with a total reduction of approx. 50% to be achieved by 2021 (SenGuv 2011). For two of nine sub-catchments, basin-wide decentralised stormwater management concepts will be required to achieve the set goals, either because central treatment and storage capacities are not feasible or not efficient (SenGuv 2009). Further agreed measures for all basins include strategic improvements to river morphology, which will require improved connection of existing green spaces that will benefit biodiversity and provide flood management services. Although at an early stage of implementation, the WFD river basin approach is greatly valued by city officials and utilities alike because it demands communication among all relevant stakeholders, provides an evidence-based method for prioritising measures according to their cost-effectiveness, and helps to avoid decisions that might reduce future options for action (Rehfeld-Klein 2011, Lemm 2011).

4.4. Fees and regulations

In the year 2000, Berlin stormwater management regulations were reformed so as to improve groundwater recharge through stormwater management at the source. Most notably, the reform included the introduction of separate stormwater and wastewater fees based upon individual parcel assessment and a more stringent approach to permitting separately collected stormwater to surface waters. These regulatory changes have prompted the widespread use of GI for stormwater management in the last 10 years.

Typical for split fees in Germany, the stormwater fee provides discounts or exemptions for surfaces based on their contribution to runoff, thereby incentivising green roofs, other typical LID for stormwater management (rainwater harvesting and infiltration) if these comply with existing technical rules, and the reduction of impervious surfaces (SenStadt 2002, Keeley 2007). At €1.90 per unit area (m^2) of impervious surface per year, Berlin's stormwater fee is the highest in Germany and is currently the greatest financial incentive for promoting green infrastructure in the city. This is particularly true in relation to industries and businesses operating large sites with considerable amounts of impervious cover and for the public sector (including schools, sports fields, hospitals, administrative offices, etc.), who had long profited from a combined wastewater and stormwater fee based on water consumption (SenStadt 2002, Reichmann 2011, Sieker 2011). For example, in 2002 it was estimated that the total fees for water services increased by 60% in the public sector as a result of the new fee system (SenStadt 2002). In response, the city published a catalogue of measures, building costs and decision strategies for reducing the costs of water in the public sector, which is equally applicable in other sectors (SenStadt 2002). According to the perceptions of public officials and professionals in stormwater management, home owners and owners of residential buildings are also becoming increasingly aware of fee reduction options (Reichmann 2011, Sieker 2011). The central finding is that separate fees work best when used in conjunction with other instruments and incentives, and particularly so with respect to existing developments. Viewed in the absence of other incentives, fees are too low to stimulate significant land use changes. This finding confirms the results of both Keeley (2007) and Buehler *et al.* (2011). Although the new fee system conforms to legal practice, transparent communication of its benefits proved central in establishing sufficient acceptance for the new instrument.

Years before the adoption of a similar approach in German Federal Water Law (see Section 2 Management and policy context in Germany), Berlin introduced the 'rainwater-management-at-source' paradigm under the Berlin Water Act (Berliner Wassergesetz) in 2000 with the aim of improving groundwater recharge (BWG 2005). The provisions specified differentiated technological and permit requirements for the infiltration of rain from different surfaces according to expected pollution and provided for permit-free infiltration of only lightly polluted rainwater. These new regulations combined effectively with a pre-existing but increasing tendency to define permissible stormwater discharges to surface waters according to pre-development, natural runoff rates in response to mounting water-related and environmental pressures in the inner-city area. For example, a stormwater discharge permit allowing a maximum discharge rate of 3l/s per hectare (0.035 ft^3/s per acre) led to the development of a rainwater management concept in connection with the redevelopment of the 7 ha Daimler-Chrysler section of the Potsdamer Platz, the city's former city centre which was destroyed during the Second World War and was first redeveloped in the late 1990s (Gellert and Nonnenbroich 2002). With conditions inappropriate for infiltration, a rainwater harvesting concept was required to manage an average of 32,000 m^3 rainwater/year. The rainwater harvesting concept was implemented with the aim of controlling urban flooding, saving water and operating costs, and creating a better micro climate. Rainwater is collected from 44,000 m^2 of mostly greened roof space, treated, and finally stored in large rainwater basement tanks. It is then used for toilet flushing, watering of green areas and the replenishment of an artificial urban water body (Figure 3), which enables the evaporation of nearly half of the yearly rainfall (Gellert and Nonnenbroich 2002).

