© IWA Publishing 2016
176

Water Practice & Technology Vol 11 No 1
doi: 10.2166/wpt.2016.022

New paradigms in urban water management for conservation and sustainability

Andrea G. Capodaglio[a,*], Paolo Ghilardi[a] and Joanna Boguniewicz-Zablocka[b]

[a] Department of Civil Engineering & Architecture, University of Pavia, 27100 Pavia, Italy

[b] Department of Thermal & Industrial Engineering, Opole University of Technology, Opole, Poland

* Corresponding author. E-mail: capo@unipv.it

Abstract

In order to achieve a sustainable degree of water resources usage, new paradigms in urbanized basins planning must be adopted. Worldwide urbanized areas total population has overcome in 2010, its rural counterpart. While urbanization can be a powerful driver of sustainable development, as the higher population density enables governments to more easily deliver essential infrastructure and services in urban areas at relatively low cost per capita, these benefits do not materialize automatically and inevitably. Water bodies are usually severely hit and impaired by poorly planned urbanization. Old water resources planning paradigms must be abandoned and new ones, which include the connection of 'green cities' and their infrastructure with new modes of drainage and landscape planning and improved consideration of receiving waters, ought to be adopted. These must not only be environmentally and ecologically sound, but also functionally and aesthetically attractive to the public. New eco-cities shall no longer rely on excessive water volumes withdrawn from often distant surface and groundwater sources, with a once-only use of the resource, and large water losses due to leaks and evapotranspiration. Long-distance transfer of wastewater and high energy usage and emissions for its treatment should be avoided by distributed and decentralized integrated water/wastewater management. Effluent-domination shall no longer be a characteristic of urbanized river basins. The paper examines some of the paradigms that have been proposed for improving integrated water resources management in urban basins and illustrates some recent examples whether already implemented or still at the proposal stage.

Key words: urban water planning, water resources, urban watershed protection, sewerage, conservation, water reuse and recovery

INTRODUCTION

Worldwide urbanized areas total population has overcome, in 2010, its rural counterpart (WHO 2009); it is expected that, by 2030, urban dwellers will constitute 60–70% of the world's total population. Many cities in the world (in the USA as well as China and elsewhere) are subject to droughts and water scarcity of severe proportions; however, not all of these are located in naturally arid areas: Beijing, for example, has reached a 3.6 billion cubic meters water consumption (BWA 2013), far more than the 2.1 billion cubic meters locally available (Gangsheng & Jun 2005). This is not surprising, in the general consideration that China has about 20% of the world's population but just 7% of the world's freshwater resources. The lack of available freshwater water will in many case not only hamper development of a city, but can in the long run result in true 'human disaster' conditions.

In the past, Beijing had an abundant supply of water from the five rivers that flow through the city. Yongding River, one of the main tributaries in the Hai River system and best known as the largest river to flow through Beijing Municipality, has now almost dried up, a clear example of hydrological

Water Practice & Technology Vol 11 No 1
doi: 10.2166/wpt.2016.022

drought (i.e. the occurrence of anomalously low streamflow), caused by human water consumption (Wada *et al.* 2013). A similar fate has been occurring to the Colorado River for years, due to overuse from both agriculture and urban users.

Nearly one in 10 watersheds in the United States is 'stressed,' with demand for water exceeding natural supply – a trend that appears likely to become the new norm, according to a recent study. (Averyt *et al.* 2013), with cities being the greatest stress on the surface water system, in densely populated regions like Southern California. Cities that could be deeply affected by water shortages in the not too distant future include: Sal Lake City (UT), Lincoln (NE), Cleveland (OH), Miami (FL), Atlanta (GA), Washington (DC), El Paso, San Antonio and Houston (TX), San Francisco and Los Angeles (CA).

At the same time, water-related natural disasters (not to mention deliberate man-made disasters, such as acts of war and terrorist attacks) threaten the sustainability of cities, disrupting services, damaging property and directly putting resident's lives at risk. The goal of building resilient urban communities is also closely related to the issue of sustainable development: decisions made today concerning a city's water infrastructure will affect its sustainability for decades to come.

In order to achieve a sustainable degree of water resources usage, new paradigms in urbanized basins planning must be adopted. While urbanization can be a powerful driver of sustainable development, as the higher population density enables governments to more easily deliver essential infrastructure and services in urban areas at relatively low cost per capita, these benefits do not materialize automatically and inevitably. Water bodies are most often severely hit and impaired by poorly planned urbanization. Old water resources planning paradigms must be abandoned and new ones, which include the connection of 'green cities' and their infrastructure with new modes of drainage and landscape planning and improved consideration of receiving waters, ought to be adopted. These must not only be environmentally and ecologically sound, but also functionally and aesthetically attractive to the public. New eco-cities shall no longer rely on excessive water volumes withdrawn from often distant surface and groundwater sources, with a once-only use of the resource, and large water losses due to leaks and evapotranspiration. Long-distance transfer of wastewater and high energy usage and emissions for its treatment should be avoided by distributed and decentralized integrated water/wastewater management. Effluent-domination (defined as the predominance of wastewater effluents flows during all, or part of the year) shall no longer be a characteristic of urbanized river basins. Finally, resiliency of the water infrastructure (one of the most important elements in every city) must be a built-in feature in the new paradigms.