With similar stormwater discharge restrictions in place, and additionally motivated by both the current stormwater fees of an estimated €1 million/year and climate concerns, the pending urban redevelopment project of the 405 ha, city-owned site of the former Tempelhof Airport will also entail a comprehensive strategy for on-site stormwater management with green infrastructure elements (SenStadt 2009, Sieker 2011).

Despite these and other successful examples, the widespread use of this management approach is often thwarted by a belated consultation of the water

Figure 3. The artificial urban water body on Potsdamer Platz provides for rainwater storage and purification, recreation, and natural habitats. © PPMG Potsdamer Platz Management GmbH.

authority in the urban planning process, which then precludes the integration of optimal stormwater management options (Rehfeld-Klein 2011).

5. Discussion and conclusion

The Emscher region and Berlin have both successfully integrated and implemented meaningful plans and policies for stormwater management and GI. These case studies are notable for their innovative character, the long-term tenacity of actors involved and the demonstration that progress is possible in spite of adverse economic or social-cultural circumstances. In each case, robust European-level and national-level policies to promote river basin management, integrated spatial planning and ecological compensation measures merged with creative regional and local innovations for financing and managing stormwater management at the source. The implementation of these policies has been critical to the transformational 'greening' and regeneration of both regions (Beatley 2000).

A number of generalised (de-contextualised) lessons learned can be extracted from the specific cases analysed is this study. In summary, our findings first point to the need for an integrated environmental planning approach that helps to balance environmental and urban development. The transformation to a mixed grey and green infrastructure requires both a quantifiable long-term goal with an accompanying strategy and a suite of policies to incentivise green infrastructure and support implementation. Policy instruments that show bias for a specific technology should be avoided. Finally, our findings highlight the need for public authorities to assume leadership while enabling the participation of stakeholder groups in the transformation process.

The experiences of the Emscher and Berlin offer insight into the value of an integrated environmental planning approach. By this we refer to planning that considers and includes landscape and watershed planning into the broader urban fabric. Integrated planning identifies and optimises the multiple benefits provided by GI and helps reconcile conflicts of interest. Integrated planning allows for incremental steps and an effective distribution of scarce funds over a long implementation process which has an agreed upon defined goal. Integrated planning also provides a platform for the various actors involved in urban planning to exchange and begin to understand different perspectives, as has been expressed in connection with the implementation of WFD. Integration of the water and environmental authorities at an early stage in the urban planning process is a key to success. Integrated planning binds resources and is likely to be controversial, therefore political endorsement, as provided for example by the WFD, will increase the likelihood of success. However, the Emscher case also demonstrates that long-term political will and perseverance on a regional level can also bring about the integration of key actors in a planning process and secure commitment needed on behalf of all key actors. A signed political commitment can also help ensure that a medium to long-term water management goal can outlast possible changes of government.

The definition of a common and quantifiable long-term goal or perspective is central to promoting long-term and transboundary transformations such as a mixed grey and GI approach to stormwater management. It provides the basis for the planning exercise and for strategy development. It is necessary to assess the cost-effectiveness and appropriateness of management options, to measure the distance to goals and the success of implemented options. The specific goal in the Emscher case (15% in 15 years) was arguably the single most important factor of success. It enabled the identification of appropriate measures; whenever larger plots or areas (up to the watershed scale) are planned for redevelopment, water management is 'rethought' and opportunities are sought for including concepts of GI to separate clean stormwater from sewerage at source in an incremental process. Such a common clear goal related to stormwater management and the inclusion of GI elements does not exist in the Berlin case. So although Berlin has experimented with a wide range of innovative policies, the impetus and a reference system for measuring improvements for stormwater management is lacking. On the other hand, the political decisions to close the water cycle and to halve nutrient input to surface water bodies within the next 10 years do provide a continuous motivation to protect water resources within the city boundaries which reflects positively on stormwater management.

Both case studies also highlight the value of incentivising GI for stormwater management through a mix of policies, including separate stormwater fees, direct financial support (especially early on in the initial phases of change), integrated planning, water rights for stormwater discharges, and other regulatory approaches. For long-term reform (and the utility of any given model within the transfer process), most of the options discussed have a specific scope of impact and therefore reach only a limited target group (stormwater managers, private persons, etc.), frequently even only within a specific 'window of opportunity' (i.e. within new urban development projects). For this reason, a suite of policy instruments is beneficial. Used in conjunction with one another, they can achieve a greater overall benefit than the sum of the individual benefits. This finding coincides with similar findings by Buehler *et al.* (2011) and Keeley (2007). Specifically, it seems that early use of financial incentives is crucial for promoting the use of GI. Direct support in the form of subsidies and grant programmes was shown to be advantageous for attracting 'lead users', gaining first-hand experience with new technologies and adapting them to regional needs, thereby building trust and know-how. While such instruments were preferred in the early years of promoting GI, planning instruments, non-financial incentives, fees and regulations later assumed the dominant role. Separate stormwater fees in particular can potentially influence a wide range of actors, both public and private, if cost reduction potentials and technical alternatives are known.

On a technical level, there is clearly no one-size-fits-all solution. The specificity of local land conditions will be a critical predictor of GI effectiveness. The suitability of technological options and the scale of solutions is a function of the local physical conditions such as location-specific soil permeability, density of the urban area, and baseline water quality. Therefore, regulations and incentive mechanisms that reduce flexibility and demonstrate bias for a specific technology are more likely to generate resistance, miss cost-effective alternatives and hamper innovation.

The experiences in the Emscher Region and in Berlin highlight the need for public authorities to assume leadership in the transformation process and demonstrate how this can be done in a variety of ways. Implementing projects on public grounds, raising awareness, sharing the risks and costs of introducing GI and providing assistance with implementation and maintenance are just some of the means that have proven useful. Public authorities appear to be in the best position to provide extensive information and guidelines. Guidelines support the choice, implementation and maintenance of cost-effective LID. It is necessary to have a solid data basis to assess possibilities for applying GI and their contribution to the total desired outcome, as was demonstrated by the Emscher case. Working with innovative architects, planners and engineers on demonstration projects eases the integration of GI into the existing urban fabric. In Berlin it was found that governmental support for innovation and innovation networks (competence hubs) helped to ensure that technological know-how is available at the regional level. Innovation networks and research competencies may best generate the types of data necessary to plan and design GI.

Finally – and ideally – to increase validity of and support for new approaches, opportunities for including participation of various stakeholder groups in the process of transforming from a grey to a grey/green infrastructure for stormwater management should be seized. This can happen on many levels, e.g. in infrastructure rehabilitation planning, urban planning and watershed planning, but also during the introduction of new fee systems or regulations. Yet, at a minimum, supporting the introduction of new policies and instruments with accompanying public relations activities and stakeholder specific information on financial and other implications has proven effective for increasing acceptance.

The experiences and outcomes of the Emscher region and Berlin can possibly provide a number of valuable lessons regarding a diverse range of options for transformation processes in stormwater management taking place in other developed countries. However, the transfer of policy and practice is by no means an automatic or self-sustaining process (Dolowitz and Medearis 2009). With all individuals coming from specific policy, institutional, socio-cultural and environmental settings and disposing of case-based knowledge, the challenge of any transnational learning process is not just to generalise case-specific knowledge for a wider audience (as we have done above), but to then adapt – not just borrow – this knowledge within a new and again specific context (Hassink and Lagendijk 2001, Potter 2007). Retaining an understanding of the institutional, political or environmental contexts of Germany's experience remains, however, the necessary basis for adapting and applying the lessons learned under differing contexts. Successful examples for transnational learning to improve stormwater management do exist, e.g. between Germany and the US. Two US cities, Seattle and Washington DC, have implemented Green Area Ratios (GAR) in conjunction with urban landscaping in dense urban areas based upon the Berlin model. Since 1999, the Northern Virginia Regional Commission has successfully worked to study and apply GI and related stormwater lessons from Germany, especially from the Stuttgart region. These successful examples of transnational learning and policy transfer can serve as models for engaging in grounded, careful, long-term and systemic study of the environmental, structural, financial and political contexts in which pieces of the Germany model may transform to fit within a new context.

Acknowledgements

This work was supported by the US EPA Office of Research and Development (ORD) and National Risk Management Research Laboratory (NRMRL), under contract EP-11-C-000067. The authors wish to thank Katrin Lemm, Hans Neifer, Matthias Rehfeld-Klein, Brigitte Reichmann, Pascale Rouoalt, Heiko Sieker, and Brigitte Spengler for their contributions to this study. The authors also appreciate the helpful input of Laura Grape and Sayedul Choudhury.

References

Ansel, W., *et al.*, 2011. *Leitfaden Dachbegrünung für Kommunen*. Nürtingen: Deutscher Dachgärtnerverband e.V.