Cities and their dwellers are parts of ecosystems, and they are ultimately dependent upon the resilience and renewability of their ecosystem resources and services. Communities must therefore find ways to live adaptively within the capacity (waste assimilative capacity, loading capacity, resources use capacity) afforded to them by the ecosystems of which they are a part (Rees 1992, 1997).

The concepts of sustainable water use and drainage/sewerage infrastructure have been evolving in literature and laboratories since the early article by Okun (2000), and were summarized by Novotny (2008), who also put emphasis on the implied energy-water nexus resulting from the full application of these concepts.

FIRST NEW PARADIGM: RESILIENCE, FLEXIBILITY (AND VULNERABILITY)

Many old cities, towns and villages have a long and intimate relationship with water. In ancient times cities were usually erected near a watercourse or a coastline, and even today water is often central to their identity. The relationship between places and water resources, however, is rarely prioritized in urban planning and design nowadays. Among the negative consequences of this neglect, urban

Water Practice & Technology Vol 11 No 1
doi: 10.2166/wpt.2016.022

environments are increasingly afflicted by increased floods and droughts intensity and pollution effects, and are stressed by insufficient resilience due to poor water-conscious design. For many cities today, water was eventually transformed, through the centuries, from an opportunity to a risk.

Among various new paradigms recently faced by urban studies in recent times, resilience and flexibility have a predominant position. There are many different interpretations about these issues, but in general they can be synthesized as follows (Steiner 2000; Doepp & Edelmann 2006; De Lotto 2011):

- the relationship between human beings, their artifacts (city, infrastructure) and the environment (including water resources) must follow ecological principles of adaptation and evolution;
- territorial and urban planning should refer to changing scenaria defining equilibria that can only be temporary, once it becomes evident that rigid city planning is, by nature, inefficient.

There is a significant difference between *engineering resilience (*intended as a *structural* property*)* and *ecological resilience*: engineering resilience considers systems to exist close to a permanent, stable steady state. In this context, therefore, resilience is defined as the return time to steady state following a perturbation, implicitly carrying an assumption of single, global equilibrium. Ecological resilience, on the other hand, considers the magnitude of disturbance that can be absorbed by a system before this needs to redefine its functional structure by changing variables and processes controlling its behavior. The latter view, clearly, allows the assumption of the possibility of multiple, static steady states (Blackmore & Plant 2008). Urban environments' dynamics are governed by continuous transformations due to internal (changing inhabitants' needs) and external (general socio-economic context, environmental conditions and climatic changes) pressures. Achieving a balance among these pressures (themselves having different – and often unpredictable – rates and patterns of evolution) is one of the key point of sustainable and resilient urban water resources planning. Traditional paradigms, such as *robustness* of water systems (i.e. systems performing nearly optimally under a wide range of past conditions) as an index of sustainability, assume that historical hydrology will always be representative of future conditions' variability, and that water demand can be predicted accurately. These assumptions, as we are starting to realize, are not necessarily granted. In addition, in recent times, water, energy and their interrelationships are starting to assume strategic roles in all sustainable planning and design processes.

In the past, any uncertainty deriving from various sources was accounted for by adopting high safety factors in the design of urban water infrastructure, according to static concepts. This approach does not take into account the peculiarity of urban areas, and of their surrounding environment. Simonovic (2013) proposed instead the adoption of probabilistic, system reliability analysis, in which fuzzy theory-derived criteria can be introduced in order to incorporate all types of system responses to potential failures.

In general, resilience could perhaps be more easily obtained by a combination of a few structural, and many nonstructural, interventions, including hydrologic modification (infiltration increase, landscape adjustments, diffuse storage. LID (low impact development) is an approach to land development (or re-development) that works with nature to manage stormwater as close to its source as possible, employing principles such as preserving and recreating natural landscape features, minimizing effective imperviousness to create functional and appealing site drainage, and treating stormwater as a resource rather than a waste stream (LID 2014). Many ecologically engineered approaches may serve multiple purposes (flood control and conveyance, support for aquatic biota, primary and secondary recreation, etc.) and result to be both functional and aesthetically pleasing. Landscape ecologists (Ahern 2007) have suggested ecologically balanced types of urban landscapes in which a river and a series of urban lakes constitute interconnected ecotones that can preserve/imitate nature, naturally attenuating pollution from the surrounding areas and forming a natural floodplain during extreme events.

Water Practice & Technology Vol 11 No 1
doi: 10.2166/wpt.2016.022

SECOND NEW PARADIGM: THE CLOSED WATER LOOP CONCEPT

Novotny *et al.* (2010) identified a new paradigm in urban water management with the concept 'water supply, stormwater, and wastewater managed in a closed loop'. Water resources are, in most cases, used in a linear system of mass and energy flow in a once-through fashion. This way, the sole lasting benefit deriving from last century's pollution control practices is that the effect of such disposal on the receiving environment has been limited.

The integration of the complete water management cycle, including water conservation and reclamation, storage of reclaimed water and stormwater for reuse, wastewater treatment and energy from waste recovery, cannot be achieved in a system that is designed for long distance flow transfer, with underground subsurface/deep tunnels storage and conveyance, and distant wastewater treatment plants. Clustered, decentralized models have been proposed instead. A cluster is a semiautonomous urban water management/drainage unit that receives water, implements water conservation within, reclaims sewage for local reuse, such as toilet flushing, irrigation and providing ecological flow to restored streams, recovers heat, biogas, or electric energy and nutrients from wastewater and organic solids. Such concept could enable service privatization, cost savings, and commercialization of recovered resources.

Clusters may vary in size, ranging from a single, large high-rise building or a group thereof, larger shopping centers, subdivisions, to entire portions of a city: the size of the cluster and the number of people it serves must be optimized taking into account local conditions. It is quite possible that cluster management could make infrastructures such as deep tunnels and large interceptor sewers obsolete. By bringing stormwater conveyance to the surface, existing sewers can turn out to be oversized, and these could be used for other purposes, such as fiber optic/phone cables conduits for which water management utilities could charge a fee to other service companies: this is actually already being done in Tokyo and other cities.

Water reclamation plants and energy recovery units could be installed in most clusters at the points of reuse. Sanitary sewage can be conveyed there mostly by conventional underground sanitary sewers, or by low-flow (vacuum) sewers. The latter would have the advantage of providing substantial water savings for flushing and 'moving around' fecal matter, while providing more concentrated waste directly suitable to anaerobic digestion with improved energy recovery. Solid/liquid separation at the source could also be implemented, with recovery of nutrients (struvite) or pharmaceuticals from separately collected urine.

Recently, *sewer mining* has been proposed as a way to convey recycled water to non-drinking purposes such as toilet flushing in commercial buildings and industrial sites, cooling towers, and irrigation of sports fields, parks and golf courses (Sydney Water 2013). Sewer mining is the process of tapping into a wastewater system, (either before or after the wastewater treatment plant), and extracting wastewater, which is then treated and used as recycled water for a specific end use. Local regulation in areas where sewer mining is applied may consider acceptable to return sewer mining by-products to the wastewater system as industrial wastewaters.

GENERAL PARADIGMS APPLICATION CONTEXTS

It is well known that applying hard environmental targets in newly developed cities is easier than in existing, perhaps historical, contexts. In many new 'green' or 'eco-cities' (i.e. Masdar City in UAE or Dongtan City in Chongming Island, in front of Shanghai, China), infrastructure integration and sustainable use of resources are perfectly programmed from blueprint, however, a relevant issue arises: 'how can similar sustainability performances be reached in existing urban contexts'?

Water Practice & Technology Vol 11 No 1
doi: 10.2166/wpt.2016.022

To reach the same level of performance, existing cities have much more constraints (physical, architectural, cultural, social and economic) than brand new ones. In the greater part of the urbanized world (and certainly in Europe), the real issue is more 'how to make existing cities sustainable?' than 'which are the best technologies that we can use in new cities?'.

Henceforth focus will be put on case studies of improving water control and loop management in existing contexts.

BAF application in the city of Pavia (Italy) for infiltration improvement and CSO control

Among diverse available indexes in the literature, the Biotope area factor (BAF) has been studied and tested demonstrating repeatability and suitability to address tangible decisions in urban water management. BAF is defined by the ratio between 'ecological surface' and the total considered area. The ecological surface is calculated as the sum of different surfaces, weighted by specific coefficients representing: evapotranspiration efficiency, suspended dust fixation, water capturing of soil, improving soil functions (filtering and buffering), new habitat construction (Figure 1). For each specific urban destination and fabric characteristics, a target BAF value can be defined (AAVV 1990). In a city center, using the BAF constitutes a particular approach to securing 'green qualities'. In the city of Berlin, for example, BAF values can be established in landscape plans as a mandatory city ordinance for

Surface type	Weighting factor
Sealed surface Impermeable to air and water and has no plant growth (concrete, asphalt, slabs with a solid subbase)	0.0
Partially sealed surfaces Permeable to water and air, but no plant growth (mosaic paving, slabs with a sand/gravel subbase)	0.3
Semi-open surfaces Permeable to water and air, some plant growth (gravel with grass coverage, wood-block paving, honeycomb brick with grass)	0.5
Surfaces with vegetation unconnected to soil below On cellar covers or underground garages with less than 80 cm of soil covering	0.5
Surfaces with vegetation unconnected to soil below No connection to soil below but with more than 80 cm of soil covering	0.7
Surfaces with vegetation connected to soil below Vegetation connected to soil below, available for development of flora and fauna	1.0
Rainwater infiltration per m^2 of roof area Rainwater infiltration for replenishment of groundwater; infiltration over surfaces with existing vegetation	0.2
Vertical greenery up to 10m in height Greenery covering walls and outer walls with no windows; the actual height, up to 10 m, is taken into account	0.5
Green roofs Extensive and intensive coverage of rooftop with greenery	0.7