ATT, *et al.*, 2011. *Profile of the German water sector 2011*. Bonn: wvgw Wirtschafts- und Verlagsgesellschaft.

BauGB, 1960. *Baugesetzbuch in der Fassung der Bekanntmachung vom 23. September 2004 (BGBl. I S. 2414), das zuletzt durch Artikel 1 des Gesetzes vom 22. Juli 2011 (BGBl. I S. 1509) geändert worden ist*. [online] Available from: http://www.gesetze-im-internet.de/bbaug/index.html [Accessed 28 August 2012].

Beatley, T., 2000. *Green urbanism*. WashingtonDC: Island Press.

Becker, C., *et al.*, 1990. *The biotope area factor as an ecological parameter: principles for its determination and identification of the target*. Report for the Senate Department for Urban Development and Environment Berlin.

Becker, M. and Raasch, U., 2005. *Abkopplung im Siedlungsgebiet – Strategie und Umsetzung im Emschergebiet*. Hennef: DWA.

Beenen, A.S. and Boogaard, F.C., 2007. Lessons from ten years storm water infiltration in the Dutch Delta. *Proceedings of Novatech 2007*, Lyon, France.

Benedict, M. and McMahon, E., 2002. *Green infrastructure: smart conservation for the 21st century*. The Conservation Fund and Sprawl Watch Clearinghouse.

BMU, 2010. *Die Wasserrahmenrichtlinie: auf dem Weg zu guten Gewässern*. Bonn: Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit.

BNatSchG, 2009. *Bundesnaturschutzgesetz vom 29. Juli 2009 (BGBl. I S. 2542), das zuletzt durch Artikel 5 des Gesetzes vom 6. Februar 2012 (BGBl. I S. 148) geändert worden ist*. [online] Available from: http://www.gesetze-im-internet.de/bnatschg_2009/index.html [Accessed 28 August 2012].

Bolund, P. and Hunhammar S., 1999. Ecosystem services in urban areas. *Ecological economics*, 29, 293–301.

Boogaard, F.C., Van de Ven, F.H.M., and Palsma, A.J., 2008. Dutch guidelines for the design & construction and operation of SUDS. *In*: *Proceedings from the 11th international conference on urban drainage 2008*, Edinburgh.

Brown, R., 2005. Impediments to integrated urban stormwater management: the need for institutional reform. *Environmental management*, 36 (3), 455–468.

Buehler, R.M., *et al*., 2011. How Germany became Europe's green leader: a look at four decades of sustainable policymaking. *Solutions*, 2 (5), 51–63.

BWG, 2005. *Berliner Wassergesetz (BWG) in der Fassung vom 17. Juni 2005 (GVBl. S. 357, 2006 S. 248, 2007 S. 48) zuletzt geändert durch Gesetz vom 6. Juni 2008 (GVBl. S. 139)*. [online] Available from: http://www.berlin.de/imperia/md/content/balichtenberghohen schoenhausen/gesetze-vorschriften/bwg.pdf [Accessed 28 August 2012].

Cloos, I., 2004. Ein Auftrag wird 25 Jahre alt. Das Landschafts- und Artenschutzprogramm für die gesamte Stadt Berlin. *Stadt und grün*, 53 (10), 13–18.

Dolowitz, D. and Medearis, D., 2009. Considerations of the obstacles and opportunities to formalizing cross-national policy transfer to the United States: a case study of the transfer of urban environmental and planning policies from Germany. *Environment and planning C: government and policy*, 27 (4), 684–697.

DWA, 2009. *Wirtschaftsdaten der Abwasserbeseitigung*. Hennef: Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e. V.

Emschergenossenschaft, 2008. *Nachhaltige Regenwasserbewirtschaftung im Emschergebiet – Regen auf richtigen Wegen*. Essen: Emschergenossenschaft.

Emschergenossenschaft, 2012. [online] Available from: www.emscher-regen.de [Accessed 15 January 2012].

Environment Agency, 2007. *Sustainable Drainage Systems (SUDS)*. Bristol: Environment Agency of England and Wales.

FBB, 2003. *SchlagLicht 3*. [online] Available from: http://www.fbb.de/dachbegruenung/fbb-schlaglicht/fbb-schlachtlicht-3 [Accessed 2 January 2012].

Firehock, K., 2010. *A short history of the term green infrastructure and selected literature*. [online] Available from: http://www.gicinc.org/ [Accessed 30 January 2012].