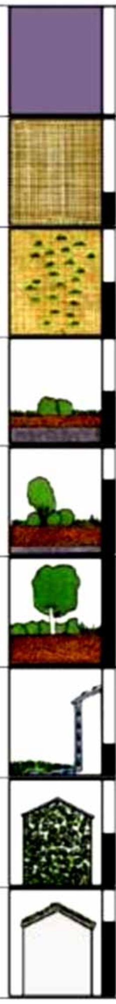

Figure 1 | Coefficients used in BAF calculation (AAVV 1990).

Water Practice & Technology Vol 11 No 1
doi: 10.2166/wpt.2016.022

new developments. Since even a small-scale development, influencing an existing urban drainage network, may have large scale consequences through increased runoff production, increased local floods or CSOs (combined sewer overflows) events risk, BAF control can at least help maintain local 'hydraulic invariance' in view of modified or new urbanization.

The city of Pavia is a small, historic city in Northern Italy, with an urban implant dating to Roman times (in the old city center, brick-vaulted sewer connectors from that era are still in operation). The BAF methodology was applied to analyze the current hydrological context in the city. For this example, two different situations will be considered (Figure 2). Block 'A' is a residential neighborhood within the consolidated old city fabric; it was built around the 1960's and consists of 7–8 floors' buildings. Residential density is high (compared to local standards), and the covered-to-open ratio is close to 50%, with surfaces mainly consisting of (traditional) asphalt and concrete. The calculated BAF value is therefore very low: 0.04 (with an ideal target of 0.3). Block 'B' was built in the 1990's. It mainly consists of low density, two floors' buildings, and the covered ratio is around 20%. The calculated BAF value is 0.46, with an ideal target of 0.6: while still not satisfactory, its current value is however not too distant from the optimal one. Similarly, the entire city of Pavia was analyzed with this methodology, and the resulting average BAF value emerged to be lower, or about 50%, of the ideally required value. The most relevant result is that BAF is influenced more by the covered surface ratio than by residential density parameters, therefore to improve overall urban hydrological performance, it will be necessary to intervene not only on public surfaces (e.g. replacing traditional asphalt

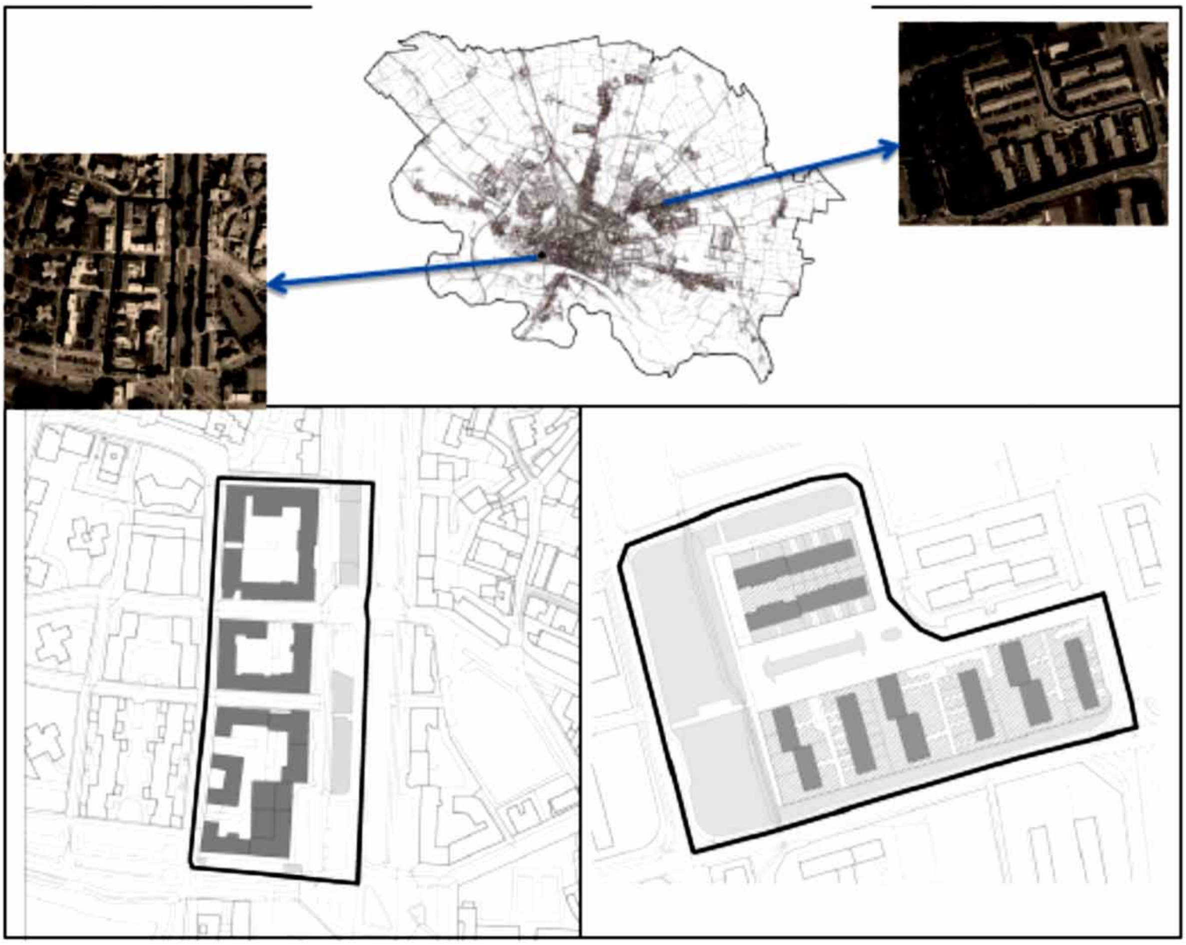

Figure 2 | Map of Pavia (center top, scale 1 cm = 2.15 km) with location of selected neighborhoods. (A, left and B, right), with their respective satellite images and the analytical definition of ecological surfaces (bottom left, scale 1 cm = 50 m & right, scale 1 cm = 40 m). (LEGEND – white: impermeable flat surface, dark grey: impermeable built, light grey: permeable flat surface).

Water Practice & Technology Vol 11 No 1
doi: 10.2166/wpt.2016.022

with semi-permeable one on low-traffic streets) but also on private lots, for example encouraging the transformation of impermeable surfaces (e.g. concrete-lined car parking lots, paved internal courtyards) into permeable ones. Intervention to improve the index to the ideal value could result in significant improvements of sewer performance, and the significant reduction of CSOs to the River Ticino.

From the morphological point of view, the application of the BAF methodology to a real context demonstrates that a dense city may still have good hydrologic performance, as long as density is concentrated in tall buildings while, in difficult contexts such as historical centers, there could exist serious landscape, and certainly economic, constraints on implementing adequate solutions.

Sustainable urban water management in Berlin

The first water shortages in Berlin date back to 1952, during the cold war, when West Berlin water supply largely depended on imports from East Germany. In the late 1970's, Berlin also experienced a strong citizens' demand for environmentally friendly living; this initiated an urban greening campaign by the city administration, that also affected the city's water management strategies with the introduction of conservation, reduction of hydraulic stress on the drainage system, and improvement of infiltration and groundwater replenishment. By the late 90's – after reunification – Berlin had the possibility to source water from the neighboring state of Brandenburg, however its administration insisted that all water consumed by the city should be abstracted from within its boundaries, and made sure that a closed-water-cycle approach was adhered to.

Sustainable solutions, in conjunction with wastewater reclamation, subsequently adopted in Berlin include (Salian & Anton 2012):

- riverbank filtration. This is the process of collecting water from wells or infiltration galleries located near a river bank. In this process, river water is allowed to pass through the riverbed into the aquifer, thus the bank acts as a natural filter removing most of the organic particles and pathogenic microorganisms Although bank filtration has been used elsewhere (e.g. Vienna, Austria and Bratislava, Slovakia), city administrators in Berlin have extensively applied this technology, in conjunction with wastewater reclamation and artificial aquifer recharge in West Berlin, boosting the citýs groundwater resources;
- green roofs. A green roof is a roof covered with a layer of vegetation planted over a waterproofing membrane. In addition to help maintaining a close-to-ideal BAF absorbing rainwater (see for example Figure 1 above), green roofs provide several additional advantages for buildings, such as improving insulation, creating a habitat for wildlife, increase air humidity, and help lower urban air temperatures and combat the heat island effect.
- sustainable rainwater management for artificial groundwater recharge. This is an important part of water resources management in the Berlin area. With an average precipitation of 600 mm/yr, the natural groundwater recharge rate of up to 200 mm/yr is not sufficient to maintain groundwater resources for the city's uses. Three groundwater recharge plants were established in order to increase groundwater quantities. Collected surface water is discharged in the vicinity of groundwater abstraction wells, into shallow earthen basins, ponds, or pits for percolation into the groundwater. In 2000 a 'rainwater management at source' strategy was adopted, by promoting disconnection of runoff originated by impervious surfaces from the urban drainage system, and providing infiltration at source. The system has two main benefits: first, it increases rainwater infiltration and, secondly, it carries significant economic savings associated with the reduction of infrastructural and operational costs linked to the treatment of polluted rainwater at a centralized location;
- demand management. Increasingly high levels of water use would eventually require ever-increasing and expensive investments in water system infrastructure. Water authorities in West Berlin