Geiger, W.F., Dreiseitl, H., and Stemplewski, J., 2010. *Neue Wege für das Regenwasser. Handbuch zum Rückhalt und zur Versickerung von Regenwasser in Baugebieten*. 3. Auflage München: Oldenbourg Verlag.

Gellert, S. and Nonnenbroich, T., 2002. *Ökologischer Stadtumbau Berlin*. [online] Available from: www.uni-weimar.de/architektur/oekologisches_bauen/11_projekte/2002_berlinex-kurs/ [Accessed 20 February 2012].

Hassink, R. and Lagendijk, A., 2001. The dilemmas of interregional institutional learning. *Environment and planning, C*, 19 (1), 65–84.

Hillenbrand, T., *et al*., 2010. *Anpassung der Abwasserinfrastruktur an den demografischen Wandel*. UBA-Forschungsbericht UBA-FB 001386. Dessau: Umweltbundesamt.

Keeley, M., 2004. Green roofs incentives: tried and true techniques from Europe. *In*: *Proceedings from 2nd annual green roofs for healthy cities conference*. [online] Available from: http://www.greenroofs.org/index.php/component/content/article/10-miscarchive/107 [Accessed 27 August 2012].

Keeley, M., 2007. Using individual parcel assessments to improve stormwater management. *Journal of the American Planning Association*, 73 (2), 149.

Keeley, M., 2011. The Green Area Ratio: an urban site sustainability metric. *Journal of environmental planning and management*, 54 (7), 937–958.

Koehler, M. and Keeley, M., 2005. The green roof tradition in Germany: the example of Berlin. *In*: Earth Pledge (eds.), *Green Roofs: Ecological Design and Construction*. New York: Schiffer Publishing.

Matsuoka, R. and Kaplan, R., 2008. People needs in the urban landscape: analysis of landscape and urban planning contributions. *Landscape and urban planning*, 84, 7–9.

Montalto, F., *et al*., 2007. Rapid assessment of the cost-effectiveness of low impact development for CSO control. *Landscape and urban planning*, 82, 117–131.

MUNLV and Emschergenossenschaft, 2005. *Zukunftsvereinbarung Regenwasser: Regen auf richtigen Wegen*. Dortmund: Emschergenossenschaft.

Ngan, G., 2004. *Green roof policies: tools for encouraging sustainable design*. Ottawa: Landscape Architecture Canada Foundation.

Niemczynowicz, J., 1999. Urban hydrology and water management – present and future challenges. *Urban water*, 1, 1–14.

Nowak, D.J., Crane, D.E., and Stevens, J.C., 2006. Air pollution removal by urban trees and shrubs in the United States. *Urban forestry & urban greening*, 4, 115–123.

Potter, P., 2007. Methodologies for generalising from the unique: knowledge transfer in territorial governance investigations and evaluations. Papers on Territorial Intelligence and Governance. Participatory Action-Research and Territorial Development. *International conference of territorial intelligence*, Huelva. [online] Available from: http://www.territorial-intelligence.eu [Accessed 31 January 2012].

Reichmann, B., 2009. Pilot projects in urban ecology and the landscaping of buildings. *In*: *International green roof congress 2009*, International Green Roof Association e.V. Berlin.

Roy, A., *et al*., 2008. Impediments and solutions to sustainable, watershed-scale urban stormwater management: lessons from Australia and the United States. *Environmental management*, 42 (2), 344–359.

Roy, A.H. and Shuster, W.D., 2009. Assessing impervious surface connectivity and applications for watershed management. *Journal of the American Water Resources Association*, 45, 198–209.

Salian, P. and Anton, B., 2010. *Making urban water management more sustainable: achievements in Berlin*. SWITCH – Managing water for the city of the future. Freiburg: ICLEI European Secretariat.

SenGuv, 2007. *Grundwasser in Berlin*. Berlin: Senatsverwaltung für Gesundheit, Umwelt und Verbraucherschutz Berlin.

SenGuv, 2009. *Ergänzender Länderbericht Berlins zum Entwurf des Bewirtschaftungsplans für den deutschen Teil der Flussgebietseinheit Elbe Dokumentation der Umsetzung der EG-Wasserrahmenrichtlinie in Berlin*. Berlin: Senatsverwaltung für Gesundheit, Umwelt und Verbraucherschutz Berlin.