Water Practice & Technology Vol 11 No 1
doi: 10.2166/wpt.2016.022

introduced since the 1980's, a water demand management strategy to curb per capita consumption: this mainly consisted of higher water tariffs, to encourage customers to adopt more sparing water-use habits, publicity campaigns, together with well-organized public communication and instructions for water saving (first in West Berlin, in the 1980's, later in the former Eastern sector in the 1990's); temporary subsidies for the purchase and installation of water saving equipment, and strong efforts to reduce leakages and pipe losses. These measures have succeeded in reducing Berlin's per capita water consumption from 250 to 112 litres/person/day. In total, the consumption of water for the entire city has dropped by 45% in the last 20 years.

Beijing, eco-city of the future?

China's water problems are ubiquitous: besides drinking water supply problems in the north, flooding is common in the south, and river pollution is common everywhere in China. In northern China there is not enough water for all the different uses (i.e. agricultural, industrial) and for big cities, which have high nominal per capita consumption, mainly because of substantial network losses. Since the mid-1980's, Beijing is faced with continuing periods of drought, and an increasing population has worsened the problem. A large number of initiatives to make Beijing a more ecological city have been launched, ranging from attempts to separate grey and brown water, to financing sophisticated ecological projects in the framework of the 2008 Olympics (van Dijk & Liang 2012).

The Chinese 11th 5-Year Plan for the water sector is quite ambitious: Authorities want to reduce water consumption per industrial unit by 30%, and increase coverage for water and sanitation facilities in line with the Millennium Development Goals. Beijing is naturally a water-scarce area, and as such it would have considerable interest in closing the water cycle, like Singapore has done recently. This means avoiding losing any of the scarce resources, and controlling quantity and quality constantly, so that no water gets lost between source and users. All of it is collected, cleaned and made available for reuse (HLLL 2014). The main reason for not doing this is in Beijing is the lack of confidence of the public in the quality of the water coming from the existing large scale centralized waste water treatment plants.

Flooding is not a big problem in Beijing, at least not as much as the declining ground water level, caused by overuse of the aquifer below the city. Rainwater harvesting is therefore promoted, both in the city center and in rural areas. However, it turns out that at the current low price of electricity maintained by the Government, and since there is no charge for ground water extraction, it is still cheaper to use free ground water than to invest in rain water harvesting projects.

Decentralized wastewater treatment is encouraged in Beijing for major new buildings, but currently this is not considered to be financially feasible by private investors, although it would be economically feasible from a societal point of view, if a comprehensive cost benefit analysis (including internalization of externalities) were carried out. Beijing also has legislation forcing all major new buildings to separate brown and grey water, and to treat grey water on the spot. The success of this policy is limited, however, since in the absence of suitable financial penalties, it is still cheaper to buy clean municipal water rather than making the effort of cleaning grey water and then using it for flushing toilets and irrigating gardens. Analysis of a decentralized greywater reuse project in Beijing, the Qing project, serving 2,500 residents and completely subsidized by the Beijing Water Saving Office, shows that people consider reclaimed water too dirty even to be used for toilet flushing, and around 20% of the residents flatly refuse its use. Also, the price of reused water was originally supposed to be lower than the price of municipal water, however, the operational cost of the Qing plant is so high that reused water has at the end the same price the other. A similar project located at Beijing Normal University, its users being students and staff of the University, was instead successful, since most residents in this case accepted the use of reclaimed water for flushing. Three reasons could explain this difference: firstly, students of a younger generation can accept new things more

Water Practice & Technology Vol 11 No 1
doi: 10.2166/wpt.2016.022

easily. Secondly, reclaimed water is used in student dormitories which differ from private homes, and students don't pay much attention on water usage. Thirdly, students don't pay for use of the water.

Driving factors for successful application of new paradigms

Examining the examples above, the driving forces and factors for the successful implementation of new paradigms can be extrapolated. In Berlin, the more or less concomitant presence of an impending water crisis, the demand for a more ecological, 'green' urban environment and the status of the city (bastion of the West earlier, Capital of the re-united Germany, later) prompted an early and strong involvement of planning authorities, the introduction of specific, sustainable-compliant building codes, and a generous inflow of money from the federal government to the Municipality. It is estimated that Berlin received 3.8 billion USD from 1950 to 1989 on investments in its wastewater reclamation and reuse infrastructure, alone. This cost was borne by the federal government and the actual costs were never reflected in the fees charged to the inhabitants of the city (Salian & Anton 2012). The measures described and introduced significantly improved the resiliency of the city with respect to potential water resources issues.

In Pavia, new building codes have improved the hydrologic invariance ratio required of new urban developments. Not much has been done on the existing urban fabric. Building codes should be amended in order to favor intervention on existing buildings and pertinent areas, with incentives to property owners for the improvement of their overall sustainability. Water resources resiliency is currently only partially achieved.

In Beijing, with regulations among the most advanced in the world (mandatory separation of grey and black water in new buildings, and local treatment of grey water), mixed results were obtained, mainly due to influence of external economic constraints: public water is still too cheap, compared with the relative high cost of grey water treatment, and use of the latter is therefore limited to specific subsidized situations. Also, rainwater harvesting, promoted throughout the city, has only partial application, as it is still more economical to pump groundwater than to build stormwater storage. In the Beijing case, pure economic factors are at the basis of a partial failure of new paradigm applications. It should be noted that Beijing's projects would be economically feasible according to a wide-scale cost benefit analysis, but, from the point of view of investors, they are not considered financially advantageous due to externalization of costs allowed by the existing system. A better degree of resiliency could be achieved by enforcing existing regulations, and by implementing a related and economically coherent general framework of water sector rules.

From the three cases presented above, Berlin seems to have adopted a set of combined policies that best enhance the overall resilience of the city to past and foreseeable water resources issues.

PARADIGMS IMPLEMENTATION IMPEDIMENTS

Brown *et al.* (2005) analyzed different separate and independent projects concerning different dimensions of the water cycle, including stormwater management, and sanitary waste management and the implementation of innovative technologies. Their analysis revealed that there are significant and recurrent sociopolitical impediments to any improved practice. In most cases, it was evident that implementing professionals and institutions seemed to be largely driven by an implicit expectation that there is a unique, clear technical solution to solve most water management issues. This is in open contrast to the current tendency of addressing issues through locally designed, broader strategies that may include also institutional reform and social change. Each of the projects investigated clearly demonstrated that, despite the significant technological advances over the last 20 years, on-ground and wide-spread implementation of sustainable urban water management (SUWM) techniques and

Water Practice & Technology Vol 11 No 1
doi: 10.2166/wpt.2016.022

processes is actually limited. The study highlighted the 'inertia of the *status quo*', i.e. the existing technocratic governance of urban water issues. This is particularly evident in the lack of uptake and retrofit of SUWM technologies in the private housebuilding sector, which inevitably perpetuates the existing unsustainable use of water, and its related expectations within the urban water environment. The study also showed that the regulatory system privileges wide-spread technocratic solutions that are considered efficient to regulate and mandate, yet are not sensitive to the local and/or regional context, and thus may not be at all effective when applied.

Different types of barriers at different levels prevent the adoption of true SUWN policies. These can be identified as follows (Brown & Farrelly 2009):

- political/administrative, due to: uncoordinated institutional framework; limits of regulatory framework; unclear, fragmented roles & responsibilities; poor organizational commitment; lack of political and public will;
- participatory, due to: limited community engagement, empowerment and participation; poor public communication;
- technical/organizational, due to: insufficient resources (both capital and human); lack of information, knowledge and understanding in applying integrated, adaptive forms of management; lack of long-term vision and strategy; 'technocratic-path' dependencies; little or no monitoring and ex-post evaluation.

It is important to point out that these barriers are predominantly socio-institutional, rather than technical. Even those listed under the 'technical/organizational' category mostly reflect impediments related to resources, responsibility, knowledge, vision, commitment and coordination issues, rather than to the current state of technical feasibility of the proposed solutions.

DISCUSSION AND CONCLUSIONS

SUWM requires an integrated, adaptive, coordinated and participatory approach, however, despite the 'new' philosophy, water management remains mostly a complex and fragmented area relying on traditional, technical, linear management approaches. While positive advances have been made, particularly concerning technological advancement, it was pointed out that there still is long way to go before this approach could be considered mainstream practice in the water and development industries.

Most current initiatives are taken at the city level, like the promotion of ecological neighborhoods and innovative housing schemes. Others come from the national level, for example direct or indirect subsidies. Even the success of subsidized initiatives (as in the Berlin example) is not guaranteed, especially when conflicting with pre-existing, and per during, socio-economic conditions (as in the Beijing example).

Initiatives at the household level depend very much on the urgency and gravity of the issue and the level of awareness of the people involved. Research has not yet explained how people and communities best respond to threats posed by environmental degradation and climate change, and what is the level of direct financial burden they are willing to bear individually (i.e. outside of general taxation) to solve them.

Following a review of available literature on institutional barriers to advancing SUWM, different typologies of the latter were identified. It appears clear that the majority of such are predominantly institutionally embedded, systemic, relating to the inter-organizational capacity of institutions involved and to external rules and incentives, and are mainly socio-institutional rather than purely technical.

All intervention approaches must be locally tailored according to specific issues and conditions, and their feasibility should be validated against a cost-benefit analysis not limited to the intervention physical boundaries, but to the larger community (citywide or larger). This approach, including

Water Practice & Technology Vol 11 No 1
doi: 10.2166/wpt.2016.022

attentive ex-post validation, provides an excellent means for communicating results both within and outside the planners' organization, and constitutes a way to benchmark actions against other plausible ones.