SenGuv, 2011. *Reduzierung der Nährstoffbelastungen von Dahme, Spree und Havel in Berlin sowie der Unteren Havel in Brandenburg*. Berlin, Potsdam: Senatsverwaltung für Gesundheit, Umwelt und Verbraucherschutz Berlin und Ministerium für Umwelt, Gesundheit und Verbraucherschutz Brandenburg.

SenStadt, 2002. *Maßnahmenkatalog Reduzierung der Wasserkosten im öffentlichen Bereich*. Berlin: Sentatsverwaltung für Stadtentwicklung Berlin.

SenStadt, 2009. *Entwicklungsstrategie Templehofer Feld*. Berlin: Senatsverwaltung für Stadtentwicklung Berlin.

SenStadt, 2010. *Konzepte der Regenwasserbewirtschaftung: Gebäudebegrünung, Gebäudekühlung Leitfaden für Planung, Bau, Betrieb und Wartung*. Berlin: Senatsverwaltung für Stadtentwicklung Berlin.

SenStadt, 2011a. *Stadtökologische Modellvorhaben (Projektarchiv)*. Berlin: Senatsverwaltung für Stadtentwicklung und Umwelt Berlin. [online] Available from: http://www.stadtentwicklung.berlin.de/bauen/oekologisches_bauen/de/modellvorhaben/index.shtml [Accessed 6 January 2012].

SenStadt, 2011b. *Guidelines for profitability analyses to evaluate rainwater management options*. Berlin: Senatsverwaltung für Stadtentwicklung und Umwelt Berlin.

SenStadt, 2011c. *Handbuch der Berliner Landschaftspläne*. [online] Available from: http://www.stadtentwicklung.berlin.de/umwelt/landschaftsplanung/handbuch/index.shtml [Accessed 31 January 2012].

Solecki, W.D., *et al*., 2005. Mitigation of the heat island effect in urban New Jersey. *Environmental hazards*, 6 (1), 39–49.

Stemplewski, J. and Raasch, U., 2002. *Die Route des Regenwassers – Eine flussgebietsweite Initiative*. [online] Available from: http://www.emscher-regen.de/service/publikationen.php?frameset [Accessed 31 January 2012].

Tillmanns, H., 2003. Ist die Gebührensplitting notwendig? *Kommunale steuer-Zeitschrift*, 3, 26–30.

US EPA, 2007. *Memorandum: using green infrastructure to protect water quality in stormwater, CSO, non-point source and other water programs*. Washington DC: US EPA. [online] Available from: http://water.epa.gov/infrastructure/greeninfrastructure/gi_regulatory.cfm [Accessed 3 February 2008].

US EPA, 2011. *A strategic agenda to protect waters and build more livable communities through green infrastructure*. Washington DC: US EPA. [online] Available from: http://water.epa.gov/infrastructure/greeninfrastructure/gi_support.cfm [Accessed 29 February 2012].
US EPA, *et al.*, 2008. *Managing wet weather with green infrastructure – action strategy*. [online] Available from: http://water.epa.gov/infrastructure/greeninfrastructure/gi_policy.cfm [Accessed 2 November 2012].
WFD, 2000. *Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy*. [online] Available from: http://ec.europa.eu/environment/water/water-framework/index_en.html [Accessed 28 August 2012].
WHG, 2009. *Wasserhaushaltsgesetz [Federal Water Act] vom 31. Juli 2009 (BGBl. I S. 2585), das zuletzt durch Artikel 5 Absatz 9 des Gesetzes vom 24. Februar 2012 (BGBl. I S. 212) geändert worden ist*. [online] Available from: http://www.gesetze-im-internet.de/whg_2009/index.html [Accessed 28 August 2012].
Zebisch, M., *et al.*, 2005. *Klimawandel in Deutschland: Vulnerabilität und Anpassungsstrategien klimasensitiver Systeme*. Potsdam: Potsdam Institut für Klimafolgenforschung.

Interviews

Lemm, K., 2011. *Interview on 31 October 2011*. Berlin: Berliner Wasserbetriebe.
Rehfeld-Klein, M., 2011. *Interview on 21 October 2011*. Senatsverwaltung für Stadtentwicklung und Umwelt Berlin.
Reichmann, B., 2011. *Interview on 18 October 2011*. Senatsverwaltung für Stadtentwicklung und Umwelt Berlin.
Sieker, H., 2011. *Interview on 7 October 2011*. Berlin: The Stormwater Experts (Sieker Ingenieurgesellschaft).
Spengler, B., 2011. Telephone interview on 3 November 2011. Emschergenossenschaft.