As cities develop, societal expectations grow, and as water resources reach the limits of sustainable exploitation, urban water managers are being faced with increasingly complex and multi-faceted challenges. Given the foreseeable climate change and population growth challenges facing large cities, there is a critical need for strategic investment in solutions that will deliver long-term, lasting sustainable outcomes.

REFERENCES

AAVV 1990 *The Biotope Area Factor as an Ecological Parameter*. Expert Report on the Biotope Area Factor. Landschaft: Planen & Bauen, Becker Giseke Mohren Richard, Berlin.

Ahern, J. 2007 Green infrastructure for cities: the spatial dimension. In: *Cities of the Future* (Novotny, V. & Brown, P., eds). IWA Publishing, London, UK.

Averyt, K., Meldrum, J., Caldwell, P., Sun, G., McNulty, S., Huber-Lee, A. & Madden, N. 2013 Sectoral contributions to surface water stress in the conterminous United States. *Environ. Res. Lett.* **8**, 035026–035037.

Blackmore, J. M. & Plant, R. A. J. 2008 Risk and resilience to enhance sustainability with application to urban water systems. *J. Water Resour. Plann. Manage.* **134**, 224–233.

Brown, R. R. & Farrelly, M. A. 2009 Delivering sustainable urban water management: a review of the hurdles we face. *Water Sci. Technol.* **59** (5), 839–846.

Brown, R. R., Sharp, L. & Ashley, R. M. 2005 Implementation impediments to institutionalizing the practice of sustainable urban water management. In: *Proceedings, 10th International Conference on Urban Drainage*, Copenhagen, Denmark, 21–26 August.

BWA 2013 *Data on Water Distribution and Use in Beijing*. Beijing Water Authority Press Release, China.

De Lotto, R. 2011 Flexibility principles for contemporary cities. In: *Changing Shanghai – From Expo's After Use to New Green Towns* (Zheng, S. & Bugatti, A., eds). Officina Edizioni, Rome, pp. 73–78.

Doepp, G. & Edelmann, G. 2006 Chaos, rigidity, and complexity and their changes caused by environmental influences. In *Proceedings 4th WSEAS International Conference on Environment, Ecosystems and Development*, WSEAS Press, Algarve, Portugal.

Gangsheng, W. & Jun, X. 2005 Sustainable water resources exploitation and management in Beijing. In: *Sustainable Water Management Solutions for Lage Cities* (Savic, D., ed.) IAHS Publ., Foz de Iguazù, Brazil, 293.

HLLL 2014 *Environmental infrastructure in Singapore – water and waste projects in the city state*. Web page at <http://www.hoganlovells.com/files/Publication/> (accessed June 2014).

LID 2014 Low Impact Development Center. Web page at <http://www.lowimpactdevelopment.org> (accessed June 2014).

Novotny, V. 2008 A New Paradigm of Sustainable Urban Drainage and Water Management. In *Oxford Roundtable Workshop on Sustainability*, 10–15 August, Oxford University, Oxford UK.

Novotny, V., Ahearn, J. & Brown, P. 2010 *Water Centric Sustainable Communities*. Wiley, Hoboken, NJ.

Okun, D. A. 2000 Water reclamation and unrestricted nonpotable reuse: a new tool in urban water management. *Annu. Rev. Public Health* **21**, 223–245.

Rees, W. E. 1992 Ecological footprints and appropriate carrying capacity: what urban economist leaves out. *Environ. Urban.* **4** (2), 121–130.

Rees, W. E. 1997 Urban ecosystems: the human dimension. *Urban Ecosyst.* **1** (1), 63–75.

Salian, P. & Anton, B. 2012 *Making urban water management more sustainable: Achievements in Berlin*. SWITCH - Managing Water for the City of the Future, Final Report annex. UNESCO-IHE, Delft, The Netherlands.

Simonovic, S. P. 2013 keynote lecture, 'From Disaster Risk Management to Quantitative Disaster Resilience: A paradigm shift'. In: *4th Conference of the International Society for Integrated Disaster Risk Management (IDRiM 2013)*, Northumbria University, Disaster and Development Centre, Newcastle, UK, September.

Steiner, F. 2000 *The Living Landscape*. McGraw-Hill Professional Publishing, New York.

Sydney Water 2013 Sewer Mining. How to set up a sewer mining scheme. Web page at <http://www.sydneywater.com.au/SW/plumbing-building-developing/plumbing/recycled-water/index.htm>.

van Dijk, M. P. & Liang, X. 2012 *Case study brief – Beijing, managing water for the eco city of the future*. SWITCH–Managing Water for the City of the Future, Final Report annex. UNESCO-IHE, Delft, The Netherlands.

Wada, Y., van Beek, L. P. H., Wanders, N. & Bierkens, M. F. P. 2013 Human water consumption intensifies hydrological drought worldwide. *Environ. Res. Lett.* **8** 034036.

WHO 2009 Urban population trends. Web page at <http://www.who.int/> (accessed June 2014).